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Agile Factor Flexible Industry 4.0 with MES Manufacturing Execution System Along with ERP Back-End Integration: Ready-Made Garments as a Case Study

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Abstract

Industry 4.0, or the Fourth Industrial Revolution, is based on digitized the manufacturing process and makes use of all digital tools so its combination of various digital technologies computers, ERP software, IoT, machine learning and AI *techniques*, Manufacturing Execution Systems (MES), and big data analytics to create a new, fully digitized manufacturing system. The Critical Success Factors (CSFs) of MES adoption are both a quantitative and qualitative measurement. We use the case of ready-made garments to improve each of the three Overall Equipment Efficiency (OEE) factors: Availability, Performance, and Quality. In this study, we adopt real-time management of production activities on the shop floor from order receipt to finished products, then measure the improvement.

Keywords

Industry 4.0, ERP, MES, IOT

1. Introduction

Industry 4.0 concerns the transformation of industrial processes through the integration of modern technologies such as MES application, communication, computational processing, Cyber Physical Systems (CPS), Internet of Things (IoT), and ERP [1]-[10]. Industrial Internet of Things (IIoT) is an application of IoT in industries to modify the various existing industrial systems [11] [12].

2. Industrial Revolutions

Industry 4.0, or the Fourth Industrial Revolution, is based on various digital technologies using modern technologies tools like computers, ERP software, the IoT, machine learning and artificial intelligence, and big data analytics to create a new, fully digitalized manufacturing environment. Industry 4.0 has a great effect like the three industrial revolutions that came before (steam power, electricity, and automation) [13]-[20].

The model is developed and maintained by the International Society of Automation (ISA), a non-profit organisation that sets standards for industrial automation and control systems. The model was first published in 1995.

It consists of five levels, each representing a different layer of the manufacturing system. These levels are:

- Level 0: Physical equipment layer such as the machines on the shop floor.
- Level 1: Physical sensors on the equipment, such as PLCs to monitor processes.
- Level 2: Monitoring and supervising layer, such as the logic in PLCs to control and monitor the process.
- Level 3: Manufacturing operations management layer, managed by an MES application.
- Level 4: Enterprise business systems layer, managed by ERP.

All of these layers communicate, allowing data to flow between the different systems in the factory.

This model is often depicted as a pyramid [21]. For the purposes of MES we can consolidate levels 0, 1, and 2 together and consider them to be an output that MES can connect to in order to take real-time readings about the production process.

3. Definition of ISA 95

- Instrumentation, Systems, and Automation Society (ISA) Standard
- Standard that defines how to link Enterprise and Controls systems using a Manufacturing Execution Systems (MES) layer. This standard describes:

  - The MES Functionality.
  - The Data base schema at the MES Level.
  - The Messages between the Enterprise system and MES.

The MESA-11 Model:

- Operations/detailed scheduling.
- Resource allocation and status.
- Dispatching Production Units.
- Document control.
- Product tracking and genealogy.
- Performance analysis.
- Labor management.
- Maintenance management.
- Process management.
- Quality management.
- Data collection/acquisition.

4. Research Criteria

In this research, the goals were to study carefully the implementation of the MES system within the production process of a ready-made garment company and to assess the resulting improvement of the competitive priorities of manufacturing, having as supporters the organizational factors.

This research is guided by qualitative research making use of interviews with the workers in the plant with different process lines, through semi structured questionnaires submitted to the main professionals working in the deployment of MES system.

The method of case study concerns the study of a problem seen through multiple perspectives and in its original context. The research was performed by the method of a single process run the three different lines function as cutting, swinging and packing, and the object of study consisted of a multinational company, market leader in ready-made garment products.

The main way of collecting data was through semi-structured interviews, additionally, the research method included visits to the factory and plant floor observation. Internal documents were consulted and selected to elaborate the questions for the interviews.

5. Database Schema at the MES Level

The architecture of an MES (Manufacturing Execution System) consists of four main layers: Data Collection, Process Control, Automation/Management, and Enterprise Integration (Figure 1).

