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INCREASING THE EFFICIENCY OF CLOSED LOOPS OF REUSABLE CONTAINERS IN PRODUCTION ENVIRONMENTS CONCERNING CONTAINER CLEANING

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Abstract: Today reusable containers, widely used in closed loops in production environments, are cleaned irrespective of their cleanliness-status and thus the actual necessity for being cleaned. This often leads to a considerable degree of technically superfluous container-cleaning, associated with high costs, transport efforts and resource utilization. This paper aims at investigating ways to harness the savings potential of a necessity based triggering of the cleaning process amid securing the quality of the container supply, controlling the uncertainty introduced into the container-loops through the status-dependent triggering of cleaning and establishing a process transparency enabling a reduction of the overall container inventory. A case study performed in an automotive supplier is included.
Keywords: reusable container, efficiency, container management, Auto-ID

INTRODUCTION

In modern production, in particular in the automotive supply chain, reusable load carriers and small containers are widely and increasingly used [1] [2] – yet, little effort and attention goes into the management of the container loops and the cleaning process of the containers, resulting in high costs of container usage. This paper presents a concept in the making, aimed at increasing the efficiency of container management and the container cleaning process in particular, by building a concept around the status dependent cleaning of containers and increasing the controllability of the container loop with Automatic Identification Technology (Auto-ID).

In the majority of current industry applications the level of transparency in container loops is very low [3]. To ensure a secure supply of containers and load carriers for production processes, companies have to rely on high safety stocks. Furthermore, since the containers have to be cleaned regularly, due to dust and dirt exposure in production and logistics processes, and are cleaned irrespective of their actual need for cleaning, the cleaning efforts – costs and resource consumption – are higher than necessary. Since the cleaning process is usually conducted by external washing-plants, transports and handling efforts arise and lead to unnecessary emissions of CO_2 gas. Although the current ineffectiveness of these container and load carrier loops leads to significant excess costs, resource consumption for the companies as well as environmental pollution and strain on transport and road networks, the problem of container management is underrepresented in both companies' development schemes and scientific publications.

The aim of the presented approach, which is currently being developed in the course of a research project, is to reduce the cleaning efforts by applying an automatic detection of the container cleanliness status and only sending the soiled containers to the cleaning-bay, while introducing an Auto-ID supported container loop monitoring and control that could enable a lower overall container stock in the system. Included in the *research consortium are Auto-ID system providers, experts in sensor-technology as well as application partners in the automotive supplier industry. A case study with the latter is an integral part of the ongoing work.*

This paper is meant to provide an overview of the subtopics involved in the project, present the approach, report on the current status and give a preview of some preliminary findings of the work so far.

FUNDAMENTALS, BACKGROUND & DEFINITIONS

The following section will give a brief background of the terminology associated with the presented problem: containers and container management as the main subject including the current concepts available for this planning task, followed by dirt detection and measurement and finally Auto-ID as the key elements of the new approach.

Container Management

In modern production reusable load carriers are widely used in closed loops inside production plants as well as in open loops including suppliers and customers. This is especially true for the automotive industry where the standardized load carriers and small containers are used in transport, consignment and picking systems. Furthermore, modern logistics concepts with standardized transport and handling concepts require standardized load carriers, which also help increasing process safety and quality – nonreturnable packaging in contrast is prone to facilitate the formation of dust on the production floor – and enable (partially) automated handling and transport processes for material [4].

The term container in this context refers not to standard metal freight containers but rather to all kinds of (smaller) Reusable Plastic Containers (RPC) and load carriers used for transporting, handling, supplying and picking of material [5]. In the latter category there are pallets, load carriers and small load carriers as well as blister trays that are tailored towards holding a batch of a certain material and are usually contained within Small Load Carriers. The standardized plastic Small Load Carriers are very common in a large variety of production environments and are the container type considered in the case study.

