Digitalization in Small-Load-Carrier Management

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Keywords: Small Load Carrier, Returnable Transportation Equipment/Item, Return-to-Deliver, Computer Vision, Localization, Citizen Development, Internet-of-Things.

Abstract: In this article, we describe our research on digitalization in the field of returnable small load carrier (SLC) management. Our findings are the result of a collaboration between three companies and an academic institution. We apply various methods for modeling and analyzing digitalization measures that are already being prototypically implemented and discuss them in terms of transparency, data quality, resource consumption and costs. Our research enables academic researchers to build on real-world data and problems. For practitioners, we offer concrete solutions to increase the level of digitalization in their organizations. Unlike most other academic work to date, we focus on SLCs with their specific characteristics. This article could be the starting point for a higher impact and a growing number of research activities on returnable SLCs to make SLC cycles more efficient, which in turn will increase the sustainability of industrial packaging in general.

1 INTRODUCTION

The EU Packaging and Packaging Waste Regulation facilitates returnable packaging for consumers. Returnable packaging is also a CO2-reduced alternative to single-use packaging in an industrial context (Coelho et al., 2020). The term container as one type of packaging refers to any container, from large intermodal containers to small boxes, while returnable transportation equipment (or item) (RTI) usually does not include intermodal containers, but pallets and small boxes (Elbert & Lehner, 2020). SLCs belong to both containers and RTIs. SLCs are stackable plastic boxes that are smaller than pallets and are used both in production and for transportation (Ziegler et al., 2023).

An SLC can contain inlays or covers, which leads to a wide variety of possible SLC-sets. In addition, SLCs cannot usually be labeled with a reference to themselves, as all the space is reserved for labels on the SLC contents. Due to the large number and high density of SLCs in a warehouse, complete tracking with GPS, for example, is not possible. The large variety of SLCs in combination with the low value of a single SLC and the labeling challenges lead to poor availability of data on SLC cycles. It follows that digitalization helps to improve decision quality in SLC cycles. Since all of the previously listed attributes relate to it, we focus on the decisions in the SLC return-

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Dobhan, A., Eberhardt, L., Haseneder, M., Raab, H., Rabenstein, S., Treutlein, A., Wahyudi, V. and Storath, M.
Digitalization in Small-Load-Carrier Management.
DOI: 10.5220/0013363200003929

In *Proceedings of the 27th International Conference on Enterprise Information Systems (ICEIS 2025) - Volume 1*, pages 848-855
ISBN: 978-989-758-749-8; ISSN: 2184-4992

to-deliver process, which begins with the return of SLCs and ends with the delivery of refurbished SLCs to the cycle partners. Decision tasks have some degrees of freedom to align the output with the respective goals of the company (Ferstl & Sinz, 2012). In SLC management, decision-makers have to make a trade-off between high availability of SLCs and low inventories. We focus on the digitalization of decision tasks. As digitalization improves transparency and data quality, a lack of digitalization leads to less transparency, e.g. in detecting machine issues, material defects, shortages, or high inventories. These issues result in less use of returnable SLCs, which in turn leads to less sustainability in packaging in general.

With the digitalization of SLC cycles, however, it is possible to identify problems within the cycle more quickly and determine stocks more effectively. Furthermore, it helps to standardize processes and facilitates process visualization and transparency. Overall, this can open up new opportunities for the use of returnable SLCs, which means greater sustainability in packaging. Therefore, we provide an answer to the following research question:

How can decisions in the return-to-deliver process of returnable SLCs be digitized?

Our research is anchored in the DIBCO project funded by the State of Bavaria and which is being carried out by four partners. Lobster DATA GmbH, as a provider of logistics cloud software, sprintBOX GmbH as a logistics service provider and SLC management specialist, TAF Industriesysteme GmbH as a logistics system provider, and THWS as an academic research partner. According to our research, this is the first academic paper that examines digitalization in the entire SLC return-to-deliver process in detail and process-oriented (see section 2). Our findings could help companies digitize their SLC cycles to make them more efficient and increase their returnable quota. Future scientific research can build on the solutions we introduce below, improve them or offer additional digital solutions for activities in the process.

The organization of this article is as follows: After the introduction, we provide an overview of recent research in the field of digitalization in SLC management. Then, we first describe our methodology and then apply it to our use case. We then discuss the results from different perspectives and provide a summary and an outlook for future research.