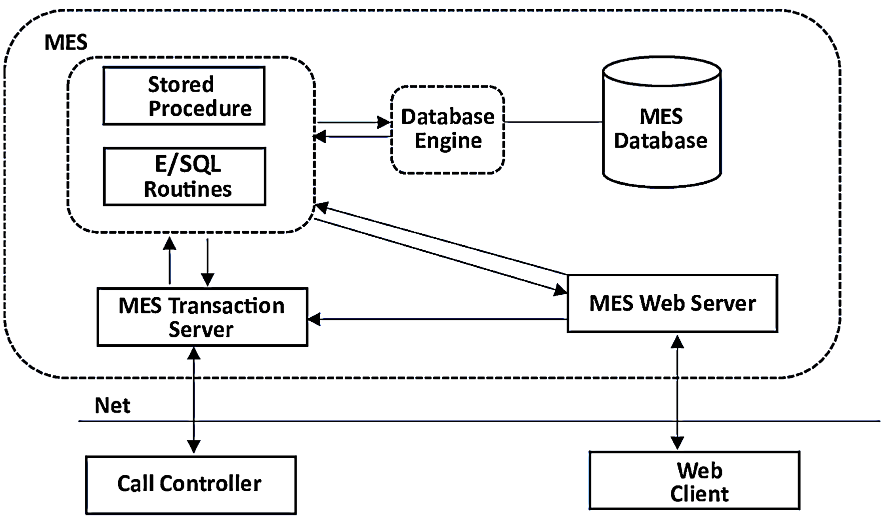

Figure 1. Data schema at MES.

6. Complementary Nature of MES and ERP

ERP and MES are complementary tools for ensuring free flow of manufacturing information, and leveraging it within the enterprise [22]-[26]. The ERP and MES do not work on the same time scale: an ERP rarely works on periods shorter than a halfday, while the MES works either minute by minute, or over ten or twenty minute stretches [27] [28]. This different time scale tends to hide another, more important difference: the ERP is not designed to collect and process finely-meshed data in real-time [29] [30]. This fine mesh is necessary to control and coordinate processes with tight constraints concerning traceability and performance improvement (Figure 2).

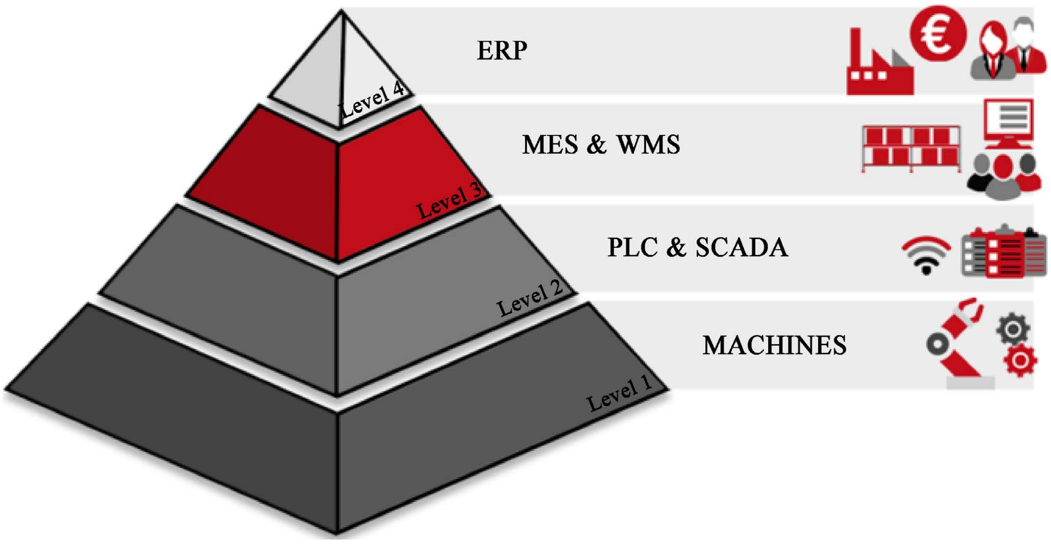

Figure 2. The complementary nature of MES and ERP.

7. Industrial Model and Communication Between Systems

7.1. ERP and MES

Data flows from ERP to MES, information like the production order schedule and shared master data is sent to MES [31]. MES then takes over and manages the factory operations, reporting key data back to ERP to keep the systems aligned. MES typically sends a subset of aggregated data back, it is not good practice to keep masses of detailed data in ERP, when MES is better suited to store, organise, and report on that information [32] [33]. ERP needs to know about anything related to costs, production volumes, order fulfilment, and inventory.

