Lean Smart Maintenance for Machine Tools

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Abstract. The Lean Smart Maintenance concept has been developed to provide an optimal and targeted maintenance strategy. By implementing this concept, manufacturing companies can achieve an efficient maintenance program for their CNC machines, which is a crucial component in ensuring the continued operation and the overall success of the manufacturing process. Moreover, maintenance resources are minimized as maintenance measures are performed more effectively. Both planned and unplanned shutdowns are considered. In this paper, the focus is on a comprehensive consideration of maintenance in a SAP-based, medium-sized company with an inhomogeneous machine park and the digital networking of all departments. The data-based model follows a centralized approach from the maintenance technician's mobile device, over the warehouse management of the maintenance to sales information with the use of advanced planning and scheduling software.

Keywords: Lean Smart Maintenance · Machine tool · Digitalization · SAP EAM · Asset management

1 Introduction

In this paper, a concept for the maintenance of machine tools according to the principles of lean smart maintenance (LSM) is presented. The aim is to increase the long-term availability of the machines by performing the maintenance measures in a condition-oriented and predictive manner using modern, data-based methods [1]. The overall system presented here is not limited to data-based methods, but also includes failure-oriented and preventive maintenance as required. With the correct application of all three maintenance strategies and the support of a software-based control system, a plant evaluation and classification should be possible.

The LSM idea describes a complete management system, which covers the goal of a high reliability and availability of plant components, but also the loss minimizing maintenance execution [1]. In the long term, the aim is to add value to the entire company. In addition, maintenance resources should be used efficiently to reduce costs, minimize downtime and improve plannability. The implementation of these goals is illustrated using an example company.

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Increasing demands for flexibility, reliability and speed in manufacturing are accompanied by an increased need for automation and complexity. This poses great challenges for maintenance. Nowadays, maintenance rarely focuses on the entire plant, but preferably on individual components [2, 3]. This makes sense not only from the point of view of minimizing downtime, but also from the point of view of steadily increasing specialization of maintenance staff. It is generally accepted that maintenance is becoming increasingly important. A comprehensive consideration of business and technical aspects is of decisive importance for effective maintenance management. An important tool in this context is maintenance planning. This requires an optimal mix of reactive, preventive and status-oriented maintenance strategies. These strategies must be individually evaluated and dynamically adapted to success [4, 5].

Furthermore, it is essential for successful companies to plan production according to plant availability. This requires production planning strategies with low uncertainty. Internal and external planning uncertainties are known to every supply chain and provide new challenges and the balancing of safety and risk on a daily basis. These challenges must be reduced through internal uncertainties in maintenance. One of these is essentially the availability planning of machine tools. In an ideal production planning of machine resources, the trade-off of planning reliability does not depend on the individual supply chain staff, but on data-based models that have a bidirectional interface - the digital twin of the maintenance process [6]. Since digital twins are extremely complex to model and their development does not always pay off in a reasonable time, alternatives are often used in reality. For example, automatic adaptation of the model is usually dispensed with and only easily evaluable parameters are used. In mass production, this can be the number of pieces; in single-item and small batch production, it is necessary to fall back on runtime-dependent data. In addition, there are also errors in the modeling that must be minimized. These include the input variables of the model, residual variations (same set variables - different results), measurement errors, interpolation errors in the model, parametric variations, etc. [7].

2 Experimental Approach

The aim of this paper is to develop a maintenance model that not only describes the maintenance processes, but also enables an overall view of maintenance and servicing. The holistic processes of maintenance and production planning are taken into account, resulting in a practical maintenance model.

In the initial situation of the company under consideration, SAP enterprise asset management (EAM) is already used in maintenance. This system already offers several advantages, which will be explained in this section. Further on, a time recording of several maintenance staff has to be carried out in order to objectively identify the pain-points. Since the optimization potentials are to be recorded and processed in a structured manner, a survey of the maintenance employees has to be carried out in order to gain a subjective impression of the initial situation.

With the software SAP EAM already in use, an excellent basis has already been created. The use of this extremely flexible and comprehensive software module from SAP enables central integration into the existing SAP ERP system (Fig. 1). This effectively prevents redundant data, as there are no interfaces at which redundancies are created. In addition, no information is lost, as data is stored exclusively in one database, making interfaces obsolete.

