Industrial Internet of Things Systems for Tracking and Traceability of Production Business Processes

Paweł Buchwald
ORCID ID: 0000-0003-2537-7085
Academy WSB, **Poland**

Artur Anus
ORCID ID: 20000-0002-3648-6503
Iconity sp. z o. o., **Poland**

INTRODUCTION

One of the aspects of industrial production management is the assessment of production processes. Many branches of the manufacturing industry also impose on production management the need to track the implementation of manufacturing and production processes. These tasks could not be performed without having current information on the state of the production company, including the current state of production. Currently, the industrial Internet of Things systems and methods of tracking products and semi-finished products are used for the acquisition of production data. The data from these systems are also used in the process of optimizing production tasks, which is based on a proactive approach. This approach is characteristic of technical sciences in areas such as IT infrastructure management, especially network infrastructure. During the occurrence of certain anomalies related to the deterioration of data transmission parameters, or the operation of the network infrastructure, actions can be taken to improve this state (e.g. using a redundant resource or changing priorities for individual data transmission packets). Similar solutions can be implemented on the production line in case of early noticing potential problems or situations threatening the quality and efficiency of production. The article presents the architectural assumptions of an automated production system, which has the properties of tracking current indicators of the production process and product quality, and in the event of detecting negative trends in their change, it allows them to take remedial measures. Thanks to this, it is possible to proactively manage production. The article presents the concept of using modern IT solutions and systems to assess the state of production processes. The concepts of using such solutions have been tested in real conditions, and the paper presents the implementation problems and benefits of the presented approach.

Contact address: pbuchwald@wsb.edu.pl; artur.anus@iconity.pl

THE PROBLEM OF TRACEABILITY OF BUSINESS PROCESSES WITH THE USE OF INFORMATION TECHNOLOGY IN THE LITERATURE RESEARCH

Tracking business processes take place in various aspects of the company's operation. The economic considerations and profitability of the implementation of such processes, the technical aspects of ensuring the continuity of the process, and the traceability and traceability of input and output products of the processes must be assessed. This problem area is referred to in the literature as observability or traceability. The problem of tracking business processes is especially important in the areas related to food supply and production. The study (Buchwald and Anus, 2020) presents the need to introduce product traceability methods to prevent animal diseases related to food circulation. The study noted that the product traceability and traceability is a product feature desired also by consumers and increases its value. For this reason, the implementation of traceability and tracking systems for business processes in enterprises becomes one of the key functionalities.

Continuous and frequently changing requirements determine the appropriate way of managing the company's business processes. Traceability is essential for managing change and analyzing its impact on the effectiveness of business processes, as highlighted in (Bashir and Qadir, 2006). This research article provides an overview of existing techniques in the field of traceability that allow you to identify problems and outlines the criteria that are used to evaluate existing traceability techniques. The study shows that in many cases the current traceability techniques are insufficient and may cause problems in requirements management for dynamically changing business processes. The authors argue that existing traceability methods should be combined to solve problems in terms of process management and maximize the benefits of traceability through the synergy of the methods used.

The synergy between IT systems supporting production and traceability methods is shown in the study (Xue et all, 2007). The authors present the key aspects of traceability for vegetable processing. The study outlines the basic elements of modern IT-based vegetable traceability systems. The study highlights the problems of implementing IT-based traceability that would meet accepted international standards. The conclusions of the study indicate that a corporation may lose much of its competitive advantage in global markets if it does not implement and enforce traceability systems.

Meeting the requirements for IT systems in terms of traceability of business processes is not easy. One of the methodologies for constructing such systems is presented in (Honghua et all, 2020). The article presents the possibilities of designing an IT system using Model Driven Architecture. The study shows modeling based on graphs for the traceability of the flow of goods. Models based on graphical notation present a list of elements – raw materials, parts, semi-finished products, and subassemblies, which during the production process are transformed into a final product through a sequence of operations. Subsequently, the graphic inventory was translated into reference data and a

