FLEXIBLE MANUFACTURING SYSTEMS: INDUSTRY 4.0 SOLUTION

I.P. Gania, A. Stachowiak, J. Oleśków-Szłapka
Poznan University of Technology, Faculty of Engineering Management, Chair of Production Engineering and Logistics, Strzelecka Str. 11, 60-965 Poznan, Poland

Abstract: The development of flexible manufacturing systems (FMSs) and solutions based on flexibility idea (flexible assembly systems, flexible selection and picking systems, automated warehouses) began in the eighties of the last century. The reason for interest in solutions representing such a high level of technical sophistication and the high level of investment required at the investment stage of the unit was cost pressure perceived by industry leading countries around the world and resulting from the differentiation of customer needs [1,2,3,4]. Hence, the change was customer-driven and led to excessive and fast changes in the assortment of assembled products, manufactured parts or completed shipments. In traditionally organized production units, the consequence was the necessity to shift from production in economic lot sizes, launched more often than justified by retrofitting schedules, decrease in effective machine load (increase in setup time), ie increase in manufacturing costs, resulting from required increase in capabilities of machine operators, increase of salaries and training costs. The above mentioned factors forced the industry to start searching for ways to reduce production costs. Flexible automation has emerged as a dominant trend. The trend and solutions were recognized as having a great potential. However, they could not face challenges of contemporary market environment as separate ideas, so they were integrated into Industry 4.0, Germany's policy answer [5] to increasing complexities of manufacturing systems and mounting external environmental challenges [6]. Industry4.0 was proclaimed as the fourth industrial revolution, and became both, paradigm and strategy, and what is more a novel approach to thinking on manufacturing and the way of “how-to” transition from traditionally centralized control structures to decentralized ones [5]. In essence, Industry 4.0 is the intelligent real-time, horizontal and vertical integration of humans and machines with objects and information and communication technology systems (“digitalization”) to enable a flexible and dynamic management of complex systems [7]. More specifically, Industry 4.0 can be defined as the “[…]integration of cyber-physical-systems in production and logistics as well as the application of Internet of Things in industrial processes. This includes the consequences for the value chain, business models, services and work environment.” [8]

The paper briefly discusses the idea of flexible manufacturing system and automation, as the solution typical for the Industry 4.0, recognizes the approach of polish enterprises towards the approach and some of the trends that seem to be the future of the FMS solutions.

Keywords: Flexible manufacturing systems, industry 4.0, production systems.

1. INTRODUCTION

The development of flexible manufacturing systems (FMSs) and solutions based on flexibility idea (flexible assembly systems, flexible selection and picking systems, automated warehouses) began in the eighties of the last century. The reason for interest in solutions representing such a high level of technical sophistication and the high level of investment required at the investment stage of the unit was cost pressure perceived by industry leading countries around the world and resulting from the differentiation of customer needs [1,2,3,4]. Hence, the change was customer-driven and led to excessive and fast changes in the assortment of assembled products, manufactured parts or completed shipments. In traditionally organized production units, the consequence was the necessity to shift from production in economic lot sizes, launched more often than justified by retrofitting schedules, decrease in effective machine load (increase in setup time), ie increase in manufacturing costs, resulting from required increase in capabilities of machine operators, increase of salaries and training costs. The above mentioned factors forced the industry to start searching for ways to reduce production costs. Flexible automation has emerged as a dominant trend. The trend and solutions were recognized as having a great potential. However, they could not face challenges of contemporary market environment as separate ideas, so they were integrated into Industry 4.0, Germany’s policy answer [5] to increasing complexities of manufacturing systems and mounting external environmental challenges [6]. Industry4.0 was proclaimed as the fourth industrial revolution, and became both, paradigm and strategy, and what is more a novel approach to thinking on manufacturing and the way of “how-to” transition from traditionally centralized control structures to decentralized ones [5]. In essence, Industry 4.0 is the intelligent real-time, horizontal and vertical integration of humans and machines with objects and information and communication technology systems (“digitalization”) to enable a flexible and dynamic management of complex systems [7]. More specifically, Industry 4.0 can be defined as the “[…]integration of cyber-physical-systems in production and logistics as well as the application of Internet of Things in industrial processes. This includes the consequences for the value chain, business models, services and work environment.” [8]

The paper briefly discusses the idea of flexible manufacturing system and automation, as the solution typical for the Industry 4.0, recognizes the approach of polish enterprises towards the approach and some of the trends that seem to be the future of the FMS solutions.