Due to the sheer number of load carriers in industry applications – in a typical load-carrier loop associated with one production plant, such as the inventory of load carriers in the case study, can easily exceed a million units – and with a unit price of ~15-4.000 € [5] the costs associated with setting up, maintaining and using this kind of load carrier are an important factor for the operating costs of a production. The costs involved are [6]:

- *inventory costs (i.e. capital holding costs)*
- *maintenance costs*
- *administration costs*
- *handling costs*
- *depreciation costs*
- *storage costs*
- *out of stock costs*

The goals for a container management system, derived from the basic logistics goals, are:

- *ensuring a timely supply of containers at the point(s) of use*
- *low operating costs*
- *low inventory costs*

Despite the importance to manage these load carrier loops efficiently to secure a reliable supply amid the lowest possible operating costs, this topic has largely been neglected by the companies that maintain the container loops as well as by researchers [6]. A study conducted by the University of St. Gallen shows that almost a third of the companies have no IT-support for their container management, another third at least registers the load carriers in their ERP system, but only a minority employs systems that support the planning, monitoring and control of their load carrier logistics.

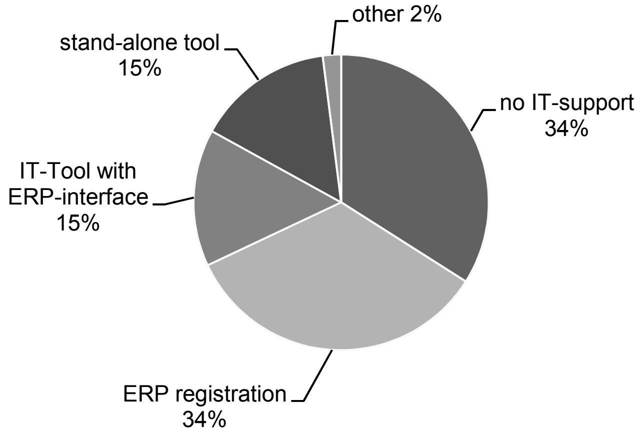

Figure 1 – Tools used by companies to manage container loops, source: [6]

One measure that is increasingly applied in the industry is outsourcing the container management and logistics to a third party logistics provider – thus creating cost awareness within the service requester.

Dirt Measurement

As mentioned in the introduction, it is common practice in companies using small load carriers to have their containers cleaned irrespective of the actual need for the specific container to be cleaned. This, together with the high number of containers in a system and the necessity of transports for an outsourced container management and cleaning, potentially leads to either excess costs plus resource consumption due to the unnecessary cleaning of still clean load carriers or to a compromised quality due to soiled load carriers being fed into production processes. An initial survey among companies indicates the first effect to be of more relevance than the latter.

To prevent this excess effort, the presented approach incorporates a cleanliness-status dependent initiation of cleaning processes for every load carrier. This can be achieved by implementing the following three options, all of which are currently being investigated in the research project:

- manual control of the container-cleanliness status (visual inspection)
- (semi-) automatic control of cleanliness status (using sensor technology)
- determining the number of cycles or time spent in the system that a container can be used before it has to be cleaned and monitoring every container accordingly (i.e. via an Auto-ID system)

The (semi-) automatic identification has to rely on the technical implementation of measuring dirt on the outside of and inside the load carriers. Dirt in this context can be residues originating from exposure of the containers to its environment in production, handling or transport processes that have the potential to compromise the quality of the material that is being transported and stored in the containers. This includes liquids, dust, chips and residues from packaging materials and labels. Figure 2 shows possible measuring principles for measuring dirt that are potentially relevant in the context of load carriers [7].

