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Introduction of Traceability into the Continuous Improvement Process of SMEs

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Abstract

The digitization in the wake of Industry 4.0 offers small and medium-sized enterprises (SME) the opportunity to improve processes and products [1]. In this regard, gapless traceability represents a crucial element but is usually introduced by SMEs only due to extrinsic motivation [2]. Insufficient funding, lack of expertise and a poor market overview hinder implementation [3]. In order to improve realization, SMEs need to gain insight into the advantages offered by a traceability system [4]. Especially the potential regarding the usage of collected data within the continuous improvement process (CIP) provides the opportunity to implement product and process optimizations more effectively and efficiently. Consequently, this paper presents a concept, which shows how traceability can support and supplement the CIP. In this context, the granularity of information in a traceability system is relevant since the amount of data required for tracking and tracing a uniquely identifiable unit scales with the level of detail [5] [6].

The paper is structured as follows: After an introduction a summary of the state of the art comprising features of a traceability system, a definition of traceability granularity and commonly used Auto-ID systems is described. Section 3 matches the features of a traceability system with stages of the PDCA-cycle (Plan – Do – Check – Act) via waste sources and point out how the traceability system can be advantageous for each of its individual phases. How the granularity of traceability information influences the performance and the benefits of the CIP is demonstrated in Section 4. In addition, benefits of a traceability system in a production context are highlighted. Section 5 specifies the preferences of commonly used automatic identification systems and their typical use case regarding derivable traceability information in relation to the granularity of a system. Finally, future developments are discussed.

Keywords

Digitization; SME; PDCA; traceability; CIP; granularity; Auto-ID; case study

1. Introduction

The 4th industrial revolution offers a broad variety of digital tools to improve and enhance the production capabilities in the industry. The digitization of production and logistics chains and the implementation of a gapless traceability system are key in advanced data driven methods. Especially, the lacking implementation of traceability systems in small and medium sized enterprises (SME) entails the risk to lose the connection to key technologies and being in a disadvantageous situation in the global competition. Furthermore, it can lead to a disadvantageous position in the global competition. A conducted survey regarding the application of traceability systems in the industry shows that already 76% of the participants count themselves as users of a traceability system [2]. However, when the analysis is limited to SMEs, the application rate decreases to 33% which depicts a scenario that urges action. Furthermore, the survey provides reasoning behind the usage of such systems and shows that SMEs mainly implement a traceability system to fulfil a customer requirement or to obtain a certain certificate. Identifying faulty components or using the collected data to improve products or processes represent potential not utilized by the recipients of the survey. Concerns regarding the implementation of a traceability system result from the lack of qualified personnel, the non-transparent market situation for traceability systems and the technical challenge. [2] [7]

This paper aims to increase the application rate of traceability systems by demonstrating the benefits of implementing such a system beyond the sole fulfilling of customer requirements. Besides this extrinsic motivation, the intrinsic motivation for implementation needs to be stimulated. Demonstrating the benefits of using the data, that even a basic traceability system generates to support the continuous improvement process (CIP), leads to a better understanding and thus has the potential to increase the realization rate.

2. State of the art

The following subsections contain definitions and explanations of the relevant topics and principles this paper contains. Different aspects of traceability and the differentiation of tracking and tracing are explained in 2.1. In subsection 2.2 the term "granularity" in the context of traceability systems is defined and we concurrently offer a definition for future publications. The last subsection discusses the commonly used Auto-ID systems.

2.1 Traceability

The DIN EN ISO 9001:2015 [8] describes the requirements for quality management systems and gives a definition for the term traceability. Traceability in its core includes the identification of a unit or service and the availability of information connected to it throughout the whole production chain [8] (see also Figure 1).

