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THEORETICAL ASPECT OF ASSEMBLY

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Abstract

Assembly plays a decisive role in global production in terms of its share in the total costs of the products assembled and in terms of the number of people working in the field. The author of (1) indicates that the percentage of the workers in assembly out of the total number of the workers in manufacturing in the U.S.A. ranged from 26.3% (bicycles) to 45.6% (automobiles), while the cost of the product assembly represented typically more than 50% of the total costs. Despite the above-mentioned importance of assembly in the industry, the discontinuous production processes have not been paid adequate attention until recently. It was sufficient to manufacture parts and then an operative reasonably and inexpensively assembled each product manually. The authors of this paper would like to emphasise "the method of a systemic approach" which focuses upon identifying the key activities to meet the objective. Harmonious interrelations of the activities are often a source of greater profit than in a system where some activities are of the top level while the others are neglected (2). The aim of this paper is to describe theoretical aspects of all the typical activities of the assembly system.

Key words

assembly system, fundamental activities, humanisation of assembly work

ASSEMBLY SYSTEM AS A SUB-SYSTEM OF MANUFACTURING SYSTEM

What is assembly? **In terms of the production hierarchy, assembly is the final phase of production, where manufactured components are assembled into a product.**

This definition is not satisfactory for deeper examination of the topic. Cybernetics (3) teaches that a so called **systemic approach** (Fig. 1) should be used for deeper examination of any object. When examining an object, firstly the objective of the research should be defined, the **critical factors** and their relationships affecting the defined objective, followed by the necessary **inputs**, potential **outputs,** and the environment (nature, market, etc.).

Generally, the examined system is a subsystem of the system of a higher order. If necessary for research purposes, relationships can be defined of the examined systems with the systems of higher or the same orders.

A studied system typically behaves as a regulation loop: a failure on the output generates the information regarding the changes needed for the input.

Warnecke (4) provides an insight into assembly as illustrated in Figure 1. The author is not concerned with the inside of the assembly system from a "bird's eye view" of the whole production; the inside of the assembly system is a "black box" performing its role within the interests of the entire production system.

The system in general is a set of defined elements with a common purpose. Its elements do not exist in isolation, but collaborate to meet the common objective. Professor Warnecke distinguished the first-level system (production) and the second-level system (sub-system of assembly).

Figure 1b provides a detailed explanation of the function of the assembly system, its inputs and outputs. Inputs of the assembly system are information, energy, components, auxiliaries, tools, fixtures and measuring equipment. Outputs of the assembly system are represented by information, heat, auxiliary substances, assembled products, tools, fixtures and measuring equipment.

Figure 1c shows the principle of feedback used in assembly: a failure occurs in the assembly system; at the end of the assembly process it is found that the assembly system does not work as expected; and interventions are made into the inputs in order to eliminate undesirable phenomena. The examined system normally behaves as a regulation loop: failure on the output generates the information on the changes needed for the input.

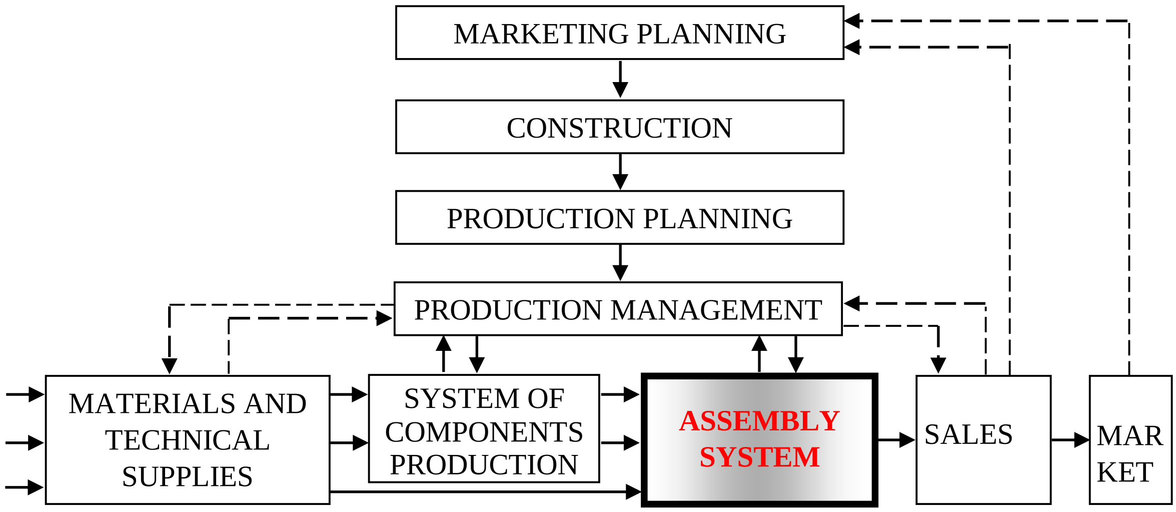
The aim of the research was to reduce assembly costs of the assembly operations. It is therefore necessary to "open the black box", define the assembly on the level of a single product, i.e. on the basic level of the hierarchy, and, in terms of a systemic approach, detect the sources of reserves for reducing the assembly costs.