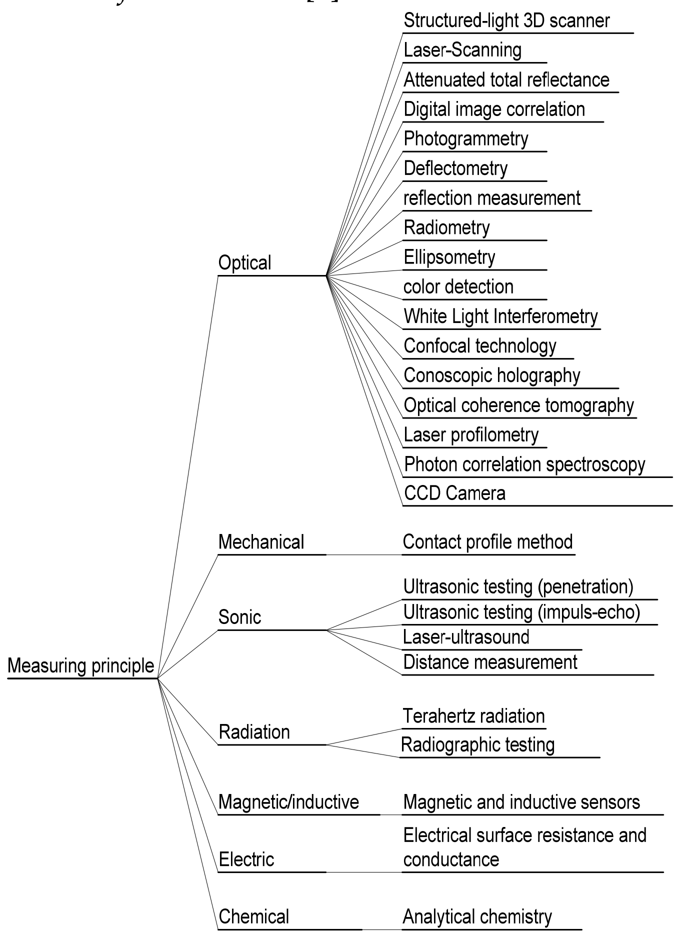

Figure 2 – Overview of measuring principles for dirt measurement

Basically the measurement can be based on identifying the shape, color and size of dirt on the container surface or it may detect changes in material behavior (e.g. conductivity, reflection) or it might identify physical characteristics of the material that constitutes the dirt (e.g. mechanical, chemical, optical or electrical characteristics).

Auto-ID

The third option of achieving a status dependent and thus demand-based cleaning of every load carrier, monitoring for every container the time spent in the system or the number of usage cycles, can best be achieved by employing an Auto-ID system. This technology enables the quick and automatic identification of every individual load-carrier in the system at every identification point – for example after being used and emptied in a production facility – so that the status of every container can be monitored, e.g. with a barcode and updated either in a corresponding database or, with *some Auto-ID technologies like RFID, directly on the container itself, thus reducing the necessity for a permanent connection to a database IT-infrastructure.*

The characteristics of Radio-Frequency Identification (RFID), compared to other Auto-ID technologies, are the ability to identify objects via electromagnetic waves sent between RFID readers and transmitters (tags), transmitting information about the object from the tags to the readers. It is possible to identify multiple tags on multiple objects virtually simultaneously and some tags also enable changing the data saved on the tag memory, which is called dynamic memory. While the basic functionality of RFID is the automatic remote identification of tagged objects, the technology offers a large variety of additional benefits and applications, utilizing the full range of technical capabilities and the versatility arising from a combination of the RFID technology with other information technologies, such as WLAN, Sensors and GPS modules [8].

Since RFID enables both options, database storage of status information and a dynamic memory with decentralized data storage, and a recent study [6] indicates that experts consider the potential for an RFID application in the field of container management as very promising, it will be the major technology investigated in the context of the current research project as well as in the case study.

METHODS AND CONCEPTS

In the section to come, the key conceptual elements of the approach and their development and adaption will be presented, starting with simulation as a way of predicting the effects of changes in the complex system of container loops and thus providing a tool to design and evaluate possible new and improved container loop configurations. This is followed by methods-time measurement (MTM) as a concept of ensuring simulation results with relevance to planning real world industry applications. Also, the development of the envisaged container management configurator concept, incorporating the simulation element, will be introduced.

Simulation

The system of a reusable container loop is a complex logistical system with a complex system of goals. The system complexity arises both from the multitude of input variables and actuating variables – e.g. work schedules, capacities, arrival rates – as well as the number of stations included in the material flow – e.g. various load carrier types and various interdependent workstations were they are combined, batched, separated, stored and transferred.