7.2. MES and PLC

MES reads data directly from the OPC/PLC layer, typically through an OPC server [34]. Other communication protocols can also be used to collect data. PLCs not only read data about the process, but they can also control the process. MES can send instructions via OPC to control the process, such as starting/stopping production orders, or setting machine set points, removing the need for the operators to define the set points manually.

8. Ready-Made Garments Manufacturing Process

Ready-made garments manufacturing includes 3 basic stages-fabric cutting, sewing and the adornment of the stitched garment. These stages are further subdivided.

Ready-made garments manufacturing consists of sequential processes like laying, stretching, marking, cutting, sewing, checking, pressing and packaging.

9. Real-Time Production Tracking System (MES)

A real-time production tracking system is an IT-enabled software tool named MES system which is designed to capture manufacturing data from the process as it occurs and seamlessly be able to provide customized production and inventory reports to its users. The real-time data received from the system enables shop floor managers to track the production of ongoing orders.

10. The Need for MES Software for Garment Manufacturers

To improve some areas inside the manufacturing process through automation with tangible benefits for the business. We list five key benefits of using a real-time production tracking system MES system by a ready-made garment factory. These will help to understand why MES essential tool is for managing a factory, detailed below.

1) **Getting order status in real-time:** This will improve the visibility and transparency of production data and employee performance.

2) **Tracking production floor data and monitoring production lines:** With the real-time production information, line supervisors can involve themselves in problem solving (instead of firefighting).

3) **Control WIP and Improve line balancing:** Line supervisors and floor in-charge can take quick actions in improving the line balancing and controlling WIP inside a production line. This will bring down the waiting time of the operators and convert the ideal time into the productive time. This action in turn will enable you to increase daily line output. A tangible gain.

4) **Track and measure individual operator performance:** In the textile business, knowing the performance of each operator and based on their skill, utilizing them for right work, helps factories in two ways: getting maximum production from the operators and keeping employees motivated as you can assign them to their preferred operations. The individual operator performance data can be used for operator bonus scheme and operator training.

5) **Performance KPIs are at your fingertips:** Design your performance KPI templates, formulate your data and let the system do the report preparation part. In real-time production tracking systems, production data is captured by operators as they work on the garment pieces. All reports are updated automatically as per desired interval. Furthermore, reports can be accessed from anywhere and anytime with internet connectivity. This improves the shop floor visibility and information transparency.

11. MES Software Components (MES365 by AppSoft)

MES Preparations

According to the plant structure operations from the shop floor to the top floor such as routing configurations of both tasks, operations, and work centers. Also, standard or ideal time whether internal or international, worker specification, machine [35] [36].

Typically, with an MES, customer orders from the Enterprise Resource Planning (ERP) system are brought to the schedulers along with current inventory. The planners use this information to optimize the production schedule. You can even schedule days ahead so that your plant has time to prepare materials.

Next, the daily schedule plan pulls in raw material quantities and alerts procurement when stock is running low. Your warehouse crews will receive pick lists and delivery times to ensure the plant has the necessary materials. On the plant floor, the operators will run production with a MES system. Any slowdowns or stoppages are fed back to the scheduler to adjust future production runs.

So, MES365 life cycle model divided into:

1) Production Planning to identify the specific orders to be executed at specific time in the meantime delegate the shift workers. So with the production planning the system identify the following information, which order will assign to which production line, the required fabrics for that order the assigned workers for the production line and the time schedule for the execution process (Figure 3).

