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CONTEMPORARY CHALLENGES TO THE ORGANIZATION OF LABOR AND PRODUCTION IN THE CHEMICAL INDUSTRY

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Abstract. The organization of labor and the production process represent one of the continuously evolving approaches in contemporary business. On one hand, this dynamic is driven by the constant development of new products and growing consumer expectations for novelty; on the other, by the rapid evolution of technologies and technological solutions. Currently, a continuous between humans and technology can be observed – a struggle characterized by the temporary dominance of technology followed by the subsequent of processes and activities. Despite the rise of technical and technological progress, the human factor remains central, even today, amid increasing discourse on a and the humanization of society.

One sector where technological solutions are increasingly replacing human labor is the chemical industry, particularly in the production of plastic products. In this sector, a reorganization of the production process is taking place, where manual production activities are being replaced by automated robotic systems, and the work of production operators is being substituted by that of automation programmers. This transformation—driven by the implementation of modern automated production systems—is the focus of this article. It examines both traditional production processes and their evolution through automation, as well as the necessary improvements and the introduction of specific social mechanisms that reflect the new role and position of humans within production-technological systems.

Keywords: production socialization, plastics manufacturing, production process, Industry 4.5

JEL: L65, O33, J24

Introduction

Understanding the changes in labor-production relations involves studying the fundamental principles governing the interaction between humans and machines over the nearly 400 years of the Industrial Revolution. Following Sterev and Penchev (2023), one can examine the evolution of this interaction:

– Industry 0.0 represents a fusion of enterprises and households, where the concept of the individual overlaps with that of the "home enterprise. labor processes are predominant, marked by the gradual development of tools used in these activities. A significant advancement during this period is the introduction of animal power to perform production tasks that exceed human physical capabilities. This era spans from the emergence of the first civilizations up to the early 18th century, when technologies harnessing natural elements such as air, water, fire, and magnetism began to develop.

– In Industry 1.0, the organization of enterprises involved the use of equipment and technology that enhanced human labor. Despite this, there remained a strong connection between the enterprise as an institution and the human element. The first Industrial Revolution is associated with the invention of the steam engine and the introduction of the first machines powered by wind, water, and steam. During this period, human labor – including the use of animal power—began to be replaced by machines. Consequently, the role of humans in the production process shifted from being providers of physical force to operators who direct and control the machines and their output.

– Industry 2.0 has been in place for approximately two centuries, marked by the Second Industrial Revolution, which introduced a distinct concept of the "business enterprise. does not correspond to the image of a single individual; rather, the organization of the enterprise is linked to increased production through the adoption of new manufacturing technologies derived from technological discoveries of that era. Specifically, this period saw the introduction of autonomously functioning machines and equipment powered by electrical energy. Human labor was no longer required to operate these machines directly but was essential for managing and overseeing their functions. Consequently, during this industrial revolution, labor and technological processes occurred simultaneously, with the outcomes of human labor complementing those produced by machines. This shift also prompted the development of the first behavioral theories in people management.

– In Industry 3.0, the emphasis remains on the human element, but enterprises focus on creating an efficient organization of labor and production. This third industrial revolution saw the rise of machines that expanded the "power of human labor the introduction of simplified computerized commands and calculations, which were previously beyond human capability in performing labor tasks during the 1960s and 1970s.

● A sub-element of this industrial revolution, emerging in the mid-1980s, is Industry 3.5, which involves the gradual replacement of human labor in performing complex production tasks with computerized systems.

In this phase of industrial development, the humanization of production processes is linked to the emergence of motivation theories for workers, who are

increasingly replaced by simplified machines performing repetitive tasks that do not require creativity or innovative solutions.

– In Industry 4.0, enterprises focus on the individual, emphasizing the use of digital tools and Internet 4.0 technologies. Over the past 50 years, the fourth industrial revolution has emerged, characterized by the replacement of human labor with robotic machines programmed to replicate human actions and movements.

● A sub-element of this industrial revolution is Industry 4.5: the transition of business enterprises into social enterprises, where robotic machines gain autonomy within entire robotic systems. Humans typically control the operation of complex production facilities remotely, using various digital tools that enhance human labor capacity.

Under these conditions, the focus on the inherent humanization of production emphasizes human leadership and its role in achieving organizational business excellence.

Traditional principles of labor and production organization

Following Sterev (2018), the current state of the Bulgarian economy is characterized as Industry 3.5, reflecting the introduction of Industry 4.0 technologies in production. This context underscores the importance of the transition from Industry 4.0 to Industry 4.5, which is essential for transforming labor-production relations and redefining the "man-machine" relationship into a mediating role of labor in managing the "machine-man-machine" interaction.

