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Automated Performance Measurement in Internal Logistics Systems

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7.1 Introduction

With ongoing digitalization, requirements regarding performance, efficiency, and adaptability of logistics systems are steadily increasing. In terms of this digital transformation, demand for an increase of performance among transparency, cost efficiency, and innovation capability of companies is growing. Studies show that industrial companies of all sectors have already recognized the relevance of automation and digitalization for planning and strategy development (Dallasega et al. 2019b, 2020; Staufen AG, Staufen Digital Neonex GmbH 2018).

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In that context, Industry 4.0 concepts, more specific automation and robotics together with cloud computing and blockchain technology have been ranked as megatrends to meet the high requests for efficiency and adaptability (SCI Verkehr 2019). Especially, in internal logistics systems approaches for implementing automation are regarded as relevant tools for increasing efficiency (Bundesvereinigung Logistik 2018).

Examples of practice show the combination of machine, storage and picking systems, which are connected by conveyor and transport systems and linked via information and communication systems. Automated high-bay warehouses and automated small-parts warehouses are often used for this purpose. These are commonly supplied by automated loading and unloading systems or industrial robots and are connected to picking stations and manual workstations via a combination of various types of carousels, conveyor belts and conveyor-based sorting systems, Automated Guided Vehicles (AGVs), automatic forklift trucks, etc. Such networked systems operate via high-performance control technology and are assisted by information and communication systems, Transport Management Systems (TMS), Warehouse Management Systems (WMS), Enterprise Resource Planning Systems (ERP), Product Lifecycle Management (PLM) solutions, Inventory Management Software, etc. (Inboundlogistics 2018).

7.2 Problem Formulation

Thus, these networked systems can be regarded as integrated internal logistics systems of high complexity. These complexity and variety emerge from the fact that the system cannot be comprehensively described by a single performance indicator (e.g., throughput). Moreover, an exhaustive characterization of the system properties concerning performance and availability is only possible employing complementary parameters (Follert and Nagel 2006).

Despite a large number of possible benefits from implementing automation concepts in internal logistics processes, Granlund and Wiktorsson (2014) highlight among other factors the need for an automation strategy and the lack of performance measurement of internal logistics as challenges to automation in this sector. Availability and performance are important parameters for monitoring and controlling of these automated systems. To track them over the life cycle of the plant and to be able to make transparent statements about the condition of the plant, it is necessary to collect selected key performance indicators (KPIs) for systematic monitoring (Gottmann 2016).

Currently, the determination and calculation of performance and availability parameters within the site acceptance tests of automated logistics systems is plant-specific and involves a great amount of manual effort. In this chapter, the authors develop a concept for the automated determination of performance indicators for storage and conveying systems. The remainder is organized as follows. In Sect. 7.3, the contribution of constant monitoring and controlling as an enabler for high-level responsiveness and systematic planning is discussed. Section 7.4 will review state-of-the-art approaches, give an overview of applied standards, and outline their limitations in practical application. In Sect. 7.5, the results of the conducted expert interviews are reported and analyzed. Taking these findings into consideration, the authors develop a concept for an exhaustive evaluation regarding the performance and availability of automated systems.

7.3 Monitoring and Controlling—Enablers for High-Level Responsiveness and Systematic Planning

The term 'Controlling' was strongly influenced by business practice and is therefore used in various fields of activity. It describes the interaction of planning, control, and information supply (Weber and Wallenburg 2010). There are different levels of the view of controlling from a pure information system to the integration of a personnel management and organization system (Arnold et al. 2008). For this reason, a large number of definitions can be found in the literature. Koch (2012) defines controlling as the task of providing information to support the decision-making process. Arnold et al. (2008) assigns controlling not only the task of processing and preparing information but also the development and support of operative and strategic planning. According to Klaus et al. (2012), controlling has the task of ensuring the rationality of management. Controlling has to ensure that management decisions are made in a ratio of intuition and reflection that is appropriate to the respective problem. A study conducted by the International Controller Association (ICV) evaluated the understanding of controlling functions based on a large-scale field study (Weber and Wallenburg 2010). The study shows that controlling is not only assigned a transparency function but also the task of ensuring the rationality of managerial activities. Rational decisions can only be made based on a comprehensive knowledge of the action alternatives and their effects on the set objectives.

