Increasing Resilience in Factories: The Example of Disturbance Management – A Research Approach

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Disruptions in in-plant production systems, such as variant-rich series production, can lead to serious production downtimes. The longer the production stoppage lasts, the greater the damage to companies and supply chains. The capabilities to ensure emergency operation until full performance is restored after disruptions as well as the fast restart of production systems represent a crucial competitive factor for companies and also increase production agility. Therefore, it is of central importance to reduce the time between the occurrence of a disruption and the return to the initial level in order to minimize downtime costs.

In the context of this paper the state of research on disturbance management and assistance systems for disturbance management ist stated and a research approach for investigating the potentials of assistance systems will be presented.

1. Initial situation

The term *resilience* is used to describe capabilities and skills that enable a return to the original state after a disruption. Resilience is quantified as the time between the occurrence of the disruption and the return to the initial level, based on the system performance, as in (Zobel/Khansa 2014). In this context, resilience can refer to the system, the human or the organization, which must be considered as factors of the entire production system (Bläsing/Bornewasser 2021). Due to an increasing individualization, flexibilization and complexity of production, there are always new demands on the employees (Wolf et al. 2018, Gronau et al. 2017), such as the elimination of new, diverse disturbances. In order to resolve the disruptions quickly, humans can be supported, for example, by additional information, data, or instructions in the form of handling instructions for decision-making and disruption resolution. This contributes to a reduction in disruption times, which increases the resilience of the entire production system.

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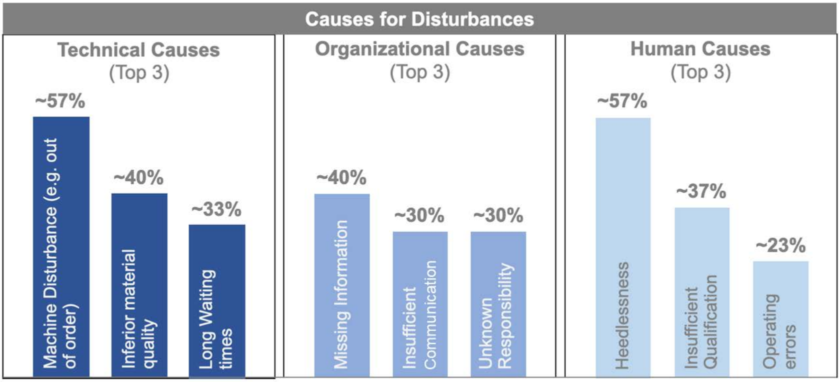

Figure 1: Causes for Disturbances (Gronau et al. 2019)

The action patterns for fault elimination can be presented to the human with assistance systems to support a quick elimination of the fault. In addition to short-term support, process-oriented, problem-based knowledge transfer with assistance systems should be used in the medium and long term to promote the development of employees' technical skills and enable work-integrated learning (Burggräf et al. 2021, Dostert/Müller 2021). To date, the possibilities for further training through assistance systems have hardly been investigated and used (Burggräf et al. 2021). The described potential can only be exploited if the selection and design of the assistance system are target-oriented in relation to the target group (Mark et al. 2020, Traub et al. 2018], area of application (Mark et al. 2021) and disruption. In order to develop expertise, understood as the transfer and application of action patterns to various disturbances, a classification and evaluation of disturbances must first be made possible depending on individual company characteristics. The identified disturbances must then be assigned to the appropriate action patterns.

2. State of research

2.1. Disruption Management

In production, disruptions are understood as unexpected temporary events whose occurrence and frequency cannot be predicted (Galaske/Anderl 2016, Stricker/Lanza 2014) and which prevent further work. An extended concept of disturbances sums up everything that prevents the factory from working optimally (Hingst et al. 2023). Disturbance variables can be subdivided into categories such as human, machine, material, management, measurability, environment, and method, among others (Meyer et al. 2013). Efficient disruption management is an important foundation for successful business operations (Burggräf et al. 2017).

