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Data based root cause analysis for improving logistic key performance indicators of a company’s internal supply chain

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Abstract

The manufacturing industry faces an increasingly complex and dynamic environment due to shorter product life cycles, advanced production structures and expanding customer services. It is imperative that logistic key performance indicators (KPIs) be considered along with product costs and product quality to obtain a competitive advantage. Numerous companies possess an internal supply chain that fails to meet logistic performance goals set by the management. The measurables for logistic performance include logistic KPIs such as delivery time as well as cost relevant figures including work-in-process or the utilization of employees. In a case of unsatisfactory logistic KPIs, it is pertinent to identify the root causes before attempting to rectify the situation.

Increasing digitalization within industry means a substantial volume of confirmation data is available regarding the core processes of a company’s internal supply chain. This study discloses a model-based analysis of confirmation data to identify the root causes of unsatisfactory logistic KPIs. A framework for the analysis is constructed by defining generic cause-and-effect relationships between the relevant logistic KPIs and influencing as well as disturbing factors. The results produced by the model-based analysis and the interpretation of the confirmation data show the occurring cause-and-effect relationships for particular use cases and deduce the root causes for insufficient logistic KPIs. From there, companies can develop and implement suitable steps to increase the logistic KPIs by focusing on the newly-identified root causes instead of non-related, but recurring, complications. A case study is included to show the practicality of the presented method. The root cause analysis provides the basis for advanced logistics controlling systems to automatically identify weak-points and propose counteractive measures and therefore continuously improve and adapt the supply chain to changing conditions.

Keywords: Data Analysis; Logistic Key Performance Indicators; Cause-Effect-Relationships

1. Introduction

In addition to product costs and product quality, logistics performance plays a highly important strategic role for manufacturing companies to successfully compete in today’s difficult environment [1, 2]. Studies show that companies striving towards consistent optimization of their internal supply chain regarding logistic key performance indicators (KPIs) can verifiably increase market success [3].

The rapid formation of trends and increasing digitalization highlight the importance of cross-linked supply chain processes and customer service. Chain-chain competition has started to replace company-company competitions [4]. In this context supply chain management (SCM) and information systems (IS) become more important. Bayraktar et al. provided evidence for a strong relationship between SCM-IS and the performance of a company [5]. They discovered a positively and significant influence, but a direct negative effect of SCM-IS inhibitors. Despite the great importance of high logistic performance,

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many companies have considerable deficits in achieving both their own and market-side logistic performance goals [6]. A main reason is that companies often lack the understanding of the manifold and multi-causal interactions in logistics [7]. This can lead to unsystematic data analysis and erroneous interpretations of key performance indicators KPIs. Hence, there is a high risk of defining ineffective measures that do not resolve the actual root causes of present problems or may possibly worsen logistic performance. This is caused by inconsistent logistic KPIs and target settings or by incorrect and inconsistent settings of production planning and control (PPC) parameters [7]. Detailed and systematic root cause analyses based on quantitative data are required to effectively improve logistics performance. Common methods like value stream design or simulation studies use too many assumptions that render them unsuitable for complex supply chains with many products or processes.

In this study, a systematic approach for root cause analysis is presented using logistic models and more suitable analysis methods. The objective is to identify the underlying reasons for insufficient KPIs and develop actionable changes. The presented approach sets the basis for future advanced information systems in the context of logistics controlling allowing automated identification of weak-points and therefore continuous improvement and adaption of the supply chain to quickly changing conditions.

In the following sections, logistic KPIs are described and placed in a company's internal supply chain. The general concept of causal networks is presented which uses logistic models to identify universal cause-effect-relationships and structures them in cause-effect relation trees. This provides a framework to analyze methods that improve certain logistic KPIs without negatively affecting others. For demonstration purposes, the cause-effect relation tree of a low schedule reliability is presented in a next step. The practicality of the analysis approach is supported by the results of a case study. Lastly, the conclusions of the paper are summarized.

2. Systematic cause-effect analysis in a company's internal supply chain

2.1. General supply chain and logistic KPIs

The overall goal in production logistics is logistic efficiency. Companies aim for high logistics output at low logistics costs. Logistics output involves short delivery times and a satisfactory due date compliance. Logistics costs can be expressed in terms of production and capital commitment costs. From the corporate viewpoint, logistics costs mainly result from work in process (WIP) and capacity utilization. [8] In comparison, the logistics costs in storage systems are measured using the KPIs inventory and storage costs. Logistics performance is defined by the means of the service level [9]. This overall logistic KPI system can be used to derive logistic KPIs for each core process of a company's internal supply chain. Generally the supply chain consists of procurement, preliminary production, interim storage (or buffer), end production and dispatch.