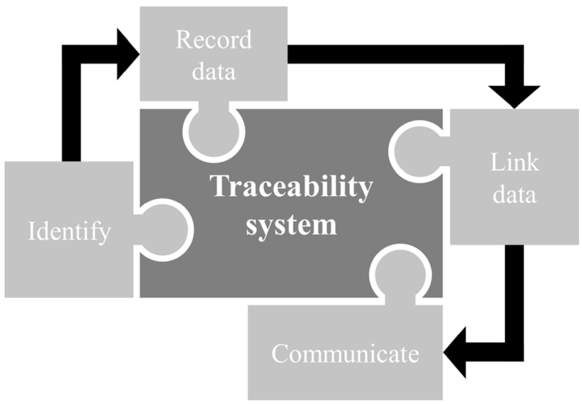

Figure 1: Core elements of a traceability system [9]

Ideally, a state-of-the-art traceability system contains the gapless history of a continuously identifiable production unit. In complex assembly groups, each unique identifier of the assembled parts is registered and attached to the finished product. Furthermore, the unique identifier is used to connect quality data, production parameters or settings of assembly machines with the final product. Ultimately, the gathered information is communicated along the supply chain and made available to the value-adding partners. [9] [10]

Traceability is no unidirectional ability. The corresponding flow of information can be interrupted and divided into tracking and tracing. Tracking can be used to locate the destination of an item and may be used to inform the successor in the production chain in case of a previously undiscovered production error. Tracing allows finding the origin of an inquired item as well as to identify the root cause regarding quality issues or reclamations (see Figure 2). This allows fast responses to deviations in product quality and quick reporting to the relevant recipient. Moreover, preemptive measures can be determined in order to avoid subsequent reclamations. [9]

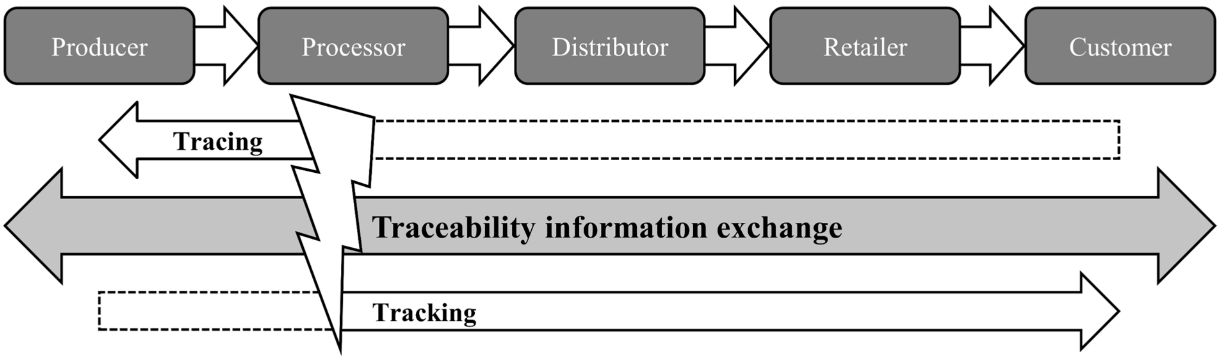

Figure 2: Traceability information exchange in case of an interruption in the production chain, according to [7]

Especially when combining quality and production parameters complex interdependencies of a system can be uncovered. Therefore, in the event of a quality issue outside of the influence of a specific actor in the supply chain, the size of recalls or compensation payments can be significantly reduced. Especially for the often used 8D reports it becomes easier to formulate an effective immediate action and to provide the root cause by reviewing the gathered production and quality data. [11]

The need to implement a traceability system can arise unexpectedly, e. g. when national laws change to protect customers. Thus, the food sector became closely monitored after food scares like bovine spongiform encephalopathy (BSE) or dioxin threatened consumer safety. Another motivation to use traceability systems is to avoid high compensation payments in case of product reclamations. [10] [11]

2.2 Granularity

Granularity is a broad term and is used in many different contexts (e. g. quantity of items inside a traceable unit, the accuracy of data, the level of detail in a supply chain, and software engineering [12] [13]) and therefore it is necessary to define the term . In the context of traceability systems, the term traceability granularity describes the level of detail concerning the gathered information for a uniquely identifiable unit or tracking unit [6]. In addition, it is important to point out that a tracking unit may not be one single item but may be a batch or bulk cargo which is unambiguously distinct regarding the connected information. The higher the level of the traceability granularity, the more specific data is acquired and needs to be managed. Furthermore, the requirements related to the identification of each level changes. [13]