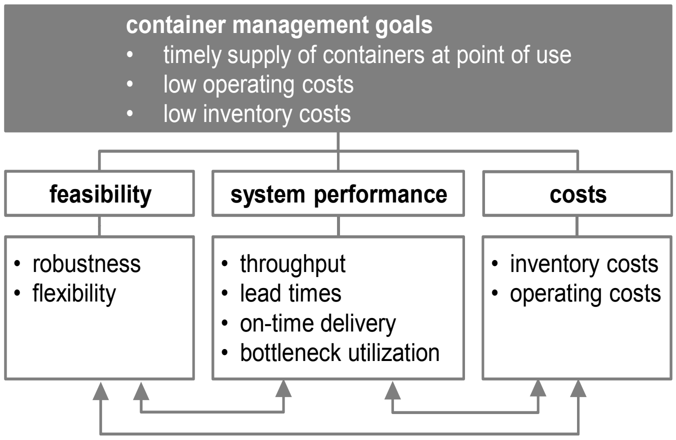

Figure 3 – Basic goal system for the simulation of container loops

Figure 3 illustrates the goal system. Another method of planning complex systems are optimization techniques that may also be combined with simulation – in that case simulation works as the evaluation function of the optimization algorithm [9]. Due to the complexity of optimization techniques and the fact that the problem at hand is not trying to optimize one given system but creating and comparing different model system variants – to be able to evaluate the effects of introducing automatic cleanliness detection and Auto-ID and to compare these variants – simulation will be used without optimization in the current work.

Simulations can either be:

- *dynamic or static*
- *deterministic or stochastic*
- *continuous or discrete*

In the context of material flow simulations in logistics processes, usually a dynamic system behavior with stochastic components is being observed at different points in time in what is called a Discrete Event Simulation (DES) [9] [10].

Determining the apt degree of detail for the simulation model is the main objective of an economic model building approach since more detail results in complexity, which in turn results in increased modeling efforts. There are different modeling environments available for simulation tasks – some of which are based on rather basic coding while others are more end-user-oriented and require less simulation specific knowledge; the latter will be used in the course of this research project.

Methods-Time Measurement

In order to create a realistic simulation model and to be later able to create reliable results of what-if scenarios of different model variants, it is crucial to determine realistic parameters for the simulation model, especially for the not yet implemented future scenarios that are to be evaluated. In order to obtain reliable parameters for logistics operations, especially those including manual operations that are prone to a high stochastic fluctuation, the planning tool Methods-Time Measurement (MTM) will be applied. MTM is a system of predetermined motion times for manual operations, originating in industry research by Maynard, Stegemerten & Schwab in 1940s [11].

The system is based on standard times for basic manual movements such as grasping, reaching, moving and releasing, which were originally analyzed by experts evaluating high speed camera footage of these operations being executed by skilled workers, considering the factors effort and skill of the workers, as well as the conditions of the working environment and consistency of the work performance [11]. While the predetermined times do factor in learning effects, they still include a certain amount of buffer capacity, so that skilled workers can achieve the times without difficulty. All movement-times in MTM are measured in Time Measurement Units (TMU), with one TMU equaling 0,036 s, and are encoded in a standardized format, defined by the MTM council. In recent decades, the standard time system for basic movements, named MTM-1, has been complemented by accumulated times for more comprehensive movements, ranging from movement combinations to basic processes to entire work procedures in specific industries [12], as shown in Figure 4. For the logistics processes in the context of simulating load carrier loops, the system of standard processes for logistics will be applied. Using these aggregated time modules defined for certain fields of application, i.e. standard logistics procedures, rather than conducting a detailed MTM planning from scratch for every process used in the simulation model, helps keeping the simulation model at an appropriate level of accuracy and thus avoiding excess modeling efforts. However, it is necessary to ensure the validity of the aggregated time modules for every processes in the simulation for which they are used.

