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INDUSTRY 4.0: SOME ASPECTS OF DEVELOPING DIDACTIC FMC

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A B S T R A C T

The paper discusses the modern concept of FMC management model intended for education in accordance with the Industry 4.0 strategy. The concept of managing didactic teaching aids should be based on intelligent interconnection of mechanical engineering, electronics and software, which contributes to the responding to the development of new technologies and business models. The integration of dozens of technologies is supported, some of which having been developed decades ago, but new technologies that are included in this concept are being developed almost daily. Mechanical engineers and specialized technicians trained on such or similar teaching aids are qualified to form cyber-physical systems in the fields of design, construction, and manufacturing.

1. INTRODUCTION

Managing flexible manufacturing systems has been of great importance since its inception, up to the present day where automation and flexibility, among other requirements, represent key aspects of computer-integrated manufacturing and Industry 4.0. Managing can be performed at different levels, starting from computer management of individual units of the manufacturing system in real-time; management of production cells, assembly cells, measurement and control cells, and transport systems, as well as coordination and control of the entire flexible manufacturing system. The introduction of new technologies that belong to the framework of Industry 4.0 (such as modern information and communication technologies, advanced levels of automation, etc.) significantly changes the concept of manufacturing systems, both in terms of their management and the functioning. That is why the model of managing didactic FMC (DFMC) is being viewed through the prism of Industry 4.0.

The fourth industrial revolution is characterized by the production of cyber-physical systems (CPS) based on the integration of data and knowledge. The main roles of CPS are to meet the dynamic manufacturing demands and improve efficiency, as well as to maximize the utilization of the entire industry. Industry 4.0 encompasses numerous technologies that are involved in horizontal and vertical integration, including radio frequency identification (RFID), the internet of things (IoT), cloud manufacturing, and many others.

The Industry 4.0 model promotes the connection and communication of physical components such as sensors, devices, and machines, both with each other and with the internet. According to M. Milosevic et al. (2019), the manufacturing process is divided into small units among which the information about successive process steps is exchanged and shared, contributing to increased flexibility and reduced coordination complexity. The goal of Industry 4.0 is to achieve higher levels of

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operational efficiency and productivity, as well as higher levels of automation. The main characteristics of Industry 4.0 are digitization, optimization, and adaptation to manufacturing requirements; automation and flexibility; human-machine interaction (HMI); and automated data exchange and communication. These characteristics not only correlate highly to the internet technologies and advanced intelligent algorithms but also indicate that Industry 4.0 is a process of creating new value and knowledge management.

The digitization of manufacturing allows people, products, and manufacturing facilities to be intelligently interconnected, creating the potential for increased quality, efficiency, and transparency in manufacturing. Simulation and virtual commissioning (Digital Twin) save time and money, providing a clear and efficient tool for training and research. It is possible to switch between the real system and the simulation in order to use the appropriate perspective for each purpose. In a modern, networked factory, machines and workpieces communicate with each other, as well as with ERP (Enterprise Resource Planning) systems and MES (Manufacturing Execution Systems). The increasing of computer power enables the analysis and classification of huge amounts of data that can be used to make profitable conclusions. The servicing of machines and equipment is facilitated and accelerated by digitization within the factory. Machines can independently order upcoming services, and automated downtime evaluation allows the efficient process improvement. Industrial robots become increasingly important when it comes to automated and optimal assembly of products and their variants. For this reason, flexible cells with robotic components/systems usually constitute the core of the entire system in CP factories. With the development of the Internet of Things (IoT), and especially with the emergence and wider availability of RFID systems and their potential applications in manufacturing, a reliable method of automatic information collection and resource identification in real-time appears. Accordingly, the product and process data can be collected, exchanged, processed, and stored in the system, and as such can be applied to improve the flexibility or desired performance of manufacturing systems, or to move towards the paradigm of intelligent manufacturing. At this point, the significant issues related to the possible application of RFID technology within flexible systems can be identified, including the development of an RFID-based framework for integrating automated manufacturing systems and management information systems in factories, where RFID technology enables real-time traceability, visibility and interoperability in order to improve the overall performance of manufacturing systems.

