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Review

Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions

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Abstract: The human–machine relationship was dictated by human needs and what technology was available at the time. Changes within this relationship are illustrated by successive industrial revolutions as well as changes in manufacturing paradigms. The change in the relationship occurred in line with advances in technology. Machines in each successive century have gained new functions, capabilities, and even abilities that are only appropriate for humans—vision, inference, or classification. Therefore, the human–machine relationship is evolving, but the question is what the perspective of these changes is and what developmental path accompanies them. This question represents a research gap that the following article aims to fill. The article aims to identify the status of change and to indicate the direction of change in the human–machine relationship. Within the framework of the article, a literature review has been carried out on the issue of the human–machine relationship from the perspective of Industry 5.0. The fifth industrial revolution is restoring the importance of the human aspect in production, and this is in addition to the developments in the field of technology developed within Industry 4.0. Therefore, a broad spectrum of publications has been analyzed within the framework of this paper, considering both specialist articles and review articles presenting the overall issue under consideration. To demonstrate the relationships between the issues that formed the basis for the formulation of the development path.

Keywords: human–machine relationship; human–machine collaboration; human-oriented manufacturing; Industry 5.0; human factor

Citation: Pizoń, J.; Gola, A. Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions. *Machines* **2023**, *11*, 203. https://doi.org/10.3390/machines11020203

Academic Editors: Raul D.S.G. Campilho and Francisco J. G. Silva

Received: 10 December 2022
Revised: 16 January 2023
Accepted: 23 January 2023
Published: 1 February 2023

1. Introduction

With the advent of new revolutions and changes within manufacturing paradigms, the human–machine relationship becomes critical [1,2]. This change is taking place whether in technical, social, organizational, or ultimately legal and ethical dimensions [3]. The machine-human relationship has evolved over the centuries. Nevertheless, it was with the advent of machines that people began to delegate manual work (or that performed by humans) to machines. However, the delegation did not mean a complete handover of work to machines. Machines were and are still supervised by humans [4]. The degree of delegation was directly dependent on the technical level of the machine in question [5]. As technology changed over time, so too did the capabilities of machines become available [6]. Machines, over time, gained a new form of propulsion—from steam power to electricity). Simple electronic circuits with the ability to control machines were introduced [7]. Sensors were added, which allowed better monitoring as well as reporting of machine status [8]. Or, finally, machines were integrated into the Industrial Internet of Things network so that they could be constantly monitored [9]. The amount of data available on the machines and their condition would allow the use of advanced analytical methods, including artificial intelligence methods (deep learning) [10]. At the same time, this was only possible with the use of advanced information system solutions enabling the processing of multidimensional production data sets. In this respect, CPS and digital twin technologies are increasingly being used [11,12].

The implementation of these technologies made it possible that the supervision of machine operations not to require significant work [13]. To a certain extent, machines have become or are becoming autonomous. Consequently, the portion of work delegated to them can increase [14]. For this reason, the human–machine relationship is changing and is directly dependent on the level of technology [15]. The more machines can act autonomously, the more work is delegated to them. At the same time as technology was changing, production paradigms were also changing [16].

The human–machine relationship was dictated by human needs and what the market dictated at the time. While this relationship was difficult to demonstrate in ancient times, technology has been serving people since after the Second World War. Its changes are strictly dependent on people's needs. Hence, the question arises as to what the perspective of these changes and what trend accompanies these changes. This question constitutes a research gap, which the following article aims to fill. The article aims to identify the status of change and to indicate the direction of change in the human–machine relationship.

The task of the authors within the framework of this paper is to identify the perspective and development path (roadmap) for the human–machine relationship. To achieve this objective, a literature review was carried out to identify visible directions and perspectives of the human–machine relationship concerning the industrial revolutions and industry 5.0 [17]. A concept development plan was then drawn up, considering contemporary conditions as well as trends around robot-machine collaboration.

2. Industrial Revolutions

Regarding changes affecting production, it has been accepted to distinguish industrial revolutions [18]. The basis for distinguishing a revolution is to indicate the technological breakthrough that caused a rapid increase in production or development in the organization of the production process. Subsequent technological solutions introduced new possibilities, which historically formed the basis for distinguishing revolutions (Figure 1).

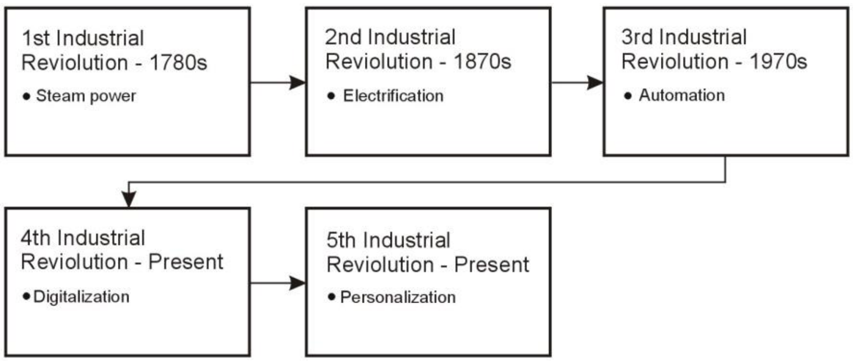

Figure 1. Industrial revolutions and their outcomes [19].

Electrification, which made it possible to transmit energy over long distances, separating where it was generated from where it was used. Or through automation, which has made it possible for machines to adapt to changing conditions and carry out repetitive work without human supervision. Or, finally, the digitalization that underpins Industry 4.0, which ensures the use of information technology in the continuous processing of real-time production data to seek optimization [20]. Personalization, on the other hand, forms the basis for distinguishing the next revolution referred to as Industry 5.0 [21]. Among the revolutions, the current ones will be detailed.

2.1. Industry 4.0

The industry 4.0 revolution was announced in 2011 at the Hannover Fair [22]. Industry 4.0 was created at the initiative of the German government as part of a strategic project to transform manufacturing factors with physical systems into manufacturing factors with cyber-physical systems [23,24]. Industry 4.0 revolution combines IoT, cloud computing, analysis of multidimensional data sets (Big data), artificial intelligence (AI), blockchain, and other high technologies into a high degree of automation and manufacturing [25].

It can offer the manufacturing environment opportunities for self-awareness, self-learning, autonomous decision-making, self-realization, and adaptation to production. Industry 4.0 integrates the production systems of various smart factories into a value chain in the form of a CPS, to obtain real-time data and make decisions for production. A CPS production system is characterized by a high degree of flexibility, adaptability, and agility [26].

2.2. Industry 5.0

Despite the enthusiasm of companies regarding Industry 4.0 pursuing the concept of the Smart Factory [27,28], both researchers and representatives of institutions have noted that this concept ignores a very important aspect related to productionthe human aspect. Industry 4.0, while focusing on the work of machines and their optimization, marginalizes the participation of people in the process implementation. This is understandable because of economic aspects or even because of employee safety. On the other hand, it should not be forgotten that it is people who are the source of disruptive innovations, i.e., solutions that have the effect of changing the manufacturing paradigm.

What is more, people can make associations of facts, technology features, and production conditions that lead to key improvements and competitive advantages at the manufacturing know-how level, in a way that is completely inaccessible to machines.

Here it is also very important to emphasize that machines have a very high capacity for analysis, if data is available. In the absence of aggregated data, there is no possibility to use it. On the other hand, people tire quickly, make mistakes, and need time to be trained before they can carry out a specific production. Nevertheless, they can make items not only guided by technical parameters of materials, equipment, and standards but above all by technical intuition. Given the above, it seems that the best solution is a synergy effect, a combination of the efficiency and reliability of machines together with the innovation of people expressed by the so-called 'human touch'. This is the basis for the announcement of the next industrial revolution, numbered 5.0.

Industry 5.0 is defined as an evolution that aims to harness the creativity of human experts working together with efficient, intelligent, and precise machines [29]. Saeid Nahavandi, on the other hand, points out that Industry 5.0 brings the human workforce back into the factory, where man and machine are paired to make processes more efficient, harnessing human brainpower and creativity by integrating workflows with intelligent systems [30].

Industry 5.0 brings human–machine collaboration to a new level. Industry 5.0 shifts the center of gravity of manufacturing from system-oriented manufacturing systems to human-oriented systems. This represents, in a way, a return to the roots of manufacturing, but aspects related to economics or sustainability remain important [31].