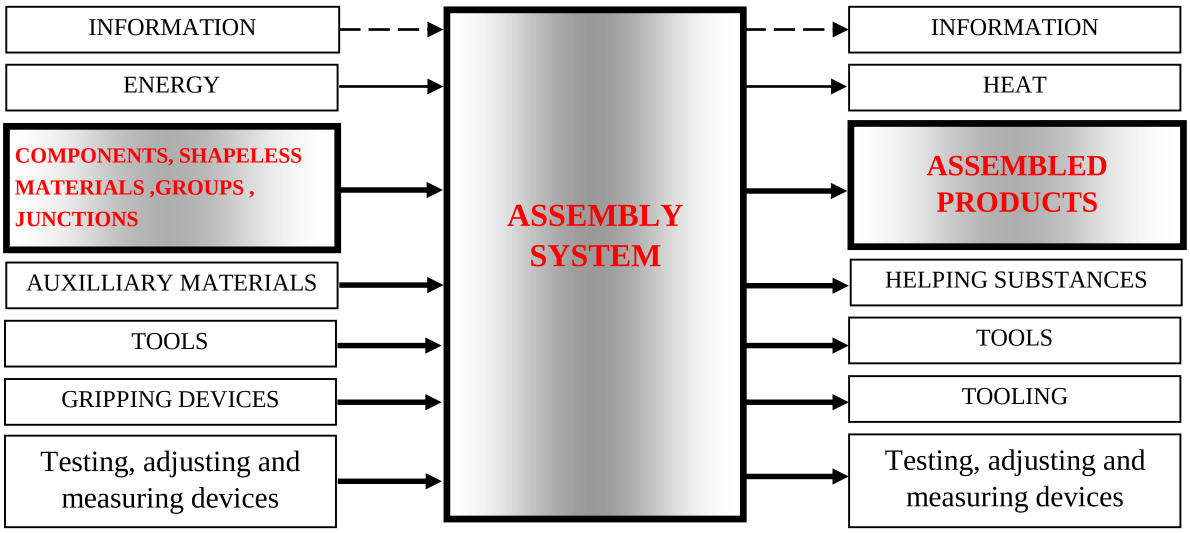
BASIC ACTIVITIES OF THE ASSEMBLY PROCESS

What activities are performed in assembly? Figure 2 lists all the generally known fundamental activities of the assembly process, such as handling, bonding and testing, along with the individual operations of these activities.

