Cross-Supply Chain Collaboration Platform for Pallet Management

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by **Roland Lehner**

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CE	Circular Economy
CSCM	Circular Supply Chain Management
EPAL	European Pallet Association
IS	Informations Systems
SCM	Supply Chain Management
OR	Operations Research
RTI	Returnable Transport Item

1 Introduction

1.1 Motivation

It is hard to imagine today's economy without pallets. Thanks to their universal dimensions, they ensure standardization of processes in transport, storage and handling (Frąś et al., 2018). Originally, the pallet was established by the US military during the Second World War (Twede et al., 2007). In combination with the forklift, which was invented in 1920, the U.S. military and its allies were able to significantly improve logistics as a whole (Twede et al., 2007). In Europe, the success of the pallet began in 1961 with the establishment of fixed standards (Bogdanov, 2013). Since then, logistics processes have been adapted to these pallet dimensions (Frąś et al., 2018). Additionally, automated processes are made possible as well (Kuhn and Zimmermann, 2015). In fully automated pallet warehouses, for example, storage and retrieval operations are handled by automatic stacker cranes (Cinar et al., 2017).

The most widespread pallets in Europe are EPAL Euro pallets (Elia and Gnoni, 2015). This pallet is made out of exactly 11 boards, 9 blocks, 78 nails, and can carry loadings of up to 1.5 tons (Niebur, 2015). According to EPAL, there are currently about 600 million pallets in circulation (EPAL, 2022). Due to their importance in the production, transport and logistics processes, the number of pallets in circulation increases with important economic indicators - e.g., gross domestic product (Accorsi et al., 2019). Thus, the number of pallets that are in use in a country can be considered as an index of economic performance. The importance of pallets for the economy was recently demonstrated in Germany through the increase in pallet prices, due to the rise of wood prices as a result of the Ukraine war and the subsequent sanctions against Russia (DVZ, 2022). Prices for solid wood were increased by 125% from June 2021 to June 2022 (hpe, 2022). Wood prices contribute about 60% to the pallet price, while the remainder is made up of supply and demand (Oczkos, 2015). A few years ago, new pallets cost about €8.00 (Oczkos, 2015). Currently, price increases of 150% are being reported. (SPIEGEL, 2022). Due to the price increase and the scarcity of pallets, this had a direct impact on logistics costs. The increase in logistics costs caused consumer goods, such as beer, to become more expensive (SPIEGEL, 2022).

Due to the shortage of pallets (DVZ, 2022) as well as their current increase in cost, there is a greater need to make the use of pallets and the related processes more efficient. In addition to current events, however, other already long-term developments in transport logistics are also demanding more efficient processes. These include a shortage of truck drivers, low margins for forwarders[1], and high fuel costs (Noerpel-Schneider and Stölzle, 2019). Moreover, along with the economic factors, there are also ecological reasons.

[1] For simplification purposes, this thesis does not differentiate between forwarder and carrier and assumes that the forwarders execute the ordered transports by themselves.

Pallets are generally considered environmentally friendly because they are usually made of wood as a renewable resource and can be used and repaired several times (Carrano et al., 2015). They therefore provide a good example of a circular economy (CE) (Meherishi et al., 2019). The aim of the circular economy is to use materials and products for as long as possible and to avoid waste (Geissdoerfer et al., 2017). However, the repeated use of pallets also leads to additional processes and transports, because after being used, the pallets must be returned to a shipper so they can be used again (Tornese et al., 2021). Thus, there are entire industries dedicated to collecting empty pallets, processing them and providing them to new locations (Roy et al., 2016).

In order to make the return of pallets as simple as possible, Germany have a so-called pallet exchange system, which is uniformly regulated by defined EPAL and GS1 standards (Niebur, 2015; Dörre, 2015). In the open exchange pool, standardized pallets can be exchanged amongst one another. The basic principle here is to exchange pallets of the same quantity and quality (Hagenlocher et al., 2013). In the simplest form, the actors that are involved exchange palletized goods for empty pallets and vice versa (Löw, 2008). This works as follows: The forwarder receives the palletized goods from the shipper. In return, the forwarder hands over a corresponding quantity of empty pallets to the shipper, which the shipper can use again for sending and handling goods. The forwarder delivers the palletized goods to the consignee, from whom they receive empty pallets (e.g. from previous deliveries) in return. Thus, all actors have the same number of pallets at the end of the deliveries as they did in the beginning, without the need for further transports to collect empty pallets. In theory, this simple system of double exchange is extremely efficient. However, in practice there are problems that ultimately lead to extra effort and additional transports (Löw, 2008). This is because in reality the return of empty pallets often does not take place directly (Hagenlocher et al., 2013). A reason for that can be that empty pallets are not available in sufficient quantity and/or quality or cannot be managed due to time pressure (Löw, 2008). This results in debts and receivables between the actors, which must be recorded and settled at a later date. In addition to the administrative effort of managing the debts and receivables via so-called pallet accounts, there then are additional trips to settle the pallet debts (Löw, 2008). This is particularly complicated, time-consuming and expensive if there are no regular business relationships between the parties that owe each other pallets.

This thesis starts exactly in this area of tension and aims to bring the actors together within the pallet exchange system via the use of a digital platform, in order to improve the existing problems, such as the need for further effort and additional transports. The pallet debts are supposed to be managed via a common system and, if possible, to be mutually balanced. The goal is to reduce additional trips by transforming the physical transport flows into digital ones. For this purpose, a digital platform will be conceptualized, which will bring the various actors in the pallet exchange together and enables cross-actor and cross-supply chain collaboration. A detailed description of the execution can be found in the following chapter. An important factor that needs to be addressed is that the digital platform will be developed on the basis of blockchain technology. Blockchain technology has the potential to generate trust among the participating actors and to enable collaboration if they do not know each other, due to its features, such as the possibility of immutability of the data once it is stored and the transparency of the transactions that are carried out (Rejeb et al., 2021). In addition, Blockchain technology has already successfully been tested in a practical project in the field of pallet exchange in Germany (GS1, 2018).

In order to demonstrate the relevance of the strategic and technological aspects of this work, three recent Gardener Hype Cycles are used. A Gardener Hype Cycle classifies new technologies and concepts in different development phases of public attention (Kreutzer, 2015). It maps the development from the beginning throughout the emerging hype to the phase of realistic expectations and useful applications (Kreutzer, 2015). Figure 1 lists the technologies or strategies of current hype cycles that are relevant to this work. These include supply chain strategy (Tohamy, 2021), supply chain execution technology (Freeman, 2020), and current applications of blockchain technology (Litan, 2021). Technologies and strategies of these three individual Hype Cycles, which are not tangential to this work, have been omitted to enable a better overview of the figure. It is visible that the topic of Circular Economy in supply chain technology is in the early phases of the hype cycle. Although the concept behind Circular Economy is very old and still practiced, especially in traditionally orientated economies, the term was only coined in the 1990s by David Pearce (Andersen, 2007; Angelis et al., 2018). In the context of supply chains, the Circular Economy, as seen in the Hype Cycle, has only recently and thus even later been considered more intensively. This development is also taking place particularly in the scientific consideration of circular economy, as illustrated in the scientific literature of supply chain research. In section 2.1 this is descripted further.

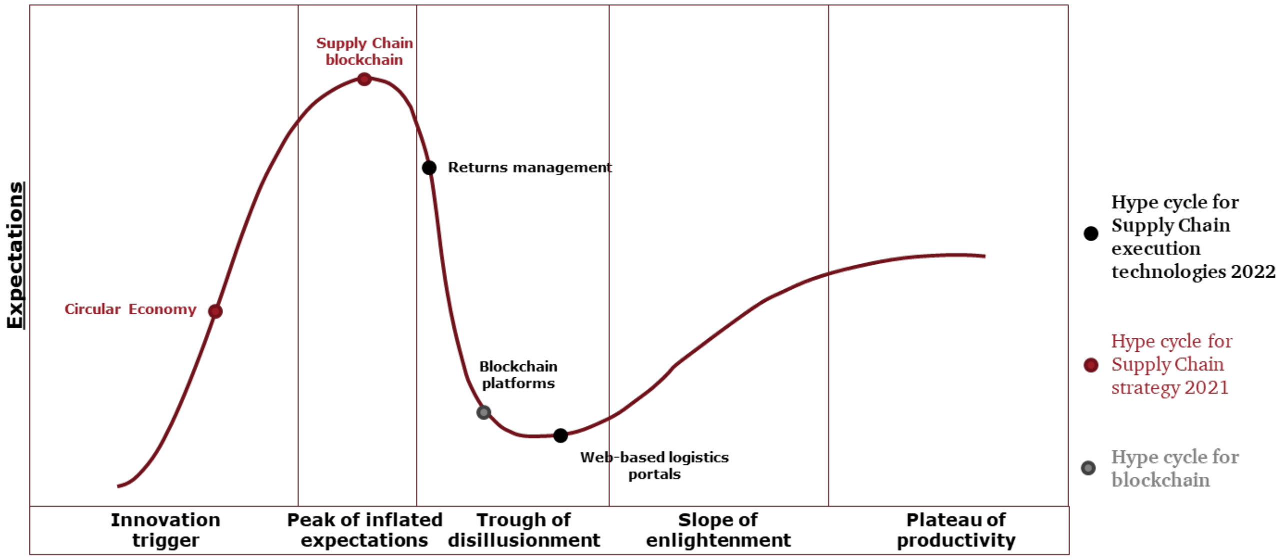

Figure 1: Hype cycle for adressed technologies and strategies (Freeman, 2020; Litan, 2021; Tohamy, 2021).

The blockchain technology for supply chains is at the peak of inflated expactations. While blockchain is already firmly established in areas such as cryptocurrency, it is still at an earlier stage as an application for supply chain. In addition to prototype applications (e.g., GS1, 2018), there are also primarily concepts that describe the use of blockchain for supply chains in the scientific literature (e.g., Chen et al., 2019b).

The biggest hype around the research field "returns management" is over as of now, and therefore this strategy is advancing in the early phase of the "Trough of disillusionment". Blockchain platforms are already in the middle of this phase, as well as web-based logistics platforms. Even though the initial hype around the strategy and technologies has disappeared, they are not yet in the final phase of the hype cycle in which the strengths and weaknesses of the technologies and strategies are realistically assessed and applied.

1.2 Platform concept

The logistics industry is still lagging behind other industries in the area of digitization (Wei and Noche, 2020). However, digitization is also becoming increasingly important in the logistics sector (Bardakci, 2020). Particularly digital platforms that enable the exchange of information and more collaboration are increasingly emerging (Gaponenko and Hvoevskaya, 2022). The central research topic of this thesis is a pallet exchange platform that is specifically designed to increase the collaboration between the different actors. In this section, the concept of this platform will be derived and presented in more detail. The basis for the designed platform are pallet accounts on which the actors can record bilateral pallet debts and liabilities. The inflows and outflows from and to specific actors can therefore be netted. This procedure is analogous to payment netting in the financial industry, which is referred to as clearing (Martens, 2018).

In addition to bilateral netting, it is also possible to settle further debts and receivables via multilateral netting. One option to use multilateral netting is the creation of exchange rings (GS1, 2018). This is explained in detail in section 1.2.1. Using data from a real pallet account platform, an estimate of the potential of such a system is given as well.

In addition to creating exchange rings, another option for netting multilateral debts and receivables is for all participating actors to transfer their entire debts and receivables to a central actor. The central actor can then offset all debts and receivables transferred to them. As a result, each actor has only one account balance, indicating whether debts or receivables exist against the central actor. The role of the central actor can be fulfilled by the digital platform designed in this thesis. In section 1.2.2, the functionality is further presented in more detail. The concept is also evaluated using real data and compared with the ring exchange mechanism. In addition to the balancing function, the platform is further used as a central planning instance. Based on the regular tours of the forwarders, it is used to plan the flow of empty pallets among the actors with the aim to reduce as many further debts and receivables in the overall system as possible. This mechanism is also further evaluated in more detail in section 1.2.2.

1.2.1 Platform with Ring Exchange

In common practice, platforms for recording pallet debts and receivables already exist. Using the platforms, actors can record the inflows and outflows of the pallets that they receive from various actors. There are currently numerous providers in Germany, such as:

- Swoplo (swoplo.com)
- Tara (tara-paletten.de)
- Logistikbude (www.logistikbude.com)
- Timocom (timocom.de)
- IPAL[2] (ipal-pallets.org)

A pilot project of the standardization organization GS1 has also dealt with the topic of digitalization in the pallet exchange system (GS1, 2018): A blockchain solution was developed and tested with companies from this field. The focus was on the development of a digital pallet voucher, which represented promissory bills for pallets. Afterwards, the pallet voucher could then be redeemed at the company that issued it or at a service provider. By digitizing the voucher, the debts and receivables could be balanced in a similar way to pallet accounts. For future projects, ring exchange transactions have been brought into consideration, in which claims between different parties in a debt relationship are balanced out.

The basic functioning of ring exchange transactions will be explained using a short example:

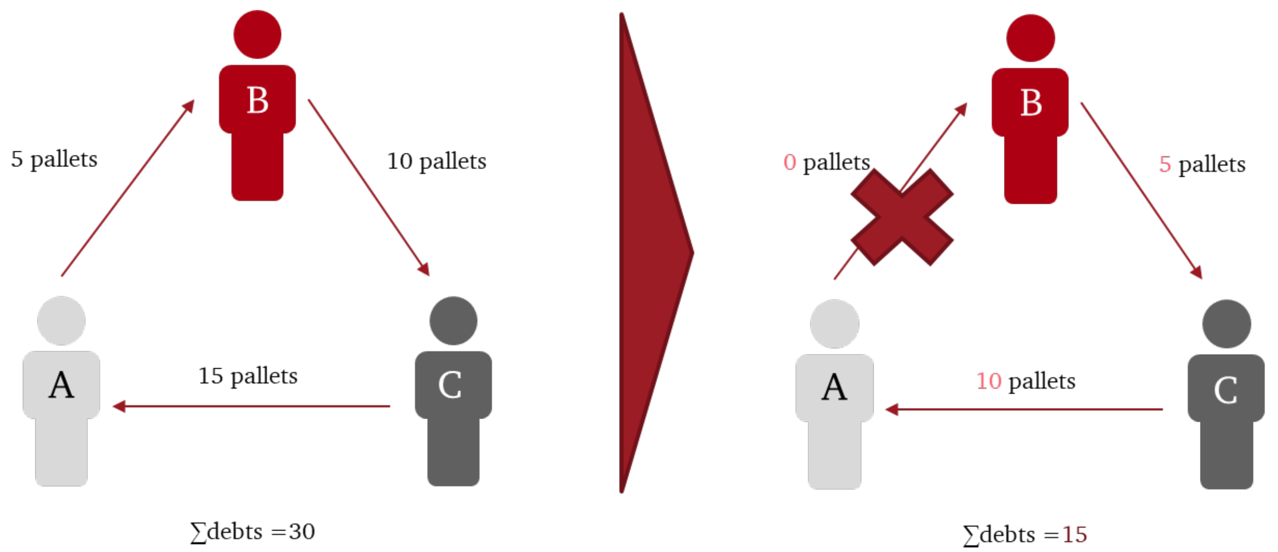

Figure 2: Concept ring exchange.

[2] In addition to managing pallet account balances, the IPAL platform also serializes pallets, i.e. each individual pallet can be identified by a unique number. This makes it possible to systematically link pallets with loaded goods and, for example, to trace the life cycle of the pallet. More information on this can be found on the IPAL website.

Actor A owes Actor B five pallets whereas Actor B owes Actor C 10 pallets and Actor C owes Actor A 15 pallets. If all actors agree, a ring exchange could be used to offset the debts between the actors. In Actor A's case, this would mean that the pallets they owe to Actor C are reduced by 5 and they would receive no more pallets from Actor A in return. The other debt relationship (C to A) would also be reduced by five pallets as a result of the ring exchange. So, in summary, the total debt in the system could be reduced by three times five pallets, thus a total of 15 pallets.

Therefore, instead of physically transporting the pallets to the individual actors, it is sufficient to adjust the pallet account balances. For that reason, we can speak of physical material flows becoming digital ones. Using a real data set provided by a digital pallet platform, the potential of such a ring exchange mechanism can be estimated. In the appendix, an exemplary excerpt of the provided data can be found, that provides details about which receivables and which debts the participating actors have. In order to be able to identify exchange rings, the existing receivables that an actor X has towards an actor Y is first converted into debts that actor Y has towards actor X. Therefore, all relationships could be represented in debt relationships. With the help of a network graph, these debt relationships between the actors can be represented graphically (see figure). The software Gephi version 0.9.2 was used for this purpose.

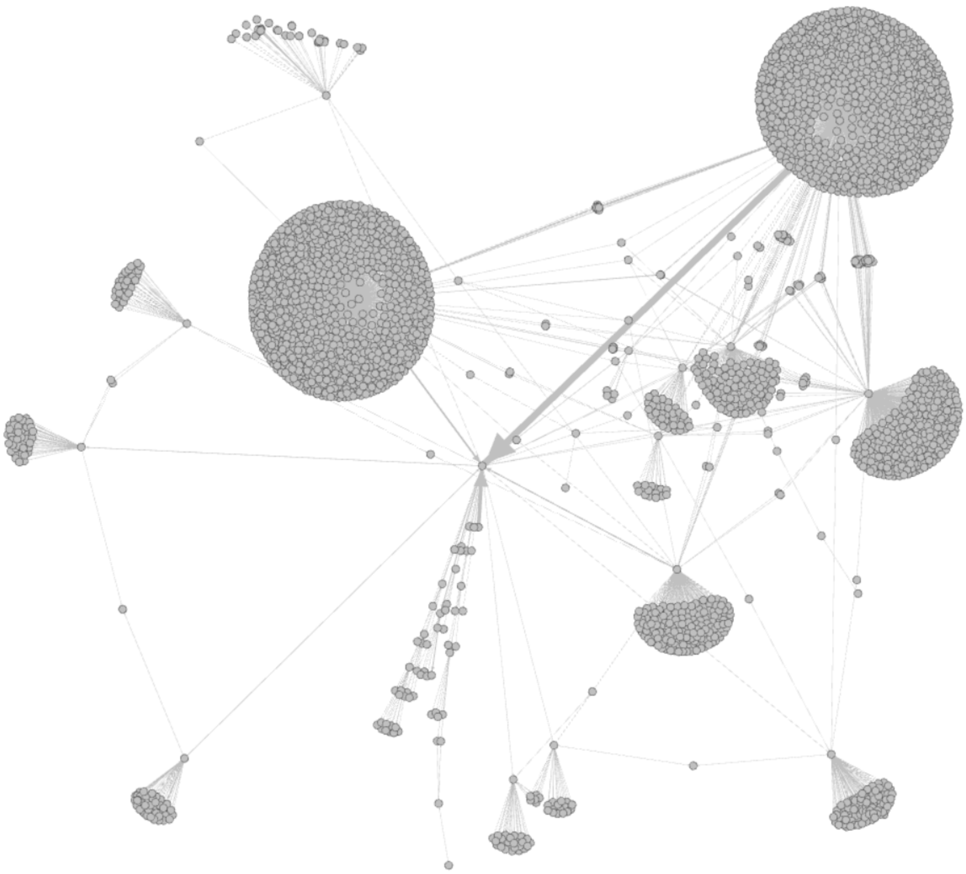

Figure 3: Debts relationship in the network (real-world data).

The nodes in the figure represent the individual actors of the platform. The edges represent the pallet debt relationships between the individual actors. The thickness of the edges reflects the amount of pallet debt between the two nodes or actors. The length of the edges as well as the location of the nodes have no further meaning. The arrangement is generated via Yifan Hu's graph drawing algorithm (Hu, 2006), used in the software Gephi, creating a clear and easily interpretable graph for the dataset. There are a total of 3,477 nodes and 3,647 edges that are shown in the network. It can thus be seen that individual nodes have many connections with other nodes, which in turn have no further connections to other nodes. This does not mean that in reality the nodes actually have only one debt relationship with another node, but that it is not included in the existing data set. The platform's customers enter the various RTI inflows and outflows to and from other actors. As long as a node is not a customer of the platform and does not appear in any other debt relationship between any other customer of the platform, it is only included in the network with one edge. For the ring exchanges, these nodes with only one connection cannot be taken into account, since they are only connected to exactly one node via an input or output in each case, and thus no rings can be formed with these nodes. The same applies if a node has only outgoing or only incoming debt connections. This means that the node either has only debts with other actors or has only claims against other actors. Under this circumstance, a ring cannot be formed with the actor either. For a more precise analysis of the network, the aforementioned nodes and edges, with which no ring formation is possible, are removed first.

In order to estimate the potential of ring exchanges in common practice, possible ring exchange options are identified based on the data. Due to the amount of debt relationships, and since there are different ways to form exchange rings based on the pallet account data which then limits or prevents other ring opportunities, a methodical approach was taken. First, all possible rings are identified. In order to achieve this the algorithm of Johnson (1975) is used. It works with a depth-first search and can determine all cycles in a network with directed edges, which are defined by graph theory as cycles, that have the same start and end points and where every other node is visited only once (Tittmann, 2019). A total of 47,309 possible rings were identified using the algorithm. The order in which ring exchanges are performed in the cycles is relevant because each exchange can limit the ring exchange potentials of the following exchanges. A complete enumeration of all possible orders is not reasonable for the given set of rings. Therefore, using heuristic solutions with different strategies, the potential of ring exchanges is determined based on the given data. Six different variants are presented, which determined the order in which the exchange rings are formed and the ring exchange is performed.

In variant 1, the ring that can reduce as much debt as possible for the involved actors needs to be identified. For this purpose, the smallest debt relationship of the respective cycle is first identified for all rings. The ring that has the largest value is thereby selected. The ring that can be identified using the real-world data with the highest debt to be reduced for the actors consists of four actors. The smallest debt relationship in this case is the debt of 2865 owed by actor B to actor A. This is the maximum amount of debt that can be reduced in this ring. After a ring exchange, there are no more debts between actor B and A and the amount of debts between A and D, between D and C as well as C and B are reduced by 2.865 pallets, too. Subsequently, the data is updated and a search is made for the succeeding largest value in order to reduce further debts. This procedure is repeated until no further ring exchanges can be performed in the network. If several of the identified rings have the same number of debts, the cycle with the smallest length is selected first, since it potentially less restricts the following ring exchanges. If the length is identical, a random selection is made from the set of possible ring exchanges.

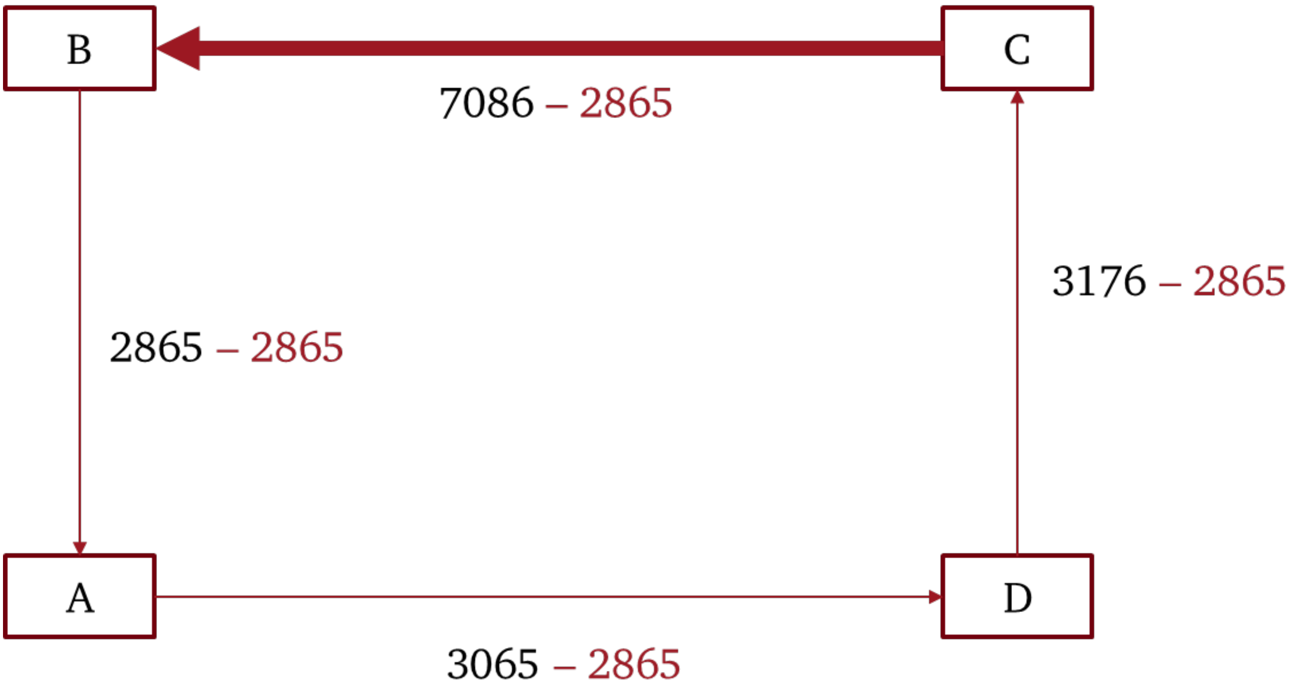

Figure 4: Performing a ring exchange.

Variant 2 works similarly to variant 1, with the difference being that not only the quantity by which the individual debt relations can be reduced is taken into consideration, but also the total sum of reduced debts by the ring swap. The outcome results from the amount of debts, which can be reduced (sum of debts, which all nodes owe each other at minimum) multiplied with the ring length. This means that the number of actors also needs to be taken into account in the selection. Rings with more actors, but with fewer debt reductions between the actors, can thus be preferred to rings with fewer actors and higher maximum debt reductions. If the amount of debt is the same for several rings, the shorter ring is selected, as in variant 1.