In addition, Industry 5.0 is a motivated change in sustainability in the area of manufacturing related to the use of creativity and human skills in collaboration with machines. At the same time, maintaining the cost criterion together with a high production volume to meet the needs reported by the market.

As a result, the customer will not have to give up his or her individual preferences in favor of cost-optimized production of the good in question—thus reducing the preferences resulting from mass production or mass customization. The prospect opens up for mass customization leading to the satisfaction of the needs of both parties, producer and consumer [32,33]. This approach to production implies the development of collaboration between machines and people. Industry 5.0 will revolutionize production systems around the world, taking tedium, drudgery, and repetitive tasks off the hands of workers. Intelligent robots and systems will infiltrate supply chains and factory floors to an unprecedented degree [30].

Importantly, Industry 5.0 is also a focus of the European Commission's commission studies. According to the commission, the strength of Industry 5.0 is a societal goal that goes beyond job creation and development to become a resilient provider of well-being by ensuring that manufacturing respects the limitations of the planet and puts the well-being of industrial workers at the center of the production process [34,35]. In addition, research conducted on the critical elements of Industry 5.0 for successful adaptation in manufacturing. The study suggests that Industry 5.0 enables smart manufacturing through the intelligent use of data by combining multiple factory data and advanced technologies, thereby producing more personalized products [36].

In addition, the literature review also identified five trends in which Industry 5.0 is heading, namely:

- Industry 5.0 in the context of assessing and optimizing the supply chain in manufacturing processes,
- Industry 5.0 in the context of business management, innovation, and digitalization,
- Industry 5.0 in the context of intelligent and sustainable manufacturing,
- Industry 5.0 transformation driven by IoT, Bigdata, and AI,
- Human–machine connectivity and coexistence [37].

Finding solutions to the management challenges posed by modern industrial revolutions will require governments, businesses, and individuals to make the right strategic decisions regarding the development and implementation of new technologies [16].

With new technological solutions, a whole new perspective is opened to meet the needs of individual customers on both large and small scales. Thus, particular revolutions have led to a change in manufacturing paradigms in terms of both volume and variety of products.

2.3. Main Differences between Industry 4.0 and 5.0

Industry 4.0 and Industry 5.0 have many common features. This is primarily due to the fact that Industry 5.0 is a development of Industry 4.0. The definition of Industry 5.0 is dominated by two basic visions. One of them concerns the technical approach (see e.g., [38]) while the second one focuses on biological aspects (see e.g., [39]). From a technical perspective, there are several elements that definitely differentiate them. The distinction between revolutions is based on questions of interest. On the one hand Industry, 4.0 focuses on digitization (i.e., the implementation of advanced data processing techniques and the implementation of advanced algorithms) mainly focusing on artificial intelligence in production. On the other hand, Industry 5.0 is described as a revolution paying special attention to the human aspect. This is due to the fact that in Industry 4.0 (if modern systems and a high level of automation are implemented) the domain of progress is innovation and creativity. Although modern advanced technologies (such as neural networks) are already able to create images or texts, the domain of production is innovation provided by people. So they are supposed to be a source of inspiration. Another field of interest is the manufacturing paradigms of both revolutions. Industry 4.0 is (thanks to vertical and horizontal integration) dedicated to the realization of mass customization ideas. On the other hand, Industry 5.0 (focusing on people) refers to new idea craft production paradigms using mobile collaborative robots. The main features that constitute the differences between the Industry 4.0 and Industry 5.0 paradigms are presented in Table 1.

Table 1. Main differences between Industry 4.0 and 5.0 paradigms [40].

	Industry 4.0	Industry 5.0
Objective	• Smart manufacturing (smart mass production, smart products, smart working, smart supply-chain), • Systems(s) optimization.	• Sustainability, • Environmental stewardship, • Human-Centricity, • Social benefit.
Systemic Approaches	• Real-time data monitoring, • Integrated chain that follows through the end of life-cycle phases.	• Utilization of technology ethically to advance human values and needs, • Socio-centric technological decisions, • 6R methodology and logistic efficiency design principles.
Human Factors	• Human reliability, • Human-computer interaction, • Repetitive movements.	• Employee safety and management, • Learning/training for employees.
Enabling Technologies and Concepts	• Cloud computing, • Internet of Things, • Big data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual or mixed technology), • Automation (advanced robotics, remote monitoring, autonomous robots, machine-to-machine communication), • Cyber-physical systems, • Horizontal and vertical integration (PLC, Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP)), • Additive Manufacturing.	• Cloud computing, • Internet of Things, • Big data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual or mixed technology), • Human–machine interaction, • Multi-lingual speech and gesture recognition, • Tracking technologies for mental and physical occupational strain, • Collaborative robots • Bio-inspired safety and support equipment, • Decision support systems, • Smart grids, • Predictive maintenance.
Environmental Implications	• Systems are economic, • Waste prevention per data analytics, additive manufacturing and optimized systems, • Increased energy usage, • Extended product life cycle.	• Waste prevention and recycling, • Renewable energy sources, • Energy-efficient data storage, transmission, and analysis, • Smart and energy-autonomous sensors.

3. Production Paradigm Shift

Over the centuries, production methods have been defined by the technical solutions available, but also by product preferences (Figure 2). New technical solutions allowed for increased volume and variety (Figure 3), but this also involved changes in the organization and also entailed social changes.

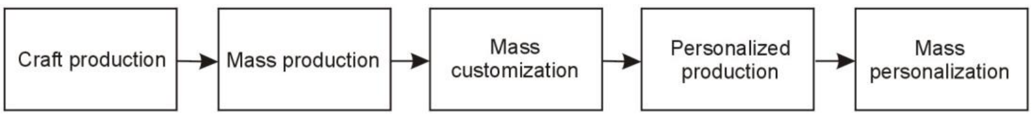

Figure 2. Production paradigm shift [40].

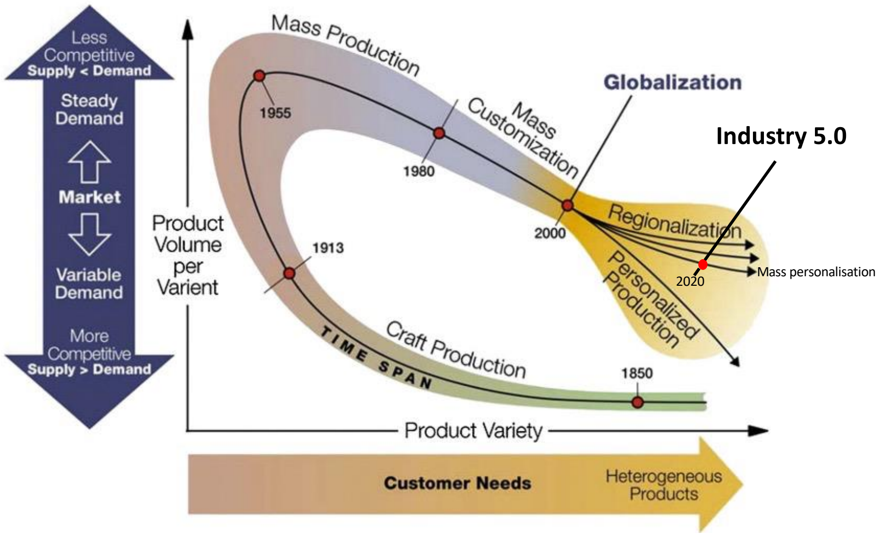

Figure 3. Shifting manufacturing paradigm and factors implying change (based on: [40]).

Artisanal production made it possible to meet the needs of selected customers. It was limited in terms of territory and resources. Products were targeted at the local market. Production was only possible with machinery available on the market. In this production, the overriding role was played by man. All elements of the technological process were made by hand and their quality depended on the skill, knowledge, and ability of the person making them.

With the advent of mass production, the role of man was reduced, but on the other hand, the scale increased. Goods were mass-produced, and the volume of production was for the local, national but also international markets. Specializations were introduced so that a given worker performed a specific task repetitively, and thus the quality of his work was repeatable. On the other hand, the introduced production tactics ensured that production became repetitive and predictable. On the other hand, it lacked variety, which is best expressed by Henry Ford's statement that the Ford Model T car produced was available in every possible color if it was black.