For a detailed description of a traceability system the terms breadth, depth, precision and access are used. Breadth is used to quantify the amount of information and therefore data a traceability system has to record. Depth describes how far tracking and tracing is possible in a product life cycle. Precision measures the certainty of the location or the characteristics of a unit. The speed at which information is communicated to the stakeholders is described by access. [7]

To fully understand granularity in the context of a traceability system it is important to understand the differentiation between the amount of data and their quality. A traceability system with a high level of granularity not only has breadth but also precision. The data available is highly specific and connected to only few if not even a single distinct unit. Vice versa a traceability system with a low granularity level connects fewer data to more units, like batches or bulk cargo (see Figure 3).

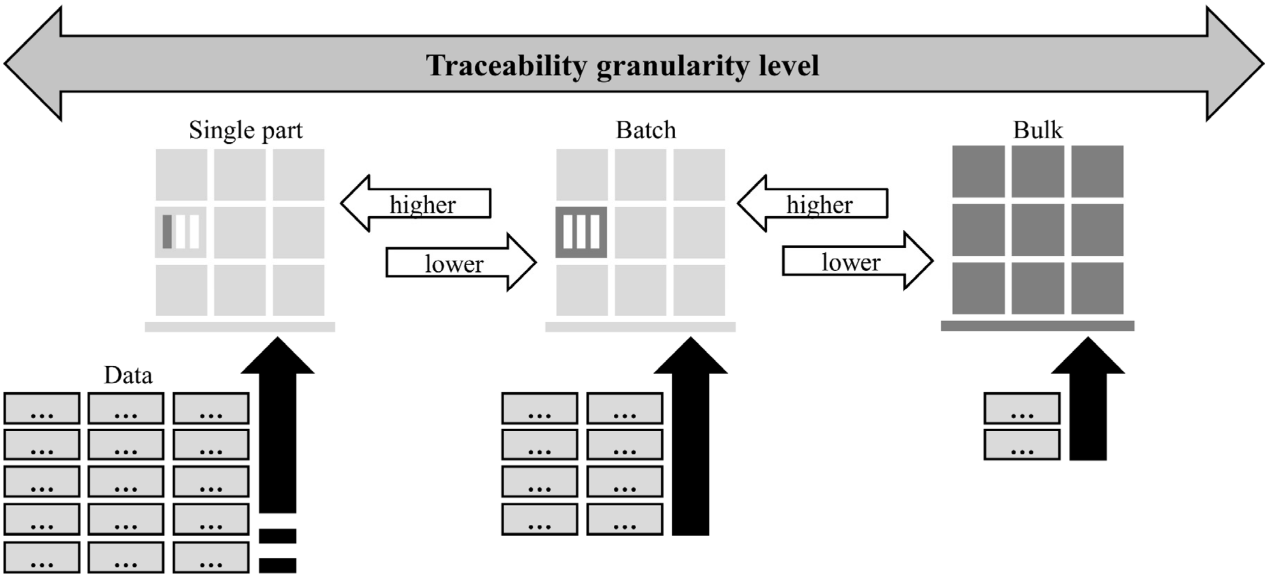

Figure 3: Traceability granularity level from single part to bulk

2.3 Auto-ID

Auto-ID systems are used to mark and identify a track and traceable unit. The key component of those systems is a unique identifier for each marked item. The previously mentioned traceability granularity determines the quantity inside a unit. [14]

The most common technology worldwide is the 1D-barcode. Within this system, every item in a store is identifiable by its product specific code. An evolutionary advancement is the 2D-barcode in form of quick response codes (QR-Code) or Datamatrix-Codes (DMC) which can store additional information. Thus, these codes can be used to not only identify a general product but also apply a unique serial number containing batch information or machine data. The reading of the labels is done by scanners or camera systems which need line of sight and enough contrast. [14] Marking via laser, printer, engraving or applying a label are common ways of applying the code to the item [15] [16].