The elimination of disturbances can be divided into preventive and reactive measures (Stich et al. 2017). A distinction is made between combating the causes and containing the effects (Schröder et al. 2016).

An operational task of reactive fault management is the elimination of the above-mentioned faults (Spath/Braun 2021). The process of disruption management includes four steps: Detecting the disturbance or disturbance effect, finding the disturbance cause, developing an appropriate response, and eliminating the disturbance cause (Bauer et al. 2014, Galaske/Anderl 2016). The time from the occurrence of the disturbance to the end of the disturbance effect can be divided into a latent and a manifest phase (Stricker/Lanza 2014). In the latent phase, the disturbance already occurs, but its elimination does not begin until the manifest phase starts.

In order to perform the fault elimination more efficiently and economically, manufacturing execution systems (Hingst et al. 2023) are used and approaches of manufacturing analytics are tested to be able to detect faults from the multitude of data provided by sensors (Denkena et al. 2020, Jordan et al. 2015). Finally, expert systems were built to increase efficiency and troubleshoot faults (Iwanek et al. 2015). The knowledge management approach has been adopted to increase the resilience of production through knowledge transfer (Hingst et al. 2021). Institutional learning is also rarely incorporated in the field of disruption management (Pantazopoulos 2013).

In principle, holistic disruption management also includes avoiding disruptions through appropriate preventive measures (Foon/Terziovksi 2014; Fraser et al. 2015). This contribution concentrates only on the so-called Breakdown Corrective Maintenance.

Simulation as a method for mapping production processes and for investigating effects that cannot be investigated to the same extent in reality is widely used in engineering (Riley 2013; Trigueiro de Sousa Junior et al. 2019]. In the environment of disruption management, among others, (Galaske/Anderl 2016) use simulation to test resilience strategies, (Trigueiro de Sousa Junior et al. 2019) to increase transparency in case of disruptions in global production networks (Burggräf et al. 2018) or to determine the advantageousness of preventive measures to avert disruptions. Simulation is also widely used to study supply chain disruptions (Ivanov/Sokolov 2013).

Enterprise resilience can be considered statically as a result of preparedness and preventive actions, or dynamically when disruptions can be handled appropriately and the previous state can be quickly restored (Annarelli/Nonino 2016). However,

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reactive measures must not be neglected to achieve the highest possible resilience, since disruptions cannot be avoided entirely. While the robustness of a production system is described by its ability to react to changes (Hingts et al. 2021), resilience additionally considers dynamic components in dealing with disturbances (Stricker/Lanza 2014). Accordingly, resilience is defined, among other things, by how quickly a production system can restore its original state as a result of a disruption (Tierney/Bruneau 2007). The role of the employee is a central component in this context, since the employee is directly involved in the elimination of the disturbance. Due to a large number of possible forms of disturbances (Stricker/Lanza 2014), the individual consideration of possible disturbances or disturbance patterns is particularly relevant.

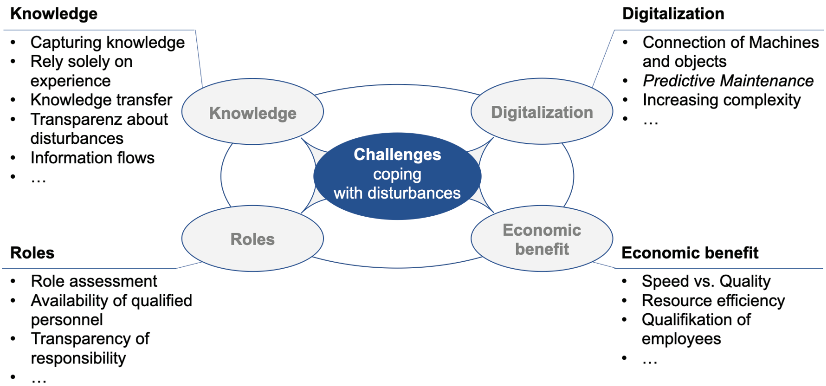

Figure 2: Challenges coping with disturbances (Gronau et al. 2019)