2 STATE OF THE ART

To get an overview of the current research on digitalization in SLC management, we conducted a literature search with the following search term (digit* OR automat*) AND ("Small Load Carrier" OR "Returnable Transport*") in Scopus, Springerlink, and IEEE transactions. To focus on recent results, we only considered articles and conference proceedings published between 2019 and 2024. Scopus provided 10 publications, IEEE 2 publications and Springerlink 19 publications. The low number indicates that not much research has been published on this topic. This is due to the specific focus on SLCs or RTIs, which leads to an exclusion of intermodal containers, to which most research in this area refers. The relevant literature can be categorized into 3 groups: *Planning* which includes management and coordination activities, object recognition and sensors for *monitoring* the process, and *execution* activities, in particular SLC handling.

One *planning* task is the allocation of SLCs in the SLC cycle. Elbert & Lehner (2020) solve this problem for pallets using an agent-based exchange platform. Schneikart et al. (2024) discuss and partially prove the viability of using returnable SLCs for three use cases in the pharmaceutical industry. Cycle coordination requires data on cycle inventory and lead times of an SLC. In practice and in science, however, there is a lack of corresponding data, which is mainly due to a lack of data collection or an unwillingness to share data with the cycle partners (Müller et al., 2025).

One way to overcome these problems is to *monitor* the SLCs using sensors. Bemthuis et al. (2023) use pallet-specific data from temperature, vibration, and GPS trackers to predict the state of individual SLCs using decision tree models. Kreutz et al. (2021) focus on the fill level of the individual SLCs. Gan (2019) discusses an approach to find the best position for an RFID tag on an RTI. While all of the findings in the sensors category relate more to the SLC sensors themselves, the articles in the object recognition category contain findings on how to identify unlabeled SLCs. Rutinowski et al. (2024) set out to create a dataset from real-world data for the recognition of logistics objects on a store floor. They conducted experiments to create a large dataset for different logistics objects including SLCs. Abou Akar et al. (2024a), Abou Akar et al. (2024b), and Mayershofer et al. (2021) aim to create synthetic datasets for SLCs. Beloshapko et al. (2020) used a Mask R-Convolutional Neural Network to identify the bins.

Another perspective of digitalization relates more to the activities during process *execution* performed to the SLC, such as handling, cleaning, or transport (e.g. Blank et al., 2023). Overall, the literature review shows the following:

- The digitalization of SLCs mainly relates to the areas of object recognition, sensors, and handling.
- There is a lack of real data on object recognition, but also on SLC cycle data in general.
- The investigation of sensors refers to the pallets that store the SLCs and to the contents of the SLCs instead of the SLCs themselves.
- In terms of activities, the reprocessing activities such as cleaning are not digitally monitored or at least the research does not address this monitoring.
- There is little research on the coordination (management) of SLC cycles, although SLCs have specific characteristics described in the introduction.
- No article explicitly addresses the decisions in SLC cycles, despite their importance for sustainability in packaging.
- The detection of SLC defects is not part of the digitalization approaches published so far.

Our research aims to improve decisions in SLC cycles based on individual SLC data and the collection of real-world data in the three areas of *planning*, *execution*, and *monitoring*.

3 METHODOLOGY

To answer the research question, we apply a use case analysis as described in Eisenhardt (1989). The selection of companies was completed before the start of the project. To collect data, we used expert interviews, participative observation, analysis of documents from our project partners (e.g. defect catalogs), and project documents (e.g. requirements documents). From these, we extracted a BPMN model (OMG, 2013) that describes the return-to-deliver process from the arrival of soiled SLCs at the SLC depot to the delivery of clean SLCs. Based on the BPMN, we identified three relevant fields of decisions that had a low level of digitalization before the project and that we expected to significantly improve when digitized. To map these decisions, we applied a modification of the model by Dobhan & Zitzmann (2022), which is based on Sieben & Schildbach (1975). According to them, a decision consists of 5 elements (figures 2, 3, 4): Information gathering (1) refers to the collection of all necessary data and information. The objectives (2) include all relevant objectives for the decision. The decision field (3) contains possible decision options. The evaluated alternatives are listed in the results matrix (4), while the selected alternative is highlighted in the decision matrix (5). These activities are either implicitly conducted as thoughts or explicitly as a discussion on a sheet of paper, or within a software. In order to examine the degree of digitalization and automation of a decision, it is necessary to assign both degrees to each of these activities. In information gathering, digitalization means that the information is made available in digital form, while automation means that all the required information is automatically available to the decision makers in the right format at a glance. Manual information collection in ERP systems means manual effort and reduces the degree of automation to non-automated or only partially automated. The same applies to the consideration of objectives and the creation of the decision field, the decision matrix, and the results matrix.