For variant 3, rings with the smallest amount of debt between the actors are identified. Initially, these are debt relationships between the actors in the amount of one pallet. The second criterion is the length of the rings: The largest rings are selected. If several rings have the same conditions, one of the rings is randomly selected. With this variant, the longest possible exchange rings are formed, which initially reduces only a few of the debts. This removes as few existing debts as possible for future runs, so that the longest possible rings can also be formed in further iterations.

In variant 4, the most important criterion is the length of the rings. The longest rings are selected first. The second criterion concerns the amount of debt reduction that the cycles provide. Here, the cycle that has the highest amount of debt is selected. The strategy behind this approach is to be able to form as many cycles as possible with as many different players as possible.

In variant 5, the possible exchange rings are randomly selected one after another. After a cycle is selected, the ring exchange of the debts is carried out. Subsequently, the adjusted debt relationships are updated, and another exchange ring is randomly identified. This procedure is repeated until no further exchange rings can be formed.

Table 1: Heuristics for ring exchanges (results).

Variant Selection criteria	Debts removed	Edges deleted	Used cycles	Average length of selected cycles
1 1st: Highest Debts 2nd: Shortest Cycle	14,733.8 [±15.8]	35.1 [±0.3]	33 [±0]	4.3 [±0.1]
2 1st: max(Highest Debts x Cycles Length) 2nd: Shortest Cycle	14,821.9 [±17.8]	38.3 [±0,7]	27.3 [±0,7]	7.3 [±0,1]
3 1st: Lowest Debts 2nd: Longest Cycle	14,499.5 [±16.9]	63.7 [±0,5]	59.8 [±0,5]	11.4 [±0,1]
4 1st: Longest Cycle 2nd: Highest Debts	14,528.6 [±22.2]	44.9 [±0,5]	35.9 [±0,5]	9.6 [±0,1]
5 Random selection	14,527.1 [±31.9]	56.5 [±0,9]	52.1 [±1,1]	8.4 [±0,1]

Table 1 summarizes the results based on the real-world data using the different variants. Since in some cases several rings from the practice data correspond to the same criteria for variants 1 to 4, one of the potential rings was randomly selected. Therefore, several replications (20) are performed for the different variants and corresponding mean values with the calculation of the standard deviations. The results are shown in the table. In Variant 5, all exchange rings are selected randomly, which also requires multiple replications to be performed. In variant 5 it is visible that the fluctuations are generally greater than in the other variants.

The amount of the total reduction of pallet debt ranges between 14,527.1 and 14,831.9 on average. The highest values are achieved by variant 2, which also has the highest absolute debt reduction of 14,914. It is important to note that a single ring consisting of four actors is responsible for the majority of all savings (see Figure 4). The resulting savings from this ring are in form of a reduction of 11,460 pallet debt, which is over 75% of the total reduction.

The variants differ significantly in the amount of debt relationships that were able to be reduced to zero. The variant that was able to dissolve the most debt relationships is variant 3, in which the used cycles and their length are the highest as well. This means that in this variant, although less debt is reduced overall compared to the other variants, the highest number of different actors would benefit from the ring exchanges and the most debt relationships would be reduced to zero. This is particularly interesting, as it would mean that a later settlement would not have to take place at all and thus no physical transports or financial settlements would need to take place.

Whether the higher reduction of total debt, or the amount of debt relationships that have been reduced to 0 are more important, cannot be assessed conclusively at this point. Both goals are meaningful, and it respectively depends on the additional conditions, e.g., whether the various actors have regular business relationships or whether one-time transactions have occurred.

The variants that are applied are iterative and do not claim to find the optimal solution but are intended to show the level of possible savings through ring exchanges. It is possible to develop further heuristic variants. It would also be possible to develop an optimal solution algorithm that can solve this problem in an acceptable computation time. However, finding the optimal solution was not the intention at this point. The evaluation was only intended to assess the dimensions of the potential debt reductions. The results show that the variants all have similar outcomes. Even with the random selection of the cycles, the values are not particularly far behind the more structured variants.

The ring exchange potential serves as a reference in the following chapter to show the potential of the platform that is the main subject of this thesis: A platform to which actors transfer their debts and receivables in order to enable a global netting system.

1.2.2 Platform with Claim Transfer

Instead of forming exchange rings, and thus carrying out a partial netting of outstanding receivables and existing debts with individual actors, the concept of the extended platform is for it to assume all debts and receivables of the individual actors. This can be achieved under the condition that the participating actors transfer their receivables and debts to the platform. The platform can then offset the debts and receivables between all participating actors. Consequently, the individual actors have a single account balance towards the platform, which shows whether they have outstanding debts or receivables towards the platform (Figure 5).

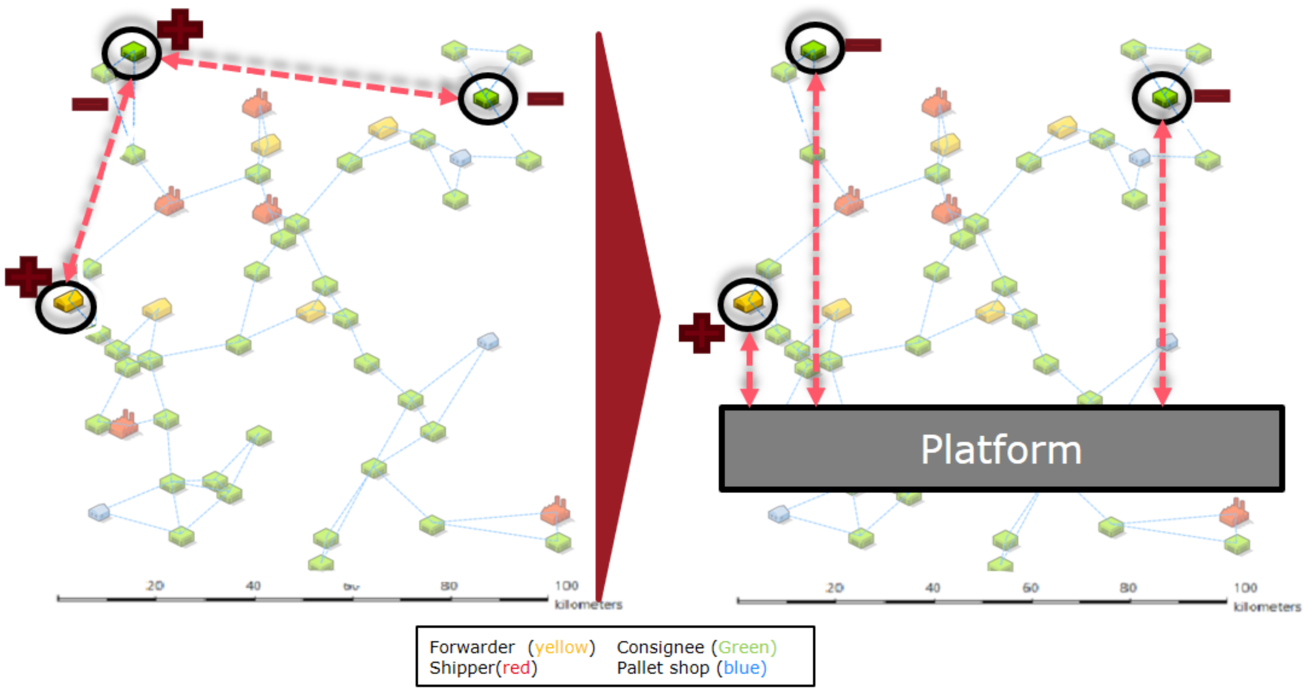

Figure 5: Concept of platform with claim transfer.

To achieve a comparison to the ring transfer system that is mentioned above, the described mechanisms of a platform with claim transfer are applied to the real-world data, which is described in section 1.2.1. If all the debts of the actors in the system are added up, the total pallet debts amount to 3,084,200 (the claims are therefore 3,084,200 pallets). If the proposed mechanism is applied, the total debts are reduced by around half, to 1,475,711 pallets. Thus, significantly more debt will be saved by netting, than by forming exchange rings (about 14,800). Here, the enormous potential of a platform with this principle can be recognized (Figure 6). However, it is important to point out that the calculated debt reductions reflect the maximum value that is possible. To achieve this, all companies in the data set would have to participate in the platform. Since the platform's customers also deposit debts of non-participating actors (with official and unique company numbers), the implementation of a claim transfer (as well as ring exchanges) would not be possible to this degree in reality.

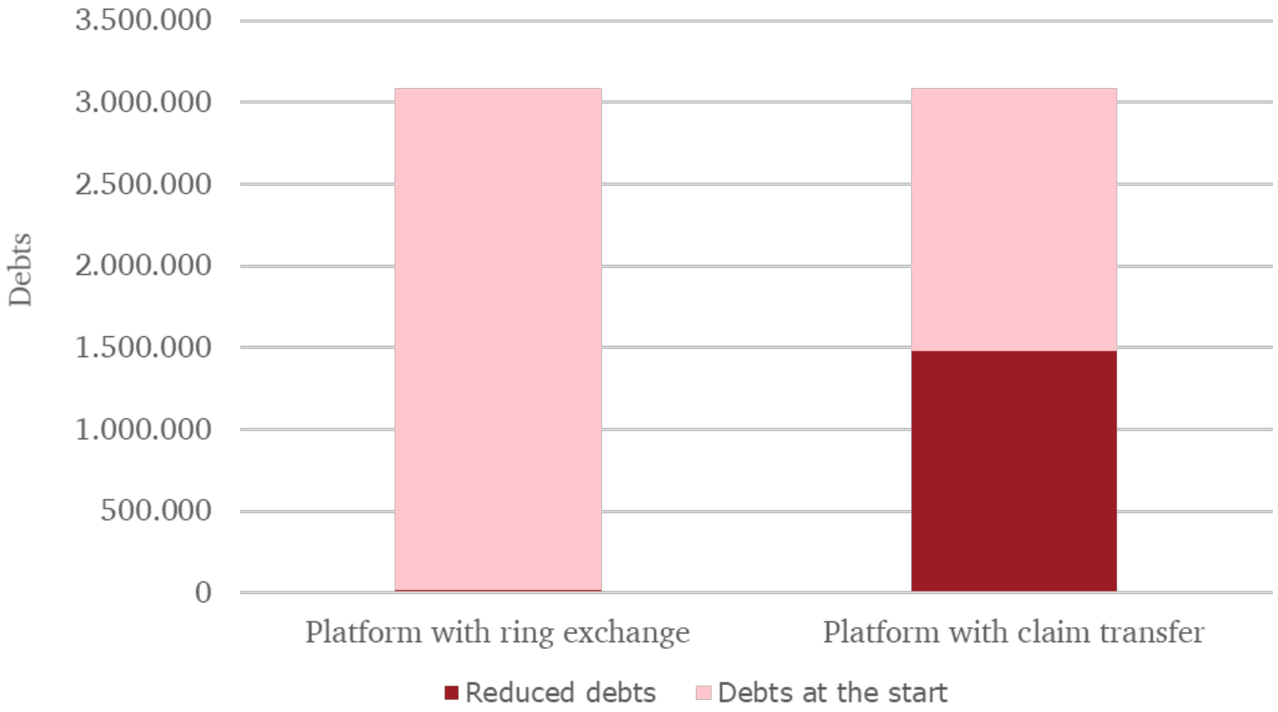

Figure 6: Potentials of a platform with ring exchange and a platform with claim transfer.

In addition to the administration and balancing purposes of the platform, it is also supposed to provide a further function. The available information regarding the debts and receivables of the participating actors can be used as a basis for a planning instance, in order to balance the existing debts and receivables against the system among the actors. To achieve this, the forwarders would need to provide information about their regular routes and the free capacities in their trucks. Based on this information, the platform can then be used to centrally plan an empty pallet flow between the actors to balance as many debts as possible. The forwarder therefore takes on a central role in balancing debts, while also becoming the procurer for empty pallets.

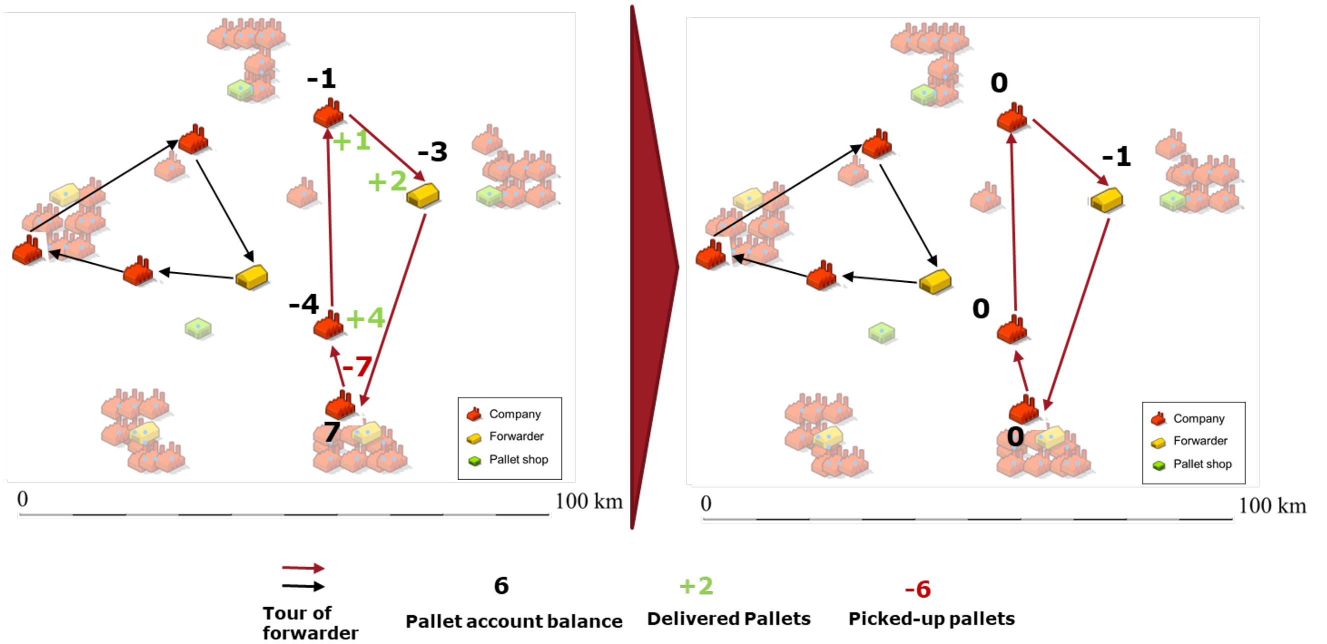

Figure 7: Planning of empty pallet flow (concept).

Figure 7 shows an example of the results from using a planning instance. The red arrows indicate the route that the forwarder takes from the depot. The forwarder drives to three companies. For the companies and the forwarder, the left side shows the pallet account states before the tour is carried out. The actor with the lowest amount of pallets has an account balance of seven, which means that they owe seven pallets to the system. All other actors still have claims against the system. With this information, the platform is now used to plan at which stops the forwarder should pick-up empty pallets that are owed, and where they should be delivered. In the illustrated tour, seven additional pallets are picked up at the first stop, four of them are delivered at the second stop, and one at the third stop. The remaining two pallets are claimed by the forwarder. On the right side, the account balances after the tour is carried out are shown. The pallet debts and receivables of the actors could be balanced in the best possible way by the pallet flows that are planned by using the platform. Now only the forwarder still has a receivable of one pallet.

1.3 Research Gaps and Research Questions

The overall objective is to improve the current pallet exchange system and the return processes. The central object of investigation is a digital platform concept for pallet management, which has special mechanisms for collaboration and joint planning. During the investigation of such a digital platform concept, different research areas need to be addressed. Accordingly, the research gaps and research questions are derived from different scientific areas.

Since the digital platform is intended to improve the processes surrounding pallets, the work of this thesis is initially related to the area of pallet research. According to research conducted in the area of logistics, reusable pallets belong to the group of returnable transport items (RTI) (Glock, 2017). The central issue is the return of items after their use, in order for them to be reused for transport and storage processes (Tornese et al., 2021). Efficient management of the return processes is crucial for this. In the scientific literature on pallet management, the pallets are usually either owned by the supplier, to whom the pallets must be returned once they were used (Tornese et al., 2021), or by a service provider, who rents out the pallets and takes care of their return processes (Prataviera et al., 2021). The use of an open-pool system, which is widespread in Germany and in which different actors each bring in their own pallets and exchange them among one another, has barely been acknowledged in scientific literature so far (see section 5.1). This thesis addresses the research gap by using the first two studies to investigate the processes of such an open pool and examines ways to make them more efficient, through the use of digital platforms.

Apart from the research into RTI Management, the use of digital platforms for transportation is also an important research stream in the area of logistics and transportation (Wang and Sarkis, 2021). This stream has become increasingly important in recent years (Wang and Sarkis, 2021). Particularly in the B2B sector, it is very difficult to make general statements about digital platforms; instead, each platform must be considered specifically in its respective area of application (Reuver et al., 2018). Digital platforms have the potential to connect different actors, to exchange information and to enable cross-company collaborations (Freichel et al., 2022). Enormous potentials are attributed to cross-company collaboration to design processes more economically, but also more ecologically (Zhang et al., 2021). This aspect is the focus of this work. Hence, the designed digital platform is primarily seen as a technical enabler for collaborations in returnable transport item (RTI) management.

While vertical collaborations, primarily from the shipper to the forwarder and then to the consignee, are the norm in RTI management along with supply chains, collaboration between actors on the same level and between supply chains often does not take place (Renko, 2011). This is also apparent in the pallet management literature. Pallet management is very often considered from a supply chain perspective

(Tornese et al., 2021), whereas only specific supply chains with long lasting relationships are examined (e.g., Accorsi et al., 2019; Elia and Gnoni, 2015). The collaborations of different actors and different supply chains are seen by Meherishi et al. (2019) as a promising research avenue. In particular, the open pallet exchange pool, in which basically every company can participate, offers a suitable foundation for collaborations.

The research field of pallet management can also be viewed from the perspective of circular supply chain management (CSCM). CSCM is investigating the implementation of circular economy principles into the field of supply chain management (Farooque et al., 2019). Since open exchange pool pallets are reusable, repairable, and recyclable, they are an example for the application of the circular economy principle in supply chain management (Meherishi et al., 2019). In this branch of research, horizontal or cross-supply chain collaborations also represent a research gap. In addition, there is a lack of empirical studies of this field in the scientific literature (Zhang et al., 2021).

Since the forwarder usually has the most disadvantages in the currently practiced pallet exchange system (Elbert and Lehner, 2019), the effects on the forwarder by the designed platform are examined first. Despite their central role in RTI management, the role of freight forwarders is hardly considered in the scientific literature (Glock, 2017). Therefore, the first study examines the effects of the platform, particularly on the forwarder. The forwarder is the most important actor in the empty pallet flow planning mechanism, which is investigated by the second study, since the forwarder distributes the empty pallets between the other actors.

This leads to the first research question:

RQ1: Is the developed platform concept with claim transfer for pallet management in an open exchange pool advantageous for the forwarders?

Two sub-questions can be operationalized from this primary question. These sub-questions can be measured and evaluated using the simulation modeling method. Since the positive effects of a collaboration platform through emerging network effects depend significantly on the number of participants, these must also be taken into account in the evaluation. In study 1, the following questions are addressed:

> **RQ 1.1: How high are potential transport savings in RTI management for the freight forwarder when using a cross-actor pallet exchange platform?**
>
> **RQ 1.2: What is the minimum participation rate of consignees for a freight forwarder in order to implement transport savings?**

After demonstrating that forwarders benefit from the platform, the next step is to consider the effects on the other relevant actors in the pallet exchange. This refers to the shippers and consignees of palletized goods. The functionality of the digital platform will also be expanded, as the platform is used to take over the planning for the management of the flow of empty pallets between the actors. Currently, such an overarching planning method in pallet management is only conducted when the actors hire a pallet service provider to collect, repair, procure, and distribute the empty pallets after their use (e.g., Tornese et al., 2018). Usually, in such a case, the pallets belong to the service provider, who rents out the pallets and is compensated accordingly (Chen et al., 2019a) The advantage of centralized planning lies in the fact that the planner has a lot more information than individual actors in decentralized planning, which enables a more efficient planning of the processes (Gansterer and Hartl, 2020). With the aid of the digital platform, the independent actors can use these advantages of central planning as follows: Based on the commodity flows that are centrally planned by the digital platform, the forwarders take over the distribution of the empty pallets on their regular routes, with the aim of balancing the debts of the actors involved. As a result, in the context of collaboration, the digital platform enables a centralized planning process to perform a joint empty pallet flow planning, based on shared information among the actors. This leads to the second research question:

RQ 2: What effects does a collaboration platform with central planning instance have on the overall system of the open pallet pool?

Similarly to RQ1, two sub-questions can be operationalized from this question, and is therefore made measurable. Here, the savings aggregated from all actors, or the entire system, are relevant. Part of the savings are, on the one hand, the kilometers saved by all actors, but also the amount of all debt reductions that are made possible, and the quantity of pallets required in the system in total. Due to network effects, the savings are dependent on the number of participants as well. Thus, the following sub-questions arise, which will be investigated in study 2:

> **RQ 2.1: How high is the savings potential of a pallet exchange platform with "claim transfer", and which acts as a a central instance for planning the commodity flow of additional pallets that are to be distributed by the forwarder, compared to the current reference situation?**
>
> **RQ 2.2: How high is the influence of the number of participants and the number of pallets on savings?**

In addition to evaluating or quantifying the potential of the designed collaboration platform, the next step is to determine how a technical implementation can be achieved. The platform is intended to attract as many independent actors as possible who participate in it. Participation in the open pallet exchange is therefore free to all. Since companies also collaborate with anonymous actors (e.g., receive or provide pallets from other actors), there is a risk that such a platform will not be used, because there may be a lack of trust in the system and in the other anonymous participants. However, trust is a key success factor for efficient reverse logistics, and also particularly important for the adoption of new IS systems. In the case of the designed platform, trust of companies in the platform is particularly relevant. On the one hand, data (e.g., on planned tours) is transferred to this platform, and on the other hand, there needs to be trust in the fact that the platform is able to manage and clear the pallet accounts correctly. Behind the account data are physical pallets, most of which have a considerable financial value.

One way to create trust in such a platform is to use blockchain technology, which is often referred to as the „trust-engine“ (Lim et al., 2022). It is a distributed ledger technology that allows all transactions that are made to be represented transparently and makes it nearly impossible to change the data after the transaction. Blockchain technology is a backend technology, with which the user of a system does not interact directly. Therefore, the question is which features that the user perceives can provide trust in the application. The adoption of new technologies in organizational and business environments is a main field of IS research. In this context, the question of how blockchain is able to generate trust in the technology for its users has not yet been analyzed in depth in IS research. This also concerns the influence of key features that distinguish blockchain from other technologies (including anonymity, traceability, and immutability) on the topic of trusting in technology. The corresponding effects have not yet been empirically proven in the scientific literature (see also section 6.2).

Based on the research gaps listed above, the third and final research question of this thesis is as follows:

RQ 3: Can the use of blockchain technology build trust among users of a collaboration platform where anonymous participants interact with one another?

To answer the question, two sub-questions are formed. These concern the effect of essential blockchain features on the trust in technology. Furthermore, the effect of the features is investigated when anonymous actors interact with one another within the platform. The questions are answered by conducting an empirical experiment.

> **RQ 3.1: What is the impact of the blockchain technology features immutability, traceability and anonymity on trust in technology?**
>
> **RQ 3.2: How does anonymity interact with immutability and traceability?**

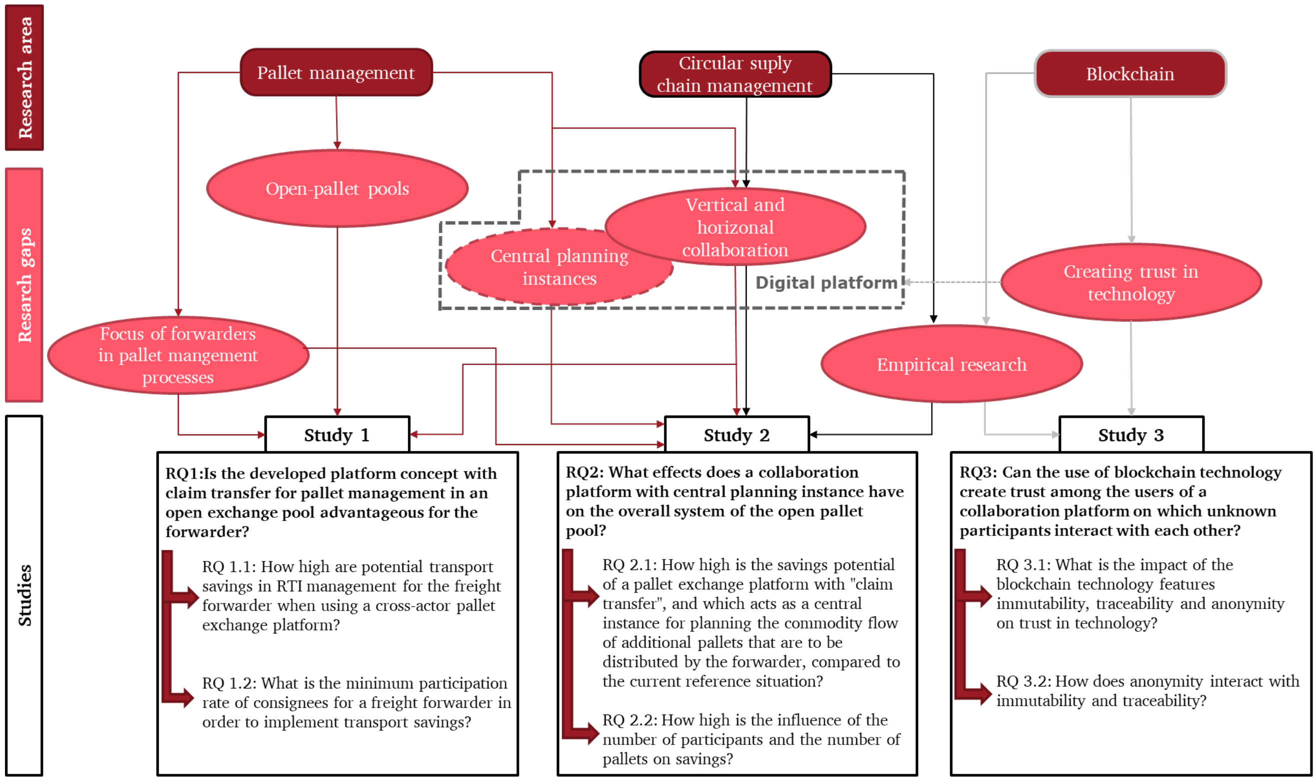

Figure 8: Adressed research gaps.

