Co-funded by the
Erasmus+ Programme
of the European Union

MIND

Erasmus+ strategic partnership for Higher Education

DEVELOPMENT OF MECHATRONICS SKILLS AND INNOVATIVE LEARNING METHODS FOR INDUSTRY 4.0

IO1 REPORT

Project Title	**Development of mechatronics skills and innovative learning methods for Industry 4.0** **2019-1-RO01-KA203-063153**
Output	**IO1 - Mapping and scientific literature review on the mechatronics skills for Industry 4.0**
Date of Delivery	**January 2020**
Authors	**Dan Rusu, Alexandru Ianoși (UTCN)** **Miloš Simonović, Milan Banić (NIS)** **Erwin-Christian Lovasz (UPT)** **Dusan Krstic (CC)** **Peter Košťál, Vanessa Prajová (STU)** **Alina Băbășan, Andreea Mureșan (IHR)**
Version	**V4, 23.01.2020**

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Contents

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

1 Introduction and objectives of IO1

In order to meet the strategic objectives specific to the entry into the information society, organizations must have a flexible structure hardware and software as well as human resources that have a high degree of competence [DOR12]. A World Bank survey showed that a lack of digital and mechatronics skills within production companies is inhibiting “urgent needed” investments in Industry 4.0 technology. Industry 4.0 will require teams of people to work and hold interdisciplinary or multidisciplinary competencies to address emerging challenges. One of these requirements refers to the convergence between mechanical/electronic/software systems, and as a domain it is represented by mechatronics. The MIND project is focused on developing mechatronics skills and innovative learning methods for Industry 4.0. To meet the employment needs of the next 5-10 years, universities must train students and develop interdisciplinary skills that combine mechatronic qualification with IT knowledge and superior social skills to create 4.0 specialists.

The objectives of IO1 are:

Mapping the latest common and specific mechatronics skills needed for industry 4.0 in the countries represented in the partnership in the first part of the implementation period [COM19]. In the first part of this review, it will be done of a general image of Industry 4.0 (definition, evolution, components, state of the art, and advantages industry 4.0). Also, this chapter will also include an approach to Industry 4.0 in the partner countries of this project (RO, SRB, SK). Another subchapter will cover the limitations of the bibliographic research in which the methodology for carrying out this review will be explained as well as a quantitative and qualitative analysis of the information on this field. An important aspect of this review is the identification of the defining competencies of mechatronics in the context of industry 4.0 prior training. The skills in mechatronics are formed by a modern approach to the education process, characterized by the accumulation of competences.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Skills in mechatronics are formed from a modern approach to the education process, characterized by the accumulation of skills and competences.

At the base of the modern education systems are found principles such as: the student becomes the subject of the whole system, the use of modern teaching means, modern means of teaching, learning, evaluation (learning based on project, peer to peer learning, problematization, etc ...), developing critical thinking and problem solving. Changes in the educational system have occurred due to the evolution of society, and universities have had to adapt their methods to the demands of industry, economy, etc.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

2 Industry 4.0 and Mechatronics

2.1 Industry 4.0-General concept, definition and review method.

Throughout history, industry has become part of the national economy of any state and with the role of producing material goods, contributing to the evolution of the society of which it is a part, etc. Figure 1 shows the evolution of the industry from industry 1.0 to 4.0 where we are today, identifying the elements specific to each stage of evolution. It can be seen very well that, with the evolution of the industry over time, there has been an increase in the level of complexity of the respective industry. We can say about this evolution of the complexities, that it would be a natural one due to the increase of the consumption demand of the people forcing the industry to increase the production capacity by creating more complex systems and with a higher degree of productivity.

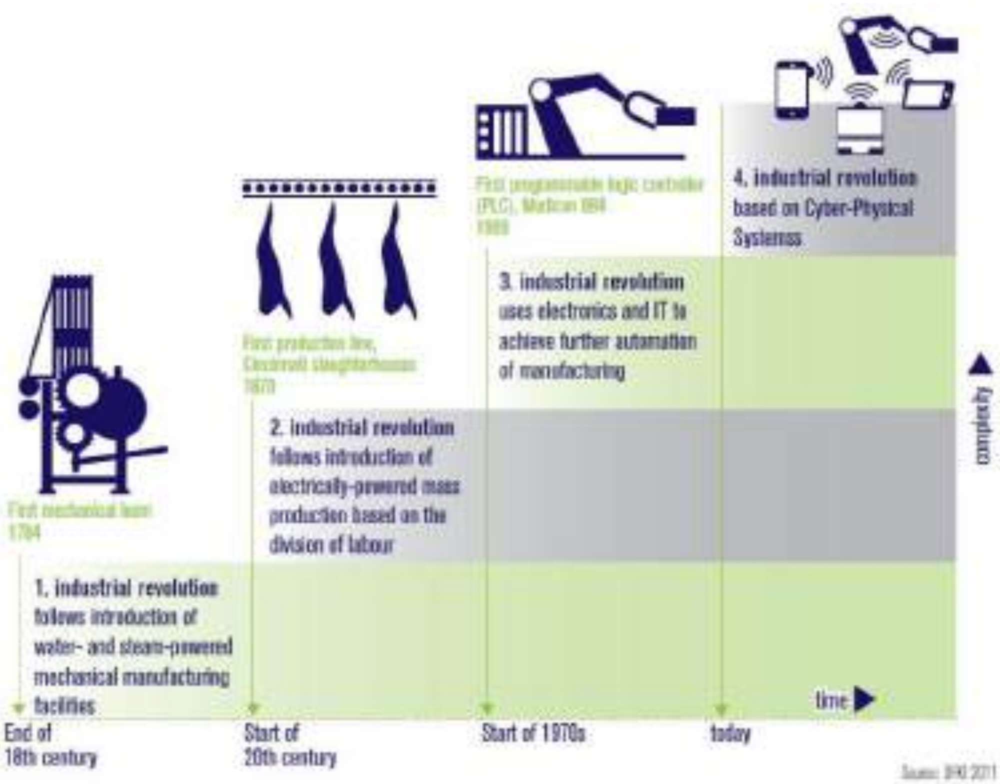

Figure 1 The evolution from Industry 1.0 to Industry 4.0 [DFK11]

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

- 1st Industrial revolution was characterized by exclusively mechanical systems, operated by steam and water. The systems were characterized by low productivity.
- 2nd industrial revolution was characterized by the use of electricity as an element for the production of movements through electromechanical systems. However, mass production was characterized by reduced flexibility during that period.
- 3rd industrial revolution, besides the mechanical or electromechanical elements, were introduced also the electronic and IT elements. One thing that greatly influenced the development of automation was the emergence of the transistor in the 20th century. This third stage of the evolution of the industry was one characterized by a high degree of flexibility due to the appearance of industrial robots, CNC machines, quality management systems, etc [FEN01].
- The 4th industrial revolution in which we are today is an intelligent one with a very high degree of automation and flexibility and which allows the production "reconfiguration" very quickly depending on the market creation.

The first appearance of Industry 4.0 concept was chosen at the Hannover Fair in 2011, and in 2013, Germany officially announced Industry 4.0 as a priority and strategic aspect of revolutionizing the industrial sector in Germany.

Definition of Industry 4.0:

Today, anyone who intends to study Industry 4.0 faces the problem of finding a definition that is generally accepted by everyone. This issue poses major problems in understanding and constructing research based on this topic. With the conceptualization of the 2011 phenomenon by Germany, they have managed to make some considerable changes in the understanding of the concept but have come to other problems and confusions [GIO20].

