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Automating the process of method-time-measurement

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Abstract

Purpose – This work reports on a developing method time measurement system for measuring manufacturing and assembly processes automatically. This automatic system enables the production engineers and management to detect, process, and display concise and accurate information about the operations in real time.

Design/methodology/approach – This system is based on Internet of things technology and RFID-antenna. This methodology consists of seven main steps and one final optimization step. Mainly, the operator is equipped by RFID reader, and the work station tools and devices are provided by RFID tags. Responding the RFID tags to the reader will refer to the certain operations, the difference time between start and end of the operations will be collected immediately and calculated by the microprocessor of the system.

Findings – This automatic system is promising, considering the accurate time measurements and recommendations that obtained from the case study which includes measuring manual assembly operations to be followed in order to overcome the limitations which are not only technical but also managerial, legal and organizational.

Research limitations/implications – The acquired data about timing and duration of individual operations are anonymized to guarantee the compliance with respect to the privacy laws (GDPR and Italian work's laws).

Originality/value – This work presents a unique system to measure the time instead of traditional methods in the factories environment and satisfies the requirements to study the recommendations in order to overcome the challenges.

Keywords Method time measurement, Internet of things, Operation management, Time study, Work study

Paper type Research paper

1. Introduction

Nowadays, Industry 4.0 paradigms are increasingly applied in manufacturing environments due to their impact on the efficiency, productivity and quality of the performance of companies. Improving the performance and increasing the efficiency by gathering and analyzing data, simulation and communications require technologies and methods that allow the communication between processes, machines, tools and employees in integrated networks. Several techniques 4.0 have been used in recent years, such as Industrial Internet of Things, Cyber-Physical Systems, big data and simulation, in different scopes of work (Nagy *et al.*, 2018). Hence, Industry 4.0 aspects like the Industrial Internet of things (IoT) are changing companies' way of working. The digitalization and communication technologies are not just two of the most fast-growing disciplines but also play a crucial role in the fundamental changes in the global manufacturing systems

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and smart factories (Nick and Pongrácz, 2016). Referring to some sources (Eric *et al.*, 2017; Ateeq and Claus, 2016, and Eunsung and Sung-Yong, 2016), Industry 4.0 is one of the essential promising solutions: in fact, Industry 4.0 factory could result in production costs reduction by 10–30%, logistic costs by 10–30% and quality management costs by 10–20%. The adoption of Industry 4.0 concepts provides several advantages and reasons including shorten time-to-market for the new products, improvement of customer responsiveness, enabling a custom mass production without significantly increasing overall production costs, more flexible and friendlier working environment, and more efficient use of natural resources and energy (Rojko, 2017).

Involving the advanced technologies is a useful way to get real-time feedback to the designer, planner, manufacturer and management. So, to support measurement methods field, reliable methods for the improvement of the measurement capability have been developed to avoid measurement uncertainty and obtain more accurate data than using conventional methods (Maropoulos *et al.*, 2007). Based on the more global definition of Industry 4.0, which is defined as a set of initiatives for improving the processes, products and services allowing decentralized decisions based on real-time data acquired, the goal of this work is improving the measurement of production processes. The goal is achieved by providing real-time synchronization of operation flow, referring to Industry 4.0 concepts which enable better measurements to be integrated in real-time, in spite of the unstable manufacturing environment and dynamic competitive markets. Industry 4.0 technologies, such as IoT, should improve the transmission of information through the whole system, in order to obtain more reliable data, real-time communication and monitoring of physical objects, and decentralization of decision-making (Moeuf *et al.*, 2018).

Time studies have been divided into three classes: (1) stopwatch or direct timing, (2) instantaneous observations and (3) predetermined time-motion studies. Time studies belonging to these three categories depend on the estimation, using statistical tools, and they are affected by human factors (Polotski *et al.*, 2019). For this reason, there is no high confidence probability, especially for measuring the short time operations. Therefore, there is the necessity to use IoT technology to fill the gap between the practical needs and the errors that probably would happen in using these methods.

In the next sections of this paper, the authors will review state of the art, including the integration of operation tools with method-time-measurement (MTM) system and the possible technological solutions. Later scenarios and requirements will be presented, and then material and methods with a case study mimicking an industrial assembly process. Finally, the paper illustrates the limitations and challenges, and ends with the conclusion and future work.

2. The state of art

The understanding of methods, operations and procedures adopted in manufacturing and assembly, and the measurement of the real lead time is a challenging research area, due to the several issues that span from technical, legal to organizational aspects (Alkan *et al.*, 2016; Panhalkar *et al.*, 2014) as long as these issues are related to the continuous improvement (Jurburg *et al.*, 2019).

The well-known trends towards automation and the one of industry 4.0 push to reconsider on a broader perspective the interplay of humans and machines for the space they share (Monostori *et al.*, 2016) or environment where they collaborate (Krüger *et al.*, 2009).

New technologies (Cecila *et al.*, 2019; Ghini *et al.*, 2019; Cao *et al.*, 2019; Harari *et al.*, 2017) and old/standard tools (Bi *et al.*, 2011; Inasaki, 1998; Schwarz *et al.*, 2018) can be exploited to automatically gather information about planned methods, real human behavior and times (e.g. setup time, assembly, manufacturing, material handling activities).

Smart technologies (e.g. Industrial Internet of Things IoT) for monitoring and measuring the industrial manufacturing and assembly activities demonstrate to be valuable, especially in the environment that requires automation, high accuracy and reliability.

The literature review was achieved by searching the query "method time measurement" on the Scopus database, obtaining 494 papers as output. Standard queries in Scopus in almost any technological fields usually produce a country distribution that sees USA and China over-exceeding the other countries. In the case of the present query the result is surprisingly different: USA remains at the first place (130 papers), but Germany follows (75 papers) and then Sweden (40 papers). Then a group with around 20 papers is composed of United Kingdom, Italy, Canada, Austria and Australia. The final positions are for Israel and China.

Such a distribution probably underlines a different interest concerning other technological-based research. It can also be a sign of the pressure of laws, standards and a highly regulated labor market or a strong presence of syndicates.

More in detail we can distinguish some papers focusing on technological aspects (about 56%), on ergonomic aspects (about 62%), on safety (about 26%), on performance evaluation (almost 50%), on productivity (almost 35%) and on human factors (almost 35%). These percentages reflect the overlapping of some areas: this means that some papers belong to more than one field. Of particular interest are those concerning planning and design (about 74%), assembly (about 53%), manufacturing (about 46%), both manufacturing and assembly (almost 40%), logistics (about 12%) and maintenance (almost 13%). The target for the analyses mentioned above is the automotive industry (16%), the steel industry (3%), but also plastic (about 2%), glass and ceramic (about 3%) and chemical industry (about 4%).