model which was the basis for designing an IT system for tracking and identification. By registering all operations and their input parameters and products, a method of tracing the composition of the final product and the performance of the production process is obtained. The data obtained in this way can be used to assess product quality, select products containing a specific ingredient, and allow you to adjust production processes to optimize the quality of the product with its production characteristics (e.g. shortage, costs, or time). One of the technologies that significantly facilitate the tracking of products created during the execution of business processes is tag methods of product identification, including RFID, which was presented in the publication (Lee et all, 2008). RFID (Radio Frequency Identification) technology is used in areas such as supply chain management and computer identification, thanks to its special features allowing for the economical implementation of detection and identification methods RFID technology is an alternative to barcode identification systems and is gradually adopted and implemented in a wide range of applications, including supply chain management. The article presents the possibility of tracing the supply chain consisting of four basic levels: supplier, producer, wholesaler, and retailer. The authors focused in particular on presenting the possibilities of using RFID on the side of production processes, which consist of processing, combining, and aggregating individual components. The study proposes a data model and system architecture that will offer full traceability functionality by extracting BOM information from ERP (enterprise resource planning) and performing activities related to connecting production paths. The authors point out that the production path search module for given components is an essential element of the identification system and requires data integration with the databases of the manufacturing company. Without this, companies will only have a huge amount of raw RFID data for products and components. Existing enterprise applications and IT systems require a simple path inference module for traceability.

Printed tags such as the QR Code are also often used in traceability tasks. The use of this type of tag in traceability systems is presented in the study (Tarjan at all, 2014). The article presents the concept of traceability, which is to provide insight into key data about the product to the user (mainly the final consumer), in this article, it is suggested to save the data on the product packaging in the form of a two-dimensional barcode (QR code) at key points in the life cycle of the production cycle. For the efficient functioning of the proposed system, it is important to ensure fast and reliable operation by appropriate code placement on the packaging during production and quick and easy reading of the data by the consumer of the product. The article presents the results of the analysis of the readability of a QR code with variable content, size, and level of data error correction, which are read by smartphones with the Android system. The experiments were carried out with different types of base material onto which the code was printed. Moreover, the readability of the QR code was analyzed in the case of the geometric deformation of the code. An example of a proposed

traceability system where QR codes are used to track data for fruit yogurts is presented below in this article. According to the authors, this concept of the identification system is universal and can be applied to various products with slight modifications.

In the study (Hamilton and Beeby, 1991), the authors emphasize the advantages of business process traceability, at the same time paying attention to the difficulty in meeting traceability requirements in enterprises with a lower degree of computerization, where part of the information flow is carried out without electronic media. In these types of cases, the cost of practically meeting traceability requirements can be significant, and often problems with implementing the observability and traceability of non-computer-managed processes outweigh the benefits of traceability. As computerization of ever-larger parts of the lifecycle increases, the benefits of traceability also become available to smaller, less computerized organizations. The article discusses the concepts of tool integration, tool integration technologies, and future directions of development of identification systems.

In the article (Cleland-Huang, C.K. Chang, 2003) it was noted that the actual practice of maintaining traceability systems is not always fully successful. The underlying infrastructure and software tend to become outdated throughout a system's lifetime, as practitioners under time pressure cannot consistently maintain connections between essential information after changes are made, even with the support of automated systems. The article proposes a new tracking method based on event notification. According to the authors, it can be used even in a heterogeneous and globally dispersed production management environment. Traceable objects are linked through events that generate a change in the production system. According to the authors, the presented method also supports improved project management in the process of updating and maintaining the functionality of the process and product identification system.

The study (Maro and Steghöfer, 2016) noted that one of the main challenges in constructing traceability systems is that there is no single solution that will solve the traceability problems for all companies, even in the same industry. Traceability needs depend on the context of the organization and may differ from project to project within the same organization. To address this issue, the authors developed the proprietary Capra system, an open-source traceability management tool that is flexible, configurable, and extensible. Capra can be tailored to the specific traceability needs of individual projects and organizations. Based on the literature research, it can be concluded that the IT system for traceability should be highly flexible and use the product information that is present in other enterprise management subsystems to the greatest extent possible. An important factor supporting the effectiveness of the practical application of the traceability system is the automation of the transmission of information about the performance of the process, and the ability to identify the results of business processes by eliminating the human factor from the process

of obtaining information about the operation of production. For this reason, an important aspect of the preparation of an IT traceability system is the adaptation for a specific case of methods of obtaining data from production tracking systems and tag systems for identifying items (resources and products) (Buchwald 2015).

