Systems and Productivity Metrics – a Review

Mauro Almeida
Polytechnic Institute of Castelo Branco
6000-767 Castelo Branco, Portugal
mauro96alex@gmail.com

Filipe Fidalgo
R&D Unit in Digital Services, Applications and Content, Polytechnic Institute of Castelo Branco
6000-767 Castelo Branco, Portugal
ffidalgo@ipcb.pt

Ângela Oliveira
R&D Unit in Digital Services, Applications and Content, Polytechnic Institute of Castelo Branco
6000-767 Castelo Branco, Portugal
angelaoliveira@ipcb.pt

***Abstract*— Nowadays, the industry produces a large amount of data in its daily activities. Invested time and resources in acquiring, storing, and managing this data can represent a huge added value to organizations decision makers. Besides data produced by information systems used to support operational tasks, additional data can also be acquired and stored automatically, without human interaction. In Industry 4.0, technologies are becoming more prevalent in production and logistics. Intelligent sensors can generate a large volume of industrial data, so it is crucial to collect, store, analyze, and distribute this data in organizations. Dashboards allow operators to make informed decisions and solve issues on the fly. Thus, to address the presented concepts, a systematic review was conducted, based on Preferred Reporting Items for Systematic Review and a Meta-Analyses guideline (PRISMA). These studies address some consistent positive evidence on the use of Internet of Things (IoT) technologies to support productivity metrics in industry, creating knowledge for the development of a digital solution.**

Keywords: Productivity metrics; Industry 4.0; Internet of Things; Systems; Key Performance Indicators.

I. INTRODUCTION

Making a good plan for a given task is the key to success in any business area. To make the best decisions, an analysis of the organization's data is necessary. Data collection is as essential as its analysis. In a computerized world, data collection is fundamental, regardless of the business areas in which this collection occurs. Fortunately, IoT solutions and computer solutions collect a huge amount of data every day and help us optimize and analyze a specific business area in the best way, thus supporting decision-making through data analysis. These IoT solutions are found in different business areas, from small to large technology companies. One sector that has been growing with the help of IoT is the primary sector, giving rise to IoT Smart agricultural solutions [1]. The present study follows the PRISMA [2] methodology. It provides a comprehensive review of the scientific literature on the use of IoT technologies to support productivity metrics in the industry. This review is important because it presents an identification of the approaches used in productivity metrics in the industry and identifies a set of opportunities that can be explored in future research. However, it also has some limitations. The literature search was performed only in three databases (IEEE Xplore, ACM Digital, and Scopus), which may have influenced the number of relevant studies obtained. The use of other databases could possibly have increased the number of studies analyzed and contributed to improving the general analysis, as well as the search strategy, which had restricted the number of non-relevant studies (studies published many years ago, very general studies, studies that do not focus on the research objectives, or studies not written in English). However, these restrictions did not have a significant effect on the discussion and conclusions.

This paper is organized as follows. Section II presents the details of the methodology and the results that were obtained through the research. Section III presents the conclusions and directions for future work.

II. METHODOLOGY

This section aims to analyze scientific articles that contain information related to tools and technologies associated with data collection and visualization and treatment of related data and respective metrics. This review includes the following topics: research questions; inclusion criteria; search strategy; results; extraction and data analysis; discussion.

Research Questions

According to the proposed objectives, the research questions are addressed in this topic are:

Question_1: What systems exist to measure productivity?
Question_2: What kind of metrics are used to collect information?
Question_3: What kind of frameworks/tolls allow the data collection?
Question_4: What data analysis and visualization tools are possible and used?

Inclusion criteria

The literature studies are selected according to the following criteria.

Criterion_1: Studies published between 2017 and 2021.
Criterion_2: Studies written in English.
Criterion_3: Studies where the full texts are available free of charge.
Criterion_4: Studies regarding IoT solutions.
Criterion_5: Studies concerning tools and technologies associated with productivity and the identification of metrics and data visualization/treatment.

Research Strategy

The IEEE Xplore, ACM Digital and Scopus databases were used in the research to identify the articles. The set of search terms was: "Industry 4.0", "IoT", "Framework", "Assessment", and "Key Performance Indicators (KPI)". The search was carried out between November and December 2021.