Mass customization, on the other hand, is a solution that has ensured product variety. The consumer can choose the product and customize it based on the possible options presented by the supplier. Thus, a customized product is already realized at the production stage. At the same time, to optimize costs, the base on which the product is made remains the same. With changing preferences and the desire to express individuality, the demand for personalized goods has emerged. The ability to meet the individual needs of individual customers on a large scale has come to be known as mass personalization [41,42]. In this way, the products provided, not only are better in terms of how they are produced, but also express the customer's needs. Given that mass customization is currently the dominant paradigm, it is crucial to understand the differences between the paradigms, as presented in Table 2.

It is also worth noting that mass personalization is the limiting case of mass customization. While both strategies are guided by a product price criterion consistent with mass production efficiency, the former (mass customization) targets a specific customer segment (individual customers), while the latter (mass personalization) targets segments dedicated to many different customers [43].

Table 2. Key differences between production paradigms (Source: based on [43]).

Features \ Paradigm	Mass Production	Mass Customization	Personalized Production/ Mass Personalization
Production Aim	• Scale	• Scale • Scope	• Scale • Scope • Value
Desired properties of the product	• Quality • Cost	• Quality • Cost • Variety	• Quality • Cost • Variety • Efficacy
Role of Customer	• Buy	• Choose • Buy	• Design • Choose • Buy
Production System	• Dedicated manufacturing system	• Reconfigurable manufacturing system	• On-demand manufacturing system/ • Cobot-oriented manufacturing system

4. Human–Machine Relationship

With successive industrial revolutions and accompanying changes in the production paradigm, an evolution of the human–machine relationship is practically taking place, referred to in the literature as the 5C model: Coexistence, Cooperation, Collaboration, Compassion, and Coevolution (Figure 4) [44].

Figure 4. Human–machine 5C relationship model [44].

The different stages signify the successive change that took place in the relationship. At the same time, the successive stages did not exclude the previous ones. Evolution rather than revolution in this respect means that constant change opens new perspectives. Thus, the man-machine relationship is undergoing constant change, which now, due to unprecedented technological developments, is entering a completely new level. Therefore, an extremely important question is the direction in which it will change.

What is important is that the above changes took place over the revolutions indicated in the previous chapter. Therefore, it should be noted that during the first and second industrial revolutions, machines were the equipment of factories. Thus, they formed a 'cold' coexistence relationship in which machines were simple tools for humans or worked independently under supervision.

Reconfigured machines and production lines forming dynamic cooperative human–machine teams in integrated production processes is a characteristic of the third industrial revolution. In this case, humans, and machines, depending on the process, temporarily share a workspace and share some of their physical, cognitive, and computational resources. At the same time, it should be noted that they are not working on the same task at the same time.

In the next, already the fourth industrial revolution, intelligent machines collaborate with humans in a shared workspace, with a specific goal of completing tasks through synchronized interactive joint actions of all parties within a common team identity [45].

In contrast, at the level of the fifth industrial revolution, workers together with robots (cobots) form teams to carry out production tasks [17]. Central to this relationship is how workers feel in this environment, how decisions are made, who makes them, and how such teams are formed. In the case of mixed human-cobot teams, there can be trust challenges. Particularly in the engineering industry, where the work requires not only good qualifications but the ability to work, many challenges arise. Methods and ways of developing trust in collaboration with the machine are needed. So that the worker knows that the machine is working towards the same goal and is not in danger from the machine. So that the worker can communicate effectively with the machine and understands the decision-making process when working with the machine. Depending on the manufacturing system, it is determined who ultimately makes the decisions.

Today, due to the development of advanced information technology and the transition to the Industry 4.0 era, the human–machine relationship is turning towards the human. Therefore, human-centered production systems need to be characterized by bidirectional empathy, proactive communication, and collaborative intelligence to establish reliable human–machine co-evolution relationships and thus lead to high-performance human–machine teams. Thus, on the one hand, the evolution of relationships and on the other hand a series of challenges [18] that need to be met to realize mass personalization (Figure 5).

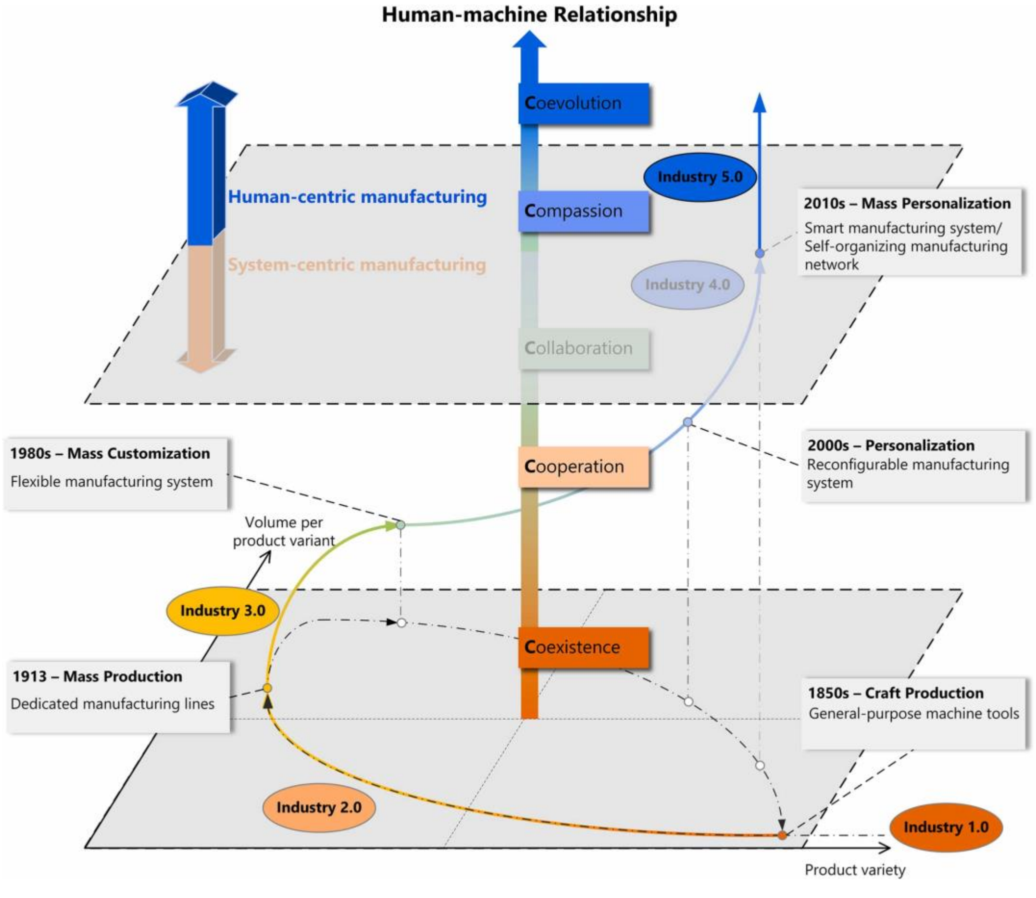

Figure 5. Evolution of the human–machine relationship towards human-centric production [27].

To fully characterize the human–machine relationship, further characteristics for the types distinguished within the 5Cs are indicated below.

4.1. Human–Machine Coexistence

This type of relationship envisages that man and machine are in the same environment and share the same space. Within this case, one speaks of monitored coexistence, that is when a robot and a human work closely together without the need for mutual contact or coordination, thus requiring continuous opportunities for the robot controller to avoid obstacles [46].

Furthermore, the coexistence of machines and humans for the enterprise realizes the goal of balancing automation/productivity and flexibility/capability. For example, using the human–machine interface, the operator is associated with a set of behavioral roles as a supervisor of multiple semi-automated production processes. The proposed model can be used to design manufacturing systems at different levels of enterprise architecture, particularly at the machine level of the manufacturing system, where operators interact with semi-automated machines to realize the goal of human-enhanced automation [47].

The coexistence of machines and humans in the production space creates the risk of collisions. Therefore, there is a need to adopt appropriate policies that safeguard production efficiency using safety features such as emergency stops [48].