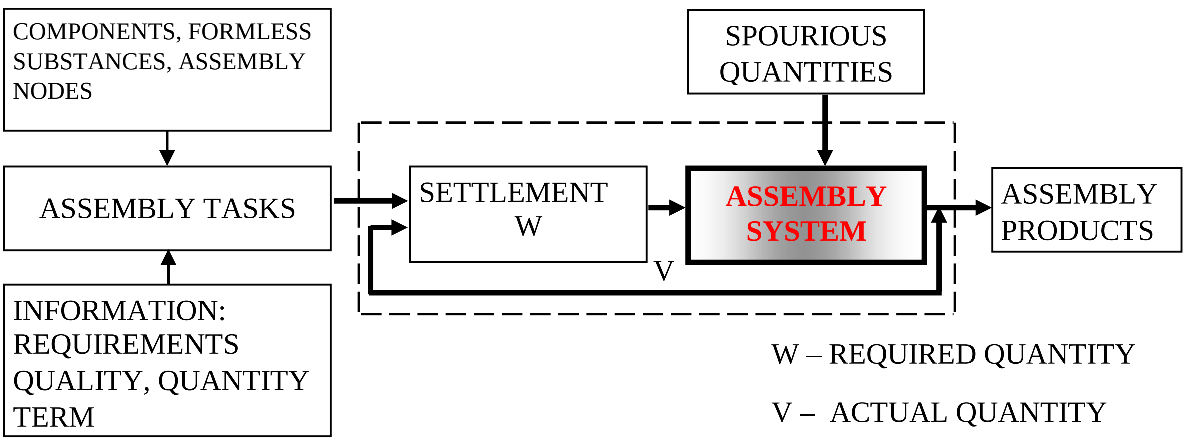
The typical feature and principal activity of assembly is the operational and inter-operational handling comprising storage (pouring, storing, loading, stacking), orienting (random, forced, splitting the flow of components, separating parts) and transferring (gripping, moving, releasing). These activities are followed by bonding (shape bond, force bond, material bond, and special bond).

Unlike other technologies, assembly is typical for a wide scale of handling and testing products (testing for presence, position accuracy, correctness of composition, special tests). In addition to these operations, assembly comprises special support processes such as adjusting, additional machining, surface treatment, packing, lubrication, disassembly etc. (5).





b – function of assembly system



c – assembly process as a regulation loop

Fig. 1 *Assembly system. Function schemes (4)*
a – assembly as a sub-system of production system, b – function of assembly system, c – assembly system as a regulation loop.