Results

As shown in Figure 1, after carrying out the search and applying criterion 1, 206 scientific articles were found, 24 from the IEEE Xplore database, 86 articles from the ACM Digital database and 96 articles from the Scopus database. Applying criterion 2 and removing duplicates resulted in the exclusion of 18 studies. Thus, 188 studies were analyzed based on title and abstract, and 152 were excluded, based on criteria 4 and 5. Complete text analysis of the 36 resulting studies was performed, applying criteria 3, 4 and 5. The remaining 13 studies were included in the review.

A. *Extraction and Data Analysis*

Data were extracted from all identified studies using a predefined format: Study; Year of publication; Metrics; Technologies, and Data Visualization. Table I presents the extracted data. The characteristics of the included studies are summarized below.

In [1], the authors explore ways of visualizing data collected from IoT systems. They address the importance of data and its visualization to support decision-making and indicate some of the most used tools in different industries, such as Tableau, *Thingsboard*, *Plotly*, IBM Watson IoT Platform, Power BI (Business Intelligence), Gephi, Grafana, Kibana Tool, JavaScript libraries, frameworks, and toolkits. They refer to these tools as the most used for viewing data quickly and dynamically. This article refers to different business areas, highlighting the importance of viewing these collected data.

The study carried out in [3] focuses on the importance of data collection and the monitoring and productivity of employees, developing an Industrial Internet of Things (*IIoT*) system. The project primarily addresses business areas where employee monitoring is required. Additionally, machines need to be used on the shop floor to operate, where the information collected through "wearable sensors" and processed and stored in the Cloud. KPI are produced for each employee through this collection of information. In this study, a factory where employees must cut meat was used as an example. In addition, to propose a solution to the problem, the employees use a wearable technology called “MetaWear”. The sensors send the information through Bluetooth Low Energy (BLE) to the Raspberry Pi, used as a gateway. All the collected data is sent to the Cloud. As an interface for employees, Andon systems were used. However, several KPIs were calculated, with the data collected and analyzed without referring to the tools used for their visual analysis.

In the study presented by [4], a new Andon system was proposed, referring to the importance of the employee on the factory floor being able to quickly, through the colors, understand what is happening and act accordingly, as quickly as possible. Thus, a new interface was proposed to maximize

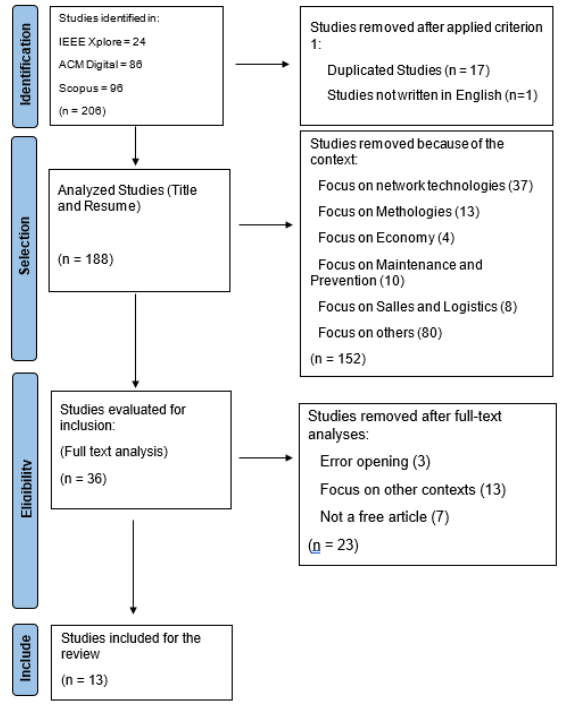

Figure 1. Flow diagram for new systematic reviews (adapted from [2])