4.2. Human–Machine Cooperation

Human–machine cooperation is defined as a group of agents in a collaborative situation when two conditions are present. The first occurs when the agents pursue goals that may conflict with those of others, at the level of their own goals, sub-goals, processes, or resource. The second, on the other hand, is that each agent seeks to manage these interferences to facilitate its tasks and those of others on a common task [49].

Some research work has applied the principles of interpersonal cooperation to the dynamic sharing of tasks between human operators and automated systems. These shared tasks are decision-making tasks (e.g., conflict detection, problem-solving, diagnosis, or image analysis and retrieval) and may involve several organizational configurations of the human–machine system. In this mode of human-robot interaction, the human operator and the robot are placed at the same decision-making level. The two agents work together to achieve a common goal by initiating an interactive dialogue. In the approach presented in this thesis, this dialogue can take different forms depending on the collaborative situation. This dialogue is carried out using various forms of collaboration [50].

While considering the human–machine collaboration relationship, it should be noted that the inclusion of the human in this type of relationship, even if it integrates the machine, can be justified as contributing to solving part of the automation problems in terms of human–machine relationships [2].

4.3. Human–Machine Collaboration

Technological advances increasingly envisage the use of robots interacting with humans in everyday life. Human-robot collaboration (HRC) is an approach that explores the interaction between a human and a robot, while pursuing a common goal, at a cognitive and physical level [51].

The human–machine collaboration relationship is a key means of manufacturing. The system that results from it performs surveillance, prognostics, and health management is related to the safety and sustainability of manufacturing [52,53].

Human–machine collaboration has great potential for making risky decisions. Machines could be more helpful in gathering information and assessing uncertainty and communicating key information to human decision-makers to save cognitive resources. Moreover, human decision-makers could debate their judgments with the help of a machine and reduce emotional influences [54].

As machines become increasingly intelligent and can perform more complex functions, a new relationship between humans and automation is emerging. This relationship is changing from 'master-servant' to 'master-collaborator' and requires a different approach to system design, human–machine information exchange and interface, and the imposition of additional requirements on the machine [55].

Current technological trends are enabling more and more physical contact between humans and machines. Humans and machines act together and communicate with each other not only through gestures and speech but mainly through the haptic channel. This current phase of human–machine interaction can be referred to as human–machine collaboration [1].

This has resulted in the development of a new type of robot—cobot, collaborative robot— which is geared towards human collaboration [56]. This term describes a robot capable of working and collaborating with humans. These collaborative robots will be aware of human presence and will therefore take care of safety and risk criteria. They will be able to notice, understand and feel not only the human but also the goals and expectations of the human operator. Similar to a learner, cobots will observe and learn how to perform a specific task. Once learned, the task will be performed by the cobots as it would be performed by a human [57].

4.4. Human–Machine Compassion and Coevolution

In human-centered production, given the successes in cognitive science and personalized AI, it is conceivable that empathic machines that sense human emotions, needs, and preferences could provide situational assistance to humans in addition to situational cooperation.

In such circumstances, based on reciprocity, humans will willingly monitor and take care of the 'health' of empathic machines. At the same time, this machine's health will be expressed in terms of quantitative measures related to workload, level of task fluctuation, etc. Such optics represent a whole new chapter in the human–machine relationship—human–machine empathy. It is also worth adding that intimate human–machine interactions will ultimately enable the growth of both human and machine capabilities, leading to continuous human–machine co-evolution in the future [45]. This mutual co-evolutionary development may lead to new forms of relationships no longer focusing on competition but on creating a better new future for machines and humans [58].

5. Perspectives and Future Roadmap for Industry 5.0 Solutions

5.1. Research Process

The development perspective and roadmap are issues that are conditioned by a broad spectrum of issues. Therefore, to be able to speak of a perspective, a view is needed, which is formulated by analyzing several approaches to the issues in question. Unlike in the case of specialized issues, one can only speak of a perspective and a roadmap when the entire context is known.

Therefore, to define a perspective and be able to indicate a roadmap for development, it is necessary to examine a wide range of different scientific publications on the issues addressed in this article. For this reason, the author's attention has mainly been focused on both review articles, presenting the overall issue under consideration, and specialized articles. Therefore, it was considered that the review would refer to publications that contain references to the issues addressed within this paper.

The review focused on the renowned databases Web of Science and Scopus (Figure 6). These databases were considered reference databases, as their scope includes publications cited and produced worldwide. Based on the Scopus and Web of Science databases, a search was carried out, using as keywords those topics that relate to the human–machine relationship as well as Industry 5.0. Therefore, the following were included in the query: human–machine relationship, human–machine coexistence, human–machine cooperation, human–machine collaboration, human–machine compassion, and human–machine coevolution or Industry 5.0. In addition, to keep the context up-to-date, the research was carried out regarding the last five years.

Figure 6. Research process.

This resulted in 9533 publications from the Web of Science database and 8430 records from the Scopus database. Furthermore, since the human–machine relationship is often indicated interchangeably with human–machine interaction, this word was also adopted as a keyword implemented in the analysis.

This was followed by a technical analysis using the data processing methodology of the VOSViewer software [59]. The analysis used a method of counting the type of term weights using full counting, which counts the occurrences of a given term in all processed documents. Based on the occurrences, it counts the weight of the relationship between the given terms. The result was a co-occurrence map of the terms with their assigned relationship strength. In the next step, text mining was carried out using Orange Data Mining analysis [60] indicating the weight of the given words related to the topics to demonstrate the topics through topic modeling with Latent Dirichlet Allocation.

5.2. Results

The results extracted from the Web of Science database (Figure 7) will be presented first. Both title and abstract were technically analyzed. The demonstrated study, based on the analysis criteria adopted, showed several clusters. The results showed that, despite the oriented query, the topics indicated in the query were not the dominant content of the analyzed publications. Furthermore, due to the broad spectrum of the inquiry, the analysis showed both technical issues (red) but also application-specific clusters (green, blue, orange, and mixed). It can be assumed that four main clusters were distinguished. For this analysis, the focus will be on the technology cluster.

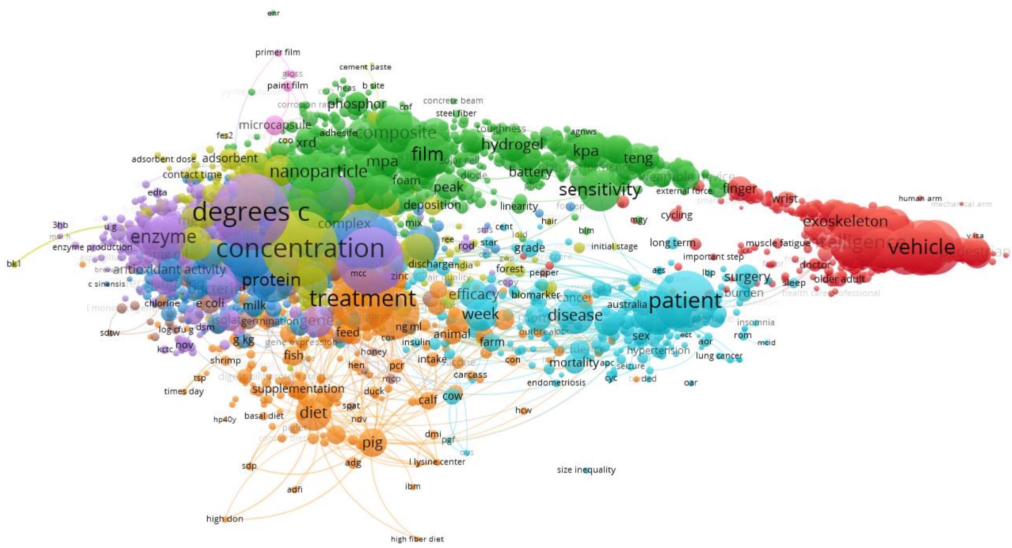

Figure 7. Term co-occurrence map based on provided publications Web of Science.

In the technology cluster (Figure 8), it is notable that the keyword highlighted is: collaboration. This is significant insofar as the other 5C terms are missing at this level of significance. On the one hand, this is due to the study's time horizon of 5 years. On the other hand, however, it confirms the thesis that the 5th industrial revolution is indeed taking place today and that man-machine collaboration is a topical and widely described issue. In the following section, key relationships are highlighted in the terms of greatest importance.