The use of RFID devices provides new possibilities for modeling Flexible Manufacturing Cells (FMC), opening up new directions in design aimed primarily at achieving greater flexibility. Decentralized management in FMC is based on a computer intelligence system that uses the information carried by RFID tags. This RFID tag information, using adequate software solutions, provides intelligent, adaptable, and active management in obtaining the manufacturing procedures. The data for individual processing operations (e.g. specific operations, technological procedures, quality, time, priority) can be entered via RFID technology on an adequate information carrier (tag) connected to the component, decentralizing the management process and making the process more flexible. Properly placed RFID readers in the working environment, i.e. near the manufacturing line, have the role of tracking, controlling, and detecting objects. This system based on RFID technology should potentially provide high system flexibility, which is the subject of this research.

The limited flexibility and insufficient speed response to the rapid changes in the manufacturing program in classical FMC architecture can potentially be compensated for by using RFID technology, and it is reflected in the ability increase of the subordinate computers within the system, i.e. the computers within the system gain importance in relation to the previous partial autonomous control. The flexible system gains a new role in this new situation, and the performed tasks are more complex, previously unknown to management, i.e. unpredictable, processed in real-time or, in special cases, called from the memory of the control system computer.

2. FMC STATUS (DFMC)

In the operation of classical flexible systems, in the case of didactic FMC, multiple problems arise which can be grouped into several categories. One of them relates to the weaker flexibility of the transportation system, i.e. the parts distribution, the causes of which can originate from the central control system, and it particularly shows in the case of smaller parts with more complex configurations. Another problem is related to the small number of controlled input-output functions and incomplete integration of DNC (Direct Numerical Control) into the control system. These shortcomings directly affect the modification of programs in control units, reducing the flexibility of the entire system. One possible problem within a flexible system is the temporary storage of parts in a manual warehouse.

When studying didactic flexible machining systems, the elements of the educational process must also be taken into account (safety, clarity, dual control of the process and verification of written programs, etc.), as well as the selection of adequate components that make up the system as a whole. Since there are only a few companies in the world dealing with this issue, solutions must be sought in laboratories of higher education institutions, which, in order to ensure a proper educational process, must leave certain program codes open, taking into account the specificity of integrated equipment, educational process, maintenance, machine learning, or reengineering.

3. LITERATURE REVIEW SEEN THROUGH THE FLEXIBILITY PRISM OF INDUSTRY 4.0 FLEXIBILITY

Companies strive for internal flexibility by adopting Industry 4.0 technologies. They perceive Industry 4.0 technologies as drivers of various internal manufacturing flexibility strategies. In this sense, findings show that cloud computing, big data, IoT, and data analytics (including AI techniques) affect all segments/dimensions/parameters of flexibility. Therefore, they can be characterized as general-purpose technologies or fundamental technologies that enable flexible manufacturing (Frank et al., 2019). These technologies do not provide flexibility on their own, but enable the identification and traceability of products, machines and materials, and provide real-time data on operations, allowing faster decision-making. The results of the analyzed study, as well as some others, show that achieving different degrees of flexibility largely depends on specific factors of the particular manufacturing, such as company manufacturing volume, process types, product diversity, life cycle, complexity, etc. Dalenogare et al. (2018) pointed out the results of research that show that companies seek flexibility mainly through investments in equipment. One of the key questions is: Why don't industries achieve operational flexibility as one of their main benefits from Industry 4.0? The explanation is given in the answer that the factory conditionates the investments in Industry 4.0, limiting what companies can implement for flexible manufacturing lines. The need for investment in upgrading the company's infrastructure is one of the biggest challenges in achieving flexibility, according to Contador et al. (2020). The analysis results showed that in companies with a large product range and short life cycles, the implementation of advanced technologies such as robots is hindered because they need to be frequently reprogrammed, thus increasing manufacturing time and costs. In such cases, technologies that increase the work productivity and flexibility are more productive because their workers are still the most flexible part of manufacturing system. On the other hand, the companies with great scope and low variations of manufacturing facilities demand highly automatised machines for special purposes in order to achieve market competitiveness. This compromise between productivity and flexibility is in accordance with areas of mass production, which is illustrated by problems with collaborative robots being very flexible, but ceasing to function all the time.