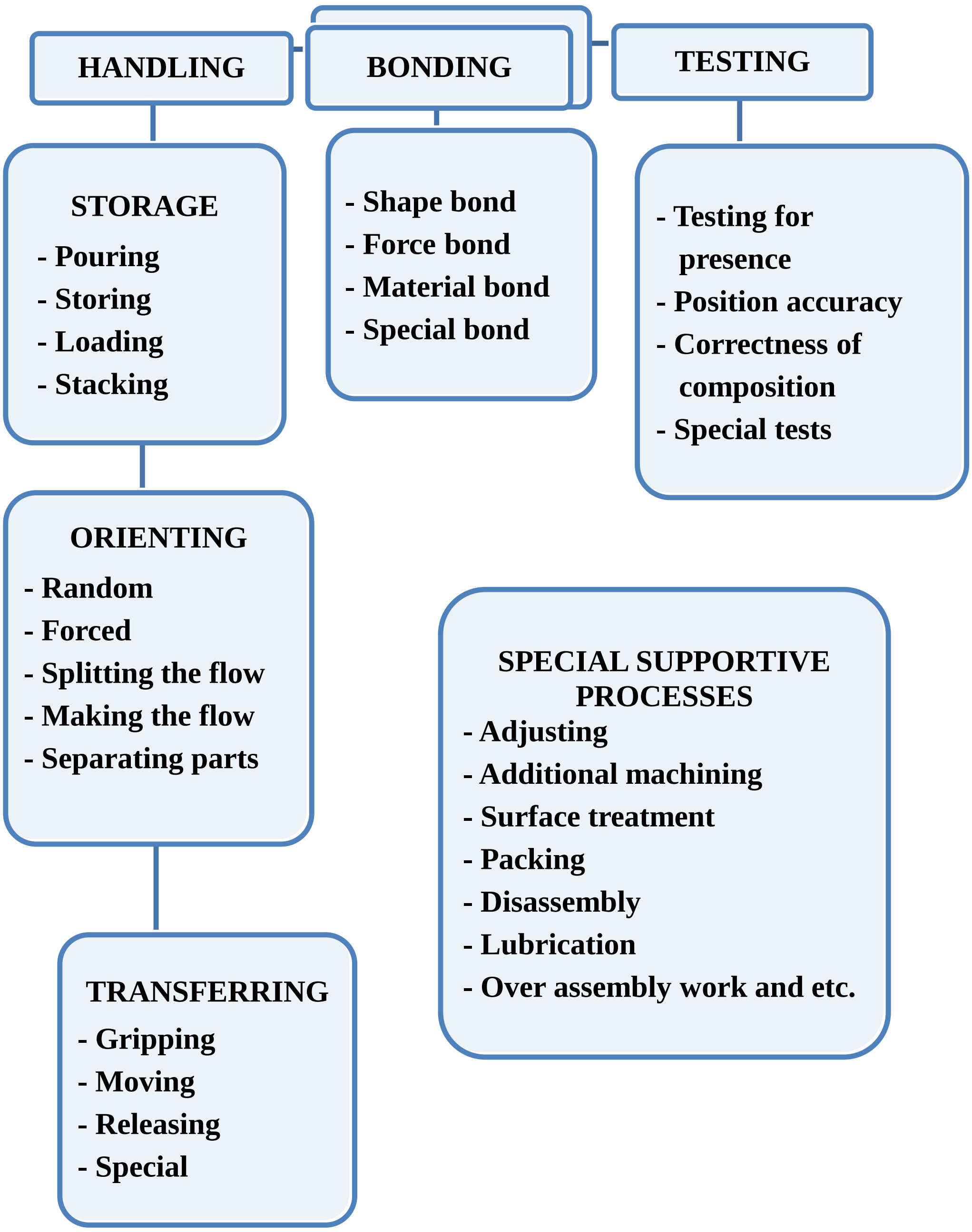


Fig. 2 *Fundamental activities of assembly (7)*

ASSEMBLY AS A SYSTEM

According to the theory of systems, each system is a set of activities working together to perform a specific task. A system consists of inputs, processes and outputs.

Figure 3 shows the inputs, processes and outputs of an assembly system as well as its goal: to make a profit in the assembly of products. A special feature of the assembly system is that it is the most complex sub-system of the production system. All manufactured and purchased parts pass through the assembly system (6). Typical features of assembly system are the complex pre-installation, installation and post-installation handling, utilisation of numerous bonding technologies, implementation of natural and artificial intelligence, rich material and information flows, less energy consumption than in the production of parts, a greater concentration of people involved in the management and performance of work than in the manufacturing system.