In the Figure 8, the research gaps from the different research areas that are described in this section and their links to the three studies are shown graphically. You can see that there is no link between the first study and the research gap "Empirical Research". This does not mean that it should be classified as non-empirical. However, in the second study, the research focuses on the CSCM perspective, which has a lack of empirical research, as pointed out above, as opposed to studies from the field of pallet management (see sections 5.2 and 5.6). Furthermore, the edge of the text box on central planning instances is dashed and connected to the Vertical and horizontal planning text box. This is due to the fact that the topic of central planning instances is considered as a possible configuration of especially horizontal collaborations for this thesis.

1.4 Scientific Theoretical Classification

This thesis can be classified in the context of the philosophy of science. The philosophy of science is a sub-discipline of philosophy and deals with the prerequisites, methods, and goals of science as well as the procedure of gaining knowledge (Helfrich, 2016). It is superordinated to the individual scientific disciplines and forms a meta-level (Kornmeier, 2007). The philosophy of science is based on the epistemology of the 19th century (theory of knowledge), which pursues the question of how knowledge can be obtained and what conditions must be met for something to be classified as knowledge (Helfrich, 2016).

In terms of scientific theory, formal and real sciences can be distinguished from one another (Kornmeier, 2007). The formal sciences investigate abstract, logical content, such as in mathematics, while the real sciences investigate facts and phenomena from the real world (Jung, 2010). The real sciences can in turn be divided into natural sciences, which consider nature as the object of research, and social sciences (Kornmeier, 2007). The latter investigate the social coexistence of people (Kornmeier, 2007). Therefore, this thesis can be classified in the field of social sciences, more precisely in the economic sciences. This is because companies, their actions and collaborations are the focus of this work. While the economic sciences primarily belong to the real sciences, since they describe phenomena from the real world of companies and their interactions, they are also applicable to the principles and methods of the formal sciences (Helfrich, 2016).

Moreover, the research in this thesis can be assigned to the application sciences, which have the goal to investigate concrete improvements for common practice (Helfrich, 2016). They thus differ from basic research, which focuses on theoretical findings and exist either for an end in itself or are intended to serve as a basis for application research (Helfrich, 2016). The research area of Business Economics describes existing systems, as well as also new possibilities and design alternatives (Siemoneit, 2009). The aspect of developing new systems is central to this thesis. The potentials of the aforementioned digital platform are analyzed, which enable more efficient processes for the companies.

Business economics can be differentiated according to their corporate functions (Domschke and Scholl, 2008):

- production management,
- materials management,
- logistics (procurement, warehousing and transport),
- marketing,
- investment and financing,
- accounting and corporate management.

Since the transport of goods, their return, and the (re)procurement of loading equipment are researched in this work, it can be classified within the area of materials management and logistics.

According to Picot et al. (2020), three organizational levels can be distinguished as the object of study in business economics: First, the internal organization of the firm; second, the organization of cross-actor forms of collaboration; and third, the competitive environment (including government intervention). This thesis focuses on the second organizational level, since the collaboration in the field of pallet management between different actors is investigated. However, the other two levels are also affected because of the implication of internal processes in pallet management as well as superordinate framework conditions and standards for pallet exchange.

The main source of knowledge, especially in business economics as an applied science, is based on empirical implications (Helfrich, 2016). They are thus contrasted to implications drawn from an intellectual process (rationalism), which are logically derived without the needed reference to reality (Helfrich, 2016).

In addition to the research in the logistics environment of Business Economics, IS-research is also covered in this thesis. Furthermore, methods of Operation Research (OR) are being used. According to Domschke and Scholl (2008), both IS research and OR occupy a special position next to the classical branches in the field of Business Economics research. OR deals with the development of mathematical methods for decision support (Werners, 2008). In this thesis, methods of this research area are also used: heuristics for route planning, as well as an optimization model for the planning of empty pallet flows. Hence, methods of the formal sciences are also used in this thesis.

IS research deals with the application of information systems and thereby considers the organizational and managerial needs (Herzwurm and Stelzer, 2008). In this thesis, a digital platform is examined, including the extent to which blockchain technology is useful for this type of designed platform (see section 6). This thesis explores a digital platform, while also examining the extent to which the usage of blockchain technology makes sense for this type of designed platform. The effect of the technology on people, specifically the effect on the perception of trust in technology, is investigated. This aspect of the thesis can thus be classified as IS research. The user is not seen as a classical “Homo economicus”, who acts strictly following economic criteria (Krumay et al., 2018). Instead, psychological mechanisms of trust are taken into account. Therefore, it also becomes clear that IS research has overlapping fields with psychology as well (Dinev et al., 2015).

This thesis uses quantitative methods. Quantitative research methods are based on the classical methods of the natural sciences for structured data collection (Döring et al., 2016). This results in numerical data that is evaluated by means of statistical data analysis. Thus, they differ from qualitative methods, where data, which is for example collected from interviews, is used for primarily interpretative methods of data analysis (Döring et al., 2016).

One central method used in qualitative research is a scenario-based experiment in which participants are presented with different situations after which they have to complete a questionnaire. In the experiment, hypotheses were first determined and are then tested on the basis of the data which is collected in the experiment. This procedure corresponds to critical rationalism according to Popper (1984), in which an explanatory statement is compared with real observations that confirms or refutes the hypotheses. However, this confirmation or refutation is generally regarded as temporary in critical rationalism.

The second central method is simulation modeling. Here, the investigation is not carried out directly in the real world, but in a simulated system. For this reason, there is a lively discussion in the philosophy of science about the extent to which the method of simulation can be used as a tool for gaining knowledge. While, for example, Morgan (2003) argues that simulation modeling as a method is no different from other experiments in terms of epistemological implications, many other scientists argue that simulation modeling is different from other experiments in this context (Grüne-Yanoff and Weirich, 2010). In order to address the epistemological challenges of simulations, verification and validation of the simulation models play a crucial role (Kalua and Jones, 2020). Especially in the field of economics, where predictions of future conditions also play an essential role, the use of simulations is basically considered uncritical and a suitable method of gaining knowledge (Weber, 2004).

1.5 Outline of the Thesis

After outlining the motivations of the thesis in section 1.1, the central platform concept was also presented in section 1.2. Then, the existing research gaps were identified, from which the research questions for this thesis were derived. Finally, the thesis was classified in the context of the theory of science.

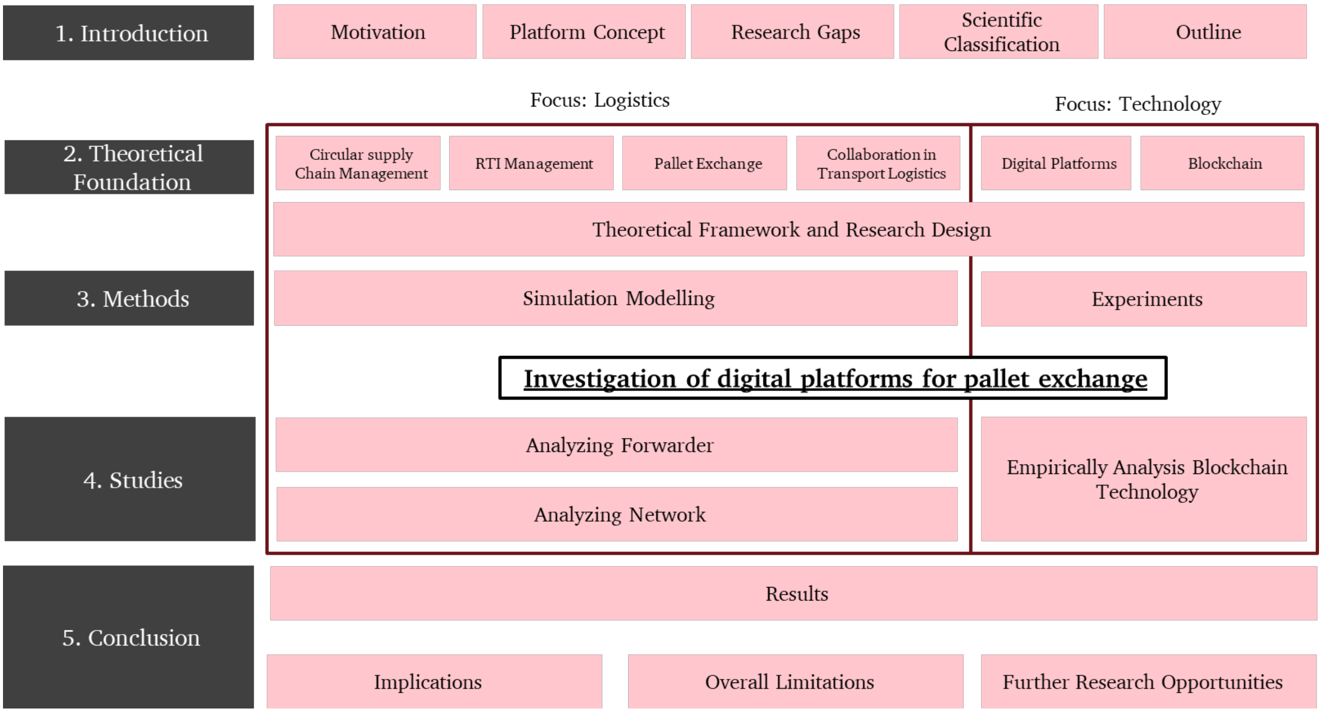

Figure 9: Outline of the thesis.

In the next section (theoretical foundations), the topics that are covered in the three main studies are discussed in more detail. Since the three main studies were published as papers, the theoretical foundations are only briefly described in them. For a better understanding, the corresponding foundations are therefore examined with more detail in section 2. Specifically, these are fundamentals from circular supply chain management, RTI management, pallet exchange, collaborations in transport logistics, digital platforms, and blockchain. Derived from these fundamentals, a framework is formed at the end of section 2, which represents the overarching research design of the thesis.

The third section presents the research methods that are used in the studies. Closer attention is paid to the basic principles and procedures of the methods, which could only be described briefly in the studies.

Thematically, the work can be divided into two major subject areas, as shown in Figure 9. On the one hand, there is the area that focuses on the topic of “Logistics” and an area that focuses on “Technology”. This reflects the two focal points of the thesis, which deal with the effects of the digital platform for the logistics and transport sector, and while also dealing with the technical design using blockchain technology.

In the final section, the two streams are merged again. In this section, the results of the studies are summarized, and the overarching research questions that are introduced in section 1.3 are answered. Finally, the limitations of this thesis are listed, and further research opportunities are described.

2 Theoretical Background

A requirement for the examination of pallet exchange platforms is to take different scientific fields into account. This includes CSCM as an overarching field, RTI management in general, and pallet exchange in particular. Additionally, collaboration forms in logistics, as well as digital platforms (as a key option to realize collaborations), have to be considered.

2.1 Circular Supply Chain Management

Circular Supply Chain Management (CSCM) describes the implementation of the Circular Economy concept into Supply Chain Management (Lima et al., 2021). The objective of Circular Economy is to save resources, as well as energy, and to avoid waste (Bocken et al., 2016). The Circular Economy stands for the following principles: reuse, reduce, recycle, redesign, remanufacturing and the repair of products, by-products, and services (Lahane et al., 2020; Lüdeke-Freund et al., 2019). Currently, Circular Supply chain management is frequently investigated in science and common practice. Farooque et al. (2019, p. 878) define it as:

> *„Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including.“*

Furthermore, Farooque et al. (2019) divide the literature in the field of CSCM into two streams: on the one hand, a supply chain wide integration of CE, and on the other hand, the examination of individual supply chain functions. This includes designing, production, procurement, logistics, consumption as well as end of life, and waste management. According to Meherishi et al. (2019), there are four key factors that are required to implement a CSCM: Circular Economy designs (e.g., sustainable material), new business models (e.g., non-bottled water in retail), reverse cycles (e.g., returning packaging), as well as enablers and favorable systems (e.g., government restrictions).

Using a literature review, Zhang et al. (2021) have created a multi-dimensional framework on CSCM, in which the discussed research themes are mapped (Figure 10). These include recycling SCM, remanufacturing SCM, industrial symbiosis, forward and reverse SCM, legislations and policies, closes-loop SCM, technologies and information, and supply chain collaboration.

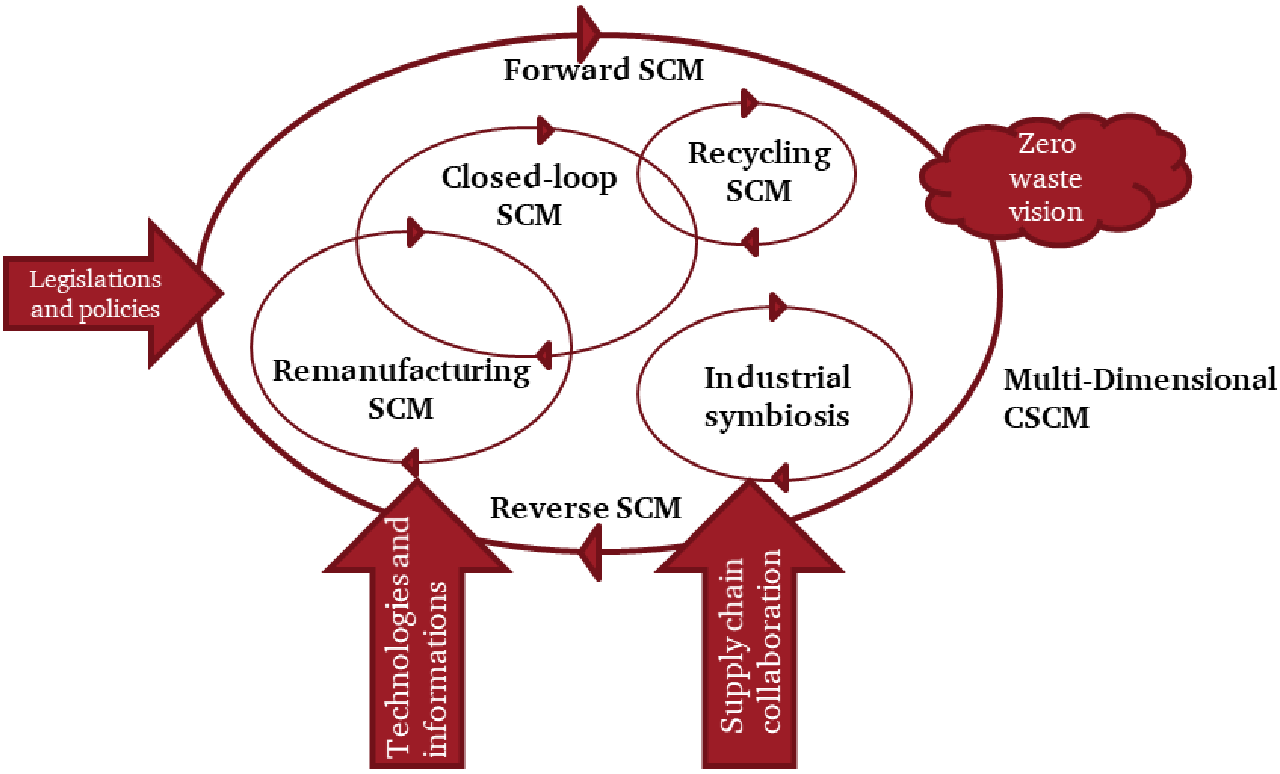

Figure 10: Multi-dimensional CSCM framework (adapted from Zhang et al., 2021).

Technology is classified as an enabler for CSCM. This particularly includes digital technologies (Liu et al., 2020). The same applies to information and the exchange of information (Tura et al., 2019; Lahane et al., 2020).

In addition, collaborations between SC actors are also seen as drivers for CSCM (Moktadir et al., 2018), whereas the lack of coordination and collaboration are considered to be barriers of CSCM (Mangla et al., 2018; Tura et al., 2019). In general, collaboration in CSCM can be divided into horizontal and vertical collaboration (Weetman, 2017). Vertical collaborations improve cooperation along the supply chain, for example by closing material loops, whereas horizontal collaborations involve actors on the same level of different supply chains that are working together by, for example, sharing resources (Weetman, 2017). Chen et al. (2017) additionally list internal collaborations, where different organizational units of a company work together with others.

In the existing CSCM literature, there are several practices to support collaboration (Sudusinghe and Seuring, 2022; Chen et al., 2017). Here, a distinction is made between the actors with whom collaboration takes place, such as NGOs, the government, or collaboration with innovators and with competitors (Chen et al., 2017; Sudusinghe and Seuring, 2022).

The closed-loop supply chain describes the return of material or products to an upstream point in the supply chain. Since the flow here is not forward (forward logistics) but in the opposite direction, this is also referred to as reverse logistics (Zhang et al., 2021).

In CSCM, the circularity can be either open, closed, or a combination of both. In a closed circularity, materials are brought back to the original SC (e.g., Bottani et al., 2015). In the case of an open circularity, the materials are brought to other supply chains. Collaboration between supply chains is an important factor (Kalverkamp, 2018), which can also happen between different industrial sectors. In general, the open loop circularity is assigned a greater potential (Zhang et al., 2021; Weetman, 2017). Even though the topic of open loop circularity is frequently represented in common practice, this aspect is not yet strongly covered in the scientific CSCM literature (Zhang et al., 2021).

Related to the closed-loop supply chain are remanufacturing and recycling supply chains, which utilize the products after the end of their use phase (Zhang et al., 2021). The term industrial symbioses describes the exchange of materials, by-product, etc. with companies located in the direct neighborhood (Zhang et al., 2021).

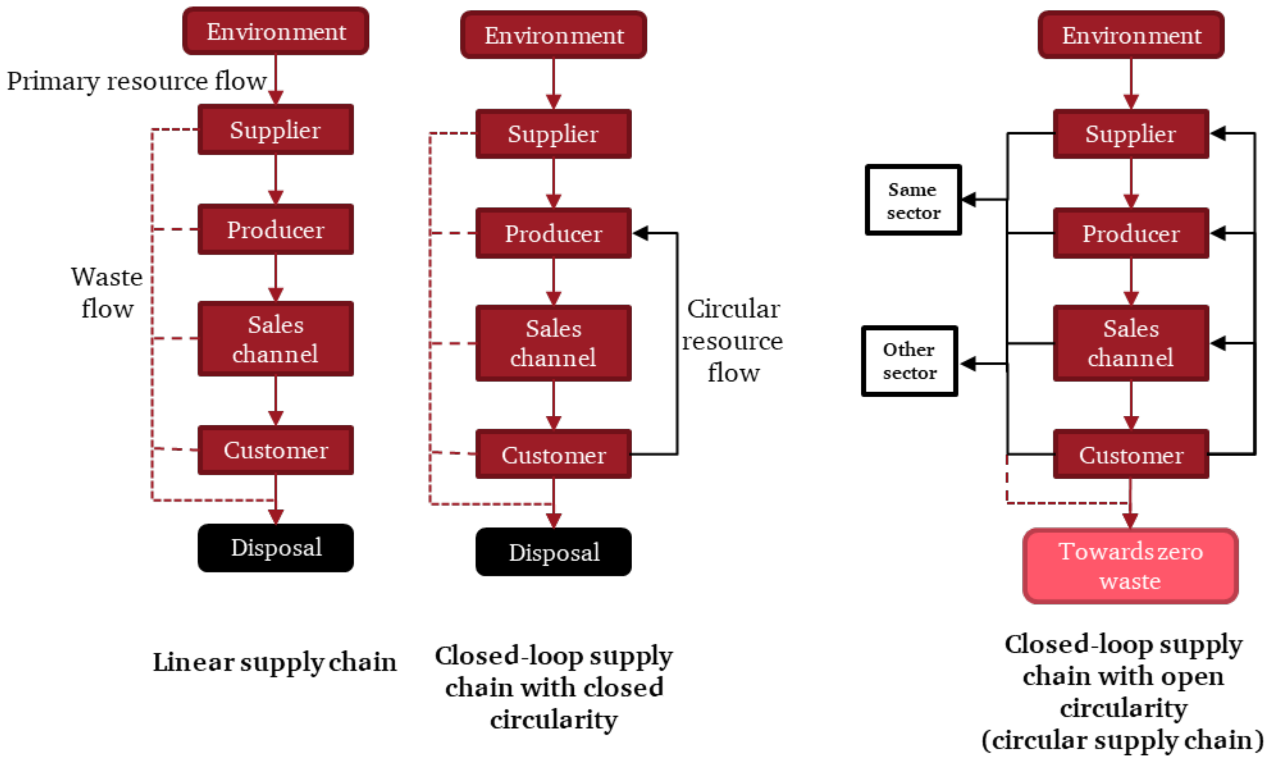

Figure 11: Linear, closed-loop, and circular supply chains (adapted from Farooque et al., 2019).

2.1 Returnable Transport Item Management

Returnable Transport Items are characterized by their reusability. Unlike disposable transport items, they can be reused several times, and thus contribute to a more sustainable economy (Accorsi et al., 2019). However, the reuse of RTI also means that the return processes and procurement processes have to be organized efficiently (Glock, 2017).

In the context of RTI management, the term "open-loop supply chain" is not used consistently and differs from the CSCM definition. For example, the term is used to title a one-time use of pallets in one case (Gnoni et al., 2018), while open-loop is also used to represent that the pallets belong to the consignee, and closed-loop when the pallets belong to the shipper in another case (Glock, Bilbao et al 2011). Since the focus of this work is on the reuse phase of pallets, in which the pallets are used multiple times and pass through the same or different supply chains multiple times, the term closed-loop is used to refer to the return of pallets for reuse according to the definition in section 2.1.

Besides the commonality that RTIs are reusable and improve the transport, storage, and handling processes, there are very many different variations of them. These range from gas cylinders (Mason et al., 2012), pallets (Tornese et al., 2021) to beer kegs (Breen, 2006). Due to the high diversity and the different purposes, the use and management of RTI must also be considered in a differentiated manner.

According to Glock (2017), research in RTI management can be divided into four research streams. First, different variants of RTI management systems are examined. For example, it is investigated whether the RTI should be purchased or rented e.g., Cheng and Yang (2005). This also includes investigations on the question whether reusable RTI should be used at all for the individual case, or whether a disposal alternative should be chosen. In most cases, the reusable options are the best solutions (e.g., Menesatti et al., 2012). However, there are also individual cases, for which the disposal alternative turns out to be the best option (Mollenkopf et al., 2005).

The second research stream focuses on forecasting RTI returns. Due to the uncertainty that arises regarding the timing, the quantity, and the quality of the returns, this poses a particular challenge for management (Elia and Gnoni, 2015; Glock, 2017). The third research stream deals with the purchase of new RTIs, especially the corresponding timing and quantity (e.g., Buchanan and Abad, 1998). The fourth and final stream deals with the management of RTIs, for example network design for RTI reverse flows (Bottani et al., 2015; Thoroe et al., 2009). The research of this stream is the objective of this thesis as well.

2.2 Pallet Exchange

Similar to RTI in general, there are also many different types of pallets: They can be made out of different materials, such as wood and plastic, have different sizes, and be either disposable or reusable (Leibrandt, 2015; Carrano et al., 2015). If the pallets are not disposable, it is necessary to arrange that the pallets are returned. This can be arranged in different ways, depending on the form of the pallet management.

Another possibility of pallet management is the transfer of ownership (Ren et al., 2019), which is also called buy/sell program (Tornese et al., 2021). Here, the pallets are sold as part of the packaging, along with the goods. If the recipients do not need them, they can resell them, for example to service providers who buy such pallets, repair them, and then resell them to companies that need pallets to deliver their goods (Roy et al., 2016).

Another option is the pooling of pallets (Chen et al., 2019a). Companies can also use pallets from pallet rental companies. Not only do pallet service providers offer the supply of pallets, but also the maintenance, repair, and the return of the pallets from the customer (Tornese et al., 2018).

A pallet exchange system is another alternative way of pallet management (Grimm et al., 2010). In the scientific literature, an open pallet exchange pool, in which all actors can acquire standardized pallets and exchange them with one another, is hardly considered. However, this topic is heavily focused on the practical literature in Germany (Elbert and Lehner, 2019).

Two forms of pallet exchange are widespread in Germany (Löw, 2008). One is the so-called "Kölner" pallet exchange, or double exchange, and the other is the “Bonner” pallet exchange, or exchange of pallets with a return obligation. Both ways have predefined, contractual terms (Knorre, 2015). In the “Kölner” pallet exchange, the shipper, the consignee, and the forwarder bring in their own pallets, which they then exchange with one another (Löw, 2008). In this case, the forwarder loads the truck with empty pallets and drives to the shipper of the goods. There, the shipper receives the empty pallets from the forwarder, and in return, the palletized goods are loaded onto the truck. The forwarder now drives the palletized goods to the consignee of the goods, unloads them there, and receives the corresponding quantity of empty pallets back from the consignee. With the empty pallets, the forwarder now drives back to the depot. With this exchange procedure, all actors end up with the same number of pallets that they initially brought into the system.