Radio frequency identification (RFID) can store large amounts of data and can be read across long distances with a high speed. Depending on the design three types can be differentiated. Passive RFID labels consist of a chip containing the stored data and an antenna for transmission. Rewriting data is possible but in terms of industrial application, they are mostly read only. Apart from that, they need the energy transmitted by the readers signal in order to receive or send information. Active RIFD labels have an additional power source and can emit a long-range signal with just a trigger signal from a nearby reader. Semi-passive RFID systems also use a power source but lack an own antenna. Transmitting data works only by modulating the back scatter. [17]

The magnetic identification uses magnetic stripes attached to the traceable unit and carries a unique number to identify the item. A reader needs to be brought close to the magnetic surface to pick up the contained data. [14] Biometric identification or fingerprint technology uses randomly formed aspects of an item for an unambiguous identification. The tagging of an item is not needed but the reader needs to be configurated for the specific item in order to identify it reliably. [18]

3. Mapping of Traceability and CIP

The CIP as well as traceability systems are both customer-driven [19]. To gain a better understanding of the benefits of using a traceability system beyond the mere fulfillment of customer or legal requirements the added utility of such a system needs to be emphasized. One way to use traceability data from products or production facilities is to integrate the traceability system into CIP. The CIP, as part of a lean approach, aims to reduce waste in a production system by utilizing the PDCA-cycle. [20] In this context, a functioning traceability system is a key factor for the identification and elimination of the main factors influencing the generation of waste.

The most expensive waste in production is a defective product or scrapping of a finished product [21] [22] [23]. In some cases, rework is feasible and recovers some of the value which otherwise would be lost [19] [21] [23] [24]. The origin of faulty products is often hard to find and can be a result of design discrepancies or inadequate measurements to uncover quality issues. An incoherent database filled with redundant, non-uniform or even useless data can be a result from a lack of deep understanding of the processes or products involved [22] [23]. Over processing in form of converting or formatting data due to different systems used or a non-standardized interface for data exchange [21] [22]. This results in needless movement of information or redundant staff meetings [21] [22] [23]. Furthermore, a lack of convenient access to information wastes resources via transporting the information to the corresponding recipient [22] [23]. An additional issue of receiving and delivering information are communication barriers; whether cultural, physical or digital, they hinder or prevent the direct transfer of valuable knowledge and important information [21] [25]. Thus, inconvenient access to data combined with tedious formatting leads to extensive waiting times when providing relevant information to decision makers and participants in the production chain [19] [21] [22] [23] [25].

Other types of waste do exist, but a traceability system does not aid in their elimination. Since its features do not provide the necessary information as they are situated in a different organizational section in a company. Those are overproduction, non-standardized processes, outdated technology, useless information, lacking customer orientation and unused resources in development or scale effects [19] [21] [22] [23] [25].

The eliminable types of waste can each be assigned to a phase of the PDCA-cycle which in turn can be mapped with a core element of traceability systems. Consequently, the Plan-phase consists of checking the examined system for wasted resources, like defective or reworked products. The phase greatly benefits from the capability to identify parts unambiguously which assists in defining measures and identifying key performance indicators. Regarding the Do-Phase where the measures are implemented a proper recording of the identified key parameters is essential and a first impression of the effectiveness of the measure can be gained. A coherent database avoids over processing of data and assists in locating the root cause. In case of a severe problem or a customer reclamation the collected data from the traceability system can be used for an immediate response. Needless movements of data, information or employees obstruct the Check-phase and it becomes challenging to ensure whether the taken measures are robust. Being able to link the performance indicators to each identifiable unit allows to evaluate the actual outcome. In the Act-phase an optimized standard is implemented and needs to be communicated among all stakeholders across potential communication barriers. Especially customer reporting greatly benefits from the reduced waiting times provided by a traceability system. In addition, the change is easily monitored continuously and tracks the long-term effectiveness of the measures and their sustainability.

To visualize the previously described method the known PDCA-cycle is extended by the mentioned core elements of a traceability system as shown in Figure 4. After the successful completion of the PDCA-cycle a new cycle can be started. The gained knowledge can act as a foundation for the next iteration by identifying improvable potential in the product life cycle.