When assessing and identifying the specifics of labor and technological processes, as well as evaluating the challenges associated with changing the type of basic production processes, the following processes – used evolutionarily in real production enterprises – should be taken into account (Georgiev et al., 2012):

– Manual processes involve only human participation in the execution of various technological tasks and operations. This approach is typical of pre-industrial production.

– Machine-manual processes involve both machines and humans working simultaneously to carry out technological operations. This approach is characteristic of industrial production during Industry 1.0 and Industry 2.0.

– Machine processes involve various machines sequentially executing technological operations, with minimal human intervention. These processes are characteristic of technologies based on autonomous robotic systems from Industry 3.0, Industry 3.5, and Industry 4.0.

– Instrumental processes involve the transformation of materials within closed apparatus complexes, minimizing human participation. These processes are characteristic of Industry 4.0 and Industry 5.0.

Following changes in these processes, it can be concluded that the transformation of human-machine relationships and the optimization of fundamental economic

outcomes are essential prerequisites for enterprise growth (Doncheva & Stoyancheva, 2024). For this reason, they are considered major drivers and challenges for subsequent changes in these relationships (Blagoev et al., 2012).

Understanding these changes and addressing the challenges of modern production requires presenting the fundamental principles of organizing the production process, from Friedrich Taylor and Henri Fayol at the beginning of the 20th century to the present day.

– The principle of proportionality refers to the necessity of maintaining balance between two adjacent production units, ensuring that neither faces difficulties in the exchange of materials, technology, or labor. Additionally, proportionality involves determining the optimal ratio of labor productivity to production, so that the rate and speed of production remain relatively equal across the individual production units.

This principle applies both to individual production units – such as machines, robotic systems, and workplaces – and to larger production units, including sections, sectors, workshops, and factories within a production chain.

– The principle of parallelism is expressed through the simultaneous execution of all production actions, activities, or operations. This concurrent activity does not interfere with any elements of the production and labor process.

Failure to comply with this principle is associated with increased downtime in the material and technical flow, as well as difficulties in the overall production activities of the individual enterprise. This principle requires reducing the production process to the smallest labor-production units while identifying micro-production elements that can be performed concurrently.

Compliance with this principle is associated with a reduction in the total technological time required for production, which, all other factors being equal, allows for an increase in labor productivity within the enterprise. Conversely, failure to adhere to this principle leads to an increased production and economic risk of interruptions due to varying rates of individual production actions, activities, and operations.

– The principle of straightness represents the need to maintain a precisely defined "production and technological" order from the beginning to the end of each production cycle. The straight path is defined as the most direct route for the movement of labor objects between two distinct production-technological and/or labor workplaces.

Compliance with this principle involves both adhering to a clearly defined direction of material flow in production and minimizing the time required to move from one workstation to the next.

Failure to comply with this principle results in the "mixing" of material flows, which increases the risks of producing poor-quality products, duplicating production and technical operations, or omitting such operations altogether.

– Principle of continuity of production: Within an independent production system, it is assumed that the individual elements of the system are in continuous interaction, even when downtime is necessary or has been scheduled within the production system.

In addition, compliance with the principle of continuity is maintained throughout the entire technological and labor production process. This process comprises not only the immediate activities and operations performed on the materials of labor but also the movement between individual production, technological, and labor stations and workplaces, as well as any downtimes occurring before or after each technological activity or operation.

Failure to comply with this principle is associated with an increase in unplanned interruptions or downtimes within the production and labor processes, as well as an increase in technological waste caused by the deterioration of optimal production conditions resulting from these interruptions.

By adhering to the principles outlined above, optimal production is achieved, and the total production time is minimized to the lowest feasible level. In practice, applying these principles involves managing the production cycle and the time elapsed between the start and completion of all operations on the workpiece within an independent production unit.

Peculiarities of labor and production organization in plastics production

Plastic products are becoming increasingly important in modern industry. There is no sector in which plastic products are not used, either alone or in combination with components made from other materials. The moulding of plastic parts is a complex technological process involving multiple factors that directly or indirectly affect the quality of the final product. Plastic products are manufactured by injection moulding, where molten plastic is injected into a mould or matrix using an injection moulding machine.

