THE ROLE OF MES IN SUPPORTING THE IMPLEMENTATION OF CIRCULAR ECONOMY PRACTICES

DOI
https://doi.org/10.18690/um.fl.1.2023.2

ISBN
978-961-286-800-0

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Industry 4.0 concept represents a digitalization process that allows manufacturers to produce in a more automated way, through an integrated infrastructure consisting of assets, machines, people, mobile devices and information systems. MES (Manufacturing Execution System) represents Digital Technology (DT) for the complete digitalization of the manufacturing plant. In fact, MES provides real-time information to manage and control the entire manufacturing process, from order to product delivery. In today's business philosophy, the only sustainable way of production is the transition from the classic approach of the "linear" business model, which implies "make-consume-dispose", to the sustainable model of the Circular Economy (CE), which is a way of eliminating all types of waste of already used raw materials. The application of DT enables the implementation of CE practices. The paper will discuss the position of MES digital technology on the implemented practices of CE, classified according to the model of Garza-Reyes et al. (2019).

Keywords:
MES,
Circular Economy (CE).
Digital Technologies (DT),
manufacturing,
industry 4.0

Univerzitetna založba
Univerze v Mariboru

1 Introduction

Although the term "Circular Economy" or abbreviated CE is considered a new concept of economic development, the forerunner of CE can be seen in the definitions of system sustainability as far back as the 1960s. First, the author Boulding (Boulding, 1965) states that the planet Earth is a unique system similar to space and in order to have constant reproduction and sustainability, it should have a sustainable cyclic ecological system. After this definition of system sustainability, two more concepts appeared that influence the creation of the CE concept, namely the concept of industrial ecology (IE) and the concept of extended product life (Gregson et al., 2015). From a practical point of view, IE was presented as a concept that took into account material and energy flows, with the aim of recycling residual waste, in order to create industrial "symbiosis" and sustainable development of the business system. As a result of applying the concept, IE offers minimization of the use of raw resources and promotes "clean" production technologies. On the other hand, the concept of extending product life refers to the prevention of waste generation, the creation of sustainable production and sustainable consumption techniques (Andersen, 2007; Gregson et al., 2015). The mentioned directions represent the development path of the new concept, called "Circular Economy - (CE)". The concept of CE is based on the circular flow of materials and energy and transforms the traditional linear “make-consume-discard” model into a circular “resource-product-renew resource” model (Li et al., 2010). In this way, CE aims to reduce the consumption of primary resources, waste and pollution and paves the way for resource recovery and increasing their efficiency in further use (Hu et al., 2011). Although the development and implementation of CE concept practices have great benefits for the natural environment, the CE concept is not an environmental strategy, but rather a sustainable economic strategy, whose main goal is to ensure the continuous development of the economy (Yuan, Bi, & Moriguichi, 2006). There is a common view that the only sustainable way of production is a transition from the current approach of the "linear" model of the economy, which implies "make-consume-discard" to a sustainable model of the circular economy (CE), which contributes to a more environmentally responsible and socially equal society (Gregson et al. , 2015). The concept of CE has the potential to create new ways to eliminate environmental waste in production, as well as to encourage the return of used materials to the material flow using renewable energy sources and new production methods in order to achieve the concept of sustainability (Ciani, Gambardella & Pociovalisteanu, 2016; Yuan, Bi, & Moriguichi, 2006). The concept of CE implies a shift from traditional "linear" production, i.e. consumption in one direction, towards the circular principle of consumption, by closing the circular flow of materials in order to reduce production and disposal of material waste (Moreno et al., 2019). It also replaces the concept of "end of life cycle" with the reduction, reuse, recycling and recovery of materials in the processes of production, distribution and consumption. The practices of the CE concept can be applied at different levels of the economic system, i.e. at the micro level (one firm), meso level (industrial systems) and macro level (society or country) (Kirchherr et al., 2017). The adoption of digital technologies (DT) of Industry 4.0 can enable the implementation of circular economy practices. However, current indications suggest that how to use the broad set of DTs to transition towards CE is unclear for industry practitioners. In particular, there is general agreement that DTs are critical to enabling the implementation of CE practices (Ertz et al., 2022; Patyal et al., 2022). Industry 4.0 focuses on the development of intelligent factories and products, which implies enormous opportunities for improving production performance, organizational strategy, business models and skills (Massaro et al., 2021). Also, it facilitates interaction and communication between different stakeholders in business (Upadhyay et al., 2021). In this area of digital technology (DT), such as the Internet of Things (IoT), "big" data analytics (BDA) and additive manufacturing (AM) are recognized as essential tools in Industry 4.0 for the transition towards a circular economy (Ardito et al. , 2019).

