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Use of Green Industry 5.0 Technologies in Logistics Activities

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Abstract: Industry 5.0 is a human-centred concept of industrial development towards the sustainable and resilient system presented by the European Union which aims to become the global both innovation and industrial leader. It should overcome the barriers of the previously presented Industry 4.0. This paper presents the research conducted in the 112 Croatian manufacturing companies, dealing with their awareness level of the Industry 5.0, as well as the use of green and digital elements in logistics activities. The results have shown that the awareness of the digital concept of both Industry 4.0 or 5.0 remains low, but the companies are more open towards the implementation of the green elements than the digital ones, with the potential for future development recognized.

Keywords: ergonomics; Industry 4.0; Industry 5.0; green industry; green logistics; logistics 4.0; sustainability

1 INTRODUCTION

Industry 5.0 is a strategy presented by the European Union to overcome the shortcomings of Industry 4.0 implementation. Regarding the many unexpected distributions of the market industry must be resilient, sustainable, and human-centred [1]. Green transition, therefore, remains imperative, with a human worker placed again in the centre of the system to improve efficiency and productivity with a special contribution to general society [2]. Physical worker remains therefore a valuable resource, but the jobs now are improved to increase safety and avoid the decrease of productivity due to monotonous repetitive tasks. Therefore, new skills and knowledge is required, to provide the optimal transition towards the new system. Lack of needed knowledge and skills was previously recognized as one of the most common barriers in the implementation of Industry 4.0, included in control, optimization, and decision-making processes rather than manual work [3]. Industry 4.0 technologies in the beginning were subject to availability and required a very high investment cost, but with time, their availability on the market has increased, while the trend of high variability and fast customization of products remained, which requires a design of systems of high flexibility and modularity with unclear predictable benefits in the future [4]. Therefore, Industry 5.0 focuses on developing a human-centered, sustainable, and resilient production system, which should answer the market demands, but also the unpredictable local and global events in society that might occur and affect the production in a negative manner [5]. Sustainability is encouraged to be achieved by using green technologies following the principles of circular economy, which also implies the use of the renewable energy resources in the production, but also a recyclable and re-useable materials, resources, and tools [6].

In this paper, the research will be conducted to get an overview of the current state of the Croatian manufacturing industry regarding the use of the green principles in the logistics activities such as warehousing, transport and picking. The implementation and awareness of green and digital elements will be examined and compared to the previous researches, not only in Croatia, but also on the global level. Based on the research results, the potential for the future development of the Croatian manufacturing companies will be presented.

2 IMPACT OF INDUSTRY 4.0 AND 5.0 ON GREEN LOGISTICS

The Web of Knowledge platform was browsed, as the most relevant database of published scientific work. The searched terms were "Green Logistics", "Logistics 5.0" and "Industry 4.0" or "Industry 5.0". The timespan was set from 2011 to 2023 since Industry 4.0 dates back to 2011. The research field was limited to "engineering, industrial", "engineering, manufacturing" and "engineering, multidisciplinary".

The green initiative in the manufacturing processes can often be used as a marketing asset, while many works in the literature deal with the relation between the actual implementation of green technologies within the manufacturing companies and the corporate brand strategy. Environmental awareness should certainly be part of the business strategy, but alongside continuous integration and evaluation of green elements [7]. Local governance regulations and taxes have an influence on the green and digital technologies implementation in the logistics processes [8]. The price of conventional vehicles, such as a carbon tax, may lead to both an increase and a decrease in environmental performance [9].

Green technologies enable significant energy savings, especially with the use of renewable energy sources. Energy management of warehousing tends to be one of the key factors in the future development of logistics activities of manufacturing companies. Industry 5.0 technologies enable the monitoring of energy consumption in real-time, as well as its optimization.

