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AN EVALUATION OF THE EFFECTIVENESS OF APPLYING THE MES IN A MAINTENANCE DEPARTMENT – A CASE STUDY

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Abstract: The issue of adapting enterprises to operate in accordance with the assumptions of the Industry 4.0 concept now requires performing highly complex and responsible analyses in manufacturing enterprises. Based on the Industry 4.0 concept, maintenance services and also the implemented IT solutions in a production enterprises are now a significant factor in their development process. The article presents an analysis of the degree of use of the Manufacturing Execution System (MES) in the maintenance department based on an example of a manufacturing company in the automotive sector of this industry. The analysis was performed in terms of the degree of execution of specific business processes in the maintenance department with the help of MES. The results of the analysis allow to confirm the possibility of adapting the enterprise to the Industry 4.0 concept.

Keywords: effectiveness, MES, maintenance department, case study.

JEL: L6.

1 Introduction

The Industry 4.0 Concept assumes the implementation of IT-assisted connections between people, objects and systems, thanks to the exchange of data and information in real time (Dorst, et al., 2015; Spath, et al., 2013).

In order to be able to implement the objectives of the Industry 4.0 Concept, manufacturing companies should invest in those IT technologies that support the implementation of processes or activities, since IT systems are the basis for further investments in "smart" technologies.

The transition to "level 4.0" also requires huge investment in supplementing the knowledge of managers and engineers, so that they may implement and use the latest IT technologies supporting the production processes.

Implementation and use of the Manufacturing Execution System (MES), may enable activities related to the automation of production in the enterprise and may constitute the first stage of development, within an enterprise, in line with the Industry 4.0 Concept.

The functional complexity of the processes performed by employees in the maintenance department requires the application and investing in increasingly specialized IT systems and technologies as well as software packages, which can provide a competitive advantage to their users.

MES directly supports the implementation of production processes and, at the same time, is used to support activities carried out in the maintenance department of production enterprises. The aim of the MES implementation is to support the activities within a company to optimize the production operations (Jacobson, et al., 2005, 2006).

The functional areas of the MES systems include Process Management, Performance Analysis, Production Tracking and Genealogy, Traceability, Quality Management, Data Collection and Acquisition, Document Control, Resource Allocation and Status, Labor Management, Maintenance Management, Operations/Detailed Scheduling and Dispatching Production Units (MESA International).

MES implemented in the production area, which combines planning systems with industrial automation systems, controls the course of production processes and also performs the characteristic functions

of the Supervisory Control and Data Acquisition system, that is, a unified interface to production controllers and autonomous industrial systems.

This article analyses the effectiveness of the implementation and the use MES in a maintenance department, based on an example of a manufacturing company in the automotive sector of industry; analysis was provided on three levels of management, viz., operational, tactical and strategic.

2 Effectiveness of the application of the MES in manufacturing enterprises

Polish manufacturing companies, to adapt their structure and activities to the assumptions of the Industry 4.0 concept, should implement and use IT systems. Knowing that the average robotization density, in Poland, is 4 times lower than in the rest of Europe (Fig. 1), research should be conducted in the field of the computerization and automation of Polish manufacturing enterprises.

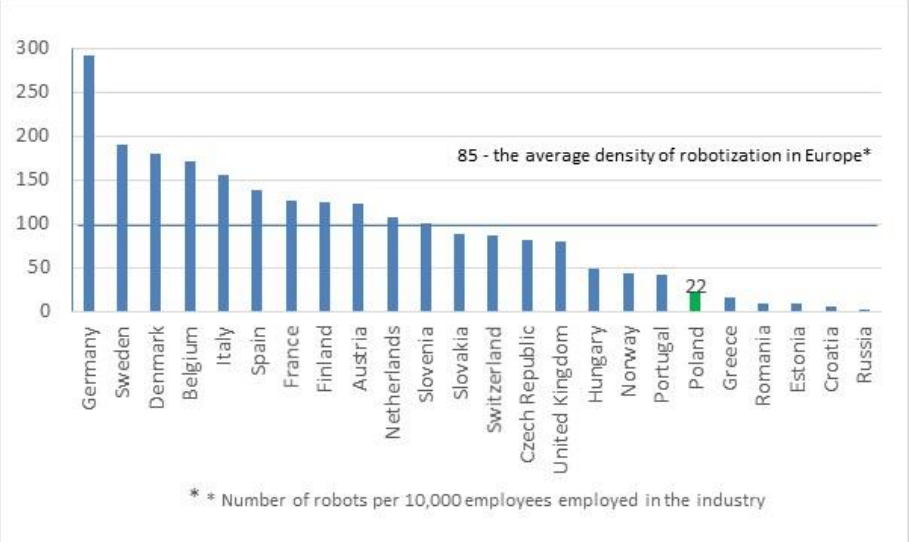

Figure 1. The average density of robotization in Europe (2014)
(*Source*: Łapiński, 2016)

MES is an integrated solution that supports computer-aided planning and the control of continuous and discrete production processes. An example of a model of MES that tracks production processes and resources, as well as production control, is shown in Fig. 2 (Klonowski, 2004).