The first keyword is collaboration. The dependency associated with this word shows a possible link to the issues of automation, trust, or intelligence. This indicates that machine-to-machine collaboration is only possible with intelligence and automation, however, trust is needed for collaboration to take place. Trust is a key factor for the development perspective (Figure 9).

Based on the collaboration dependency (Figure 10), it is then indicated which elements make up its components. In this, intelligence is closely linked to data (big data) and the issue of collaboration.

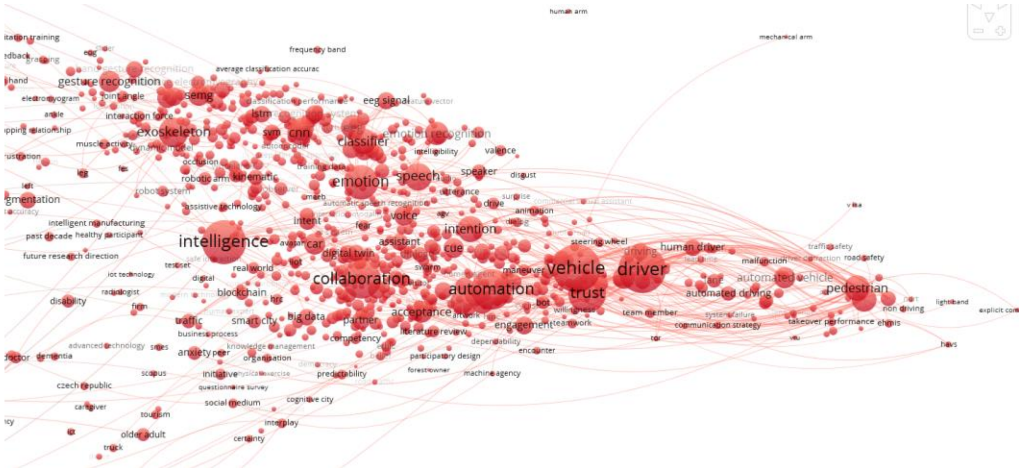

Figure 8. Technology cluster.

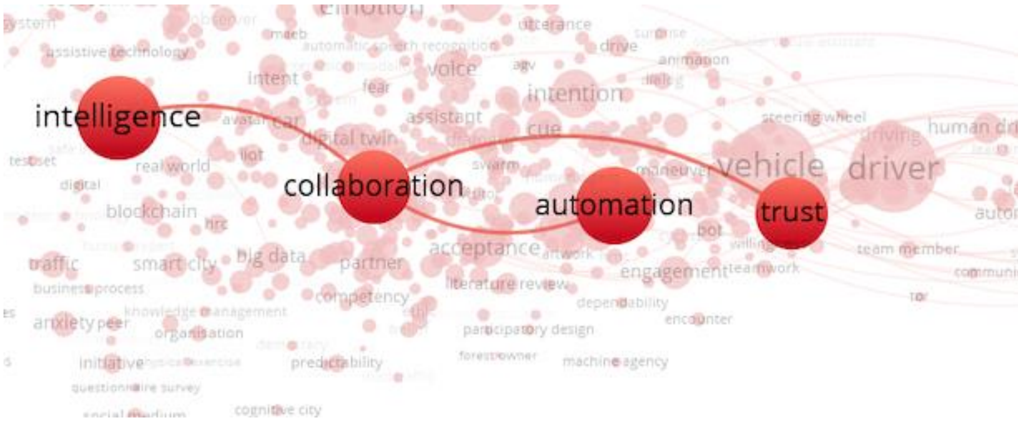

Figure 9. Collaboration dependency.

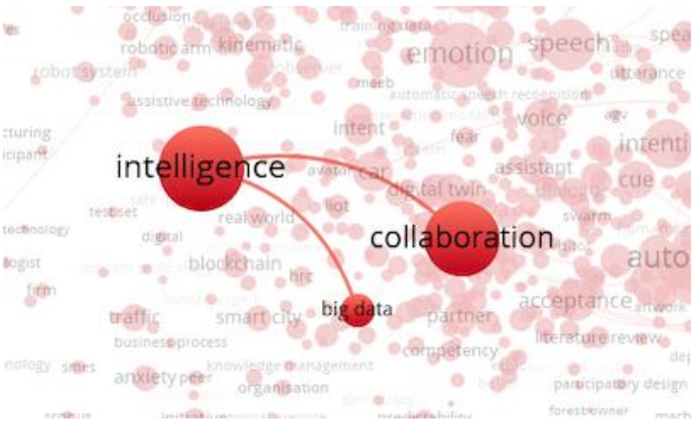

Figure 10. Intelligence dependency.

In a further step, attention was turned to the issue of automation. Here, two new issues arise vehicle and driver (Figure 11). Thus, cooperation in automation must concern the control of different vehicles, but there is a need to develop a specific control agent.

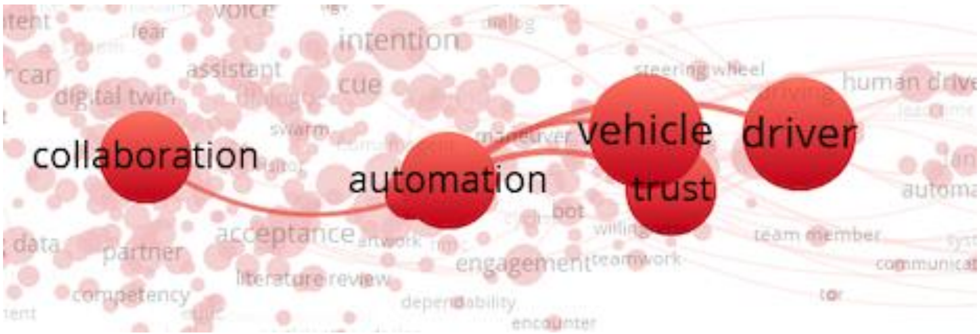

Figure 11. Automation dependency.

The issue of trust relates to issues of collaboration but touches on issues of acceptance, errors, automated vehicles, passers-by, or communication interfaces (Figure 12).

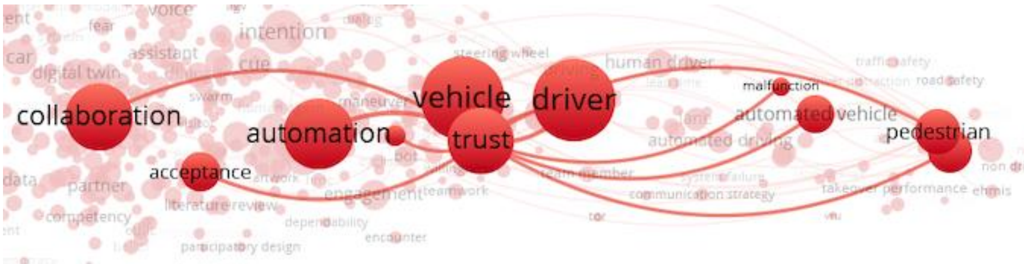

Figure 12. Trust dependency.

Vehicle dependency introduces human driver or road user issues (Figure 13). Thus, this dependency indicates the perspective of placing human–machine cooperation in terms of the environment. It returns to the issue of intention detection.

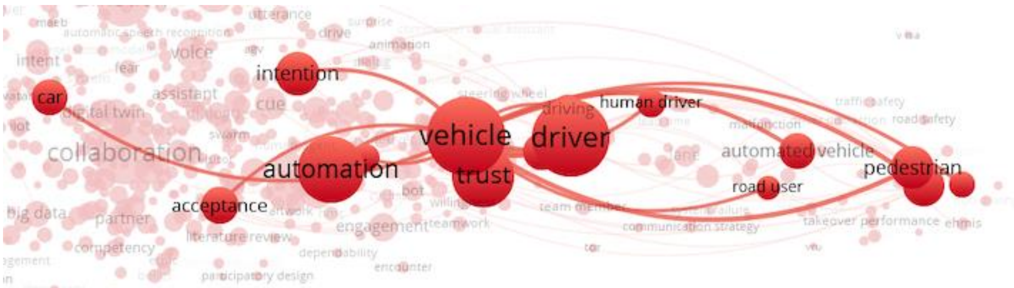

Figure 13. Vehicle dependency.

In addition to the previously indicated ones, driver dependency points out that it depends on both the emotions and the vehicle in which it is managed (Figure 14). Furthermore, attention is drawn to issues of engagement.