With adequate energy management, sustainable and green development can be achieved, which significantly impacts warehouse building and its management [10]. Different material handling activities have different constraints in this matter, while adopting smart automatic picking systems by Industry 4.0 standards increases energy efficiency. In this case, managerial strategies also play an important role in the adoption of available equipment to increase warehouse productivity at negligible costs [11]. When comparing manual and fully automated warehouses, it is suggested that an energy balance should be established for the material handling equipment, energy consumption for building maintenance (heating, cooling, lighting, etc.), and energy generated by the photovoltaic system on the roof. Part of the energy consumed is noticed to be spent on maintenance activities, especially in the case of facilities with a low degree of automation [12, 13]. Use of advanced optimization methods have a positive impact on energy optimization, such as genetic algorithms, hybrid simulated annealing and tempering algorithm [14] two-step optimization model based on integer programming or Mixed Integer Linear Programming [15]. This can generate higher investment costs in the beginning but enables the sustainability of the system in the future [16].

One of the key goals in the EU, but also in global environmental strategies, is the reduction of the carbon footprint. The reduction of the carbon footprint enables the decrease of overall costs and leads to economic sustainability. 10% of worldwide CO_2 emissions derive from logistical supply chains, while 20% of the overall logistical cost relates to the amount of energy required for heating, cooling, and lighting as well as material handling equipment [17]. Therefore, optimal managerial decisions should be made, for both economic benefits and environmental impacts [18].

One of the motivational factors in implementing green warehousing is social responsibility, while one of the biggest barriers was local law and regulation. Therefore, it is suggested that top management be the key initiator of green technologies implementation in the warehouse. Moreover, waste reduction through green management can improve employees' living conditions and productivity, by Industry 5.0 human-centric and sustainable standards [19].

Green transportation methods and vehicles can have a positive impact on energy efficiency and reduction of the carbon footprint but there are several challenges for the internal and external transportation system to remain efficient and achieve sustainability of a system.

Transport is referred to as the fastest-growing source of greenhouse gas emissions. It should provide environmental safety, new customer relationships, and product experience [20].

The performance of electric vehicles has numerous constraints such as battery performance, technological advances, and energy management, so routing challenges must be considered [21].

Routing optimization is also shown to be very useful in improving the environmental impact [22, 23], while the decisions on supply lead time, reorder quantities, and storage equipment also have an impact on costs and emissions [24].

Using biofuels is another way to reduce environmental impact in transport, but it also has certain limitations. The main risks can be such as lack of investor confidence in biofuel developments (the highest score); energy or fuel security issues; negative public perception of biofuels (equal second highest); increased food prices; high barriers to entry into the fuel market; and misdirected agricultural expansion or land use (equal fifth highest) [25].

Proper human interaction with technology within the human-centric systems by Industry 5.0 standards [26].

Collaborative robots in the logistics sector enable cost savings, as well as the reduction of CO_2 emissions [27], but the workplace should be designed to create a safe environment for the human worker [28].

Automatic warehousing systems are one of the green technologies and their implementation is influenced by perceived advantage, cost, technological turbulence, business partner influence, firm size, firm scope, and operational performance, especially in SMEs [29].

3 RESEARCH DESIGN

The goal of this research was to get a general insight into the current state, potentials, and challenges in the implementation of green and digital logistics activities of Croatian manufacturing companies. Therefore, a survey was created based on the theoretical framework and research results from the previously published works, explained in Chapter 2.

For the purposes of the research structuring, the following research questions were set as a guidance:

RQ1: *What is the awareness level of the Croatian manufacturing companies with Industry 4.0 and 5.0 elements and its implementation into logistics activities?*

RQ2: *What is the awareness level of the green digital elements in Logistics in the Croatian manufacturing companies?*

RQ3: *What is the perception of the implementation and use of the green and digital elements of logistics in Croatian manufacturing companies?*

The research questions lead to definition of target group of the research, which was Croatian manufacturing companies. The companies included in the research were found in the digital repository of the Croatian Chamber of Economy, which is publicly available. This was a starting point for the web search of contact of the companies. Therefore, the target group was manufacturing companies, not exclusively specialized for warehousing or transport, but with warehousing and transport as a standard part of their organizational system. The data was collected through an online questionnaire, structured in the Google Forms online application, and sent to 952 active manufacturers with available contact. The results were received from a total of 112 participants, which makes a total response rate of 11.76%. Since the survey was sent to manufacturing companies with no limitations of their industrial field, there are various types of participants, but one of the most common was from the metal machining industry (27,6%) and process industry (18%).