The main task – which the solutions for MES systems seek to improve – is efficiency in the production processes. The elements of such a solution are:

- a server with a database – where data is collected and processed,
- elements of automation – necessary for obtaining data (e.g., drivers),
- end devices – which enable communication with the server and machines and thus allow data to be read and presented (e.g., HMI panels, mobile devices, computers),
- user software – a programme, or an application with an appropriate interface, enabling employees to read, enter and process data, using end devices.

According to (Muhammad, et al., 2009) the main functions of the MES include:

- the allocation and status of resources,
- the sending out of production units,
- the collection and acquisition of data,
- quality management,
- the management of maintenance and repairs,
- analysis of the results,
- detailed operations – scheduling,
- document control,
- personnel management,
- process management,
- tracking the product.

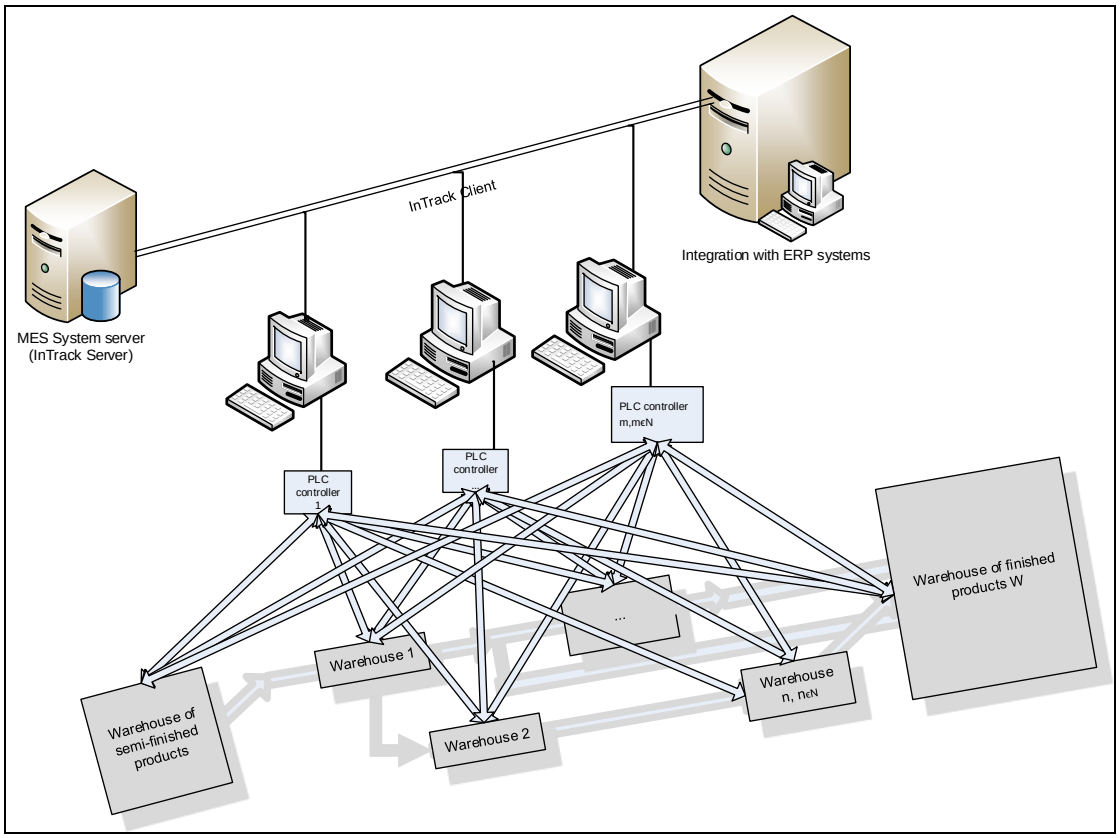

Figure 2. An approximate model of MES – tracking of production processes and resources and production control (*Source*: Klonowski, 2004)

An analysis of the functionalities of MES systems available on the Polish market was carried out in terms of supporting the defined activities in the maintenance department (Table 1).