Dispatch, the final step in the internal value chain, is the process where output measures closest to the end customer are analyzed. Delivery time to the customer equals the sum of throughput times of the order-specific processes in the internal value chain. The delivery due date compliance achieved, results from the lateness of the single processes. The timeliness in processes with a storage or buffering function is evaluated using the KPIs service level (storage) or due date compliance (buffer). According to the definition of due date compliance, orders are considered on time if completed up to the date of demand. Materials provided too early can incur negative effects on the resulting stock level. In order to evaluate the scheduling situation in production processes, the KPI schedule reliability is applied. In that case, orders are considered on time only when finished within an interval of the accepted lateness. Delivery capability is another important indicator regarding the scheduling situation. While due date compliance and schedule reliability are computed by comparing actual to planned finishing dates, delivery capability compares planned to the desired delivery date of the customer. Figure 1 summarizes the resulting KPI system across a company's internal supply chain sorted by logistic costs and logistic output. [8]

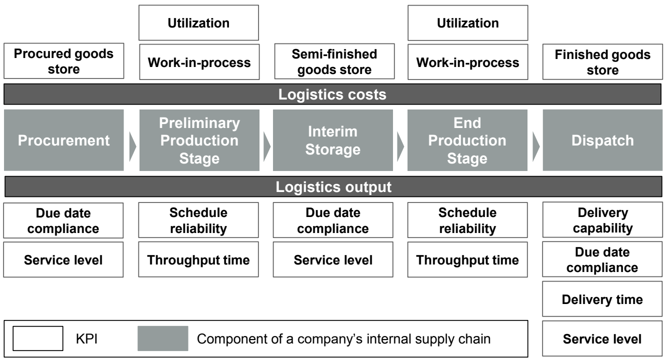

Fig. 1. Logistic KPIs in a company's internal supply chain

2.2. Quantitative analysis of influencing factors on logistic performance using logistic models

Universal cause-effect-relationships were identified to construct cause-effect relation trees for each logistic KPI (throughput time, service level and stock level) in a company's internal supply chain. The relation tree is used by first identifying a logistic key figure that deviates from its target value. Possible causes are then structured over several levels until the primary root causes are discovered and further subdivision into universally valid causes is not feasible. The single cause-effect relation trees are interconnected as deviations from one KPI may concurrently influence other KPIs. The developed cause-effect relation trees consider these interactions to form a consistent causal network along the internal supply chain. For each decision point in the cause-effect relation trees suitable analysis methods and logistic models as well as detailed analysis guidelines have been assigned allowing a structured and systematic quantitative analysis. These analysis methods and models are suitable to evaluate the logistic performance by describing and illustrating essential correlations between logistic KPIs and adjustable parameters. Hence, a generally valid analysis procedure has been developed leading the users to discover the underlying root causes of poor performance. Figure 2 visualizes the general concept of the developed causal network.

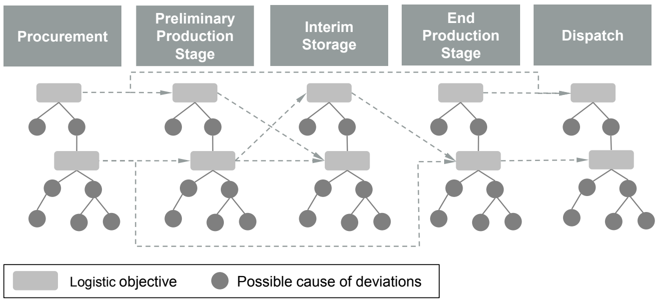

Fig. 2. Schematic illustrating the general concept of the causal network [10]

With the QuantiLoPe demonstrator a free tool to analyze and evaluate causes of a poor performance was provided [11]. Actions can be developed that resolve the identified root causes and improve logistic KPIs.

3. Cause-effect relation tree of schedule reliability

As an example of fundamental cause-effect relations, Figure 3 illustrates the cause-effect relation tree of schedule reliability.