TABLE 1. EXTRACTED DATA

Study	Metrics	Technologies	Data visualization
Data visualization on the internet of things: tools, methodologies, and challenges [1]	N/A	N/A	Tableau, Thingsboard, Plotly, IBM Watson IoT Platform, Power BI, Kibana Tool, JavaScript libraries, etc.
An Industrial IoT Solution for Evaluating Workers' Performance Via Activity Recognition [3]	Productive and non-productive work time	Wearable Technologies, Cams, RFID, NFC, Bluetooth Low Energy Sensor	Andon Systems
Designing usable interfaces for the industry 4.0 [4]	N/A	N/A	Andon Systems and Stacked Bar, Line and Ring Graphs
Microservice architecture in industrial software delivery on edge devices [5]	N/A	Microservices and Pipeline	N/A
Modelling and assessing the effects of digital technologies on KPIs in manufacturing systems [6]	Overall Equipment Effectiveness (OEE), Time, Quality, Product Quantity	RFID, VR (Virtual Reality)	N/A
Key performance indicators in the production of the future [7]	Data Management, Transparency and networking, Product Management	Profitability-Liquidity KPI system, DuPont System of Financial Control	N/A

Study	Metrics	Technologies	Data visualization
Developing key performance indicators tree for lean and smart production systems [7]	Product Control, Equipment Productivity	Bosch Production System, PLCs, CNC Work Centers	N/A
Motion Analysis System for the digitalization and assessment of manual manufacturing and assembly processes [9]	Movement distance and speed, Vertical movements, Workstation utilization, Productive and non-productive work time.	Motion Analysis System, MOCAP (Motion capture system)	Bar and circular bar chart
MAESTRI Efficiency Framework: The Concept Supporting the Total Efficiency Index. Application Case Study in the Metalworking Sector [10]	Manufacturing process	ecoPROSYS	Bar and pie charts
Line Balancing Assessment Enhanced by IoT and Simulation Tools [11]	OEE, Employee Performance, Productivity Collection	N/A	N/A
Auditing and Assessment of Data Traffic Flows in an IoT Architecture [11]	Traffic Flow	Application & Microservice Monitor and Analyser	DevDash
Modelling food supply chain traceability based on blockchain technology [13]	Product Control, Quality, Process Control	N/A	N/A
Cognitive internet of things for smart water pipeline monitoring system [14]	Control and monitoring of water pipes, water leakage, water pressure and flow rate	N/A	JavaScript e Ajax

usability. The rapid transmission of knowledge and events is vital so that accidents or more serious problems do not happen. In addition, it refers to the KPI of machines on the shop floor and not the employees. A prototype was made for the Andon systems, where the following principles were implemented and tested: information made available in a hierarchy; multi-window interaction; multitouch interaction and self-explanatory diagrams. To test usability, 18 participants tested the system, playing the role of a worker. Through this test, it was possible to visualize that with the new interface, the efficiency, and the interaction of the employees with the system improved.

The work in [5] portrays a microservices system and pipeline in Industry 4.0. Unlike what happens in monolithic systems, this approach allows the management and delivery of software to the different devices without stopping the entire production system to simply apply new features. This problem happens when the system "is dominated by the monolithic architecture", and this type of system requires "a production stop planning for the manual installation" of updates. The author defines as primary objectives of the study the focus on the requirements and architecture of the application system and the introduction of pipelines for the delivery of software that comes against the manual installations in traditional industries. In addition, an analysis application was developed in Supervisory Control and Data Acquisition (SCADA) systems, where the objective is the analysis and measurement of data, where the end-user defines what type of metrics can be taken from the system, which, according to the author, could be "productivity, Overall Equipment Effectiveness (OEE), etc.". Despite referring to these KPIs, the article focuses more on the application of pipeline systems in the industry, which, in a way, comes to revolutionize with cutting-edge technology that, monolithic systems are dominant in traditional industries present in the market.

The work in [6] mentions an approach for companies to select an appropriate digital technology, considering the objectives of each business idea. Thus, different KPIs are approached and categorized, the best forms of information collection are exemplified, and some examples of technologies to be used are also presented. This study made it possible to identify some types of indicators for which information can be collected. In addition to the OEE, information such as time, quality and quantity of product can also be collected. The KPIs presented are structured in 4 groups: Process, Worker; Financial; and Customer. Two types of technology were also proposed, depending on the objectives: Radio Frequency Identification (RFID) and Augmented Reality (AR).