Table 1. A comparative analysis of the functionalities of MES systems (S*ource*: Own elaboration)

Item	Functionalities of the MES system supporting production processes	Wonderware (MES1)	Queries (MES2)	ProSeS BDE (MES3)	PSI*mes* (MES4)	BPSC (MES5)	Progress 500 (MES6)
I. Management of production processes							
I.1	Automatic and manual input of production data		x	x	x		
I.2	Management of control cards			x			
I.3	Managing DNC (Direct Numeric Control) Parameters			x			
I.4	Analysis of machine statuses and production in progress					x	x
I.5	Information on alarm statuses					x	
I.6	The ability to transfer data to HMI/SCADA					x	
I.7	Settlement of working time for an order (quantity and value)					x	
I.8	Settlement of costs, both planned and actual					x	
I.9	Settlement of production in progress					x	x

	II. Analysis of effectiveness						
II.1	Automatic calculation of the OEE value	x	x	x		x	x
II.2	Support for quality control processes		x	x			
	III. Monitoring						
III.1	Managing production orders	x			x		x
III.2	Managing material lists (BOMs)	x					
III.3	Tracking production (traceability)	x	x		x	x	x
III.4	Visualization of production in real time		x	x	x		
III.5	Warehouse management	x					x
III.6	Real-time testing of machines	x					x
III.7	Detection of downtime		x		x		x
III.8	Immediate notification of downtime		x	x			x
	IV. Management of document flow						
IV.1	Electronic registration of production					x	
IV.2	Transmission directly to CNC machines					x	
IV.3	Transfer to the supply warehouse					x	
IV.4	Transfer to the tool supply shop					x	
IV.5	Information (by e-mail/SMS) to the appropriate quarters when an incident occurs (e.g. machine failure)					x	x
IV.6	Transfer of documentation, drawings, job instructions to operators' terminals					x	
IV.7	Storing attachments: a) drawings b) instructions/manuals for workstations c) implementation procedures d) CNC programmes e) changes introduced by technologists					x	x
	V. Management of the allocation of resources						
V.1	Identification of bottlenecks	x		x	x		
V.2	Completion of materials for appointments to individual positions					x	
V.3	Completion of instrumentation for individual resource deadlines					x	
	VI. Management of Human Resources						
VI.1	Availability of human resources/calendar					x	x
VI.2	Qualifications of human resources					x	
VI.3	Developing employee availability plans					x	
VI.4	Preparation of the demand for human resources required, for implementing the plan					x	
VI.5	Preparation of the demand for seasonal workers					x	

	VII. Traffic management						
VII.1	Current information regarding the production line: a) production completed b) production planned					x	x
VII.2	Maintaining plans for repairs and maintenance of devices					x	x
VII.3	Integrated controlling functions					x	
VII.4	Integrated accounts and cost functions					x	
	VIII. Production scheduling						
VIII.1	Scheduling the production of orders		x		x		
VIII.2	Scheduling the order pool					x	
VIII.3	Analysis of the implementation of the schedule					x	
VIII.4	Confirming deadlines for customers' orders					x	
VIII.5	Scheduling updating (e.g., in case of derogations)					x	
	IX. Collection and acquisition of data						
IX.1	Data from the maintenance of machines, forms and peripheral devices			x	x		x
IX.2	Information on product quality deviations		x				
IX.3	Archiving production and quality data			x			x
IX.4	Recording the start and end of operations: a) automatically b) by touch screen c) on a mobile device					x	
IX.5	Recording downtime periods and their types: a) automatically b) by touch screen c) on a mobile device					x	x
IX.6	Recording of data about correct production and shortages					x	
	X. Quality management						
X.1	Quality control related to a specific version of the product					x	
X.2	SPC/SQC Analysis (Statistical Process Control/Statistic Quality Control)					x	
X.3	Operations management and LIMS analysis (Laboratory Information Management Systems)					x	
	XI. Additional features						
XI.1	Integration with the ERP system	x	x	x	x	x	x
XI.2	Simulation of planned production				x		
XI.3	Project Management				x		

It was found that the analyzed systems support activities carried out by employees on three levels of management, viz., operational, tactical and strategic in the maintenance department and it can be analyzed by their level of use in this section of an enterprise.

The effectiveness is not a clearly defined concept, either in the Polish or in the foreign literature; synonymous concepts such as efficiency, productivity and functionality can be found.

The effectiveness is usually considered at three levels:

- organizational – strategy, structure, method for using resources,
- process – implementation of processes and their co-operation,
- work positions – a set of activities in the workplace, personnel competences.

According to Drucker, effectiveness is a key factor in the development of a company, serving its self-fulfillment and survival (Drucker, 1994); it is an organization's ability to implement strategy and achieve its goals (Skrzypek, 2000).

The effectiveness of using information technology results from using the technology's potential, in order to improve the efficiency of supported operations (Laudon and Laudon, 2001). In economic terms, effectiveness is the result of an enterprise's business activity, being the ratio of the effect obtained, to the expenditure incurred (Szafrański, 2007).

In the article, it has been assumed that the effectiveness of the application of the MES is treated as the degree of utilization of available system functionalities in a production company, on three levels of management: strategic, tactical and operational and using, as an example, a maintenance department.

3 A Case Study

An analysis of the degree of use of the MES, at strategic, tactical and operational levels in a maintenance department, was carried out assuming that the manager of the maintenance department supervises the work of 13 employees who operate 380 machines throughout the production enterprise. Production is carried out in the company in a two-shift operation.