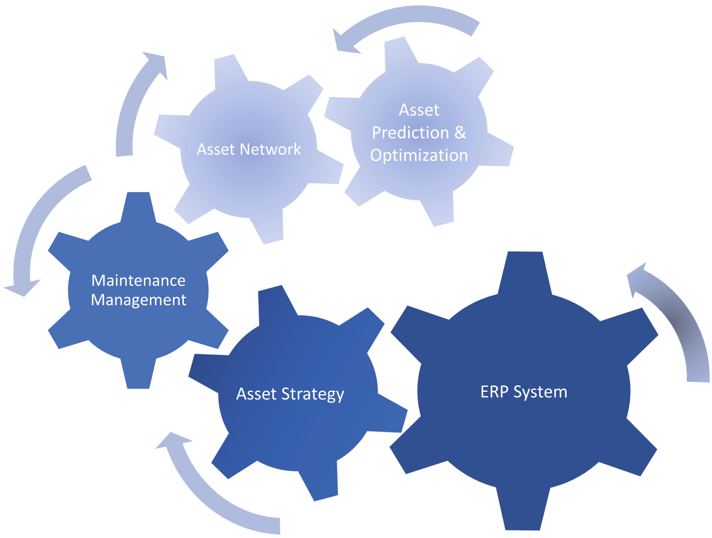

Fig. 1. Centrally organized data structure of the ERP system with the subordinate subareas of the SAP EAM software suit.

The structured recording and processing of fault messages is also possible. Among other aspects, this has the advantage of being able to explicitly assign the required resources to each operation. The creation can be carried out by any user, which avoids latencies in the failure demand creation. The necessary transparency of the order status can also be controlled by every user, since the information is stored centrally in the ERP system. In this paper, three different maintenance strategies are considered:

- Failure-oriented maintenance strategy [8]
- Preventive maintenance strategy [9, 10]
- Condition-oriented maintenance strategy [11].

The maintenance strategy currently consists only of strategies one and two. Failure-oriented maintenance reacts exclusively to component failures, i.e. repairs. It reacts only after the wear reserve of a component has been used up.

In order to avoid unplanned and high downtimes of equipment, preventive maintenance focuses on high equipment availability. Maintenance work on a machine tool is carried out at a predefined interval. In order to nevertheless cover a large part of the wear and tear, it is necessary to determine as precisely as possible the time of failure of the respective unit under consideration. Therefore, the knowledge about the failure behavior, the load as well as the utilization time and reliability of the unit is very important for an optimal maintenance time [9].

2.1 Creation of an Evaluation Matrix for Maintenance

The evaluation matrix (Fig. 2) serves as the basis of the SLM process and is intended to define the risk cost potential and the maintenance strategy. It provides an important basis for determining the maintenance strategy for specific machines and assemblies.