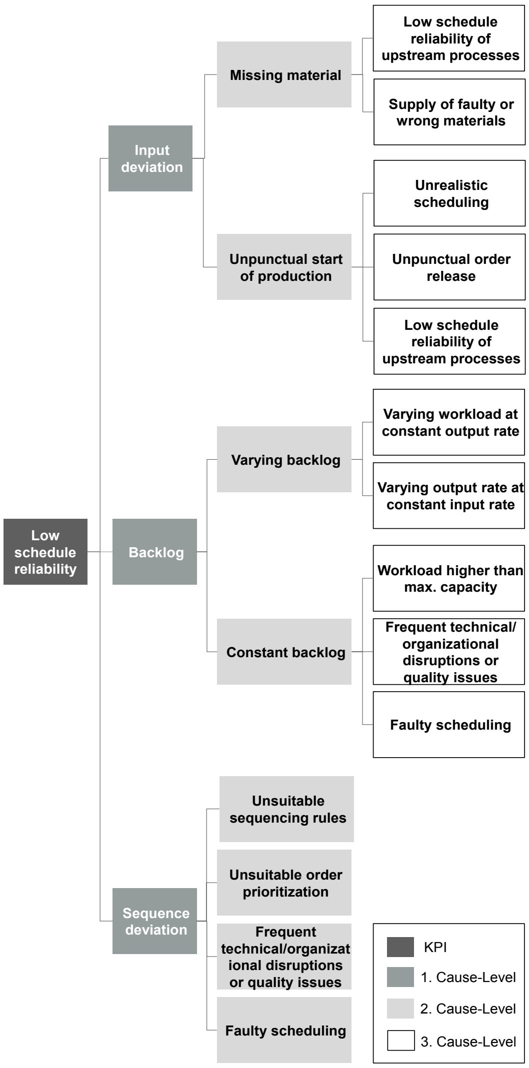

Fig. 3. Cause-effect relation tree of schedule reliability

According to well established approaches for modelling schedule reliability, the two main influencing factors on schedule deviations are backlog and sequence deviations [12]. Additionally, input deviations can be identified on the first level. Lower levels split the main causes into more details and were constructed using an increasing amount of empirical data from various industrial projects and literature reviews with each level. The number of cause-levels depends on the last universally valid cause. Below the last in Figure 3 shown cause-level the underlying reasons are company specific.

3.1 Cause-effect relations regarding input deviation

Input deviation occurs when the material, required to process a production order, is not available on the planned start date of production. Required materials might be missing due to high output lateness of upstream processes (procurement, preliminary production stage, or storage stage) or due to faulty supplies in terms of material type and material quality. In these cases, upstream processes need to be analyzed.

Input deviation can be impacted if production orders are not initiated on the planned start date, even if the required materials are available. This is due to a low schedule reliability of upstream processes resulting in missing order documents, drawings, or confirmations of quality or required tools. Furthermore, unrealistic scheduling can cause input deviation. It occurs when the planned order start date cannot be met, which causes backlog at order entry. This happens for instance, if unrealistic delivery dates are promised to fulfil customer requests. Using backward scheduling, the respective production orders show planned start dates already being placed in the past when the order is generated. Additionally, unpunctual order releases can cause input deviation. They originate either from individual mistakes or systematically due to unsuitable order release procedures, which do not take the planned start date of a production order into account. The result is delayed or early releases of production orders. It is particularly true for load- or work in process-oriented release procedures meant to improve workload and optimize plant utilization, such as the ConWIP procedure.

3.2 Cause-effect relations regarding backlog

Backlog describes the difference between the planned and actual output of a capacity unit [12]. If production output is higher (backlog < 0) or lower (backlog > 0) than planned, schedule deviations occur. In this context, differentiation between a constant mean backlog and varying backlog is needed. The mean backlog occurs if the workload is higher than the available capacity and can be mathematically converted directly into a mean schedule deviation [12, 13]. It means too many sales orders are accepted at unrealistic confirmed delivery times without considering the current workload of the production department. The effects are more drastic if the workload is permanently too high. As a result, there is a steady increase in backlog and mean lateness if additional capacities are not provided. A mean backlog occurs from a variety of reasons including repeated technical or organizational disruptions and frequent process or product quality issues.

This is particularly true if disruptions occur at workstations already operating at full capacity. Furthermore, a mean backlog implies planned throughput times are not matching the actual throughput times. Possible reasons include faulty work schedules and outdated or incorrect master data. A varying backlog primarily affects the variance of the resulting schedule deviations. Backlog variation occurs when work systems in the analyzed production stage incur a highly varying workload at a constant output rate. This typically implies volatile demand behavior, but variations in performance in a production area, given a constant load, display a similar result. One example is inconsistent staff availability or frequent changes from a single-shift operation to a two-shift operation and vice versa.