During the “Bonner” pallet exchange, the forwarder does not bring their own pallets into the system (Knorre, 2015): This means that the forwarder receives a corresponding number of empty pallets from the consignee of the palletized goods, which afterwards must be returned to the shipper of the pallets. This variant is especially useful for regular deliveries.

Theoretically, the swapping of pallets results in an efficient system without great expenses (Löw, 2008). However, problems arise in common practice. A major factor here is that it is not always possible to exchange pallets on site. Due to time pressure or an insufficient quantity or quality of the empty pallets, the exchange often has to occur at a later point in time (Hagenlocher et al., 2013). As a result, the pallet debts must be recorded and administrated. For this purpose, the actors can either keep pallet accounts among themselves, in which debts and receivables are recorded, or they are recorded in the form of pallet vouchers, which are issued as promissory bills (GS1, 2018). In addition to the administrative effort, a deferred pallet exchange often leads to additional trips being needed to return the empty pallets (Glock, 2017). Furthermore, the different pallet qualities also lead to disputes during the pallet exchange (Hagenlocher et al., 2013).

In conclusion, the forwarders suffer the most under the current system. For instance, whether an exchange is fairly conducted in terms of pallet quality is up to the consignee of the goods, who decides which pallets are offered as exchange pallets (Elbert and Lehner, 2019). In common practice, it can happen that only bad pallets are exchanged, out of opportunistic behavior (Löw, 2008). Due to this circumstance, costs for the repair and replacement of pallets are transferred to the forwarder (Lange and Hoffmann, 2011). As the forwarder usually only has a contractual relationship with the shipper and not with the consignee, the forwarder has little possibility to influence this behavior (Knorre, 2015). The situation becomes even more difficult if the forwarder is only a subcontractor of the hired forwarder and does not even have a contractual relationship with the shipper (Figure 12).

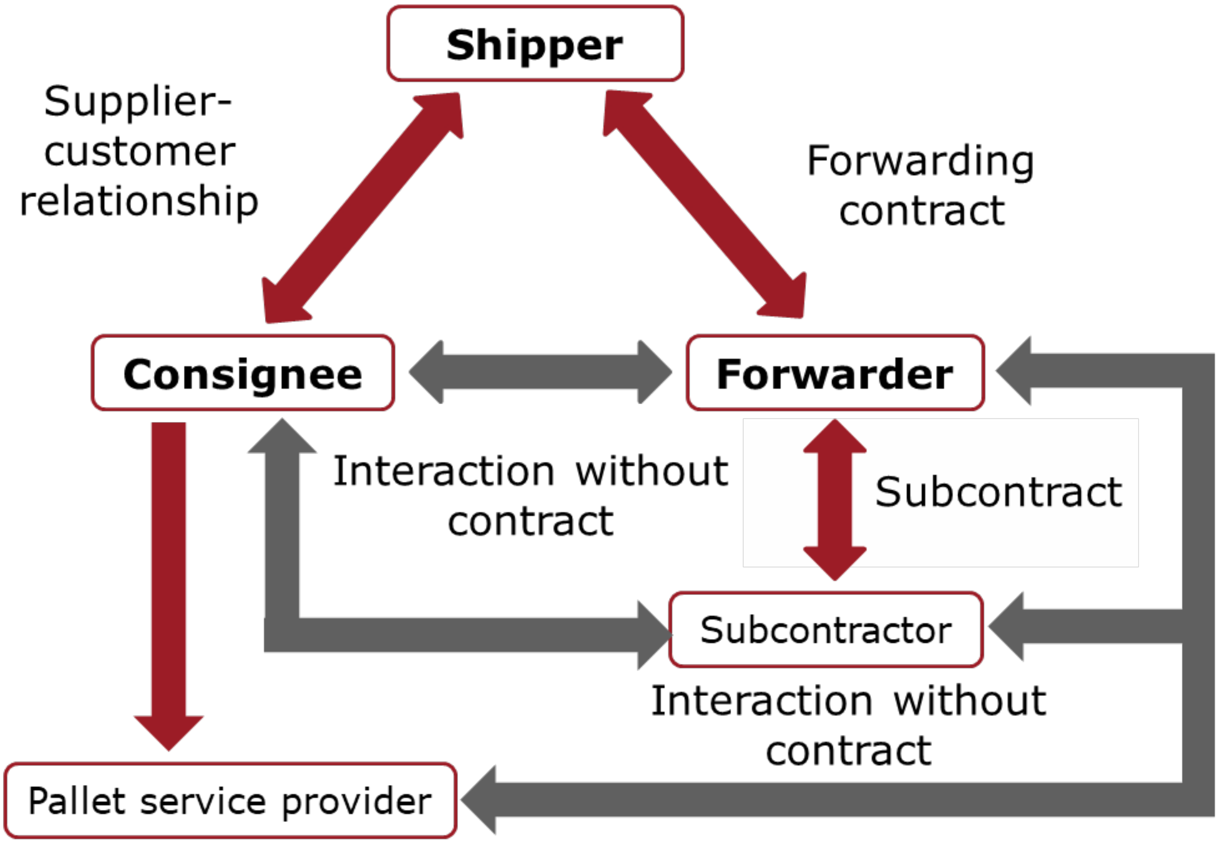

Figure 12: Contractual relationships of actor in the open-pallet pool (adopted from Knorre (2015).

2.3 Collaboration in Transport Logistics

Collaborations in supply chains are defined as „two or more independent companies work jointly to plan and execute supply chain operations with greater success than when acting in isolation“ (Simatupang and Sridharan, 2002, p. 19). In the field of supply chain management, the terms coordination, cooperation, and collaboration are defined in various ways and sometimes used as synonyms (Wankmüller and Reiner, 2020). In the field of CSMS, however, the term collaboration is widely adopted (Farooque et al., 2019; Zhang et al., 2021) and is therefore used in this paper. Due to the increasingly complex supply chains or networks, the role of collaborations is becoming more important than the prevailing bilateral supplier-buyer relationships (Ramanathan and Gunasekaran, 2014).

As already stated in chapter 2.1, a distinction between vertical and horizontal collaboration can be made. In vertical collaboration, partners from different levels of the supply chain work together. This is the more common form of collaboration (Renko, 2011). A classic supply chain consists of numerous of such collaborations, ranging from the manufacturer of raw materials, through the producing companies, to wholesale and retail.

Horizontal collaborations, on the other hand, in which the actors are on the same level in the supply chain, are rather rare (Basso et al., 2019). There are various objectives for horizontal collaboration. The most important goal is cost reduction, but improved customer service, increased responsiveness, and environmental issues are also listed as goals (Pomponi et al., 2015). It is crucial that a win-win situation is created for all involved parties (Cruijssen et al., 2010).

Different stages of collaboration can be distinguished into operational, tactical, and strategic collaborations (Pomponi et al., 2015), which can evolve over time from operational, to tactical, to strategic collaboration. In the first form of collaboration, the exchange of data is focused on, whereas in the tactical collaboration, the development of common IT tools and a collaborative event management, such as joint planning (Whipple and Russell, 2007) or common use of logistics facilities (Olorunniwo and Li, 2010), are in the center of attention. An example of this are urban logistics facilities, which are located at the edge of urban centers, and which are supplied with goods by various forwarders; these are then transshipped to destinations within the city and shipped out in smaller vehicles (Elbert and Friedrich, 2018). In the third form, the collaboration extends to fully integrated supply chain processes, in which, for instance, the manufacturing scheduling is harmonized (Whipple and Russell, 2007).

In research, horizontal collaborations in the transport sector are more and more investigated. For example, joint route planning has been increasingly considered in recent years (Aloui et al., 2021). In this process, customer orders are distributed to different forwarders, enabling them to each operate their routes as efficiently as possible (Los et al., 2020; Rabe et al., 2016). In this case, a certain authority collects the information, and can thus carry out central planning (Wang and Kopfer, 2014). For collaborative planning, it may be necessary to share private information with competitors (Gansterer and Hartl, 2020). Accordingly, the different actors must have trust in each other. Trust is an essential factor in the area of collaboration. This is true for both forward logistics collaboration and reverse logistics collaboration (Paula et al., 2019). According to Lambert et al. (1999), the degree of collaboration can increase accordingly with time and increased trust.

2.4 Digital Platforms

Digital platforms are a useful tool for interorganizational collaborations (Freichel et al., 2022). Different definitions of digital platforms can be found in literature (Freichel et al., 2022). Moreover, these are often dependent on the context in which the digital platform operates (Koskinen et al., 2019). According to Reuver et al. (2018), digital platforms are business models for conducting value-creating interactions between suppliers and consumers, in which the platform provides the infrastructure and defines the framework conditions for the exchange.

Digital platforms can have different characteristics, for instance regarding the business model, the technology that is used, or the provided service (Hodapp et al., 2019). Another distinction between platforms is whether they operate in the B2B area, or in the consumer market (Hodapp et al., 2019). This is important, as studies indicate that the findings from the consumer market, which are more frequently the focus of scientific studies (e.g., Hein et al., 2019; Loux et al., 2020), cannot simply be transferred to B2B platforms (e.g., Loux et al., 2020; Wallbach et al., 2019).

Basically, a distinction between transaction and innovation platforms can be made (Gawer, 2021). Transaction platforms focus on the exchange or execution of transactions (e.g., goods or services) between participants (Gawer, 2021). In the context of bringing together different groups, it is also referred to as multi-sided platforms (Reuver et al., 2018), or, in the case of two groups, as two-sided platforms (Belleflamme and Peitz, 2019). The networking effect is relevant for these platforms: The benefit of the platform increases exponentially to a higher participation rate in the platform (Hein et al., 2019). It can be distinguished between a same-sided network effect if the actors are of the within-sided type, and a cross-sides network effect if other sides are relevant (Xie et al., 2021). In addition to pure transaction and innovation platforms, there are also hybrid forms that fulfill both functions (Gawer, 2021).

Examples of digital platforms in the transport sector are freight platforms, such as Uber Freight, which is a transaction platform that brings forwarders and customers together (Selvaraj et al., 2020). Another example in the transportation sector are time slot management systems, with which forwarders can book different time slots for their delivery to consignees (Stefansson and Lumsden, 2008). This is intended to equalize the time of deliveries and reduce waiting times. There are also information systems at transportation hubs (such as ports and airports) that are designed to bring local companies together and facilitate the exchange of information (Carlan et al., 2016).

These examples show that there are various possible applications for digital platforms in logistics. When examining such platforms, it should be noted that the platforms must be examined in their respective contexts (Reuver et al., 2018). There are numerous factors that influence whether a platform will be successful. One factor here is trust, which must exist between the user and the platform (Huurne et al., 2017). For example, there may be concerns about whether the platform actively controls which connections are generated between platform participants (Abdelkafi et al., 2019).

2.5 Blockchain

The blockchain technology became known through the creation of the cryptocurrency Bitcoin in 2008 (Yin et al., 2019), and since then has been classified as a disruptive technology that has the potential to cause significant changes in business processes and business models (Nofer et al., 2017).

Blockchain is a distributed-ledger technology, in which data is stored in blocks (Beck et al., 2017). New blocks are generated and attached to the existing blocks, thus creating a chain (Hughes et al., 2019). Consensus mechanisms are used to attach a new block, which create a consensus in the network and determine which blocks are generated and attached to the blockchain (Beck et al., 2017). Bitcoin uses a proof-of-work mechanism, in which mathematically complex problems must be solved using trial-and-error. Other blockchains also use more efficient mechanisms, such as proof-of-stack (Li et al., 2020).

This example already shows that the blockchain technology can have different characteristics, depending on the specific application. In addition to different consensus mechanisms, a blockchain can be permissionless, so that anyone can participate (Ølnes et al., 2017). The public blockchains Bitcoin or Ethereum are examples of this (Fernandez-Vazquez et al., 2021). In contrast, there are also permissioned blockchains; these are private blockchains to which only certain users have access (Rossi et al., 2019a).

Furthermore, the blockchain is often referred to as a “trust engine” (Lim et al., 2022)or “trust-free” technology (Hawlitschek et al., 2018). In science, this is viewed in a more differentiated way and is referred to, for example, as a shift from institution-based trust to trust in technology (e.g., Lustig and Nardi, 2015). Ostern (2018) establishes a framework, in which different factors are listed that can have either a positive impact on trust (e.g., immutablity) or a negative impact on trust (e.g., anonymity, no central liable party) in the Blockchain.

Moreover, the Blockchain has specific key features that only occur in that specific constellation of this technology. Central features are immutability of a recorded data, traceability of transactions, and anonymity and pseudo-anonymity (Hughes et al., 2019; Wickboldt and Kliewer, 2019). Pseudo-anonymity means that, in case of Bitcoin, the user's transactions can be traced exactly, without identifying the user (Sas and Khairuddin, 2015; Scott and Orlikowski, 2014).

For the use in SCM, various possible applications are discussed in literature, such as the tracking and tracing of products in a blockchain database, e.g. in combination with GPS sensors (Kshetri, 2018). Likewise, the immutability properties, as well as the traceability of the transactions of the blockchain, are possible, so that the origin of products such as critical products, like diamonds, can be determined (Choi, 2019).

2.6 Theoretical Framework and Research Design

Based on the theoretical backgrounds, a theoretical framework for this thesis is developed, and the research design is derived.

Pallet management in the open pallet pool can be seen as an example of a successful implementation of CSCM: The 4 key factors for CE implementation – CE design, (new) business model, enabling and supporting systems, as well as reverse cycles (Meherishi et al., 2019) – can be applied to pallet management in open-pallet pools.

The CE design can be applied to the design of standardized and reusable pallets. The business model can be seen as a pallet open pool concept, where individual actors own the pallets themselves and can trade them with other participating actors. The factor of enabling and supporting systems can be seen in the standard and guidelines for pallet exchange in the EPAL open pallet pool, as well as the contractual terms for pallet exchange ("Kölner," "Bonner"). The principle of reverse cycles, in the case of pallet management, describes the downstream recovery, so that the pallets can be reused (e.g., Elia and Gnoni, 2015) or repaired (e.g., Park et al., 2018).

Since pallet exchange in the open-pallet pool can thus be seen as an implementation, the multi-dimensional CSCM framework of Zhang et al. (2021) is used as the basis for the theoretical framework of this thesis. Since only the use-phase of the pallets is considered in this work, the recycling and remanufacturing SCM were not transferred from Zhang's framework, as well as the industry symbiosis. However, in the developed framework, technology and information sharing are still considered to be enablers and success drivers for CSCM, respectively. Since digital platforms are both a technology for information sharing and a tool for collaboration (see section 2.4), both aspects are combined for the adapted framework.

The aim of the collaborative platform is to enable a closer collaboration between the various actors. This does not refer to actors who already have regular, well-functioning business relationships. Instead, a higher collaboration across the supply chain should be achieved, in order to make the overall system more efficient, and therefore also more efficient for the individual participants. For this purpose, the innovative platform concept presented in section 1.2.2 is evaluated. Since a corresponding system does not yet exist and many different actors would be needed for a real implementation, the concept is examined in the context of this thesis by means of simulation modeling. In section 2.2 it became clear that in the pallet exchange that is currently used in common practice, forwarders are in the weakest position, compared to shippers and consignees. Since the forwarder plays a special role in the platform concept, we will first investigate whether and to what extent the forwarder would benefit from a digital pallet form with claim transfer for the balancing of pallet debts. Due to network effects (see section 2.4), the potential of a platform depends on the number of participants. Therefore, the number of participants is implemented in the analysis.

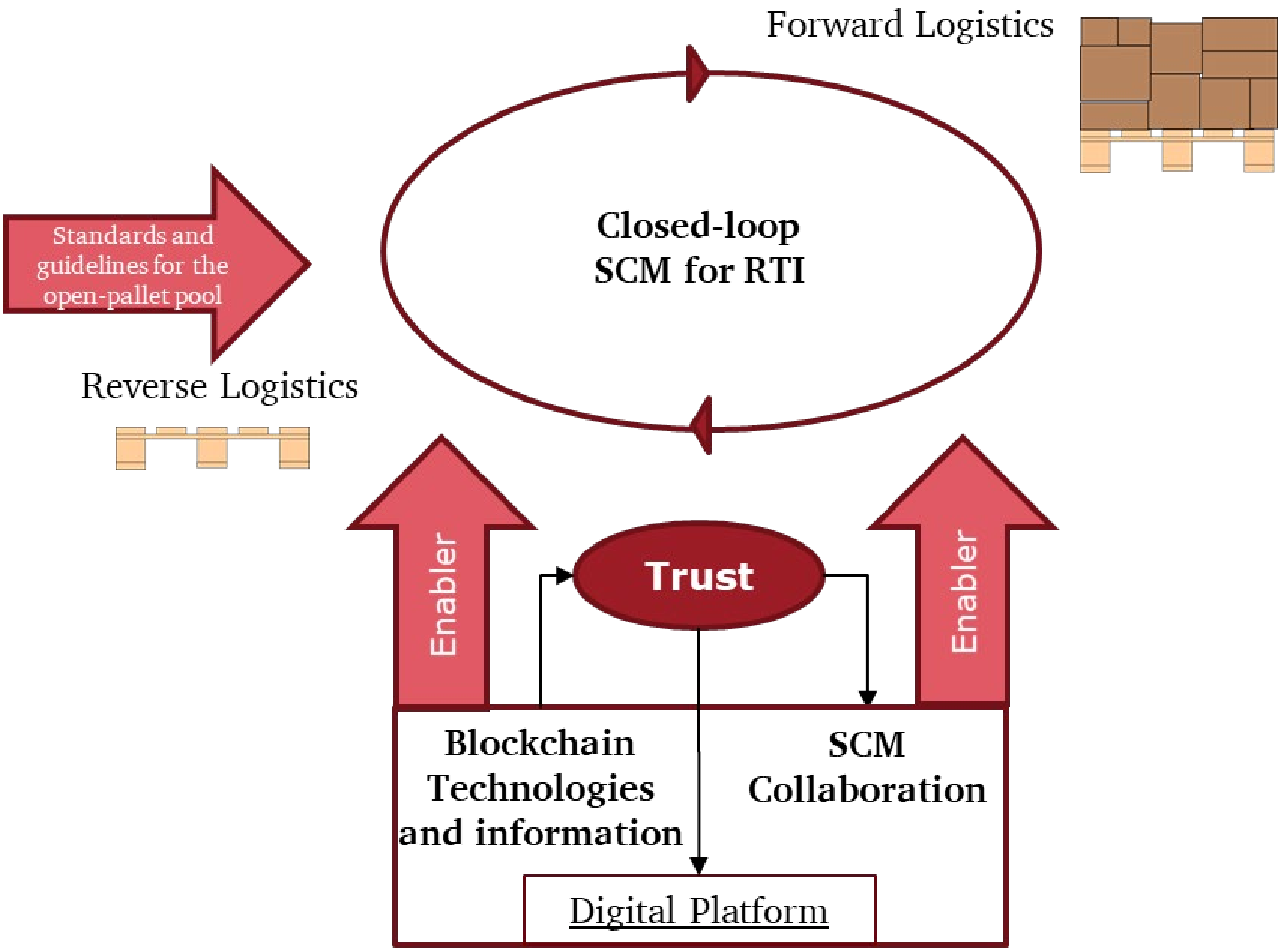

Figure 13: Framework for the thesis.

After ensuring that forwarders would be the main beneficiary from the platform designed for this thesis, further mechanisms, which enable a joint planning of empty pallet flows between the actors, and therefore a strengthened form of collaboration (see section 2.3) will be evaluated. A key element that plays a decisive role for collaboration in forward and reverse logistics, as well as in the adoption of digital platforms, is trust. For this reason, the topic of trust is added to the framework. One technology, that is said to generate trust, is the blockchain. In chapter 2.5, it became clear that the use of blockchain technology does not automatically generate trust (GS1, 2018), but that, like other technologies, it has special features that are responsible for generating trust. Based on this, the empirical study 3 determines which features of the blockchain generate trust. However, blockchain is a back-end technology, with which users have no direct interactions. Therefore, the question arises how blockchain technology can generate trust for end users (in our case, users of the pallet exchange platform), in order for them to use the platform. Therefore, the approach taken in the study is to visually represent the key features of blockchain and have them rated according to the perceived trust in the presented application. To attract as many participants as possible to the study, the setting is carried out independently of the logistical context, and a digital platform for storing and managing language certificates is chosen as an example that is easier to understand.

3 Methodology

The research questions in this thesis are answered using quantitative methods. The central methodology is simulation modeling, which is often used in the field of logistics research. In section 3.1.1, the basic principles and the procedure that is deployed for simulation modeling are described. The two simulation studies use heuristics from literature, as well as an optimization model which is developed in this thesis. These methods are primarily deployed in operation research to solve planning problems in logistics and transportation. The combination of simulation modeling and optimization is discussed in section 3.1.2.

The second central method that is used, in addition to simulation modeling, is a scenario-based experiment. Participants are shown different scenarios and are then questioned about them afterwards. The data is analyzed and used to test previously developed hypotheses. More detailed information on this method is provided in section 3.2.

3.1 Simulation Modelling

The term simulation modeling describes a problem-solving method, in which experiments are performed in computer-based models which usually represent real circumstances (Gutenschwager et al., 2017). The knowledge gained in the model must then be transferred to the real world. The models represent a simplified image of reality, in which, however, the properties relevant to the problem that need to be investigated, must be present. Here the meaning of the often quoted saying "all models are wrong, but some are useful" by George Box becomes clear (Wit et al., 2012). By systematically changing input parameters, the effects on the output of the model or the behavior of the system can then be determined in experiments.

One of the advantages that a simulation has over mathematical methods, is the representation of time. Time is a monotonically growing variable which can be manipulated (acceleration, deceleration) (Gutenschwager et al., 2017). When experiments are conducted, it is often important to keep in mind that the behavior of a system at the beginning of the simulation run may be different than at later times (Gutenschwager et al., 2017). A typical example of this is a case where very few parts are within the system at the beginning of a production simulation, resulting in queues not being formed initially (e.g., Wilson and Wendt, 2020). Only after some time passes, the system fills up and simulates the typical processes, thus reaching a so-called steady-state (Goldsman et al., 2002).

Furthermore, the simulation has the advantage that randomness can be represented rather simply, for instance via probability distributions and randomized numbers (Law, 2013). The random distributions can be obtained in different ways, such as through the evaluation of real data (Gutenschwager et al., 2017). For this reason, simulation modeling is also presented as a link between the empirical world and the world of stochastics (Eichler, 2014).

It is possible to distinguish different modeling approaches, which are used in the research on logistics and transportation: discrete-event simulation, system dynamics and agent-based simulation (Owen et al., 2010). In discrete-event simulation, events are created and executed sequentially (Banks, 1998). Thus, the changes of the simulation states occur discontinuously. Essential elements in this type of simulation are passive entities that move through different stations, at which queues are often formed and processed, depending on their properties, such as different available resources (Gutenschwager et al., 2017). A typical example of a discrete-event simulation is the material flow through a production (Mayer et al., 2020). The objects (entities) are processed sequentially by different machines (stations) and transported by vehicles, for example forklifts, (resources) to the next station.

System Dynamics takes a holistic view of a complex, dynamic system. The fundamental concept behind this approach are feedback loops that represent dependencies (Borshchev, 2013). An overall view of a system can be achieved with the help of stocks, the flows between stocks, as well as information that is needed to determine the flows (Borshchev, 2013). In contrast to discrete-event modeling, this approach does not consider individual events (Law, 2013). A case where this approach is used in supply chain management is the consideration of demand increases on transportation costs (Owen et al., 2010).

The third approach is the agent-based simulation, which became popular around the 2000s and is therefore a more recent approach, compared to System Dynamics and discrete-event simulation (Borshchev, 2013). Here, the focus lies on the agents, which are autonomous and can be programmed to be arbitrarily complex and intelligent (Law, 2013). The special feature consists in the fact that the agents operate with individual behaviors and interact with one another and the environment, resulting in the global system behavior (Bandte, 2007). Consequently, this is a bottom-up approach (Bandte, 2007).

Simulation modeling is widely used in the scientific literature on logistics and transportation (Owen et al., 2010). This is especially true for the RTI Management research stream (e.g., Bottani and Casella, 2018; Elia and Gnoni, 2015). As a result, this modeling approach is used in studies 1 and 2 as well.

3.1.1 Development process

For the implementation of the two simulation studies of this thesis, the simulation model development process according to Manuj et al. (2009) was used, since their development model was specifically adapted for applications in the field of logistics and supply chain. Therefore, in the following chapter, the model of Manuj et al. (2009) is used to describe the steps that were taken in more detail. Figure 14 lists the individual steps that will then be explained. Subsequently, it is shown how these were considered for the execution of simulation studies.