The authors conducted a questionnaire survey on the current state of disruption management as well as the identification of challenges in dealing with production disruptions (Gronau et al. 2019). The results of the survey illustrate the relevance of disruption management, but also show that disruption management is still at an early stage in many companies despite many years of studying this topic. The reasons for this include problems in dealing with empirical knowledge and a lack of information and transparency. The study also revealed that, in addition to obvious technical causes of disruptions, organizational and human causes also frequently lead to disruptions in production systems. In this regard, employee carelessness can be cited as one of the most common causes (Gronau et al. 2019).

2.2. Demand-oriented competence development through assistance systems in production or disruption management

Assistance systems are used in a variety of ways. In the literature, assistance systems are divided into sensory (e.g., haptic glove, arm support, smart watch), physical (e.g., robots, AR and VR applications), and cognitive (e.g., computer assisted instruction, voice control, AI-based intelligent personal assistant) assistance systems (Mark 2021). In the proposed research project, the use and design of assistance systems in the context of production and industry will be investigated. There, work environments are characterized by increasing complexity, flexibilization and individualization (Kagermann 2014), which is why assistance systems are used to support humans (Bläsing/Bornewasser 2021). By providing additional information (e.g., instructions) and data, assistance systems can support decision-making and troubleshooting and, provided they are designed correctly and used appropriately, minimize the cognitive workload (Bläsing/Bornewasser 2021).

In automated production environments, such as variant-rich series production, humans increasingly take on complex tasks that, in combination with performance monitoring, can lead to increased stress among employees (Kaasinen et al. 2020). In particular, when a malfunction occurs, he or she has to overview complex situations and diverse data in a short time, make decisions, and carry out the troubleshooting. For this purpose, data from various sources must be integrated and interpreted. Assistance systems support humans, for example, by bundling information from various data sources and enabling decision and action recommendations. For example, data glasses can be used to provide employees with additional information while leaving both hands free to perform tasks (Danielsson 2020). In this way, employees, as active agents in the troubleshooting process, are supported, which helps to resolve the malfunction faster and thus increases the resilience of the production system.

Various types of assistance systems and (potential) technical implementations are described in the literature, but only some of them are used in industry. It is clear, however, that there is a lack of scientific foundation for target group and context-specific selection and design of assistance systems as well as experimental validation of their effectiveness (Mark et al. 2021). (Burggräf et al. 2018) also describes the potential and necessity of an individual and adaptive design of assistance systems, which is adapted to the target group, field of activity and company specifics. Particularly in the event of a malfunction, which causes great time pressure, assistance systems can only have a supporting effect if they are adequately selected and designed and recommend suitable instructions for action for the malfunction in

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question. This is the starting point of the present application. First, a systematization of disturbances and the derivation of action patterns for the specific selection of assistance systems will be developed and then the effectiveness will be investigated experimentally.

In addition to short-term effects in the use of assistance systems on rapid fault elimination and increasing the resilience of production systems, medium- and long-term effects on the competence development of employees are pursued in this application. The assistance system-supported troubleshooting promotes the technical competence of the employees, so that a transfer of specific action patterns to further disturbances is made possible. The universal application of learned action patterns reduces the time required for troubleshooting and thus increases the resilience of the entire production system.