In [7], the main objective is to present new KPIs for the industry in the future and mentions some challenges that it must face in relation to the availability and collection of information. Some current KPIs in the financial sector are discussed, such as the "DuPont System of Financial Control" programs, "ZVEI KPI System"; "Profitability-Liquidity KPI system". In addition, reference is made to ISO 22400 as a framework for structuring production KPIs. However, despite these examples, it is mentioned that they are not useful, as they are not flexible enough for the collection of information and as such, they propose a new framework considering Porter's Value Chain. In addition to existing KPIs, such as Logistics, Production process, and Quality, the work proposes three new groups: Data management, Transparency and Networking, and Product Management. Once collected, the data can be visualized and analyzed using the "Harvey-Balls" graph. These pie-shaped graphs are used to visualize qualitative data. Although they refer to this type of graph, it only represents a form of information visualization and not a data visualization framework.

The authors in [8] propose a KPI tree structure to describe a Performance Measurement System (PMS), with the data collected, the system recognizes the failures in the actual productivity. This study used as an example a Bosch factory where "Lean Manufacturing" or "Lean Production" is applied. This system called Bosch Production System (BPS) is based on the maximum reduction of the waste in the production flow, with the ideal state of 100% deliveries, 100% added value and 0 defects. The system also supports the decision-making process. They identify three areas of process cycles: "Source", "Make", and "Deliver", which describe the objectives of projects related to Industry 4.0. In this way, the hierarchical structure of the proposed KPIs offers real-time measurements and performance calculations. Using the identified process cycle areas helps collect all the information to focus on continuous improvement and thus achieve the defined objectives.

In [9], the authors present the "Motion Analysis System" system that digitizes employees' operations in different production environments. A Motion Capture (MOCAP) system was introduced and adopted, initially used in the gaming industry for the manufacturing environment. This system can collect and analyze measurements related to productivity and performance. Cameras were used to capture the employee's movements, which are connected to a computer via USB, whose main function is to send data via Wi-Fi. The main KPIs which can be analyzed through this system are: Physical distance travelled and speed of movement; Vertical movements (operator needs to lift or lower something); Use of the workstation by the employee; Working time (productive and non-productive).

In [10], the main objective is to collect information and reduce waste, focusing on sustainability. This project is based on "Multi-layer Stream Mapping", responsible for accessing process efficiency and ecoPROSYS, a quantitative management tool that assesses the environmental impacts of a production cycle. The collected data is transformed into KPI where Value Added (VA), Efficiency, Ecoefficiency, and Total Efficiency Index (TEI) are calculated.

In [11], the main objective is to propose a framework that, from Industrial Internet of Things (IIoT), collect information regarding the performance of employees and machines. Thus, the proposed system has the collection and sending of production data in real-time as its main objective. Employee data is calculated and collected. There is an evaluation of the employees in terms of workload, the number of parts produced and OEE for the equipment. It presents formulas for calculating the indicators mentioned above. However, it does not refer to the technology used, focusing more on the result and analysis of the calculations of the optimization of production processes, seeking the efficiency of the process and employees.

The study in [11] has as main objective a solution that processes, stores, monitors, and indexes data from different IoT and Smart City devices to control and monitor the flow of traffic of motor vehicles. The solution uses *DevDash* (Developer Dashboard) to index data from devices and Application & Microservice Monitor and Analyze (AMMA) tools for real-time data control and monitoring the traffic flow. Data is collected in real-time and stored in a non-relational database. This data is processed by a tool called "Apache NiFi", whose main objective is to optimize big data flow. The *DavDash* and AMMA tools also contain and work data, placing it in a visual way ("Both AMMA and *DevDash* include a set of classical dashboard widgets to visualize data such as histograms, time-pickers, filters, facet selection on the different kind of data managed, heatmaps, pie charts, tables, and newly created panels (...)").