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

But industry 4.0 for some states is something that is in the field of the future, but it is a phenomenon that will grow more and more, and its introduction will become inevitable [RAI14]. Some of the definitions about Industry 4.0 have been extracted and will be exposed below:

1. *"Industry 4.0 represents the current trend of automation technologies in the manufacturing industry, and it mainly includes enabling technologies such as the cyber-physical systems (CPS), Internet of Things (IoT) and cloud computing*" [HER16], [JAS12], [KAG13], [LAS14], [LUY17].
2. Kagermann et al. (2013) describe their vision of Industry 4.0:

   "In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber- Physical Systems (CPS). In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management. The Smart Factories that are already beginning to appear employ a completely new approach to production. Smart products are uniquely identifiable, may be located at all times and know their own history, cur- rent status and alternative routes to achieving their target state. The embedded manufacturing systems are vertically networked with business processes within factories and enterprises and horizontally connected to disperse value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics. In addition, they both enable and require end-to-end engineering across the entire value chain" [KAG13].

2.1.1 *Industry 4.0 – State of the art:*

To study the state of the art in industry 4.0, a search was made of the articles that have the most citations on the Web of Science platform:

Table 1: Top ten articles regarding industry 4.0

№	Title	Author(s)	Year	Cit.	DOI
1	Towards smart factory for industry 4.0: a self-organized multi-agent system with big data-based feedback and coordination	Wang, SY. et al.	2016	270	10.1016/j.comnet.2015.12.017
2	Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal	Liao, YX. et al.	2017	186	10.1080/00207543.2017.1308576
3	Software-Defined Industrial Internet of Things in the Context of Industry 4.0	Wan, JF. et al.	2016	182	10.1109/JSEN.2016.2565621
4	Industry 4.0 and the current status as well as future prospects on logistics	Hofmann, E. et al.	2017	177	10.1016/j.compind.2017.04.002
5	Cloud Computing Resource Scheduling and a Survey of Its Evolutionary Approaches	Zhan, ZH. et al.	2015	164	10.1145/2788397
6	Industry 4.0: state of the art and future trends	Xu, LD. et al.	2018	146	10.1080/00207543.2018.1444806
7	A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0	Ivanov, D. et al.	2016	124	10.1080/00207543.2014.999958
8	Blockchain technology in the chemical industry: Machine-to-machine electricity market	Sikorski, JJ. et al.	2017	111	10.1016/j.apenergy.2017.03.039
9	Fog of Everything: Energy-Efficient Networked Computing Architectures, Research Challenges, and a Case Study	Baccarelli, E., et al.	2017	93	10.1109/ACCESS.2017.2702013
10	A Manufacturing Big Data Solution for Active Preventive Maintenance	Wan, JF. et al.	2017	76	10.1109/TII.2017.2670505

Industry 4.0 is yet in its infancy; there are enabling technologies, such as RFID, wireless sensor networks, cloud computing, etc. that allows its growth, but, as Xu et al. [XUL18] pointed out, there are some challenges that are to be overcome before the concept becomes mature enough: some business models does not cope well with end-to-end integration, massive interorganizational data sharing could essentially give tremendous power to an already strong business partner, especially in unbalanced consortiums; another problem identified by the cited source is related to scalability: interconnecting vast arrays of 'things' in an IoT environment floods the system with data that, without proper analyses, renders the decision making factors clueless, as decisions are made on information, not mere raw data. Consequently, data science must play an important role.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

A concurrent opinion is expressed by Hoffman and Rusch [HOF17], who asserts that the concept of Industry 4.0 lacks a commonly agreed-upon definition, which on one hand enables everyone to apply what they feel relevant to their business, but on the other hand defies on important pillar of Industry 4.0, that is IoT: without a common framework there is no hope for decentralization, self-regulation and, ultimately, efficiency across different organizations that operate in a specific ecosystem. The cited source proposes solving the problem starting from the logistic side, as in this area there would be a tangible benefit of implementing an interconnected data infrastructure that could reduce inventory cost, which makes a big enough portion of corporate spending.

Reducing the scope from big multi-partners industry conglomerates to a single factory, Wang et al. [WAN16] propose a self-organized multi-agent intelligent negotiation mechanism that would allow the transition to smart manufacturing; in such a context, fabrication evolves from a planned resource allocation, that might take long to implement and validate, to a more flexible on-the-fly resource allocation, where every node (machine, workstation, workbench, etc.) negotiate the workload and (re)configures the material flux based on goals. In such a context implementing an artificial intelligence becomes stringent.

A key concept of decentralized decision making is trust; one must be sure that there are no malevolent nodes in the network, and if this is not possible, to ensure that their action does not perturb the functioning of the entire network. A technology that has the capability of ensuring that is blockchain. Sikorski et al. [SIK17] propose a model for the electricity market which would facilitate machine-to-machine interaction that could support cost efficiency gains, as the overhead associated with billing, reconciliation, hedging and purchase agreements often constitute a large part (up to sixth) of the final electricity price. Concepts from blockchain technology are doubles the answer for building trust among weak-supervised IoT networks.

IoT path the way for Industry 4.0, by enabling a high degree of flexibility; but IoT itself needs a more flexible network architecture, which might be achieved by software defined networks. Wan et al. [WAN16a] asserts that a software-defined architecture must provide integration of the main 3 layers: physical infrastructure, control and application layer; one of the main obstacle is the lack of unified standardization of interfaces from different market actors, which inhibits deployment; another problem identified by the cited source is that data generated by a IoT network is bound to have a high market value, which might transform IoT cloud centers in predilect targets of syndicate cybercriminals or even governments actors; as such, network security is a concern, especially for low-computational nodes that, currently, are not capable of providing complex authentication methods.

Cloud computing is another important piece in the increasingly complex puzzle of Industry 4.0: regardless of how the industry evolves, cloud computing resources has already changed the way modern interaction between users and the internet takes place. Its clear that now the question is how cloud computing will influence the advent of Industry 4.0; Zhan et al. [ZHA15] identifies that the crucial point of efficient cloud computing is resource scheduling, which takes places at 3 distinct layers: application layer (efficient allocation of virtual and physical resources to maintain an optimal level of quality of service), virtualization layer (efficient allocation of physical resources with regard to energy conservation and load balancing) and deployment layer (efficient allocation of infrastrucure). The cited source identifies the following challenges that must be met for a mature Industry 4.0: real-time scheduling, adaptive dynamic scheduling, multi-objective scheduling, distributed and parallel scheduling.

A final Industry 4.0 related paradigm which will be discussed here is fog computing; the main weakness of cloud computing is its inherent centralized architecture, which amounts to delays that makes real-time intensive usage impossible in a real environment. Fog computing aims to move mission critical computations near to the network node that require it, by employing the computational resources of the nods in a distributed computation model. Baccarelli et al. [BAC17] states that a key challenge is the unpredictable nature of volume of data generated by an IoT network, making it difficult to reconfigure on the fly the network from fog computing to cloud computing.

2.1.2 Advantages of Industry 4.0

We can say that industry 4.0 has benefits over the entire production system and we can break down the advantages into several sectors of it (Figure 2). These benefits refer to the components of productivity, flexibility, agility, cost reduction, profitability and product quality. Investments in technology and advanced production equipment or improvements regarding the existing production line represent an investment that is often identified directly to the profitability of the company:

Industry 4.0 offers high productivity, which allows the company to produce more and faster with lower material resources. It also allows the elimination of dead times, as well as reducing the downtime of the machines for monitoring and optimizing the machines or the production process [KEI18].

A substantial advantage of Industry 4.0 is that it offers a high level of flexibility. By flexibility we mean the ability of a system to be able to accommodate to different changes of

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

the production flow, both from the perspective of changing the shape and dimensions of the product as well as the production process. The concept of flexibility is complex and quite difficult to define, analyze, or quantify. The high flexibility of a company can be a decisive factor in comparison to other companies that do not have a high level of flexibility. The social and economic context forced the industrial environment to adapt to the new demands and challenges in order to face the economic market. The trends of social evolution that forced the change in the industrial field are characterized by:

- Reduction of energy resources and raw materials.
- Increased level of competition in international markets.
- Increasing the level of comfort and preparation of individuals.

In order to keep up with these changes, the production industry should take into account several elements:

- Reducing material and energy costs for each product.
- Increasing labor productivity.
- Increasing product reliability.
- Reduction of design time – manufacture [DOR12].