Worker adaptation to Industry 4.0 technologies has been the most frequently mentioned challenge for flexibility, as workers currently lack the necessary knowledge and training to handle the technologies (Dornelles et al., 2021). Industry 4.0 requires a different type of worker, capable of performing cognitive labor, including data processing, information interpretation, and decision-making (Ortt et al., 2020). Operators can also participate in design and decision-making, providing operational information for greater work flexibility. Although these technologies are important, their design is still limited for wider use. More ergonomic and flexible design allows better configuration processes and helps operators in more complex tasks (Longo et al., 2017). Despite the potential of these technologies to help workers, their use is still limited, and only a few companies use them in the production applications for specific uses, such as maintenance and quality inspection (Holm, 2018).

Material (working piece) flow flexibility offers the possibility of manufacturing products by different paths, increasing the use of a larger number of machines and reducing the time flow. Traditionally, automated material handling systems are not designed to be reconfigurable, and changes in material flow arrangements often require significant halts for physical modifications and reprogramming. By applying the technologies used in Industry 4.0, new opportunities arise for creating flexible material handling systems, manufacturing management systems (ERP, MES), and material traceability systems, which are recognized as essential technologies that allow the management of many materials within factories. Moreover, autonomous robotic vehicles such as AGVs improve flexibility in terms of the ease of programming and automatic reconfiguration of transport routes. However, their use is still limited by the physical aspects of products, such as the size and cubage of transported materials.

Companies face serious challenges in achieving flexibility in their manufacturing processes (in our discussion, machining and routing). This is mainly because these two types of flexibility depend heavily on the effort required for flexible planning and design of processes and products, such as design for manufacturing techniques. In this sense, companies define their sequence operations and routes in order to optimize manufacturing time and process quality, which limits the flexibility of the line. In the case of routing flexibility, this may happen because it requires high availability of alternative resources (Eiers et al., 2018). It has been observed that the studied companies primarily focus on increasing quality and productivity; therefore, they invest in resources for special purposes and equipment for each type of the product, limiting routing flexibility (Eiers et al., 2018). In that regard, simulation technologies can be an important tool for managers to define new route plans (Chan et al., 2006).

In flexibility operations, companies have stated that changes in the sequence of the same are still a major obstacle. Companies tend to define the manufacturing sequence in line with the technical requirements of the product or to optimize the line, making it difficult to influence changes in the sequence. Simulation tools can improve operation flexibility because they allow process modeling and analysis to find alternative sequencing of the operations. Therefore, PLM and CAD systems are useful tools for translating knowledge between fields.

The results have also shown the significance of other concepts that are factors of unforeseen circumstances for the analyzed Industry 4.0 technologies, such as modularity. These systems can be integrated with CPS for managing complex, customized manufacturing processes and rapidly adapting production capacity and functionality over time (Morgan et al., 2021). Additionally, Lean tools, ERP, and MES are expected to aid flexibility when combined with Industry 4.0 technologies (Marcon et al., 2022).

Andon systems in combination with IoT allow the equipment to respond to error warnings, stop operations, or change product routes (Rosin et al., 2020). Electronic "Kanban" (Kanban is a visual signal used to trigger action. Kanban is a Japanese word and a popular method in managing Lean flows. Roughly translated, it means "you can see the card" (Wikipedia).) can automatically detect their inventory levels and order parts, enabling a more diverse configuration for different product designs (Marcon et al., 2022). Moreover, IoT can ensure that the right products go to the right workstations and automatically redirect products in case of errors, which is part of the "Jidoka" (By definition, Jidoka is a "Lean" method widely accepted in manufacturing and product development. Also known as autonomy, it is a simple way to protect your company from delivering low-quality products or defects to your customers while trying to maintain your time pace. Jidoka relies on four simple principles to ensure that the company delivers defect-free products: detect abnormalities, stop the process, solve the immediate problem, and investigate and solve the root of its cause.) principle. The complementarity of these concepts with unforeseen company circumstances is crucial for flexibility and productivity.