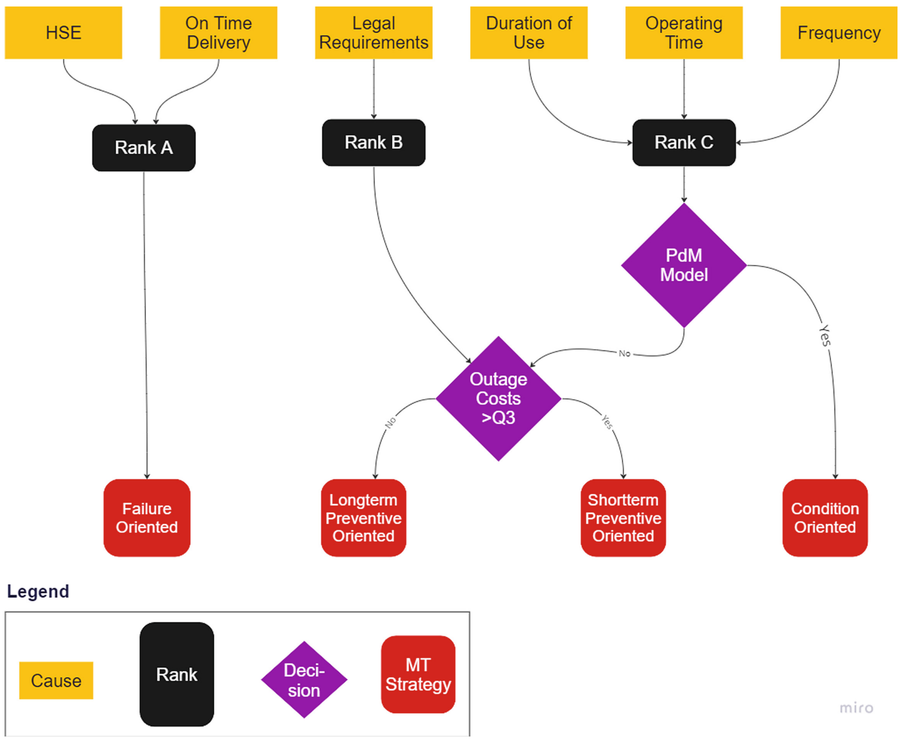

Fig. 2. Evaluation matrix of an LSM process to determine prioritization rank and maintenance strategy.

The maintenance objects are examined for their failure consequences and their impact on the company - but also for the maintenance costs incurred. From the causes of downtime, the plant priority can be determined (rank A to C).

The health, safety & environment (HSE) status is listed here as a representative of all concerns that are not foreseeable but affect at least one of these HSE areas. A possible example for a machine tool is a leakage of the cooling lubricant. A hose could be defective, causing cooling lubricant to leak and enter the groundwater. In this case, immediate maintenance intervention is required, so no further maintenance strategies are considered. The same applies to any error that leads to machine downtime. These usually cause an on-time delivery (OTD) problem, requiring immediate response. Another problem with unplanned machine downtime is, among other things, redundant operators who should be occupied with other activities.

While these two concerns are immediately given a high priority, the root cause must be investigated after the failure has been corrected. Ideally, the cause of downtime can be covered by condition-based maintenance in the future, allowing rank C to be defined. This ensures optimal plannability for the maintenance staff, but also for the production.

Service life is a very simple type of preventive maintenance. However, reasons for preventive maintenance measures may not only be necessary from the point of view of the risk of failure, they may also be necessitated by legal requirements. For example, in the case of machine tools, the cyclical inspection of jaw chucks and pressure accumulators ensure fixed maintenance intervals that may not be extended. However, if the risk of failure and thus the costs are considered high, the maintenance interval must be shortened. The cost analysis includes all cumulative costs related to the failure - machine hourly rate, employee costs for production and maintenance, spare parts, lubricants, etc. The cost threshold is defined here as the fourth quartile (>Q3) of all machine repairs of similar machines. This ensures that high-precision grinding machines are not compared to milling machines for rough machining. If the repair costs are in the last quartile, a short-term preventive strategy is recommended.

Another reason for preventive action is to maintain a fixed grooving time. In the case of machine tools, for example, this category includes checking for compressed air leaks, as these are cost-intensive and can be responsible for possible malfunctions and cycle time extensions. Since these can be planned, they are assigned priority rank C. In addition, however, it is possible that there is a predictive maintenance (PdM) model for this reason.

The last category includes the criteria operating time and frequency. The operating time is not to be mixed up with the service life, because the operating time only refers to the time in which the component is used. In the case of hydraulics, for example, a distinction can be made between the state machine switched on and machining process. As a rule, the hydraulics are used, among other things, for clamping the workpieces. It is irrelevant whether chips are currently being produced, as the workpiece must also remain clamped for the setup process. Consequently, the hydraulic system operates for a longer period of time than chips are produced.

The frequency (number of pieces, number of strokes,…) is also a main reason for the consumption of the wear reserve. To stay with the example of the clamping device, it plays a significant role how often the clamping cylinder is moved until the seals are worn out and have to be replaced. In the PdM model, however, it is not only the tribological wear of the seals that must be considered, but also their aging.

These causes fall into prioritization rank C, since they are predictable - analogous to rank B. However, a shift does not ensure legal consequences this is the reason for this lower ranking. However, they also ensure perfect planning of production and maintenance. PdMs for machine tools planned for implementation are as follows:

1. Central cooling lubricant supply with condition sensors, particles and filling level
2. Central hydraulics with condition sensors & filling level
3. Pressure monitoring of pressure accumulators in hydraulics
4. Monitoring of compressed air leakages at the machines
5. Differential pressure of exhaust filters of the cooling lubricant mist.