It is also worth describing here, the issue of emotions, which often identifies personality, which is closely related to the human being. From the perspective of identified relationships, the emotion is closely linked to the tools for classifying it, recognizing it or expressing it in speech (Figure 15).

In the next step, a volume analysis of the Scopus database documents was carried out (Figure 16). The analysis resulted in as many as eight clusters. This indicates a much greater fragmentation of the issues described from the perspective of the realized query. Given this, the dependencies obtained are not so clearly visible. Hence, clusters will be presented as dependencies to the highlighted terms with the highest weight—thus forming the largest perspective.

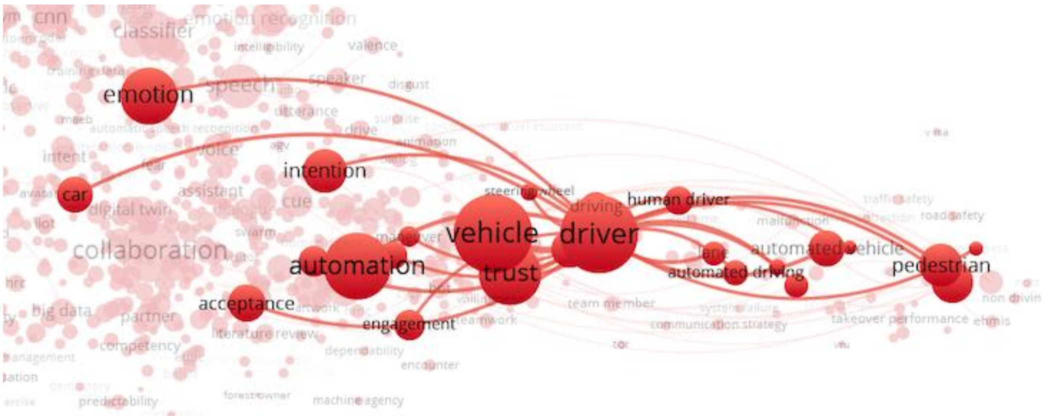

Figure 14. Driver dependency.

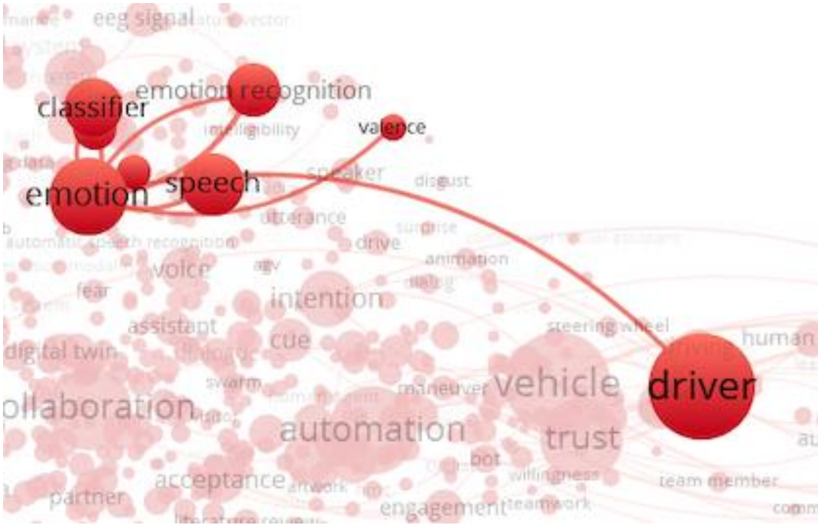

Figure 15. Emotion dependency.

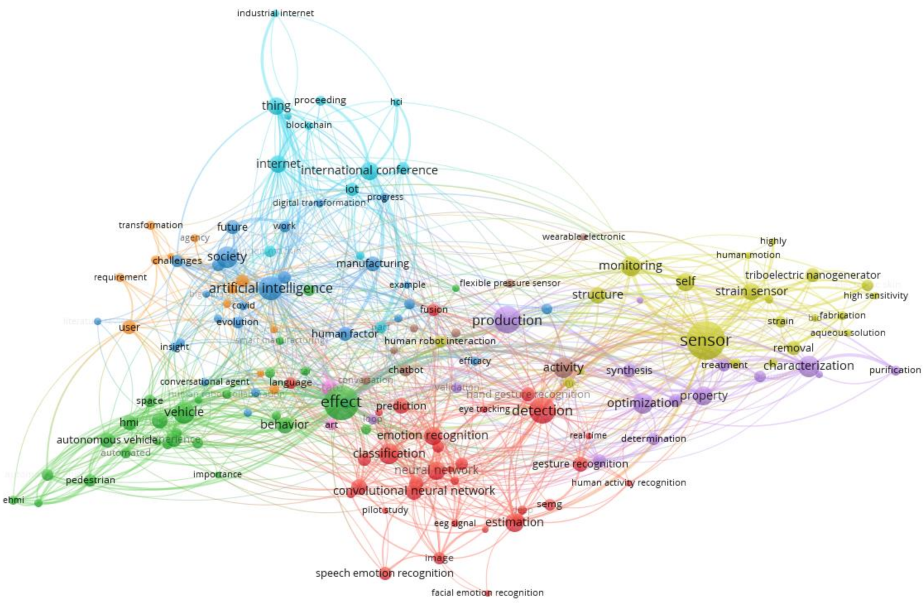

Figure 16. Term co-occurrence map based on provided publications Scopus.

One of the key dependencies highlighted within the analysis, linking to different scopes, is sensors (Figure 17). Here, several strong connections to issues such as artificial intelligence, monitoring, sensing, estimation, or neural networks can be identified. However, there is no explicit indication here of the issues present in the 5C model.

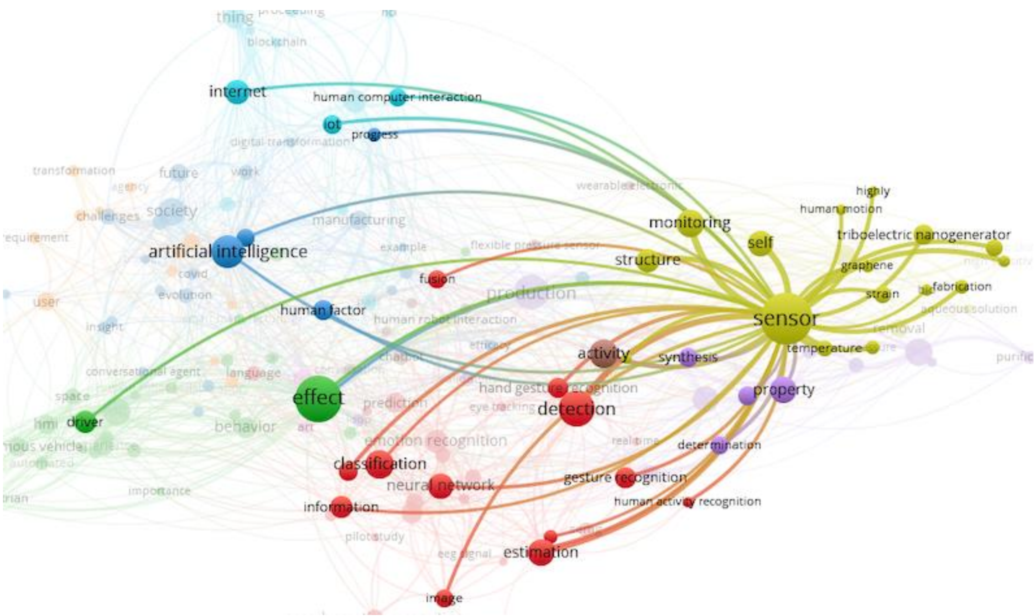

Figure 17. Sensor dependency.

Then there is the effect dependency (Figure 18), which relates to a broad spectrum of issues while linking the most important ones, such as artificial intelligence, sensors, and vehicles. This dependency is a good illustration of the range of tools used to obtain the causal result—the effect—of the work carried out. The issue of effect is crucial in managerial terms. Tools and technologies are used to achieve technical, social, and, above all, economic results.