The survey was structured to have four parts. In the first part, basic information about the manufacturer was collected, such as the company size, years of active presence on the market, number of participant's work experience years within the current company, and if the green technologies and the use of renewable energy sources are part of the corporative brand and strategy. The second part of the survey was related to the current level of digitalization and the general use of digital technologies. Familiarity with Industry 4.0 or 5.0, the current level of digitalization within the company, challenges in the digitalization process as well as the current use of green technologies, renewable energy sources, and interest in green technologies implementation was examined. In the third part, the participants had to answer questions regarding digitalization and green technologies implementation in logistics activities. The data was collected in March 2023, while the statistical analysis was provided by IBM SPSS v27 software.

The data will be analyzed with z-test, t-test (with Bonferroni correction), and the Pearson correlation coefficient.

A z-test [31] is used to determine whether two population means are different when the variances are known and the sample size is large ($n > 30$). A z-test is used in hypothesis testing to evaluate whether a finding or association is statistically significant or not. In particular, it tests whether two means are the same (the null hypothesis). A z-test can only be used if the population standard deviation is known and the sample size is 30 data points or larger. Otherwise, a t-test will be employed.

For Null hypothesis H0: $\mu = \mu_0$ vs alternative hypothesis H1: $\mu \neq \mu_0$, two-tailed test is used.

A t-test [32] is a statistical test that is used to compare the means of two groups. It is used in hypothesis testing to determine whether two groups are different from one another. The 95% confidence interval is considered. This is the range of numbers within which the true difference in means will be 95% of the time.

The Bonferroni test is a type of multiple comparison test used in statistical analysis. When performing a hypothesis test with multiple comparisons, eventually, a result could occur that appears to demonstrate statistical significance in the dependent variable, even when there is none. The Bonferroni test is a statistical test used to reduce the instance of a false positive. The Bonferroni test, also known as "Bonferroni correction" or "Bonferroni adjustment" suggests that the p-value for each test must be equal to its alpha divided by the number of tests performed.

The Pearson correlation coefficient (r) [33] is the most common way of measuring a linear correlation. It is a number between –1 and 1 that measures the strength and direction of the relationship between two variables.

4 RESULTS

As shown in Fig. 1, more than half of the companies which participated in the survey are not yet familiar with Industry 4.0. Among those familiar with the concept, only 27.7% of the companies have already implemented certain element of Industry 4.0 or 5.0 (Fig. 2) while 28.6% did not. Size of the company is shown to be influential on the familiarity with the Industry 4.0 or 5.0 and the significant difference in familiarity has been proven between the middle and large companies compared to micro and small companies ($p < 0,05$).

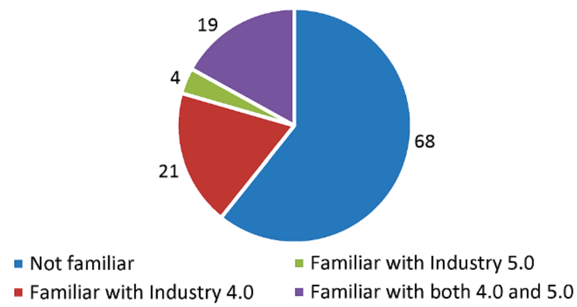

Figure 1 Familiarity with Industry 4.0 and 5.0

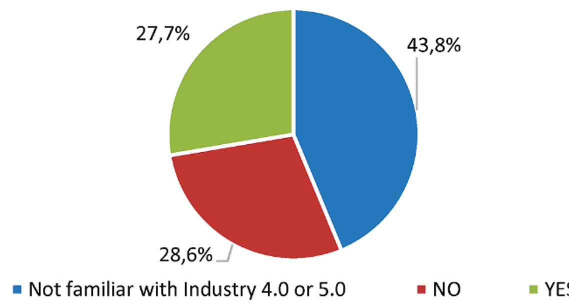

Figure 2 Implementation of Industry 4.0 or 5.0 elements (in general)