Based on this definition of controlling and the described lack in performance measurement, greater relevance can be accorded to the monitoring and controlling of internal logistics systems. Within the concept of controlling, monitoring is intended to take over tasks to provide support via regular reports. This includes the rapid availability of key figures and graphical preparation and visualization. Standardized monitoring is realized with the help of precisely defined key figures to record processes and document their development (Wagner and Patzak 2015). However, the comprehensive performance measurement enables the early detection of deviations from set objectives. Thus, non-value-adding activities and rationalization potentials can be identified (Werner 2014).

In the control of internal logistics systems, the economic aim is the optimal and efficient operation of the system. In this context, automation offers possibilities to optimize material availability and material flow coordination as well as to gain error reduction and to improve machine utilization. Automated material flow systems are based on information and control technology which are linked via suitable communication technology (Jünemann and Beyer 1998). According to that, the described systems also have the task to continuously record the movements of storage objects to enable value- and quantity-based reporting. The control technology of these material flow systems is designed to enable the mapping of control functions at different system levels, to provide a high level of data security and availability (Schulte 2013). At all these system levels, the data required for monitoring and controlling are collected to help to quickly detect and eliminate faults and malfunctions in the system and keep downtimes low (Jünemann and Beyer 1998; ten Hompel et al. 2008).

7.4 State-of-the-Art and Literature Review

In the context of monitoring the condition of internal logistics systems, respectively, plants in general, literature frequently refers to the term 'reliability of technical systems' (Eberlin and Hock 2014; vom Bovert and Jünemann 2001; Gudehus 1976). Thereby, the term reliability covers the technical availability of a system and describes it as the expected value for a plant component to be in a functional state at a certain time under given circumstances (VDI 4001).

The performance of internal logistics systems in line with defined requirements represents a crucial success factor for plant operators as well as for plant suppliers. Typically, within the site acceptance tests, the two main performance measurement indicators, throughput and technical availability are calculated (Maier et al. 2011). Since the 1970s the term technical availability has been continuously developed and several standards have been created to regulate the definition and calculation (Fig. 7.1).

The chronological classification of the development of the valid set of standards ranges from basic thoughts on availability, as Timm Gudehus introduces them, to current considerations on the term performance availability. In practice, the elicitation of the two factors performance and availability is regulated by the following set of defined standards (Table 7.1).

FEM 9.851 describes a procedure for calculating the cycle time and the related handling performance of storage and retrieval machines (SRM) with automatic control and pick-up of a loading unit. Despite simplifications, such as the definition of typical movements and average cycle times, a good approximation to the exact average value can be achieved.

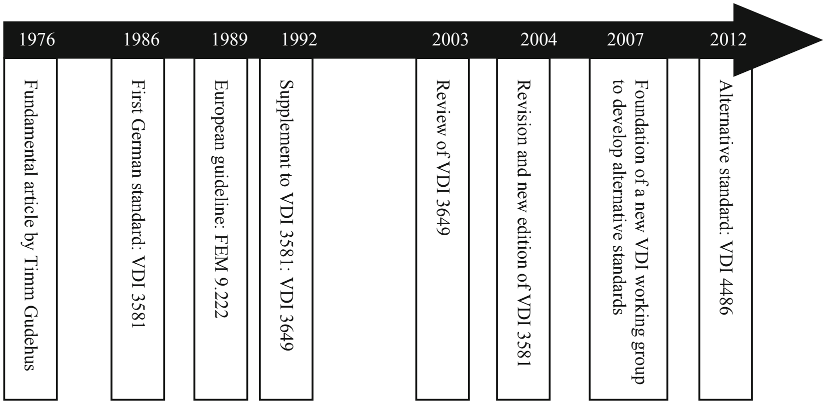

Fig. 7.1 Chronological classification of the development of the standards

Table 7.1 Selected standards for performance and availability measurement

Standards number	Thematic content
FEM 9.221	Proposes a method for the determination of reliability and **availability** of storage and retrieval machines and defines a procedure for carrying out related tests in practice
FEM 9.222	Proposes further methods for determining the **availability**, and regulates the steps for putting into operation, handing over and acceptance of storage and conveying systems
FEM 9.851	Specifies a method for determining the cycle times and thus the handling **performance** of storage and retrieval machines
VDI 3580	Provides instructions on tracking failures for the **availability** calculation
VDI 3581	Contains theoretical basics and generally applicable formulae for the **availability** calculation considering the material flow structure
VDI 3649	Represents a supplement to VDI 3581 and shows the influence of the availability of individual elements on the entire system and possibilities for increasing **availability**
VDI 4486	Introduces the term of **performance availability** and describes a method for availability measurement under consideration of the operator´s business process