Another advantage is the efficiency in the rapid change or reconfiguration of the production process when changing the part that is to be realized [KEI18].

Figure 2 Advantages of Industry 4.0

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Sustainability is another important factor that can be brought by Industry 4.0 and which offers manufacturers the possibility to approach modular design, engineering, manufacturing and logistics modular [AKE18]. In turn, each element has its benefits, as well as the modular design that offers the advantage of reducing the design time of a new product, lower production costs as well as higher product quality [PIR17].

2.1.3 Industry 4.0 concept in the MIND project consortium (RO, SRB, SK)

This part aims to provide a state-of-the-art stage in terms of the performance level of the member countries of the MIND project on Industry 4.0.

According to Hayriye Atik and Fatma Ünlü who wrote an article entitled "The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries" that rank the countries in terms of the level of implementation of industry 4.0. In this article the author tried to determine the relative performance according to 10 criteria extracted from the Eurostat and TUIK database. These 10 indicators are:

1. Enterprises who have ERP software package.
2. Enterprises using Customer Relationship Management (CRM);
3. Sharing supply chain management information.
4. Enterprises giving portable devices for a mobile connection to the internet.
5. Enterprises having received orders online.
6. Enterprises using software solutions like Customer Relationship Management (CRM);
7. Enterprises who have ERP software package to share information between different functional areas.
8. Enterprises with broadband access.
9. Enterprises using internet in communication with public institutions.
10. Enterprises using the Cloud Computing applications.

According to the ranking, Romania has the lowest level of performance in terms of Industry 4.0 in the European Union countries and Turkey. In contrast, Slovakia ranked 22nd

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

and Serbia ranked 27th in this top, ranking better than Romania in terms of Industry 4.0 (Table 2). Slovakia, characterized by some as a traditionalist, together with Lithuania, Hungary, Slovenia and the Czech Republic, are among the countries that have understood the trend and are moving towards Industry 4.0, proposing solutions to reach the new industrial stage. The values found in the table are between 0 and 1, and if the value obtained is close to 0 then the performance is low and if the value is close to 1 then the performance is high [HAY19].

In 2019, two important documents have been adopted in line with setting implementation of Industry 4.0 as one of key strategic elements for National industry policy of Serbia 2021-2030. The first one is "The Digital platform for Industry 4.0" as a plan of digitalization and automation of Serbian industry on all levels by using Industry 4.0 components. The second one is "The Report on Quality Analysis of Preliminary Prioritized Areas in Smart Specialization Process of Republic of Serbia" [IZV19] where Industry 4.0 and digitalization of industry is one of key priorities. These two documents will be involved in final version of strategic document "National industry policy of Serbia for period 2021-2030".

In the meantime, according to survey results presented in the article "Challenges and Driving Forces for Industry 4.0 Implementation" written by A.Vuksanović Herceg, Vukašin Huč, Veljko Mijušković and Tomislav Herceg, contrary to expectations, digitally transforming enterprises do not see human resources as a driving force, but rather as an obstacle to Industry 4.0 implementation, when they lack necessary competences and skills. Resistance to change caused by Industry 4.0 implementation is not seen as an important barrier. On the other hand, efficiency factors represent the main driving force, while the lack of competences and financial resources represent the greatest barriers to Industry 4.0 implementation. Furthermore, this survey indicates that a lack of competencies is an equal problem at the managerial and lower hierarchical levels. In addition, lack of competencies is marked as more important barrier than financial sources [HER20].

In that sense, development and improvement of technical skills and increasing competencies for Industry 4.0 become the most important challenging task and MIND primary objective is fully in line with.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table 2: Industry 4.0 Index for Turkey and European Countries [HAY19].

Country	Secondary Indicators								Industry 4.0 Index			
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)	Score	Rank
Denmark	0.8043	0.5924	1.0000	0.9623	0.9259	0.6561	0.8043	0.9545	0.8824	0.7576	0.8340	1
Finland	0.5870	0.7554	0.6364	1.0000	0.5556	0.7884	0.5870	1.0000	0.9412	1.0000	0.7851	2
Belgium	0.8696	0.8098	0.7273	0.7358	0.7778	0.8148	0.8696	0.8636	0.7059	0.4545	0.7629	3
Netherlands	0.7609	1.0000	0.5909	0.5283	0.4815	1.0000	0.7609	1.0000	0.7353	0.6667	0.7524	4
Germany	1.0000	0.9457	0.7727	0.4906	0.8519	0.9471	1.0000	0.7727	0.5294	0.1818	0.7492	5
Sweden	0.5000	0.7011	0.2273	0.8302	0.8889	0.6825	0.7174	0.8636	0.8824	0.8182	0.7112	6
Lithuania	0.6522	0.6739	0.7273	0.7547	0.5926	0.6561	0.6522	1.0000	1.0000	0.2727	0.6982	7
Norway	0.2174	0.7283	0.5455	0.8302	0.8889	0.7354	0.4783	0.6818	0.7059	0.8182	0.6630	8
Austria	0.6739	0.9457	0.3182	0.6604	0.4444	0.9206	0.6739	0.9091	0.7941	0.2121	0.6552	9
Ireland	0.3261	0.5380	0.2727	0.5660	1.0000	0.6296	0.3261	0.9091	0.8824	0.5758	0.6026	10
Portugal	0.7391	0.5380	0.4091	0.5660	0.5926	0.5238	0.7391	0.8182	0.7941	0.2727	0.5993	11
Luxembourg	0.6304	0.7011	0.4545	0.7170	0.2222	0.7090	0.6304	0.8636	0.7353	0.2424	0.5906	12
Cyprus	0.7174	0.8098	0.4091	0.3585	0.3704	0.7884	0.7174	0.8182	0.5882	0.1818	0.5759	13
France	0.6304	0.5652	0.2273	0.5849	0.5185	0.6032	0.6304	0.8182	0.9118	0.2121	0.5702	14
Spain	0.5435	0.6467	0.4091	0.6604	0.5926	0.6825	0.5435	0.8636	0.5000	0.2424	0.5684	15
Czech Republic	0.4348	0.2663	0.5909	0.6792	0.8889	0.2857	0.4348	0.9091	0.8529	0.2424	0.5585	16
Slovenia	0.4348	0.5380	0.2727	0.6981	0.4074	0.5238	0.5000	0.9545	0.8235	0.3333	0.5486	17
Croatia	0.4130	0.3207	0.7273	0.7925	0.5926	0.3386	0.4130	0.5455	0.8235	0.3636	0.5330	18
Iceland	0.0217	0.5109	0.3636	0.8679	0.7407	0.2593	0.0217	0.7273	0.7059	0.9091	0.5128	19
Malta	0.4348	0.4565	0.2273	0.6038	0.6296	0.4974	0.4348	0.7727	0.6765	0.3030	0.5036	20
Estonia	0.2609	0.4293	0.3182	0.6415	0.4815	0.4709	0.2609	0.7727	0.8824	0.4242	0.4942	21
Slovakia	0.4348	0.2935	0.5909	0.6226	0.3333	0.3386	0.4348	0.6364	0.7941	0.2727	0.4752	22
UK	0.1522	0.4837	0.1818	0.5094	0.5926	0.5503	0.1522	0.7273	0.7647	0.5455	0.4660	23
Italy	0.5652	0.5109	0.2273	0.4528	0.1852	0.5503	0.5652	0.7273	0.5882	0.1818	0.4554	24
Poland	0.2391	0.4022	0.4091	0.4528	0.2963	0.3915	0.2391	0.6818	0.7353	0.0909	0.3938	25
Macedonia	0.4565	0.5109	0.3636	0.5283	0.0000	0.3386	0.1739	0.7273	0.7059	0.0909	0.3896	26
Serbia	0.0000	0.5109	0.3636	0.5283	0.6667	0.1534	0.0000	0.9545	0.7059	0.0000	0.3883	27
Greece	0.5870	0.2935	0.3182	0.1321	0.2593	0.3386	0.5870	0.3182	0.5588	0.0909	0.3483	28
Latvia	0.1304	0.2391	0.0000	0.4717	0.1852	0.2328	0.1304	0.8636	0.8235	0.0909	0.3168	29
Hungary	0.1304	0.1304	0.0455	0.4717	0.3333	0.1534	0.1304	0.6364	0.5588	0.1515	0.2742	30
Turkey	**0.2196**	**0.0000**	**0.0455**	**0.4245**	**0.2926**	**0.0000**	**0.2196**	**0.6545**	**0.4206**	**0.2818**	**0.2559**	**31**
Bulgaria	0.3261	0.1848	0.4545	0.0000	0.0741	0.2063	0.3261	0.0000	0.5294	0.0606	0.2162	32
Romania	0.2609	0.2663	0.0909	0.0377	0.1481	0.2857	0.2609	0.0909	0.0000	0.0909	0.1532	33

2.2 The limits of our bibliographical scientific research

Web of Science, IEEExplore, Science Direct, and Google Scholar are the databases that were used in the documentation of this Industry 4.0 analysis. The information taken from these articles was of course accompanied by the citation.