EXPERIMENTAL EVALUATION OF THE TRACEABILITY USING IOT SYSTEMS

The conducted research experiment was aimed at assessing the possibility of using selected Internet of Things solutions for automatic production traceability. The assumptions regarding the conducted experiment had to allow it to be carried out in a real enterprise without the need to modify the existing IT infrastructure. It was only possible to add additional hardware components or programming components integrated with the management systems present in the enterprise. During the experiment, however, it was not possible to modify the software, which was closely related to production control. All integration modules in the form of dedicated programming solutions could not affect the time determinism of production management systems and could not hinder the data flow in the enterprise. As shown in the literature research, the currently used traceability support systems need up-to-date data from the production process. Self-implementation of such software would be a task requiring a long implementation time, so to reduce the time needed to execute the tests, it was decided to integrate with the solutions existing in the company that can be used to read data on the production processes in progress. The construction of architectural concepts of the IT system supporting traceability was therefore preceded by an analysis of the possibility of obtaining the latest data on the production process. The diagram of the general architecture of the IT system implemented to acquire data on the course of production is shown in the Figure 1. The main source of information on the implementation of production was the SCADA system. Possibilities of data acquisition from this system are presented in the next chapter of the study. Full identification of production also required obtaining data from the integrated management system, which allowed for the use of timestamps for product identification. An additional feature of the designed system was obtaining a high degree of autonomy from the company's IT system. Therefore, it was decided to build an experimental computer network based on the 802.11 wireless network standard and to run the integrating software on separate devices – servers. The adopted production tracking methods depended largely on the activities performed by employees. They could not be too burdensome for workers to execute production, and they had to be applicable for the counting and identification of products. To ensure such identification properties, experiments with the use of barcodes and NFC tags were carried out.
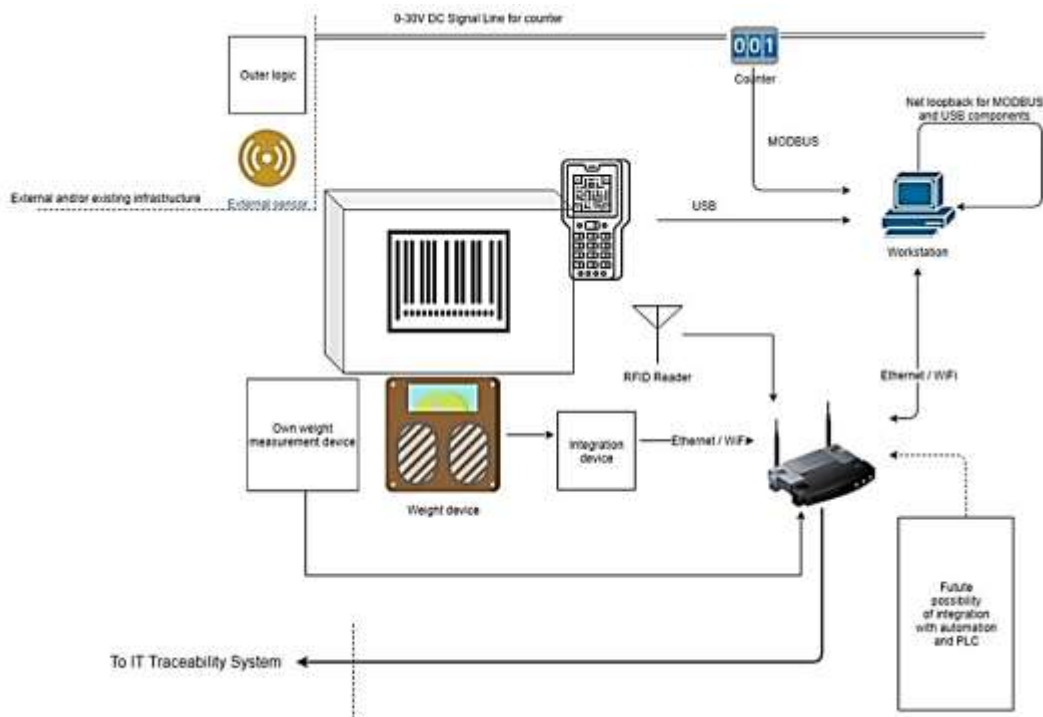
Fig. 1 The general architectural concept of an IT system for tracking production processes