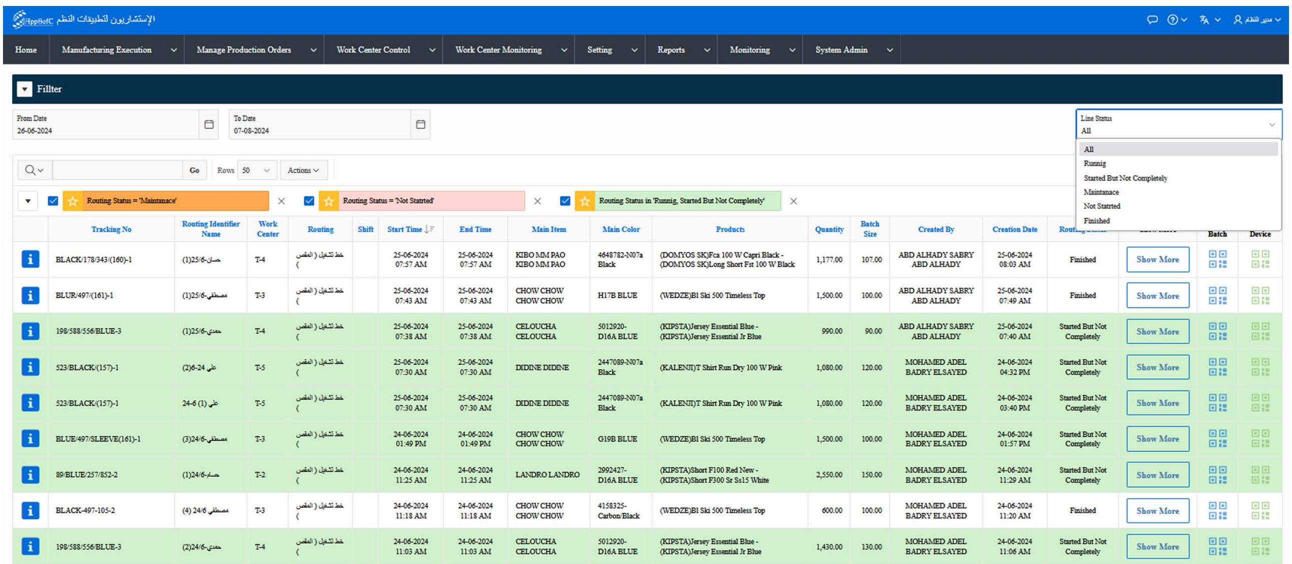

Figure 3. First step of MES365 life cycle.

2) Administration Tools: These tools augment administrator decision makers with AI algorithms to help the users with fast and right decisions. In mean time follow the online performance to identify the bottlenecks or low performance points to have the online right action with machine or worker replacement. Also the plant supervision will be segregate according to its jobs:

a) Shop Floor Supervisor (Figure 4):

i. Raw material feeding for the planned order.

ii. Follow up the plant progress online.

iii. Alert for any abnormal event during the online process.

b) Maintenance Administrator.

3) Worker Devices: Workers are divided as follows.

a) Technical Shift Workers: Figure 5 shows the application interface for the

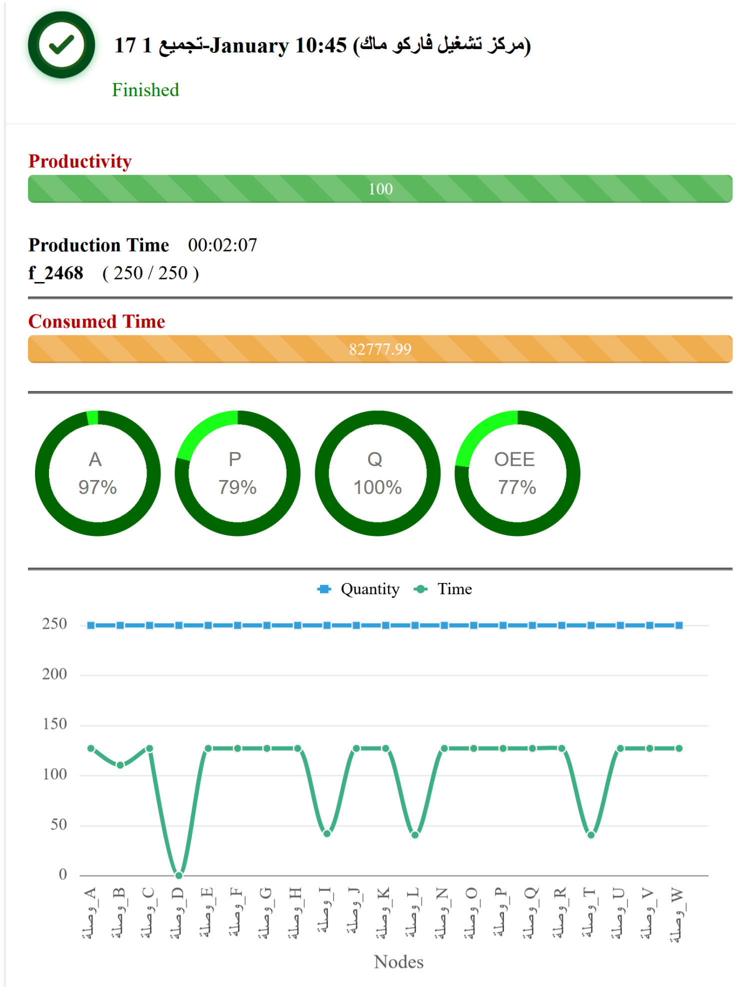

Figure 4. Shop floor supervisor role.