Plastic products are increasingly used across all sectors of the economy, including households, industry, light and heavy manufacturing, precision mechanics, and medicine. In many cases, they replace various traditional materials. Moulding tools enable the production of items ranging from miniature to large sizes. These products offer advantages such as process automation, minimal or zero waste with the potential for recycling and reuse in production, high product accuracy, cost efficiency, and reduced production cycle times.

Plastic products are made from polymer materials, which are classified into thermoplastics and thermosets. These two types impart different qualities to the products.

– Thermoplastics soften when heated and harden when cooled without undergoing any chemical changes. This process can be repeated multiple times. Examples include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and ABS.

– Thermosets, such as Bakelite, polyurethane, and epoxies, cannot be repeatedly processed by heating.

Depending on the type of plastic, the tool is either cooled or heated to facilitate the removal of the part from the mould. Thermoplastics require rapid cooling to ensure an efficient cycle and high productivity. Some materials, such as ABS and PC, require heating the mould to release the part.

The traditional work processes that can be automated using robotic stations include the following:

1. Material Preparation

– Selecting a suitable thermoplastic material (e.g., ABS, PP, PE).

– Mixing additives or colorants as needed.

– Drying hygroscopic materials to prevent moisture-related defects.

2. Installation and Adjustment of the Mould

– Mounting and centring the die on the machine.

– Connection between cooling and hydraulic systems.

– Cleaning the mould and applying release agents to it.

3. Machine Setup

– Entering production parameters into the machine, such as injection pressure, screw speed, cooling time, and clamping force.

– Performs test cycles to verify accuracy.

4. Production Control

– Monitoring production cycles to ensure consistent injection moulding results.

– Check the panel on the injection moulding machine control module for any alarms or errors.

– Refilling material in the injection moulding machine hopper as needed.

– Performing quality checks during production.

Visual inspections – for cracks, defects, and deformations.

Measurement checks using callipers and micrometres.

– Maintaining a statistical quality control log

– Adjustment of parameters in the presence of defects (e.g., insufficient material dosage, burnout).

– Changing dies is required when switching the products being produced or during maintenance, especially if the quality of the products decreases.

5. Post-Production Operations

– Removes excess material and cleans channels.

– Assembling plastic components by heat welding, using screws, or applying adhesives.

– Packaging finished products into boxes.

– Labelling production with batch numbers and control marks.

– Filling out production logs and quality inspection protocols.

Table 1 presents a summary of the technological scheme, including labor and production operations.

Table 1. Combination of operations in the chemical industry

Process stage	Technological operation	Accompanying labor operation
Preparation of raw materials	Mixing, drying	Loading materials, monitoring production parameters
Moulding	Injection / Blow Moulding	Format setting, cycle start
Cooling	Thermal regulation	Temperature monitoring, cooler maintenance
Removing a product	Open a form	Working with a manipulator or manual removal of finished products
Finishing	Cutting, circumcision	Manual cutting, grinding, inspection
Quality control	Test operations	Instrument measurements, visual inspection
Packaging and storage	Palletizing, labelling	Sorting, barcode scanning, entering into system

As can be seen from the technological scheme of labor and production operations, in modern conditions there is an opportunity to replace "people" with "machines" in almost every one of these operations.

Challenges to the organization of labor and production in plastics production

Given the specifics of the production process in plastics manufacturing and the necessary automation of work processes—particularly the integration of automated robotic systems replacing human roles in production (Idriz & Sterev, 2022)—key directions for "human-machine" interaction in plastics production under the modern Industry 4.5 framework can be identified. (see Table 2). Making the reliability of AI-enabled systems a top priority contributes significantly to stimulating investment in smart economics (Molhova & Biolcheva, 2023)

Table 2. Redistribution of human-machine operations in plastics production

Type of operation	Performed by	Note
Programming, setting	Man	Via HMI, teach-in
Loading material	Robot	Automated submission
Removing a product from a mould	Robot	Time-critical, automatic
Visual inspection	Robot + AI	Machine vision + defectology
Final control of complex products	Man	Subjective assessment
Inserting inserts	Human or robot	When flexibility is needed
Printing/marking	Robot	Precision in high runs
Sorting / palletizing	Robot	Integrated with conveyor belts
Support and emergency response	Man	Not automatable yet

Accordingly, a significant portion of labor-intensive production operations is being replaced by automated robotic processes. However, human involvement in the production process will continue (StandardBots, 2025; Segura et al., 2025; Universal Robots, 2020) This is found by Stoycheva and Vitleemov (2023) who set that AI policy involves socio-technical elements that companies have to effectively rule to capitalize on its benefits. Accordingly, main AI involvement in human labor could be found in next processes:

1. Programming and setting up robots

– Configure parameters for different product lines.