These methods are widely used in the identification of production, but the possibility of using such tags in a specific enterprise had to be confirmed experimentally. The experiment was aimed not only at assessing the operation of measuring devices, but also the cooperation of production personnel with the system. Only in the case of the effective operation of the IT system and production personnel, it is possible to obtain reliable data on the production process. If the applied measurement methods make it too difficult to implement the production or are not adapted to the specificity of the implementation of production tasks, they cannot be used. A time analysis was adopted to verify the applicability of the selected measurement methods. The experiment was to show whether the applied methods of detecting the progress of production fulfill the criterion of keeping up. In the case of using automatic data acquisition methods, this criterion is met by assumption. With the participation of the human factor, delays related to the implementation of tags on products or the need for employees to cooperate with devices recording data from tags could cause additional delays, which could adversely affect the monitoring system's compliance with the monitored production process. For this reason, a research experiment was undertaken to empirically assess the times of collecting information on the progress of the production process. The usefulness of selected methods of reading data on the implementation of production in a specific case of the production system was also checked. It should be remembered that each production process has its specificity, however, the Internet of Things devices available on the market provide great flexibility of monitoring. Therefore, according to the authors, the proposed approach can be

considered applicable in most production systems based on the process approach. Especially in the case of small and medium-sized enterprises characterized by a large share of the human factor in production processes, the proposed methods of tracking production may be an interesting solution from the economic and functional point of view.

OBTAINING DATA FROM SCADA SYSTEMS

The term SCADA (Supervisory Control And Data Acquisition) – means an IT system that supervises the course of the technological or production process. Its main functions include collecting current data (measurements), their visualization, process control, alarming, and data archiving. One of the popular SCADA systems on the market is the Indusoft software. The leading product of InduSoft Web Studio is the HMIA/SCADA system of the RACE type (Rapid Application Configuration Environment), which is a set of tools enabling the visualization of technological processes and offering full integration via the Internet and wireless connectivity. InduSoft Web Studio software can be used to create applications compatible with all supported Windows systems and to create an HMI/SCADA system without the need to install additional programs. As part of this software, synoptic panels and operator panels are created, enabling the control of machines and devices at the level of production process control. Individual parameters can be controlled hierarchically, taking into account aggregated values and detailed values. One such parameter is electricity consumption. It is an indicator that enables a highly accurate assessment of switching on/off machines and devices. The synoptic panel that allows for the control and visualization of data on electricity consumption with a breakdown into individual switchboards is shown in Figure 2.
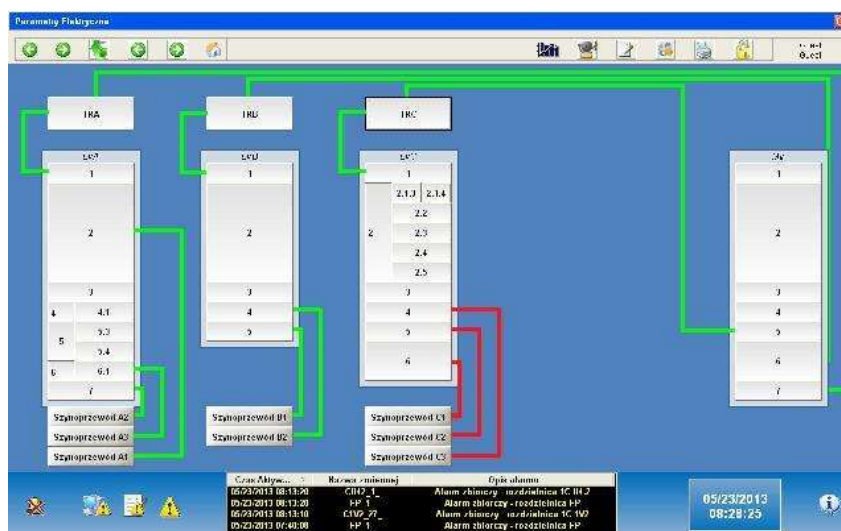