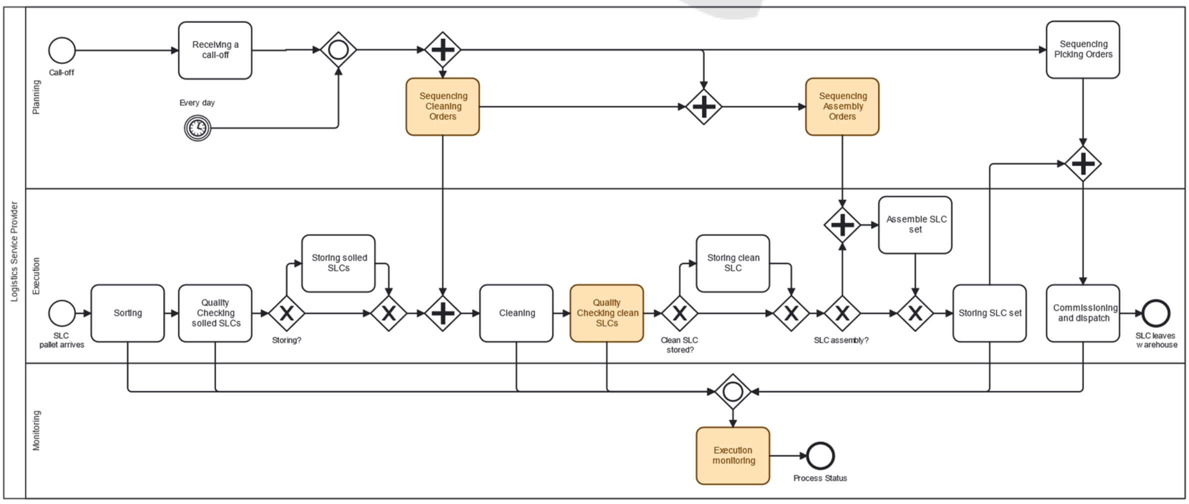

Figure 1: Return-to-Deliver Process for SLCs.

According to Ferstl & Sinz (1998), automation is represented by a square. In our application a filled square means that the task is fully automated, a white rectangle means that the task is not automated. A partially filled square means that the task is partially automated. The same applies to digitalization, but with a circle. The symbols on the left-hand side of the activity box represent the status before the project, while the activity on the right-hand side represents the (prototypical) achieved status with the proposed solution. In addition to this semi-formal description, we describe the measures taken in the use case in the text.

4 USE CASE ANALYSIS

Our use case analysis refers to the SLC management for an SLC cycle with more than two partners, which is mainly coordinated by sprintBOX GmbH. The solutions described are implemented as prototypes in the company. As technological partners, TAF Industriesysteme GmbH and the logistics cloud software provider Lobster Data GmbH supported the implementation of the required technological solutions. The return-to-deliver process is mapped as BPMN in figure 1.

We developed technological solutions for decisions that are currently carried out manually and partly digitally and for which suitable solutions are not readily available. We identified key *planning* decisions, a strongly experience-based decision during process *execution,* and decisions during the process *monitoring*. The technical solutions described below are prototyped.

Planning Decisions. The main planning task for the return-to-deliver process described above relates to the decision on the order sequence for the three main, partially decoupled activities of the process: cleaning, assembly, picking. In our project, we focus on cleaning order sequencing. Currently, the planners perform the sequencing tasks with paper and office software based on data from the SLC management software. The cleaning order is manually transferred to the store floor. During the project, it turned out that no standard software adequately met the requirements. Another problem is the dynamics behind the SLC business. After signing a contract with a customer, there is only a short period of time (from 6 months to a year) to implement processes in an often customer-specific depot. This requires highly flexible systems or at least a certain amount of development work. Therefore, and because a MS Power App environment was already in place, we decided to use Citizen Development. Citizen development means that non-IT personnel are enabled to take on development tasks (Binzer & Winkler, 2022). We implemented a prototype for sequencing cleaning orders based on a priority-based algorithm. To transfer the results digitally to the store floor, we have developed specific store floor views that show the results of the sequencing and allow the order to be started and stopped.