The employees of the maintenance department carry out defined activities:

- at the strategic level:
  - by monitoring/tracking the production schedule,
  - by monitoring/tracking the production plan,
  - by inputting records relating to the withdrawal of equipment/machines from operation,
  - by identifying the availability of equipment/ machinery,
  - by monitoring the retooling of equipment/ machinery,
  - by planning for downtime,
  - by recording completed activities,
  - by monitoring equipment in operation,
  - by monitoring production lines,
  - by flagging up/maintaining records of equipment/machinery downtime,
  - by checking the availability of parts in the warehouse,
  - by reviewing the technical documentation of equipment/machinery,
  - by inputting/updating the technical records of equipment/ machinery
  - by inputting/updating other/remaining/ different (non-technical) records,
  - by improvements in the modification of devices, the modernization of machinery, the organization of working practices and the flow of information,
  - by computer simulation of the retooling of equipment/machines,
  - by computer simulation of the retooling of the production line,
  - by identifying production bottlenecks,
  - by notifying – via text messaging – about upcoming events (scheduled maintenance, repair),
  - by notifying – via e-mail – about an upcoming event (repair, inspection),
  - by the on-line monitoring of machines/ equipment,

- by generating/triggering the alarm system in the event of a break-down,
- by analyzing the real costs of Traffic Maintenance Services,
- by analyzing the costs of planned Traffic Maintenance Services,
- by generating reports,
- by monitoring technical tests of equipment/ machines,
- by scheduling human resources,
- by planning human resources,
- by planning external training,
- by planning internal training,
- by planning ongoing training,
- by monitoring training,
- by analyzing training costs of Maintenance Service,
- by analyzing the assessment of the effectiveness of Maintenance Service training,
- by creating a staff development plan for Maintenance Service,
- by creating workplace standards for Maintenance Service,
- by accessing the menu/desktop of another level (lower or higher) of another user from Maintenance Service,
- by reporting the need for external service,
- by monitoring the MTTR indicator (Mean Time to Repair),
- by monitoring the MTTF indicator (Mean time to Failure),
- by monitoring the MTBF indicator (Mean Time Between Failure),
- by monitoring the OEE indicator (Overall Equipment Effectiveness),
- by documenting accidents at work,
- by archiving data;

- at the tactical level:
  - by monitoring the daily inspection of equipment/machines,
  - by monitoring the periodic inspection of equipment /machines,
  - by monitoring reviews of the implementation of machines/equipment,
  - by maintaining notification records of the "readiness for work" of machines/ equipment,
  - by maintaining notification records of the "readiness for work" of the production line,
  - by introducing record keeping about the withdrawal from operation of equipment/machines,
  - by identifying the availability of machines /equipment,
  - by monitoring the retooling of equipment/ machines,
  - by recording details on the repair of equipment/machines,
  - by recording details on planned repairs to equipment/machines,
  - by recording details on ad hoc repairs to equipment/machines,
  - by maintaining records on completed activities,
  - by monitoring the maintenance of equipment/ machines,
  - by flagging up/recording machine/equipment downtime,
  - by reporting the demand for parts/ consumables,
  - by creating stock lists for parts/consumables,
  - by maintaining a stock of parts/consumables for a given device/machine,
  - by selecting parts/consumables for devices/machines, from those proposed by the programme,
  - by checking the availability of parts/ consumables in the warehouse,
  - by reviewing the technical documentation of equipment/machines,
  - by maintaining the technical documentation of equipment/machines and affixing it thereto,
  - by incorporating any remaining/ non-technical documentation,
  - by improvements in the modification of devices, the modernization of machines, the organization of working practices and the flow of information,
  - by monitoring/tracking the production schedule,
  - by monitoring/tracking the production plan,

- by the computer simulation of the retooling of equipment/machines,
- by the computer simulation of the retooling of the production line,
- by monitoring the retooling of equipment /machine,
- by monitoring the retooling of the production line,
- by identifying bottlenecks,
- by notifying -via text messages- about upcoming events (scheduled maintenance, repair),
- by notifying- via e-mail- about an upcoming events (repair, inspection),
- by the on-line monitoring of machines/ equipment,
- by generating/triggering an alarm in the event of a break-down,
- by monitoring the OEE indicator (Overall Equipment Effectiveness),
- by generating reports,
- by monitoring the technical testing of equipment/machines,
- by scheduling human resources,
- by planning human resources,
- by monitoring internal, external and ongoing training,
- by maintaining a repairs calendar,
- by accessing the user's menu/desktop, at the operational level, from the console;