Fig. 2 View of electrical switchboards
Source: (own work based on Indusoft software)

This view allows you to quickly visualize the power status of individual switchgear bays and busbars. It shows the approximate distribution of the

switchgear of the Transformer Station with the lines illustrating the distribution of power. A hierarchical analysis of electricity consumption allows you to visualize the continuity of operation of individual electrical devices. At the level of a single device, it is possible to evaluate its shutdown and activation - including planned interruptions in operation related to routine maintenance and interruptions resulting from the production process. The appearance of the synoptic panel allowing for the assessment of the continuity of operation of individual devices is presented in Figure 3. These data must be accurately interpreted in the context of the processes being performed, because the lack of information about turning on the devices may mean failure, or a break resulting from the nature of the production process. In the SCADA system, it is also possible to define a preliminary interpretation of measurement data, and in the case of detection of irregularities, generate a special message in the production system.
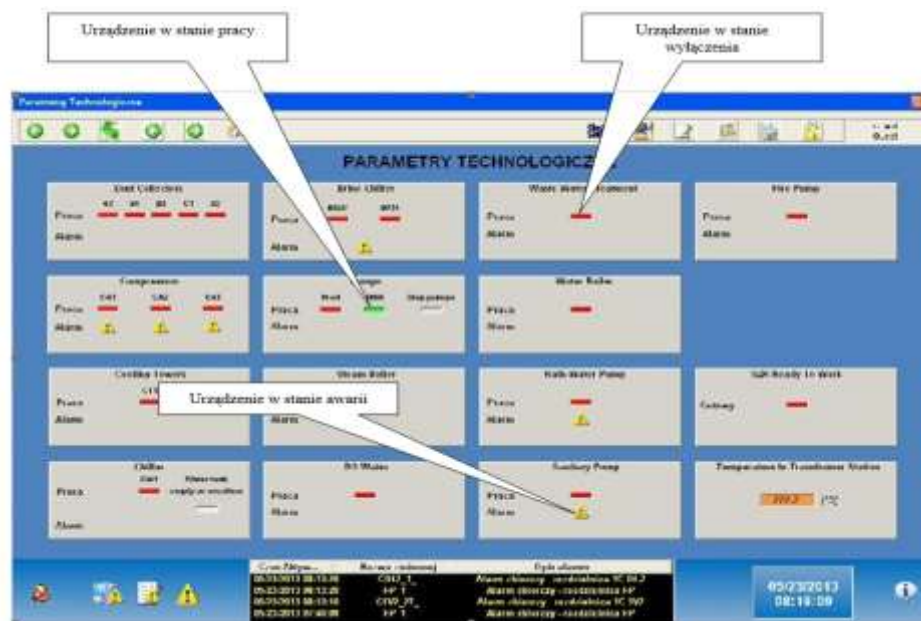

Fig. 3 Information on the continuity of production devices operation visualized by the SCADA system
Source: (own elaboration based on Indusoft software)

The event messages can also be distributed and analyzed by external IT systems. The data from the business continuity analysis can be used not only for visualization but also to evaluate the operating time of devices for analytical purposes. Modern SCADA systems are equipped with interfaces allowing the transfer of required data to external IT systems, such as relational databases.

METHODS OF TAGING PRODUCTS

In the case of less automated production processes, it was proposed to use additional sensors to assess the progress of work, which helps not only in the identification of process progress but also in the identification of products. The