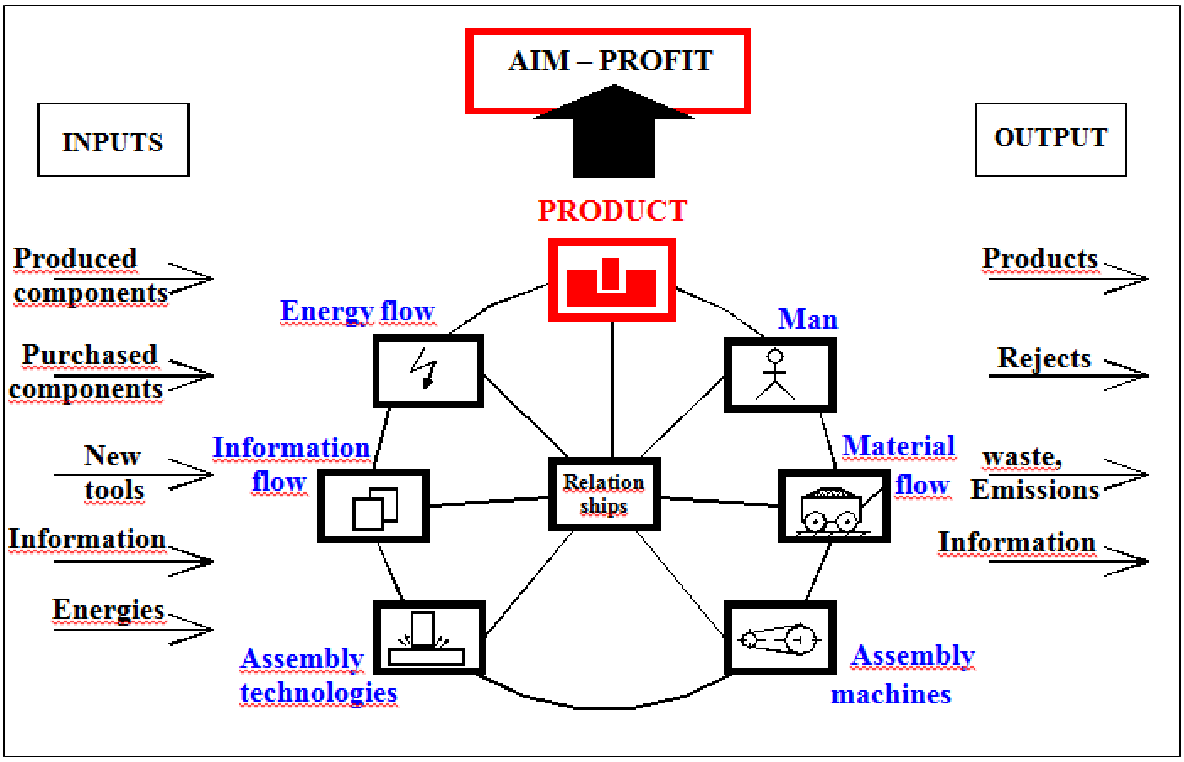


Fig. 3 *Assembly as a subsystem of manufacturing system*

The plan of the factory is implemented into the assembly system (7) which represents the final stage in the process of products manufacturing in the discontinuous production process.

Figure 3 describes the content, objectives and functions of the key activities of the assembly system as well as theoretical problems of these activities and factors influencing the system.

As mentioned above, each system must have its goal. Similarly to other industrial systems, the goal of assembly is to create profit.

Let us pay attention to the key factors affecting this goal and their mutual relations. The key factor is a product that must be designed at the lowest possible assembly costs. Other factors comprise of manpower, material flow, information flow, energy flow, assembly technology and assembly machines. These are the main factors determining the quality of the product.

The above-mentioned suggest that, to achieve the objective, it is necessary to develop each of these factors and the relationships between them. The assembly system consists of inputs (manufactured components, purchased parts, new tools, energy) and outputs (products, rejects, waste). The entire system is criss-crossed by the information flow (data collection, transmission and processing).

Figure 3 indicates the following decisive factors reducing the installation costs: 1. assembled product (mainly its construction), 2. bonding methods (technology), 3. assembly machines, 4. information flow, 5. material flow, 6. energy flow, 7. manpower (8).

An appropriate change in the design of an assembled product element generally radically reduces the assembly costs, though the change itself is the least costly (just wages of designers, technologists, overheads, etc.) (8).

In terms of a systemic approach, assembly is a sub-system of the production system aimed at achieving the maximum profit by bonding the components. The profit is crucially affected by the elements, inputs and outputs as shown in Figure 3.

ASSEMBLED PRODUCT

There are typically several potential construction versions of a product. They all may meet the requirements of the purpose, but only one of them requires the minimum pre-assembly, assembly and post-assembly handling, and therefore also the least assembly costs (9).

The role of the theory of assembly is to find a construction design for the product, which reduces necessary handling of parts and products to the minimum, starting with the origin or purchase of parts to the storage of the product in a distribution warehouse.

Construction design of the product generally does not influence the costs of pre-assembly and post-assembly handling, as universal means of inter-operational handling are equally applicable to all construction versions of the product.

The design of the product, however, affects the assembly handling and its main activities, such as orientation, relocation, positioning and bonding.

The role of the theory of assembly is to use fundamental sciences to reduce the above-mentioned activities, i.e. their number, trajectories and time, to a minimum. This is the role of the discipline called the "Technological Construction of Product Design in Assembly".