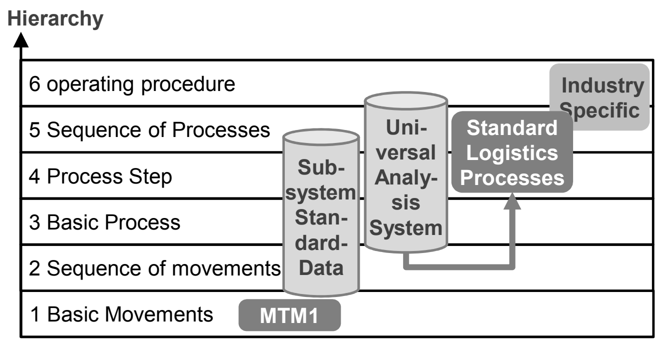

Figure 4 – Overview of the system of MTM standards, see: [12]

Resulting Concept

Simulation and the MTM aided configuration of the logistics material flow model of container loops are the core methods that will be adapted and developed, together with technology selection methods for Auto-ID and dirt measurement, into a configurator for an optimized container management, including a demand dependent container cleaning scheme. An overview of the configurator concept currently in the making is depicted in Figure 5.

The configurator is meant to provide planners with a tool with which to assess the opportunities of integrating a status dependent cleaning of containers as well as integrating an Auto-ID supported container management. It will support the selection of both technology systems, according to the requirements, using a questionnaire, by giving recommendations for suitable system variants. The tool will further assist in mirroring the current situation of a container loop and generating possible future state variants. As a last step, the system will enable a comparative evaluation of current state and the generated *future state variants, according to logistics performance criteria – the goals of which are defined in the sections 2.1 and 3.1 – thus providing planners with recommendations for improving their container loops.*

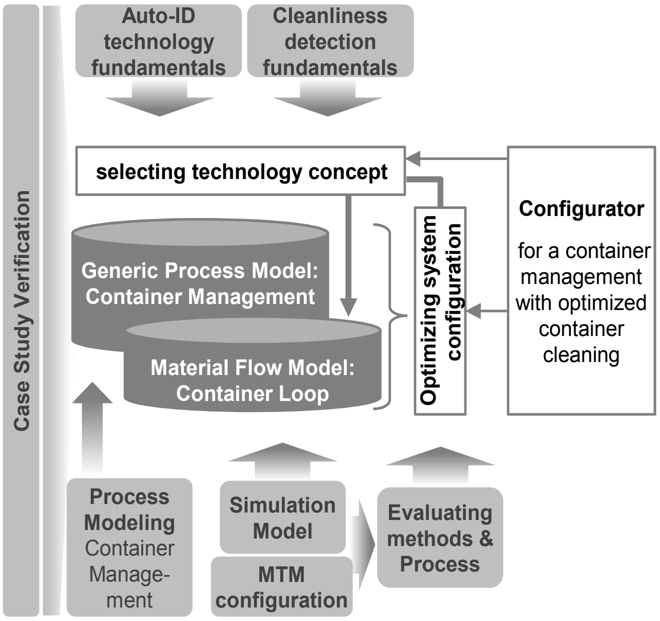

Figure 5 – Overview of the container management approach

CURRENT AND PRELIMINARY RESULTS

The section to follow is meant to give a brief report on the current status of the research work and show exemplary preliminary results gathered so far.

Technology Selection

In order to find a suitable technology for the semi-automatic detection of dust, thus enabling a cleanliness evaluation of the containers in a loop, the measuring principles and options in section 2.2 have been investigated. All options have been evaluated according to their principal technical ability to detect the type of dirt that is to be expected in container loops in industry settings.

Furthermore, an evaluation concerning the prospect of each technology to be implemented in a real life factory environment and the effort associated with this implementation have been evaluated. An evaluation table on the example of optical measurements is shown in Figure 6.

Due to its availability as standard products, its robustness and history in other industry applications – e.g. quality control applications – and the relative versatility in detecting a variety of "dirt" types, the first technology to be investigated in detail is the use of CCD-cameras, in combination with an image processing algorithm to detect dirt particles in container images.