In the next paragraphs, the authors (1) review the past operation management tools that can be helpful to be adopted with the new MTM system, (2) explain the MTM system itself and then (3) focus on many solution methods that have been used in different applications.

2.1 Integration of operation management tools with MTM system

Building a baseline is not an easy mission, whereas it needs time, efforts, group thinking and it is sometimes considered the low value-added. So integrating operation management tools will provide more probability of the system to be reliable, effective and high value-added. Hence, all the methodologies need to be evaluated and measured to check the efficiency and obtain evident vision to improve the built system, especially the methodologies that are highly related to the human being.

(1) 5S (seiri (整理), seiton (整頓), seisō (清掃), seiketsu (清潔) and shitsuke (躾)), Six Sigma-DMAIC (Define, Measure, Analyze, Improve and Control), Poke Yoke or PDCA (Plan, Do, Check and Act).

(2) Method Time Measurement (MTM) systems have their roots in time studies as a predetermined motion time system. It can also be used in the field of workplace design and improvement.

So many essential tools can be integrated with these methodologies (Morlock *et al.*, 2017).

In the next paragraphs, it will be explained how Operation Management tools could be advantageously integrated with an automatic MTM system. The purpose of using these tools is to support the idea of measuring times automatically based on Radio Frequency-IDentification (RFID) solutions. Hence, RFID technology is a wireless communication technology based on electromagnetic waves used to identify and transfer information for an object (Cecilia *et al.*, 2014).

The most useful tools that can be integrated with MTM system are:

(1) Six Sigma DMAIC methodology. It can be used to implement Lean Manufacturing (LM) concepts that will be integrated with MTM system concurrently (Arafeh, 2015).

Using Six Sigma DMAIC tool will support the automatic MTM system through finding and eliminating causes of defects that may appear during the operation measurement, getting high-quality performances and good results. Hence, this methodology focuses on process outputs, reducing manufacturing cycle time and improving production flow by smoothing the flow of measurements (Patil and Inamdar, 2014). Six Sigma is an evolution of PDCA we will describe briefly below;

(2) Plan-Do-Check-Act (PDCA). This methodology can be applied in manufacturing environments to follow the measurement system based on these four practices. It allows the balancing of the opportunities and priorities, the monitoring of measurement execution considering safety and reliability, the analysis of measurement results and the update of the system to guarantee a high probability of system improvement. This methodology is an efficient approach to maintain the quality of measurement performance and continuous improvement (Nascimento *et al.*, 2018);

(3) 5S (Sort, Set, Shin, Standardise and Sustain) technique. The aim of the implementation of 5S in the organization is organizing a workspace to increase the efficiency of the manufacturing system and the effectiveness of labors and measure the performance, hence this technique works to identify and store the items, maintain the cells, workshop, floors, facility, and sustain the new order (Indrawati *et al.*, 2018). The process of taking a suitable decision usually comes from a conversation about standardization, which builds well understanding among employees on how they should perform their work (e.g. the measurement operation). The need to implement 5S in the organization comes into existence due to unorganized work-stations, uncomfortable working environment and the unnecessary wastes in the company (Kobarne *et al.*, 2016). When the 5S technique is applied to the manufacturing environment or the work cell, it enables the system to work smoothly; MTM system will able to reach the goal with fewer obstacles, especially in synergy with this technique based on training the workers and operators;

(4) Poka-Yoke method (mistake-proofing, error proofing). The philosophy of Poka-Yoke method is based on human rights. Above all, the method aims to improve the mentality of the human in order to increase its value (Dudek-Burlikowska and Szewieczek, 2009). Poka-Yoke probably saves time and release the mind of a worker for making operations more creative and increasing their value. This technique aims to avoid or reduce human error as much as possible during the measurement operation. The defects are exist in either of two states: (1) the fault has already occurred, calling for defect detection, or (2) it is about to happen, calling for defect prediction (Yi and Yusof, 2007).

2.2 Method-Time-Measurement methods

In the adoption of new technologies and systems toward the Industry 4.0 paradigm, several authors and practitioners (Carolis *et al.*, 2017; Chiarello *et al.*, 2018; Cuzzilla and Fazion, 2017) strongly encourage the initial assessments of the readiness level or maturity level of a company that approaches to Industry 4.0 paradigm. All the models provide a framework and a series of question to be evaluated by an auditor who visits the company, interviews the employees and management and provide a picture (the assessment report) on the readiness or maturity level of the company, plant, facility, shop floor, cells, etc.

After the assessment, several improvements can be identified, and a suitable strategy designed and implemented. The actions could be local improvements, or the redesign of a process through the Lean Manufacturing methodologies, or the adoption of one of the enabling technologies of Industry 4.0.

For all the situations mentioned above, an initial baseline has to be defined. It means decomposing each process and measuring the lead time (average and deviation) for each operation or process. Usually, in the past, the baseline was obtained thanks to a human being measuring with a chronometer the time spent by each operator in doing a specific operation, while MTM methods were used to structure sequences of operations into necessary activities (Almeida and Ferreira, 2009). Nowadays, many approaches have been conceived and successfully adopted in real cases, especially the time measurement and analysis that are related to the ergonomics in manufacturing and assembly workplace; these approaches that enable quantitative measures to estimate time spent and to analyze effective use of time in the production system are mainly based on Industry 4.0 elements, such as IoT (Maksimov and Kalkis 2016, 2018; Thramboulidis *et al.*, 2019).

If we refer to Small Medium Enterprises (SMEs), where only a fraction of the tasks is automatized, we can recognize how MTM could be useful to assess a process, a procedure, etc. and the measurement at $t = t0$ could be used as a baseline. After the processes have been redesigned and implemented, the measurement can be repeated to quantify the effect of the improvement (if any).

In an Industry 4.0 environment, we do not think it is useful to measure by using an employee, but we can use Industrial IoT systems to measure all the durations of tasks. Hand tools, such as jaws, screwdrivers, etc., personal protective equipment (PPEs), such as gloves, helmets, goggles and shoes could be equipped with RFID tags, while small machines, such as drills, hot glue guns and soldering machines could be equipped with current sensors and other basic ones.

The operator wears a glove equipped with an RFID reader able to read the RFID attached to tools or PPEs (usually passive), the sensors located at the machine level are connected and a capturing data system collects all the data. Such a system can disambiguate all the operation and assign them the measured duration.