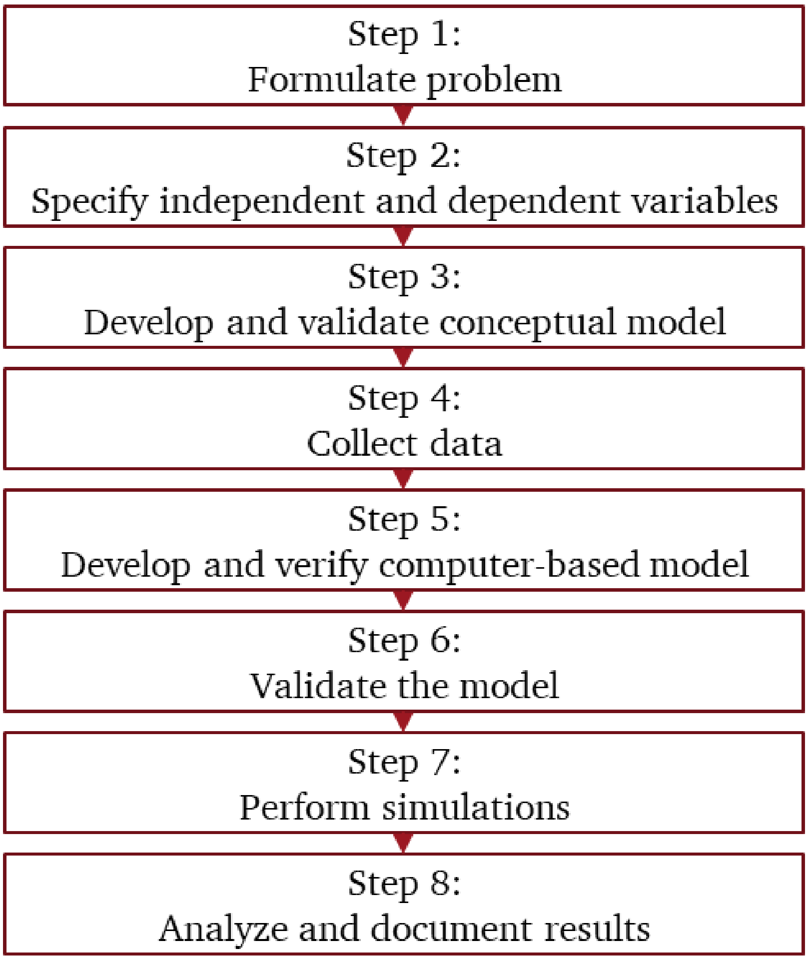

Figure 14: Development process for simulation modeling

Step 1: Formulate problem

The first step in a simulation study is formulating the problem, including the questions that need to be answered by the simulation study (Manuj et al., 2009). The two developed simulation studies aim to evaluate the benefits and impacts of a collaborative platform in pallet exchange. In the first study, the focus lies on freight forwarders, as they face the most challenges in the current practice of pallet exchange. In the second study, the functionality of the platform will be extended to implement centralized joint planning for the return flow of empty pallets. A more detailed description of the problem can be found in sections 1.1 and 1.2.21.1 of this thesis.

Step 2: Specify independent and dependent variables

The second step is to specify the independent and dependent variables. This step represents a special feature in the model of procedure according to Manuj et al. (2009) in comparison to other models (e.g., Robinson, 2008). By specifying the independent variable, the values that will be varied in later experiments are determined. The dependent variables represent the output, which changes depending on the independent variables.

In the first simulation study, only the participation rate in the platform is varied (Figure 15). Therefore, the dependent variables consist of the distances that have to be covered additionally for the RTI management. These consist, on the one hand, of extra round trips, in which empty pallets are collected by various actors, and of trips to the pallet store where new pallets are purchased.

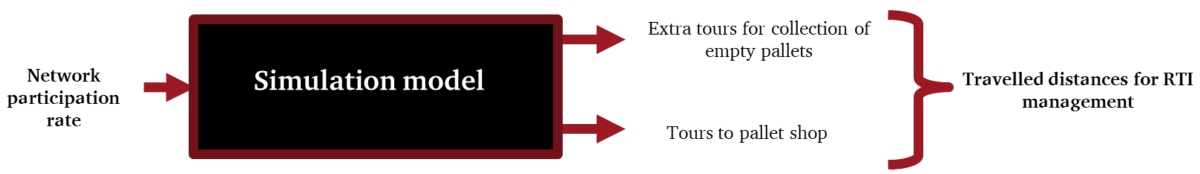

Figure 15: Independent and depended variables of the first simulation study

In the second simulation study, the participation rate is supplemented by the maximum number of pallets that can be taken by the trucks, in addition to the regular empty pallets that are distributed between the actors (Figure 16). The independent variables consist of the additional distances that need to be driven and the number of pallets in the overall system. It should be noted that the independent variables do not only refer to the forwarders, as it was the case in the first study, but also to the shippers and consignees. The last independent variable that was defined is the total debts of the system. These are also considered separately for both the forwarders and the shippers or consignees.

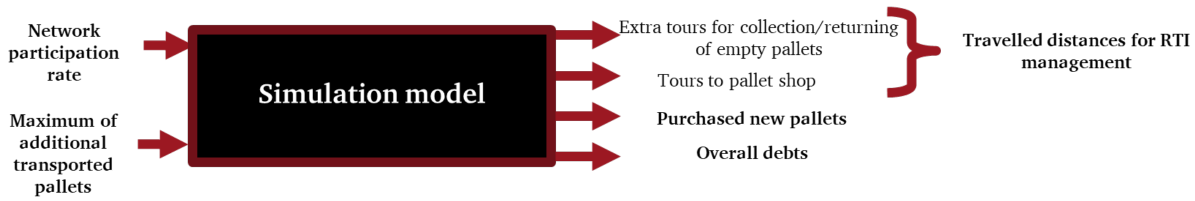

Figure 16: Independent and depended variables of the second simulation study.

Step 3: Develop and validate conceptual model

A conceptual model describes the system that needs to be mapped in an abstract way, while addressing the various components, their logical relationship to one another, as well as the assumptions and simplifications (Robinson, 2008). A detailed description of the conceptual models for study 1 can be found in section 4.3.1 and 4.3.2 for study 2 in section 5.3. The independence from a software also allows an uncomplicated exchange with participants, whereby a validation of the conceptual model can take place as well (Furian et al., 2015). For validation, evaluation and further consultation, representatives from common practice were involved in a committee for the conceptual models of both studies (see step 6).

Step 4: Collect data

Collecting data is another important step (Manuj et al., 2009). This can be done through interviews, company data, surveys, but also by means of books and scientific literature. Using the collected data, parameters can be defined for the simulation model or probability distributions can be derived (Gutenschwager et al., 2017). An essential source of information for the two simulation studies that are presented in this thesis was the practice committee. In addition to information on specific parameters and process sequences, practice data was also made available (section 5.5).

Step 5: Develop and verify computer-based model

In step 5, the conceptual model is converted into a computer model (Robinson, 2008). For the implementation, the Java-based software AnyLogic is used, and an agent-based simulation is chosen as the modeling approach. An important step during the implementation is the verification of the model. Here, it is checked if the programmed code works as planned according to the conceptual model (Sargent, 2010). Various methods are used to ensure this, such as monitoring or extreme value tests (see step 7).

In the following section, the relevant agents of the simulation model are briefly introduced. Since study 2 was developed using study 1 as a basis, the final simulation model of study 2 is taken as the basis for the following description.

Shippers/Consignees

Figure 17 shows a screenshot of the Company agent class with parameters, variables, collections, and various functions. In addition to a uniquely assigned actor number and company number, each company has a fixed location in a 100km x 100km field (pointNode). Furthermore, the actor has collections for their pallet stocks. Within these pallet stocks, the pallets (sorted by quality) are stored as agents. An important task for the companies consists in the ordering of (palletized) goods from other companies. However, this is not conducted through the individual Company agents in the model, but is executed in the so-called Main-agent, which represents the top-class of all other agents that are described here. Likewise, the Main-agent determines, which Company agents are chosen as shippers that day. Subsequently, this information is stored within the Company agents in the variable "todayShipper". If the company agent acts as a shipper, it receives an order with information about the customer and the ordered quantity. The shipper prepares the order by taking pallets from the stock and storing them in the collection "transportedPalletList", until the truck picks them up. However, for the pallets to be picked up, the Company must first engage a forwarder. This is triggered by the "generateTransportRequest" event. A transport request is generated and sent to the forwarder. The transport request is also modeled as an agent, but it is passive and only contains information about the ordering company, the consignee, and the quantity of ordered and palletized goods.

In order to have enough pallets for shipping, the actors have to keep track of the stocks. For this purpose, the current stock is checked daily by triggering the event "checkPalletAmount" and, if necessary, the process “empty pallet procurement” is initiated. This is either done by purchasing new pallets in the nearest pallet store or by claiming open receivables from the forwarder.

The pallet debts and receivables that arise between the different actors during the simulation run are stored in the collection “palletAccounts”. To verify the account balances, the individual entries in the list are displayed on the right-hand side. Consequently, it can be checked at any time whether debts and receivables have been mapped correctly.

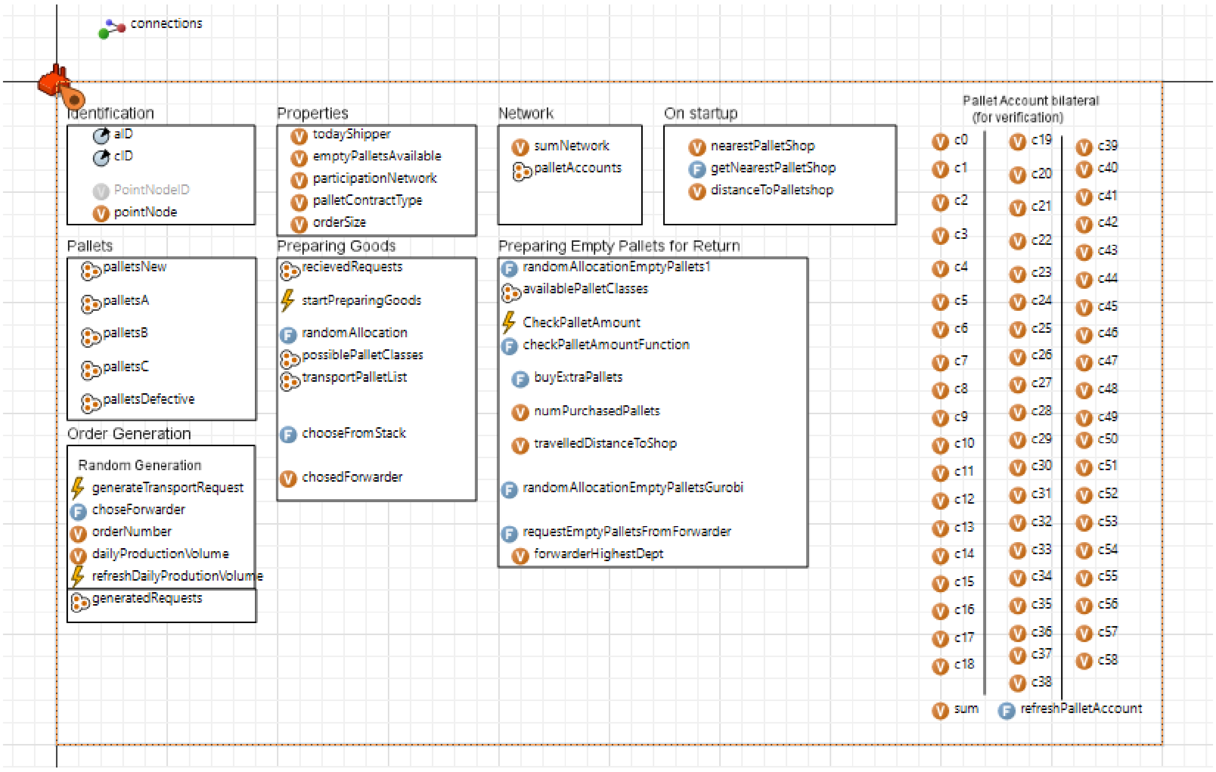

Figure 17: Screenshot of agent class "Company".

Forwarders

Major variables, parameters, and functions of the companies can also be found in the agent class of the forwarder. An additional task of the forwarder is the route planning, which is triggered by a daily event. For this purpose, functions of the open-source Java package jsprit are used, which were integrated into the model. On request of the companies, regular deliveries as well as round trips for collecting empty pallets and trips for the return of empty pallets are triggered. The regular tour is also transferred to both the global optimization model that plans the empty pallet flows and to the trucks that execute the physical material flows.

Truck

The trucks are responsible for delivering the palletized goods as well as collecting empty pallets from debtors and purchasing new pallets. Figure TR shows the behavior of the truck in the form of state charts. A state describes the certain status of the agent. The transitions between the states can be triggered in different ways: by the reception of messages, after defined time spans, or by Boolean conditions. For example, the truck starts in the state "Waiting" until a message is triggered by the forwarder to start a specific process. A regular tour (yellow state charts) is started with the loading of empty pallets. These are then stored in collections in the individual agents. After a defined time span, the truck drives to the shipper. The state is completed when the truck has reached the destination on the map (figure). In this case, the truck hands over the palletized goods and gives out empty pallets (depending on the pallet management type that is used). Afterwards, the next consignee is approached, and the palletized goods are delivered. In the state chart, a loop is coded, which runs through as often as necessary, until all consignees have been visited. Once this condition is fulfilled, the truck returns to the forwarder's depot and waits there until the next tour. In addition to the regular tours, the truck also undertakes round trips to collect empty pallets or to drive to the pallet store to purchase new pallets.

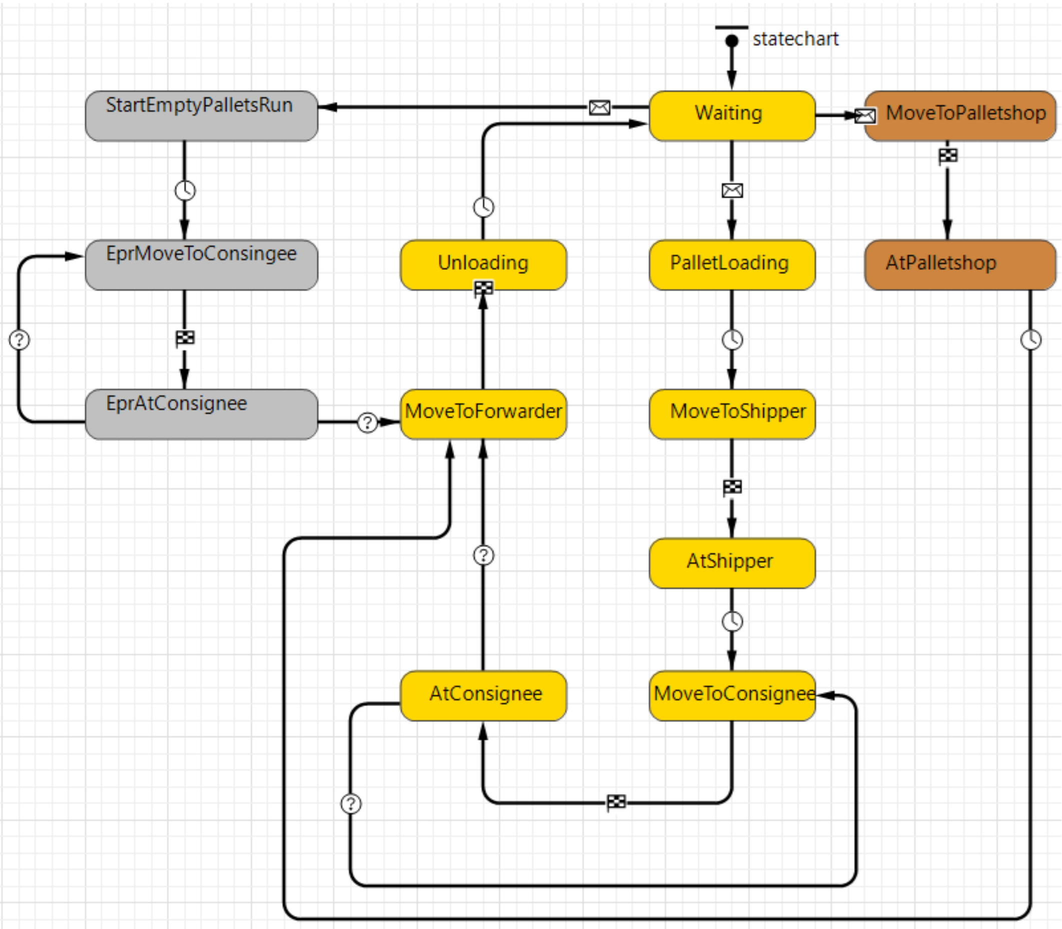

Figure 18: Statechart of the agent truck.

In addition to delivery, the truck agent takes on another important task in the simulation model: the accounting of debts and receivables. As soon as an exchange of empty pallets has or has not taken place, the pallet accounts of the actors involved are updated accordingly, based on functions triggered in the state charts. The changes are either adjusted in the pallet accounts of the individual actors or, in case of a participation in the pallet platform, in the aggregated balances ("sumNetwork", see figure XY).

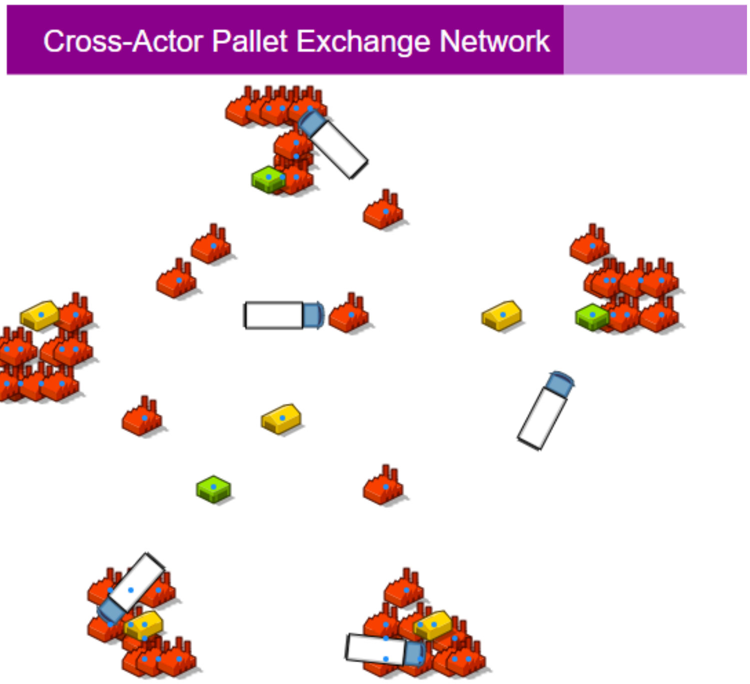

Figure 19: Screen-shot of the network.

<u>Platform</u>

Although the digital platform is the central object of investigation in the simulation study, it is not explicitly represented in the simulation model, for example, as an agent. It only appears indirectly as the variable "sumNetwork" within the agent classes Forwarder and Company. The number stored there indicates whether debts or receivables exist against the platform for the respective agent. In the so-called main agent (Borshchev, 2013), which represents the top-class of all other agents that are described here, optimization functions can be found as well. These agents receive data from the forwarders about the tour as well as their free capacities and have access to the respective account balances of the individual agents. This information is used to solve the resulting commodity flow problem and to determine where each forwarder agent should pick up and drop off pallets on their transmitted routes to minimize overall system debt. Therefore, the commercial solver Gurobi is implemented into the simulation model. The results are then transmitted to the forwarder's truck, as well as to the individual agents, who should transfer additional pallets to the truck.

Pallets

The pallets that are exchanged between actors are also modeled as agents. However, unlike the other actors, the pallets do not actively engage in interaction with other actors or the environment. They can be viewed as passive agents. Nevertheless, the pallets have parameters and properties that also change dynamically during the simulation run. In this case, the relevant factor is the location, for example, if it can be found in the truck or in a collection of actors, which represent the pallet stock. Furthermore, the pallets wear out after a defined number of handling operations. The wear and tear is also mapped via a state chart. At the beginning of the simulation, these are randomly sorted into one of the four quality levels. During an envelope handling or exchange process, a message is sent to the respective pallet agent, which stores the number of envelopes. If a certain number of envelopes is reached, the pallet changes to a lower quality status.

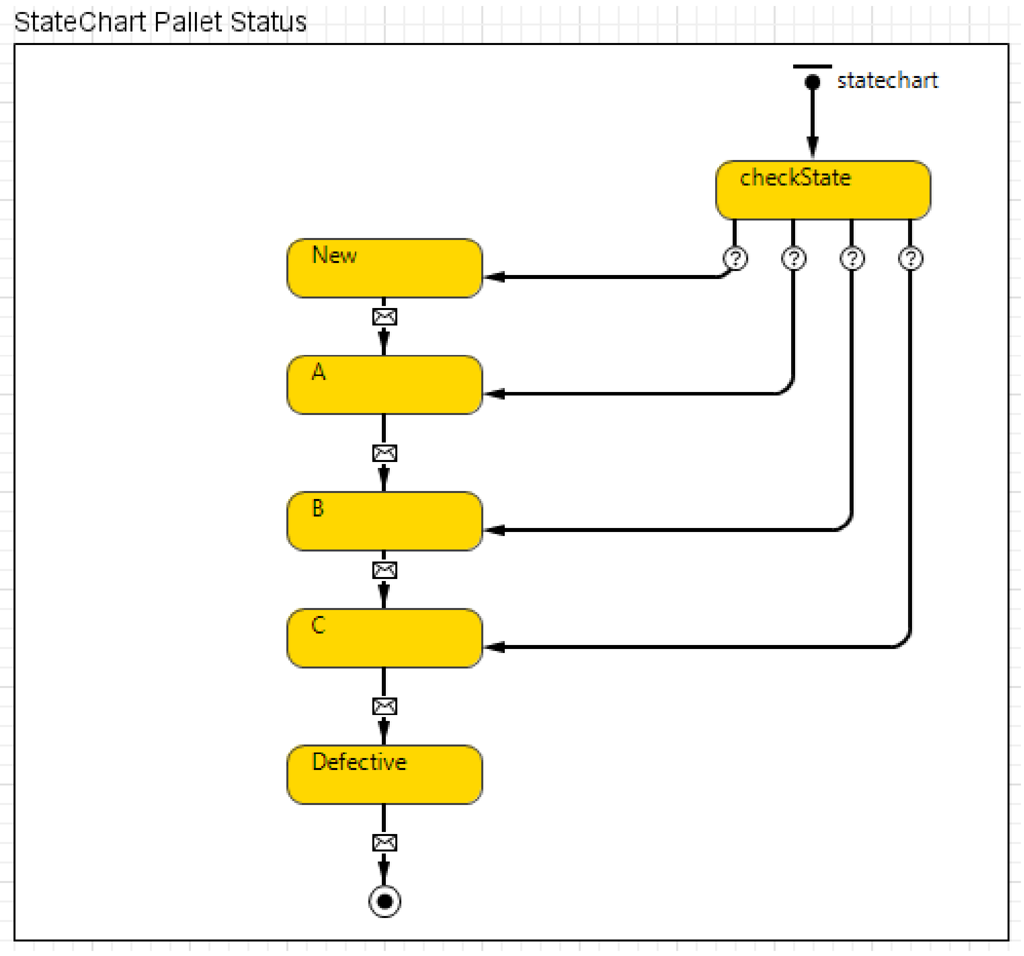

Figure 20: Statechart of the agent pallet.

Step 6: Validate the model

Validation describes a process which is intended to ensure that a model represents reality with the appropriate accuracy. This is not a one-time step, but it is repeated continuously during the modeling process. There are numerous procedures for the verification and validation of simulation models. For instance, Banks (1998) considers 77 different techniques in a taxonomy. Due to the amount of different techniques, a selection is necessary (Rabe et al., 2008). However, the different techniques can be used in different phases in the simulation process. In this thesis, the techniques animation, monitoring and extreme value tests were used throughout the development of the two simulation models.

In animation, the dynamic behavior is visualized by the use of a graphical output during the simulation run (Rabe et al., 2008). Both studies feature animations in their simulation. A 2-dimensional image of the created network can be produced, in which the locations of the actors are visualized. In the first model, a graph was created with connections between different actors, representing a road network. In the second model, this was not implemented. Instead, the actors were approached by the trucks in straight lines and the corresponding Euclidean distances were used for the route planning of the trucks. In addition to the locations within the network, the journey of the trucks to the different locations are visualized, depending on the model time, for example the tour to deliver goods or to pick up empty pallets. Through the visual representation of the trucks, it is always possible to track which actors are approached. As a result, it was possible to check whether the route planning had delivered efficient routes. Consequently, it could be traced at which actor a possible error occurred.

While monitoring, variables are checked during a simulation run and controlled for plausibility (Law, 2013; Sargent, 2010). An example of this are the updates on the pallet accounts, which can be observed in the agents of the individual actors during the simulation run.

In extreme value testing (Rabe et al., 2008), input parameters are set to their extreme values and the results are then checked for plausibility. An example of this is increasing the proportion of pallets that are sold with the goods to customers to 100 percent. If there were still debts between the actors when the test was run, there would be an error in the computer model. Many of these tests were performed during the development of the simulation model. If the results were not plausible, errors in the model were searched for and corrected.

Step 7: Perform simulations

In the seventh step, simulation experiments are performed. Here, for example, different model concepts are tested in order to find the best alternative or to compare systems to a set standard (Goldsman and Nelson, 1998). If a stochastic simulation model, for which the results depend on chance, is used, replications must be performed (Law, 2013). A mean value can then be calculated from the individual results. To ensure that the calculated mean value is as close as possible to the true mean value, a corresponding number of replications must be performed. There are different ways to determine the necessary number of replications (Hoad et al., 2007). In the literature, replications of less than 30 are often considered low (Kwak and Kim, 2017). According to the confidence interval method, the precise interval within which the mean value should range needs to be specified in advance (see Kelton, 2016).

In addition to the number of replications, the length of the warm-up phase and the length of a single run must also be taken into account if it is a non-terminating simulation (Law, 2013).

Step 8: Analyze and document results

In the last step, the results are (statistically) analyzed and documented. The simulation studies in chapters 4 and 5 are the results of this step.

3.1.2 Hybrid simulation-optimization

Besides simulation modelling, there are other methods in quantitative research that can be used to solve planning problems in logistics and production. These include exact methods for solving mathematical problems, special heuristics, and meta-heuristics (Gutenschwager et al., 2017). The combination of simulation with exact methods, special heuristics, or meta-heuristics is called "(hybrid) simulation-optimization" (Figueira and Almada-Lobo, 2014).

In exact methods, the problems are usually set up as formal models with a maximization or minimization objective function (Gutenschwager et al., 2017). The parameters or decision variables with the objective function that have the largest or smallest value are determined (Werners, 2008). Restrictions thereby limit the solution space of the considered system (Gutenschwager et al., 2017). Exact methods are used to identify the optimal result, or several results with the same optimal result values (Pieper, 2017). The modeling of specific problems can be seen as templates that are filled with different input data (Gutenschwager et al., 2017). The combination of the models with the input values is called problem instances (Gutenschwager et al., 2017). There are different exact methods for the solution of these instances, for example, Simplex algorithms (Nabli, 2009). Moreover, in order to find an optimal solution, a complete enumeration and comparison of all possible combinations is also a possibility (Kastner, 1984). So-called solvers can be used in the solving of problem instances in common practice and in science (Gutenschwager et al., 2017).