2.2.1 Quantitative and qualitative analysis

From the diagram presented we can draw a very clear conclusion about the evolution and interest in this field in the last 49 years (fig. 3). The chart below extends between 1980 and 2019. The diagram shows two very important stages. These are the launch stage and the development stage. We can say that this method has not reached maturity being in the

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

current stage of development. We used as keywords in the search for "Industry 4.0" data (Source: Science Direct).

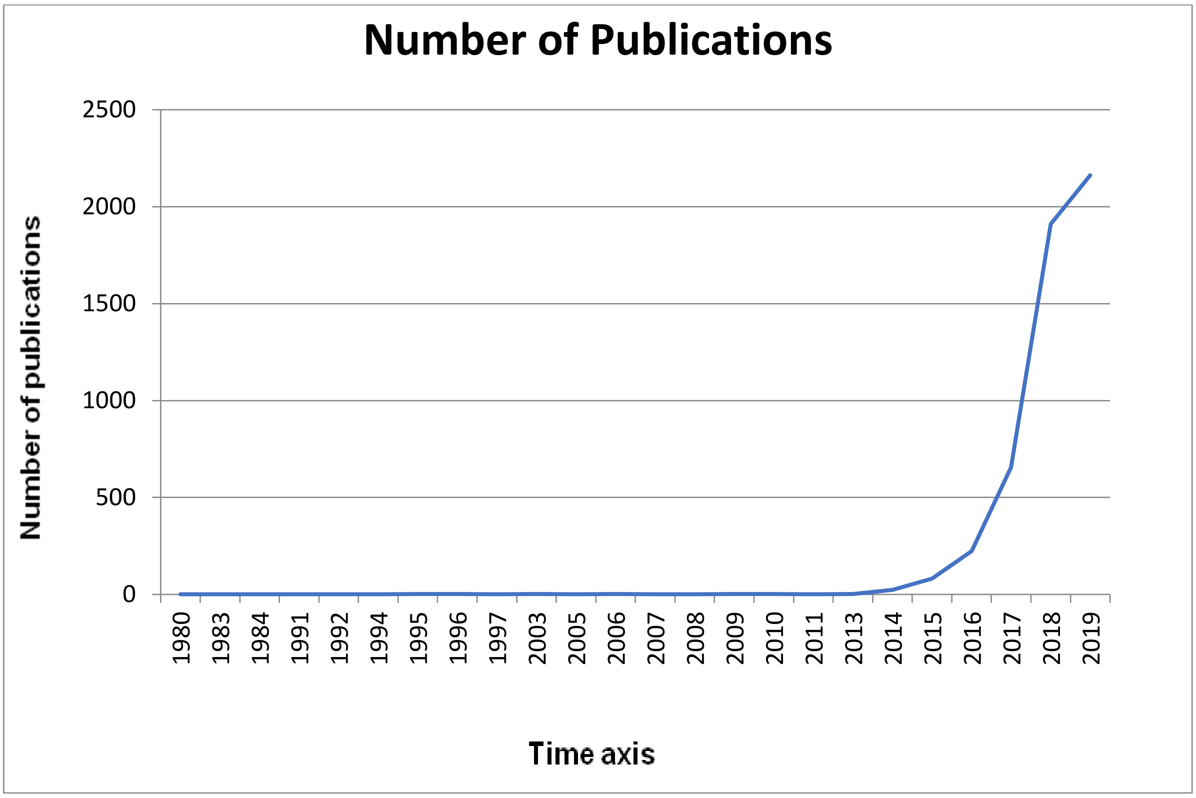

Figure 3 Number of industry-related publications 4.0 published annually on the Science Direct platform.

The beginning period of the Industry 4.0 was between 1980 and 2013, being characterized by a small number of articles published on the platform. During this period one or two articles are published each year. At that time, industry was in the third stage of evolution, and companies were slowly preparing for a fourth industrial revolution. Since 2014, articles published on the Science Direct platform have started to grow considerably. The growth was spectacular, starting with a few articles in 2014 and reaching over 2000 articles published in 2019. It is obvious that interest in this area has increased greatly, and research on Industry 4.0 has started to multiply from year to year. Industry 4.0 is still in the development stage where the concepts of Industry 4.0 are implemented, tested, optimized, simulated. It is certain that research in this field will continue intensely and the number of articles will also increase from year to year.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The change in approach of production and including services is increasingly based on the software component through IoT, sensors, industrial robots and intelligent equipment with numerical control. All these technologies and intelligent equipment produce a large amount of data that must be processed, reaching a very high level of information [CHE18]. The utility

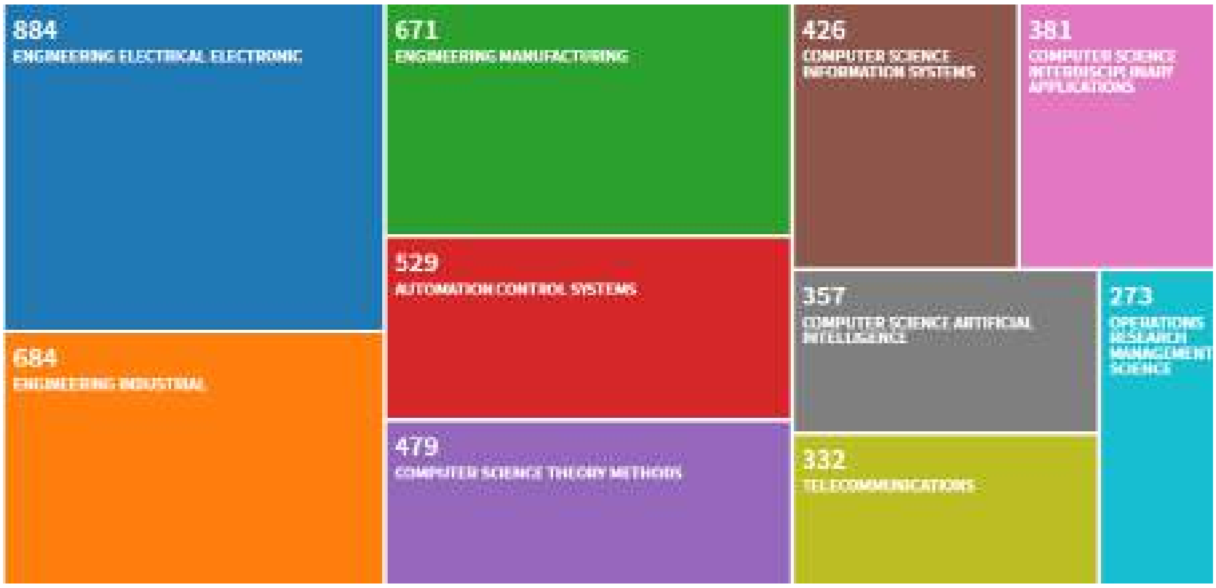

Figure 4 Number of industry-related publications 4.0 per domain, made using the Web of Science database [WWW01]

of software in industry 4.0 is a very important component, which is why many published articles are in the field of electronic engineering and computer science (fig. 4). Also, many articles have been published in the field of industrial and production engineering, which have a direct impact on industry 4.0.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Figure 5 Number of publications about industry 4.0 by source type on the Web of Science platform.

