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MANUFACTURING DATA ACQUISITION IN NON-AUTOMATED PRODUCTION SYSTEMS

6.1 INTRODUCTION

In a competitive and globalized economy, data acquisition from production systems is becoming a more important issue because it is a means to improve the company's performance through the integration of the business and manufacturing company layers. The management of the company should obtain updated information on the situation in the production system – the execution of production orders, effectiveness of machinery and equipment, circulation of materials, semi-finished and finished products, activities performed by employees, quality of products, etc. This information should be relayed to the management of the company and to information systems supporting the company operation and its resource planning (ERP), either directly or via middleware – Manufacturing Execution Systems (MES).

Integration of company layers, realized by middleware systems (MES) is well described and standardized in ANSI/ISA-95. This standard, however, focuses on collaboration between MES and ERP systems, leaving unresolved communication issues between the physical production process and MES systems. Solutions described in the standard mainly concern the acquisition of data from production systems in which most of the technological processes are automated. This implies the need to systematize and develop methods to obtain information on production from the companies in which the degree of automation of technological processes is low. This is the case in companies where the majority of operations are performed using simple equipment and tools, or completely manually. There may be some other hurdles for data capture, such as the movement of workers and machines over a large area, unstable and variable technological processes, the multi-assortment manufacturing of small quantities of products.

6.2 DATA ACQUISITION IN VARIOUS PRODUCTION SYSTEMS

Solving the problem of data acquisition for the purposes of management requires, in the first instance, the classification of production systems due to the characteristics that affect the availability of the data. The basic criterion for this classification may be the degree of automation of the technological processes. This is due to the fact that the introduction of automatic process control requires the installation of the sensors and measuring devices closing the feedback control loop. The data obtained from these devices can be extracted and used as well for tasks that are not directly connected with the control of the process.

Due to the criteria of the degree of technological processes automation, it is possible to specify the following types of production systems:

- automated systems using modern control devices, equipped with a network interface, using contemporary programming and communication standards,
- automated systems using older or less sophisticated types of control devices, without communication interfaces,
- mechanized systems, in which no means of automation are used,
- systems in which most of operations are performed manually or using simple equipment and tools.

The analysis of the needs of ERP and MES systems, used as modern enterprise management tools, results in the following list of types of information to be obtained from the production system [11]:

- information about the usage and state of machinery and equipment,
- information about the production tasks performed in the system,
- data on flow of materials, parts, work in progress, and finished products through the manufacturing system,
- information about the activities of employees,
- data on the quality of the products.

The data obtained from the control system, intended originally for the purpose of process control often do not carry all the information needed to assist in the management of production processes. In this case, there is a need to use different solutions to fill in the missing information.

In the companies characterized by a predominance of processes performed manually the basis of information retrieval is the method referred to as the manual acquisition.

Manual acquisition is based on direct communication between employees at different levels of the hierarchy of management. It can be verbal or conducted by various forms and reports filled in by staff. This solution has many drawbacks, first of all, it is inefficient in the context of modern industrial systems. Manual acquisition is often associated with the appearance of errors and delays. There is a risk that important information will be transmitted with a delay or even suppressed, as there is a lack of efficient mechanisms to verify the information entered [1]. Also removal of workers from their primary tasks in order to keep records is unwanted and reduces their overall productivity.

The requirements of modern management support systems (ERP, MES) make it necessary to use solutions that are more reliable and faster. This leads to the definition of the acquisition method, referred to as semi-automatic acquisition (otherwise called assisted manual acquisition). Figure 6.1 shows the proposed classification of methods of data acquisition for the purpose of the company management.

Automatic acquisition means retrieval of data from technological processes automatic control systems that take place without human intervention. The data comes from sensors, industrial controllers, CNC machines and other sources. A SCADA (Supervisory Control and Data Acquisition) system often plays a role of a link, that allow integration with the upper layers of the company [10, 18].