2. STAGES OF DEVELOPMENT OF FLEXIBLE MANUFACTURING SYSTEMS

The manufacturing system is influenced by many different factors, which are ‘types of operations’, ‘number of workstations’, ‘automation level’, and ‘system flexibility’. Based on these factors, six general types of a manufacturing system are defined as ‘single-station manned cells’, ‘single station automated cells’, ‘manual assembly system’, ‘automated assembly system’, ‘cellular manufacturing system’ and ‘flexible manufacturing system’ [9]. Besides these six typical manufacturing systems, there are many other manufacturing systems defined by engineers, such as computer-integrated manufacturing system, reconfigurable manufacturing system, etc. With these fundamental manufacturing systems, the Industry 4.0 has been conceived.

Flexible solutions differ on account on flexibility they provide. Some focus on organizational aspects, and are based on implementing management solutions resulting in flexibility of operating time available, flexibility of competencies and operators skills (multi-skilled operators), as well as general flexibility of resources benefiting from sharing resources. The others embrace modern technologies to, in the end, obtain similar results: flexibility of time, operation and resources in general. In the literature, the most important and often discussed solutions are identified as:

- Solutions based on Japanese approach, such as linear work-in-progress flow or „zero inventory” idea [10, 1, 7, 11],
- Humanization of work environment – work in autonomous teams, work broadening and enriching, flexible working time and flexible employment forms(freelancing) [1],
- Flexible automation [12, 13, 1, 5],

In the present-day practice of the Polish machining industry, trends corresponding to all three above
mentioned classes of solutions are being successfully applied. Each of them, however, is subject to certain restrictions. The limitation of the “zero inventory” method is its low flexibility and low dissemination, in authors’ opinion resulting from the fact that its implementation is not well recognized among managers. In the case of flexibility of employment, the constraint is the resistance of employees, especially against flexible working time and flexible forms of employment [3]. On the other hand, in the case of flexible automation, the most frequently identified and obvious barrier is its high costs, to implement the solution, investments need to made [14].

Over the 30 years of development of flexible manufacturing, assembly, and logistics systems, most of the problems associated with their design, implementation and operation in the enterprise have been successfully solved, resulting in flexible production systems and complementary solutions becoming an integral part of the industrial systems in high-developed countries [13, 15, 16]. Companies have been forced not only to introduce new forms of production organization or new technologies and new production techniques, but also to move towards modernizing their resources. Examples of such activities are the solutions that allow proper allocation of functional subsystems (manufacturing, storage, transport) and their interconnection, providing a free and fast flow of material, according to FMS requirements.

In contemporary manufacturing enterprises, disregarding whether they are flexible or conventional, integration of the individual functional areas of an enterprise into an integrated computer-aided system seems to be crucial. Such integration enables through automation realization of almost all of the company's functions by computers or devices operating under their supervision. This eliminates human participation in the implementation of technological and auxiliary operations such as manufacturing, transport, storage, manipulation thanks to numerically controlled devices, and implementing information systems to control and monitoring processes [12, 2].

Implementation of automated and numerical solutions brings companies closer to Industry 4.0 requirements. The differences between contemporary manufacturing companies and industry 4.0 company are refer to the level of component, machine and production systems [17].

As far as the component is considered, contemporary companies benefit from sensors and strive for precision that can be obtained with technologies such as smart sensors and fault detection. The machines are controlled with controllers that focus on productivity and performance. The technologies implemented for machines management and maintenance are condition-based monitoring and diagnostics.