Figure 5. Worker's application interface.

workers to follow the different activities for the worst during the shift in the mean time capture the quantities working rate for different workers.

b) Helpers: They will have different application module with another interface to measure the KPIs for that category.

c) Maintenance Technicians: They will have different application modules with other interface to measure the KPIs for technical maintenance so they can enhance the machine availability.

4) Quality Control Module: They will have different application module with other interface to measure the KPIs for technical maintenance so they can enhance the quality factor for the in process semi-finished items as will for the line final products.

12. The Three Different Business Lines of Ready-Made Garments

1) Cutting: Fabric cutting is the first phase in the garment production process; it is the process of breaking a spread into garment sections that are the exact size and shape of the pattern pieces on a marker (by sectioning, bending, and cutting). With the using of MES365 you can merge different orders using the same fabric materials in one process on the same patron so we can reduce the material wastage.

2) Sewing: After the clothing maker has washed the fabric, they choose their pattern, measure out the needed fabric, cut it, and sew the pieces together. To finish off the garment, a clothing maker may use the dog-eared pocket method to strengthen the garment's pockets so they don't tear away from the fabric.

3) Packing: Garments are folded and placed into protective plastic bags to keep them clean during shipping to prevent them from being wrinkled and crushed. Factories use different packing methods for different garment types. Depends on the shipping destination we can have different packing techniques for different model with different sizes and colors as well in the mean time we will measure the performance for the packing line to enhance there KPIs.

13. ROI for a Manufacturing Execution System

Now using digital manufacturing software to integrate Industry 4.0 technology in their operations. This enables them to go paperless on their shop floor and to improve their manufacturing processes [37] [38].

Here are the benefits based on the experiences of manufacturers who have implemented an MES in the past few years.

1) Labor productivity improvements

Corresponds to reducing time spent capturing shop floor data, product traceability, and quality inspections. Key ROI Indicator: Increased throughput per operator standard hour/reduced labor cost.

2) Reaching improvement goals (KPIs) faster:

This is due to real-time accurate data. By capturing real-time, accurate production data, an MES can drive faster progress towards meeting and exceeding improvement goals, KPI's and generating a good ROI. MES will be tracking real-time cycle times. This data will then be immediately available for comparison against baseline process time and therefore, can show if a positive improvement has been made.

3) Labor and material cost savings by reducing scrap and wastage

Adding checks into the manufacturing process to ensure the correct process is adhered to at every stage. This has the following effects:

- Improves Product Quality.
- Enhances the reliability of supply chains.
- Reduces material and labor cost on scrapped parts.
- It can help to transform an organization: Reactive > Proactive > Predictive.
- Reduces cycle time.

Note that the Key ROI Indicator is: Reduced cycle time/standard time per product; Time and materials lost through rework.

4) Increased sales turnover: This is a consequence of better on-time delivery performance. When manufacturers rely on manual systems for managing customer demand and suppliers, they find it difficult to manage the supply and demand fluctuations and cyclic nature of business.

A Manufacturing Execution System can deliver ROI by automating the data collection and tracking of customer's order status throughout the factory and displaying its shipment status. This makes it easier to manage your customer relationships. By identifying and resolving problems that cause delays with customer orders as early as possible, it makes it easier to meet on-time deliveries and production targets each month.

14. Using the Application for Measuring Worker KPIs

For the cutting processes line divided into the four main operations. Unrolling, Cutting, Bundle Packing and Numbering.

Then A share device was fix on every table for cutting process.

Introducing the system to workers providing each on with ID card to use the device (Figure 6).

For Sewing every user will have a separate device which belongs to the Sewing machine defined in the database so any connection with that device identify the machine using.

For Packing stage, we will return back to the shared devise to perform the packing function following the rules predefined in the order level.

15. Business Case

In the ready-made garments company, we have the following measurements for a sample of 10 different styles based on 10 machines we get the following values for the parameters: Machine Availability; 94.0% Performance; 90.5% Quality; 94%.