The focus of the solutions discussed here is primarily on economic considerations in the sense of the lean concept. Recently, many companies and publications have been dealing with various possibilities of PdM models (often using machine learning). However, upon closer examination, not all of them are economically feasible, especially if they are developed in-house. An example of common publications is the use of tool life models in machining, such as in [12], or vibration measurement of spindle bearings and ball screws. These solutions are worthwhile in mass production where one type of machine is used redundantly, but not in medium sized companies - as it is considered here.

Medium-sized companies are usually characterized by a high product diversity and small to medium-sized quantities, which is why they often have an inhomogeneous machine park. Consequently, the model has to be applied anew for each machine, since the mechanical surfaces are different.

2.2 Selection of a Suitable Maintenance Software Landscape

With the determination of the SLM evaluation matrix and the PdMs, it is possible to specify the requirements for the software landscape in detail. The focus here is on seamless integration of the acquired data on the store floor, their evaluation and the derivation of maintenance measures.

In the infrastructure layer, a Beckhoff industrial PC is used as an edge device (ED) and connected to all machine controllers. The advantage of such an integration is that it is possible with all controllers and thus a factory standard is defined.

The ED runs parallel to the PLC and only picks up the programmed signals. There is no signal processing with the PLC or the actual machine control, which means that performance and safety of the running machine are not affected. Additional sensors, which are not necessary for the machine operation, are integrated directly at the ED in order to forward the data. This reduces integration costs and avoids warranty issues with machine manufacturers.

Data-based processes for maintenance require a rethinking of previous system landscapes. On the one hand, this involves the introduction of software that can handle large volumes of data. SAP databases are certainly suitable, but it is only since the introduction of the S4/Hana version that SAP has offered detailed evaluation options for this data. In this case, the project of integrating ED's started already before the S4 update. In addition, the SAP cost structure is not optimal for data volumes such as those generated by high-frequency process analysis. With Microsoft's Azure solutions, customized packages are available that offer a better cost structure. These new analysis methods, require the breaking of the typical layer structures of a company, see Fig. 3.

As shown in the figure, a new two-part data layer has been added and the reporting layer has also been extended and divided into two parts. The data layer contains the necessary Azure packages, but they form a closed overall system. This means that the data scientist still has very few points of contact with the SAP process world and can focus fully on data analysis and PdM model creation. Nevertheless, for a closed loop it is necessary to create an interface to the ERP, which is made possible with SAP business warehouse (BW). For example, to generate SAP EAM orders automatically.

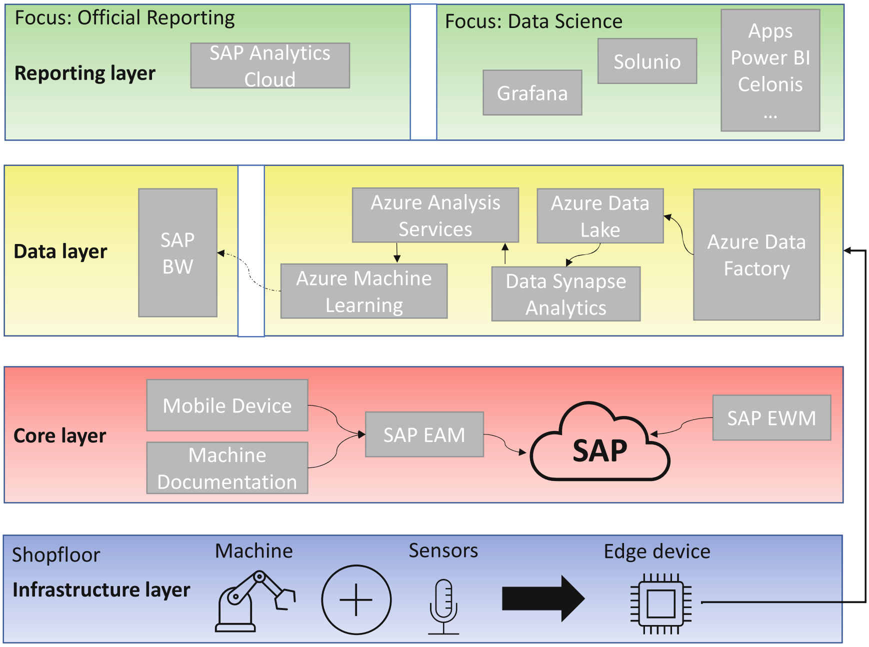

Fig. 3. Software landscape with the different layers and new data layer for the LSM.