Most of the knowledge about industry 4.0 is published in conferences, followed by publications in the form of articles. Much less knowledge can be found in books or chapters of books, editorial materials, reviews or early-access. The large number of publications in conferences is very beneficial and normal because conferences play an important role in the exchange of knowledge between researchers. Another advantage for which most publications are published through conferences is the fact that it allows researchers to be aware of current trends in industry 4.0 [BOR11].

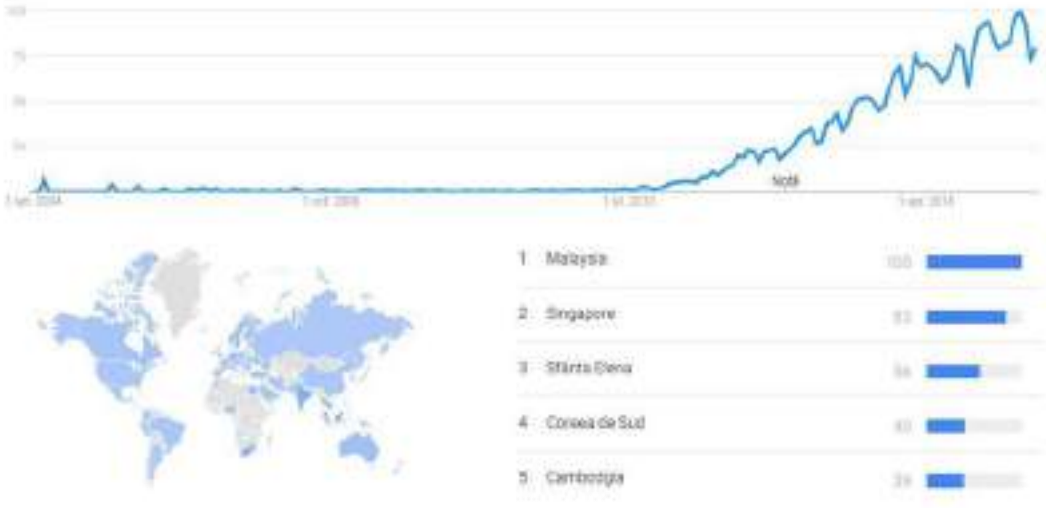

Figure 6 Google Trends analysis for search criteria "Industry 4.0"

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Using the search criteria: "Industry 4.0" on google Trends shows a big increase, especially since the end of 2013 of using this phrase in the search engine, worldwide (figure 6).

The graph is somewhat similar to the one in figure 3, in which we can easily identify the evolution of the number of articles, as well as the evolution of the number of searches about industry 4.0 globally. Other interesting information from this chart shows us that the largest number of google searches on industry 4.0 has been identified in Asian countries (Malaysia, Singapore, South Korea, Cambodia).

2.3 Mechatronics skills in the context of Industry 4.0

As the industry evolved from Industry 1.0 to 4.0, the skills needed for workers increased more and more. These changes have affected operators, engineers and administrative staff. Industry 4.0 needs people with skills from interdisciplinary or multidisciplinary fields to be able to respond to future challenges. It is certain that the staff employed in the 4.0 factory must possess the knowledge and skills corresponding to the technical field as well as the software [LIV19]. According to a survey conducted by PwC Global in 2016 on Industry 4.0 among SMEs, it shows that their greatest challenge is caused by the lack of staff with digital skills, as well as the inability to train them. Many people expected that the great difficulty in achieving the goals of Industry 4.0 would be choosing the right technologies, but it seems that the skills of the workforce are an even more important aspect [PWC16]. The current education systems do not address very seriously the issues related to the accumulation of 4.0 industry-specific skills such as technical, software, as well as digital and business skills. Instead, the industry assumes a dynamic and creative role in completing the key competences needed to integrate into industry 4.0 [COM16].

Due to the fact that the industry branches differ by manufacturing, and the education system cannot cover all its fields, it is important that the employees are trained in the workplace or in the academic language of work-based learning (WBL). Of course, work-based learning is only an educational method by which individuals accumulate skills and are more

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

specific in the industrial environment. On the other hand, in the educational environment, in the university there are modern methods of accumulation of competences that can be successfully applied in achieving the proposed objectives. Project based learning (PBL), peer-to-peer learning (P2PL) are just a few of the modern methods by which individuals accumulate skills that are so important in their integration into the social and industrial environment. This new approach to the education system is part of the modern education that is characterized by the positioning of the student as a subject of the educational process, the accumulation of competences, the development of critical thinking and problem solving [ION01]. In the case of Industry 4.0, one or two skills are not sufficient to solve certain complex problems, a larger set of skills is required that includes mechanical, software and electronic components [LIV19]. Mechatronics prepares and trains individuals on a very applied and interdisciplinary basis, characteristics so important to industry 4.0. The individual studying mechatronics, in the educational process, acquires a series of basic competences in the fields of 3D design, automation, software, advanced control of electromechanical systems, databases, unconventional process control, etc.

Mechatronics as a field covers a wide range of skills required for industry 4.0. Of course, improvements and additions to the skills required are needed. In order to identify the skills needed for Industry 4.0 in the partner countries of the MIND project, we have developed a form on the Google Forms platform that we have distributed to companies in the three partner countries (Serbia, Slovakia, Romania). This form was attended by 55 companies of large, small and medium size; the majority of these companies being producers, and a small part are in the field of development research and distributors. An important part of companies operates in the automotive field, the rest being in the field of mechanical, electronic engineering. From the chart below we can say that mechatronics skills are significant and extremely important for the development of their companies (figure 7). Some companies say that mechatronics skills are not too important or not important, because these companies do not work directly with the production or mechatronics field. These companies are in the field’s related services such as consulting, palletizing, industrial construction, finance services, etc.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

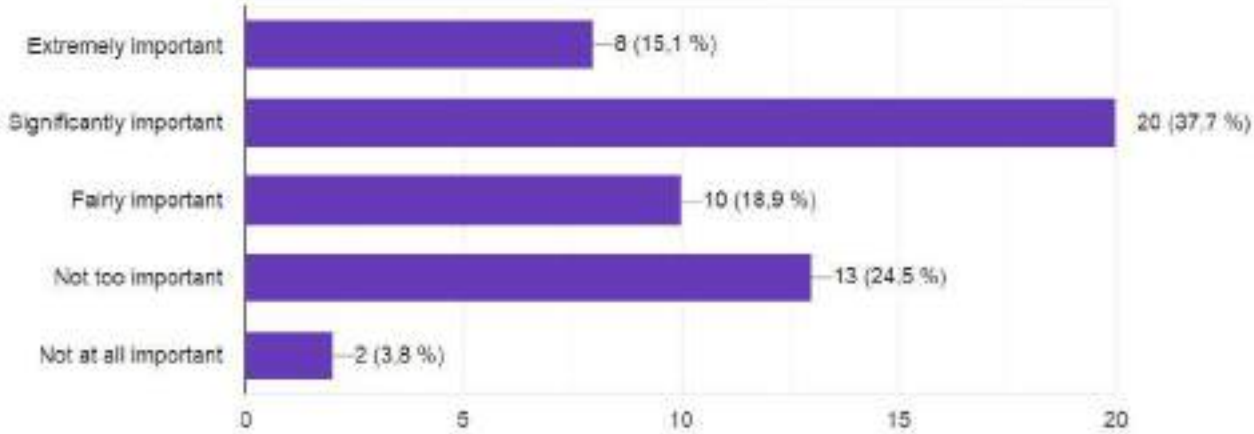

Figure 7 Importance of mechatronics skills.

The question addressed to companies regarding how well trained their employees are in the field of mechatronics, most answered that they are trained in the 1-50% range. There is also a small part of companies that claim that their employees have a very high degree of mechatronics training (figure 8).