MES (Manufacturing Execution System) is software that manages and controls the entire production process, from issuing orders to the production of the finished product. MES software solutions simultaneously close the "gap" between the company's ERP system (Enterprise Resource Planning systems - ERP system) and special systems for data collection in production (Supervisory Control And Data Acquisition - SCADA). ERP systems usually contain modules for commodity and financial accounting, as well as other business support modules, but they do not contain modules for monitoring, planning and traceability of material flows. Today, production management implies the integration of ERP and MES systems, which is becoming one of the most important activities of production management. The availability of Web-based XML standards successfully overcomes the "gap" between MES and ERP systems. The ISA SP-95 standard represents the structure of production operations divided into four levels. Levels 1 and 2 include the process control zone. MES level 3 consists of management and control functions, which depend on different types of production. Level 4 corresponds to business planning and logistics operations. The goal of the ISA-95 standard is to reduce risks, costs and errors associated with the implementation of interfaces between ERP and MES systems.

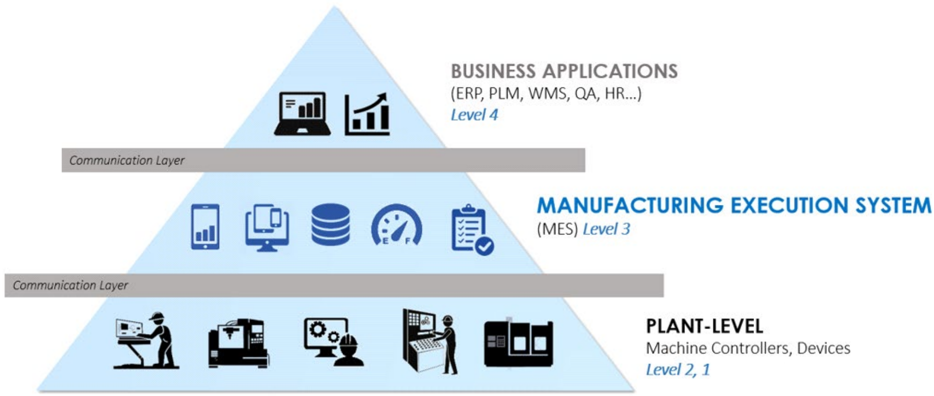

Figure 1: Structure of operations at the factory level
Source: (ANS/ISA-95.00.03, 2000)

2 Production intelligence - the result of using Digital Technologies (DT)

Based on the classification proposed by Rüßmann et al. (2015), as well as the description of digital technologies according to Cagno et al. (2021), digital technologies relevant to CE can be:

- Internet of things (IoT) - represent DTs that enable the collection and exchange of data between people, devices, things or objects using modern wireless telecommunications;
- Big data analytics (BDA) - DT which is characterized by a large volume and variety of data, that is, it requires analytical methods to convert data into information;
- Cloud technologies (Cloud technologies - CLOUD) - DT that enable practical network access to shared resources such as networks or servers;
- Cyber security and blockchain (Cybersecurity and blockchain - CYB) - DT, guidelines and policies that guarantee the protection of the cyber environment;

- Horizontal/vertical system integration (Horizontal/vertical system integration - HVSYS) - Enable an automated value chain within or between companies by connecting software, plants, manufacturers, customers and suppliers;
- Additive manufacturing (AM) - Production of objects directly from computer-aided model design;
- Autonomous robots (Autonomous robots - ROBs) - Robots capable of working completely autonomously, communicating with each other and cooperating with human beings;
- Simulation (Simulation - SIM) - Model of the physical world in real time in a virtual environment. It serves for testing and optimizing the system before implementation;
- Augmented reality (Augmented reality - AR) - Technologies that provide interactive computer simulation, "immersing" the user in a programmed environment, i.e. simulating the feeling of reality either through the sense of sight, hearing or touch.

Considering the presented classification, MES belongs to the DT listed under ordinal numbers 1,2,5, that is, it uses the mentioned DT in the process of production management and control and enables the following:

- Process management with minimization of raw material waste via IoT - machine management via IoT, stopping of machines, enables the automation of the process of monitoring raw materials and products on the "floor" of production, the "pull model" of withdrawing raw materials;

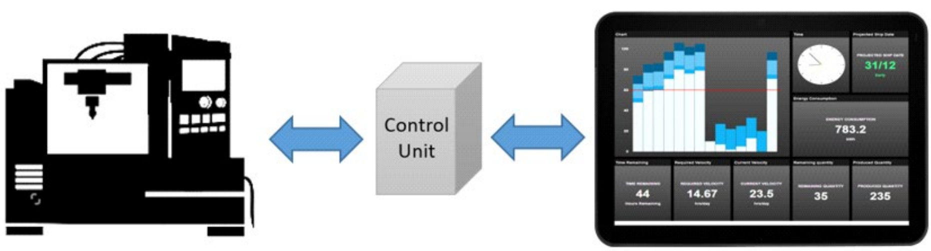

Figure 2: Intelligent factory
Source: (Key-IT, 2022)