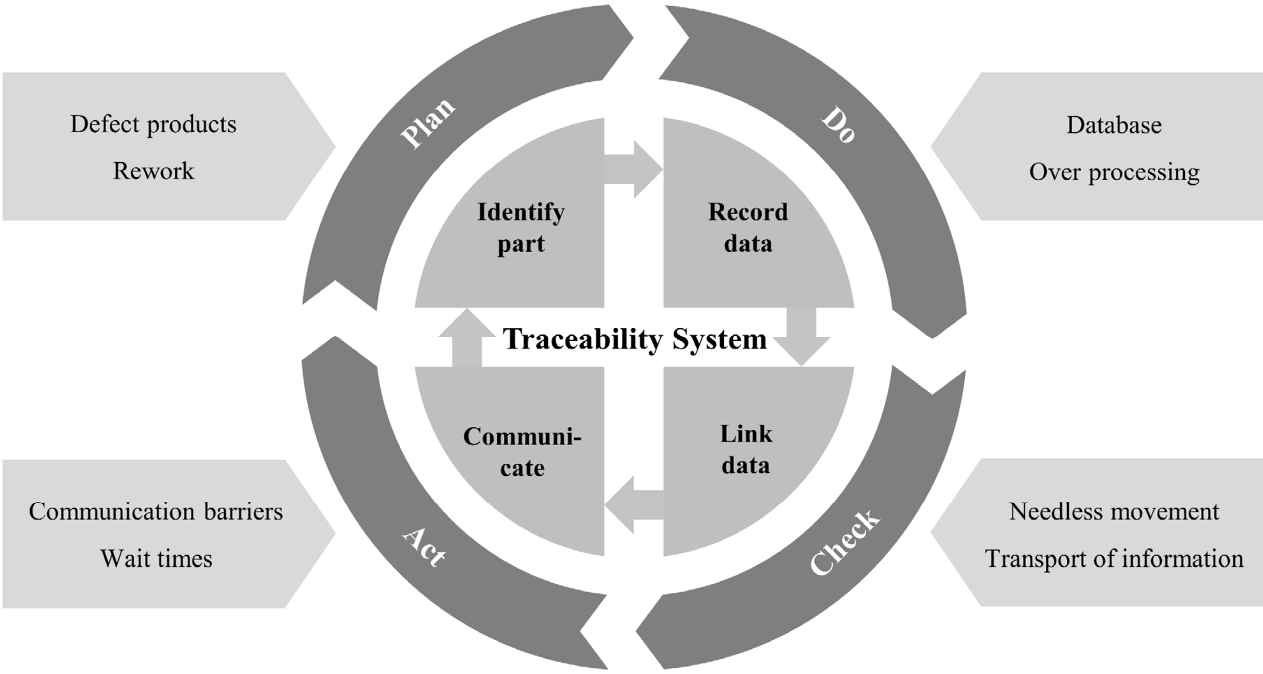

Figure 4: Extended PDCA-cycle with the core elements of a traceability system

4. Benefits of using a traceability system

This section is dedicated to highlight the benefits of using a traceability system via a few published use cases. Furthermore, it is outlined how different approaches can lead to different results. Special attention is given to the traceability granularity and the associated expenses to implement and operate a traceability system.

In general, not only the location where the tracking and tracing happens but especially the entrances and exits of closed systems like a factory or a chained production system are important aspects for the introduction of a traceability system [5] [26]. In order to select the best traceability system for a given task, investment and expected results, simulation can assist in comparing different solutions [27]. Resources spent on more granular data in traceability systems will be wasted if the return is not a more precise traceability [5]. Therefore, the technology and expected results regarding the introduction of a traceability system need to be evaluated. In this context, not only the investment for the system is relevant but also the added value for the customer can act as a unique selling point and increase sales. In order to estimate the value of implementing a traceability system, the failure mode and effect analysis can be used as a guidance to assess risks and responsibilities regarding faulty products. Furthermore, it has to be clarified that even a traceability system designed with a financially restricted budget can still be beneficial to the company itself and increase customer´s satisfaction [27]. With the introduction of a traceability system, the production chain becomes transparent and data of all relevant processing factors (e.g. order number, machine and tooling used, assigned personnel or quality measurements) can be tied to the finished product [10].