- at the operational level:
  - by maintaining records of the periodic inspections of equipment/machinery,
  - by maintaining records of the daily inspection of equipment/machinery,
  - by maintaining records of the implementation of equipment/machinery,
  - by maintaining records on tuning the parameters of equipment/ machinery,
  - by maintaining records of the testing of equipment/machinery,
  - by maintaining records of the notification of the readiness for work of equipment/ machinery,
  - by introducing record-keeping on the withdrawal from operation of equipment/ machinery,
  - by maintaining records on the retooling of equipment/machinery,
  - by maintaining records on planned repairs/ overhauls,
  - by maintaining records of *ad hoc* repairs/ overhauls,
  - by recording activities completed,
  - by choosing from the list of activities to be registered,
  - by recording the maintenance of equipment/machinery,
  - by maintaining records relating to the flagging up of machinery/equipment downtime,
  - by reporting the demand for parts/ consumables,
  - by maintaining records of the parts/ consumables required for a given device/machine,
  - by selecting parts/consumables for devices/ machines, from a list,
  - by checking the availability of parts in the warehouse,
  - by reviewing the technical documentation of equipment/machines,
  - by improvements in the modification of devices, the modernization of machines, the organization of working practices and the flow of information,
  - by monitoring the production schedule,
  - by the sending of text messages regarding upcoming events, such as planned maintenance, repairs,
  - by e-mailing about upcoming events, such as repairs and reviews,
  - by the on-line monitoring of equipment/ machines,
  - by activating/triggering the alarm system in the event of a break-down.

For example, the process in the maintenance department: a preventive inspection is shown in Fig. 3, which is supported by the MES, in which the following activities are defined:

- analysis of the schedule,

- checking the availability of parts in the warehouse,
- preventive inspection,
- adjusting machine parameters,
- the testing of devices,
- parameters for the tuning of devices,
- analysis of the parameters of devices,
- reporting the readiness of a device, recording activities,
- keeping records,
- receiving information about the status of machines,
- monitoring,
- reporting incidents,
- archiving data from the inspection of the device.