The disadvantage of exact methods consists of long computation times for complex problems and large instances (e.g., Müller et al., 2021). Therefore, the use of special heuristics can be reasonable for these types of problems. These are algorithms which cannot guarantee an optimal solution, and which are usually developed for special problems, but that can be expected to give good results (Gutenschwager et al., 2017).

Another possibility for solving optimization problems is the use of metaheuristics (Gutenschwager et al., 2017). Unlike special heuristics, these are not related to specific problems, but can be used for a wide variety of optimization problems (Figueira and Almada-Lobo, 2014). They can also be used to improve solutions from the special heuristics (Gutenschwager et al., 2017).

A metaheuristic is also applied for the route planning in study 1 and 2. The method of Schrimpf et al. (2000) is used as a basis, which is a ruin create method. Here, different orders, stops, or sequences of orders are removed from an initially created tour (ruin step) and inserted at another position (create step). If the solution reaches a certain quality, it is accepted as the new best solution. This process is repeated iteratively until a final criterion (e.g., number of iterations) is reached. Different selection methods can be used for the removing and adding of orders. For example, the open-source tool jspirit, which is used for both studies, also uses selection algorithms from Pisinger and Ropke (2007).

The methods described above are often used in operations research. These methods can also be combined with simulation as a methodology, which can then be called hybrid simulation-optimization (Figueira and Almada-Lobo, 2014). The combination possibilities of the methods are broad and depend on the considered problem, or the corresponding underlying conditions.

On the one hand, the combination of simulation and optimization can focus on the input data of the simulation (Swisher et al., 2000). In the "evaluation function" approach, the input parameters in simulation models are changed iteratively, and the respective results are checked until a parameter combination leads to the best possible output result (Figueira and Almada-Lobo, 2014). In the "surrogate model construction" variant, a surrogate model is developed by the results of the simulation, in which the minima or maxima can subsequently be determined by means of an optimization algorithm (Juan et al., 2015).

On the other hand, the combination of simulation model and analytical model can be created separately in a common system, and they can solve the problem together. "Analytical model enhancement" uses simulation to improve an analytical model, e.g., by determining the parameters by simulation (Juan et al., 2015). In the "solution generation" approach, optimization is used within a simulation model for certain calculations (Juan et al., 2015). This combination is also used in the present studies. Within the simulation model, heuristics are used for route planning, and a mathematically optimization model is created and solved in an exact way for planning the commodity (empty pallet) flow.

3.2 Empirical Experiments

In study 3, an empirical, scenario-based experiment is conducted. This chapter therefore explains the procedure of the experiment. In addition, the basics of conducting empirical studies and the moderation effect relevant to the study are explained. Finally, the conducted pre-study will be discussed.

In an investigation, experiments involve the intentional manipulation of independent variables, followed by the measurement of the dependent variables (Kuß, 2005). The procedure of empirical experiments is shown in Figure 21. Based on an initial observation or concrete research questions, hypotheses are generated using the relevant theory (Field, 2018). The linkage to theory is important because experiments can only prove correlation of factors and data, and not causality (Opp, 2010).

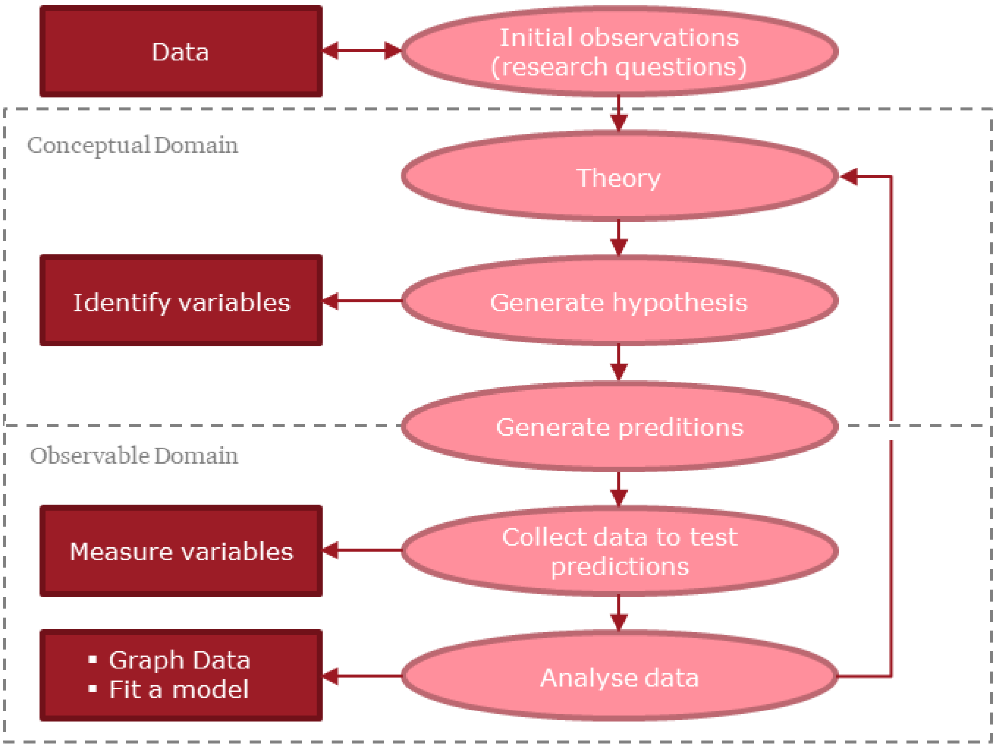

Figure 21: Development process of empirical experiments (Field, 2018).

In the study conducted in this thesis, the aim is to empirically investigate whether the use of blockchain, when it is used in the application, increases user trust. This research question is not specified by examining the blockchain itself, but by looking into the central properties of the blockchain, immutability, traceability, and anonymity. For the experiments conducted in Study 3, it is hypothesized to what extent central properties of the Blockchain influence trust in the technology (see section 6.3). The properties of the experiments are depicted graphically and subsequently, the trust which is shown by the participants in the application is measured. Trust in technology is a latent variable that cannot be measured directly. Therefore, this latent construct is represented by various items that can be evaluated by the test participants in questionnaires. The items are measured using the seven-point Lickert scale 7, from strongly disagree (1) to strongly agree (7). This scale is frequently used in research, as it offers the possibility of adopting an indifferent attitude to a question, in contrast to the 5-point Lickert scale (Joshi et al., 2015). It is possible to use so-called reversed items (Vigil-Colet et al., 2020). In this case, the questions are formulated in the opposite way (see Table 2, Item 3).

Table 2: Items for Anonymity.

Anonymity (Ayyagari 2011)
I can remain completely anonymous when using MyLanguageCertification.
I can use fictitious personal data (not my true personal data) when registering in MyLanguageCertification.
The personal data (e.g., name, driving licence number) provided by users when registering in MyLanguageCertification is consistent with their real personal data. (reverse)

For study 3, a full-factorial design is used (Figure 22). This means that all the different expressions of the factors are examined in all possible combinations. A total of 8 variants must be examined, since 3 factors with 2 characteristics each are used.

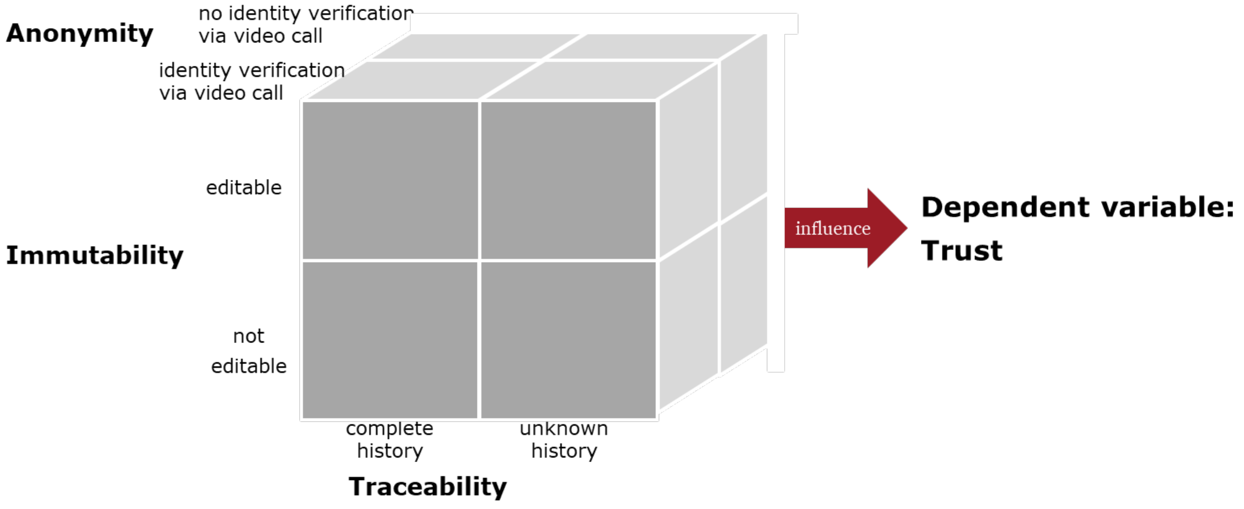

Figure 22: Full-factorial design for study 3.

In addition to investigating the direct effects of the different representations of the technology-specific features, a possible moderation effect is also investigated. A moderation effect is characterized by the fact that a moderation variable (M) influences the effect of an independent variable (X) on a dependent variable Y (Figure 23). A moderation effect is thus an interaction between the independent variable X and the moderator X (Field, 2018). To statistically prove this effect, the interaction of the independent variable and the moderator must be significant in a regression model (Dawson, 2014).

An example of the moderating influence is the effect of a percussion player's talent (M) on the musician's practice frequency (X), which influences success in playing the drums (X). For a musician with high aptitude, frequent practice leads to high success, whereas for musicians with low aptitude, frequent practice only slightly improves success in drumming. Such a moderation effect was even studied in the combined field of reverse logistics, information systems, and collaboration: Evaluation the effect of collaboration and IT competency on reverse logistics competency (Campos et al., 2020).

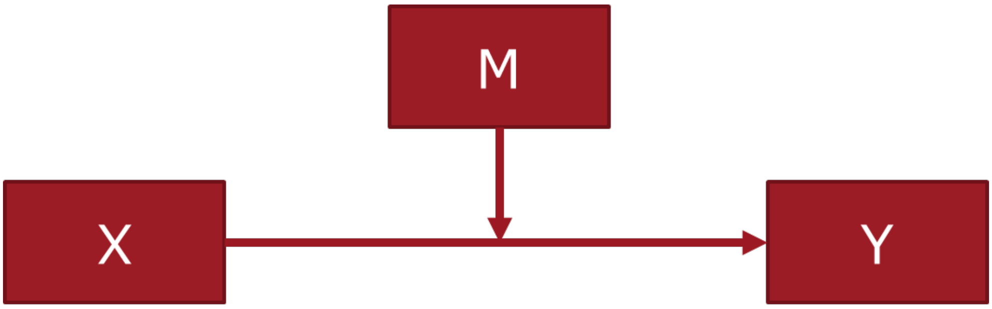

Figure 23: Moderation effect.

In addition to the constructs that are relevant to the research questions, so-called control variables are also included in the experiments and analyzed in the regression model (Bernerth and Aguinis, 2016). These are constructs that could also have an influence on the dependent variable. They are included to prove that the results are only caused by the variables that are manipulated experimentally. For Study 3, different controls are used. Table 3 lists the different constructs, and the items behind them.

Table 3: Control variables for Study 3.

Product Knowledge - audit-proof storage of data (Qiu and Benbasat 2010)
I know pretty much about audit-proof storage of data.
I do not feel very knowledgable about audit-proof storage of data (reversed)
Among my circle of friends, I am one of the experts on about audit-proof storage of data.
Compared to most other people, I know less about audit-proof storage of data (reversed)
When it comes to audit-proof storage of data, I really do not know a lot (reversed)
Trusting Disposition (Gefen and Straub 2004)
I generally trust other people
I generally have faith in humanity
I feel that people are generally well meaning
I feel that people are generally trustworthy
Institution-based trust - Situational normality– benevolence (Vance et al. 2008)
I feel that most app provider would act in a customer's best interest.
If a customer required help, most app provider would do their best to help.
Most app providers are interested in customer well-being, not just their own well-being.
Institution-based trust - Situational normality– integrity (Vance et al. 2008)
I am comfortable relying on app providers to meet their obligations.
I feel fine doing business on with mobile applications because app providers generally fulfill their agreements.
I always feel confident that I can rely on app providers to do their part when I interact with them.
Institution-based trust - Situational normality– competence (Vance et al. 2008)
In general, most app provider are competent at serving their customers.
Most app providers do a capable job at meeting customer needs.
I feel that most app providers are good at what they do.

To verify that the research design works, it is common to conduct a pretest, which is used to examine the reliability of the constructs and therefore to test the internal consistency (Table 4). The extent to which the individual items of the constructs are related to one another can be investigated with different measures. The most commonly used measures are Cronbach's alpha, composite reliability (CR) and average variance extracted (AVE). Cronbach's alpha values from 0.7, for CR from 0.5 and for AVE from 0.5 are considered appropriate (Fornell and Larcker, 1981; Shrestha, 2021; Taber, 2018). All constructs correspond to the values, with the exception of Cronbach’s alpha of anonymity, since its value is below the recommended value in scientific literature. However, since this is only just below the recommended level, and the other measurement figures show a recommended level, this is considered to be uncritical. In addition, a reverse item was used for anonymity, which could explain the somewhat poorer performance in comparison. For the final sample, all recommended values are adhered to (see section 6.4.2).

Table 4: Evaluation of items (prestest).

Construct	Cronbach's alpha	CR	AVE
Traceability	0.76	0.51	0.78
Immutability	0.94	0.84	0.94
Anonymity	0.66	0.57	0.74
Trusting Belief-Specific Technology—Reliability	0.9	0.78	0.91
Trusting Belief-Specific Technology—Competence	0.95	0.9	0.97

Furthermore, it was evaluated in the pre-study whether the manipulations had an effect on the participants' perceived immutability, perceived traceability, and perceived anonymity (Figure 24). For the evaluation in the pre-study with 80 participants, the mean values were measured with a 95% confidence interval. For the main study or the total sample, a significance test was then performed for this (see section 6.4.2).

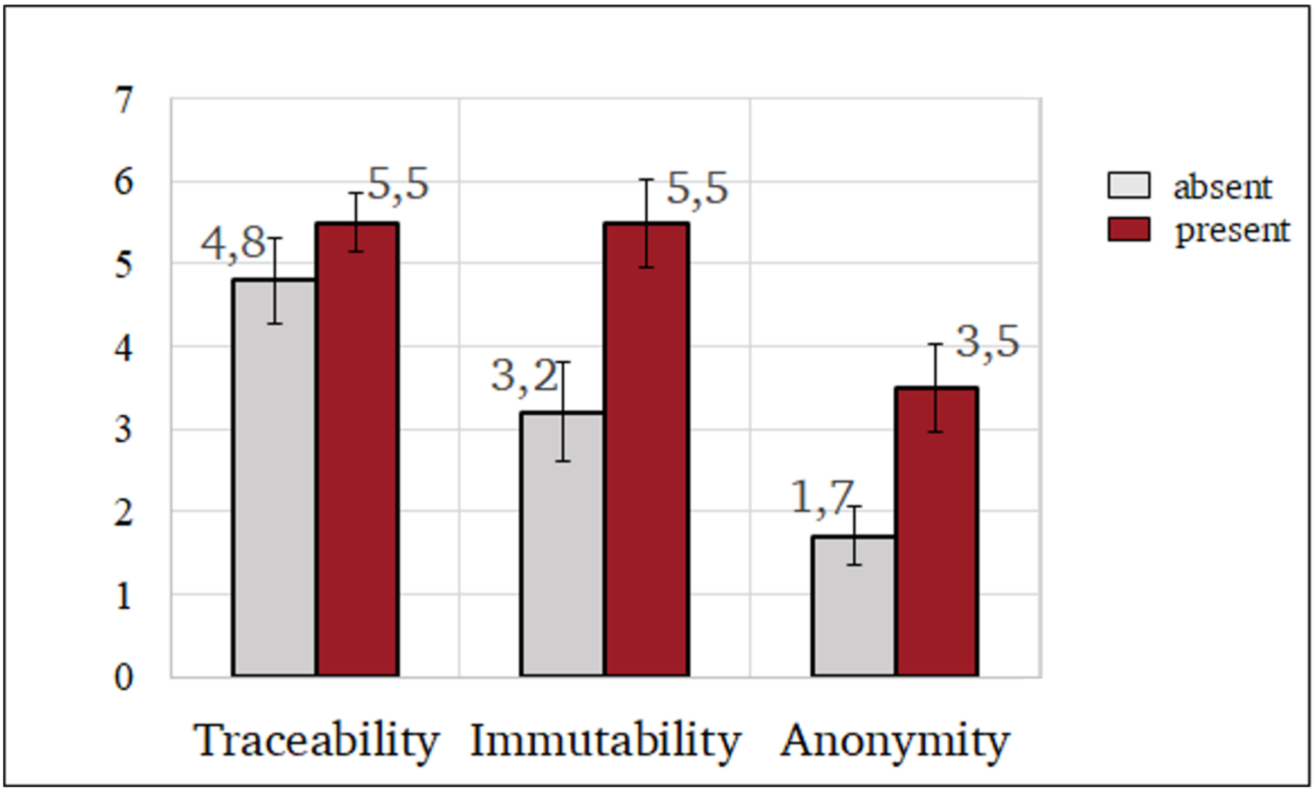

Figure 24: Manipulation evaluation (pretest).

4 Study 1: Simulation-based analysis of a cross-actor pallet exchange platform[3]

Pallets are returnable transport items and of great importance for supply chains. They ensure efficient storage, transport, and handling processes. The pallet cycle, however, is associated with a substantial effort. In addition to administrative costs, extra trips and detours must often be taken by forwarders to retrieve pallets or buy new pallets. In this paper, a fictitious cross-actor pallet exchange platform is analyzed, which manages pallet debts and receivables between the different actors of a supply chain. A claim transfer is performed, and the actors no longer owe pallets to each other, but to the system. This provides greater flexibility, as actors with open claims can collect pallets from all actors that have a negative balance according to the system. Our analysis shows that with such a system, additional trips can be reduced by 70 %, thus making the management of pallets more efficient.

4.1 Introduction

Road freight transport has a high contribution to CO_2 emissions (Demir et al., 2019). Therefore, it is the goal in the field of logistics to reduce transports in order to achieve climate goals and save costs at the same time. Besides the forward flows from the production to end-users, there is also a backward directed flow. This is known as reverse logistics and is currently becoming increasingly important (Kazemi et al., 2019). An example are returnable transport items (RTI), which ensure efficient material flows in the supply chain. Since RTIs are used several times depending on treatment and transported goods (Carrano et al., 2015), they must be returned to an upstream location in the supply chain after they have completed the delivery (customer receives goods on pallets). When arriving at the starting point, the cycle restarts again. For that reason, this is also referred to as a closed-loop supply chain (Kazemi et al., 2019). RTIs have to be managed efficiently in order to draw environmental and operational benefits from their use (Bottani et al., 2015). It is, therefore, not surprising that RTI management has gained importance in the scientific literature (Glock, 2017). Pallets are the most widely used RTIs (Roy et al., 2016). The current scientific interest is focused on an actor-specific view of pallet management. Research questions in the spotlight explore which system an actor should use (e.g., Menesatti et al., 2012), which organizational structures companies should use (e.g., Elia and Gnoni, 2015), or how the tracking of RTIs via RFID can lead to improvements (e.g., Hellström and Johansson, 2010). Although logistics service

[3] and slight modifications from Elbert, R. and Lehner, R. (2020), "Simulation-based Analysis of a Cross-actor Pallet Exchange Platform", in: Proceedings of the 2020 Winter Simulation Conference / ed. by K.-H. Bae et al.: IEEE, pp. 1396-1407. ISBN: 978-1-7281-9499-8. DOI: 10.1109/WSC48552.2020.9383943.
In this section, the pronoun "we" refers to the authors of the paper.

providers play a decisive role in the handling of RTIs (Gnoni et al., 2011), they have hardly been investigated so far (Glock, 2017). In a pallet exchange system, where the actors bring in their own pallets and exchange them with each other (Bottani et al., 2015), forwarders are important (Gnoni et al., 2011). They supply the manufacturers with empty pallets and receive empty pallets in return from the receivers of the goods. They, thus, take over the supply and return of the pallets. Since deferred exchange often takes place, the forwarder has to make detours to collect empty pallets on additional tours or to purchase new pallets.

In order to reduce the administrative effort, the first digital logistics platforms are already available, in which the players can manage their pallet accounts (receivables and debts) via a common system. In Germany, examples of this are swoplo as a RTI management platform (Hector; sennder, 2018) and the "pallet exchange using blockchain" project launched by GS1 (GS1, 2018). Furthermore, there are already examples of networks of partner companies that collect and aggregate the balances in order to carry out as few bilateral compensation trips as possible (EUROLOG, 2016; Wild, 2015). There are also examples of logistics service providers with whom customers exchange pallets at various depot locations. Here, the incoming and outgoing flows of the individual depots are collected and calculated as a balance against the overall system (AMETRAS; IDS, 2013). This means that customers do not have to go to different depots, but only to one that handles the aggregated exchange of empty pallets. Our focus is on the combination of both approaches. The central question of the paper is how to reduce the transports by consolidating debts and receivables on digital platforms. In this approach, the bilateral pallet debts between individual, independent actors are converted directly into debts to a digital platform. Such a claim transfer has the advantage that pallets do not necessarily have to be requested from the original exchange partner, but can also be collected from other network participants who have debts to the system. For the forwarder, this has the effect that pallets could be taken along on regular stops at the customers' sites instead of having to drive to specific actors and possibly having to cover long distances to collect the empty pallets owed. In practice, round trips are often made just to collect empty pallets. The system, in which a claim transfer is possible, therefore offers the potential to save transport distances traveled for the RTIs.

In this paper, we investigate the potential of such a cross-actor pallet exchange platform compared to the current system without such a platform. Since the potential of networks always depends on the number of participants, we also want to investigate from which participation rate the system with claim transfer becomes advantageous. This leads to the following two research questions:

RQ1.1: How high are potential transport savings in RTI management for the freight forwarder when using a cross-actor pallet exchange platform?

RQ1.2: What is the minimum participation rate of consignees for a freight forwarder in order to implement transport savings?

These research questions are analyzed based on simulation modeling. This methodology is suitable for investigations in RTI management (Glock, 2017). In the proposed approach, the focus is on a network of different actors interacting with each other. Stochastic influences play an important role since the random ordering of consignees and the assignment of different carriers by the shipper leads to different pallet flows, which have to be balanced.

The remainder of the paper is structured as follows: section 4.2 presents the relevant literature on simulation-based analysis in RTI management and a brief overview of platforms. Section 4.3 presents the conceptual model leading to section 4.4 with a description of examined scenarios. In section 4.5, the results of the simulation experiments are presented. Finally, the findings are summarized in section 4.6 and an outlook on future research is given.

4.2 Related literature

According to Glock (2017), there are four main research streams in the RTI research. In the first stream, different packaging systems are compared, such as using their own RTIs or rental RTIs (e.g., Cheng and Yang, 2005). In the second stream, the focus is on inventory management of RTIs, where topics such as optimal time of ordering and order quantity of RTIs are investigated (Buchanan and Abad, 1998). The third stream focuses on the forecasting of RTI returns, since these are characterized by high uncertainty (e.g., Bojkow, 1991). The fourth and last stream is the management of RTIs, where, for example, different organizational structures are compared (e.g., Elia and Gnoni, 2015). In these research streams, mainly analytical methods and optimization are being used. Only in a few papers the method of simulation was used in the area of RTI management, whereas Glock (2017) recommends gaining new insights using simulation modeling in the future. Simulation modeling is used in the first and second research stream. These simulation studies are discussed in further detail below.

Simulation modeling is used to decide whether an RTI management system could be profitable and, consequently, which system should be used. Under certain conditions, the use of single-use packaging material can be economically more reasonable. Mollenkopf et al. (2005) have shown with their simulation model that the container cost factor ratio (which represents container costs in one factor calculated by reusable unit costs divided by expendable unit costs) and average daily volume are the main driving factors for the decision between reusable and non-reusable or recyclable containers. The delivery distance plays a less important role and the cycle time of the RTI (total time for completing a loop between supplier and customer) even proved to be relatively insignificant. Cheng and Yang (2005) also compared three container systems (disposable containers, recyclable containers, and reusable containers) in a case study in the automotive sector using simulation modeling. Disposal containers are disposed after a single use, the materials of the recyclable container are sold, and the reusable containers can be used for further transportation processes. They concluded that reusable containers are economically more reasonable in the long term in their considered case. Menesatti et al. (2012) came to the same conclusion in their simulation-based analysis of a case study in the floricultural sector. In addition to the decision between reusable and non-reusable RTIs, companies can still decide whether to buy or rent the RTIs. In the case of rented RTIs, service providers assume the responsibility of the allocation of RTIs, the return as well as maintenance and repair. As a result, the degree of utilization can be increased (Cheng and Yang, 2005). While in the case study of Cheng and Yang (2005) the costs between rental and purchased RTIs were almost identical, Ray et al. (2006) show in their case study that the rental option was more expensive.