The food sector in the US offers examples regarding fresh produce, grain and life stock. Producers with a low packaging size transition easily to a higher level of granularity. When handling grain the elevator as a bottleneck serves as a batch size and allows traceability on a satisfying level. Regarding cattle, traceability systems allow for supply management and production planning as well as securing food safety. [28]

The Arizona State University demonstrated that the PDCA-cycle can be used as a tool to reduce energy consumption of the campus. However, to effectively plan an improvement they had to monitor and measure energy usage data for each of the buildings on the campus. Even though the available data had low level granularity it was enough to start the PDCA-cycle and begin with the improvement process [29]. Another example for the usage of low level and fuzzy data in combination with statistic modelling of product flow was showcased in factories processing fruits as well as dairy [30]. Especially when bulk cargo like apples in large bins is involved, changing packaging and reducing batch size can lead to better traceability even with documentation gaps in the product flow [5] [31].

Another example comes from a production line in an automotive plant where the quality team was unable to detect the root cause of a quality issue even though a traceability system was implemented. The result were extensive reworks of each suspected batch. A temporary increase of traceability granularity in the context of a PDCA-cycle was able to help identify the root cause by linking the parts with machine data and quality measurements. After the successful identification a new standard for the production was formulated. Additionally, the gained insight into the interrelations of different parameters offered new approaches for further improvements and can be used as a foundation for the start of the next PDCA-cycle. [32]

The above-mentioned cases demonstrate how traceability systems can improve product quality, assist in driving change in a production environment, serve as a foundation for the CIP and increase customer satisfaction. A functioning traceability system even with low level granularity can already help identify sources of waste, substantiate business decisions or serve as a database for simulations. The improved product quality and deeper process knowledge are beneficial for all parts of the value chain and can create an advantage in global competition. Since the presented use cases are insufficient for a general approach, they at least show the potential of implementing a traceability system. Furthermore, additional case studies could lead to a conclusive analysis of the benefits.

5. Auto-ID usage

The previous sections have demonstrated the benefits of using a traceability system and being able to uniquely identify a unit. Therefore, the use of Auto-ID systems becomes almost obligatory. Whether this unit is a single part, a whole batch or bulk cargo needs to be decided by the stakeholders of the product life cycle. In order to allow SMEs to focus their resources on selecting only the relevant systems available on the market, a small survey is conducted to narrow down the selection. The survey illustrates tendencies for common use cases of Auto-ID solutions regarding the identification of single products, batches or bulk cargo.

The interview partners are sales experts of different sensory system suppliers currently active in the market for traceability systems. The combined revenue of the companies in question surpasses €7bn. The first task in the survey is a paired comparison of the four Auto-ID systems mentioned in 2.3. Each system is compared with each other and the one more important gets a point. The cumulated result in form of a total score is illustrated in Figure 5. The experts emphasize that generalization in this regard is only possible to a very limited scope and highly dependent on a specific application. Nevertheless, the results allow a tendential assessment regarding the significance of the different ID systems. Especially the frequently predicted prevalence of RFID as the main ID system [18] [33] may not be true and should be further investigated via a wider survey. In the context of this survey the 1D / 2D-Barcode or QR-Code systems are most likely used for Auto-ID purposes. This does not mean that RFID is irrelevant since it also scores high on the 2nd place and should be considered when selecting a traceability system. Regarding biometric ID systems the experts also see a huge potential for identification purposes when mass marketability is achieved. The lowest score is awarded for magnetic ID systems and may have a use in certain applications.

Related to the common use case of each Auto-ID solution, the five interview partners are asked to rank the Auto-ID systems by their favorable application regarding traceability (see Figure 6). For each given use case the achievable score for the most relevant technology would be four points whereas one point would be awarded for the least relevant. For the tracking of single parts, the barcode is the preferred technology followed by RFID. The same applies to the traceability of batches. Regarding tracking and tracing larger quantities of units, the bulk case points out RFID technology as the preferred system of identification.