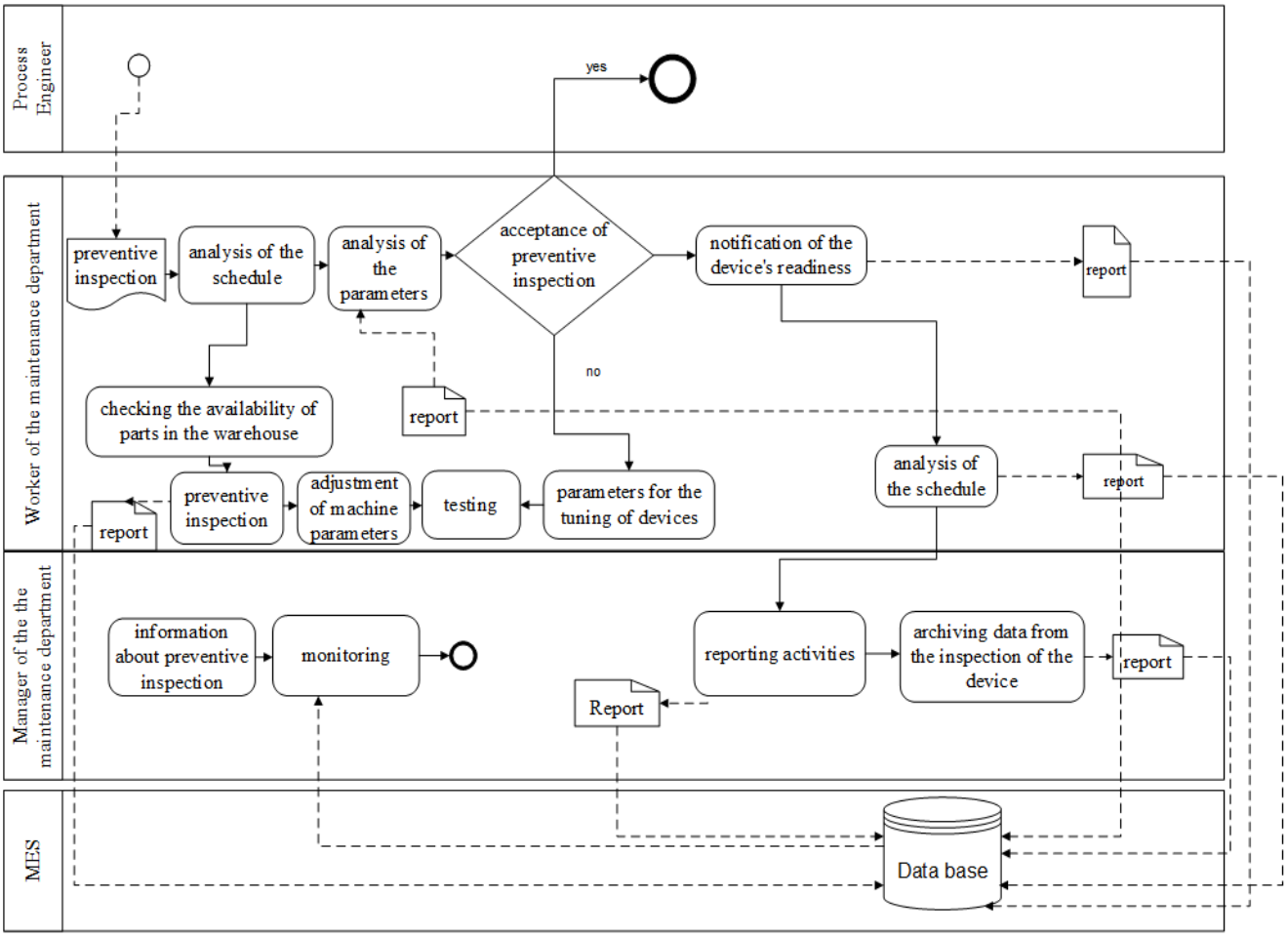

Figure 3. An example of the process carried out in the maintenance department: a preventive inspection (*Source:* Own elaboration)

In order to analyze the effectiveness of the use of the MES at the strategic, tactical and operational levels, in the maintenance department of the Polish manufacturing company within the automotive sector of industry, specific activities have been identified by the employees, that are realized using the MES completely or partly (Fig. 4).

These are defined as:

- tracking the status of devices/machines in real time (on-line),
- checking the availability of parts in the warehouse,
- reporting the demand for parts/consumables
- recording withdrawal of equipment/machines from the operation,

- generating reports for machines/devices/other events,
- flagging up the downtime of equipment/ machinery,
- flagging up/informing about the readiness for work of the equipment/machines/production line

The analysis of the use of the MES in the maintenance department is shown in the Fig. 4.

In most cases, the use of the MES, in the maintenance department, is supported only partially at all three levels of the employees' work in this department, *viz.*, on the strategic level at almost 50%, on the tactical level at 30% and on the operational level at more or less the same percentage of around 26% (Fig. 4).

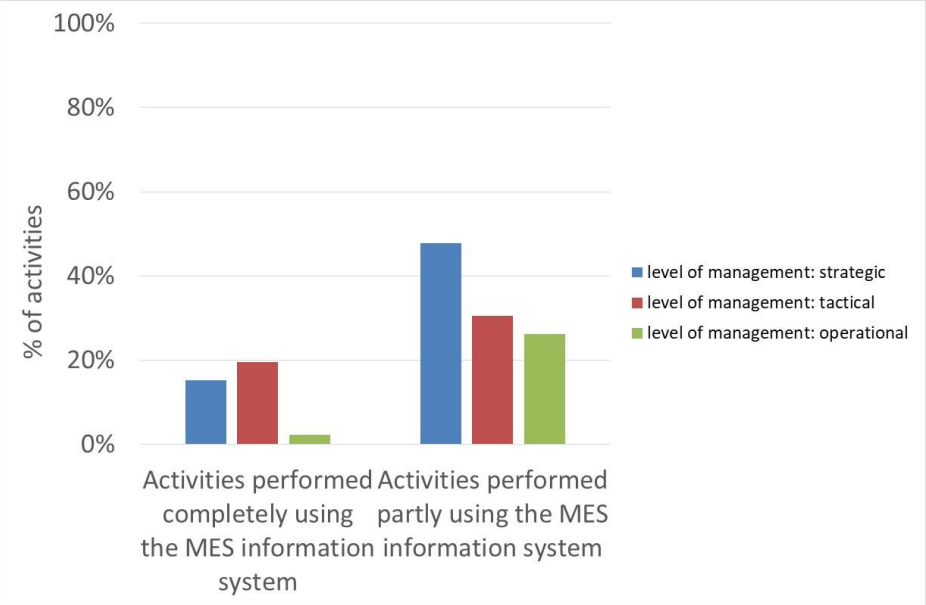

Figure 4. Activities carried out in the maintenance department, divided into three levels, using the MES information system. Test results (*Source:* Own elaboration)