In guideline VDI 3581 the preparation and realization of availability tests are regulated. Equivalent circuit diagrams are established and calculation schemes in line with the structure of the system, more precisely with or without redundancies, are described. Using Boolean theory, complex structures are divided into simple serial or parallel substructures and thus calculated in several iteration steps. Though, taken into account that the presence of buffers and the coincidence of downtimes of different elements cannot be considered, the Boolean method reaches its limits (Maier et al. 2011). After the development of the first form of VDI 3581 and the FEM 9.222 based on it, VDI 3649 was created as a supplement to evaluate the influence of individual system elements on the overall system availability and discuss how it can be increased by a revised element arrangement.

Regarding systems performance, the existing guidelines and consequently the proposed acceptance tests assume an idealized order structure. However, a deviating structure and internal company strategies for maintenance and monitoring of the system have a significant influence on the performance (Hegmanns et al. 2014). For this reason, an extended performance and availability analysis is required. VDI 4486 introduces the term performance availability and attempts to focus on the business process of the plant operator. Associated with the idea of being able to supply all customers of the logistics service on time and in line with their needs, performance availability indicates the degree of fulfillment of processes under agreed requirements and deadlines. For this purpose, redundancies, performance reserves and buffer capacities are taken into account in the calculation.

The dependencies between the individual components and the subsystems of the plant are critical for determining this parameter, as is the uncertainty about the extent to which various influencing variables affect the overall system. For this reason, and due to the lack of maturity of various approaches, an analytical calculation of performance availability proves to be very complex and not appropriate (Schieweck et al. 2016).

Following the methods presented in the guidelines, the parameters and details of the acceptance tests are determined for each project individually for each customer. This involves a high level of manual effort in the preparation, execution, and processing of the test results. Despite the necessity for manual documentation of the plant malfunctions, examples of practice show that the preparation and execution of the availability tests are personnel- and thus cost-intensive. Further restrictions in the performance measurement lie in standardized measurement scenarios. These are used to generate sufficiently good statements about the system in a reasonable time, yet, they allow only limited conclusions about the performance at full load. The manual execution and the associated effort in determining performance and availability result in only limited performance checks.

Automation regarding the information flow of the internal logistics system can increase the overall efficiency (Granlund and Wiktorsson 2014), hence it is vital to provide readily available information concerning the performance of the plant. Named restrictions can be overcome with the implementation of automated performance measurement. Whereas many research projects deal with concepts for performance measurement in manufacturing processes, a literature review on performance measurement and monitoring in internal logistics systems reveals that there have been relatively few attempts to systematically address the lack of automation and continuity in the measurement of performance and availability of these systems (Table 7.2).

The literature review outlines the shortfall of related work on automated performance measurement in internal logistics systems. Table 7.2 provides some examples of publications on this topic. Mörth et al. (2020) proposes an approach for performance monitoring based on Cyber-Physical Systems (CPS). For testing, a CPS demonstrator was implemented on a real conveyor belt. This offers a small-scale realization of a data process chain, from data generation and processing followed by the estimation of the visualization of appropriate performance monitoring on a dashboard. Pei et al. (2019) develops a method to develop an assessment tool for intralogistics. To analyze and evaluate intralogistics´ current status quo the authors consider Cyber-Physical Production Systems (CPPS) enabling technology. Alves et al. (2015) proposes a framework for mapping the current performance of internal logistics flows. Based on Multicriteria Constructivist methods the approach aims to assist in the identification, organization, measurement, and integration of performance variables.