Currently used international acronyms within the field are: DFA – Design for Assembly (10), DFMA – Design for Manufacturing (11) and Assembly (12).

The practical part of the discipline, i.e. the rules and examples of appropriate and inappropriate solutions, is explained in detail in the following chapters. One of the goals of this paper is to enhance the theoretical knowledge of the discipline.

Both techniques are effective ways of reducing the assembly costs. An example is e.g. a clothes hanger made of wood or plastics. The plastic hanger is a single part which does not have to be assembled. Its design is the example of the well-known slogan:

"Best assembly is no assembly."

ASSEMBLY TECHNOLOGY

Orientation, positioning and relocation are the assembly operations. The term "assembly technology" means the method of bonding parts with the aim to produce a movable or a stationary bond (16).

The range of new non-traditional ways of bonding to reduced assembly costs keeps increasing. Product designers must be familiar with the traditional (13) as well as new bonding elements and methods.

A new method e.g. the utilisation of flexible reed bonds: demountable bonding of two plastic parts does not need a bonding component. The strength and durability of adhesives has increased, the noiseless method of riveting have appeared, the quality of bolt tightening via electronic check of the required voltage has improved, etc.

The findings are summarised by (14), who also provides an extensive list of references.

ASSEMBLY MACHINES

Assembly is a part of the discontinuous production process, comprising the following activities: inter-operational handling, operational handling, post-operational handling and technology (as a change of properties of the processed object).

The German VDI Directive (15) lists the following processes: 1. urformen (production of a substance), 2. umformen (change of shape), 3. trennen (division), 4. fügen (bonding – assembly), 5. schichten (surface treatment), 6. materialeingeschaften ändern (change of the material properties).

Discontinuous processes differ in the machines used. Methods for inter-operational and operational handling are common to all technologies. Production and assembly both use the same machines for inter-operational and operational handling, such as nested workplaces, automatic machines (5, 17) synchronous and asynchronous lines (18) and robots (19).

Assembly machines (20, 21) differ from other production machines as they have a more complex role in the operational-handling, which often performs also the role of technology (e.g. insertion of the pin into the hole).

Production machines differ from the assembly machines as they "borrow" the operational-handling part for bonding.

The designer of assembly machines must possess a general understanding of planning and designing of the technology for discontinuous processes, enhanced by the specific knowledge typical only for assembly.

The role of theory is to classify the established and new organisational and technical arrangements (layouts) of discontinuous processes in general and assembly processes. In particular, to classify the construction of the assembly technology machines (electric, pneumatic and hydraulic motors, solid cam and step mechanisms), and to develop the theory of their construction both individually and in mutual interaction with the automated control systems, the hard and sequential CNC machines, as well as the CNC machines with AI (22). A significant amount of research on the topic can be found in the literature on the theory of mechanisms and production machines (24, 25).

MANPOWER IN ASSEMBLY

Requiring a high degree of system intelligence, assembly is the most sophisticated stage of the process (8).

For economic and technical reasons, artificial intelligence and artificial visualisation can be used for assembly only in a limited way. The involvement of manpower in assembly is and will always be irreplaceable. The costs are significantly lower when performing assembly using manpower, rather than with an intricate intelligent machine.

For these and other reasons, the human operator of the assembly process is irreplaceable and thus far full automation in mass assembly remains unrealistic.

A "tayloristic" assembly line, where a human operator performs an elemental act in a forced pace belongs to the past. The current search is for new ways of designing an operator-friendly assembly which would not pose risks to the physical and mental health of workers.

The contemporary assembly regards three principles of humanisation:

1. Job Enlargement
2. Job Enrichment
3. Job Circulation (8).

In addition to meeting the above-mentioned principles of assembly, the knowledge should be applied regarding the physical abilities of the workforce, work breaks, regulation of the work pace during shifts, climate and noise levels, ergonomics of the workplace etc. The assembly system should be designed in accordance with the current regulations and standards in these areas.