– Training robots for new movements through " teach - in " (the leader physically demonstrates the movement).

– Setting up HMI interfaces, AR systems and digital twins.

2. Service and maintenance

– Mechanical, electrical and software maintenance of equipment.

– Diagnostics and troubleshooting (diagrams, log file analysis, alarm response).

3. Monitoring the production process

– Monitoring the operation of automated lines through SCADA / MES systems.

– Reaction to unexpected events – accidents, lack of material, incorrect position of a part.

Following this change, there is an introduction of artificial intelligence tools in the production of plastics:

– Machine vision and intelligent automation

Robotic systems in plastics manufacturing are often equipped with machine vision (Vision-guided robotics), which allows for the recognition, orientation and processing of parts with high precision, even when they are randomly arranged on a conveyor belt. This technology leads to real-time quality control – detection of discrepancies and immediate response – which reduces scrap and increases efficiency.

Modern plastics factories use robots equipped with AI-based machine vision systems. These systems replace or supplement human inspectors. High-resolution cameras capture an image of each manufactured part, and deep learning algorithms compare it to a database of perfect samples.

This not only allows the robot to identify physical defects such as deformations, punctures or defective edges, but also to distinguish between tolerances and actual manufacturing errors. This significantly improves quality control, especially for products that come out of the mould every few seconds.

According to Craig (2022), such a system can inspect over 200 items per minute, maintaining an error rate below 0.1%. This is impossible to achieve with human labor, even at the highest level of concentration.

– Intelligent HRI technologies: AR interfaces and digital twins

Human-Machine Interfaces (HMI), including Augmented Reality and digital twins, offer powerful opportunities to make interactions not only more efficient,

but also safer and more intuitive. AR interfaces provide visualizations of the work environment – delineating safe zones, guiding actions, supporting training and emergency response.

In this way, AI finds application in predictive maintenance – i.e. predicting when a piece of equipment will break down or start working outside of specifications. By analysing sensor data – vibrations, noise, electrical consumption, temperature fluctuations – "hidden" signs of depreciation are detected. And instead of doing expensive routine maintenance or waiting until a failure occurs, intelligent systems notify operators exactly when and what needs to be repaired. This saves huge amounts of money and prevents unexpected stops on the production line.

– Intelligent production process management

One of the most key aspects of using AI in the plastics industry is process optimization through machine learning. Algorithms analyse thousands of parameters in real time – injection temperature, pressure, cooling time and flow rate – and create models that predict deviations from the norm even before they occur. In this way, machines can automatically self-adjust, without operator intervention.

For example, AI algorithms in injection moulding machines can reduce scrap by up to 30% by detecting micro-defects that would otherwise go unnoticed during manual inspection (StandardBots, 2025). In addition, better product repeatability is achieved – especially important for high-tech components in the automotive and medical industries.

The above challenges are related to changes not only in the performance of work tasks, but also to the introduction of humanization in the "man-machine" relationship in the production of plastics, related to a change in the necessary competencies of people in the "equation". On this basis, appropriate mechanisms should be developed for training the labor resource not only in the performance of their work duties in conditions of automated robotic systems, but also in terms of "communication" and joint work with these robotic machines.

Conclusion

The application of artificial intelligence (AI) in industrial production is emerging as a key element in the evolution of modern production systems. In the context of Industry 4.5 and the growing need for automation, flexibility and sustainability, the possibilities for intelligent data processing, parameter prediction and process optimization are gaining particular importance.

The plastics manufacturing sector, characterized by diverse technological operations and a high degree of cyclicity, provides a broad base for the implementation of AI-based solutions. However, the industry faces a number of challenges that hinder the full realization of this potential. The adaptation of technological and labor processes in plastics manufacturing is based on the ability to use large data sets with high dynamics and variability, which makes it difficult

to create robust machine learning models. The insufficient use of production sensors and the lack of standardized real-time data collection further limit the possibility of a reliable digital representation of the production process in the chemical industry.

AI in plastics manufacturing is not just another technological innovation – it is the intellectual infrastructure of the new industrial era. The combination of autonomous robots, machine vision and self-learning creates conditions for higher efficiency, less waste and better quality, without excluding humans from the production process. On the contrary, it assigns them a new role – that of an "intelligent systems manager" who monitors, adapts and manages the entire digital ecosystem of the modern factory, and this requires new skills from workers in this field.

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