3.3 Cause-effect relations regarding sequence deviations

Sequence deviations occur if production orders are not processed in the planned order, i.e. the actual sequence of finished orders does not correspond to the planned finishing sequence. Sequence changes in the waiting queues at workstations lead to an increased variation of the actual throughput times. For instance, sequence deviations can be intentionally induced by given sequencing or priority rules. Set-up-optimal sequencing is considered beneficial in order to increase the effective performance of a work system. Although such rules negatively affect schedule reliability, these may be crucial from a technological or economic point of view. Another possible cause of sequence deviation is incorrect prioritization of production orders by employees. Employees often optimize their own workload or the workload of their machine at the expense of schedule reliability by bundling similar orders or selectively processing small orders to maximize order completion during their shift. Besides sequencing and order prioritization, other factors influence the completion order.

Malfunctions in technical systems lead to deviations between planned and actual throughput times for individual production orders. This causes the actual completion sequence to deviate from the planned completion sequence. A lack of process and product quality, requiring additional work processes to cope with the necessary rework, has similar effects. Frequent disturbances are correspondingly more impactful to performance. Additionally, imperfectly planned throughput times can cause sequence deviations, as these determine the planned start and completion dates of the production orders. Planned throughput times may be incorrect if based on wrong or outdated assumptions.

4. Case study

4.1. Initial situation

In this section, the initial situation of an injection molding tool manufacturer is presented as a step-by-step example for using systematic cause-effect analysis. As shown in Figure 4 the manufacturer's internal supply chain was composed of the core processes procurement, preliminary production stage, interim storage, end production stage and dispatch. The analysis was focussed on the preliminary production stage, which is a machine shop in this case. The machine shop contained approximately 50 work systems. The production orders for the manufactured components and assemblies were directly related to customer orders, which means a positive schedule variance in the machine shop would generate longer delivery times in many cases. From the machine shop, the material flowed via a buffer in the core process intermediate storage into the end production stage. This was an assembly area in which the manufactured components and assemblies were assembled to a specific customer order. Especially due to the high number of components and assemblies, the punctual supply of the end production stage from the preliminary production stage was extremely important. In the manufacturer's machine shop, approximately 6,800 production orders were completed during the investigation period of one year. Assuming a standard 5-day working week with one shift, this output yields an average of 30 orders per day.

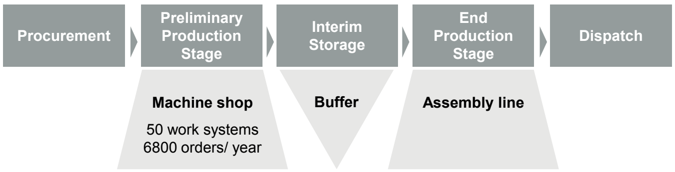

Fig. 4. Internal supply chain injection of a molding tools manufacturer

Analyzing the database showed a low schedule reliability of the preliminary production stage towards the next core process of the supply chain. The comparison of the customer requested delivery time with the actual delivery time indicated the main problem is the high schedule variance. The associated assembly line documented a schedule reliability of 60% with a mean schedule variance of 1.4 days, a standard deviation of 20 days and a maximum schedule variation of far more than 30 days. Figure 5 illustrates the situation as a histogram. A detailed analysis was necessary to identify the root cause(s) for low logistic performance.

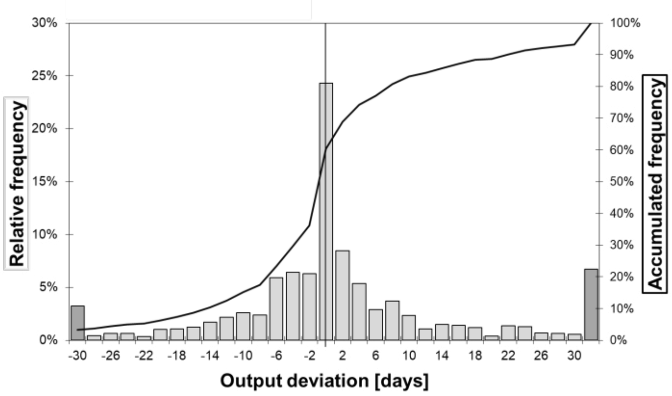

Fig. 5. Schedule reliability histogram of the preliminary production stage

4.2. Application of the systematic approach

According to the cause-effect relation tree of low schedule reliability, the analysis focused on the following three underlying factors:

- Backlog
- Input deviation
- Sequence deviation

First, a high backlog was considered. The mean backlog was not significant, but there were significant variations in the total backlog. The maximum occurring backlog was around 150 orders, corresponding to approximately 5 days. The maximum schedule variation highly exceeded 30 days, which implied backlog itself was not the primary cause. Figure 6 shows the backlog run over the investigated time period.