The problems associated with manual data acquisition has led to the development of a variety of solutions that can be described as semi-automatic or assisted manual acquisition. In these methods, operator intervention may be required, but it is minimized, and the actions of the employee are supported with hardware and software solutions, that enable the reduction of the error rate of data acquisition and increase its speed.

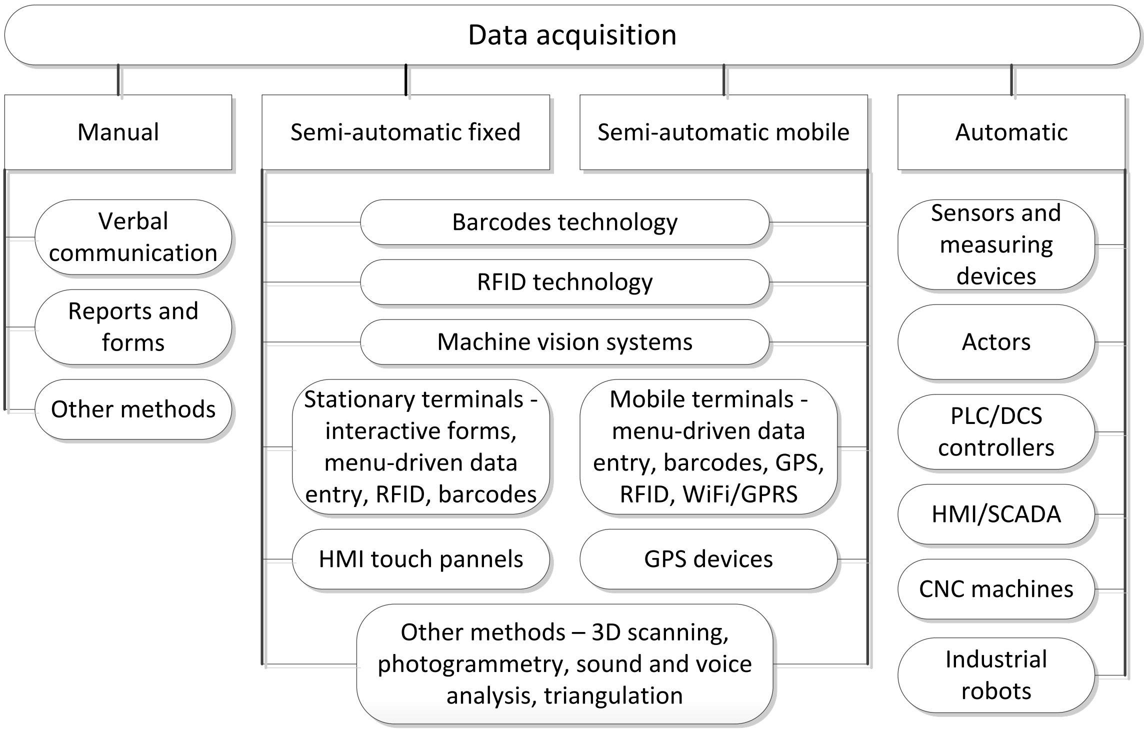

Fig. 6.1 Classification of methods of data acquisition from production systems

Technology of automatic identification of objects is the basis of these solutions. The use of different types of automatic identification systems has become a necessity due to the increase in the number and variety of manufactured products. The first applications of automatic identification were introduced in storage systems. With the improvement of technology and the introduction of information systems for different areas of the company business, the importance of automatic identification systems continues to grow. Solutions of this type allow the acquisition of information for management purposes, from non-automated and semi-automated production systems. Semi-automatic acquisition can be carried out using fixed or mobile devices.

Currently, there are many methods used in the automatic identification of objects. They can be based on: barcodes (optical reading), magnetic track, radio frequency (RFID), the analysis of voice (audio), image, etc [6].

The following chapters present the characteristics of manual, automatic and semi-automatic solutions of data acquisition for the purposes of production management.