4. CHARACTERISTICS OF INDUSTRY 4.0 IS INTEGRATION

One of the main characteristics of Industry 4.0 is integration. Industry 4.0 is characterized by three main types of integration: horizontal integration, vertical integration, and end-to-end integration (Kin, Liu, & Grosvenor, 2016). Liao et al. (2017) have specified these three types of integration:

- Horizontal integration is the integration of different IT systems used in various phases of manufacturing process and business planning within a company (e.g. inbound logistics, manufacturing, outbound logistics, marketing) and between several different companies (value networks) (Kusiak, 2017)
- Vertical integration is the integration of different IT systems at different hierarchical levels (e.g. sensor and actuator level, manufacturing and execution level, manufacturing control level, and corporate planning levels) for end-to-end delivery solutions; and
- Digital end-to-end integration represents integration throughout the entire engineering process so that the digital and physical worlds are integrated throughout the product value chain, as well as in different companies, while also incorporating customer requirements.

Horizontal integration in didactic conditions can be sought in the integration of similar, independent educational technological systems at different levels. This integration simulates the integration that would occur between corporations. An example of this could be the integration between institutions that possess Industry 4.0-compliant equipment and complete the given technological process. Vertical integration plays an important role in flexibility routing and operations, as the management of a flexible string of operations and routes requires an integrated system. Vertical integration enables the information about the manufacturing complexity to be automatically sent to all subsystems (workstations) during rapid production change phases. Smart machines form a self-organized system via vertical integration that can be dynamically reconfigured to adapt to different types of products, and massive amounts of information are collected and processed to make the manufacturing process transparent.

5. MULTI-AGENT DFMC MANAGEMENT SYSTEM BASED ON MACRO PROGRAMMING AND RFID

The modified block diagram of the DFMC control model based on a multi-agent structure, macro programming, and RFID is shown in Figure 1 (Gligorije, M. 2021). The main characteristics of the presented control model are:

- The carrier of technological and manipulation information is an RFID tag attached to the work piece (in cases of combination with pallet transport, the tag can be moved to the bottom of the pallet),
- Agents and multi-agents manage processes in approximately real-time (operation sequence, system reconfiguration, supervision, etc.) which increases DFMC flexibility,
- The transport system is based on a robot that has the property of reconfigurability (Reconfigurable robotic systems consist of at least two collaborative robots, one of which has the ability to be reconfigured. Reconfigurable robots and reconfiguration robotic systems are types of robotic systems that have the ability to restore their original function, completely or partially, after the partial damage of the system or the need for a change in certain characteristics. This is

achieved by making changes to individual components.),

- DFMC modularity is achieved by using different types of flexible processing and additional machines, as well as different types of transport systems,
- Open modular structure that allows combining and mixing different intelligent transport and manipulation systems in the manufacturing process,
- Openness of software codes for research and analysis purposes,
- Partial approach to adjusting and analyzing DFMC processes (belonging to Industry 3.0), etc.