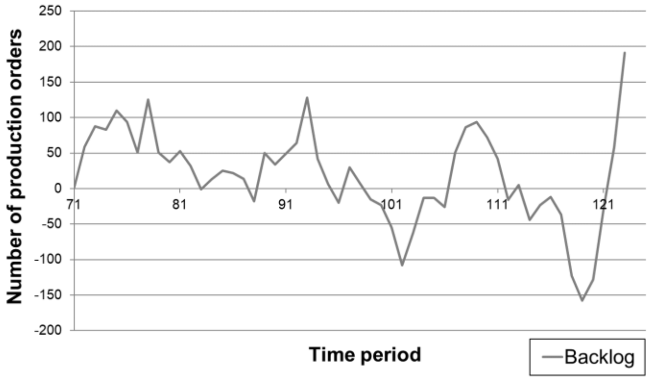

Fig. 6. Backlog run over the investigated time period

Another possible factor was the pre-existing high input schedule deviation. The data showed the required material was on stock and material provision was not the problem. In case of a too low stock level this would have led to a different cause-effect relation tree. Comparing the production orders' scheduled arrival time to the actual arrival time demonstrated a significant difference. On average, production orders were started 10 days earlier and the arrival time was widespread in either direction. This indicated the orders were released too early. Figure 7 illustrates the situation in a histogram.

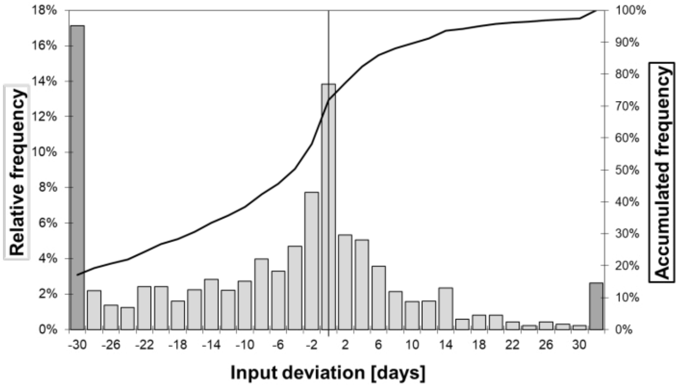

Fig. 7. Input deviation histogram of the preliminary production stage

Moving down the cause-effect relation tree, existing input schedule deviation could result from unrealistic scheduling, untimely order releases, or a low schedule reliability of upstream processes in the internal supply chain. The general scheduling was reasonable. However, untimely order releases and the schedule reliability of the upstream processes were identified as issues. Only a small number of the delays were explained by the same behaviour of the employees regardless of their working area. For all processes, there was a similar amount of sick days and employees used flexible working hours depending on their personal circumstances while ignoring the actual order situation. Thorough examination of the upstream processes revealed two are especially critical. The construction process was the first bottleneck due to the capacity overload. This could explain the rest of the delays, but not the too early arrival of orders. The root cause was tracked back to a different process, namely the saw process. Although the mean utilization of the saw station should be only 50%, it appeared to be a bottleneck. The employee working on this machine had health issues, therefore many sick days. In an attempt to compensate, the individual worked on orders as soon as possible without authorization. Scheduled start days were ignored which created irregularities that explain the schedule variations. The analysis showed 60% of the orders were released before their scheduled date, around 20% more than 30 days in advance. The backlog and the input schedule deviation combined did not completely account for the schedule reliability shown in Figure 5.

As a final step, the sequence deviations were considered. On average, the actual throughput time was 12 days longer than the planned throughput time. A critical aspect was the enormous variation of the relative schedule deviation. Figure 8 illustrates the situation in a histogram.