<table>
<tr><th rowspan="2">Measurement Principles</th><th colspan="4">Dirt Type</th></tr>
<tr><th>Chips</th><th>Liquids</th><th>Dust</th><th>Packaging residues</th></tr>
<tr><td>Structured-light 3D scanner</td><td>◕</td><td>◑</td><td>○</td><td>◕</td></tr>
<tr><td>Laser-Scanning</td><td>◑</td><td>◑</td><td>◔</td><td>◑</td></tr>
<tr><td>Attenuated total reflectance</td><td>◕</td><td>◕</td><td>◑</td><td>◕</td></tr>
<tr><td>Digital image correlation</td><td colspan="4">○</td></tr>
<tr><td>Photogrammetry</td><td colspan="4">○</td></tr>
<tr><td>Deflectometry</td><td colspan="4">◔</td></tr>
<tr><td>Reflection measurement</td><td>◕</td><td>◕</td><td>◕</td><td>◕</td></tr>
<tr><td>Radiometry</td><td>◕</td><td>◕</td><td>◕</td><td>◕</td></tr>
<tr><td>Ellipsometry</td><td colspan="4">◔</td></tr>
<tr><td>Color detection</td><td colspan="4">◔</td></tr>
<tr><td>White Light Interferometry</td><td colspan="4">◑</td></tr>
<tr><td>Confocal technology</td><td colspan="4">◑</td></tr>
<tr><td>Conoscopic holography</td><td>◑</td><td>◑</td><td>◑</td><td>◑</td></tr>
<tr><td>Optical coherence tomography</td><td colspan="4">◔</td></tr>
<tr><td>Laser profilometry</td><td>◕</td><td>◑</td><td>◕</td><td>◕</td></tr>
<tr><td>Photon correlation spectroscopy</td><td colspan="4">○</td></tr>
<tr><td>CCD-Kamera</td><td>●</td><td>●</td><td>◑</td><td>●</td></tr>
</table>

● **"suitable":** technically fit for the application, practical implementation well foreseeable

◕ **"limited suitability":** technically fit for the application, practical implementation complex

◑ **"possibly suitable":** technically in principle fit for the application, practical implementation probably problematic

◔ **"impractical":** technically theoretically fit for the application, practical implementation not foreseeable

○ **"not suitable":** technically theoretically fit for the application, practical implementation not foreseeable

Figure 6 – selection of measuring methods – example optical measuring methods.

Currently a trial application is being tested with example load carriers in different cleanliness states in the case study. First experiments have shown that it is necessary to use multiple cameras from different angles and a light source, all encased in a tunnel-like structure to ensure stable lighting *conditions, to properly check the load carriers for dust and other types of soiling. Using reference images of clean containers to compare them to be tested containers against, the major task now is to distinguish visual conspicuities other than dust and dirt – e.g. dents and scratches that do not affect the quality – from dirt. One possible approach is the use of additional image processing algorithms looking for the characteristics of these "not-problematic" visual signs, while another would be supplementing the camera system with another type of sensor or adding a pressured air cone to detect whether the suspected particles change their position in-between two successive scans while being exposed to an air stream – thus indicating they might be dirt particles. To utilize the full potential of automatic dirt detection it is beneficial to consider the use of a system of conveyor belts. The conveyor belts are able to place the load carriers in the camera-cell described above and hold it in place exactly long enough for the system to measure the dirt level and still being able to keep the time the container has to stay still in the camera cell as short as possible, enabling the fastest possible material flow through the dirt detection unit. The conveyor belt system with a few switch plates would also be able to take over some of the sorting of load carriers, thus potentially increasing the sorting process and relieving the workers assigned to the sorting task of a considerable amount of their workload. Whether the conveyor belt system will prove economically beneficial to the overall system performance and efficiency according to the described goal system is the subject of current simulation experiments, which are elaborated on in the following section. To be able to transport all kinds of containers, which in the case study are small load carriers and blister-trays, without having to use additional transport skids, the conveyors have to be of the belt conveyor type.*