6.3 MANUAL DATA ACQUISITION

Despite the trend towards reducing the human role in the manufacturing process, it is still not possible to completely eliminate it. Automation, robotics and mechanization allows the significant reduction in human participation in the production process, but still there are processes that are not automated, mainly due to insufficient profitability. Supervision of automated devices is still necessary. Moreover, support and maintenance processes in industry are rarely the subject of automation.

Depending on the specifics of the production process, the employee may act as:

- The performer of manual operations – perform tasks manually or with the use of simple tools. An additional difficulty in the acquisition of data is a situation where the employee performs his duties in locations far away from the main area of a company or in a large area. Often, the employee must be mobile in the production halls or in the open field. Information is required on employee activity – the degree of realization of contracted tasks, materials used and problems encountered.
- Warehouse worker – responsibilities of warehouse workers usually involves accepting deliveries, issuing materials, completion of shipments, etc. Warehousemen activities should be recorded, but there is no need to report their exact location.
- The operator of machinery, equipment, means of transport – it is necessary to obtain information about the activity of the worker, the task stage, the problems encountered, machine location, the estimated time of completion of the tasks, etc.

Information obtained from these groups of workers are often put into the management support systems by mid-level supervisory staff or data entry operators. Data can be entered directly into the business layer systems. Often, the common practice is the entry of the data into various types of document templates in a standard word processor or spreadsheet. These documents go via e-mail to people who put it into the ERP system. Delays and errors may appear at each stage of the transmission of information. You can also not rule out the possibility of hiding information from senior management by subordinates.

The results of research, and practice, indicates that the employee is not a reliable source of information, forwarding it with considerable delay and errors resulting from subjectivity, negligence or malice [3]. The most commonly used method of manual data acquisition is the acquisition from employees during conversation (direct or phone) or by filling in forms and reports. These methods are not sufficient in the modern enterprise, and it is necessary to create alternative, more reliable methods.

6.4 AUTOMATIC DATA ACQUISITION

Automatic data acquisition for the purpose of management is possible in automated production systems. These solutions cover most of the needs for the data acquisition from part of the production system, covered by the automatic control [6, 19]. Data acquisition for the purposes of control is usually realized automatically, without the involvement of employees. Data acquired for control purposes can be simultaneously used for management purposes after pre-processing. Often it is necessary to create the appropriate interfaces.

The list of elements of industrial automation systems that can be a source of data to ERP systems include:

- control and measurement devices installed on machines and equipment - measuring instruments (sensors, transducers, etc.), equipment used in quality control,
- actuators for industrial automation – solenoid valves, servo drives, frequency inverters, metering pumps etc.,

- control devices: PLCs, industrial computers, operator panels (HMI), distributed control systems (DCS),
- human-machine interface/supervisory control and data acquisition systems (HMI/SCADA),
- machinery and equipment carrying out processes: machines, CNC machine tools, industrial robots, transport systems, palletizing systems and other devices.

The above devices, as a data source, can be divided into two categories: primary and secondary. Typical primary sources are sensors and measuring devices, directly responding to changes in the physical process. Devices such as industrial controllers (PLC, DCS), CNC control systems and industrial robots can be regarded as a secondary source, because they relay signal from primary sources. At the same time they generate new data resulting from the operation of control algorithms processing original data from primary sources.

SCADA systems are also secondary sources, integrating data from different types of sources. At the same time SCADA systems can also collect data from process operators or supervisors (commands and data entered manually) or generate it, thanks to implemented master control algorithms [16].

Data obtained from the control systems must be sent to the systems in the upper layers of enterprise through appropriate interfaces, enabling the integration of these systems, both at the hardware and software levels. There are a lot of problems arising from high fragmentation on the market of automation systems – there are many competing standards and solutions promoted by the various hardware and software manufacturers. This applies to both the control systems and industrial communication networks.