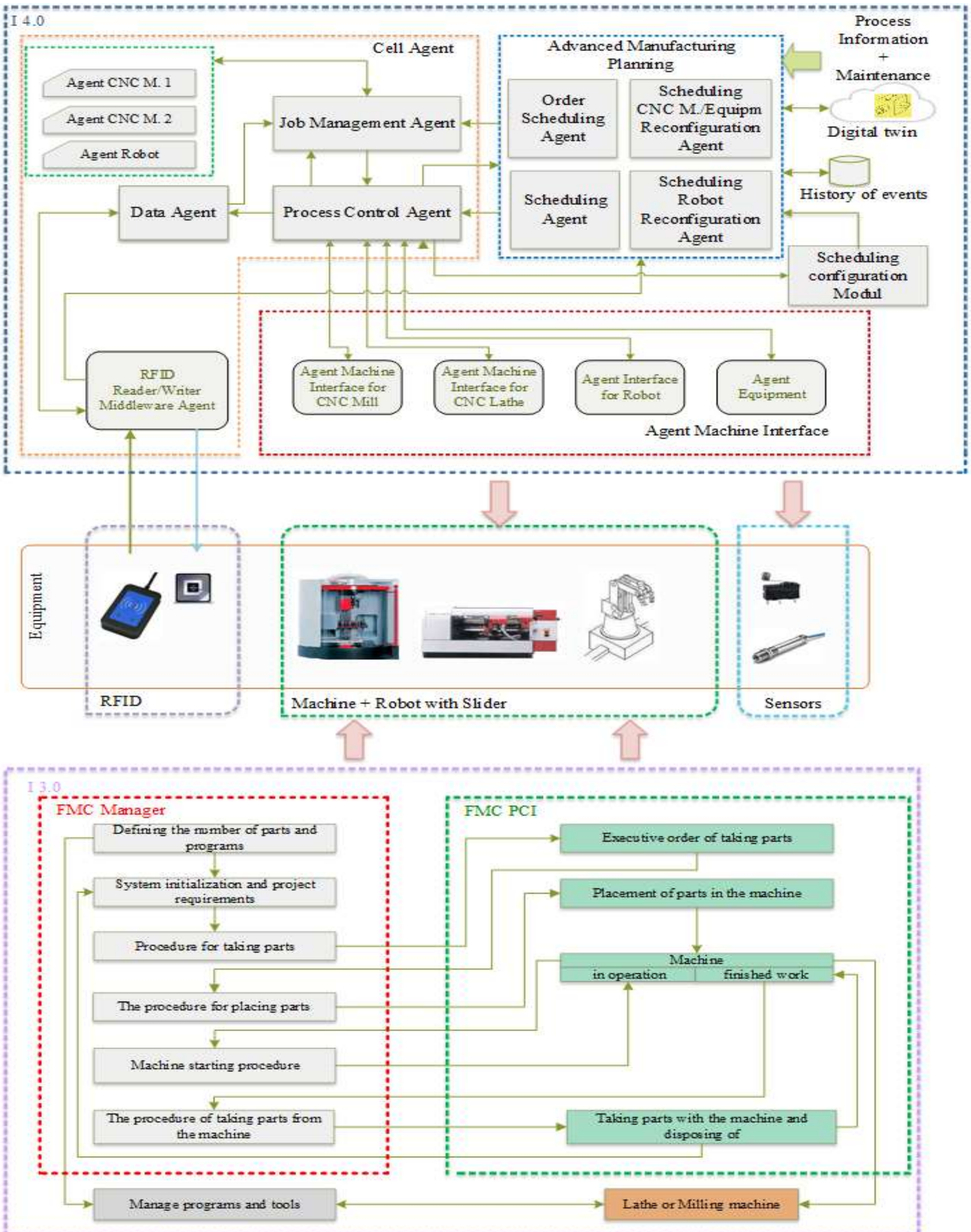

Figure 1. Block diagram of DFMC control

6. CONCLUSION

The competencies, knowledge outcomes, and skills for "smart" personnel need to be modernized and upgraded by incorporating the knowledge necessary to implement the requirements of Industry 4.0 strategy. In order to achieve this, it is necessary to provide adequate teaching aids that offer: automatic product identification, real-time process technology planning, and disburdenment of the control system, i.e. management localization. The multi-agent architecture of the proposed model for managing didactic flexible cells is capable of providing interoperability of RFID technology for a given constructive solution, as it enables a distributed system of management and supervision for DFMC. The management model has an advantage over smaller-sized parts that require fast program changes in processing (CNC machines) and manipulative systems (robots with external peripheral axes) as it tends towards adaptive, "ad-hoc" management, solving unknown and unpredictable situations. This designed model introduces a flexible cell to a higher level of management. The management model combines: technology based on agents, parametric programming of CNC machines, and flexible tools and methods in the processes of generating technological procedures and transport within DFMC.

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