A new part has also been added to the reporting layer, as a distinction must be made here between the users of the processes and the official reporting. The official reporting is e.g. characterized by the reporting to the management and other official instances. The new part on the right side of the reporting layer is designed for data science and the dynamic and volatile daily business. Here, the user can create dashboards and trigger predefined actions or receive notifications on the smartphone.

When using maintenance software, it is essential to eliminate all documentation in Excel or other non-system data formats. For example, machine documentation must also be available in digital form in order to access the data on the machine to be repaired. Filing maintenance plans and repair cards is still a common medium, but is contrary to end-to-end digitalization. The integration of mobile devices is indispensable to ensure that these processes can be carried out by the maintenance staff throughout and directly at the plant (core layer). Thus, [13] shows a significant increase in productivity in different areas of maintenance through mobile devices. Subsequent maintenance and repair documentation or the requesting of spare parts can also be carried out directly.

In typical maintenance, a continuous warehouse management is often omitted. The reasons for this are manifold, but previous time recordings clearly show the necessity of warehouse management. Since the SAP infrastructure already exists in the company, the SAP Extended Warehouse Management (EWM) extension is a logical step (core layer, Fig. 3).

2.3 Target Processes for the Maintenance Software

The LSM target processes are based in their entirety on the results shown in Fig. 2. The various maintenance strategies ultimately always generate a request in SAP EAM, whereby the priority field is filled with the corresponding rank. This field is used in detailed maintenance planning as an evaluation criterion for the processing sequence.

Inventory management is often dispensed with in maintenance. A decisive reason for this are the employees who are not bound to a particular location. Central warehouse management in the maintenance or logistics buildings is only useful to a limited extent, since very long distances are involved, especially for repairs. The reason for this is that the tools and spare parts required are not known in advance. Centralizing the warehouse in logistics would prevent redundancies, but slow down the process for the maintenance engineer. An efficient solution while accepting redundancies is described in the following text. The manufacturing company already has several warehouse lifts on the shop floor, but they do not have SAP EWM connectivity. Therefore, the connection of the warehouse lifts to the warehouse management system is carried out completely, also for the components of the production. If components are removed from the lifts, they must be booked out in SAP in advance, and only then is the tray made available. This process efficiently prevents stock shortages. Furthermore, access to these trays is only possible for maintenance staff.

Figure 4 shows the overall process flow, which is explained below. Unforeseen and thus manually created EAM demands (e.g. machine downtimes) are an exception and must therefore be evaluated according to on-time delivery (OTD). For this purpose, the failure must first be viewed in order to estimate the downtime. This requires communication between the two detailed planning tools from production and from maintenance. The ranking is limited to A and B (Fig. 2) only, because there are two unknowns at this stage: the maintenance duration and the delivery time of the spare parts, since these are not known in advance.

A rigid ranking on rank A to evaluate the maintenance duration is not used, because this can shift already existing orders intraday. Furthermore, it should be mentioned that the separation of the detailed planning tools is necessary, since in production a daily update at 0:00 is sufficient. In the detailed planning of maintenance, this short update time is used to be able to react intraday to machine failures. Thus, in the detailed planning of the maintenance there is an update in real time. As a result, maintenance tasks that have already been started may no longer be given the highest priority due to the planning run at 0:00 h.

For example, a repair of an A-ranking machine started today can be suspended the next day because the machine is downgraded in the ranking by the planning run of the production at 0:00 o'clock due to the standstill of a more OTD-critical machine. This circumstance provides for a longer repair duration, by setup times with the maintenance engineer, but ensures a very good OTD and brings thus a high customer satisfaction. However, this approach can of course be adapted to the company's requirements.

At the end of an unplanned shutdown or manually created demand, the sales department may be informed about the postponed delivery date for the customer.