In [13], the main objective is to create an "autonomous, functional and back-end system where data is not centralized" that benefits all food-related industry players. The tracking includes the process, the product, and the quality control. For tracing a Table of Content (ToC) is suggested, containing all product information stored locally in an Interplanetary File System (IPFS). Some KPIs are calculated, however, for the system itself "efficiency, responsiveness, required trust assumptions, context requirements, required consensus mechanisms and food quality of the proposed blockchain-enabled mode". Despite referring to a good form of data transmission and tracking, they do not indicate what type of IoT technology was used, nor what type of system was used to visualize the KPI themselves indicated above.

In [14], the authors have as their central objective the proposal of a system of "control and monitoring of water pipes". The IoT solution presented uses the Apache Spark framework for big data processing. A "Wireless Actuator Sensor Network" sensor was used to detect and locate water leakage. Data such as water pressure and flow speed are collected and sent over Wi-Fi. This data is processed and placed in the Cloud. It was then worked and presented on a website using JavaScript and Ajax.

B. *Discussion*

The discussion is based on the results presented in Table 1. The articles analyzed were published between 2017 and 2021. Of the 13 articles for more detailed analysis, 46% refer to the year 2018, 30 % to 2019, 24% reference 2020, and 0% for 2017 and 2021. Figure 2 describes the result obtained in several articles per year, where it is verified that in three of the years analyzed, no results were obtained. Although specific studies refer to quality control or process and product management, it could be tried to infer what kind of metrics could be collected; however, their description was not explained.

In Figure 3, some of the metrics referenced in the analyzed studies can be observed. Although 19% of the articles did not refer in detail to what metrics were collected, all referenced the collection of information and the importance of obtaining, or not, a vision of achieving the defined objectives, thus allowing the identification of improvement points, either at the level of quality control or at the human or machine level. Two critical metrics, illustrated in Figure 3 are the employee's productive and non-productive working time. Productive work can be counted (concept mentioned in 19% of studies), and the non-productive work deduced (this concept mentioned in 14% of studies).

As for technologies, as illustrated in Figure 4, there is no reference in 29% of the studies. The other studies analyzed refer to technologies dedicated to the problem in question, something expected for projects where IIoT is present. Despite this, RFID and Microservices and Pipeline technologies outnumbered the remaining ≈6% of the remaining technologies. The RFID technology was referenced in cases where the authors intended to have greater process control, quality control, product tracking and real-time and automatic data collection. Concerning achitec-

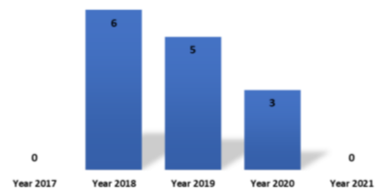

Figure 2. Number of studies per year

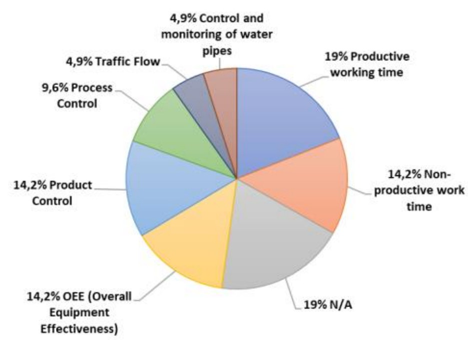

Figure 3. Metrics Used

ture in Pipeline, it was referenced as an innovative architecture for industrial systems, thus contradicting the old monolithic system. Near Field Contact (NFC) technology was also referenced as a suitable technology for tracking, however, it was only reported in 5.9% of studies. The collection of all information is an important process, but no less relevant is the analysis and study of the data collected. Given the vast alternative solutions for data visualization, as in technologies, no emphasis was observed, as illustrated in Figure 5. The highest visualization reference in the studies concerns the graphic representation, yet 41% of the studies did not refer to the type of tools used to visualize the data. However, analyzing the two tools that obtained a higher percentage of reference stand out with 9% the Andon systems, something expected to exist on any fabric floor. For systems that use JavaScript, a percentage of 9% was also obtained compared to the systems mentioned in all articles. Andon systems make sense for the fabric floor and sometimes on the same interface of the machine where the operator is working. Systems developed in JavaScript make more sense in being used when a website is needed, usually to represent data collected in production. After analyzing scientific articles, it became clear that IoT systems are highly sought after in different sectors and business areas, being very understandable for their usability. This study was essential to identify which technologies should be implemented and which KPIs to be calculated. After analyzing the different articles and obtaining the answers to the questions at the beginning of this document, we can conclude that there are different technological solutions for each problem. General systems and/or systems may be developed to address a particular problem. Thus, of the thirteen articles analyzed, the main conclusions drawn were:

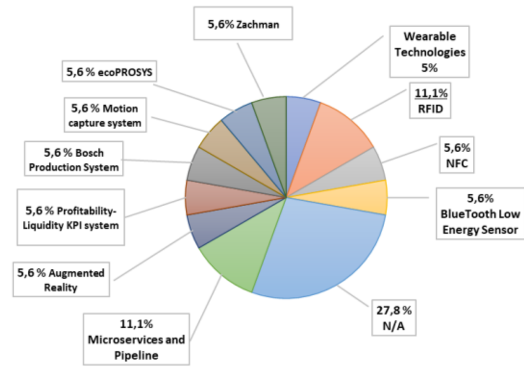

Figure 4. Percentage of technologies

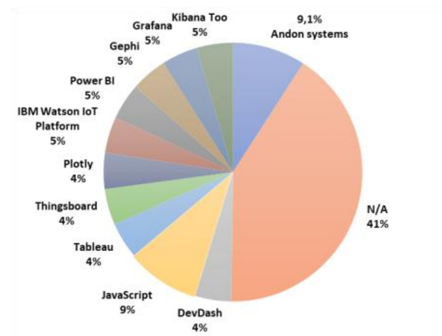

Figure 5. Data Visualization Tools

Question 1: What systems exist to measure productivity?

Several systems have been put forward to answer this question. Some studies had the presence of a new tool for measuring productivity as their primary objective. Others chose existing systems as the basis of their study and presented proposals for improvement. Thus, information collection systems can be divided into two groups: the first group belongs to the general systems, which serve as a solution for various business ideas. The second group refers to the dedicated systems developed to respond to a given problem. In the general systems group, some names appeared throughout the study, such as: Bosh Production System [7], and MAESTRI Total Efficient Framework [10]. In the second group, the systems are based on the development of IoT [3][11]-[14]. These systems are flexible in the type of technology they use, but all with a single common goal, data collection. In addition to these groups, articles brought another type of innovation to the industry, such as pipeline systems, focusing on the importance of not having a monolithic system and the management issues that these monolithic systems bring to the industry or any system that implements it [5]. A group of systems was also mentioned throughout the study, the Andon systems. Despite being significantly related to the fabric floor's machinery and color system, these systems can also contribute to the collection of productivity information. These systems allow for measurements and present visual solutions that help improve the interaction with the machines by the employee. [4] proposed a new interface in Andon systems that significantly improves the usability of systems.

Question 2: What metrics are used in the collection of information?

Throughout the research, it was clear that the metrics to be used were dependent on the type of analysis desired. Metrics can refer to equipment but also the employees, depending on what you want to measure, as well as the context, such as measuring the temperature of an oven or the humidity of a warehouse. In the previous articles, we have been presented with solutions to specific problems, and these problems are overcome by collecting information. Although process control, product tracking and quality are one of the most referenced metrics [7][13][14], others, such as OEE, movement speed, distances travelled, productive and non-productive working time, water pressure were also mentioned in the articles [3][7][8].

Question 3: What frameworks/tools are used to collect information?

Although there are some dedicated frameworks for collecting information [7], there are many other things developed for a given case study, being almost dedicated systems, only developed to respond to a particular problem. These end up having as technological base IOT systems, which collect information and send it to bases of relational or non-relational data through sensors. Thus, the tools to be chosen and mentioned in the studies also end up being dynamic depending on the problem because they try to apply the best technology to which it fits, trying to respond to a particular problem. We can see this in [14], where the main objective was to construct a system in which it was possible to "control and monitor water pipe". For this, an IoT solution was developed that answered this issue.

Question 4: What data analysis and visualization tools are possible and used?