Once an RTI system is chosen, the RTIs must be managed. In research, simulation-based studies are carried out with a focus on a specific actor and usually for a case study. For example, Bottani et al. (2015) examine a manufacturer in a real network with one pallet provider and seven retailers in their simulation study. With the help of multi-objective optimization, they analyzed the best configurations for individual scenarios to minimize the costs of purchasing new pallets or collecting empty pallets from the receivers. The time of order and the minimum stock for the order placed from the manufacturer at an RTI service provider are defined as decision variables. A follow-up study (Bottani and Casella, 2018) was conducted based on this research. Here, the environmental impact was minimized by means of optimization. It was shown that the kilometers driven have a significant influence on the environmental impact, while the purchase of new pallets (taking into account emissions of pallet manufacturing, maintenance, and end-of-life processes) plays a secondary role. The study for a food company by Hellström and Johansson (2010) examined the impact of a tracking system and the option of setting up pools for different consumers. Both options were more efficient than the actual reference scenario, with RTI tracking proving to be the more cost-efficient option.

In their simulation model, Accorsi et al. (2019) investigated a pallet pool service provider that designs its processes according to the retailer's network configuration. Various scenarios with the combination of selling pallets and integrating the retailer network into the pool service provider network were examined. It was shown that scenarios with a pool service provider and a central hub, through which the flows of goods and empty pallets pass, lead to a reduction in traffic and, thus, to a lower environmental impact in the considered supply chain.

Elia and Gnoni (2015) examine a logistics service provider that maintains a distribution center as an interface between a manufacturer and a retailer. The effects of different organizational structures on RTI management were analyzed. A distinction was made between two pallet flows. The upstream flow, in which the logistics service provider receives pallets from the manufacturer and must return them, and the downstream flow, in which the logistics service provider transfers pallets (with goods) to the retailer and receives empty pallets in return. Depending on the organizational variant, the exchange can be postponed. In the variant without postponed pallet exchange, the manufacturer has to bear the lowest costs, but the scenarios with postponement were more cost-efficient for the logistics service provider and retailer as well as for the entire supply chain.

On the subject of RTI management via a cross-actor platform, no scientific work could be found. However, there are many digital logistical platforms. They can basically be divided into multi-sided platforms and innovation platforms (Parker et al., 2017). The multi-sided platforms bring together different actors and enable an exchange of information, goods, and services (Reuver et al., 2018). An example of this is Uber Freight, which brings together carriers and customers (Hofmann and Osterwalder, 2017), or cargo community systems, in which different players can post and retrieve information on goods (e.g., Wallbach et al., 2019). Innovation platforms offer specific services for the participants of the network. In the field of logistics, for example, there are time window management platforms that organize the allocation of time windows for their customers (Elbert et al., 2016).

4.3 Methodology

Simulation is a well-established methodology in the scientific field of logistics and transport. An agent-based simulation is used, which is ideally suited for use in RTI management: various actors with individual interaction among each other and the environment are considered (Law, 2013). The simulation modeling method is suitable in the context of RTI management, because different concepts such as organizational structures can be compared with each other easily, quickly, and without large investments for implementing real-world systems (e.g., pallet exchange platforms). The systematic procedure for the development of the simulation model is based on the development model according to Manuj et al. (2009).

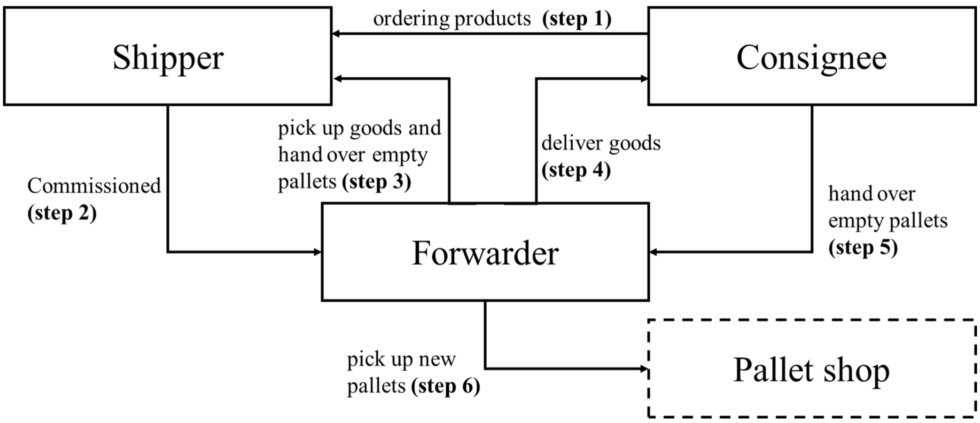

Figure 25: Main actors and their interactions.

4.3.1 Conceptual Model of Modeled Agents and Interactions

The investigation is based on the concept of pallet exchange, in which all actors (shipper, forwarder, consignee) bring in their own pallets and exchange them with each other (Gnoni et al., 2011; Hector et al., 2015). The main actors of the simulation model, which are modeled as agents, and their interactions are shown in Figure 25. The consignees order goods from the shipper (step 1). The shipper then commissions a forwarder to transport the goods to the consignee (step 2). A truck modeled as an agent carries out the transport of the pallets and palletized goods for the forwarder. The shipper provides the goods on pallets. When the forwarder picks up the palletized goods, they hand over empty pallets to the shipper in the corresponding number (step 3). The forwarder then transports the goods to the consignees(s) and delivers the goods there (step 4). For this purpose, delivery tours are planned and executed. The forwarder demands the corresponding number of empty pallets back from the consignee (step 5). If the consignee cannot hand over the appropriate number of empty pallets to the forwarder, it is recorded in pallet accounts, which list the respective pallet debts and pallet receivables. The forwarder can then claim the pallet debts at a later time. Another actor is the pallet shop. If the forwarder needs new pallets, the pallets can be purchased and collected from a pallet shop (step 6). This happens either when the forwarder no longer has enough empty pallets to carry out the next order or when the quality of the pallets in stock falls below a critical value. The pallets, which are also modeled as agents, wear out during the transportation processes. According to Carrano et al. (2015), pallets with medium-weight goods and average handling and treatment last for an average of 15 cycles. The quality of the pallet during the exchange is not taken into account, but pallets are taken at random from the stock.

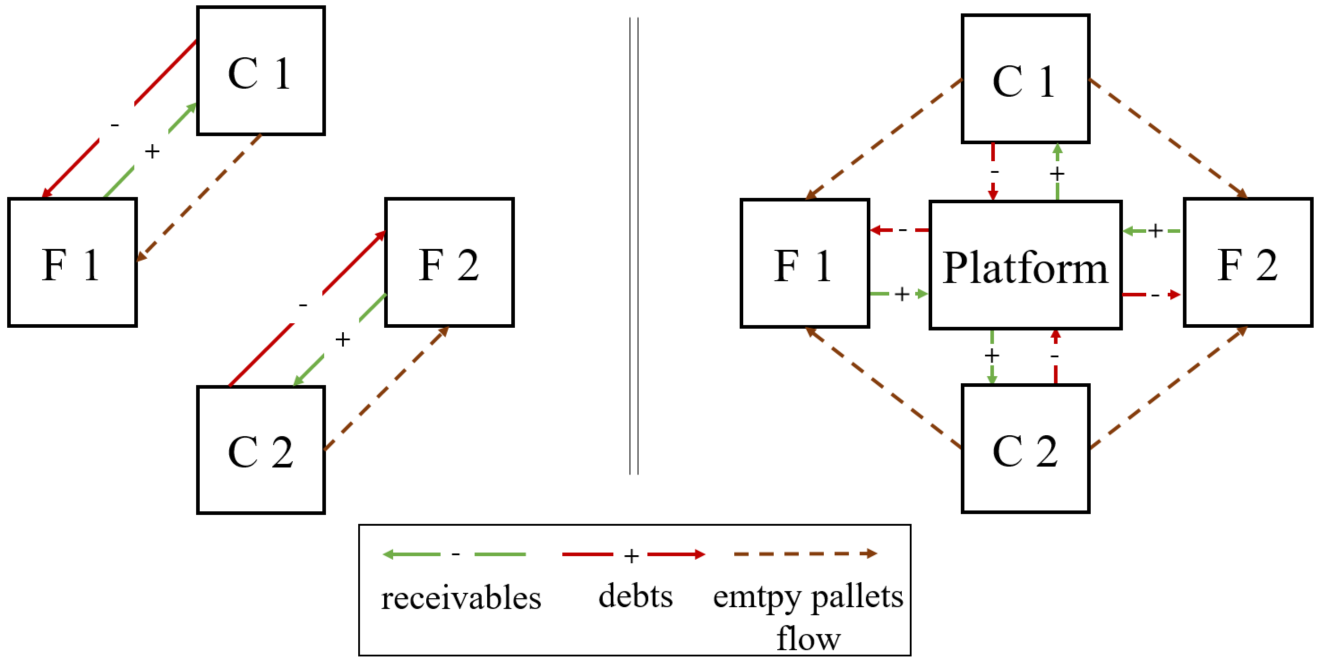

Figure 26: Comparison of bilateral balancing (left) and balancing over the platform (right) with two forwarders and two consignees.

4.3.2 Concept

There are already first platforms for pallets that offer network participants a system in which they can uniformly record their pallet debts and receivables via a jointly used platform. For the concept of this paper, it is assumed that the debts and receivables are completely transferred to this system. The platform, thus, acts as an independent third party similar to a bank. As a result, the network participants have debts and receivables only against the system and no longer among themselves. The actors, who have pallet receivables from the system, claim their receivables from all actors, who in turn have debts to the system. Therefore, a forwarder with pallet receivables outstanding from the system can collect the pallets from other consignees who have outstanding debts, even if these were originally owed to another forwarder. In Figure 26, the system with the platform as a mediator (right) is compared with the current system in which bilateral exchanges between actors are made and cleared (left). In the current system, the receivables and debts, as well as the pallet flows, are settled bilaterally between the actors. In the concept with a platform model (right), all liabilities and receivables are transferred to the platform. This gives the forwarder more flexibility in collecting pallets from various actors and enables the forwarder to avoid additional trips to collect empty pallets. A forwarder can make claims during regular stops at consignees and pick up additional empty pallets (provided the consignee has a negative pallet balance and, thus, owes pallets to the system). For example, forwarder F1 can pick up empty pallets from consignee C2 in the system with the cross-actor platform, although both have no bilateral receivables and debts.

4.3.3 Evluation Criteria

In order to examine the concept of a cross-actor RTI management platform, the length of the detours made for the supply of pallets s^D is recorded as a central evaluation criterion. The costs are not a major evaluation criterion. The detours driven could be evaluated with costs, but there is no added value because costs for driven kilometers depend on factors such as use of a special truck and current fuel prices, which are not considered in the simulation model. The meaningfulness of the number of purchased new pallets is limited as well. This is due to the fact that the purchase of new pallets does incur costs, but the forwarder receives the equivalent value of a pallet, whereas costs for storage or ordering processes are not recorded. The length of the detours s^D is calculated from the sum of the detours made by the individual forwarders i with $i \in I$, where I represents the set of all forwarders. On the one hand, these are calculated from trips to the pallet shop for purchasing new pallets, which are determined from twice the distance s_i^{PS} between the respective forwarder i and the nearest pallet shop, multiplied by the number of trips x_i made by the respective forwarder to the nearest pallet shop in the simulated period. On the other hand, the number of kilometers driven on round trips to collect empty pallets is added. Here, various consignees who have a pallet debt to the forwarder are approached in extra tours in order to collect empty pallets. These are calculated on the basis of the total distances traveled by the individual forwarder on the round trips for collecting empty pallets $s_{iz_i}^{REP}$. Here, z_i represents the respective round tour and Z_i is the set of all round trips driven by the forwarder i in the simulation run.

$$s^D = \sum_{i \in I} (2 s_i^{PS} x_i + \sum_{z_i \in Z_i} s_{iz_i}^{REP})$$

The route planning, which is largely responsible for the length of the tours, is based on optimization algorithms developed by Schrimpf et al. (2000) and Pisinger and Ropke (2007). For this purpose, the open-source toolkit jsprit was integrated, which has already been used for various scientific contributions (e.g., Elbert and Friedrich, 2018). With the help of route planning, the tours are planned efficiently, so that the transport steps can be realistically evaluated and compared using a cross-actor exchange pallet platform.

4.4 Simulation Study

The simulation model is created using AnyLogic 8.5.2, a software from the AnyLogic Company. AnyLogic is widely used for studies in the field of logistics, transportation, supply chains, and RTI management (Elia and Gnoni, 2015; Elbert and Friedrich, 2018). AnyLogic is based on Java and provides high modeling flexibility (Borshchev, 2013).

4.4.1 Network Design

Since there is currently no exchange network platform with pallet claim transfers in practice, experiments were carried out in a generic environment in order to be able to make statements that are as generally acceptable as possible. For the investigation, a randomly generated network of 50 nodes in a field measuring 100 km by 100 km was created (Figure 27), using the algorithm developed by Leyton-Brown et al. (2000). This algorithm has already been used in the logistics context for the simulation of road networks (Elbert et al., 2020). The nodes represent the locations of 50 actors: 5 forwarders, 5 shippers, 37 consignees, and 3 pallet shops. The edges between the actors correspond to road links that the trucks use to reach the different actors. The trucks use the shortest route between start and destination via the different edges. A matrix, which lists the shortest distances over the different edges from all nodes to all nodes, is used for the route planning algorithm.

4.4.2 Analyzed Scenarios

For the investigation of a cross-actor pallet exchange network concept, two scenarios are created to answer the first research question. Scenario 1 represents the reference scenario without a pallet exchange platform and Scenario 2 represents the situation including an exchange platform. In both scenarios, the 37 consignees randomly order a number of 1 to 30 full pallet loads (following a uniform distribution) of products daily from the various shippers. The shippers have a daily contingent with a maximum of 30 full pallets (one full truckload). The consignees order daily at different times from randomly selected shippers for the next day. Here, first-come-first-served applies until the shipper's contingent is exhausted. If the requested order quantity of the consignees exceeds the available contingent, the maximum order possible is ordered. As soon as all consignees' orders are received, the shipper instructs one of the forwarders randomly for the next day to pick up the full pallets from the shipper and distribute them to the consignees. Due to the randomly generated orders and the random allocation of the carriers, there are constantly varying interactions between the different actors.

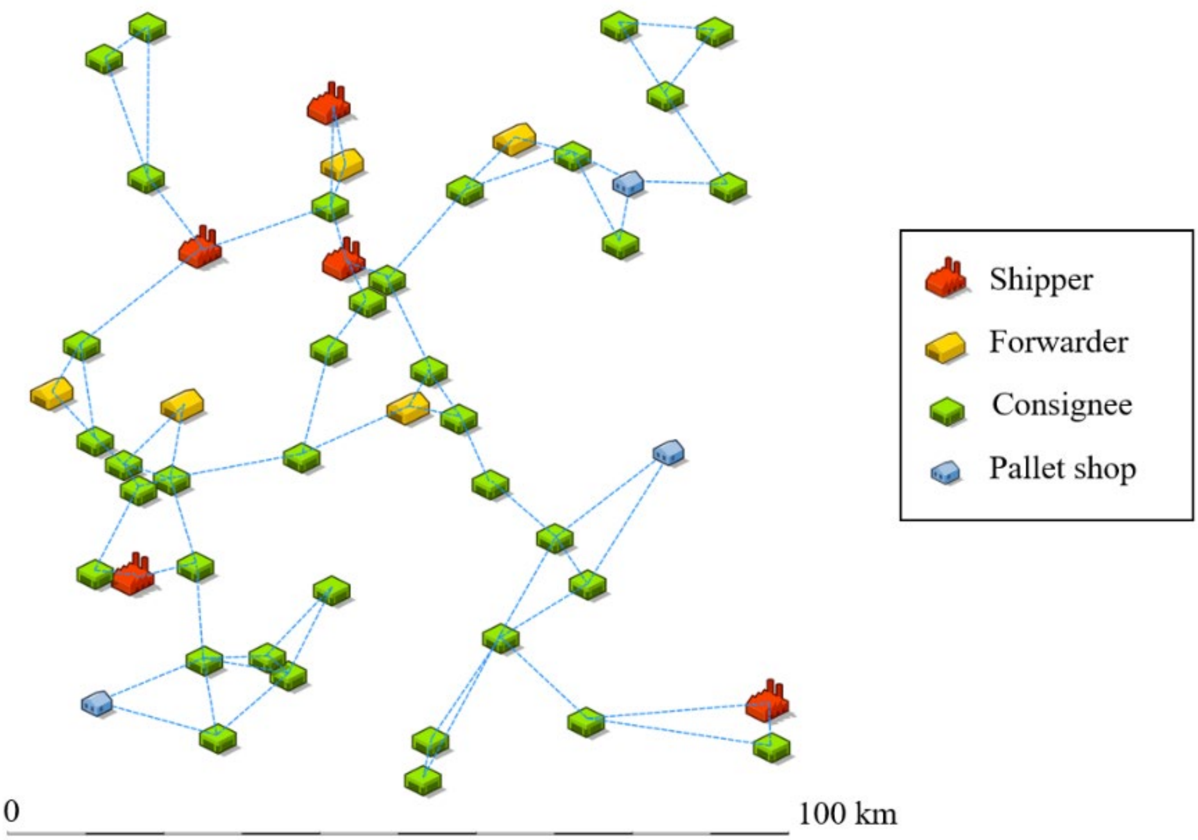

Figure 27: Generic network consisting of shippers, forwarders, consignees, and pallet shops.

The orders of the consignee are handed over to the forwarder as transport requests, which contain information about the shipper, the consignee, the forwarder, and the quantity of palletized goods ordered. These transport requests are transmitted to the route planning algorithm. Using a distance matrix (lists all distances between the actors), the algorithm calculates the number of kilometers to be driven in a round trip for different sequences. The shipper is always the first stop, as the goods are initially loaded there. As a result, the route planning algorithm sends the transport requests to the trucks in an order that enables an efficient round-tour. After the route planning, the forwarder loads the appropriate number of empty pallets into the truck. In the simulation model, the pallets are stored at the individual agents (trucks, shippers, forwarders, and consignees) in collections. After loading the empty pallets, the truck starts its tour and drives to the shipper. There, the truck of the forwarder hands over the empty pallets (corresponding to the number of full pallets to be transported). From the shipper, the truck drives to all consignees in a round trip and delivers the palletized goods there. When the goods arrive at the consignee's premises, they are handed over, and the forwarder receives empty pallets back from the consignee in return. Since a direct exchange does not always take place in reality, e.g. due to a lack of time or insufficient empty pallets at the consignee's premises, the forwarder does not always receive pallets back. In the simulation model, a variable is set to true or false for each consignee daily with a probability of 50 %, which indicates whether empty pallets are available on that day. In Scenario 1, the pallet debts between the actors are posted bilaterally. In Scenario 2, the receivables and debts are added to or subtracted from the current balance of the participants, i.e., for each participant the total number that is owed to the system or that the system owes the actor is stored. If the current consignee has empty pallets available, the forwarder checks whether the truck can pick up additional empty pallets. Here, the two scenarios differ considerably from each other. In Scenario 1, additional empty pallets are only taken along if the forwarder still has receivables from the specific consignee. In Scenario 2, however, additional empty pallets can always be taken along if the forwarder has receivables from the system, and at the same time the consignee has debts to the system, regardless of whether the forwarder has previously interacted with this consignee. In both cases, the maximum number of additional pallets that can be taken along is limited to 18. This is based on the assumption that the supply of empty pallets plays a subordinate role in the delivery runs. A number of 18 pallets can easily be loaded into the truck at once with a forklift truck. Loading more pallets would take more time, which could be problematic, e. g., due to the time window that needs to be reached. Furthermore, it would also take up more space in the truck, which could hinder the unloading of the palletized goods. The truck then drives to the next consignee. After all consignees have been supplied, the truck drives back to the home depot of the forwarder.

In both scenarios, the freight forwarders must ensure that there are always enough empty pallets available to be able to hand over the corresponding number to the shipper in the next delivery tour. As soon as the number of pallets in stock of the forwarder falls below a value of 30 pallets (number required for the next day's tour), the forwarder must obtain additional pallets. There are two options available to the forwarder in Scenario 1 (reference scenario). The preferred option here is to collect empty pallets from consignees who still owe the forwarder pallets. For this purpose, additional round trips are planned in which the forwarder collects empty pallets from various consignees. Round trips are typical for collecting RTIs (Glock, 2017). A maximum of eight consignees will be approached (in order not to exceed the driving limit of eight hours per driver and day). It is checked whether the variable for pallet availability of the particular consignee is set to true. The variable is independent of the pallet stock from the consignee. The consignees have a stock of 60 pallets at the start. If the stock falls below this level, 30 new pallets are created and added directly to the stock. This procedure is simplified since the focus is on the RTI management of the forwarders and the processes of the consignee are not considered in further detail. The consignees with the highest debts to the forwarder are approached. It is also checked that the consignees are not on the next delivery tour. Here, too, the route planning is done using the jsprit tool. If less than 30 pallets would be collected in a round trip, this is not carried out. Instead, a truck from the forwarder drives to the nearest pallet shop and buys 30 new pallets there. In the scenario with a cross-actor pallet exchange platform, no round trips for empty pallets are carried out. It is assumed that the consignees are more willing to hand over empty pallets in addition to those that they must hand over anyway than to organize additional pick-ups with forwarders they may not have worked with before. Thus, open pallet claims are only collected in regular delivery runs. In Scenario 2, forwarders can also buy new pallets from the pallet shop.

In both scenarios, new pallets are only purchased if the other measures do not allow the forwarder to organize enough empty pallets following Bottani et al. (2015). The reason for this is to keep the costs of capital for the pallet stock as low as possible. There is one exception to this: If the quality of the pallets in stock is too low (as pallets wear out by going through a high number of exchange cycles), new pallets are purchased. At the start of the simulation, the forwarders have a stock of 60 pallets, which covers the demand for two days and ensures that the model quickly reaches a steady-state status. The two scenarios described above represent extreme points of a continuum, respectively discrete set of various solutions. Either the cross-actor exchange platform is used by all participants or none. However, it is also interesting to examine the effects of only certain consignees participating in the cross-actor pallet exchange network. For this reason, the participation rate of consignees in the cross-actor exchange platform was varied for further analysis. This results in two consignee groups for the forwarder. Firstly, the group that participates in the network and from which pallets can be collected more flexibly from another consignee, and a group of which owed pallets are still collected via round trips.

Table 5 summarizes the input parameters for the simulation. The parameters used as well as the modeling of the current system without a pallet exchange platform were presented and validated in a focus group interview. This group consisted of people who deal with the topic of pallet exchange daily (forwarder, manufacturing industry, trading industry). The interview took place on May 8th, 2020.

Table 5: Simulation parameters.

Parameter	Value
Participation rate	0 % - 100 %
Number of pallets at start	60
Purchased pallets at pallet shop	30
Probability no direct pallet exchange	50 %
Max. stops for empty pallet run	8
Max. additional pallets per stop	18
Order size consignee	1-30
Contingent shipper per day	30

4.5 Results and Discussion

In this section, the results of the scenarios described were examined. First, the two scenarios with a participation rate of 0 % and 100 % are examined. Since no seasonality was implemented, each simulation run is simulated over a month so that the time of simulation runs is limited and at the same time it is long enough that all other events (accumulating debts, compensating debts, and broken pallets) occur in evaluable numbers.

Table 6: Detours for RTIs.

Variable	Scenario 1 (Participation rate 0 %)	Scenario 2 (Participation rate 100 %)
Detours to pallet shop (mean)	1,885.1 km	2,563.5 km
Detours empty pallet run (mean)	7,109.6 km	-
Detours overall (mean)	**8,994.7 km**	**2,563.5 km**
Sample Variance	307.9954,6	106.006,8
95 %-confidence interval	[8,134.2 , 9,854.2]	[2,403.5 , 2,772.5]

Here, two systems are compared, which were simulated independently. The number of replications (16) was determined by using the method described in Goldsman and Nelson (1998). It can be seen that the total number of detours made to ensure the supply of pallets is significantly higher in Scenario 1 than in Scenario 2. In Scenario 1, freight forwarders have to drive to the pallet shop more often and buy new pallets there. In Scenario 1, an average of 1,211 new pallets are purchased by all forwarders, whereas in Scenario 2 1,635 new pallets are purchased. In Scenario 1, however, the forwarders have to make long detours for round trips to collect the empty pallets. In Scenario 2, in which all actors participate in the cross-actor pallet exchange network, the total number of tours driven specifically for pallets is reduced in average by almost 71.5 % from 8,994.7 to 2,563.5 km. The simulation did not consider any detailed operational planning, in which, for example, trips to pallet shops or other consignees are integrated, if, for example, waiting for time windows for the next consignee is necessary. Thus, the additional kilometers driven for empty pallets would still be reduced. Even though, the savings of over 70 % show the advantages of a cross-actor pallet exchange network.