For the Auto-ID technology selection, a capability profile of existing technology variants has been compiled. This was then compared to a requirements profile. The case study showed that the ability to not only identify the container type but also individual containers would be of additional value: It would on the one hand enable precise statistics for the container inventory – e.g. how often have containers been used in production or for transport and how long have they been circulating in the system – that would enable a precise planning of successive container circles as well as planning the substitution of old containers before they break in use, and on the other hand the loss of containers, especially of valuable types, could be precisely monitored. The precise statistics for each container would also enable the possibility of not having to implement the automatic cleanliness detection at all – in less quality sensitive applications, the containers could be monitored and after a certain number of use-cycles they could be transferred to the cleaning process. To ensure no soiled containers are used, experiments have to be executed to determine the number of permissible cycles each container type is allowed to accumulate before they need washing. This counting of cycle times can either be done by keeping and updating a variable inside a database for each container or by storing that information on each container – the latter option is only enabled by RFID Transponders with a dynamic memory. Due to the benefits of identifying individual containers in the system and the possibility of also storing and manipulating data on transponders applied to the load carriers themselves, RFID technology has been selected as the preferred Auto-ID technology within the case study.

Within RFID technology the same selection procedure applies: the capability profile of different RFID variants is compared to the requirements profile, ranging from read-distance to mechanical durability requirements due to the environmental conditions in the washing plant through which the containers have to pass frequently. In a first step, passive Ultra High Frequency Transponders have been selected for the first case study trials, mainly due to their combination of low prices, availability of durable PU adhesive labels and their reading range.

It is important to note that the abovementioned technology selection is only a preliminary selection for the first trials currently in progress in the course of the case study within the research project. For the configurator tool as the pursued end result, *this technology selection process is currently being implemented in a selection assistance system that will allow planners to be provided with technology suggestions by entering key characteristics of the respective application environment they are faced with.*

Status of concept and Case Study

Concerning the general concept and the configurator functions regarding the creation of possible future state variants of the container loop and its management, the first efforts have been dedicated to setting up a simulation model in a suitable DES environment. With an apt simulation model it will be possible to run a number of experiments to determine the savings potential achievable by introducing cleanliness detection and RFID into container loops and gain data on how to configure the resulting system for efficiency, according to the goals described in section 2.1 the simulation model also serves as the basis for the to be compiled optimization routine that the resulting container management configurator will eventually include.

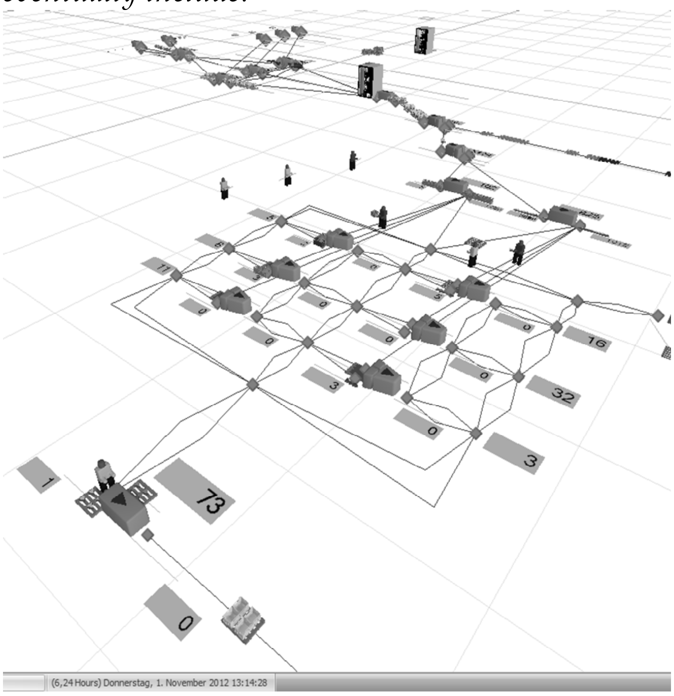

Figure 7 – container loop simulation model in Simio – in progress

Figure 7 shows a section of the basic simulation model layout derived from the work on the case study. It is implemented in the simulation program Simio, a popular commercial DES simulation environment for material flow applications. The current state of the simulation design has produced a simulation model that is able to reproduce the current state of the container loop quite accurately with regard to major variables and performance indicators. This is a key step on the way to test possible system variants including Auto-ID implantation as well as automatic cleanliness detection and a demand driven cleaning of containers. These variants are currently being modeled and tested.