The visual, auditory, or haptic provision of information, data, and action instructions is directly linked to the motor execution of the troubleshooting process in the event of a malfunction and is confirmed by feedback as a success or failure in troubleshooting. A transfer to other malfunction classes enables the embedding of the conveyed information and action instructions by the assistance system in the overall context. The addressed development of expertise is necessary to counteract the effect of the "Ironies of Automation". The effect was already described in 1983 and has been unsuccessfully attempted to address since then, which is why it is still highly topical. The effect describes the fact that in the context of industrial production environments, humans increasingly find themselves in the role of supervisors. Thus, he takes over fewer operational activities, but must, for example, carry out the rectification in the event of a malfunction. On the one hand, increasing automation causes a loss of situational awareness and skills of humans, since they act less actively (Strauch 2018; Bainbridge 1983). At the same time, however, the high complexity of fault recovery requires detailed knowledge and knowledge of the context and overall process in order to resolve the specific fault case (Bainbridge 1983). Current training structures such as off-the-job training, training courses, e-learning or one-time on-the-job briefings are not sufficient to impart this specific and problem-based technical and contextual knowledge so that knowledge and action patterns can be adapted and applied to different situations. This prevents a sustainable transfer of what has been learned to the workplace (Rangratz/Pareto 2021). The assistance systems present the employee with problem-based information and data in the event of a malfunction. By embedding the information in a context-specific manner and linking it to action patterns, process-oriented learning of technical competence is to be promoted Cooper et al. 2010). Competencies are skills and knowledge to cope with a specific problem in a practical way. Competencies are divided into different facets (Oberländer et al. 2020), whereas in this contribution the technical competence is addressed. By means of an assistance system-supported troubleshooting, the development of technical competencies has to be promoted and thus the transfer problem of formal, external further training has to be addressed.

3. Derivation of the research gap

Based on the described state of research in incident management, the essential goal of research in this area has to be to investigate the current situation of incident management in companies, to identify suitable characteristics and action patterns and to transfer them to incident management. The achievable benefit is investigated using a simulation and in practice through the situation-optimized selection of assistance systems. Following this research path it is possible to extend the theory of management science on reactive fault elimination by innovative aspects using the example of variant-rich series production. For this purpose, it fits into a simulation-based research framework that is spanned by approaches such as (Mason et al. 2005) (mapping human performance) and (Barad 2001) (improvement models for manufacturing strategies).

So far, no approach exists which links disturbance classes, action patterns and assistance systems. Therefore, no artifact exists that helps companies identify these connections and use them to increase resilience. In addition, companies face the problem of continuously training employees in a practical manner so that a transfer of what they have learned to work problems is ensured. Therefore the following research questions arise:

F1): How can specific action patterns be derived and generalized for application in production for the employee in relation to the disturbance classes of a production?

F2): How can assistance systems be assigned to the different action patterns according to need for optimal elimination of the disruption and increase of the resilience of the production system?

F3): What are the effects of assistance system-supported fault elimination on employees' long-term competence development?

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4. Research proposal

To answer the research questions, an improved design of assistance systems in different production scenarios is necessary. It has to be be enabled on a technical-conceptual level based on a generic fault classification framework. An experimental study may provide insights into the effectiveness of competence development measures for specific disruption patterns.

4.1. Objectives

Essentially, the following four objectives have to be fulfilled in order to reduce fault rectification times, to sustainably qualify the worker to rectify the fault and to minimize the consequences of the disturbance for the company:

- Identification of malfunction classes for the development of a classification framework, which enables a malfunction classification in the production
- Determination of a solution-oriented classification of the specific action patterns, which are suitable for the disruption management, in a classification framework
- Derivation of a procedure for fault elimination with the help of a demand-oriented selection of the considered assistance systems to increase the resilience of the production system
- Based on the findings, expand existing innovative approaches to incident management and formulate implications for incident management to accelerate the selection and deployment of assistance systems, thereby enhancing the expertise of employees, enabling the transfer of learned patterns of action across different incidents

4.2. Procedure

On the one hand, the knowledge gained from the disturbance classification framework should enable further development or redesign of the integration of assistance systems for disturbance elimination, and on the other hand, it should also produce new procedures or methods for disturbance elimination. A key objective must be to investigate the effectiveness of the assistance system-supported troubleshooting on the development of the professional competence of the employees and thus to achieve an increase in the resilience of the production system.

Accordingly, the proposed research design is a combination of desk research (literature review, conceptual work), case studies, simulation, and expert interviews and uses both qualitative and quantitative research methods.