The companies have rated their interest for the digitalization with an average grade of 3.47 in which 1 represents no interest at all interest and 5 very high interest, while their approximation of the current digitalization level is 2.82, where 1 represents no elements of digitalization present in the company and 5 represents that all the processes in the company are digitalized. Regarding the use of green technologies, the average grade is 2.53 with a significant difference noticed between the companies with and without green corporate strategy. Similar difference is found regarding the interest for the implementation of renewable energy resources, which was rated with 3.48.

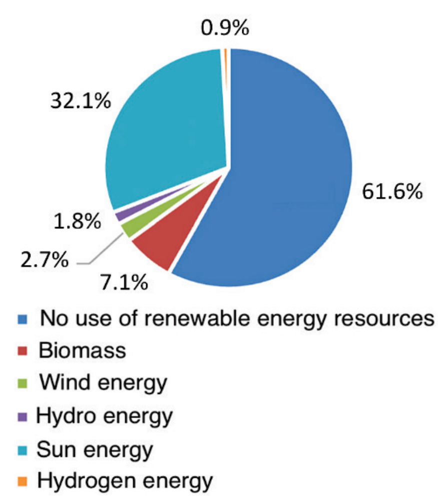

Figure 3 Use of renewable energy sources

As shown in Fig. 3, majority of the companies (61.6%) do not use renewable energy sources in their processes while most common used renewable energy source is Sun energy 32.1%.

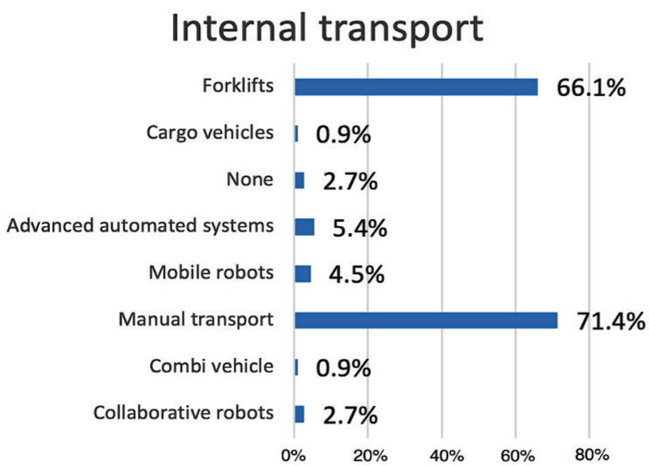

Figure 4 Use of renewable energy sources

In internal transport, most companies rely on manual transport (71.4%) and the use of forklifts (66.1%). Less than 5% of the companies use robots while only 5.4% use advanced automated transport systems.

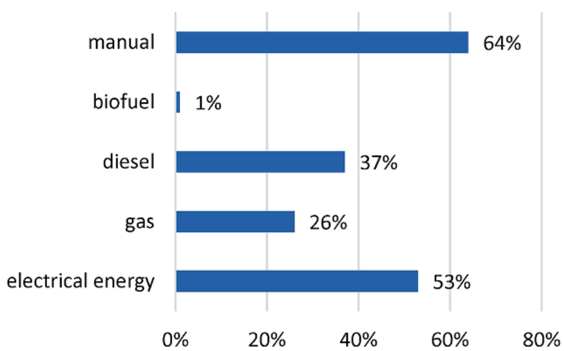

Figure 5 Internal transport drive

Results in Fig. 5 reveal that the most common drive of internal transport is manual, followed by electrical energy (53%). Only 1% of the companies use biofuel as the drive for internal transport vehicles. The need for the automatization of internal transport was rated with 2.64 where 1 represents that there is no need for the automatization and 5 that there is a very high need for automatization. There is a significant difference noticed ($p < 0.05$) regarding the company size and the presence of a green corporate strategy in the company. Similarly, the need for the implementation of renewable energy sources in internal transport is rated with 2.98, with a significant difference noticed groups those with and without green corporate strategy. The influence of the human in the internal transport is rated with 4.03, where 1 represents no influence at all and 5 very high influence.