Another element of the configurator concept that is currently in progress is the compilation of a standard generic process and process variants for container management loops, both including open and closed loops. The goal is to develop a standard set of processes and process variants that fits almost every container loop commonly found in real life applications. Figure 8 shows an example process variant for such a standard process. In this example the introduction of a demand driven initiation of the cleaning process for containers creates a transport path from the production plant directly to customers and suppliers. This transport path is shorter than the alternative of going via the external container-cleaning service provider. Therefore, every container that does not require cleaning can be transported directly to the supplier or customer, thus shortening the transport route and of course the resource consumption for the cleaning process. However, it is important to note that a direct transport from the production plant to the customers and suppliers is not always economically sound – if for example the container quantities per customer/supplier are too low, the containers have to be transported via transport hubs that are usually operated by logistics service providers – thus increasing the complexity of the transport logistics involved.

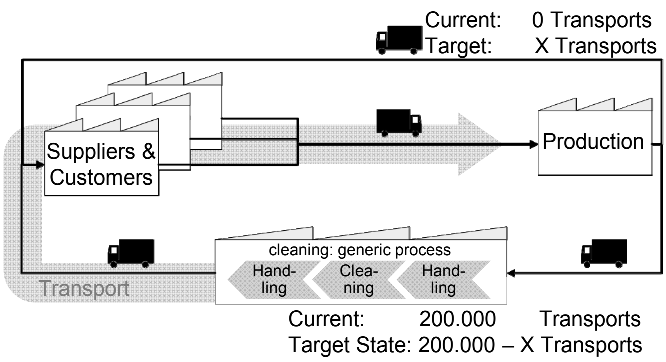

Figure 8 – example of a generic process description - container loop

The case study is being conducted in a production plant of a supplier in the automotive industry and will be focused on a particular set of products and the corresponding load carriers. The container inventory associated with the selected products amounts to approximately 300.000 units. Every day about 30.000 containers exit the production and have to be forwarded to the cleaning process that is executed by a third party logistics provider located in a considerable distance from the considered plant. In a first step to assess the potential of introducing a demand driven cleaning process, the container flow in the case study has been temporarily changed, so that workers assume the task of deciding whether the containers require cleaning and sorting them accordingly. In preliminary trials approximately 75% of the containers proved to be clean and could be directly forwarded to the suppliers and customers. Since the RFID system is not yet implemented, it is not possible to verify how often some of the containers have been used without being cleaned – first experiments indicate that most container types can be used multiple times before they have to be sent to cleaning. This would be equivalent to a reduction of cleaning efforts – including transportation and cleaning itself – of well over 75%. The first simulation experiments indicate that for most load carrier types the necessary inventory could be reduced by 20-30%, thus potentially lowering inventory costs.

CONCLUSIONS & OUTLOOK

Although still in the first half of the project duration, the research work has already produced preliminary results indicating that the savings potential is of considerable magnitude. The entirety of implications still has to be investigated but a reduction of the cleaning frequency of containers would greatly reduce the efforts and expenses associated with the cleaning process. Since the supply of containers would still be ensured, the efficiency of the reusable container loop would increase accordingly, with regard to the goal system of container loops.

The immediate next steps will be overcoming problems with the automatic measuring of the cleanliness status of the containers. Furthermore, the simulation experiments with system variants have to be finalized, thus producing empirical data for the effective configuration of container loops. Also, the process variants and the evaluation and assessment tools have to be developed into an accessible tool for practitioners. This will include trying to derive empirical data from the experiments, both with simulation and in real life trials, in the course of the case study, into generic formulae and reference tables, thus reducing the need for users of the configurator tool to adapt the simulation models to calculate the potential benefits and the proper configuration of their future state container loop as much as possible. Moreover, the real life trials have to be finalized and eventually the best system variants determined with the help of the simulation models have to be implemented in the case study application.

A combined optimization procedure and simulation could prove a promising way to further improve the results of the container management configurator – this could be the subject of future research in this field.

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