Table 7.2 Literature on performance measurement in internal logistics systems

Literature	Description
Fabri et al. (2020)	Uses a Discrete-Event-Simulation and a set of KPIs to assess the logistics flows' performance
Mörth et al. (2020)	Introduces a conceptual model for Internet of Things (IoT)-enabled data process chains linked to performance measurement for internal logistics systems
Moons et al. (2020)	Uses a logistics performance measurement framework based on the Analytic Network Process to assess the efficiency of replenishment scenarios
Guerreiro et al. (2019)	For intralogistics process planning the paper presents a Big Data architecture to extract, handle, further process data and apply analytics
Pei et al. (2019)	Develops an assessment tool to analyze and evaluate the intralogistics´ performance by considering Cyber-Physical Production Systems enabling technology
Alves et al. (2015)	Based on Multicriteria Constructivist methods, the paper proposes an evaluation framework for performance measurement of the internal logistics for service companies

Synthesizing the findings of the reviewed literature, previous studies are dealing with the evaluation and performance measurement of internal logistics in the scope of manufacturing operations and production systems. Recent works often take Industry 4.0 concepts—Internet of Things, Big Data, Cyber-Physical Systems, Cloud Computing, etc.—into consideration. The main distinction of the present work is the focus on internal logistics consisting of storage and conveying systems. A specific selection of input parameters for the evaluation of the combination of machine, storage and picking systems is investigated and the automation and real-time data availability for performance measurement is discussed.

7.5 Deduction of a Model for Availability and Performance Assessment

The design of a system concerning its performance is one of the most important tasks in the planning of internal logistics systems. For this purpose, there is a multitude of possibilities to make statements about the expected performance and availability. As addressed in the previous section, common practice procedures are linked to high personnel and cost intensity. Nevertheless, the effort required for this purpose should be in appropriate relation to the quality of the result.

Performance, information, and process factors are seen as key success factors for internal logistics systems (Granlund and Wiktorsson 2014). The logistics performance determination is subject to uncertainties. Performance in this context can be very diverse and therefore difficult to measure. Logistics performance can be shown by a specific selection of objectively measurable variables (Weber and Wallenburg 2010).

To be able to monitor and evaluate the two factors of availability and performance over the life cycle of the plant, key figures and corresponding monitoring are necessary (Müller and Lenz 2013). For controlling and management, the key figure system is an important instrument for making changes more transparent and monitoring the effects of decisions through target/actual comparisons. The approach also allows activities in individual areas of responsibility to be reviewed and weaknesses to be identified. This enables effective control (Vollmuth 2007). Due to its adaptability to different application purposes, the KPI system is also suitable as a basis for the sought-after model for performance and availability evaluation. Thus, a dashboard with key performance indicators is designed based on this concept.

To gain the input parameters for the searched conceptual model, a qualitative research approach is applied. The explorative interview aims to help raise awareness of the problem and generate hypotheses. To facilitate this, the interviews are conducted relatively openly and the respondents are given the opportunity for digressions and changes of topic. Nevertheless, a conversation guideline is used to ensure the comparability and completeness of the data (Bogner 2005).

Table 7.3 Selection of interview partners, field of activity, location

Expert	Department	Country
Expert 1	Research area plant management	Austria
Expert 2	Project Realization	Germany
Expert 3	Spare parts management	Germany
Expert 4	Sales	Germany
Expert 5	Project Realization	Austria
Expert 6	Maintenance and Support	France
Expert 7	Maintenance and Support	Switzerland
Expert 8	Sales	Germany
Expert 9	Software development	Austria

Semi-structured expert interviews were conducted to collect data and input parameters. For this purpose, a representative selection of experts from different departments of a leading intralogistics provider with multiple offices in Europe was made in advance, which was complemented by experts in the field of plant management (Table 7.3). All interviews were carried out as one-on-one interviews.

Furthermore, the systematic conduct of the interviews was ensured by the preparation of an interview guideline based on the examples and design recommendations discussed in (Kruse 2009). The following issues have been taken into account in the preparation of the guideline:

- No closed questions
- No alternative or multiple questions
- No direct suggestive questions
- No judgmental questions
- A simple choice of words adapted to the sociolinguistic level of the interviewee.