Since Industry 5.0 is a human-centred system, with a special emphasis on human safety and well-being, the safety methods and measures in the internal logistics activities were examined. Most companies use protective footwear and clothing, while only 25% have implemented sensors for stopping the machine in cases of potential danger. The average grade of the safety of the human worker in the working area is rated 4.0.

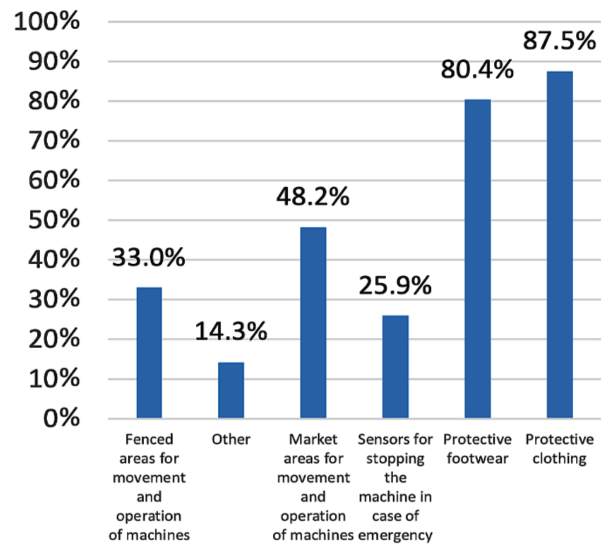

Figure 6 Safety methods and measures in internal logistics

Regarding reusable containers, pallets, and other material handling equipment, 79.5% of the companies have stated that they use it on a regular basis, with no significant differences noticed between the groups. The level of resource recycling is rated at 3.40 where a significant difference is noticed between the companies with and without green corporate strategy. The monitoring of the energy efficiency of the internal transport vehicles is rated at 2.48.

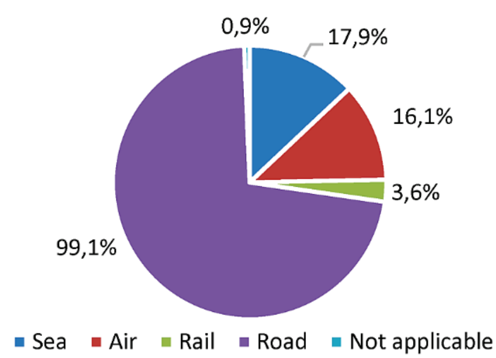

Figure 7 External transport methods

When it comes to external transport, most of the companies in Croatia use road transport, as could be expected since this kind of transport is the most common with the highest proportion among the other transportation possibilities. This is why 92% of the companies use diesel fuel for the drive of external transport vehicles, only 5.4% use electrical driving while 2.7% use gas. The need for autonomous vehicles is low, rated with 1.95 with a significant difference noticed between those familiar and unfamiliar with Industry 4.0 or 5.0. 60.7% of the companies do not track the driver's condition in real-time, while 39.3%

claim that they do. The predicted savings of the implementation of the green technologies in outer transport is rated with 2.49 where 1 represents the prediction of the minimal savings and 5 very high savings.