Some tools were indicated throughout the analysis of the studies. Sometimes they were tools and graphics in the framework or application itself, such as Andon systems [3][4]. Others are well-known frameworks in the industrial world, such as PowerBI and Thingsboard [1]. The study by [1] emphasizes the importance of these tools in supporting decision-making. Some of these tools are known and widely used, such as: Tableau; Thingsboard; Plotly; IBM Watson IoT Platform; Power BI; Gephi; Grafana; Kibana Tool; JavaScript libraries, frameworks e toolkits. Some tools can be incorporated into a website [14] using JavaScript or tools such as DevDash [11]. However, today has the same objective: The valorization of the collected data and subsequent treatment and analysis. This type of tool is extremely important because it is through the visualization of the data that we can make decisions or see the system's state for analysis.

III. CONCLUSION

Production control systems are complex. Several technologies can be used, such as the use of contact technologies or the collection of information through sensors, using IoT technologies. In this type of application, it is important for the visualization of information that can be simpler as Tableaux or more complex platforms, such as Amazon Web Services (AWS), integrate into it all the operations. In this type of approach, KPIs are the focus in what concerns the search to improve productivity factors, resulting from metrics and information analysis, also in this field studies refer to several approaches. According to the problem to be solved, IoT can be used, associating platforms for data visualization and analysis that allow productivity to be improved for the situation in question. For future work, we recommend a larger study to tackle the presented limitations in the introduction and to develop a system that combines IoT technologies to support productivity metrics in the industry.

REFERENCES

[1] A. Protopsaltis et al., "Data visualization in internet of things: tools, methodologies, and challenges", in *15th International Conference on Availability, Reliability and Security (ARES '20)*, New York, NY, USA, 2020.

[2] M. J. Page et al., “PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews”, BMJ, vol. 372, doi: 10.1136/BMJ.N160, 2021.

[3] A. R. M. Forkan et al., "An Industrial IoT Solution for Evaluating Workers' Performance Via Activity Recognition," 2019 IEEE 39th International Conference on Distributed Computing Systems (ICDCS), 2019, pp. 1393-1403, doi: 10.1109/ICDCS.2019.00139.

[4] M. Di Gregorio et al., "Designing usable interfaces for the Industry 4.0 | Proceedings of the International Conference on Advanced Visual Interfaces", in *Advanced Visual Interfaces. Association for Computing Machinery*, New York, 2020.

[5] F. Li and L. Gelbke, "Microservice architecture in industrial software delivery on edge devices", in *19th International Conference on Agile Software Development*, New York, 2018.

[6] C. Siedler, L. Pascal and A. Jan, "Modeling and assessing the effects of digital technologies on KPIs in manufacturing systems", Procedia CIRP, vol. 93, pp. 682-687, 2020.

[7] Robert Joppen et al.,"Key performance indicators in the production of the future", Procedia CIRP, vol. 81, pp. 759-764, 2019, ISSN 2212-8271,https://doi.org/10.1016/j.procir.2019.03.190.

[8] G. Ante et al., "Developing a key performance indicators tree for lean and smart production systems", *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 13-18, 2018.

[9] E. Ferrari et al., "Motion Analysis System for the digitalization and assessment of manual manufacturing and assembly processes," *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 411-416, 2018.

[10] A. Baptista et al., "MAESTRI Efficiency Framework: The Concept Supporting the Total Efficiency Index. Application Case Study in the Metalworking Sector", *Procedia CIRP*, pp. 318-323, 2018.

[11] M. Fera et al., "Line Balancing Assessment Enhanced by IoT and Simulation Tools", 2019 II Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0&IoT), 2019, pp. 84-88, doi: 10.1109/METROI4.2019.8792889.

[12] P. Nesi et al., "Auditing and Assessment of Data Traffic Flows in an IoT Architecture", in *IEEE 4th International Conference on Collaboration and Internet Computing*, Philadelphia, 2018.

[13] F. Casino et al., "Modeling food supply chain traceability based on blockchain technology.", *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2728-2733, 2019.

[14] M. Abdelhafidh et al., "Cognitive internet of things for smart water pipeline monitoring system", *IEEE Press*, pp. 212–219, 2018.