Production systems in contemporary companies are networked, and their most important attributes are productivity and OEE (Overall Equipment Efficiency). Nowadays it is believed that they can be obtained with lean approach to manufacturing and management and waste reduction.

The Industry 4.0 companies focus on different attributes, namely:

- Self-awareness,
- Self-prediction,
- Self-comparability,
- Self-configuration,
- Self-maintenance,
- Self-organization.

The technologies applied for components management include degradation monitoring and remaining useful life prediction, those referring to machines include up time with predictive health monitoring, while the production system perspective benefits from worry-free productivity. The differences are substantial and result in necessity to implement completely different approach to production system design.

Examples for Industry 4.0 could be machines which can predict failures and trigger maintenance processes autonomously or self-organized logistics which react to unexpected changes in production. Cyber-Physical Systems (CPS) are integrations of computation and physical processes [18, 19]. The basic principle of Industry 4.0 is that by connecting machines, work pieces and systems, businesses are creating intelligent networks along the entire value chain that can control each other autonomously. This is the reason why we also call the Industry 4.0 in terms like “factory 4.0” (Factory, 2015) or “smart factory” [20]. This designation is a continuation of the term “digital factory” in previous years.

The value added processes in the “factory of the future” are transparent and flexible. That also means that the production workflows, including preparation and set up time can be calculated with pinpoint precision so that free capacity can be identified, accurately measured and consistently used. However a new generation of machines is required to benefit from these new opportunities. The production plant of the future will house multifunctional machinery as well as adjustable and intelligent production facilities.

2.1. Design framework

The basis for the design of each production system is the assortment produced and complexity of production processes (both basic/core and auxiliary) to be carried out therein that is emerging from products structure and characteristics.

Realization of production processes depends on material flows and the associated information streams flow realization in the company. These, in turn, depend primarily on the type of assortment produced in the enterprise. In each production system, sets composed of a number of flow subsystems can be identified, and in each set there can be subsets of tasks, processes and their components extracted together with their space requirements. Correct design of the production system requires a number of factors to be taken into account and concerning production assortment, which is a reference to the layout of the production system being developed and the list of the production process of all functional subsystems of the flexible production system together with their allocation on the facility floor [14, 21].

- Designing production subsystem.

The manufacturing subsystem includes workstations that perform technological operations, as well as washing, inspection, changeover, etc. operations. The workstations are of various character/capabilities and include machining, preparatory, auxiliary and control stations. The basic factor determining the way a FMS is designed is an assortment of manufactured products that has a decisive impact on the solutions used not only in the manufacturing subsystem but also in the manipulation, transport and storage subsystems, which in turn determines the layout of the production system [3, 14, 22].

- Designing transportation subsystem

The transport subsystem in flexible production systems has a number of functions that enable both the transport of raw materials and materials necessary for the production process, as well as the transport of tools that ensure the implementation of the manufacturing process,
workshop equipment, post-production waste, etc. The implementation of these functions is possible through the use of various types of means of internal (inbound) transport, which have a significant impact on the layout of the developed system, including:
- numerically controlled gantry cranes for transport and handling, without the need to expand the facility floor space,
- hanging conveyors, which are used for steady flow of materials, do not interfere with the production unit space and deliver materials directly to the workspace of the workstation, however requiring the adaptation of the facility building and working space,
- Induction carts, the most flexible means of transport used in flexible production systems, but requiring adaptation of the facility to the specific requirements of the solution.

The result is determination of the type of mean of transport to be used (based on its characteristics and its suitability for the system) in the developed FMS.

### 2.2. Integration of CAD/CAM systems vs. effectiveness of company functioning

As it was mentioned above in technical production preparation of flexible manufacturing systems the key role plays an integration of computer aided design (CAD), computer aided engineering (CAE), computer aided process planning (CAPP), computer aided manufacturing (CAM), computer aided quality (CAQ). The relations are presented in the figure 1.

![Figure 1. Integration of CAD/CAE/CAPP/CAM systems within an information system of a company. Source: prepared on the basis of [3].](image)

Unquestionable are also the benefits resulting from the applied systems, like [3]:
- diminishing labor consumption of the designed products,
- product and solution quality improvement,
- possibility of optimization methods usage.