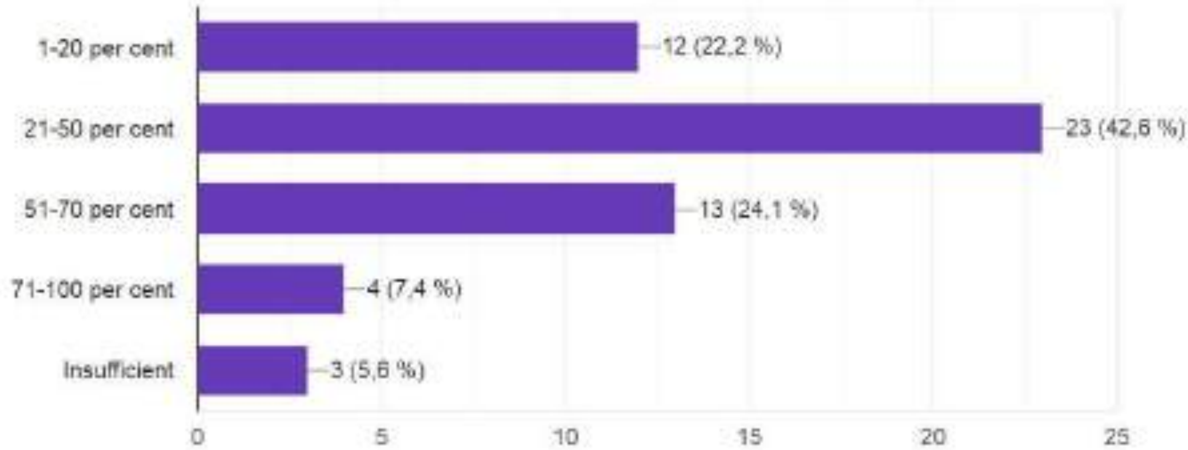

Figure 8 Training of employees in the field of mechatronics.

Most companies need a high level of mechatronics training, which is why most companies need a master's degree, followed by a bachelor's degree. A significant number of companies also need technicians who know the field of mechatronics at a lower level, but who have growth potential within the company in certain sectors (figure 9).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

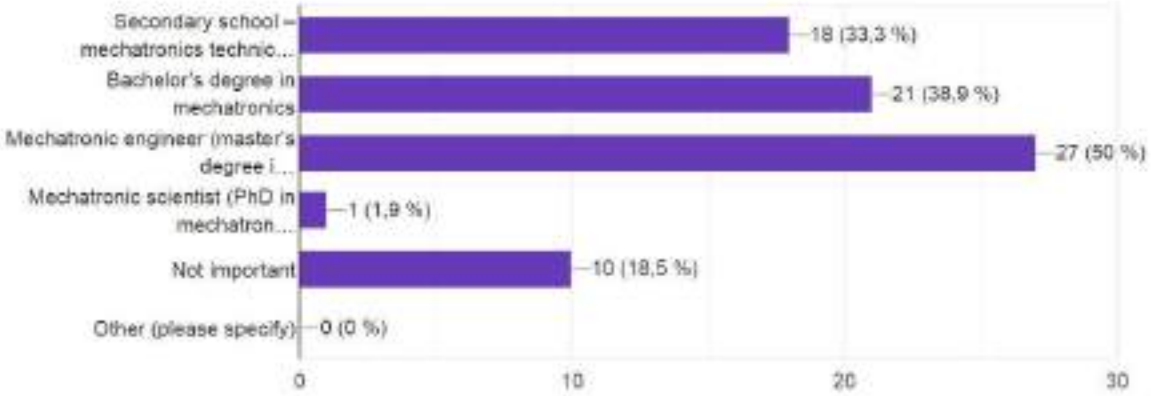

Figure 9 Level of education.

In the case of the competences that the specialized human resource must have to cope with the challenges of industry 4.0, the companies have chosen the competences of automation and those of the manufacturing technology. These two components are the majority in the preferences of the employers regarding the competences necessary to the individual in the industry 4.0. Another competency preferred by companies was ITO, due to the interconnectivity it offers between the common elements of the industrial process (figure 10).

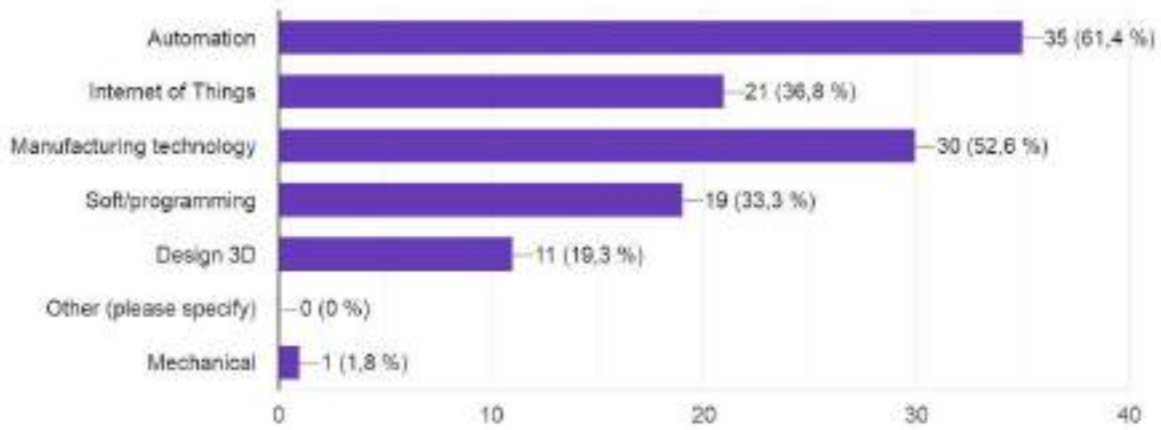

Figure 10 Required skills in industry 4.0. Choose max 2

Most companies recommend students to study more automatic control systems, as well as the mechanical part of the engineering. Also the software and electrical engineering part obtained a significant percentage.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

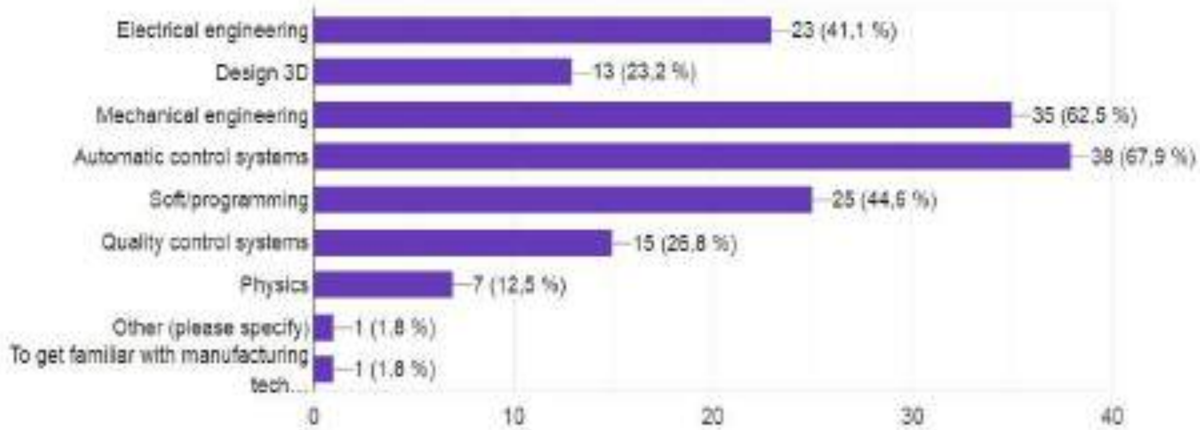

Figure 11 Important issues for students to treat seriously. Choose max 3.

Internet of things and 3D printing / additive manufacturing are the preferred courses of most companies for master's students. Companies believe that these courses would be useful to masters students, as they are a key element in reaching the 4.0 industry threshold (figure 12).