MTM can be integrated with different tools and areas to make them more powerful than using them alone (Pelissari *et al.*, 2018): an example is the Sequence-based Activity Method (Sam) in the planning of production systems, which related to the ergonomics aspect. Hence, the use of these two methods shows considerable promise for predicting stressful work situations (Christmansson *et al.*, 2000). Most of MTM applications require using the software, computers, microprocessors or other devices such as antennas, ultrasonic devices, cameras, or digital cameras, to obtain reliable data and measurements and to avoid the errors that may be made. The same devices could be used not only for measuring the time, but also to measure the distances, to identify the location and to evaluate the situation. In order to do this, digital cameras could be used, but there are such limitations for this method: for example, camera lens height cannot change during the clip, in order to measure the distances. This limitation involves using video clips with known camera heights. Moreover, if the camera moves along with the worker, it is very difficult to use the distance module for video clips, since there might be a change in the camera height. In short, the camera must be set in a stable specified position and should be fixed to that position (Elnekave and Gilad, 2006). One more efficient technological solution for identifying the location is RFID localization technology which transreceives data through non-contact two-way communications for the purpose of mobile device identification and positioning (Shen *et al.*, 2019).

Creating a solution that can automatically transform manufacturing and assembly processes data into high-level management within real-time information system, is a promising idea to be demonstrated for filling the gap between the engineering data issuing from the shop floor and the higher-level production management data (Such integration like IoT technology should facilitate effective communication between day-to-day production management and that of strategic decision-making at board levels (Mousavi and Siervo, 2017).

In this work, we focus on two enabling technologies (IoT and RFID), which play an important role in Industry 4.0 applications (Thramboulidis *et al.*, 2019; Rosalie *et al.*, 2019). These two interconnected technologies shall enable the traditional system of MTM to be transformed into automated system and recognized as (MTM4.0) in this paper.

The main roles of IoT in industry 4.0 applications are to sensor the data from the physical environment, communicate the objects such as machine, tool, equipment device or worker, and take a part of visualization (Cecil *et al.*, 2019).

The role of RFID technology is to be a part of IoT system representing the sensation tasks through using RFID reader and tags, where RFID technology supports the management to collect production shopfloor data in real time for advanced production planning and scheduling considerations (Ray *et al.*, 2014).

2.3 Useful technology for MTM: an overview

Many technological solutions, such as anti-counterfeiting, logistics and warehouse management, could be used in practical applications to efficiently identify, track and manage items and to monitor machines, operators' position in the assembly or production cell and line, tools and the proper use of PPEs (with also critical positive effects on the employee's safety) (Michel *et al.*, 2014).

The most known solutions could be classified into three classes:

(1) *Physical sensors to gather positions (field solutions):*

- Laser barriers/curtains. They are used to detect the operators passing through and are mainly adopted for safety reasons. Laser scanners are suitable for the vertical monitoring of facades, perimeter walls, building walls or windows, and the horizontal monitoring of open spaces. People or objects entering the detection range of the laser scanner are reliably detected. The mechanism is based on the laser pulse that hits an object or person, when the laser pulse will be reflected on the surface of the object or person. A photo-diode can register the reflection in the laser scanner receiver. Detection systems using laser scanners functions (2D and 3D) are reliable regardless of weather, lighting conditions, or the size and properties of detected objects. When a person enters the area that is monitored, the laser scanner sends a signal, which can be used to take reactions, such as alerting the principal office of the security services, setting off a silent alarm or audible siren, switching on lighting, or activating a follow-up system for controlling dome cameras (Rex and Stoli, 2014; Yin *et al.*, 2019);
- Ultrasonic sensors. They are used to detect the presence of an operator nearby and offer robust functionality, taking notifications by transmitting high-frequency sound pulses that are completely inaudible to humans. This solution is quite useful to monitor indoor movements of people, and to capture and classify the trajectories. Many types of sensors are deployed to collect data and fuse the data to obtain useful information. The main problem with ultrasonic equipment is that the quality of data coming from these sensors varies with many factors such as temperature, target location, target composition, and transmission media and interference from other sensors. The problem of quality at the level of individual sensors manifests itself as the problem of information quality at the level of networks of distributed sensors (Pham *et al.*, 2007; Jimenez *et al.*, 2014);
- Barcode readers' technology. It depends on photoelectric scanner principle that is based on image processing using the laser beam over the barcode area and measuring the amount of the reflected light. Barcode recognition process reads the contents and transmits the signal to the main system. There are many types of

barcodes (such as Numeric, Alpha-Numeric, 2-Dimensional and Industry Standards for barcode and labels). This technology can be overlapped with other technologies, such as digital cameras that enable each other and do better recognition to different patterns of barcode, measuring and identifying the items and the movable and fixed objects (Narayan and James 2012; Cases *et al.*, 2017);

(2) Wireless sensors:

- RFID and other types of wireless devices. These devices can be thought, in the context of manufacturing, as "an umbrella term" for manufacturing solutions to directly or indirectly determine the moving objects (including operators, Automated Guided Vehicles (AGVs), forklifts, etc.) (Zhong and Ge 2018). RFID allows for unique, fast, and easy identification and tracking of objects without the need for a line of sight. It consists of two parts: the tag and the reader. The tag is essentially a microchip attached to an antenna with housing and stores a unique electronic product code (EPC). Tags can be split into two categories, referring to the power supply: passive and active. The RFID readers trigger the transmission of the tag by generating a signal to which the tags respond. Typically, passive RFID tags are the most commonly used in the industry. Beside RFID technique, there are many other solutions such as Bluetooth, which is used for machining and manufacturing information integration and 3G, 4G, 5G, LET and Wi-Fi solutions. This solution is the base and the first level of Cyber-Physical System, which relies on data gathering, analysis, communication and human interaction (Michel *et al.*, 2014; Kao *et al.*, 2015; Bergweiler, 2015);
- Beacon sensors. They can be used specifically to measure important operations. This technology that based on using small, portable Bluetooth-enabled devices, is able to measure the location of an event, and it can be used to "tag" objects that deal with and around the operator in the manufacturing and assembly workstations, so that the objects are identifiable when a user interacts with them. By linking beacon sensors to meaningful activities, along with the passive sensors, it is possible to obtain a robust dataset of interactions which can be used to identify a greater range of detailed activities within the manufacturing. This method is designed to attach the device to the objects and so it could be useful for our requirement of measuring the important manufacturing operations and can broadcast their information over proprietary protocols (Tewell *et al.*, 2019);

(3) Camera-based solutions:

- Video Surveillance. It is used for object motion detection. Background subtraction techniques usually perform object detection in the video. A camera is fixed at the monitored space and, if there are objects, they are detected, the data processed and the system made able to produce and realize the alerting notifications. This solution does not require any sensors, which will participate in reducing the cost of the existing system and the consuming power, but that requires increasing the camera's range to the monitoring area, too. This solution depends on using microcomputers for communicating and processing the collected data and using a computer network to display the operation in the monitoring area (Vijayakumar and Narmatha, 2017; Cocca *et al.*, 2016);
- Smartcams. This technology is based on computer vision techniques and allows the manufacturing management. It is possible to monitor workstation assembly

cells and upload the reports on visual information, which is the most direct and normal way for describing an operation, a person, an object, actions and interactions. These features have given video cameras the ability of "seeing", thereby becoming smart cameras. They are used for several applications, from tasks, such as face recognition, people identification, object recognition and tracking, to the recognition of actions and activities of daily living or even human behavior analysis during a long period of time (López *et al.*, 2015). In some technical operations that require higher accuracy, it is difficult to recognize whether the operation has been done completely or not, so other techniques may be involved to avoid the faults that can happen. Hence, this technique captures the information with uncertainty, especially those that deal with highly human interaction during the activity execution (Urgo *et al.*, 2019);

- Structured Light Measurement technology. It integrates the camera and the digital light projector and has characteristics of fast speed, high precision and non-contact. This technology is applied to industrial environments that require high accuracy such as 3D body scanning, inspection, heritage conservation and other fields. The structured light measurement system with fringe-encoding is mainly integrated with a digital projector and a camera, in which the projector projects series fringes into the measured object surface and, accordingly, the camera takes pictures of those deformation fringes modulated by the surface. Then the 3D coordinates of measured points of those fringes can be obtained through the geometric triangle formed by the camera, projector and measured points. Generally, the structured light measurement system with fringe-encoding can be modeled as camera imaging and projector projection (Huang *et al.*, 2012; Lei *et al.*, 2015).

Table 1 shows the pros and cons of each of the described solutions.

It has been decided to compare four systems currently on the market with our system, on the basis of the compliance with workers' privacy standards. In order to reach this aim, seven criteria have been identified (proportionality of monitoring to business aim and needs, non-invasiveness, inviolability, auditability by trade unions and operators, data anonymization/difficulty in depriving information about operators, continuity of production flow and imperceptibility) after discussion with the specialists and the experts (Legal specialist/Lawyer, head of the production, IoT expert, antenna expert, production engineer, manufacturing engineer and Industrial IoT supplier). Criteria are mainly extrapolated from the General Data Protection Regulation (GDPR) and Article 4 of the Italian Workers' Statute (Law 300/1970), that regulate the processing of personal data and privacy in companies:

(1) Proportionality of monitoring to business aim and needs: the extent to which the monitoring system is able to detect only that information that is necessary and sufficient to achieve the purpose and meet the needs of the company;

(2) Non-invasiveness: the extent to which the system is non-invasive for the operator in terms of type and quantity of information collected during monitoring;

(3) Inviolability: how difficult is the system to violate in order to render null the aim for which it has been designed;

(4) Audibility by trade unions and operators: how easily the system can be reviewed by trade unions and operators to verify its compliance with standards on privacy and processing of personal data;

Table 1.
Pros and cons of each solution

Class	Solution	Reference	Pros	Cons
Physical sensors (e.g. 2D/3D scanners, ultrasonic distance sensors, barcode reader)	Laser Scanner	Rex and Stoli (2014)	It can be used to monitor large spaces, it is useful for safety and security issues, it is accurate and highly detailed in the depiction of an environment in a short time	It is expensive, not useful for technical operations and requires preliminary consideration during installation, it lacks the fundamental distinction of discrete geometries available in CAD.
	Ultrasonic Sensors	Pham *et al.* (2007)	It can be used in different applications to give accurate measurements, to monitor the objects in service with high safety and to check people movements and object situation such as liquid level in a tank or degradation of metals	A widespread problem with ultrasonic sensors is the interference caused by receiving the unexpected rejected waves from other sensors in the neighborhood. Tracking of multiple individuals is almost impossible. It can be affected by the environment
	Barcode reader	Narayan and James (2012)	It reduces the time and effort consuming, especially in the inventory and warehouse, it is very effective when it is used in synergy with other technologies	Requires expensive printers, instalment of equipment and workers' training, so generally it is costly and sometimes not reliable in bad environment due to barcode damage
Wireless sensors (e.g. antenna RFID, iBeacon, Eddystone)	RFID	Zhong and Ge (2018)	It enables more efficient operations to increase customer satisfaction and production line management system; it is low cost and small size and works mostly in different frequencies for identifying the location	If there are surrounded obstructions, interference, and obstacles in such areas, RFID signals will be confined in a metal surrounded environment when using HF. It cannot provide detailed information about objects state, pin-point position, or environment. It more or less provides unique identification and general positional area and it cannot perform logic or filter/clean any data
	Beacon Sensors	Tewell *et al.* (2019)	It is accurate in identifying the location of the objects, it is adoptable in digital environments and it is not expensive comparing with other technologies	They require high management level for security, accuracy and accessibility, especially in the manufacturing environment that is affected by other communication factors

(*continued*)

Class	Solution	Reference	Pros	Cons
Camera-based solutions (e.g. Camera, Digital Camera, Structure Sensors)	Video Surveillance	Vijayakumar and Narmatha (2017)	It provides detailed information about objects state, pin-point position, or environments	It requires mini-computer and software accurately programmed and it is mostly expensive. The work stuff will be clearly recognized, so privacy-preserving is not considered in this possible solution
	Smart Cameras	López *et al.* (2015)	It provides more accurate detailed information about the locations, operators, the activities and it can participate in improving safety conditions with high level of time monitoring	Very expensive, requires using programs and smart devices to analysis the captured data and privacy-preserving is also not considered in this possible solution
	Structured Light Measurement technology	Huang *et al.* (2012)	It is characterized by fast speed, high precision and non-contact, its digital projector works like guider concurrently with the camera to the objects and the operators	The system requires calibration before the work and monitoring during the work to give reliable measurements Requires mini-computer and software accurately programmed. It is mostly expensive. The operators are monitored to be guided, so the privacy-preserving is ignored in this solution

Table 1.

(5) Data anonymization/difficulty in depriving information about operators: the extent to which the system allows data anonymization and how difficult it is to deprive sensitive information about the operator (gender, ethnicity, etc.);

(6) Continuity of production flow: the extent to which the system allows the continuity of the production flow without the need to interrupt the operator's work;

(7) Imperceptibility: how much the system is imperceptible for the operator during the performance of the operations.

In particular, our system RFID-antenna (**MTM4.0**) has been compared with four technologies: traditional cameras, smart cameras, barcodes and beacons.

In order to give each of the five tools a score for the fulfilment of each of the seven criteria, it was decided to use the Likert scale (5: criterion fully satisfied; 4: criterion partially satisfied; 3: criterion neither satisfied nor dissatisfied; 2: criterion partially dissatisfied; 1: criterion sufficiently dissatisfied). Finally, each of the tools has been assigned a total score, given by the sum of the individual scores assigned for each criterion. Table 2 shows the comparison between five technologies based on the seven criteria.