This situation is the cause of attempts to introduce uniform standards and communication protocols, allowing access to data in control systems from different manufacturers. Examples of such solutions are the OPC standard (created for access to various types of industrial controllers) [22] and MTConnect (communication interface for CNC machines) [5]. Software installed in the upper layers of a company, compatible with these standards, may obtain the required data from the control systems through the interface servers.

6.5 SEMI-AUTOMATIC DATA ACQUISITION

The use of semi-automated data acquisition methods in companies stem from the necessity of solutions that are more efficient and reliable than the manual acquisition. The easiest way to improve the manual acquisition is to provide lower-level employees with access to computer terminals equipped with software supporting data entry. The terminal can be fixed or mobile, and programs designed to input data should be written in such a way as to facilitate data entry and simultaneously reduce the risk of errors. This is accomplished through easy-to-use graphical interfaces and the implementation of mechanisms to verify the data and to prevent the introduction of incorrect information. A standard PC can be used as a terminal, although HMI touch panels are more suitable for use in harsh industrial environments.

This solution still requires the employee to use up valuable time for the cumbersome typing of long strings of characters. This problem can be solved by the use of automatic identification systems. These systems usually use a label with coded information and corresponding readers, allowing fast and reliable reading, and, in some cases, writing or editing of data [4]. These labels are not readable without proper equipment. The most widely used automatic identification systems are barcode technology and RFID technology. This category may also include vision systems, which are different from previous methods because of a lack of the need for labels, but also a slightly different range of applications. Each of these technologies has a number of advantages, but also disadvantages that limit its use in certain situations.

Automatic identification systems

The expansion of automatic identification systems, and barcode technology in particular, began with storage and logistics applications. Storage facilities were the basis for the development of MRP. In practice, this means that the automatic identification systems are often directly connected to the business systems (ERP/MRP/MRP2). Automatic identification can also be directly integrated with the process control systems. For vision systems, this is often the standard mode of operation.

The most commonly used method of the automatic identification is **barcode technology**, which is a source of data mainly for warehouse management systems [17, 21]. The most important advantage that has influenced the popularity of barcode technology is the low price of the labels and reading equipment, and the quick read time. The advantages of this technology make it the primary method of identification used in production systems, logistics and warehousing. Deployment of barcode scanners at many points of the production system and thoughtful, design allows us to get information about the objects (materials, semi-finished or finished products and equipment) movements. The limitation is that the barcodes have little information capacity, so serve only as an object identifier. The rest of the data is stored in the system database, and so in the absence of access to this database, the codes are useless because they do not carry any information, such as the product genealogy. Barcodes printed on paper are not resistant to harsh industrial environmental conditions, but it is possible to use a more robust material or print a barcode directly on the objects surface.

RFID systems (Radio Frequency Identification) are based on the wireless transmission of data between the tag and the reader [12, 24]. This technology is newer than barcodes and can solve a number of problems related to low barcode label durability, small information capacity and the need of the scanner to have direct visibility of the label. The RFID labels (tags) are compact in size, may be resistant to certain environmental factors (heat, cold, dirt, mechanical damage, moisture and chemicals) and have longer operating range (from a few millimeters to several meters). It is possible to detect and identify objects from a distance, regardless of their orientation, which eliminates the need for manipulation of objects, and thus facilitates automatic data acquisition. RFID R/W (read/write) tags allows us to write and edit the data. In industrial applications RFID technology is primarily used to control the flow of products at various stages of the manufacturing process and storage. In a situation where transponders may be reused or applied to labeling objects of great value, the higher price of tags is practically of no importance [8].