Planned shutdowns, on the other hand, are predictable. This means that the higher delivery times for new production orders are already taken into account in the quotation

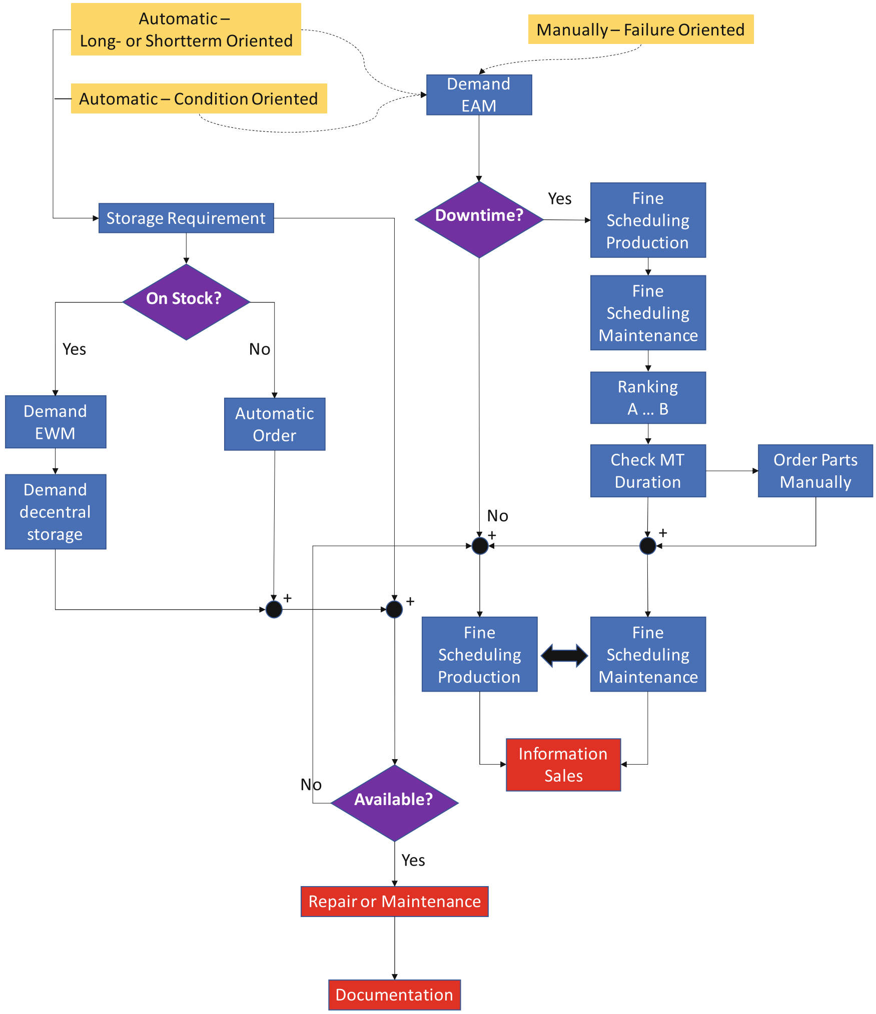

Fig. 4. Process diagram for different requirements and disturbances

process. Since maintenance is a repetitive activity, there are predefined maintenance packages. The planned downtimes therefore automatically ensure a request in SAP EWM at the nearest warehouse lift of the machine as soon as the requirement is created. If the spare part is not available, it is ordered automatically through the ERP and taken into account in both detailed planning tools. Here, too, an automatic delivery date shift takes place in Sales. The rest of the process is analogous to the one described above, but without the prior assessment of the damage.

3 Conclusion and Outlook

In summary, this paper presents how machine tools are to be handled in a modern, data-based maintenance. The focus is on the process landscape and the development of intelligent maintenance models. The environment in the described company consists of an inhomogeneous machine park and low production quantities, which is common in medium-sized companies.

Furthermore, it must be mentioned that the abstract listing of the prioritization presented here does not replace an FMEA or FMECA analysis for each machine. However, the above-mentioned supercategories provide an indication of the possible defect groups of each machine tool. For an overall maintenance concept, each machine and its components must be examined in detail for the probability of failure and its consequences for other components and production. A supplement to the process methodology illustrated here is offered, among other things, by reliability centered maintenance (RCM), since these topics are examined in detail on the basis of seven questions.

A possible further development option is the implementation of prescriptive maintenance. In this case, the intelligent models of PdM are not only used to predict errors and failures, but also to actively suggest preventive measures. The avoidance measures can then be implemented manually or automatically in the manufacturing process. The conditions for automatic implementation are already possible independently of the control system thanks to the installed edge device.

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