Integration of computer aided systems in design may be used doubly:
- In the first version the result of work of one of the subsystems may be passed to next systems using available IT systems e.g. LAN (local area network). So it is necessary for all subsystems to be available for mutual data collection.
- The second version consist of joining the abilities to do different design activities within one system by using work outcome of one system by the other one e.g. integrated construction design system.

Computer aided design systems (CAD, CAE, CAP, CAM, CAQ) are an inseparable element of the informational system of the whole company and have a significant influence on the functioning of other parts of the company, like [3]:
- marketing,
- sales,
- supplies,
- bookkeeping,
- finance
- production abilities of the company,
- human resources management.

Nowadays in the known by the authors companies of mechanical engineering industry, flexible manufacturing systems are applied in the process of simple product production. Such situation narrows down the production preparation to constructional and technological preparation and permits to omit the research stage. Also a unit and low-volume production type in conventional systems causes that the scope of activities which need a technical production preparation is on the one hand very narrowed down or on the other it doesn’t appear at all.

In turn flexible manufacturing systems encompassing a wide range of automation and auxiliary production operations require, in comparison with conventional production systems, a wider range of work connected with production preparation i.e. more detailed work.
4. ANALYSIS OF BENEFITS RELATED TO THE IMPLEMENTATION OF FLEXIBLE PRODUCTION SYSTEMS IN POLAND

4.1. Positive premises for using flexible manufacturing systems

In general, each production system should meet the following objectives: be able to deliver the right products at the right time, in the required quantity, at the specified quality level and at the acceptable production costs. These goals can be achieved by using flexible manufacturing systems, which in addition provide [22]:

- productivity growth - productivity of flexible production systems is significantly higher than the one of conventional production systems equipped with the same number of machines,
- decreased demand for space - high productivity of flexible production systems reduces the number of machines installed and thus the demand for space compared to conventional production systems that perform the same production tasks,
- reduced direct labor costs - centrally controlled machines do not require a permanent operator presence,
- reduction of work in progress and shortening production cycles by up to 80% compared to performing the same tasks in conventional systems.

These effects are achieved through [7]:

- high, for some flexible manufacturing systems, degree of product-based specialization leading to concentrating all the operations on the product within the system,
- reduced retrofitting time thanks to reducing the number of handlings,
- improving production control in the system through the use of IT support,
- improving quality of product by limiting operators errors and by reducing the number of handlings,
- increased quantitative flexibility thanks to possibility of maintenance-free operation of the flexible system during the off hours.

4.2. Negative premises for implementing flexible manufacturing systems

The potential benefits of implementation of flexible manufacturing systems such as high productivity, short production cycles, inventory reduction, quality growth, or rapid deployment to new production are not easy to achieve. Companies in many cases do not make the decision to implement flexible production systems, even if there are conditions supporting the decision, because they have difficulty in identifying such opportunities. Designing flexible solutions requires the involvement of highly qualified staff - specialists in many fields such as construction of machines and machine tools, technics and technology, IT, electronics, automation and quantitative methods in production planning and control. A typical machining company usually does not have such a broad staff of specialists. Companies are also not usually prepared to solve problems related to the operation of FMS. Effective use of high performance flexible manufacturing systems requires a high level of load. Which in turn requires increasing the efficiency of sales and acceleration of technical preparation of production (design of construction and technology). Problems can also arise in the sphere of maintenance and repair of the flexible system.