The results show that RFID-antenna (MTM4.0) system is the most compliant with the standards in terms of workers' privacy, obtaining a total score of 27 and differing from other systems for the proportionality of the monitoring to the aim, for the low intrusiveness and high level of inviolability and imperceptibility. For what concerns smartcams, even though they are very similar to traditional cameras, they obtained a higher total score than the latter (14 versus 20) because they are more proportional to company's aim (as they do not record operators' images), less intrusive and more in line with data anonymization. A total score similar to that of smartcams is that of barcodes (21), which differ from all other tools because it requires an interruption in the operator's production flow. Finally, the final high score of beacons (26) was mainly influenced by the low intrusiveness of the instrument, the difficulty in violating it and its imperceptibility by operators.

Moreover, as long as one of the most important factors for companies' managers in the global markets is the cost factor, we focused on the less expensive technologies with good and capable features that enable the specialists and the practitioners to do the time measurement of the manufacturing and assembly processes, and allow the identification of operators and equipment locations with less complicated parameters. Therefore, the technological solution of RFID-antenna is most likely to be used to achieve this mission and has been elected to be studied deeply and demonstrated practically in this study.

3. Scenarios and requirements

3.1 Preferred scenario and its constraints

The target scenario is an assembly line (or analogous process), where humans are involved with machines, such as semiautomatic assembly operations for producing the goods. In a few work-shifts, the system can capture and accumulate data and calculate parameters about all and each operation. Such an activity sets the baseline. The measurements can be repeated after applying one or more of operation management tools to be improved and obtain a reliable method of statement, such as train the operator, write suitable procedure and guidelines to check the level of improvement that can happen.

The present scenario has been conceived as a line with a single operator; the possibility of including more than one operator makes the analysis more complex, but it is feasible from a technical perspective. The aim is also to take into account the security and safety aspects, so there is guidance to the operator to prevent any possible misuse, error, or such mistakes that could affect his/her safety.

	Proportionality of monitoring to business aim and needs	Non-invasiveness	Inviolability	Auditability by trade unions and operators	Data anonymization /difficulty in depriving information about operators	Continuity of production flow	Imperceptibility	Total score
traditional cameras	2	1	1	2	2	5	1	*14*
smartcams	4	2	1	2	5	5	1	*20*
barcodes	5	2	1	3	5	2	3	*21*
beacons	4	3	3	3	5	5	3	*26*
RFID-antenna (MTM4.0)	4	3	4	3	5	5	3	*27*

Table 2.
Comparison between five technologies based on the seven criteria

In the scenario, the connection to the Internet or intranet could be difficult; therefore the system cannot rely on a stable connection with a wide bandwidth.

An automatic MTM seems to be highly valuable and to have wide applicability to many different scenarios, especially in the SMEs where much work is manually executed but also in large enterprises, where the effort of improving each single process is constant. Cases could vary from the automotive industry to white goods, from food processing industry to chemistry to pharmacies, etc.

3.2 Requirements

Even if MTM is a well-known methodology, it is often considered merely from a cost perspective (setup cost, components cost, preparations, etc.); therefore, the main goal is to design a reliable system that has characteristics of being not expensive, easy to install, use and maintain.

In an industrial environment, MTM automatic system should be installable in the fastest (requirement 1) and less invasive way (requirement 2), demonstrate the higher level of reliability (requirement 3), within a framework able to guarantee the operators' privacy and the GDPR (requirement 4) as shown in Table 3.

But the fastest way means a system that reduces the effort of operators in creating the *ad hoc* solution for each new case. It could also be written as a system that minimizes

#	Requirement	Description
1	Plug-and-play installation	Easy to be installed in short time and without almost any effort
1.1	Minimizes customization	A technological solution that fits for all the scenarios
1.2	Input analysis	All phases are automated
1.3	Automatic reporting	The operation has to be documented and transmitted to the main system automatically in real time
2	Low invasiveness	The aim is to use one measurement by one tool (if possible)
2.1	Compact device	The device has to be small, portable, wearable
2.2	Number of Technologies	Limited number of tracking technologies
2.3	Software	Software has to be compatible with the main OS
3	Reliability	The ability of the measurement system to work within design specifications as long as possible
3.1	Standardization	The solution technologies have to be standardized and consolidated
3.2	Variable environment	The system can work with different level of industrial automation systems and dynamic environment
3.3	Adaptable communication	The system can work with different communication systems and stay on line as long as possible after disconnecting from the network
3.4	Software speed	Software has to be fast to read, adapted and reconfigured
3.5	Maintainability	The system has to return online (in service) very soon after any failure
4	GDPR and Italian Workers' Statute	Respect to the privacy laws
4.1	Limited in time	Each measurement session should last few days
4.2	Anonymization	Each operator will be anonymized
4.3	Aggregated data	Calculate synthetic parameters
4.4	Operators' traceability	The operators are not traced outside the working cell/assembly line/ workstation
4.5	Data sharing	No raw data will be provided to anyone
4.6	Production and organizational needs	The monitoring and remote control devices should be used only for production and organizational purposes
4.7	Agreement of the organizations	The adoption of the system should reduce the negotiation time between the company syndicates and or internal workers' organizations

Table 3.
Measurement system requirement

customization (requirement 1.1) being customizable by definition and that embrace from the emergence of a need to the final execution of the MTM measure (requirement 1.2) and reporting (requirement 1.3).

In order to minimize the invasiveness of the solution, a compact device (requirement 2.1) based on a limited number of technologies (target = 1, requirement 2.2) equipped with plug-and-play software (requirement 2.3).

The reliability requirement could be deployed into the use of standard consolidated technologies (requirement 3.1) able to work within different industrial scenarios (requirement 3.2) and with different systems of communication (requirement 3.3). Also, the case of the absence of a continuous connection must be considered. And the software should be fast to be read, adapted and reconfigured (requirement 3.4). All the equipment and software have to be as much as possible easy to maintain, to guarantee the expedition of the repair and be in service soon after any damage or maintenance (maintainability 3.5).

Each measurement session should be limited in time (requirement 4.1): it can last for one or two days, thus collecting data coming from many operators and work-shifts. The operators will be involved in the measuring activity and the reason for such a process explained and also discussed with trade unions. The gloves, shoes and microcontrollers worn by each operator will be anonymized (requirement 4.2) and the results collected and used to calculate synthetic parameters such as average, standard deviation among work-shifts, standard deviation among the different work-shifts, etc. (requirement 4.3).

The operators must not be traced outside the work-cell or assembly line (requirement 4.4). He/she can leave the gloves, shoes, etc. in the cabinet close to the cell. No raw data will be provided to the company and the trade unions (requirement 4.5), one important sub-requirement for the measurement system is dealing with Article 4 of the Italian Workers' Statute (Law 300/1970) already mentioned in Table 2 (requirement 4.6 and requirement 4.7).