- Reduction of losses in the manipulation of the finished product through BDA and HVSYS - monitoring deadlines, planning delivery of the oldest deadlines, optimization of packaging according to delivery requirements, optimization of packaging based on complaints and the like;
- Traceability and control of raw material stock management through BDA and HVSYS – production planning according to customer orders, stock management at micro-locations, complete traceability in case of product withdrawal from the market, enabling action according to special quality standards (HCCP, BRC, FSC and similar);
- Reduction of electricity and water consumption through IoT, BDA and HVSYS - control and optimization of processes in terms of electricity consumption, automatic starting and stopping of machines. Identification of resources and energy-intensive products, Energy consumption in relation to machine inactivity, Detailed analysis of costs and work orders/stages, Correlation between energy consumption and main production variables, Correlation between energy consumption per shift, Energy consumption and possible causes of failure, KPI for improvement of corrective measures.

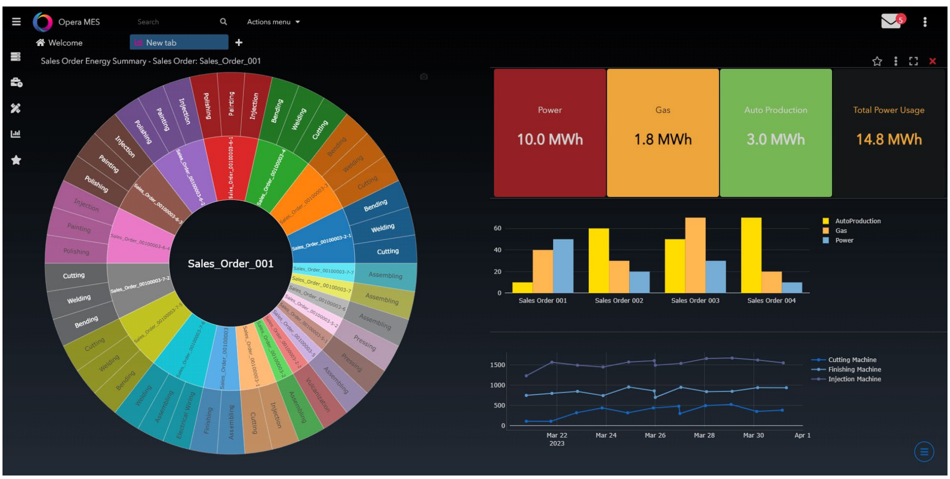

Figure 3: Energy management dashboard

Source: (Key-IT, 2022)

MES implies the following domains of production process management, according to (Key-IT, 2022):

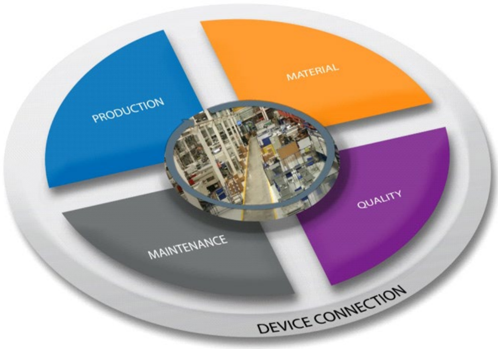

Figure 4: MES – Domain of production process management
Source: (Key-IT, 2022)

- PRODUCTION MANAGEMENT (Business Model Management, Product Management, Work Order Management, Advanced Planning and Scheduling, Electronic Sending of Tasks/Documents, Production Data Collection Paperless Factory Management , Real-time monitoring and supervision, OEE calculation and performance analysis, Web analysis of production conditions, Business application interface);
- MAINTENANCE MANAGEMENT (Asset maintenance management, Preventive maintenance, Failure management, Autonomous maintenance, Predictive maintenance, Spare parts/material consumption, Maintenance Performance Analysis);

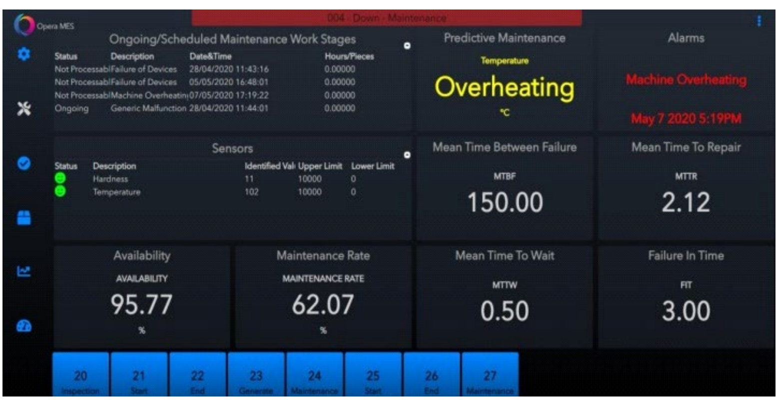

Figure 5: Maintanace management dashboard
Source: (Key-IT, 2022)