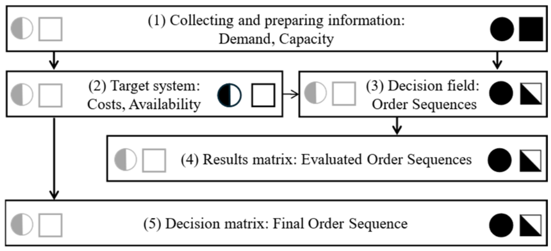

Figure 2: Digitalization and automation of sequencing.

With this solution, we are significantly increasing the degree of digitalization and automation of planning decisions (figure 2). The sequencing mainly uses demand, capacity, and inventory data as input. With our solution, most of the data is automatically collected and displayed in a software module for cleaning order sequencing. The software allows viewing different order sequences and suggests the best one.

Decisions During Process Execution. The quality of the SLCs is checked during the sorting activity and after the cleaning process. Both checks were carried out manually. We decided to develop a technological solution that digitizes and automates defect detection, built by TAF Industriesysteme GmbH and applied at a sprintBOX depot. We chose to develop the solution for clean SLCs because there are isolated components after the cleaning machines, which simplifies the handling of the SLCs for defect detection. Computer Vision (CV) as a method was at the center of the solution (Wahyudi et al., 2025; Ziegler et al., 2023). Defect detection (together with the SLC detection itself) should take place within 3 seconds, which is the cycle time of a cleaning machine. Another major challenge was to distinguish defective from non-defective SLCs. For example, it is difficult to distinguish a wet SLC from an oily one. To capture the SLC images, we implemented a portal with 5 RGB cameras. The cameras were mounted on aluminum rods and partition walls with lights ensure that the lighting conditions do not change. To find the most suitable model, we compared several state-of-the-art anomaly detection models for a selection of the 34 most used SLCs. A total set of 17,430 images was used for the experiments. After tuning the hyperparameters, the PatchCore (Roth et al., 2022) model proved to be the best in terms of the Area under the Receiver Operating Characteristic Curve (AUROC) with a value of 0.811. Our solution meets the requirements of detecting objects and defects within 3 seconds in a laboratory environment. In the SLC depot, the conveyor roller was modified to bring the SLCs into a position suitable for the cameras. The SLC images are taken automatically, the objectives are taken into account (not completely, but to a good extent), and the 3 steps to the decision are carried out simultaneously, digitally and automatically (figure 3).

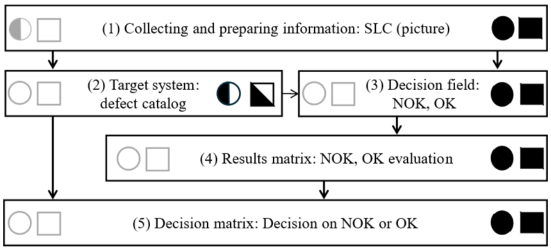

Figure 3: Digitalization and automation of quality check.

Monitoring Decisions. Process monitoring takes place in order to recognize target/actual deviations in process execution and to make a decision on how to react to these deviations. Without digitalization, monitoring was mainly experience-based and happened with the help of office documents supported by the SLC management software for the transactions with the cycle partners. The target values are specified in the order plans, the digitalization of which we described above.

Actual Values for Throughput Times. To get more information about throughput times, we have developed an approach that involves tracking only a few SLCs within a cycle. A complete data collection covering all SLCs in a cycle would be far too expensive, as each SLC costs no more than 1 Euro. Following Müller et al. (2025), we used the sample data as a basis to extend the data from there and perform a simulation analysis to help us gain more insights into the actual cycle throughput times. The technological requirements for the tracking system mainly relate to cost, precision, localization capabilities, and size. It turned out that Apple Air Tags were the most suitable technology. Using them, we collected the data for 10 runs in a test cycle (2 routes, 4 locations), enriched the data with transportation times from navigation apps, and used a PERT distribution to extend the data and apply it to a Monte Carlo simulation (Müller et al., 2025). For display and export of tracking data, we developed an app for Lobster logistics.cloud.