In order to assess the requirements, interviews and discussions have been conducted with many specialists and experts in different fields as mentioned and explained above in the last part of the literature review.

4. Materials and method

The process of MTM is usually performed according to the workflow, which relies mainly on continuous improvement philosophy for designing human work (MTM standard) and operation management tools (Almeida and Ferreira, 2009), this methodology decomposes the activity into many stages to facilitate time measurement process as shown in Figure 1. The workflow consists of seven main steps and a final optimization step as well to improve or re-design the methodology, starting from acquiring the information of the operation and variables.

The first step of data acquisition (1) could be performed through reading the observation of a work shift, the study of procedures, operative instructions, and instruction of safety, maintenance guidelines, and layouts and so on.

This process will be followed by the manufacturing engineers to define each operation and clarify the state of the activities in the second step (2). Such an analysis produces a state variable table, in which each information is based on different production variables. Examples of such variables are the following: the status of the operators, the availability and the position of the operators and tools, the level of operative of the tools and equipment or the machines, etc.

Next step (3), in case of ambiguous and interfacing operations or when it is difficult to isolate the operation from the others, the engineer tries to disambiguate them (1) by using sensors (thus increasing the number of variables) or (2) by modifying the work cell in order to alter the values assumed by some variables. Such an activity could imply necessary

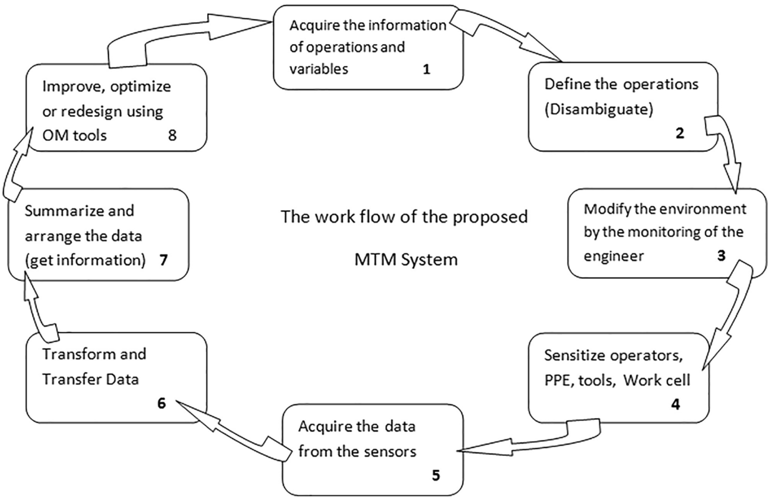

Figure 1. Workflow of the system

modification to the environment (such as the addition of platforms, physical separators, etc. or even small temporary changes in the assembly production method).

At this stage (4), the work cell is provided with a few current sensors, the tools and PPE equipped with RFID tags and the operators supplied with active gloves, shoes and belts equipped with RFID readers, as shown in Figure 2.

The embedded systems and wearable technologies foster the idea of embedding microprocessor in Personal Protective Equipments (PPEs) such as gloves, the smart gloves try to connect the physical hand to the virtual world through providing sensors or enabling

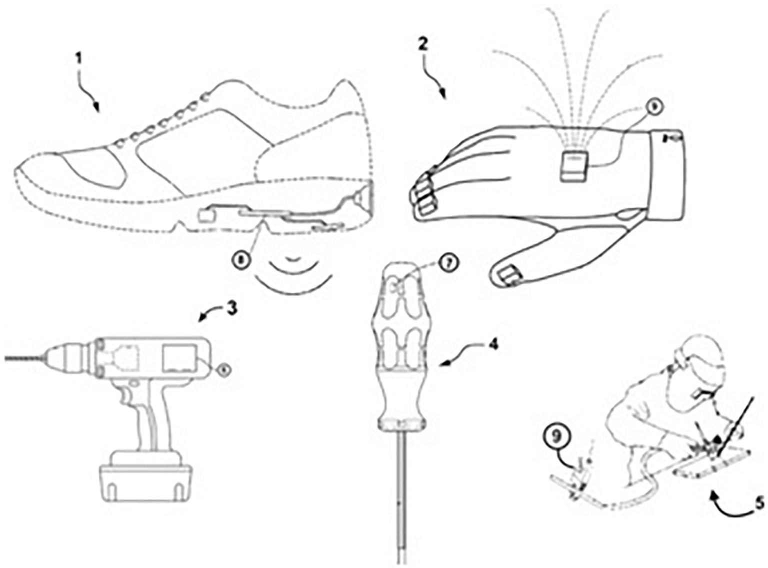

Figure 2. Embedded RFID in the tools and PPEs

technologies (Bluetooth, Arduino, RFID, etc.), many applications in Industry 4.0 era have been practiced in this field such as monitoring the motion, measuring the force or tracking. So the smart gloves proof its ability in the area of human work design through fast transmitting of the information from the real environment to the digital systems, some gloves can guide and notify (remind) the operators to follow the procedure and send signals to avoid mistakes or dangerous actions. The power supply and the size of the sensors embedded in the glove are considered a challenge in many past applications (Marion, 2009).

The microprocessors (in the gloves, belt and shoes) acquire the data coming from the sensors and store them temporarily in a table (step 5) with the indication of the time of detection (timestamp). Immediately after, they perform a series of operations such as the calculation of the duration of the operation as the difference between two following timestamps and the assignment of a random number to the ID of each operation (6). Now the temporarily stored data is deleted or overwritten, while the others are rearranged in ascending order based on the random number assigned to them.

3D (RFID) positioning system based on a 3-axis orthogonal array antenna can be used for determining the locations, where the antenna consists of 3 loop antennas of the same geometry and properties, so it is possible to identify the transponder position by comparing the strength and the phase shift of electromagnetic signals received from the transponder at each antenna (Kim *et al.*, 2004).

In order to overcome the problems related to the activity of controlling the operators in their daily work, the data must be aggregated to prevent the operator being recognizable. Therefore, data are collected from many different shifts or days to mix the results of several operators. Eventually, the data (6) are reordered according to their random number for the last time and transferred in batch to the main computer, to the company server or the cloud (7).

In order to be even more conservative in hiding the operators' personal information, additional compressions can also be made: a frequency table of operations organized according to time intervals of 3 seconds is shown in Table 4.

The information exchanged between the tools, the machines, the operator and the microcontroller or between this and the server are transferred securely, are encrypted and can be decrypted by the provider through standard IT tool. The microcontrollers and the server are subject to a process of physical priming (exchanging keys). In some applications, the microcontroller is also supported by a crypto-chip that implements the security features at the hardware level, thus guaranteeing even higher levels of security.