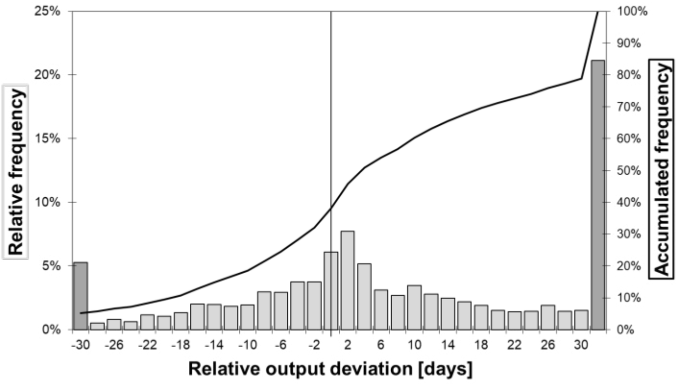

Fig. 8. Relative schedule deviation histogram of the preliminary production stage

The throughput times in the manufacturing process seemed to be uncontrollable. The sequencing strategy set by upper management was directly aligned with the planned order schedule. This implies production orders were incorrectly prioritized by the employees, and evidence is provided by a correlation analysis. Figure 9 shows a correlation between the input schedule variation and a change of the order sequences.

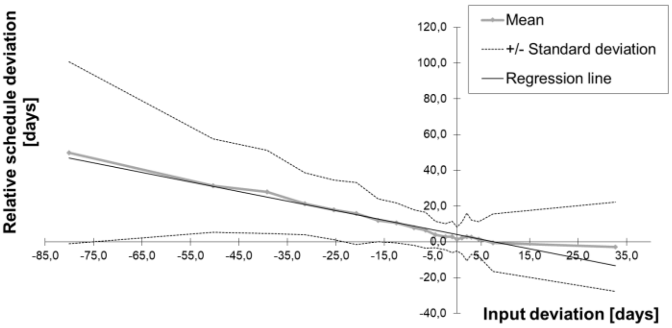

Fig. 9. Correlation analysis

Orders released too early tend to cause intentional man-made delays. The opposite case, the speed-up of delayed arrived orders, occurred in an extenuated form. Sequencing was used to balance the input schedule variation. In addition, sequence orders were changed to maximize performance. Time-consuming orders not requiring an employee's physical presence were started at the very end of a shift. As a result, the working time of the machines was on average up to 12 hours during an 8-hour shift. The existing input schedule deviation was identified as the main problem regarding the mean schedule deviations and variations. Combined with backlog and sequence deviations, the problem intensified but its relations remained hidden. The cause-effect relation tree helped to highlight the underlying reasons, identify the problem and show the complex interconnectedness between processes of a company's internal supply chain and KPIs. In this case, identifying the underlying reason could result in improvement of the schedule reliability in the end production stage, reduction of the stock level in the buffer and thus capital lockup costs.

4.3. Proposed counteractive measures

Depending on the main reasons identified by the cause-effect relation tree of schedule reliability, counteractive actions were identified. The reference to another logistic KPI was also taken into account. In this case, it led to the same cause-effect relation tree, and thus, the same actions as for a process upstream of the internal supply chain is appropriate. In this special case, the proposed counteractive actions can be summarized as follows:

- Release orders on the planned starting date.
- Qualify employees regarding double machine controlling and raise their awareness of the negative consequences of "local optimization" for the company as a whole.
- Provide replacements in case of sickness.
- Increase the capacity flexibility and reorganize the work plan of the construction process.
- Use performance orientated sequencing with consideration of the planned dates for each operation process.
- Focus on backlog when using flexible working hours.

5. Conclusions and outlook

In the complex environment of the manufacturing industry, the main reasons of low logistic KPIs are hidden. Common methods can lead to wrong interpretations because they fail to identify the underlying main reasons. Understanding the multi-causal interactions in logistics through all processes of a company's internal supply chain provides the foundation for increasing logistic KPIs and therefore market success. Systematic analysis can help to identify possible causes of problems. The presented approach helps companies to identify the relevant data and interpret it correctly. By visualizing the relations in a simple way, employees are enabled to understand the multi-causal interactions in logistics. The case study showed the practicality of the approach and that simple actions can increase the logistic KPIs. Continuously comparing logistic KPIs and applying the presented root cause analysis can be used to establish permanent control loops. Further research is planned to combine the approach with other methods. A hybrid methodology of a combination of value stream mapping and simulation models has been shown to increase efficiency in processes in other areas [14]. Given a database provided by SCM practices and IS the root cause analysis can be combined with this hybrid methodology to analysis changes in the value stream.

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