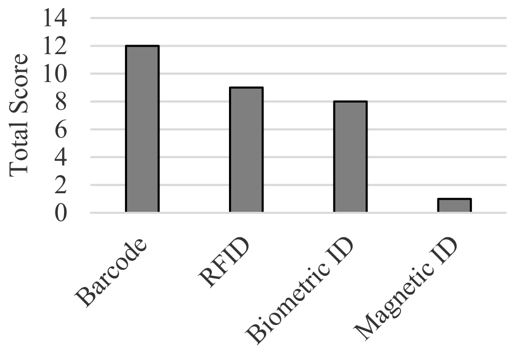

Figure 5: Comparison of Auto-ID systems

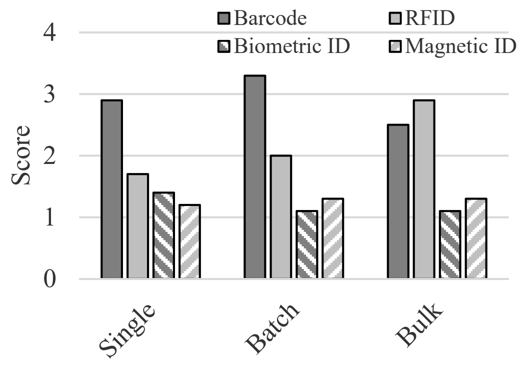

Figure 6: Preferred application of Auto-ID systems

Conclusively, a SME interested in implementing a traceability system needs to first check which level of traceability granularity is needed. Subsequently, it must be further investigated whether barcodes, RIFD solutions or a combination of both should be applied. Additionally, restrictions like reflective surfaces, electrical shielding or the involved processes need to be considered when deciding for a traceability system on a hardware level. Barcodes and scanners seem to provide a flexible solution in terms of application and achievable granularity. Thus, represent an ideal foundation for SMEs intending to gain first-hand experience.

6. Summary and outlook

The motivation behind this paper is to show the potential users of traceability systems the benefits of implementation beyond the fulfillment of external requirements. In this context the state of the art for the most important aspects and components is outlined, comprising the core of traceability systems, a definition of traceability granularity and the most relevant Auto-ID systems.

In order to motivate members of a supply chain to introduce a traceability system, the internal benefits are highlighted by combining the PDCA-cycle with the capabilities of a traceability system. This allows companies to eliminate waste sources identified by data collected via a traceability system. For a more convenient transition from a theoretical approach to practical implementation, use cases are presented that clarify the strategies for using a traceability system to improve processes.

Since the introduction of a traceability system requires specific traceability hardware, this paper further offers some guidance for choosing relevant technologies. The five experts from companies operating in the field of sensory hardware do not confirm the often-proclaimed widespread application of traceability systems via RFID. Rather, barcode technologies like QR-codes are currently the technology of choice. Nevertheless, each specific use case needs to be evaluated regarding its necessary traceability granularity. Tracking and tracing a single item is associated with a large investment, both financially and in terms of knowledge required, but also offers the most information. However, compared to bulk level traceability, realizing a traceability system for batches can already offer insights into processes and may act as a proof of concept for further traceability endeavors. Considering the limited scope of the survey further research is needed.

Especially SMEs are at risk of falling behind when it comes to the industrial developments in the wake of the 4th industrial revolution. Therefore, future research should seek to further lower the hurdles for implementations of traceability systems by emphasizing internal benefits and promoting a change within the companies. Even though the hardware aspect of traceability systems was briefly covered, each individual case must to be treated appropriately. Furthermore, the use of a suitable reference model would be advisable for planning purposes. The software side of traceability is missing in this paper because a first proof of concept or inhouse test should be kept at a manageable scope. For a holistic traceability approach including the whole production chain the used hardware and software must be considered in accordance with the concrete application.

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Biography

Nicolas Wittine has been a research assistant at the Department of Organization of Production and Factory Planning at the University of Kassel since 2019. After obtaining his Master of Science in 2016, he worked as a development engineer in the automotive industry and gained first-hand experience in the development of safety-critical components, project management and industrialization. Currently, his work focuses on traceability and production planning.

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