5. Case study

The case study shows the operation relative to the monitoring of the assembly operations of a PlayStation's memory card, consisting of four parts (p1: electronic circuit; p2: base cover; p3: the upper cover; p4: the screw).

	Duration (sec)								
	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	>24
OP1	0	200	351	140	11	0	0	0	7
...	...	...	...	...	...	...	...	...	...
OPi	0	0	3	61	560	80	2	0	3
...	...	...	...	...	...	...	...	...	...
OPn	0	23	57	81	421	72	39	0	0

Table 4. Frequency table for each operation with the occurrence of events for each time interval

In this case, as shown in Plate 1, the system is a prototype of a glove. It contains a microcontroller ESP32 by Espressif powered with Wi-Fi module able to connect it with the Internet. An RFID reader (ID-20LA by ID-Innovations operating with a frequency of 125 kHz, with a maximum reading range of 12 cm) is connected with the microcontroller and integrated in the glove and in the anklet. A battery supplies the necessary energy for both detection and communication.

The firmware was implemented in Python by using Zerynth Stack solution. In particular, the Zerynth Device Manager (ZADM) allows the management of connected devices using persistent bidirectional TCP connections. Device data received by the ZADM are then forwarded to a cloud-based platform (Mazzei *et al.*, 2016). Many statuses have been developed to simulate the activity based on different variables related to the position, the operator's availability and the equipment (helmet, goggles, gloves, etc.) or tools such as screwdriver and the level of the operative as well. Plate 1 shows a simple antenna attached to the hand of the operator.

The MTM4.0 system (hardware + software + passive tags) is able to recognize the operations that are carried out by detecting the presence of the operator in the areas delimited by the tags and keeping track of the statuses crossed by the operator and of the use of the tool (a screwdriver contained in its case).

Figure 3 shows the setup of Manual assembly work cell.

The first activity consists in taking the upper cover from the special container. As soon as the reader detects the tag on the container, the operator status changes and this allows understanding which activity is carried out. The same happens for the other activities, so that, at the end of the process, it is possible to use the time in which the state remains in the interesting statuses to measure the execution times.

If an operator can carry out activities in multiple cells, it is necessary to monitor his movements: this can be done through the RFID anklet (RFID antenna reader + ESP32 and Battery), as shown in Figure 4; moreover, it is possible to calculate the time spent to move from one place to another, by subtracting the times between two timestamps.

If we consider the collection of PPEs from a cabinet, it is possible to detect the presence of the operator in the collection cell through a tag placed on the ground, as shown in Plate 2. The withdrawal of the PPEs can be recognized by reading the special tags placed directly on them. The monitoring would also make it possible to obtain information on the movements of the

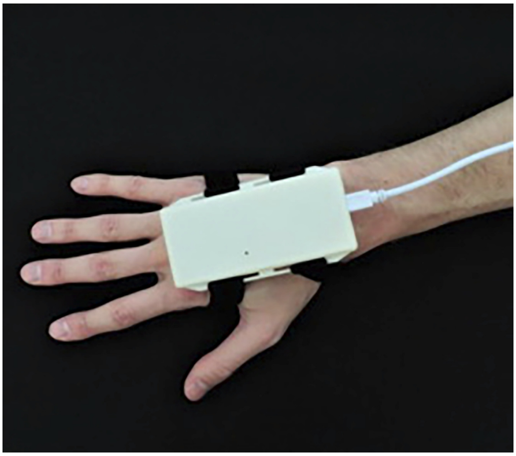

Plate 1.
Prototype of an RFID glove

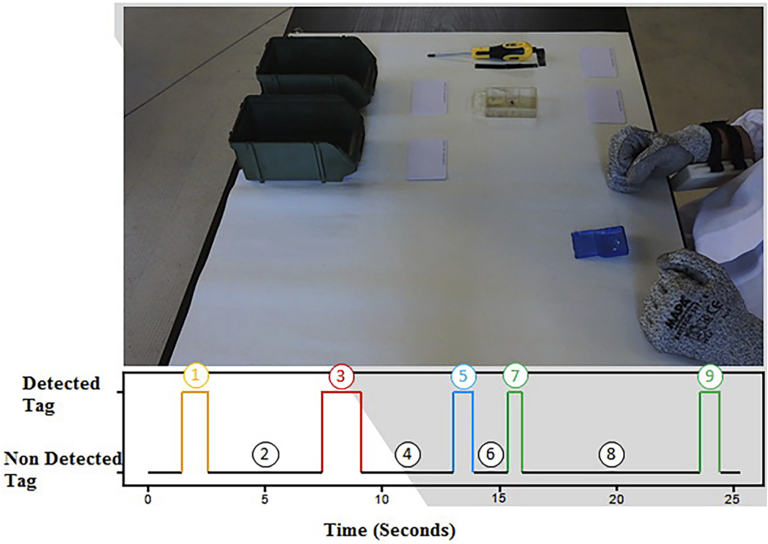

Figure 3.
Manual assembly work cell

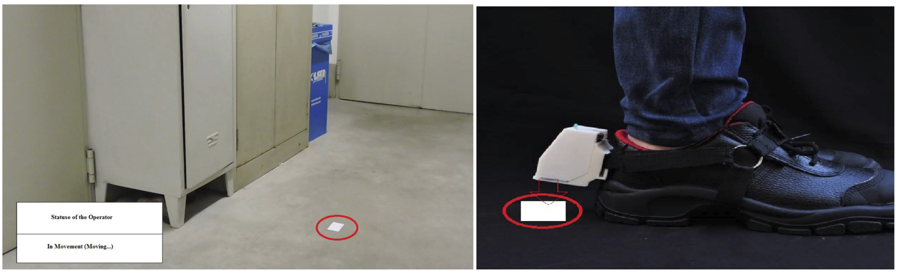

Figure 4.
Prototype of an RFID anklet system and passive tag located on the floor close to locker

Plate 2.
RFID system application by using PPE

equipment within the work spaces, allowing them to propose possible improvement actions for their management.

To investigate and check more about the time measurement using RFID-antenna, we have repeated the experiment of the PlayStation's memory card assembly many times.

Three different assemblers have performed the activity (each assembler did the activity about fifteen (15) times, so in total the experiment were done forty five (45) times), to collect reliable data and compare the operation durations that are involved (O1: picking up the electronic circuit; O2: inserting the electronic circuit into the base; O3: picking the upper cover; O4: snap-fitting the cover and the base; O5: picking the screw; O6: inserting the screw in the base hole; O7: picking the screwdriver; O8: tightening the screw; O9: returning, putting away the screwdriver into its place).