choice of product marking methods must be closely related to the specificity of the production process, the applicability of the tag on the product, and the ability to read the tag effectively for identification purposes during the production process. The economic aspect of the tagging method is also important, as it is influenced by both the costs of the tags themselves and the reading infrastructure. To use tagging methods in tracking the progress of production processes, an assessment was made of the possibility of using tagging methods based on radio wave (RFID) data acquisition in the production environment and methods based on the graphic representation of identifiers in the form of bar codes. Due to the popularity of this identification method, the degree of information packing, and the code's resistance to partial damage, this identification method was selected for analysis. For the research on tagging methods based on RFID technologies, a radio tag reading system was used, based on a device that enables the reading of RFID tags using the HF band (13.56MHz). The main controlling element of the device is the ESP12E system. The ESP12 system, which is the core of the measurement system, is equipped with the ESP8266 microcontroller. The system has an integrated TCP/IP protocol stack as well as a sufficient number of I/O ports for the device. In an industrial production environment, it is not always possible to associate individual tags with the product. Such a case occurs during the production of loose materials, fine materials, and if the placement of the marker is not possible due to its high probability of being damaged later in the production. For this reason, the study also includes a method of tracking product growth by using a measurement method based on weighing components. This method is one of the most difficult due to the necessity to use additional programming modules that eliminate measurement errors and "false" increases in the weight of semi-finished products that may arise as a result of the influence of the human factor or external disturbances. For this reason, the weighing method must be specially adapted to the specificity of production, and before its final application, it must be verified for correct reading for a given production line. The presented methods of monitoring the increase in production do not exhaust all possibilities. It is also possible to use various light curtains, pressure sensors, vibration sensors, current consumption sensors, and others that can help track the work of machines and devices actively participating in the production process (Buchwald and Anus, 2020).

Due to the necessity to implement additional data filtering modules and the elimination of disruptions related to the operation of machines and devices by the human factor, the weighing method turned out to be the most difficult to apply, but after observing the operation of the production line and using programming filters, this method also turned out to be useful in tracking the production process. The research measured the time efficiency of reading the increase in production using additionally installed devices. The results of the research on the efficiency of time acquisition of data on the increase in production with the use of tag methods are shown in Figure 4 and Figure 5. The

measurements of the reading time of the production increase using weight measurements are shown in Figure 6.

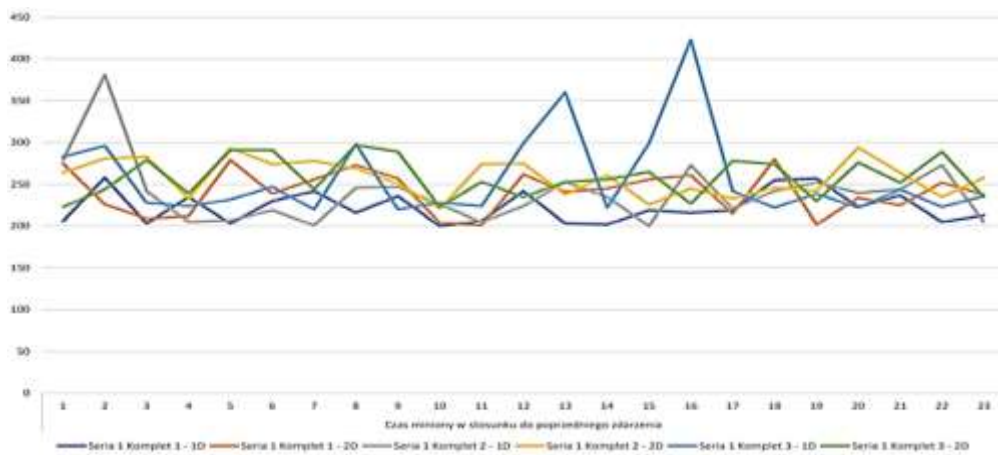**Fig. 4 Data acquisition time using RFID tags**