In total nine interviews were conducted, in which the interlocutors were asked about their experience with the determination of performance and availability in internal logistics systems and its components. The questions focused on the identification of KPIs and information that allow statements about the performance and availability of individual components as well as about the entire plant. Findings and named parameters were aggregated into factors and ranked based on the frequency of their

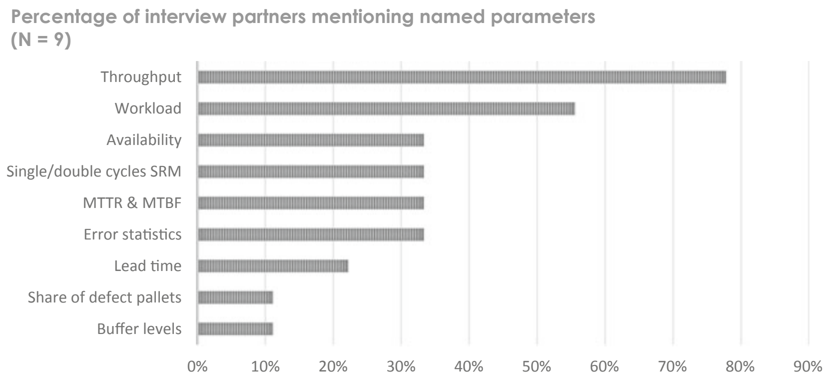

Fig. 7.2 KPI factors by frequency of mentions

mentions in the interviews (Fig. 7.2). In the process, if one parameter or a synonym was mentioned multiple times in an interview, nevertheless it was counted as one mentioning.

Additionally, four out of nine experts mentioned that for better significance KPIs should be formulated for specific subsystems—storage and retrieval machines, picking/manual working stations and conveying technology. The following five most mentioned factors were selected for describing the conceptual model:

- **Throughput:**
  As the main parameter for performance measurement throughput was mentioned in seven interviews. Further, five experts pointed out the need for historical data-comparison in form of maximum throughput and current throughput.
- **Workload:**
  Knowing the actual order strain of the entire system to evaluate a plant´s performance was considered as an important factor by five of the experts.
- **Single/double cycles SRM:**
  According to 33% of the interlocutors, the throughput and, respectively, the performance of storage and retrieval machines (SRM) are best measured by the amount of single/double cycles.

– **Availability and MTTR & MTBF:**
As reported by the interview findings, availability should be calculated using MTTR (Mean Time To Repair) and MTBF (Mean Time Between Failure) and composing the ratio. Nevertheless, three interlocutors mentioned that MTTR and MTBF should be displayed separately for the evaluation of error handling.
– **Error statistics:**
Three of the interlocutors explained the necessity of knowing the ten most frequently occurring errors. This was considered helpful for error handling and advanced planning.

Visualizing the surveyed factors for performance measurement, in Fig. 7.3 the authors propose a dashboard design. The clear depiction of relevant key figures makes it possible to quickly assess the condition of the plant and evaluate the strategies adopted.

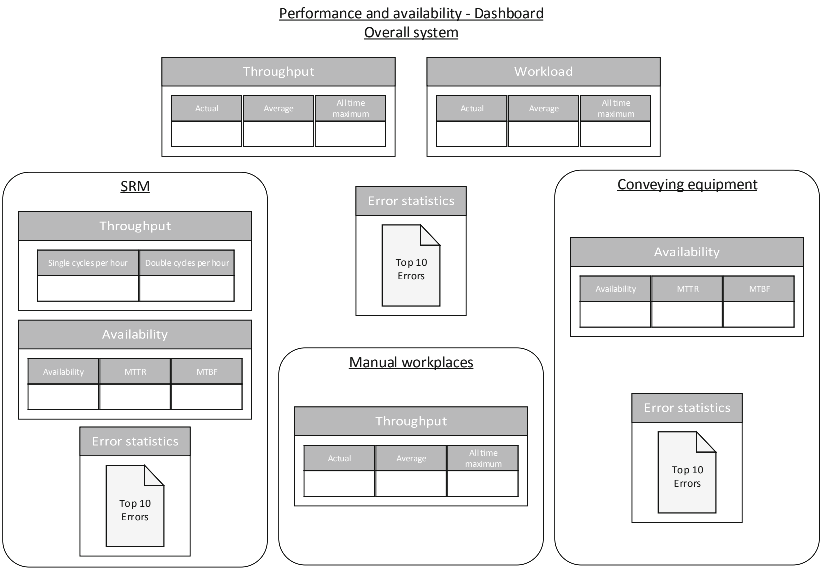

Fig. 7.3 Proposed dashboard for performance measurement

The expert interviews show that 33% of the respondents would consider the availability of the mentioned factors on a real-time basis as helpful for decision making and evaluation of operating strategies. This is in line with findings in other researches (Keivanpour and Ait-Kadi 2019; Dallasega et al. 2019a; Lee et al. 2018). Decision making and thus productivity loss can be improved by providing and processing real-time data (Syafrudin et al. 2018).