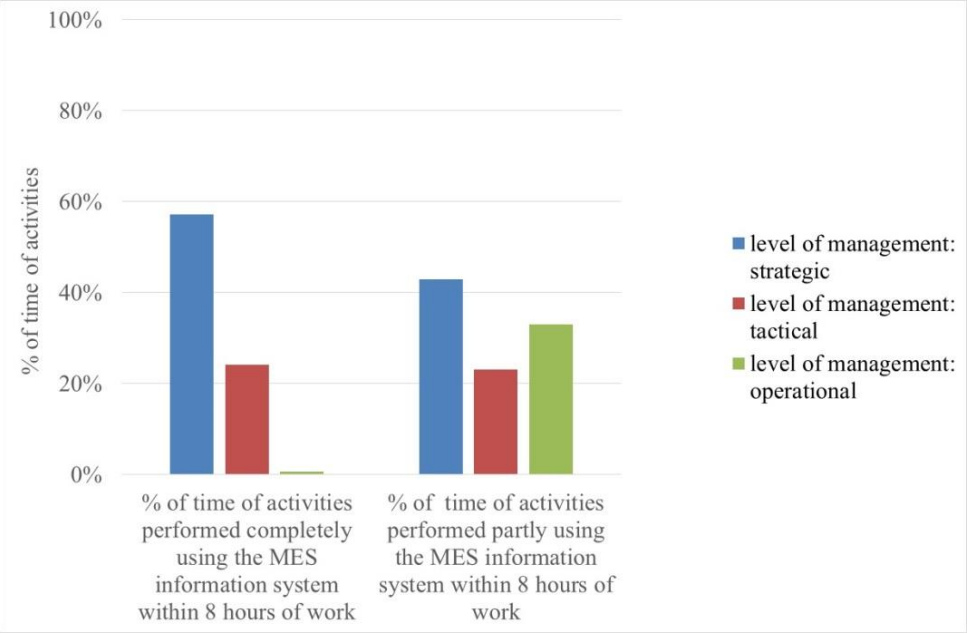

Figure 5. Activities carried out in the maintenance department, divided into three levels, using the MES information system within 8 hours of work. Test results (*Source:* Own elaboration)

In analyzing the time for those maintenance department activities, completely assisted by the MES over an 8-hour working day, it can be stated that almost 60%, or about 5 hours of work, is supported by IT in the strategic job position; while in a tactical position, this is about 25% of the time, which is 2 hours of work. The smallest amount of work time, that is, only 1%, is fully supported by the system in the operating position (Fig. 5).

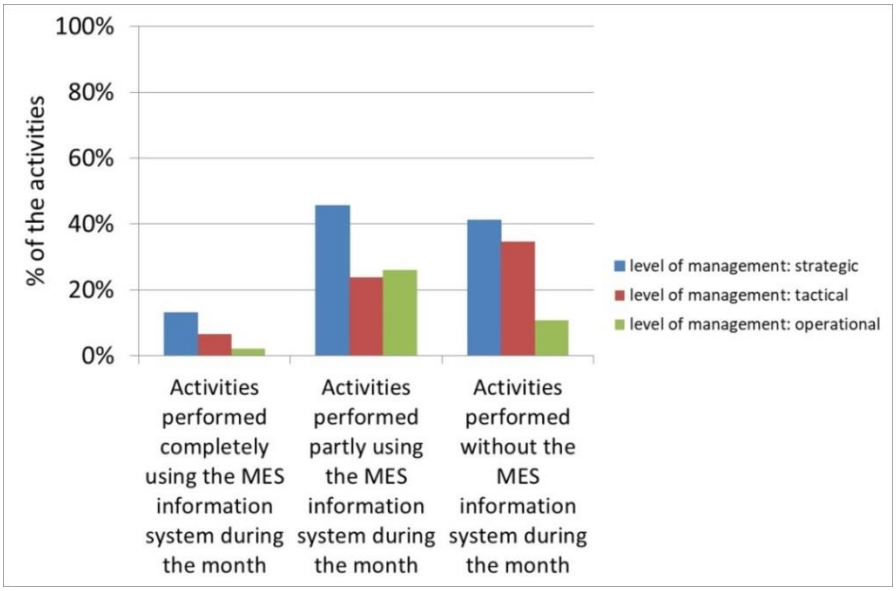

Figure 6. Activities carried out in the maintenance department, divided into three levels, during the month. Test results (*Source:* own elaboration)

In analyzing the activities performed by maintenance workers over a month (Fig. 6), it can be stated that work at the strategic level is supported most only partly by the system, that is, by about 46%. Work entirely performed by the system, at this level, is supported by about 13%.

In Fig. 6, it can clearly be seen that work performed without system support, for a strategic level employee, constitutes a large percentage of his/her work, that is, about 41% of activities. However, work carried out without system support at the tactical level constituted about 35% of the activities, while work in the operational position accounted for only about 11%. The smallest number of activities performed entirely by the MES system over a month was observed in the operational position and accounted for only 2%.

Moreover, by analyzing the activities carried out entirely by the MES, at the strategic, tactical and at the operational levels, over a one-year period, it can be seen that a very small number of activities, only about 4%, are performed entirely by the IT system at the operational level.

The realization of the activities partially supported by the system is more satisfactory at the strategic level – it constitutes some 50% of activities. At the tactical level, this is only about 20% of activities performed entirely by the IT system, as is shown in Fig. 7.