Many known assembly systems, including those brought to Slovakia by foreign companies, exhibit a low level of humanisation of assembly. Typical for such systems are lines with forced work pace, where the content of the operation and its time scale are limited and do not meet the job expectations of the contemporary skilled workers (26). The author suggests enhancing the list of the above-mentioned three principles by other rules, described below.

Basic requirements for humanisation of assembly work:

1. The operator in assembly (a turner, designer etc.) must be a "master of his own time".
2. Permanent work at a enforced pace is not appropriate.
3. The time of the operation should not be too short; it should be longer than 0.5 minutes (job enlargement).
4. Content of the operation should be reasonably rich (job enrichnent).
5. Workers must be allowed to perform different operations after some time (job circulation).
6. Permanent work while standing or walking is not appropriate.
7. Operations requiring much effort or time (screwing by many revolutions) should be carried out by motors.
8. For a human operator, the assembly is convenient from top downwards or from front backwards. A motorised positioner should be used to ensure this requirement.
9. Workers should have good conditions to communication with colleagues while working.
10. Work must not have lasting effects on physical and mental health.
11. Workplace must be attractive, aesthetic and ergonomic (7).

MANPOWER IN ASSEMBLY

For these and other reasons, the human operator of the assembly process is irreplaceable, and thus far full automation in mass assembly remains unrealistic.

The most intense flow of information in the whole production takes place in assembly. Many people are required in assembly to collect, transfer and process data. In small batch productions, the information flow is still provided verbally, by telephone or in a written form.

The information flow exceeds assembly, penetrating the whole production up to the market with products.

The information flow in assembly is a sub-system of the total information flow. It involves the tasks received from the top, checks of the conditions for performance of the tasks and communication with those creating the required conditions. Due to the development of computers, the current era is referred to as "the information revolution" (2).

Specialised companies offer businesses and institutions the application systems for the short-term and long-term process planning.

Software is employed in designing products so that its outputs are inputs into production (e.g. CNC technology programs) (23).

The above-mentioned systems utilise the well known concepts of production control, such as: Just in Time method, Critical Path method, Kanban method, Kaizen method, Chaku-Chaku method, 5S method, CAA method, TPM method, CAPP methods etc.

MATERIAL AND ENERGY FLOWS

Everything the company manufactures flows through assembly to the dispatch warehouse. Pre-assembly and post-assembly handling is a part of a special sub-system of production, often called "the enterprise system of transport and handling". The system uses mostly universal handling equipment such as the manual and platform trolleys, fork lifts, hoists, cranes, rail cars, all either operated by a human operative or by an automatic machine.

The designer of an assembly system focuses mainly on the assembly technology to be purchased. If such technology is not available on the market, the designer has to devise it.

The most energy-consuming operations in assembly (besides bonding; depending on the bonding technology used) are acceleration and deceleration of the moving masses of end-effectors which may be up to 10 times larger than the parts handled (8). The energy for the assembly handling is manifested by relatively small forces, but also big trajectories which should be minimised.

CONCLUSION

Based on theory of systems, every single system is a variety of activities. These activities are cooperating so that they can fulfil a certain task. The system consists of inputs, core and outputs. By application of this systems theory, the main factors of the assembly process were defined. The main factors are affecting the goals, and thus profit, of every production process. The particularity of assembly system is that it is a most important subsystem of production system.

In the submitted paper, included are the basic activities of the assembly process and operations from which they are made of. A typical sign and main activity in the assembly is the operative and interoperable manipulation, which consists of storage, orientation and handling. Another typical block in assembly is the testing of the product (analysis of presence, accuracy of location, accuracy of composition) from analysing to actions or operations like readjusting, additional machining, surface adjustments, packaging, lubricating, disassembly etc.

Assembly is the most sophisticated part of a process which is also the most difficult for a high degree of systems intelligence. Participation of a person in the assembly, from economic and technical perspective, is and will be absolutely needed. Because of this and other reasons, we have to count with the person as an operator in assembly.

In the modern assembly, we look for the ways of how to make assembly which does not damage physical and mental health of the operator. There are three basic principles of humanization of assembly, which are in the submitted article extended to eleven basic demands for humanization of assembly work.

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