5 DISCUSSION

Industry 4.0 was presented back in 2011, so for more than ten years it is present and known on the market. The evidence of its complete implementation in the manufacturing system on a global level remains low, although the implementation of certain elements becomes more common over time. Yet, as the research results have shown, 60% of participants are not even familiar with this term. Compared to the previously conducted research, from 2020 [33], the number of those unfamiliar with Industry 4.0 has increased, which answers RQ1. The same time, previous research was focused on the metal machining industry in which only 46% of the participants were not familiar with the term. On the other hand, in the research conducted in 2016, the average maturity level of the Croatian manufacturing industry is calculated as 2.15 [34], which means that, in average, Croatian manufacturing companies haven't reached the 3rd industrial revolution yet, which implies the use of computer technology. The current perception of the digitalization level of Croatian manufacturing companies is 2.82, which could not be described as a very high perception of digitalization, which means that there are many opportunities for improvement. In this research, no correlation was found between the level of digitalization or familiarity with Industry 4.0/5.0 and the level of interest in implementing renewable energy sources in the company. Interestingly, 70% of the participants have green technologies implemented in the corporate brand or strategy. The higher awareness of digital and green elements and the interest for its implementation was noticed within the companies, which have a green corporate strategy, and in many cases, the significant differences were found compared to those without green corporate strategy, which answers RQ2. The role of the human in the system remains high, with a large percentage of manual transportation (71.4%), while also the perceived level of safety of the worker is high (4.08), along with their awareness of safety measures and regulations (4.02), which can be a good starting point in transition towards the human-centred Industry 5.0 concept. The use of the renewable energy resources are more common in the internal than in the external transport, mainly due to the better availability of the technology (i.e. electric forklifts). The interest for the use of renewable energy resources in the external transport, or even advanced autonomous vehicles remains low, as well as the prediction of the possible savings by its implementation, which answers RQ3.

Interestingly, when observing the results, the medium and large companies in Croatia have shown a bigger interest and awareness towards the digital and green technologies. They were observed as a single group compared towards the micro and small companies. The interest in digitalization of the processes is approximated with 3.42, while those from the micro companies have an approximation of only 2.64.

The financial barrier as in very high investments when implementing digital and green elements does not seem to be a most common barrier within the Croatian companies. The lack of time to develop and implement new technologies and, unavailability of the technologies on the current market and workers' resistance to change have been found as the greatest barriers in implementation of Industry 4.0 or 5.0. The average influence of rate of energy price towards the final product is 3.40, the highest in medium and large companies (4.0) and the lowest again in companies without green strategy (2.88). They perceive customers as not ready to pay for the implementation of green technologies, with an average grade of 1.79, with a difference noticed between the groups in green strategy (1.5/1.92; $p = 0.026$).

The results of the research could lead to the development of a future strategy for the transformation of the Croatian manufacturing industry towards a green, sustainable, and resilient system by the Industry 5.0 standards. The first step s raising awareness about the concept since familiarity among the companies remains low. Especially it is important to direct the companies towards the human-centred system to overcome the barriers and challenges of Industry 4.0. The ratio of human manual work remains high, which could be a positive aspect to continue the development of new skills and knowledge of human workers. Special caution should be aimed toward the ergonomic design of a workplace and human well-being for motivational level to remain high which directly impacts the productivity. The awareness of a green digital transition is on a relatively satisfactory level, while in many parts the significant difference in the groups of those with or without green corporate strategy is noticed, both regarding the implementation green elements of the elements of Industry 4.0 or 5.0. Green and digital can lead to the positive future development of the industry with a high competitiveness not only on the local, but also on the global market.

6 CONCLUSION

Industry 5.0 is not only a trending concept but is also a needed goal for companies to achieve to remain sustainable and resilient, to keep the human as the most valuable resource in the centre of the manufacturing system, and to remain competitive in the market. Industry 5.0 elements should therefore be implemented in all the segments of the manufacturing companies, such as the logistics with its processes and activities. The digital concept demands nowadays the implementation of green elements whose combination leads to enabling the sustainable development of the company and the local and global industry. The results have shown that the awareness within the Croatian manufacturing companies about Industry 5.0 remains relatively low, while the companies are more open towards the green elements and their implementation rather than the digital. Renewable energy resources are rarely used, as well as energy efficiency tracking, but reusable and recyclable pallets, containers, and other material handling tools are often used. In internal transport, the electric drive of vehicles is being used, but the energy is not directly coming from renewable sources. The other transport depends on road and diesel fuels while the majority of those with green corporate strategy recognizes the positive impact of future renewable energy resources implementation. As for future work, according to the results, the model for the strategic transformation of a single company towards the green Industry 5.0 should be developed.

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