7.6 Discussion and Further Research Directions

The concepts of automation can be classified either into mechanization, relating to the automation of physical flows, or into computerization, referring to the automation of the information flow (Granlund and Wiktorsson 2014; Zsifkovits and Woschank 2019; Woschank et al. 2020). In this chapter, the authors deal with the topic of computerization, more precisely providing aggregated and visualized real-time data.

Taking into account the research work mentioned in Sect. 7.4, Mörth et al. (2020) proposes a set of KPIs which assesses eight key figures (throughput, cycle time, transport performance, transport utilization, effectiveness, availability and overall equipment effectiveness). Pei et al. (2019) defines a set of assessment criteria including, inter alia, communication parameters, condition monitoring, fault prevention, material supply and stock monitoring. The authors deliberately omit other parameters relevant for logistics systems, like cycle time, inventory level, and information flow, in the proposed concept. To focus on more meaningful parameters for the examined internal logistics systems, the five parameters most critically evaluated by the experts were chosen for the model. This was done to ensure the clarity of the dashboard and the possibility to quickly assess the KPIs.

An integrated monitoring system assists to prevent performance degradation and failures (Jain and Lad 2019). With the integration of the model into the existing software, control technology and information and communication systems, the collection of KPIs can be automated.

Thus, the manual effort and associated costs are reduced, the accessibility is increased and the continuous improvement in efficiency is facilitated.

Literature (Orellana and Torres 2019; Helo and Shamsuzzoha 2020; Huang et al. 2019; Lee et al. 2018; Hwang et al. 2017) shows that the availability of indicators to assess the impact of the operation on the set objectives at real-time is used to facilitate continuous improvement processes. Fawcett and Cooper (1998) conducted a survey study with 111 firms, in which the higher-performing firms were found to place greater emphasis on performance measurement. The relation between efficient logistics processes and the access to measurement information emerges and the comprehensive performance measurement is revealed as a requirement for improvement of efficiency and operational performance.

The continual condition monitoring of a plant enhances the identification of causes for downtimes. Thus, actions can be developed to eliminate them. This leads to less downtime. Maintenance strategies can also be compared, evaluated and, if necessary, adapted to changing conditions (Jünemann and Beyer 1998). Using automation and digitization enables in-depth reliability analysis and condition-based maintenance. Based on the inspection of operating conditions, optimal maintenance actions are suggested (Wang et al. 2020). Due to the described function and application, the created model not only supports the maintenance strategy but also serves as a tool for preventive maintenance.

The presented work offers a starting point for further research in the direction of extended performance measurement of storage and conveying systems. Identifying the characteristics of automated high-bay warehouses, automated small-parts warehouses and various combinations of machine, storage and picking systems enables a better understanding of internal logistics systems and their complexity. The authors propose a model extending the site acceptance tests according to the valid set of standards. Some limitations in the calculation of performance and availability parameters have to be addressed in future research work. Overcoming restrictions caused by the simplification of structures and processes of internal logistics systems for calculation purposes and the generation of data are topics for further research.

7.7 Conclusions

This chapter proposes a conceptual model for automated performance measurement of internal logistics systems. Based on an intensive literature review, semi-structured expert interviews were conducted to develop this concept, in which the possibility of monitoring the plant condition over its life cycle using selected key figures was discussed and the input for the concept sought was generated.

The model obtained provides based on meaningful key figures information about the condition of the plant and enables early detection of performance and availability losses. This allows preventive maintenance measures to be introduced, taking specific and resource-saving measures, and avoiding long downtimes.

Integrating the model into the existing software automates the collection of KPIs and hence reduces the manual effort and personnel resources required for the preparation and execution of the tests. The software integration also contributes to the standardization of the process for availability and performance assessment. A natural next step to produce industrially relevant solutions would be the formulation of a methodology to integrate the conceptual model in a software solution and to evaluate the model application in industrial environments under full load conditions. The automated data acquisition, management of data complexity and technology capabilities in this context offer a broad field for further research work.

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