- MATERIAL MANAGEMENT (Automatic Material Identification, Warehouse/Location/Batch Management, Goods Receipt/Delivery, Material Selection Management, Material Utilization/Manipulation, Condition Monitoring and Stock Level Analysis, Electronic Kanban, Interface with Automated Warehouses);
- QUALITY MANAGEMENT (Control Order Management, Quality Control, Instrumental or Visual Test Management, Quality Test Tracking, Batch Number Traceability, Batch Number Tracking/Genealogy, Automatic Batch Number Identification, Process Data Management , Automatic process data collection);

Figure 5: Quality control dashboard

Source: (Key-IT, 2022)

- DEVICE CONNECTION (Device connection logic protocols and management, Automatic data collection from devices, Automatic data sending to devices, Real-time dashboard, Real-time production data monitoring, SPC/Control chart analysis).

3 The position of the mes system in the implementation of circular economy practices

Based on the classification of CE practice categories, as stated by Garza-Reyes et al. (2019), the position of the impact of MES digital technology on applied CE practices will be determined.

Table 1: Classification of practice categories (Garza-Reyes et al., 2019) and position of MES

Broj	Kriteriumi prakse	MES
1.	Internal practices - efficiency and use of resources:	
a.	Designing products for reduced consumption of resources, reuse, recycling, recovery of materials, longer durability;	
b.	Designing processes to minimize waste;	
c.	Reduction of consumption of energy, water and raw materials;	X
d.	Use of renewable materials/energy;	X
e.	Reducing the emission of polluting substances and waste;	X
f.	Green packaging and green distribution;	
2.	Inner awareness:	
a.	Circular management, culture and continuous monitoring;	X
b.	Special training for workers;	X
c.	Inclusion of environmental factors in the internal performance evaluation system;	
d.	Environmental audit program;	
3.	External awareness:	
a.	Development of customer awareness;	
b.	Environmental labeling (customer information);	X
c.	Development of supplier awareness;	
4.	Supporting the value chain:	
a.	Selection of suppliers according to ecological criteria;	
b.	Establishment of eco-industrial chains;	X
c.	Reuse of energy and/or water throughout the value chain;	
5.	External Sustainability Practices:	
a.	Taking over of products from customers - functional life and end of life;	X
b.	Reuse as a business model;	X
c.	Repair/repair as a business model;	X
d.	Re-production as a business model;	X
e.	Recycled material for production;	X
f.	Recycling of waste, end-of-life products;	
g.	Leasing as a business model;	
h.	Updating as a business model;	X
i.	Cascading use of components and materials;	X
6.	Green market development:	
a.	Green or environmentally conscious market;	
b.	Client incentives;	
7.	Technological research and development:	
a.	Cross-functional cooperation for the improvement of the environment;	
8.	Development of legislation:	
a.	Legislation and policies.	X

4 Conclusion

In recent years, both society and business have become aware that in order to achieve rational economic development, it is necessary to use concepts that simultaneously increase productivity and reduce resource consumption. Seen in this way, there are two closely related trends that are represented in the production paradigm: innovations based on digital technologies (DT) and the transition to a circular economy (CE).

While digital innovation aims to increase productivity, developing a new product or service, the circular economy (CE) enables the reduction of production costs, ensuring the sustainability of production and development of new products in accordance with environmental requirements. DTs support the implementation of CE practices in industry, however, in practice, it seems that most companies adopt DTs for reasons related only to production savings, efficiency gains, cost reductions, and achieving better quality. Only in the second phase do they recognize the opportunities offered by DT to encourage the transition towards CE.

The development of key digital technologies, such as MES digital technologies, help the systemic transition from the "linear economy" to the "circular economy". The main advantages of MES, noted in numerous projects, are: reduction of cycle time (for 45%), reduction of data entry time (for 75%), reduction of rework (for 25%), reduction of paper between shifts (for 50%), reduction control times (for 27%), increase in product quality (for 18%), increase in productivity (for 20%), optimization of primary/secondary resources and process improvement (Lean Manufacturing).

Future research on the impact of MES technologies on CE practices involves directly surveying companies on applied DT, as well as conducting empirical analysis of collected data, in order to investigate common correlations and impacts between MES and CE practices.

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