As the main reason for the lack of interest in the implementation of FMS quoted in the literature, is the high cost of machines and equipment required to build a flexible manufacturing system, it is the consequent need to incur considerable investment costs, much higher than in conventional production systems that prevents companies from implementing the flexible solution. Because the high capital investment factor, significantly higher than conventional production systems, is the most commonly quoted in the literature FMS restriction, its logic is presented below, in a simplified, cost-only, industry-based example. Considering two variants:

A) conventional system – lathe
- purchase price of universal lathe: about PLN 40 000
- employee - net salary of about PLN1,500/a month
- income derivatives (social security, health insurance contributions) about PLN 850/a month.
- salary with derivatives per year about PLN28 200

Total expenses under the assumption a 6-year depreciation cycle account for about PLN 209 200

B) automated system - numerically controlled lathe OKUMA
- the purchase price of a numerically controlled lathe is about PLN250 000
- salary with derivatives per year - assuming (which corresponds to actual business conditions) that employee operates three machines (multi-station work) accounts for about PLN9 400

Total expenses under the assumption of a 6-year depreciation cycle are about PLN304 400.

Hence, the cost of the automated system is 1/3 higher than the cost of the conventional system. But the structure of the cost is different. While in the case of the conventional system, personal costs with derivatives account for about 4/5 of all costs, their share for the automated variant is about 1/6. The rest in both cases is depreciation. Depreciation funds remain in the enterprise and may be used, where appropriate, for ongoing business financing or reinvestment. The problem that the manager needs solve in the presented above, simplified example is the answer to the question "Do you have to invest more to improve your business in the future?"

The authors of the paper believe that such problems are currently faced by the management of many machinery companies that are modernizing their production systems. They believe that currently the good economic conditions are suitable for introducing flexible manufacturing systems in enterprises as a competitive solution to the employment of surplus workforce. However, companies do not implement flexible production systems, even if there are conditions enabling that, because they have difficulty identifying such opportunities.

5. INDUSTRY 4.0 IN POLISH ENTERPRISES

As it was presented in the previous sections, digitalizing the production is not a new trend. It started in the 80s and spread all over the world and industries, taking the form of computer integrated manufacturing (CIM) during the early 1990s and gaining a significant momentum. CIM rested on the idea of a fully automated production process from procurement and production to distribution without necessitating human interaction [24]. CIM implementation in 90s however was not as successful as expected, mainly due to missing information and communication technology (ICT) standards [6], insufficient understanding, human resistance to change,
organizational incompatibilities, and lack of skilled labour to implement and use CIM [25]. These constraints or obstacles are nowadays dealt with, as on the social dimension, industries are experiencing a shift from an economy centered on organizations to one centered on the individual [26], and communication technology has made a great progress, benefiting from extensive use of Internet as communication on multiple levels providers (human to human, human to machine, machine to machine). Based on assistive (ambient) systems and sophisticated human-to-machine interfaces production process flexibility and employees play a key role in Industry 4.0 [6]. On the technology front, wireless communication and the Internet of Things have reached industrial maturity [11].

Industry4.0 is the strategy or the concept that is widely discussed and willingly implemented as the way to gain competitive advantage and benefit from solutions available thanks to technology development. However, according to Millward Brown research on Polish industry, almost 90% of Polish companies are not familiar with the term Industry 4.0. Those recognizing the idea are usually large companies, benefiting from foreign capital, employing over 500 people, and not representing heavy industry [27]. Polish companies however benefit from some of the solutions within Industry 4.0, even if they are not aware of it. The aspect considered in the paper is flexibility of manufacturing systems, especially the one resulting from automation. According to the research by Millward Brown quoted in the paper managers of Polish companies assess their production control systems modernity as average (5 in 10 points scale; where 1 was traditional production control systems, and 10 modern, automated, flexible production control systems. Generally it means that the solution is recognized, to some extent implemented, what is more, companies generally identify the gap between solutions available and the ones that they use. The reasons for not using the latest solutions may originate in the negative premises listed in the previous section. According to experts there is 20-30% growth potential in intelligent production networks, and the companies that refuse to follow the development and modernization will fall behind in the global competition. In the near future companies will become digital corporations, which will allow them to realize custom production with maximum efficiency according to the costumers’ demands. The prior condition for this is to allow every equipment, device, workpiece to communicate with each other [28].