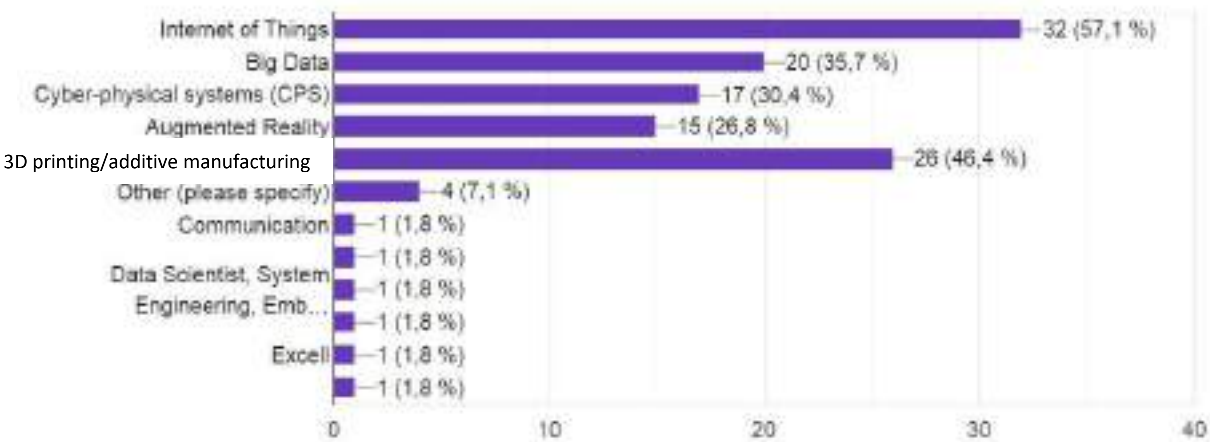

Figure 12 Useful courses for masters students. Choose max 3.

The last question addressed to companies refers to the future vision of the company, most of them focused on the implementation of the principles of lean production, as well as equipping the company with autonomous robots or the Internet of things (figure 13).

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

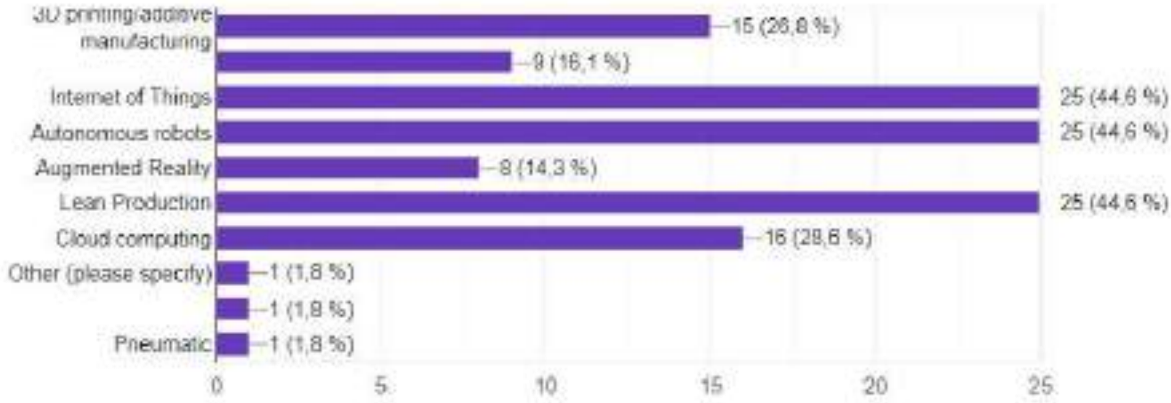

Figure 13 Future areas of interest for the company.

In the above form, an identification of the technical competences necessary for individuals to solve the problems of industry 4.0 was made. These technical skills are very important in the context of industry 4.0, but almost as important are the social skills (image source:https://medium.com/@LeadTheChange/key-competencies-for-industry-4-0-negotiation-and-creativity-2f7685f8d49f), (Figure 14 - CFI).

Figure 14 Top skills in Industry 4.0.

We can see that on the first place in 2015 and 2020 is complex problem solving as a main skill of Industry 4.0. To adopt Industry 4.0 we must be prepared to accept challenges related to the actually skill level of labor force. In the coming years the labor force will be expected to possess new skills. In that case main role has education. In the paper work

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

“From E-learning to Industry 4.0” authors induce important criteria for education in Industry 4.0 [MIK16]:

- Increasing needs on flexibility,
- University-Industry cooperation,
- Opening the learning systems,
- Shift in communication processes.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

3 Conclusions

Industry 4.0 relies on concepts that are either new or not yet fully developed: cloud computing, fog computing, blockchain, etc. Some of them have spectacularly evolved in the very recent years, but even then, Industry 4.0 its still in its infancy. Technical challenges aside, the transition to this new level will prove to be a test to the current status-quo: sharing vast amounts of information forces the industry actors to change their interaction methods, artificial intelligence decision making will render middle-management job positions obsolete, an eventual leap to a fully automated industrial park will force to rethink social norms and conventions, etc.

Since 2011 since the advent of Industry 4.0, this concept has been developed year by year. This is noted by the large number of scientific articles that have been published in this field. It is certain that this field is one of interest due to the advantages it brings over the entire manufacturing process. Some of these advantages were also included in this report. This questionnaire was addressed to the companies from the three partner countries of the MIND project.

Acknowledgments

We thank Assoc. Prof. Dr. Eng. Sergiu-Dan STAN from the Technical University for the help given in writing this intellectual result.

4 Bibliography

AKE18 M. Åkerman, Å. Fast-Berglund, E. Halvordsson, J. Stahre; *Modularized assembly system: a digital innovation hub for the Swedish smart industry Manuf*. Lett., 15 (1) (2018), pp. 143-146

BAC17 Baccarelli, E; Naranjo, PGV; Scarpiniti, M; Shojafar, M; Abawajy, JH; *Fog of Everything: Energy-Efficient Networked Computing Architectures, Research Challenges, and a Case Study; Volume: 5; Pages: 9882-9910;* DOI: 10.1109/ACCESS.2017.2702013

BOR11 Borja González-Albo, María Bordons, Articles vs. proceedings papers: Do they differ in research relevance and impact? A case study in the Library and Information Science field, Journal of Informetrics, Volume 5, Issue 3, 2011, Pages 369-381, ISSN 1751-1577, https://doi.org/10.1016/j.joi.2011.01.011.

CHE18 Chen-Fu Chien, T. Warren Liao, Runliang Dou, *Soft computing for smart production to empower industry 4.0*, Applied Soft Computing, Volume 68, 2018, Pages 833-834, ISSN 1568-4946, https://doi.org/10.1016/j.asoc.2018.05.021.

COM16 *A new skills agenda for Europe.* Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. COM(2016) 381 final. Brussels, 10.6.2016, available at: https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-381-EN-F1-1.PDF

COM19 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2019-1-RO01-KA203-063153

DFK11 https://www.dfki.de/web/forschung/projekte-publikationen/publikationen/publikation/9923/

DOR12 Dorin Telea; *Sisteme inteligente de productie*; Ed. Universitatii L Blaga; Sibiu 2012; ISBN 978-606-12-0401-4

HER20 I.Vuksanovic Herceg, V. Kuc, V.M. Mijuškovic, T.Herceg, *Challenges and Driving Forces for Industry 4.0 Implementation*, Sustainability 2020, 12, 4208; pp.1-22 doi:10.3390/su12104208

IZV19 https://pametnaspecijalizacija.mpn.gov.rs/wp-content/uploads/2019/03/4S-Finalni-izvestaj-o-kvalitativnoj-analizi.pdf

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

EMI19 G. D'Emilia, A. Gaspari, and E. Natale, „Mechatronics Applications of Measurements for Smart Manufacturing in an Industry 4.0 Scenario“, IEEE Instrumentation & Measurement Magazine, April 2019

FEN01 Feng, S., L. Li, and L. Cen. 2001. “A*n Object-oriented Intelligent Design Tool to Aid the Design of Manufacturing Systems.*” Knowledge-Based Systems 14 (5–6): 225–232. DOI:10.1016/S0950-7051(01)00100-9

GHE18 G. Gheorghe „MECHATRONICS, CYBER-MIXMECHATRONICS AND IT&C BASED ON THE DEVELOPMENT OF INDUSTRY 4.0 IN ROMANIA“ Proceedings of 2018 International Conference on Hydraulics and Pneumatics - HERVEX November 7-9, Băile Govora, Romania

GIO20 Giovanna Culot, Guido Nassimbeni, Guido Orzes, Marco Sartor, *Behind the definition of Industry 4.0: Analysis and open questions,* International Journal of Production Economics, 2020, 107617, ISSN 0925-5273, https://doi.org/10.1016/j.ijpe.2020.107617.