- **Overall Equipment Efficiency** = Availability * Performance * Quality. Thus,

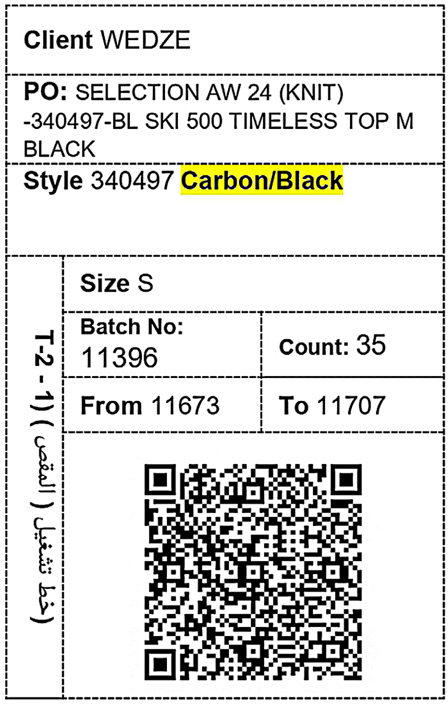

Figure 6. Worker ID card.

Overall Equipment Efficiency (**OEE**) is 79.9%.

- **Availability:** Increase the machines availability percent The Solutions AppSoft MES system assists with improvements to machine availability by reduce machine downtime for maintenance by using mobile application for the communication between the worker and technetium and maintenance manager for sending maintenance request and delegate it to techniphone till complete the repair process even with technetium performance calculation, so it will follow up and alerts.
- **Performance:** Awareness of actual time frame for every workers include the ideal intervals, Break, stop for maintenance, …, etc. can be increased through the use of the AppSoft Solutions MES system. Customizable reports provide key cycle time data which highlights opportunities for improvements.
- **Quality:** The most effective way to improve the Quality by get the measures during the running process then have a facility to do the right decision during the process life time. Through process parameter monitoring, the Solutions AppSoft MES system will provide alerts to processes that are trending out of control and stop the process once preset parameters exceed acceptable levels. Scatter plotting of defects also allows for improved root cause analysis.
- **MES Improvement Measurements:** After applying the MES Module, the new measurement of the main factors were enhanced so this table show the parameters before and after using the MES module (discussed in Table 1).
- **Annual Saving (The ROI in USD):** The following provides detailed calculations regarding the annual savings associated with the process improvements

listed above., for a small plant of 50 machines working in 1 shifts with machine rate 20 USD per hour.

$$\Delta\text{OEE} \times (\text{Hours/Year}) \times \text{no. of Shifts} \times \text{no. of Machines} \times \text{Machine Rate}$$
$$= (86.8\% - 79.9\%) \times 2080 \text{ hours} \times 1 \text{ shifts} \times 50 \text{ Machines} \times \$20/\text{hour}$$
$$= \$14352000$$

Table 1. MES improvement measurements.

Parameter	PCnt Before	PCnt After
Machine Availability	94%	96%
Performance	90.5%	95%
Quality	94%	96%
Overall Equipment Efficiency (OEE)	79.9%	86.6%

16. Conclusions

This application is a smart manufacturing execution system (MES) aimed at small and medium sized manufacturing enterprises (SMEs) to gain the most are those that rely on manual and paper based data collection of shop floor information, and do not have the spare funds to invest in the costs associated in fully setting up an ERP system. This paper contributes to several aspects related to the IoT enabled smart MES. Firstly, by proposing a mobile RT-MES, that can be used by workers as well as managers to mitigate and accurately respond to the dynamics of the shop floor. Secondly, the use of a decentralized cloud server allows the information provided by multiple ERP systems to on one database. Enabling the proposed application to be modular in nature and adaptable to any business, whether they partly use an ERP system or not.

The case study had shown the improvement of productivity with the MES and the reliability of data and information available. The possibility of having a digital database allowed the traceability of the products. With the support of WEB technology, the company can compare the projected manufacturing time with the real-time obtained, and this information can improve the decision making process on manufacturing and the equipment utilization. Usually, the MES consolidates the planning and maps all production stages, it allows improving the production processes, and the MES disseminates reliable and important information, integrating the factory as a whole and in real time.

For future work, we plan to address some of the system limitations, including automating the data entry through sensory measurements instead of relying on the current manual data entry process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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