6. CONCLUSION

Though the most common solutions implemented in Polish companies within Industry 4.0 spectrum are quality systems, environment protection systems, and work safety systems, some aspects of flexible manufacturing system seem to be important as well. Managers assess their control systems as modern and believe that automation clearly proves it. Hence, companies are striving for automation, benefit from Lean manufacturing methods. But Sustainability and Corporate Social Responsibility aspects are considered important. The direction in which development and innovation within companies is going seems to be on one hand considering human factor and knowledge as key drivers of innovation, on the other basing innovation on communication. Communication between machines and benefiting from the so called Fourth Industrial Revolution – linking manufacturing and Internet – seem to be the perspective of FMS development. Currently one of the major technologies supporting the communication process in the context of IoT is RFID (Radio Frequency Identification). In the areas of logistics and the supply chain, the RFID technology has been known for decades and is largely used for the tracking and monitoring of goods [29, 30]. The items using RFID tags are equipped with micro-processors and thus are detectable in the environment. It facilitates the processing of information and the interaction with other devices [31]. Other increasingly popular technologies are the NFC and Bluetooth Smart, used by beacons (corresponding to tags) - tiny devices consisting of a Bluetooth chip and a battery. The transmitter sends a specific signal, which is captured, for example, by the applications installed on smartphones that trigger the desired function, eg. checking in at a particular place [32, 33].

The potential of these solutions is great and continuously growing, which makes automation and flexibility a promising field for research and implementation.

References

[1] Gania I., 2002. Analiza celowości wdrażania elastycznych systemów produkcyjnych, czasopismo Logistyka, nr 3, wyd. IIIM, Poznań.
[2] Gania I., 2006. Analiza korzyści związanych z wdrażaniem elastycznych systemów produkcyjnych, W: Zarządzanie produkcją i logistyką, S. Grzybowska, Katarzyna, Stachowiak Agnieszka [red.], Poznań, Politechnika Poznańska, Instytut Inżynierii Zarządzania, 69-75.
[3] Gania I., Hadaś Ł., 2007. Ocena poziomu zaawansowania implementacji elastycznych systemów produkcyjnych w polskich przedsiębiorstwach przemysłu budowy maszyn, W: Dokument elektroniczny - CD-ROM, Logistyka, 1, (ISSN 1231-5478).
[4] Lis S., Santarek, K., Strzelczak S., 1994. Organizacja elastycznych systemów produkcyjnych, Państwowe Wydawnictwa Naukowe, Warszawa, 74 – 119.
[5] BMBF, (2013). Zukunftsprojekt Industrie 4.0. http://www.bmbf.de/de/9072.php.
[6] Spath D., Ganschar O., Hämmerle M., Krause T., Schlund S., Stefan G., 2013. Produktionsarbeit der Zukunft - Industrie 4.0.
[7] Bauer W., Schlund S., Marrenbach D., Ganschar O., 2014. Industrie 4.0 - VolkswirtschaftlichesPotenzialfürDeutschland, 46.
[8] Kagermann H., Wahlster W., 2013. UmsetzungsempfehlungfürdasZukunftsprojekt Industrie 4.0, 116 pp.
[9] Groover M.P., Automated assembly system, Automation, production systems, and computer-integrated manufacturing, Prentice Hall Press, 2007, 457-495. 2008-8, http://www.eecs.berkeley.edu/Pubs/TechRpts/2008/EECS-2008-8.html. Accessed: 2017-07-10
[10] http://dx.doi.org/10.1155/2016/3159805

61
[11] https://www.gtai.de/GTAI/Content/EN/Invest/_Share dDocs/Downloads/GTAI/Brochures/Industries/indust rie4.0-smart-manufacturing-for-the-future-en.pdf, accessed July 7, 2017

[12] Fertsch M., Gania, I., 2005, A simulation approach to the FMS implementation planning, CD-ROM, 17th International Conference on Production Research, Wirginia, USA.

[13] Evans P., Annunciata M., Industrial Internet: Pushing the boundaries of Minds and Machines, 2012, 37 pp.

[14] Brzeziński M., 2002. Organizacja i sterowanie produkcją, Warszawa, Agencja Wydawnicza Placet.