Actual Values for the SLC Quantity. Knowing the SLC quantity in the process helps to understand throughput times, but also inventory levels. Since the previously presented tracking approach mainly considers the times between cycle locations and is only designed for a small sample, it would be beneficial to know the number of objects processed by the activities within the SLC depot. Before digitalization, the number of SLCs was counted manually on a paper. The data transfer from the paper to the system leads to delays of several hours or even days. This prompted us to combine object detection with defect detection. In Wahyudi et. al. (2025), we propose a CV based approach for classification. We use ConvNeXt (Liu et al., 2022), which allows us to achieve an accuracy of 100% for the same sample as for the defect detection. We achieved that using the same portal as for defect detection. To extract the detection data we applied a prototypical IoT architecture via MQTT and Web Services. Together with tracking data the object detection data allows more insights into the current process and inventory status.

Actual Values for the Machine Status. As there are only a few cleaning machines in each depot, this is also the most critical process of the entire depot. Before the project, the cleaning machine was only monitored locally in the store floor. To improve this in order to increase capacity and reduce downtimes, dashboards of the machine data were created and made available to the central departments and site managers. To do this, we applied an IoT architecture that connects the machine control software (in the prototypical case a Siemens Simatic S7) via VT Scada (a Scada software). Even more important was the alert management. As soon as a value was outside a certain threshold, e.g. the temperature, an alert was displayed, which also enables documentation of the cleaning machine's availability.

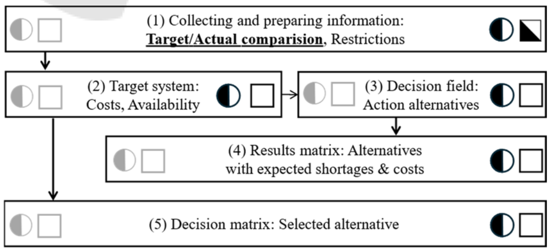

Figure 4: Digitalization and automation of monitoring.

In summary, we digitized the most relevant target and actual values to improve the process monitoring and enable decisions on how to deal with target/actual deviations (figures 4). It changes the digitalization of inputs. The trade-off between cost and SLC shortages as well as developing, evaluation, and selection of the reaction remains partially digital and not automated.

5 DISCUSSION

Our research aims to develop solutions for the digitalization of the return-to-deliver process of returnable SLCs to make the cycles more efficient and to make companies use them instead of single-use packaging. During our research, we developed prototypes for each solution mainly addressing technological feasibility for given constraints, such as the avoidance of labelling each SLC or new tracking infrastructure (other than the cameras). Therefore, our focus was not on overcoming organizational barriers to new technologies such as machine learning (Schkarin & Dobhan, 2022). Also, we cannot provide results on the scalability of our solutions or the impact of large-scale deployment. As with all case study analyses, in addition to the findings from the literature review and their embedding in academic research, it is mainly the company-specific practical experience which guided our development activities. Validity for other companies could not be proven in this article. There could be other limitations in other companies. Furthermore, the prototypes are still under development, which leads to minor implementation issues, e.g. an increase in inference time when the recognition SLC quantity advances. Nevertheless, our scientific contributions are clearly the following:

- In contrast to most previous work, we strictly focus on SLCs with their specific properties (see Elbert & Lehner, 2020; Ziegler et al., 2023).
- We collected SLC-related data from a real environment for localization technologies and CV. A lack of both has been identified in previous work (Abou Akar et al., 2024a; Müller et al., 2025)
- We discuss the application of citizen development in SLC planning as a new suitable use case for citizen development (Elshan et al., 2023).

Table 1: Impact of digitalization measures.