Also, in this maintenance department the activities that are not IT-supported by the MES, are identified:

- order management,
- reporting demand for external services,
- monitoring/tracking the production schedule
- downtime planning,
- identification of bottlenecks on each machine/device,
- review of technical documentation,
- reporting the readiness for work of the repaired devices/machines, after overhaul,
- conducting on-line/video training,
- planning training,

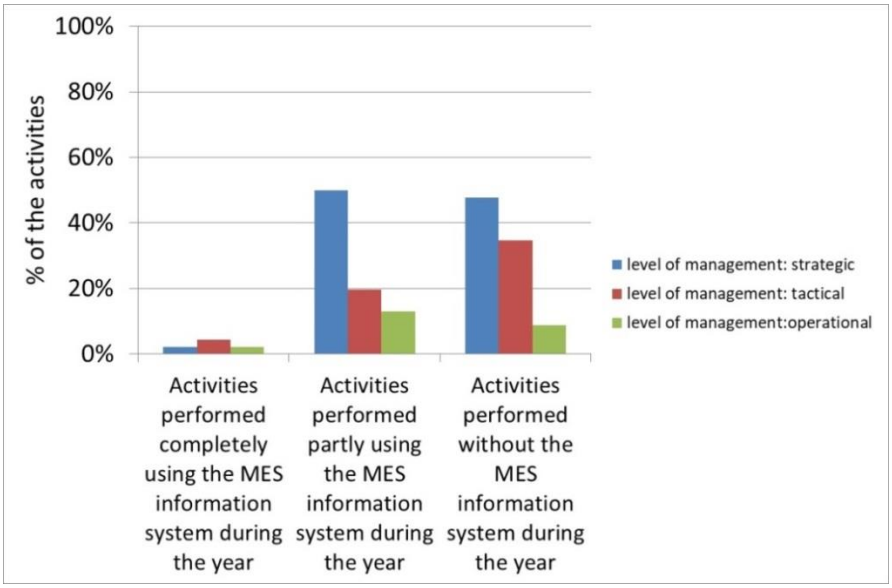

Figure 7. Activities carried out in the maintenance department, divided into three levels, over a month. Test results (S*ource:* Own elaboration)

- monitoring training,
- scheduling/planning of human resources,
- creating workplace standards for Maintenance Service,
- reporting/flagging up improvements, such as the modernization and improvement of machines, devices,
- reporting/flagging up solutions in order to improve work, such as the flow of information,
- implementing improvements in such as the modernization and improvement of machines, devices,
- implementing solutions in order to improve work, such as the flow of information,
- monitoring the technical testing of devices/machines,
- monitoring the MTTR indicator (Mean Time to Repair) – break-down time/number of corrective events (min),
- monitoring MTTF (Mean Time to Failures) – available working time – failure time/number of events (min),
- monitoring MTBF (Mean Time Between Failure, MTTR + MTTF),
- analysis of the availability of the device/machine,
- cost analysis for Maintenance Service,
- archiving of data.

Based on the conducted research in a manufacturing company in the maintenance department, in which the employees use the MES, it can be concluded that the activities performed by these workers within 8 hours of work are to a small extent assisted as a whole by the IT system. The work of these employees is only partially supported by the IT system (Fig. 4).

Almost half of the work realized by the workers within a month, especially of employees at the strategic level, is still not supported by the MES and almost the same with partial system support (Fig. 6).

A similar situation of the system's effectiveness refers to the work performed during the year for the activities of strategic employees (Fig. 4).

The work carried out by the tactical level in the maintenance department both during the month and the year are fully or partially supported by the system at a similar level, it is only about 20% of activities (Fig. 6 and Fig. 7).

The least effectiveness of the use of MES is for the activities related to employees on the operational level; during a business day, their activities are supported only in about 1% of the time of activities performed by these workers (Fig. 5).

Also, works performed during the year are the least supported both completely and partially by the system at this level (Fig. 7).

4 Conclusions

Bearing in mind that the maintenance department in this company has to service 380 machines and devices, and business processes performed at the operational level are not supported by the system, and also, activities performed by employees at the strategic and tactical level related to tracking the state of machines and devices during a month or year are also not computerized, it can be concluded that the company is very far from the enterprise model prepared for the implementation of the industry concept 4.0.

In order to achieve the objectives of the Industry 4.0 concept, systems supporting activities (business processes) of maintenance services should map the actions performed by employees at all three levels: strategic, tactical and operational in the functions of relevant software relating to the cycles of real production processes, and thus, also to the operations of the services, which contribute to the reliability of these processes.

Unfortunately, the presented research results indicate that the Polish company from the automotive industry, which is perceived as one of the most automated in our country, is not prepared to implement the Industry 4.0 concept.

Further directions of work include currently conducted research in another enterprise from the automotive industry, this is an industry branch in the field of industrial processing qualified for section C according to the Polish Classification of Activities (PKD 2007) in order to compare with current results.

Those enterprises were chosen in the context of Industry 4.0 because their employees are largely responsible for the operation and efficiency of intelligent machines and IT tools.

The need for detailed research was noted because in today's era of automation, computerization and digitalization, according to the Industry 4.0 concept, the Polish enterprises have to compete on the market.

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