[15] Gania I., Hadaś Ł., 2007. Analiza opłacalności wdrażania elastycznych systemów produkcyjnych, W: Zarządzanie Przedsiębiorstwem / pod red. Eulalii Skawińskiej, Poznań: Instytut Inżynierii Zarządzania Politechniki Poznańskiej, 283-289, (ISBN 978-83-60906-05-7).

[16] Fertsch M., Gania I., 2011, Zarządzanie przepływem materiałów, WPP, Poznań.

[17] Gania I., 2001. Elastyczne automatyzacja wytwarzania jako narzędzie integrowania systemów produkcyjnych, ZNPP, nr 26, Poznań.

[18] Lee J., Bagheri B., Kao H-A., A Cyber-Physical Systems Architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters, 2015, 3, 18-23.

[19] Wan J., Yan H., Liu Q., Zhou K., Lu R. and Li D. ‘Enabling cyber-physical systems with machine-to-machine technologies’, Int. J. Ad Hoc and Ubiquitous Computing, 2013, 13, Nos. 3/4, 187–196.

[20] Edward A. Lee, Cyber Physical Systems: Design Challenges, International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing (ISORC), May, 2008.

[21] Shiyong Wang , Jiafu Wan , Di Li , Chunhua Zhang, Implementing smart factory of Industrie 4.0: an outlook, International Journal of Distributed Sensor Networks, 2016, p.7-7, January 2016.

[22] Gania I., 2003. Elastyczne Systemy Produkcyjne, Logistyka Produkcyj wodawnicwo ILIM, Poznań, 121 – 135.

[23] Gania I., Mazurczak J., 2008. Analiza efektywności techiczno – ekonomicznej wdrażania elastycznych systemów produkcyjnych, Logistyka, 2.

[24] Lenart B., Grzybowska K., Cimer M., 2012. Adaptive Inventory Control in Production Systems, Hybrid Artificial Intelligent Systems, Emilio Corchado et al. (eds.), Part II, 7209, 222-228.

[25] Bauernhansl T., Hompel M. ten, Vogel-Heuser B. (Eds.), 2014, Industrie 4.0 in Produktion, AutomatisierungundLogistik, SpringerFachmedien Wiesbaden, Wiesbaden, 9 pp.

[26] McGAUGHHEY R.E., Snyder C.A., The obstacles to successful CIM,International Journal of ProductionEconomics, 1994, 37, 2-3, 247–258.

[27] BERMANN S., Leonelli N., Marshall A., 2013. Digital reinvention:Preparing for a verydifferenttomorrow, 24 pp.

[28] „Smart Industry Polska 2016”, MillwardBrown, https://www.automatyka.siemens.pl/docs/docs_ia/S mart_Industry_raport.pdf

[29] Guban M., Kovacs G., 2017, Industry 4.0, Conception, Acta Technica Corviniensis, Bulletin of Engineering Tome X, January – March

[30] Yuen L.M., 2012, Internet of Things, Co-creating the future INFOcomm Technology Roadmap 2012, INFOcomm Development Authority of Singapore, availableat: http://www.ida.gov.sg/INFOcomm Landscape/Technology/Technology-Roadmap.

[31] Szczuka M., RFID technology, as object of researches in a group of youngpeople, Research in Logistics &Production, 2015, 5, 2, 201-209.

[32] Clausen I.U., Holloh K.D and Kadow M., 2014, Visions of the future: transportation and logistics 2030. Examining the potential for the development of road and railtransportation to 2030, Fraunhofer IML, Daimler AG, DB Mobility Logistics AG, Dortmund.

[33] Okopień P., 2014, Beacony, czyli przyszłość internetu rzeczy, a także polskiej myśli technologicznej - raport Spider's Web, availableat: http://www.spiders-web.pl/2014/09/beacon przyszlosc-technologi.html.

[34] Magruk A. The internet of things as the future technological trend of the innovative development of logistics, Research in Logistics and Production, Poznan University of Technology, 2016.