	Planning	Execution	Monitoring
Transparency	**Recognition** of status (current plan is available for all stakeholders) and problems (delays or capacity shortage is visible for all). **Facilitation** of communication (results can be easily communicated to the store floor and the users which have access to order list). **Enabling** decision-making (information is displayed in an usable way, the decision on order sequence is simplified).	**Recognition** of status and problems (defects are detected automatically and recorded in the system). **Facilitation** of communication (digital recording and communication of the defects enabled). **Enabling** decision-making (the decision-making on defects is completely handed over to artificial intelligence)	**Recognition** of status and problems (target/actual deviations are recognized easier). **Facilitation** of system performance (digitalization of values enables to check the system performance (actual to target)). **Enabling** decision-making (more information usually can improve decision-quality on reactions).
Data Quality	**Accessibility** of plans for all relevant stakeholder every time in parallel. Software ensures **completeness** of data. Concise **representation** through development by users. **Consistency** of data because of the single source. **Timeliness** as the plan is available immediately after release.	**Alignment** with defect catalogues via training data **Consistency** because decision is made by software. **Objectivity** because decision is made by software. **Traceability** at least regarding responsibility and timestamp. **Unambigous** data (ok, nok).	**Accessibility** of monitoring data for all relevant stakeholder in parallel **Accuracy** because of detailed actual values **Believability, Objectivity** as data comes directly from sensors. **Timeliness** as sensor data is available immediately. **Traceability** because data sources are clear by design.
Resources	Avoidance of **paper** for communication, Reduction of **inventory or shortages**. Less **emergency transports or orders.**	Avoidance of **additional transportation** and **inventory** of defective SLCs, Only defective SLCs are excluded.	Early detection of problems => less or shorter machines stops => **less emergency transports or orders**. Avoidance of unnecessary resource **consumption.**
Costs	Cost for Power App **license**, Non-IT-**resource cost,** hardware **cost** (screens etc.).	Camera portal: **cameras plus lighting (< 5k)**, **Material and personnel costs** for building the portal and changing material handling.	Apple AirTags (25 Euros each plus Apple Laptops), VT Scada license (~10k euros) plus preparation and configuration of existing machine, Camera portal.

- Furthermore, we slightly modified and applied the approach of Dobhan & Zitzmann (2022), which can be easily transferred to other decisions to examine the degree of digitalization and automation.

The digitalization of business processes aims to increase transparency, reduce resource consumption, and improve data quality. On the other hand, digitalization efforts incur costs for the implementation and operation of digital solutions. We therefore shed light on the impact of our solutions on transparency and data quality as well as on resource consumption and costs (table 1).

Transparency. According to Klotz et al. (2008), transparency means that stakeholders understand the necessary aspects and status of operations at all times. In their study, they provide an overview of various attributes of transparency. Specifically, each of our digitalization efforts has the effects listed in table 1.

Data Quality. According to the extensive literature review by Wang et al. (2024), data quality has various dimensions, such as accessibility and timeliness. An overview of the effects on these dimensions is given in table 1.

Resource Consumption. The previous digitalization effects also have an impact on resource consumption. However, as we have only implemented our solutions as prototypes so far, we do not yet have any detailed figures on the impact on resource consumption in day-to-day business. Nevertheless, we describe the expected effects in general in table 1.

Costs. The implemented solutions are only prototypes of a funded research project, which makes it difficult to estimate investment costs. Our research shows that the current and future benefits of SLC digitalization should more than compensate for the costs.

6 OUTLOOK

Our research investigated the digitalization of the SLC return-to-deliver process. The technological application could be a blueprint for the digitalization of the most important activities in the SLC return-to-deliver process. In a next step, the developed solutions should be distributed to more machines, cycles, and locations in order to validate them for mass use. The solutions introduced can make returnable SLC cycles more efficient. This could lead to a higher use of returnable SLCs, which in turn increases sustainability in industrial packaging. From a scientific perspective, our research contributes real data and use cases in the context of SLC management, which according to our research has rarely been addressed before. It is the basis for further research on the following topics.

- Future research should strive for fully automated planning with automated event handling.
- Regarding sensor-based SLC time data, an approach needs to be developed that combines tracking data with data from the SLC management software to determine an SLC target inventory. To this end, it is interesting to investigate how SLC management can benefit from process mining.
- It should also be analyzed how beneficial the tracking of each individual SLC is. An SLC history could help to understand the behavior in SLC cycles.
- In terms of CV, additional research is needed on how to improve the results of defect detection considering additional data and how to recognize the degree of SLC soiling to derive information for a decision on required cleaning activities for each SLC.
- Finally, from a strategic decision-making perspective, the decision to digitize the SLC return-to-deliver process should be analyzed by using decision quality measures.

ACKNOWLEDGEMENTS

This research was funded by the research program "IKT" of the Bavarian State (DIK-2105-0044 / DIK0264), submitted by THWS. We would also like to thank Sebastian Friedl, Fabian Freund, Christian Marder, Rasha Mahodudi, Stefan Schramm, and Jan Senner for their valuable prework on this study. For grammar and vocabulary check, we applied deepl.com, for proofreading in general instatext.io.

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