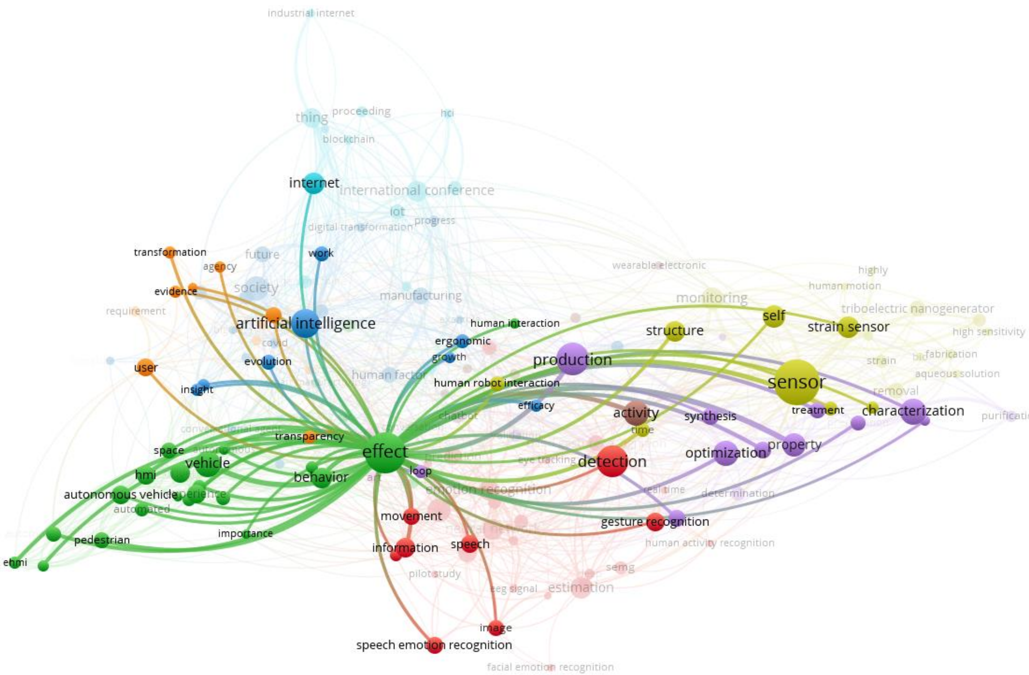

Figure 18. Effect dependency.

Another highlighted dependency relates to manufacturing (Figure 19). Here, one can see the publications focus both on technical issues, but also on application issues for optimization.

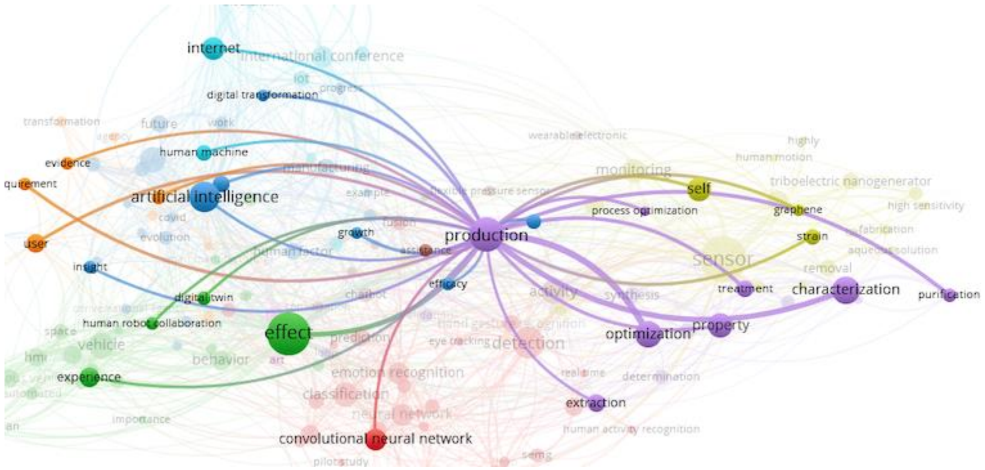

Figure 19. Production dependency.

Further, the dependency on artificial intelligence (Figure 20) brings together many terms from different scopes. It can be pointed out that it constitutes a kind of glue for all the indicated dependencies that appear in the analyzed literature.

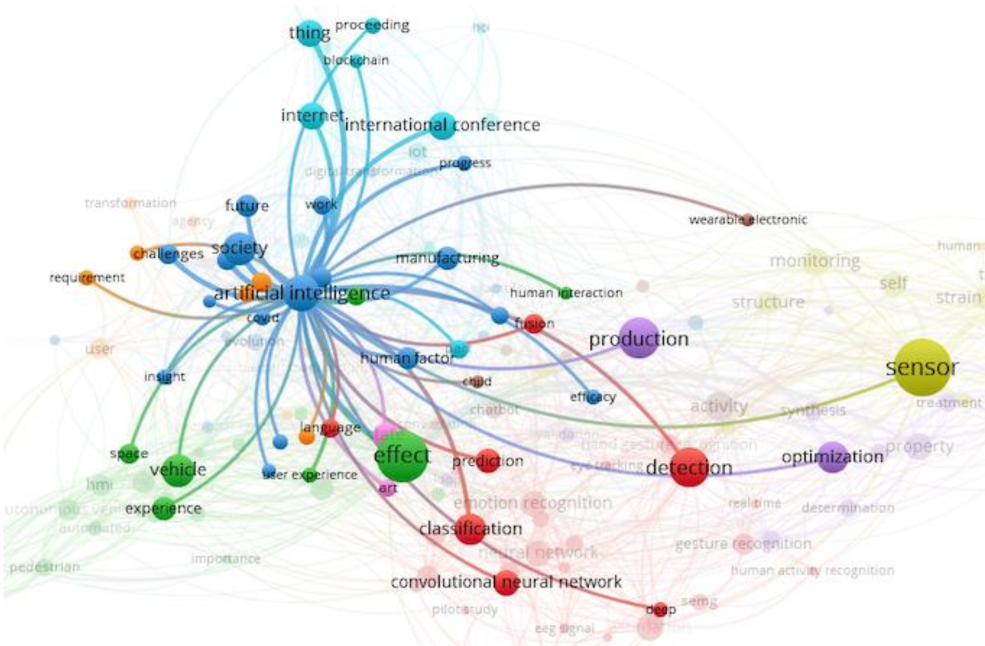

Figure 20. Artificial intelligence dependency.

Similar to the dependency on artificial intelligence, the issue of detection (Figure 21) is widely discussed within the articles. This demonstrates that it is crucial for machine-human collaboration that the machine can discover that there is a machine, product, or human in its environment.

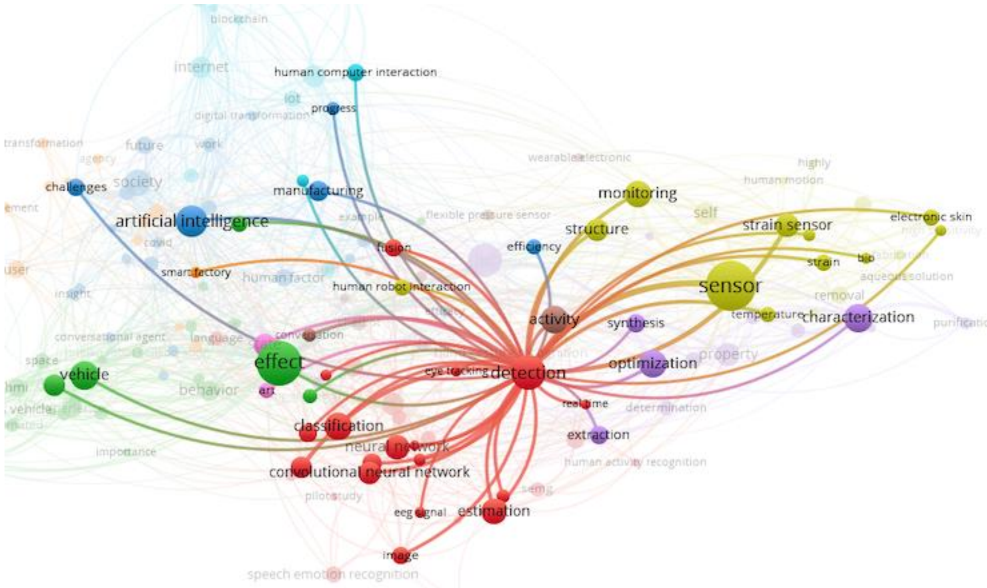

Figure 21. Detection dependency.