Machine vision technologies play different roles in data acquisition from production systems than barcodes and RFID technologies. They are usually strongly associated with the technological process, performing the function of a sensory system, directly controlling the process or a part of it. Vision systems used for quality control or sorting can provide direct access to information about the number of manufactured components or production quality [9]. A typical operation mode of the vision system is inspection triggered by control systems. Machine vision systems may also work in a continuous mode, monitoring the changes in a scene (for example, in security and surveillance systems). Efforts are also made to use machine vision systems for monitoring the progress of construction work (to measure the degree of work completion based on image analysis and comparison with the CAD model of the structure) or a visual analysis of the activity of employees (often in combination with the data from the position sensors and movement sensors) [20]. Vision systems can also be used for monitoring and controlling of mobile robots or analyzing the flow of large products (e.g. tanks, wagons, etc.) through the stages of the production process, which takes place over a wide area, often outside the production hall [2].

Other methods of data acquisition

When a standard automatic identification systems are not sufficient it may be necessary to use other solutions. This applies especially to those companies where employees or equipment are moving around a vast area and there are no typical production lines. A combination of different techniques of acquisition like barcodes, RFID, vision systems, GPS, 3D scanning, etc., can provide more possibilities of data acquisition in difficult conditions [15].

A possible solution to the problems of acquisition of information in such cases is the use of mobile devices, such as industrial data collectors, portable computers, PDAs (Personal Digital Assistants), smartphones or tablets [7]. Such devices equipped with appropriate software allow you to enter data in field conditions, have wireless connection modules and, often, GPS receivers. Most also allow you to prepare photographic or film documentation and can read bar codes or RFID tags.

In industrial applications, the most commonly used devices (data collectors) are designed for operation in harsh environments, but recently the use of consumer electronic devices, such as smartphones and tablets has become more common practice. These devices are controlled by operating systems (Windows Mobile, Android, iOS), which allows the easy design of applications. Applications usually allow simple data entry through menu systems and incorporate information from sensors built into the device (e.g. camera acting as a barcode scanner, GPS and RFID-NFC systems) and wireless communication with databases. These devices are often owned by employees – a BYOD (Bring Your Own Device) model.

There are also attempts to use sound analysis and speech recognition for data acquisition from workers, to avoid distracting them from their main work [13].

Acquisition of data about the location of objects

In many cases it is necessary to obtain information about the location of objects and workers within the production system. RFID readers and barcode scanners are installed in specific spots and cover a small area, so the RFID and bar codes do not provide continuous information on the location of labeled objects. Data is only available for the transition of the object with the tag or label through the scanning area, but there is no information about what is going on with it until the next scanner detects the object.

In the case of work carried out in a large area, positioning methods based on GPS (Global Positioning Systems) working with Geographic Information Systems (GIS) are often useful [14]. Location systems based on GPS provide continuous information in the open field, but do not work inside buildings. When the data about the position of objects shielded from the GPS signal is needed, other solutions, such as triangulation of the signals of different types (radio, optical) may be used.

Often there is a need to combine several technologies in order to obtain satisfactory results. In the most difficult cases, the common practice is to use a combination of techniques like RFID, barcodes, 3D laser scanning, photogrammetry, GPS and mobile devices with the possibility of wireless data transmission. To automatically determine the activity of mobile machines and vehicles, load sensors and accelerometers can be used. For vehicles equipped with modern CANBUS control systems, direct download of data is possible.

6.6 A PRACTICAL EXAMPLE OF ACQUISITION OF PRODUCTION DATA

Data acquisition can be a problem mainly in companies where manufacturing processes are non-automated. An example would be a company which manufactures large products (such as tanks for liquefied gases), individually or in small quantities according to the customer order. The plant do not use automated production equipment, majority of production operations are long-term operations performed manually carried out using simple tools and machines. The products are characterized by their large dimensions (typical tank: length of about 18 m, diameter of up to 3 m) and weight (14-15 tons). Within a week, the plant is capable of producing 5-10 tanks. The main techniques used in the production process is welding, machining, cutting and shaping metal sheets. Some parts are made by subcontractors. The tank assembly is long process, some operations take more than 10 hours.

In the described system acquisition of information about the tasks of production and movement of materials and finished products within the production hall is necessary.