HAY19 Hayriye Atik, Fatma Ünlü, *The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries*, Procedia Computer Science, Volume 158, 2019, Pages 852-860, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2019.09.123

HER16 Hermann, M., T. Pentek, and B. Otto. 2016. “*Design Principles for Industrie 4.0 Scenarios*.” Proceedings of 2016 49th Hawaii International Conference on Systems Science, January 5–8, Maui, Hawaii. DOI:10.1109/HICSS.2016.488.

HOF17 Hofmann, E; Rusch, M; *Industry 4.0 and the current status as well as future prospects on logistics,* Volume:89; Pages:23-34; DOI:10.1016/j.compind.2017.04.002

ION01 Ionescu, M., Radu I, *Didactica modernă*, Editura Dacia, Cluj-Napoca, 2001

IVA16 Ivanov, D; Dolgui, A; Sokolov, B; Werner, F; Ivanova, M; *A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0;* Volume:54; Issue: 2; Pages: 286-402; DOI: 10.1080/00207543.2014.999958

JAS12 Jasperneite, J. 2012. “*Was Hinter Begriffen Wie Industrie 4.0 Steckt*.” Computer & Automation 12: 24–28. Jia, X., O. Feng, T. Fan, and Q. Lei. 2012. “RFID Technology and its Applications in Internet of Things (IoT).” In Proceedings of the 2nd IEEE International Conference on Consumer Electronics, Communications and Networks (CECNet), April 21–23, Yichang, China, 1282–1285.

KAG13 Kagermann, H., W. Wahlster, and J. Helbig. 2013. “*Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group.*” Acatech-National Academy of Science and Engineering, Germany

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

KEI18 Keith Moran; *Benefits Of Industry 4.0; 2018;* https://slcontrols.com/benefits-of-industry-4-0/

KHO18 V. A. Kholopova, E. N. Kashirskayaa, A. P. Kushnira, E. V. KuKurnasov, A. V. Ragutkina, and V. V. Pirogovb, „Development of Digital Machine-Building Production in the Industry 4.0 Concept“, Journal of Machinery Manufacture and Reliability, 2018, Vol. 47

LAS14 Lasi, H., F. Peter, F. Thomas, and M. Hoffmann. 2014. "*Industry 4.0*." Business & Information Systems Engineering 6 (4): 239–242

LIA17 Liao, YX; Deschamps, F; Loures, EDR; Ramos, LFP, *Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal*, Volume: 55; Issue: 12; Pages: 3609-3629, DOI: 10.1080/00207543.2017.1308576

LIV19 Liviu Moldovan, *State-of-the-art Analysis on the Knowledge and Skills Gaps on the Topic of Industry 4.0 and the Requirements for Work-based Learning*, Procedia Manufacturing, Volume 32, 2019, Pages 294-301, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2019.02.217.

LUY17 Lu, Y. 2017b. "*Cyber Physical System (CPS)-based Industry 4.0: A Survey*." Journal of Industrial Integration and Management 2(3). DOI:10.1142/S2424862217500142

MAC18 P. MARCON, F. ZEZULKA, Z. BRADAC, „TERMINOLOGY OF INDUSTRY 4.0“, Journal of the Technical University – Sofia Plovdiv branch, Bulgaria "Fundamental Sciences and Applications" Vol. 24, 2018

MIK16 M. Huba, Š. Kozák, "From E-learning to Industry 4.0", Slovak University of Technology in Bratislava, Slovakia, November 2016, DOI: 10.1109/ICETA.2016.7802083.

PIR17 F.A.S. Piran, D.P. Lacerda, L.F.R. Camargo, C.F. Viero, R. Teixeira, A. Dresch; *Product modularity and its effects on the production process: an analysis in a bus manufacturer*, Int. J. Adv. Manuf. Technol, 88 (5–8) (2017), pp. 2331-2343

PWC16 PWC. 2016 Global Industry 4.0 Survey, available at: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

RAI14 Rainer, Drath; Alexander Horch*; Industrie 4.0: Hit or Hype?;* Volume: 8 , Issue: 2 , June 2014; DOI: 10.1109/MIE.2014.2312079

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

RAU00 H. Rauen, J. Fleischer, R. Anderl „Guideline Industrie 4.0 Guiding principles for the implementation of Industrie 4.0 in small and medium sized businesses“

SIK17 Sikorski, JJ; Haughton, J; Kraft, M; *Blockchain technology in the chemical industry: Machine-to-machine electricity market;* Volume:195; Pages:234-246 DOI: 10.1016/j.apenergy.2017.03.039

SLU18 Ślusarczyk B., „INDUSTRY 4.0 – ARE WE READY?“, POLISH JOURNAL OF MANAGEMENT STUDIES, 2018 Vol.17 No.1

STA19 S. Stanovski, G. Ostojić, X. Zhang, I. Baranovski, S. Tegeltija, S. Horvat, “Mechatronics, Identification Tehnology, Industry 4.0 And Education“, 18th International Symposium INFOTEH-JAHORINA, 20-22 March 2019.

SUA17 S. Suárez Fernández-Mirandaa, M. Marcosb, M.E. Peraltaa, F. Aguayoa, „*The challenge of integrating Industry 4.0 in the degree of Mechanical Engineering*“, Manufacturing Engineering Society International Conference 2017, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain

WAN16 Wan, JF; Tang, SL; Shu, ZG; Li, D; Wang, SY; Imran, M; Vasilakos, AV, *Software-Defined Industrial Internet of Things in the Context of Industry 4.0;* Volume:16; Issue: 20; DOI: 10.1109/JSEN.2016.2565621

WAN16 Wang, SY, Wan, JF, Zhang, DQ, Li, D, Zhang, CH, *Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination;* Volume 101; Pages 158-168; DOI: 10.1016/j.comnet.2015.12.017

WAN17 Wan, JF; Tang, SL; Li, D; Wang, SY; Liu, CL; Abbas, H; Vasilakos, AV; *A Manufacturing Big Data Solution for Active Preventive Maintenance; Volume: 13; Issue:4; Pages:2039-2047;* DOI: 10.1109/TII.2017.2670505

WOR17 A. Wortmann, B. Combemale, O. Barais, „A Systematic Mapping Study on Modeling for Industry 4.0“, 2017 ACM/IEEE 20th International Conference on Model Driven Engineering Languages and Systems

WWW01 https://wcs.webofknowledge.com/RA/analyze.do?product=WOS&SID=C58FBP6JbvHn6He62kG&field=TASCA_JCRCategories_JCRCategories_en&yearSort=false

XUL18 Xu, LD ; Xu, EL; Li, L; *Industry 4.0: state of the art and future trends;* Volume 56; Issue: 8; Pages: 2941-2962; DOI: 10.1080/00207543.2018.1444806

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

ZHA15 Zhan, ZH; Liu, XF; Gong, YJ; Zhang, J; Chung, HSH; Li, Y; *Cloud Computing Resource Scheduling and a Survey of Its Evolutionary Approaches*, Volume: 47; Issue: 4; DOI: 10.1145/2788397

[CFI] **https://medium.com/@LeadTheChange/key-competencies-for-industry-4-0-negotiation-and-creativity-2f7685f8d49f**