The demonstrated text mining analysis of the topics that dominate the analyzed Web of Science publications identified the following topics—the 10 topics with the highest weighting were assumed to be extracted:

1. *human, use, system, machin, interact, base, model, control, result, robot*
2. *human, use, machin, c, studi, robot, result, interact, industri, method*
3. *system, sensor, high, human, control, user, model, detect, applic, oper*
4. *sensor, system, model, high, human, use, method, devic, learn, data*
5. *robot, model, industri, control, sensor, data, method, base, machin, propos*
6. *industri, control, robot, human, technolog, product, propos, machin, model, research*
7. *robot, industri, human, c, data, control, sensor, technolog, studi, model*
8. *model, use, user, interact, c, control, design, interfac, industri, high*
9. *use, control, system, design, robot, user, base, human, c, interact*
10. *control, use, interact, user, robot, industri, model, c, human, task*

Similar results were obtained for the Scopus data analysis:

1. *human, machin, interact, base, system, interfac, robot, design, use, control*
2. *base, human, system, machin, use, recognit, sensor, control, network, design*
3. *system, base, industri, recognit, design, sensor, control, machin, human, network*
4. *use, base, recognit, industri, emot, network, learn, interact, neural, sensor*
5. *industri, interact, robot, system, recognit, use, human, collabor, applic, interface*
6. *interact, robot, machin, system, industri, interfac, human, vehicl, design, autom*
7. *robot, industri, interact, control, human, machin, collabor, interfac, design, intellig*
8. *design, interfac, vehicl, autom, system, robot, human, use, drive, control*
9. *sensor, high, flexibl, base, use, pressur, wearabl, strain, recognit, model*
10. *autom, design, machin, human, vehicl, intellig, drive, robot, model, artifice*

Given this, the perspective, despite the clear presence of keywords, is decisively about the human aspect—so emphasized by Industry 5.0. This confirms the chosen research direction and illustrates well the current shape of the human–machine relationship.

5.3. Roadmap

Moving towards human–machine relationship-oriented manufacturing, technologies must be made to work for people in a trustworthy and friendly way, as people are essential in creating personalised products of high value. Philosophical, social and ethical issues and theories must drive the development and implementation of assistive technologies in the real world [45]. This provides the source for the many challenges that the new industrial revolution brings with it. Industry 5.0 represents the next revolution in the development of manufacturing systems, which builds on the achievements of previous ones.

The identified dependencies were defined based on the literature review carried out by the authors. As a result of the analysis, the dependencies were extracted and put into a framework of three stages (Figure 22) forming a roadmap.

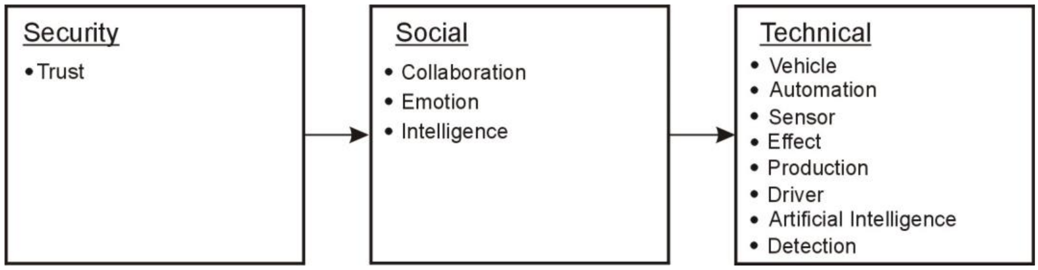

Figure 22. Human–machine relation roadmap.

The identified dependencies were used to formulate the roadmap. The proposed sequence was determined by the authors considering both their experience of working with companies and the literature review carried out.

The first stage of the roadmap concerns the security dimension. In this dimension, it is necessary to develop protocols to secure the data processed by the machine. A key focus should be on issues of remote access to manage cobots. These inherently mobile devices will be controlled remotely. Interception of cobot control could end up losing the integrity of the entire manufacturing process. This raises a new threat of intercepting the management of the process in progress.

The next stage is formed by social dependencies. This dimension is directly related to the working environment. The key here is how the employees concerned feel in this environment, how decisions are made, who makes them, and how such teams are formed. In the case of mixed human-cobot teams, there can be challenges related to trust. Particularly in the engineering industry, where the work requires not only good qualifications but the ability to work, many challenges arise. Methods and ways of developing trust in collaboration with the machine are needed. So that the worker knows that the machine is working towards the same goal and is not in danger from the machine. So that the worker can communicate effectively with the machine and understands the decision-making process when working with the machine. Depending on the manufacturing system, it is determined who ultimately makes the decisions.

Because of the answers formulated in the previous stages, the task of the technical stage is to implement solutions in line with social and safety considerations. Solutions constructed based on clearly defined boundaries can be the starting point for further work. In addition, it is worth noting the direct benefits of information technology solutions. It will be necessary to provide new learning datasets for collaborative algorithms (image recognition, self-awareness, performance of technological tasks), to develop algorithms that perform safety functions of collaborative work with a person.

In summary, the roadmap for the development of the human–machine relationship should mainly focus on how to facilitate this process for workers. True collaboration will only happen when people can trust the machine. The machine, on the other hand, will be able to identify the intentions of the people it is working with. Therefore, this dimension will need answers to the questions of how to introduce effective training models. How do we convince people to work with cobots? Only after answering these questions will it be necessary to focus on technical issues to answer other important questions such as how to create a cobot that works with people.

6. Discussion

The results presented represent a development pathway for the human–machine relationship illustrated in the literature. The path shown can be seen as a practical development framework.

The article provides direction and formulates the next steps on the development path for the human–machine relationship. By doing so, the systematization of the issue has been realized. What is most important, the path is a signpost both for researchers, but also for specialists in the areas of economics, technology, and industry, who are developing product development paths or developing strategies related to Industry 5.0. The demonstrated relationships should be considered when formulating long-term management strategies in the area of planning the development of enterprise manufacturing systems. The roadmap proposed in the article is a forecast based on the author's experience and the literature review carried out.

Of course, the issue described, for differently defined criteria, may show differences in the relationships shown. At the same time, it should be noted that the article pays attention to the development perspective and roadmap. Thus, the perspective is intended to illustrate the direction of change and provide information. The roadmap, on the other hand, is an expectation of the next development steps with a defined choreography. The issues analyzed are characterized by dynamics related to changing trends, but also the economic situation. Therefore, it can be interpreted differently in terms of the experience of different researchers. Which is understandable and appropriate for this type of study and the methodology adopted.

At the same time, in the opinion of the authors, the work carried out has made it possible to capture those relationships that illustrate contemporary transformations. Therefore, the results and conclusions of the research can be useful.

7. Summary and Conclusions

The fifth industrial revolution uses technological advances to bring the human aspect back into production. To harness the creativity and the potential inherent in workers. This has a definite impact on how the human–machine relationship is shaped. This change in the relationship involves a series of dependencies and challenges of social and legal nature.

Unlike previous revolutions, Industry 5.0 redefines the man-machine relationship by restoring the human aspect to production. This practically reverses the vector of relationships, which hitherto focused on the development of technical solutions specific to machines. The collaborative relationship dominates, with the issue of compassion and coevolution still an issue of the future. At the core is the issue of trust and automation. Therefore, such a major shift in the manufacturing paradigm, which has so far been concerned with the implementation of economically motivated new technical solutions (machines, equipment) in favor of minimizing 'expensive' human labor, will have a significant impact on how goods are produced. This shift towards sustainability in tipping systems represents an open development perspective. It holds the promise of a new shared future, where social needs and responsibility for the goods provided are the ultimate goals of manufacturing. At the same time, it opens many questions in terms of the development roadmap. Different parts require the development of methods, techniques, and the development of good practices to fully understand the potential that lies in the human–machine relationship, which will be the subject of further research.

Author Contributions: Conceptualization, J.P. and A.G.; methodology, J.P. and A.G.; validation, A.G.; formal analysis, A.G.; investigation, J.P.; resources, J.P.; data curation, J.P.; writing—original draft preparation, J.P.; writing—review and editing, A.G.; visualization, J.P.; supervision, A.G.; project administration, A.G.; funding acquisition, A.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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