Based on the knowledge gained from the literature on disruption management, exploratory case studies will be conducted to provide insight into the practical design of disruption management and thus empirically gained input.

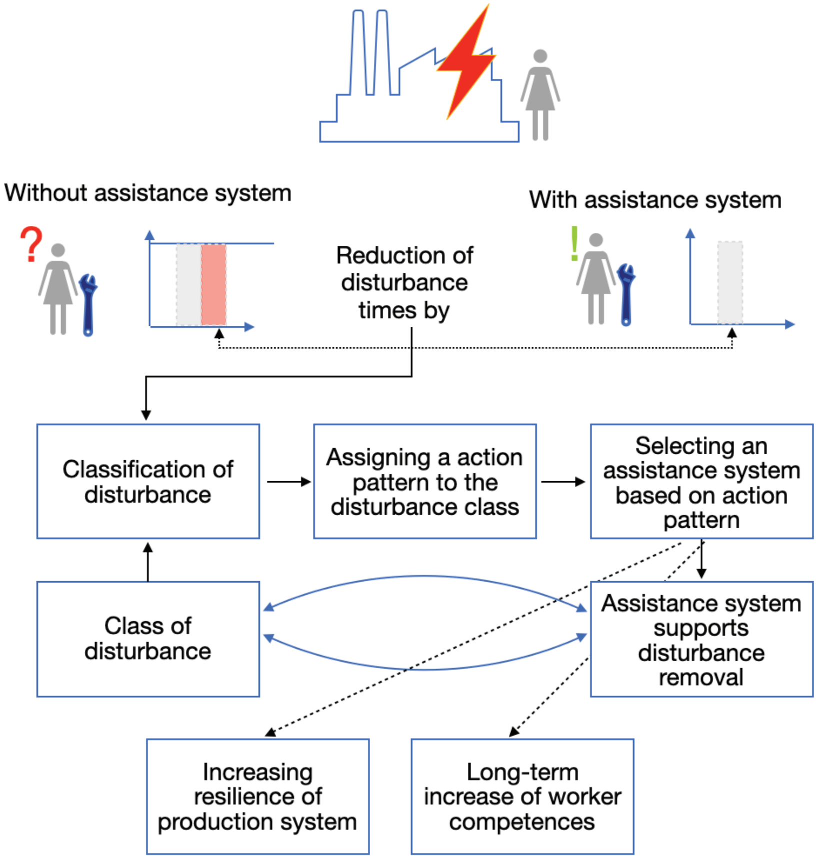

Figure 3: Proposed research design

It makes sense to develop a generally valid approach for the classification of disturbances and for simplified assistance system selection. Through an experimental study, the effectiveness of assistance system-supported disturbance elimination on the resilience of the production system and on the development of the expertise of the employees can be tested through a targeted selection and use of different assistance systems in order to derive a recommended course of action that is valid for individual company situations. This holistic method can then later be validated in industrial practice using various case studies.

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4.3. Expected Results

As a result of the research project, a basis for linking disturbances, forms of production, measures for disturbance elimination and assistance systems for the analysis and elimination of disturbances by employees is to be developed.

Identified disturbance clusters and their interaction on the production system will be supplemented by possibilities of a transfer of specific action patterns between disturbance clusters. This will enable an assessment of effectiveness and transfer possibilities in the context of disruption management.

A further result of the research should be a generally valid model which, in addition to the formation of individual clusters, enables the selection and formation of suitable action patterns. This includes an account of the effectiveness of the possible action patterns for individually occurring disturbances.

If a broad data base exists on disturbance resolution supported by an assistance system, this can be used to validate the disturbance classification scheme.

Overall, resilient fault elimination is achieved with the help of a learning-friendly design of the assistance systems.

5. Outlook and further work

The paper has shown that there is a research opportunity for the use of assistance systems in disturbance management. Further research, together with industrial partners has yet to show how these assistance systems could be constructed and implemented and how much influence they have on aspects like earlier recognition of disturbances, earlier definition of the necessary measures and less costly disturbance management over all.

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