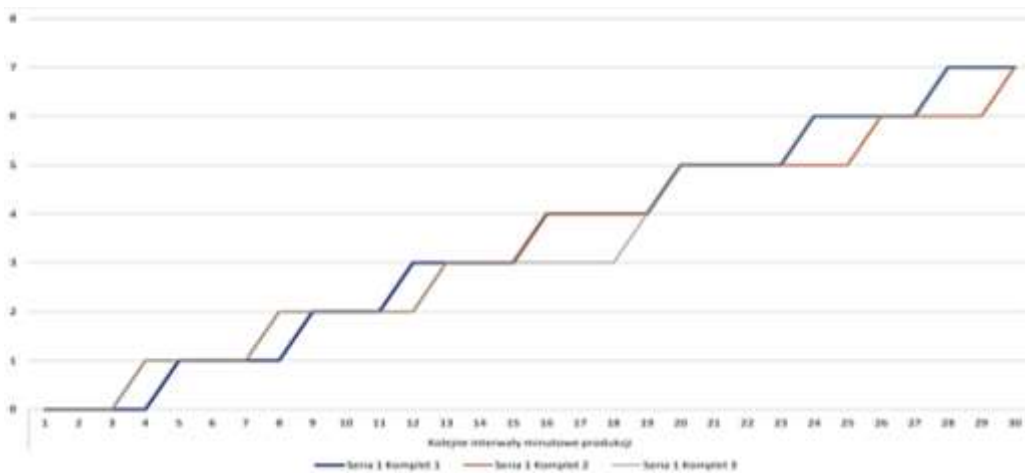**Fig. 5 Time of reading data on the increase in production using graphic markers**

Fig. 6 Counting the increase in production using the weight method.

The first type of tests consisted of the presentation of a set of 20 markers and detection of the amounts read from this pool, along with the total presentation

time. On this basis, the sensitivity of the device (the ratio of the number of readings to the number of presentations) and the theoretical maximum speed of reading was determined. The collected results indicate that the reading is noticeably worse when the tag-reader distance is increased to 5 cm. The collected data indicate that for users the necessity to present the tags is a factor that hinders their work, but with the increase of the distance from the reader, the convenience increases, and the accuracy and speed of reading decrease.

The collected data confirmed the possibility of using the method of tracking production growth based on RFID components. For the measurements of the increase in production using graphic markers, acceptable times of information acquisition into the system were also obtained. In the case of barcodes, the possibility of reading data from a greater distance than in the case of RFID codes gives the end-user less inconvenience. Unfortunately, graphic tags must be prepared and printed in advance, but this operation can be automated using dedicated software. The weight measurement technology can be used in various ways - one of them is the ability to treat the measuring device as a quasi-counter, incrementally based on the current load and a known unit weight allowing for aggregation of the initial number of components at a given stage. In the measurements presented in Figure 6, a measurement interval of 1 min was assumed, which was sufficient to control the production on the analyzed production line. Due to the necessity to use additional programming components and filtering out disturbances, the delay between the requests generated by the system and the physical production of the components was not constant, but it was sufficient to test the increase in production. Based on the conducted measurements of the time efficiency of the methods of analysis of production increases, it should be stated that the presented measurement methods meet the postulate of measurement follow-up with the production time of individual components and are suitable for production tracking.

SUMMARY

The study presents the results of the research on the possibility of using methods of measuring the increase in production with the use of proprietary Internet of Things devices and the methods of marking products used in industry and logistics. Such measurement methods, together with the appropriate interpretation of additional information included in the enterprise management systems, can make it possible to track business processes, assess their effectiveness, and traceability of products. Acquiring such knowledge about the production is also a step towards improving and optimizing production processes. The system presented in the study is supporting and does not take a direct part in the control of industrial automation processes. Thanks to this, it was possible to obtain data through hardware modules built based on the Internet of Things solutions, which reduced the costs of the analyzed system. Unfortunately, the use of feedback and adaptation of the presented method of interfering with the production process would entail the need to conduct

additional tests related to obtaining the necessary certification. In the context of the problem presented in the title of the study, the mere acquisition of data on the course of production without the need to interfere with the process control was sufficient. The research on time efficiency has shown the adequacy of the presented measurement methods in tracking the increase in production and proved their usefulness in the area of traceability.

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Abstract: The article presents the results of research on the use of measuring devices based on RFID tags and graphic tags to track the increase in production. The conducted research experiments were made in a real production company, which is characterized by an average degree of digitization of its business processes and significantly uses the human factor in production. The conducted research allowed us to show the usefulness of measurement methods in tracking business processes, and to analyze the method of obtaining production data to achieve the traceability of manufactured components. The study also presents selected examples of IT systems in solving traceability problems (traceability and traceability of production).

Keywords: Traceability, RFID, ERP, SCADA, IoT