In the business layer the ERP system – SAP R/3 SPRINT is used to support company management. This system generates orders of production operations, a printout include also a barcode, allowing worker or manager to confirm the operation execution. Initially, confirmation of the operation was carried out by the production plant manager, who collected data on the operations performed from foremen and entered it into the SAP system at the end of the production shift. It was a typical example of the manual acquisition, where the information appeared in the ERP system with a significant delay, frequently with errors and glitches.

Registration of production material flow is supported by the dedicated SAP module, but only release of materials for the production from material warehouse and the arrival of a finished products to the products warehouse are considered – there is no information about the intermediate stages of the production of tanks.

The unsatisfactory state of data acquisition in the company has led to the development of solution, that currently include tracking of production operations performed by the employees. In the later stages of development it is planned to include also materials and products flow in the reporting system.

Production data acquisition system

The main role in the production data processing system covers the *Mistrz*, which is the link between ERP (SAP) and production hall and plays role of two way interface. Scheme of the *Mistrz* is presented in figure 6.2. The *Mistrz* operation is based on production orders, imported from SAP. SAP generates a code allowing to confirm the operation in the form of a barcode. The data on ordered operations is copied to the separate the *Mistrz* SQL database.

The main source of production data are portable data collectors Datalogic Viper, equipped with barcode scanner, touch screen, keyboard, and WiFi wireless interface. Application installed on data collectors is responsible for communication with master system, allowing easy and quick data entry using barcode scanner and keyboard.

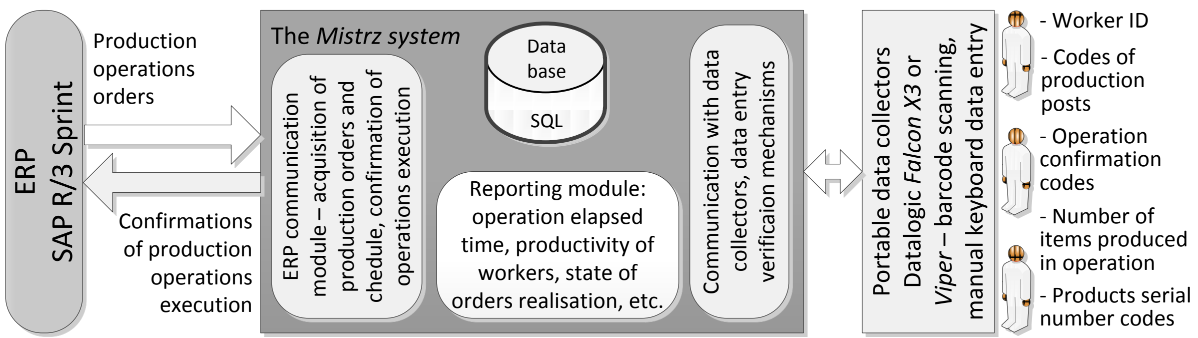

Fig. 6.2 Data acquisition in *Mistrz* system

Data collectors are placed in the data acquisition cells in separate areas of the production hall, common for a few production posts. There are three types of charts available in the data acquisition cells, each containing description and corresponding barcode. First type of charts contain codes of production posts – it allows worker to specify on which production post he was working (or will work). Second type of charts contain codes of operations confirmation in different production orders, allowing worker to confirm execution of specific operation, generated in the SAP system. The third type of charts are lists and barcodes of product serial numbers. Each employee has a badge with a personal barcode.

Before starting work, the employee should log on to work at a given post, scanning his personal badge barcode and code of the post. The worker performs operation ordered by his foreman or production manager, but there is no record on it in the *Mistrz* system. After completion of the operation or at the end of the production shift, worker goes to data acquisition cell, re-scans his personal code and confirmation code of the operation he performed. Then worker can determine degree of realization of the operation. Possibilities are: complete execution of the operation order, partial execution (e.g. employee finished 5 of 20 ordered items) or the zero-execution (the employee performed an operation, but failed to complete a single piece, due to the fact that the execution time exceeded the production shift time). If worker performed operation on a final product (with a serial number assigned), serial number barcode should be also scanned.