Passive tags have been used to identify the entrance of the containers and the screwdriver, while the antenna is attached to the right hand of each person that carries out the experiment. When the assembler passes his right hand to take or handle a part or the screwdriver, the RFID tags are detected. Then, the RFID reader transfers the signal to the central system (software) to collect the data and get the required information, especially that dealing with the time measurement. After having carried out the experiment, the time measurements have been summarized. Figure 5 shows the eight histograms that include the different operations durations in seconds in X-axes and their frequency (number of times in which each duration occurs) in Y-axes.

Observation 1. We noticed that in some cases O8 lasts more than 25 seconds longer than the other operations: this is confirmed and documented that during the experiment, when the assembler picked the screwdriver up and start to tighten the small screw, sometimes it falls on the table and the assembler has to retake it. This is the reason why O8 may last longer than the others.

Observation 2. The shortest operations generally are O1 and O7 that do not last more than two seconds: in fact, they were quite easy to perform. It is possible to improve the assembly activity execution to perform it within a shorter time by applying one of the operation management tools.

6. Discussion (advantages, limitations and challenges)

The performed experiments (case study) proved that the proposed system (MTM4.0) has advanced technical features (Setup time, accuracy, physical interruption and certainty measurement, object identification and programming, and distance-time measurement) comparing with the most useful and available technologies in the industrial market such as camera surveillance, beacons, barcode or smart cams. Let us take the smart cams for doing a simple comparison. The setup time of MTM4.0 is too short (few minutes) comparing with time consuming for installing the smart cams, which require suitable level and choosing proper angles, we did not face a physical object interruption through the experiment execution and the certainty of measurement was well, while doing measurement by smart cams could be interrupted through passing physical objects (many operators and machines), so this needs high programming level to identify the objects. This identification process requires short time with MTM4.0, which based on RFID technology comparing with smart cams, which require longer time to identify the object views (2D-3D). Economically speaking, this MTM4.0 is competitive comparing with most of other technologies used.

One of the hard limitations is the harsh manufacturing environment that probably causes damage to the RFID tags. Hence, the manufacturing processes that require robust operations will probably destroy the RFID tags; also the workstation condition could be affected by the weather or the external environment, where the high humidity influences on the efficiency of the communication between the antenna and the RFID.

The automatic system is based on electromagnetic radio concept, so the communication between the antenna and RFID can be affected by the external waves (signals) that decrease the efficiency of the system too.

Working with different materials requires using different types of tags; where tagging the metallic parts need special tags to avoid the miscommunication with the antenna. Also, some tags need to be embedded inside the materials or the parts, so that requires using different frequencies.

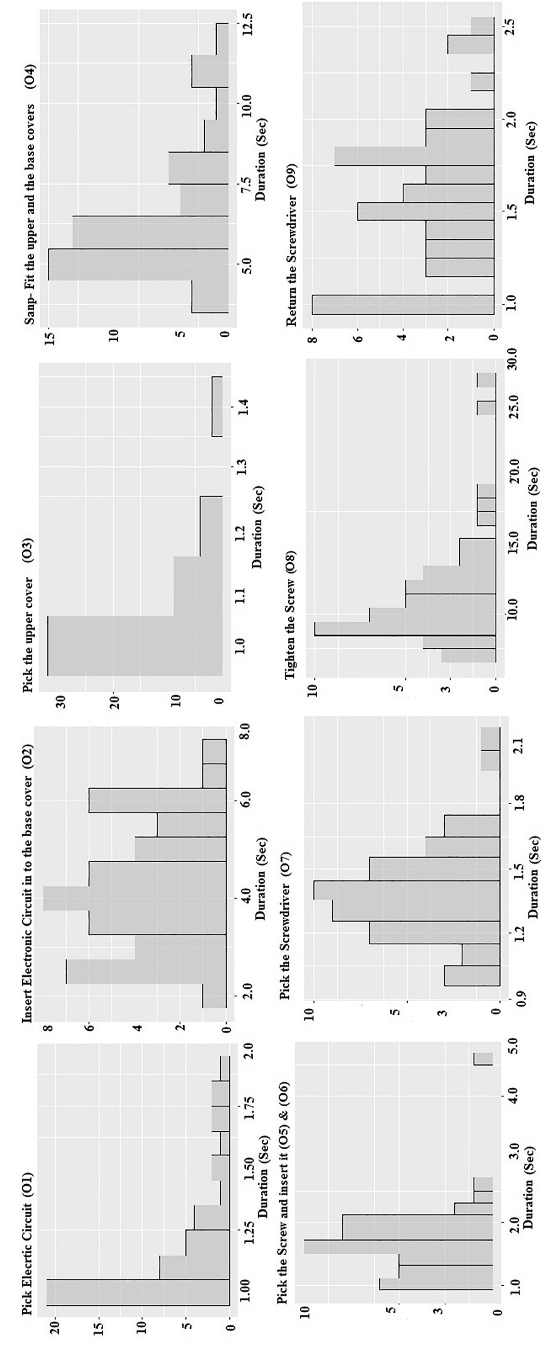

Figure 5.
Histograms of the assembly operation durations

The most critical challenges are the system security, organizational and legal aspects. Hence, the security of the system is crucial to avoid the permeation and to hack the system's software, so cybersecurity awareness is highly recommended. The organizational and legal aspects are related to getting prior approvals and coordinating with the company/organization stuff and workers, as mentioned in a previous paragraph. Therefore; these controllable limitation and challenges have to be planned, designed and engineered accurately to obtain reliable and robust MTM4.0 system.

7. Conclusion and future work

The work has shown potential in both research and application.

The system has been installed in the shop-floor in few minutes, the tools have not been considered as invasive and the operators rapidly forgot their presence. The measurement acquired demonstrated to be valuable and helped in starting redesigning the assembly process. Although the MTM4.0 demonstrated interesting outcomes in terms of speed, reliability, acceptability, etc. Numerous are the issues to be still solved and aspects to be better engineered.

The automated Method Time Measurement (MTM4.0) system has a high potential on manufacturing process planning and scheduling, workplace design, facility layout design/redesign, material handling time measurement and human machine interaction (Ergonomics), while the negative implication aspects could appear in some industrial applications, which influence on the efficiency of the system as mentioned in the limitation paragraph.

Future work will be oriented to automatize also other phases of the entire MTM4.0 process for example the construction of the disambiguation table, nowadays the longest activity we performed. Possible solutions could be found in automatic text analysis and, by using natural language processing over documents as procedures, instructions, manuals probably is feasible to reduce such a manual phase highly.

Other interesting research hints are coming from cryptography: Homomorphic encryption seems to be a technology with a potential immediate impact on MTM4.0. One of the form encryption is Homomorphic encryption that enables computation on ciphertexts. The result of the computation is still encrypted result, but, when decrypted, it matches the result of the operations performed on the plaintext. In the future, the authors believe Homomorphic encryption can be used for even better managing privacy issues in MTM4.0.

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