Employees usually leave the confirmation of orders at the end of their shift, often entering confirmation of several different operations performed during shift.

The data input is checked in real time, among others the following attributes are verified:

- worker personal code compliance with list of employees present that day at work,
- correctness of confirmation code of operation order – only codes of operations that are partially completed or not entirely completed previously are allowed,
- compliance of the number of completed items with the number specified in the order,
- correctness of serial number.

Data verification procedures introduction was forced because of large number of errors in the initial period of system functioning (workers scanned incorrect codes).

The *Mistrz* system is responsible for communication with data collectors, verification of data entry, importing of production orders from SAP, confirmation of executed orders into SAP and reporting according to the certain criteria. All required and collected data is stored in local SQL database. The *Mistrz* system administrators are responsible for the entered data, processing and export information to SAP. Those administrators have also high access privileges in SAP system, which allows correction of errors occurring despite of data verification. Production manager, his deputy and members of company management have also access to the *Mistrz* system. These people have the ability to generate reports on production orders and employee productivity. Worker productivity is determined basing on the difference between the operation execution time expected in SAP and the elapsed operation time, even though elapsed time is not measured precisely.

Further modifications for improvement of data acquisition system

The main problems with the production data acquisition system in described company are associated with the lack of information on the circulation of materials. Current data acquisition system covers only raw material issuing from the materials warehouse (in the SAP system) and introduction of the finished products into the appropriate warehouse. There is no information about the elements (parts) used to build the product. These elements do not have own serial numbers, although are produced in separate technological processes. It is proposed to introduce the serial numbers for these components and their precise evidence storage. Full evidence of the circulation of materials and semi-finished products can be achieved using a barcode labels printed on durable material or applied on the part itself (e.g. laser tagging). Also RFID tags in a durable enclosure can be used, but it require change of data collectors. Set of mid-range RFID fixed scanners, installed at production stations can automatically capture data from tags fixed to semi-finished products and parts, allowing automatic (without involvement of workers) capture of the data on objects flow.

Another problem is the delay in entering information about the execution (total or partial) of manufacturing operations and the lack of information about which production order and operation an employee performs until it will be reported at the end of the shift. There are cases of workers forgetting to confirm the operation or entering of incorrect data, despite of the data verification mechanisms. Data acquisition requires attention and diligence from ordinary employees who have been burdened with additional responsibilities. It is proposed to extend the set of data to be entered at the beginning of the shift by worker with the information about the production order and operation, assigned to a particular employee. Confirmation of orders should be made immediately after worker complete the operation, before taking other jobs.

Described problems require modification in the *Mistrz* system and data collectors software. All proposed modifications are shown in figure 6.3.

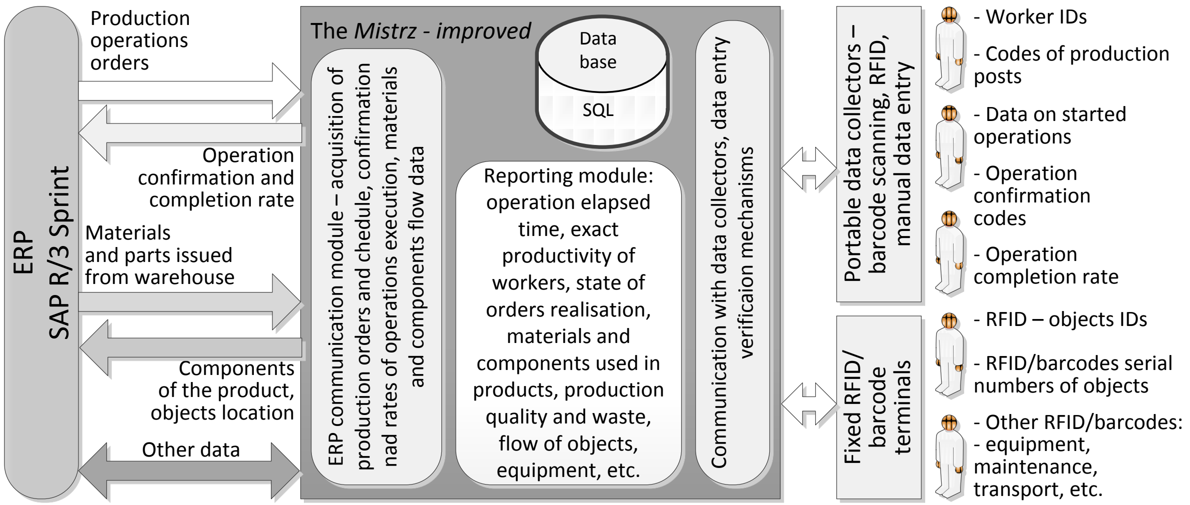

Fig. 6.3 Proposed modifications in the data acquisition system

SUMMARY

Data acquisition in non-automated production systems is much more difficult than in automated ones. In particular, it is difficult to obtain data on employees activity and circulation of materials in the production system. The standard solution for this situation is the use of automatic identification systems, but in the harsh operating conditions of the production system, hardware (data collectors) and labels resistant to these conditions should be selected.

Various types of automatic identification systems play a particular role in the enterprise, allowing the acquisition of data that is not collected with elements of industrial automation and control systems. Automatic identification systems can be seen as a data source parallel to the control system or the primary source of data.

It is necessary to create a middleware between the business and data sources layers, responsible, among other things, for the verification of entered data. In practice, there are often problems resulting from the accidental scanning of wrong labels.

Semi-automatic data acquisition systems should be user-friendly, allowing the worker to input the required data easily and quickly. Data acquisition system elements (scanners and labels) should be resistant to adverse environmental conditions (high temperatures, moisture, aggressive chemicals, weld spatter) and mechanical damage. Installation of systems identifying objects from a distance, without the need for activity from the employees (e.g. long-range RFID tags and stationary scanners in production posts) should be considered. This will allow automatic collection of data on material and production flow.

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Abstract: *This paper presents the problem of acquisition of production information from the companies in which technological processes are mostly non-automated. Data acquisition for company management is essential for the integration of the business and manufacturing layers of the company, providing access to current data on production tasks. Most of the problems with the acquisition of data from automated systems is solved, while the lack of automated systems is an obstacle in obtaining information. The paper presents and organizes the issues of methods and means of data acquisition in companies, in which the majority of manufacturing operations is performed manually.*

Key words: *manufacturing data acquisition, MES, barcodes, RFID, machine vision*

AKWIZYCJA INFORMACJI DLA POTRZEB ZARZĄDZANIA W NIEZAUTOMATYZOWANYCH SYSTEMACH PRODUKCYJNYCH

Streszczenie: *W artykule przedstawiono problematykę akwizycji informacji produkcyjnych z przedsiębiorstw, w których procesy technologiczne nie są zautomatyzowane. Akwizycja danych dla potrzeb wspomagania zarządzania jest konieczna dla integracji warstwy biznesowej i produkcyjnej przedsiębiorstwa, zapewniając dostęp do bieżących danych o realizacji zadań produkcyjnych. Większość problemów z akwizycją danych z systemów zautomatyzowanych jest rozwiązana, podczas gdy brak systemów automatycznych jest przeszkodą w pozyskiwaniu informacji. W pracy przedstawiono metody i środki akwizycji danych z przedsiębiorstw, w których większość operacji produkcyjnych jest wykonywana manualnie.*

Słowa kluczowe: *akwizycja danych produkcyjnych, MES, kody paskowe, RFID, systemy wizyjne*

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