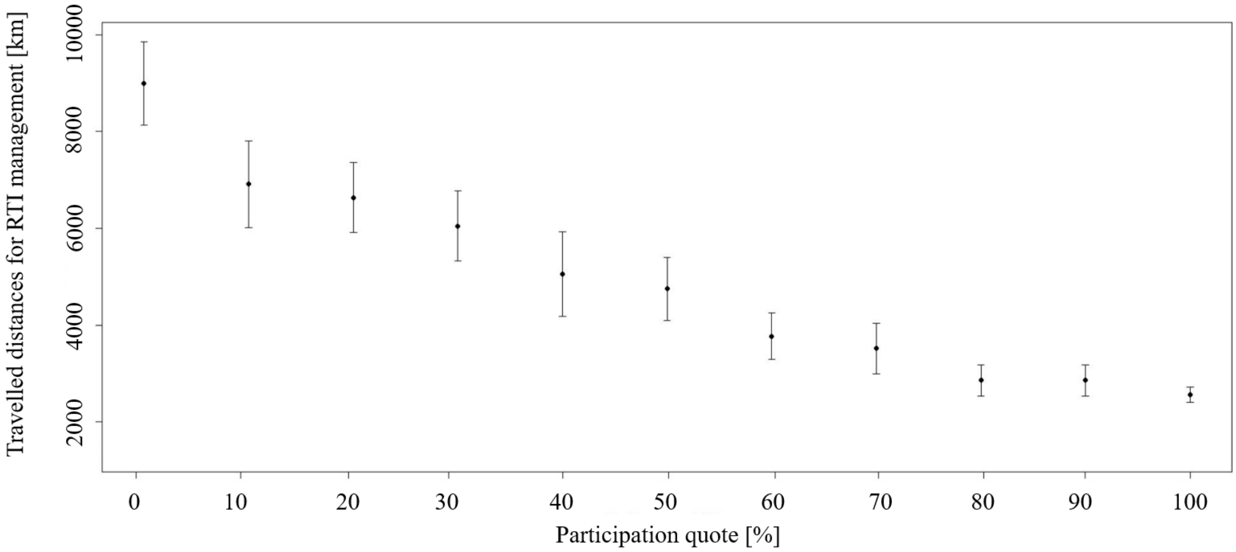

Figure 28: Travelled distances for RTI management (mean and 95 % confidence intervals).

Since not all actors will participate in such a platform from the beginning, the participation rate of consignees was gradually increased from 0 % (Scenario 1) for the next study. This shows that already from 0 % (mean=8,994.7 km ± 860) to 10 % (mean=6,911.15 km ± 891.5) considerably less needs to be driven for empty pallets (Figure 28). At a participation rate of 60 % (mean=3,772.75 km ± 475), the kilometers driven are only slightly reduced up to a participation rate of 100 % (mean=2,533.5 km ± 159.5). Overall, it can be seen that with low participation rates, the fluctuations vary significantly (Figure 29). The fluctuations can be explained by the round trips carried out for collecting empty pallets. Depending on which actors owe pallets to the forwarders, the length of the tours varies.

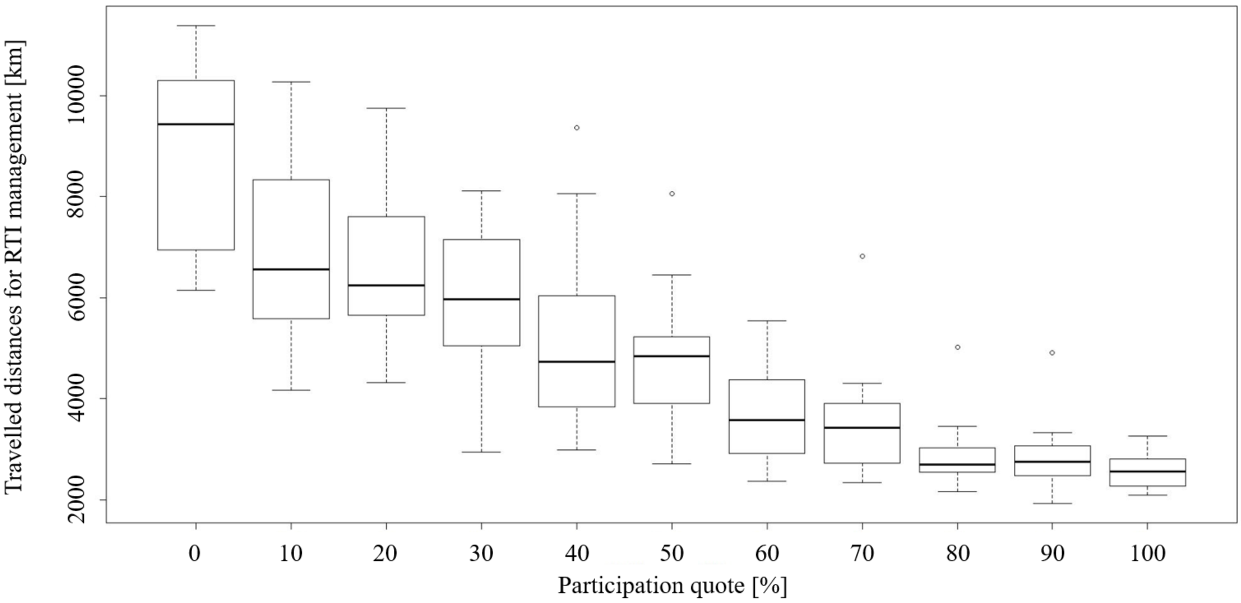

Figure 29: Travelled distances for RTI management (boxplot of data).

4.6 Conlusion

In this paper, we have shown that the actor pallet exchange network, where pallet debts and receivables are aggregated in a common system, leads to fewer detours for the forwarder to supply empty pallets. Such a system, therefore, has great potential to improve the management of pallets or other shared RTIs. As a result, the distances traveled for managing RTIs have been significantly reduced, thus saving both costs and emissions. Even a network with only a few participants can achieve significant transport savings, i.e., platforms and systems with claim transfer also make sense in small collaborations.

We looked at a system with 37 consignees, five forwarders, and five shippers in a limited space, where the pallet debts have only incurred between consignee and forwarder. It makes sense to consider other systems in the future, such as the fact that the forwarders do not bring in their own RTIs, but the pallet exchange only takes place between shippers and consignees. This also results in debts and receivables between these two actors. Furthermore, the shipper and consignees were defined, because in reality the companies both receive and send goods. For further investigations, mutual supply relationships should be taken into account.

In this study, the focus was on the shippers and the possible transport savings. However, it has to be taken into account that consignees also have to take advantage of the system in order to have an incentive to participate (e.g., Wallbach et al., 2019). In the future, motivations and barriers must be identified as with other collaborations in the logistics area (e.g., Rabe et al., 2016). In this context, it makes sense to consider the issue of trust in such a system. The platform would be a new actor in the pallet exchange system in which the network members must be able to trust. In cross-company platforms, data-related problems often arise, such as data protection and data security. These problems must first be solved so that competitors in the market use common structures and have an interest in sharing their data. A possible digital, implementable solution could be the blockchain technology (Meyer et al., 2019).

In addition to the advantages described here, which are mainly aimed at making the collection location for empty pallets more flexible, further control options can be implemented with a central pallet system. Such a system could be used to organize flows of empty pallets between the different actors via the central platform.

5 Study 2: Cross-Actor Pallet Exchange Platform for Collaboration in Circular Supply Chains[4]

Purpose: Pallets ensure efficient processes in logistics and are exchanged between the different actors, while passing through various supply chains several times. In common practice, the exchange is often not directly carried out on site, e.g. due to a lack of time, so that additional trips and new pallet purchases become necessary. To reduce these negative effects, a digital cross-actor platform is designed, and its potential is investigated.

Design/methodology/approach: We developed an agent-based simulation model with mathematical optimization. Using experience from practitioners, as well as real-world datasets which were analyzed, the authors ensure a realistic model of the pallet exchange system in Germany.

Findings: We demonstrated that, with the help of this platform concept, transport routes can be shortened, debts and receivables can partly be equaled out through balancing, and the quantity of pallets in the overall system can be reduced.

Research limitations/implications: The results are not directly transferable to pallet exchange systems in other countries without considering their general settings.

Practical implications: Digital networking increases the efficiency of the existing pallet exchange system. Even small collaborations prove to be reasonable.

Originality/value: We developed new mechanisms for a digital pallet exchange platform, which takes on the role of a central planning instance, in addition to recording pallet receivables and debts. It enables the planning of the commodity flow of empty pallets, which are transported by the forwarders on regular routes, and distributed between the platform participants.

[4] The content of this study is similar with only slight modifications to the paper Lehner, R. and Elbert, R. (2022), " Cross-Actor Pallet Exchange Platform for Collaboration in Circular Supply Chains", The International Journal of Logistics Management, Vol. 34, No. 3, pp. 772-799. DOI: 10.1108/IJLM-03-2022-0139. Thus, in section the pronoun "we" refers to the authors of the paper.

5.1 Introduction

The Circular Economy (CE) aims to create a regenerative economic system (Geissdoerfer et al., 2017). The central aspect of such a system is the closing and deceleration of resource and energy cycles (Bocken et al., 2016), which is why the implementation strategies are long-lasting designs, repair and reuse (Geissdoerfer et al., 2017). Currently, the CE approach is gaining increasing importance in common practice, as well as in science (Geissdoerfer et al., 2017). The integration of the CE philosophy into the management of supply chains and its surrounding systems is referred to as Circular Supply Chain Management (CSCM) (Farooque et al., 2019; Lima et al., 2021). In circular supply chains, as well as in regular closed-loop supply chains, materials are returned to an upstream actor of the supply chain. This creates a closed cycle, and the materials can repeatedly pass through it. In contrast to closed-loop supply chains, in which the material flow remains in the same supply chain, the objects in circular supply chains can also migrate to other supply chains with different actors and organizations or other industrial sectors (Farooque et al., 2019; Weetman, 2017).

In addition to the goods, the used packaging material can also be the focus of the material flow. The packaging materials used in closed loops are called returnable transport items (RTI). The RTIs can either be specially manufactured units, which run through special transport cycles, or they can be standardized (e. g. pallets, containers, gas cylinders). The use of reusable packaging is an aspect of circular supply chain management (Angelis et al., 2018), as these assets can be used and shared by different actors. In general, asset sharing is an essential part of CE (Angelis et al., 2018; Sposato et al., 2017), with pallets being the most common assets in logistics (Roy et al., 2016). The pallets have predefined dimensions and can be handled with standard equipment, so that transport, storage and handling processes can be organized efficiently.

In scientific literature, different pallet systems are investigated, in which the actors collaborate to different degrees regarding the pallet management. If there is no collaboration at all, the products have to be loaded from one pallet to another on delivery, which leads to additional effort, resulting in a waste of time and money (Ren et al., 2019). Alternatively, the pallets can be sold together with the product (e.g., Accorsi et al., 2019). This leads to a higher demand of new pallets for the shipping companies and an increase in effort for the consignee, as they must deliver the pallets to the actors who need them (Accorsi et al., 2019). The third option, in which the collaboration is the highest, is to participate in a common pallet pooling program, where the pallets can be shared and exchanged with one another; this alternative is considered to be more cost-efficient and ecologically sustainable (Chen et al., 2019a).

The literature review by Tornese et al. (2021) shows that scientific literature mainly focuses on pooling systems, in which the pallets in a pool are owned by one actor throughout the supply chain, and the actor is responsible for return, maintenance and re-procurement. To the authors' knowledge, participation in open exchange pools for pallet exchange, where all actors can own standardized pallets and exchange them with one another, is only studied in a single paper, one by Elia and Gnoni (2015). This is surprising, as this is a widely used system in Europe (Elia and Gnoni, 2015), the European Pallet Association (EPAL) organizes the open exchange pool by setting uniform exchange criteria and standardizing the pallets (Beyer and White, 2016). Standardized EPAL Euro pallets are the most widely used in Europe (Elia and Gnoni, 2015) with a total of about 600 million EPAL pallets currently in circulation (EPAL, 2022). The widespread use of the system is due to its simplicity and easy implementation (Bottani et al., 2015). Furthermore, the flexibility is higher than in closed pools, as the exchange is only possible if the supply chain partner also participates in the same pool (Chen et al., 2019a). Especially with increasingly fast-moving business relationships (Angelis et al., 2018), a cross-sector pallet system is advantageous when using one-off transactions by freight exchanges, such as Uber Freight (Gallay et al., 2017) or the involvement of changing subcontractors when performing regular delivery.

However, there are also problems in common practice when using the open exchange pool. One reason for this is different qualities of exchanged pallets. Due to a defective behavior, it is possible to transfer costs for the other supply chain partner (Elbert and Lehner, 2019). In addition, if a direct exchange (return of empty pallets in exchange for receipt of palletized goods) is impossible due to a lack of time or empty pallet capacities, pallet debts arise between the actors, which must be recorded and administered. As a result, detours, additional trips or purchases of new pallets are necessary (Glock, 2017), thereby reducing the efficiency of the overall system and leading to the waste of resources. These problems can be addressed by promoting collaboration between the actors that are involved. In scientific literature on pallet management, collaboration is generally limited to asset sharing and vertical integration of the return processes in long-term business relationships (see section 5.2). However, the open exchange pool provides a very good basis for promoting collaboration between different, independent actors, as well as competitors, since they can all use the same RTIs and exchange with one another.

Collaboration in RTI management with players from different supply chains is seen by Meherishi et al. (2019) as a research avenue. In the area of CSCM, collaboration in and between supply chains is also identified as a research gap (Farooque et al., 2019). To promote collaboration, this paper aims to investigate a digital RTI management platform that is available to independent actors. Specifically, this involves a platform concept with claim transfer, which was first described by (Elbert and Lehner, 2020). Instead of recording the pallet claims and debts bilaterally, and thus also handling the flow of empty pallets bilaterally, the debts and claims are recorded multilaterally by the platform, and their records are transferred from the individual actors to the platform. The debts and claims are offset against each other for the individual actors, so that each platform participant has only one aggregated account balance. An additional function of the platform to enable collaboration between the actors across supply chains is introduced in this paper. Using the routes that are planned by the forwarders, the platform – in the form of a central instance (Gansterer and Hartl, 2020) – can be used to plan the flow of additional pallets, which can be transported by the forwarders on regular delivery tours and distributed between the actors.

By examining this platform type, we first address the research gap on collaboration in CSCM (Farooque et al., 2019) and collaboration in pallet management (Meherishi et al., 2019). In addition, we address the integration of horizontal and vertical collaborations in the context of centralized collaborations, which are seen as promising future research directions (Gansterer and Hartl, 2020). For this purpose, the potential of such a cross-actor platform is to be analyzed, from which the following research questions can be derived:

RQ 2.1: How high is the savings potential of a pallet exchange platform with "claim transfer", and which acts as a a central instance for planning the commodity flow of additional pallets that are to be distributed by the forwarder, compared to the current reference situation?

RQ 2.2: How much does the number of platform participants and the number of additional transported pallets affect savings?

The research questions are answered by a combination of simulation modeling and optimization, a combination widely used in the field of RTI management (Glock, 2017). In our approach, we create a network of different actors in the simulation model, comprised of forwarders and companies which act as both shipper and receiver. The random interactions of the actors create pallet flows, and as a result, a flow of empty pallets between the actors emerges. The planning of the return flow of empty pallets is supported by a central instance. Therefore, the central planning solves a corresponding commodity flow problem. The developed simulation model uses data, information and empirical findings from German companies that are involved in pallet exchange. Thus, forwarders, traders, production companies and providers of digital pallet accounts are included in the work.

The remainder of the paper is structured as follows: in section 5.2, we present the relevant literature on CSCM collaborations in RTI management. In section 5.3, we describe the concept of the platform with commodity flow planning of empty pallets between supply chain actors. In section 5.4, the mathematical formulation of the underlying commodity flow problem is presented, followed by an explanation of the simulation model in section 5.5. Section 5.6 presents the results of the simulation model and their discussion. Finally, the results and an outlook on further research are described in section 5.7.

5.2 Related Literature

Pallet management can be seen as a part of CSCM (Meherishi et al., 2019). In this sense, Angelis et al. (2018) refer to the sharing of pallets as an example for implementing circular supply chains. However, following the classification of Farooque et al. (2019), pallet management is not a supply chain-wide integration of CE but an individual supply chain function, namely the logistics area. The CE principle of closing resource loops in pallet management is apparent: pallets can be reused (e.g., Elia and Gnoni, 2015), repaired (e.g., Park et al., 2018) and recycled (Tornese et al., 2021). The existing literature on pallet management deals with different systems and the related types of collaborations between the involved actors in the reuse phase. When reviewing the existing literature, we identified four dimensions for classifying how pallet management is investigated in the CSCM context: supply chain circularity, pallet system, horizontal and vertical collaboration, and information sharing. The dimensions target which actors are involved and how they collaborate in pallet management. In the following, these dimensions and their characteristics are described individually, and representative studies on collaboration in pallet management are categorized in Table 7.

Supply chain circularity

Returning the pallets to an upstream point in the supply chain for reuse creates a loop. The circularity of this loop can either be open, closed or a combination of both (Zhang et al., 2021). In a closed-loop circularity, materials are brought back to the original supply chain. An example is the study by Elia and Gnoni (2015): they examine a supply chain of a logistics service provider, which collects palletized goods from a manufacturer in a distribution center and delivers them from there to a retailer. Lastly, the pallets are returned to the manufacturer. Likewise, Tornese et al. (2018) and Bottani et al. (2015) describe a closed-loop circularity in their studies, as the pallets are transported back from the retail stores to their original starting point (manufacturer). The only difference between the two studies and the work of Elia and Gnoni (2015) is that the manufacturer supplies several retailers, so that the pallets go to different customers, while the starting point lies with the same manufacturer.

In the case of open-loop circularity, the materials are brought into other supply chains; both possibilities can occur in combination (Zhang et al., 2021). For instance, this is the case in a study by Accorsi et al. (2019). They investigate different pallet management combinations for a retail network. After the pallets are transported through the supply chain from the vendors via the regional depots to the retail stores, they are returned to the vendors. Since the pallets are not only returned to the original vendor, but also to other vendors, this is an open-loop circularity as well as a closed-loop circularity. The same applies to the research work carried out by Achamrah et al. (2020), in which two different producers participate, and to whom the empty pallets are returned by different retailers. Ranjbaran et al. (2020) also consider a combination of open and closed-loop circularities of supply chains: the empty pallets are picked up from assembly plants and taken to various suppliers, who use them for further deliveries.

In general, greater potential is attributed to the open-loop circularity (Weetman, 2017; Zhang et al., 2021). While the usage of open-loop circularity is frequent in common practice, it is still scarcely represented in CSCM literature (Zhang et al., 2021). However, due to the nature of pallet circulation, open-loop circularity of supply chains is common in the literature stream on pallet management.

Table 7: Related literature.

						Dimensions			
Article	**Actors**	**Empirically**	**Supply chain circularity**	**Focus/ Central actor**	**Sector**	**Pallet system**	**Vertical collaboration**	**Horizontal collaboration**	**Information sharing (for pallet management)**
Accorsi et al. (2019)	Pallet pool provider and retailer supply chain (vendors, regional depots, retailer stores)	X	Open- and closed-loop circularity	Network configuration of a retail supply chain	Retail	Pallet pool of provider and buy-sell-system	X		
Achamrah et al. (2020)	Two producers, nine retailers, raw material supplier, pallet supplier		Open- and closed-loop circularity	Producer	Retail	Private pallet pool	X	X	
Bottani et al. (2015)	Pallet shop, manufacturer, seven retailers	X	Closed-loop circularity	Manufacturer	Retail	Private pallet pool	X		
Elia and Gnoni (2015)	Logistics service provider, producer, retailer	X	Closed-loop circularity	Logistics service provider	Retail	Open pallet pool	X		
Gnimpieba et al. (2015)	Digital platform for pallet tracking		Not specified	Digital platform	Cross-sector	Not specified	X		X
Chen et al. (2019b)	Digital platform for collaboration in various pallet pools		Open-loop circularity	Digital platform	Cross-sector	Various pallet pools	X		
Ranjbaran et al. (2019)	Suppliers, assembly plants, warehouses	X	Open- and closed-loop circularity	Forwarder	Auto-motive	Private pallet pool	X		X
Tornese et al. (2018)	Product manufacturer, distribution center, retailers, pallet repair facility, pallet manufacturer	X	Closed-loop circularity	Pallet pool provider	Retail	Pallet pool of provider	X		
Our study	50 companies, five forwarders, three pallet shops	X	Open- and closed-loop circularity	Digital platform, network of independent actors	Cross-sector	Open pallet pool	X	X	X

Pallet system

The organization of return flow, and which actors are involved in it also depends on the pallet pool system used in pallet management. Various systems are used in common practice. One possibility is the involvement of a service provider who rents out pallets and takes care of the procurement, repair, and their distribution. In their study, Tornese et al. (2018) focus on such a pallet pool provider. They investigated a network, consisting of a product manufacturer, various distribution centers, retailers, as well as a pallet manufacturer and pallet repair facilities. The pallet pooling provider takes over the organization of the return, maintenance and procurement of the pallets. Additionally, Accorsi et al. (2019) consider the option of a retailer network using a pallet pool provider that procures and returns the pallets. In addition, buy-sell programs are also examined, in which the pallets with the goods are sold to the stores and later sold back to the vendors via an intermediary.

Furthermore, actors can create a private pool of pallets, which they will reclaim from their customers. In a study of Bottani et al. (2015), the manufacturer purchases pallets from a pallet provider. The pallets are delivered with goods to the retailer, who must return the empty pallets to the manufacturer. Also, Achamrah et al. (2020) consider a private pool of pallets used by two manufacturers to supply common customers.

Other than a private pool, an open pallet pool can also be used, in which individual actors own the pallets themselves and trade them with other actors. Elia and Gnoni (2015) use an open pallet system, in which the pallets belong to the individual actors and that they can exchange with one another. The study of Elia and Gnoni (2015) is the only identified scientific work which explicitly considers an open pallet pool.

Horizontal and vertical collaboration

To implement loops in pallet management systems, the involved actors must work together. The collaborations between supply chain actors are seen as drivers for CSCM (Moktadir et al., 2018; Zhang et al., 2021), whereas the lack of coordination and collaboration are considered to be barriers of CSCM (Mangla et al., 2018; Tura et al., 2019). In general, collaboration in CSCM can be divided into horizontal and vertical collaborations (Weetman, 2017). Vertical collaborations improve cooperation along the supply chain, for example closing material loops, while horizontal collaborations involve actors on the same level of different supply chains working together by, for example, sharing resources (Weetman, 2017).

The vertical collaboration in the field of pallet management is often examined in literature. The flow of pallets is usually considered to travel from a producer of goods to the customer and back. In most of the mentioned studies (see Table 7), the customers are stores in the retail sector which sell the delivered goods (Achamrah et al., 2020; Bottani et al., 2015). In the studies of Accorsi et al. (2019), Elia and Gnoni (2015) and Tornese et al. (2018), distribution centers of palletized retail goods are also involved in the form of additional actors. In the study of Ranjbaran et al. (2020), a supply chain in the automotive sector is examined, in which assembly plants are supplied with parts by suppliers and warehouses. Potential cross-sector collaborations are only addressed in the theoretical concept studies of Chen et al. (2019b) and Gnimpieba et al. (2015) on digital platforms for the collaboration of various actors.

Vertical and horizontal collaboration in pallet management literature is only discussed in the study of Achamrah et al. (2020). In this case, two manufacturers operate a joint private pallet pool for the supply of shared retailers, where the pallets are purchased collectively.

Information sharing

Technology is classified as an enabler for CSCM, which particularly includes digital technologies Liu et al. (2020). The same applies to information and the exchange of information (Lahane et al., 2020; Tura et al., 2019), the latter making it possible to design cross-actor processes more efficiently (Vaz et al., 2013). Due to the high level of uncertainty regarding returns, the exchange of information in reverse logistics is limited (Glock, 2017). The exchange of information on pallet management is taken into account in conceptual studies on digital platforms: Chen et al. (2019b) designed a digital pallet pool platform based on blockchain to promote the collaboration of actors using different pallet information platforms. Gnimpieba et al. (2015) created a concept for a shared platform to track pallets in the transport chain via Radio Frequency Identification (RFID) technology. The shared information of, for example, tracking is made available on a digital platform to other involved actors. Apart from the conceptual studies on digital platforms, only Ranjbaran et al. (2020) consider sharing information (ordering the return of empty pallets) in a pick-up and delivery route planning model. Here, the number of empty pallets is shared, which should be picked up at the assembly plants and brought back to the supplier. This information is relevant because the return flow of the pallets is implemented in forward logistics and influences the capacity of the trucks.

Table 7 summarizes the collaboration in pallet management literature in the context of CSCM and positions our study accordingly in the existing literature. In our study, we broaden the scope. We do not look at a specific supply chain with a limited number of actors and long-term partnerships, but at a network of independent actors with constantly changing customer–supplier relationships. Therefore, we take the potential of an open exchange pool into account. We also consider the horizontal collaborations between competitors, which goes beyond the use of the same pool and is based on information sharing and joint planning. Furthermore, we empirically evaluate an innovative digital platform concept, as well as the combination of vertical and horizontal collaborations in the context of pallet management for the first time.

5.3 Conceptual Model of Pallet Exchange Platform

Digital platforms offer the possibility of collaboration and the sharing of resources (e.g. pallets) or information (Freitag et al., 2016) and can promote sustainability (Liu et al., 2020). In addition, platforms can also help to transform linear processes into circular ones (Fraccascia and Yazan, 2018)).

Digital platforms enable both vertical and horizontal collaboration in the logistics sector. One example of a digital platform for vertical collaborations in the logistics sector is Uber Freight, which matches shippers and truckers for individual transport orders (Gallay et al., 2017). These kinds of platforms, which bring together different actors to exchange information, goods and services, are called multi-sided platforms (Reuver et al., 2018). In addition to multi-sided platforms, there are also innovation platforms which offer special services for participants (Parker et al., 2017). Another example of vertical collaborations via a digital platform is time slot management systems. The forwarders can use them to book time slots for the delivery, so that consignees can prepare for the arrival, and the trucks can benefit from reduced waiting time (Elbert et al., 2016). In horizontal systems, digital platforms are used to promote collaboration between transport companies, so that, for example, fewer vehicles carry out transport in urban regions (Gansterer and Hartl, 2020). A combination of horizontal and vertical collaboration can be seen in cargo community systems. Here, all actors involved in the supply chain of a specific airport come together via a platform for information exchange (Wallbach et al., 2019). The examples show that platforms enable both short-term and long-term collaborations, while also demonstrating that the purpose of the platforms can be different. Thus, platforms can also be differentiated according to the type of collaboration. They can enable information sharing or joint planning (Chabot et al., 2018; Freitag et al., 2016; Los et al., 2020), whereby for joint planning, a central decision maker is necessary. In the example of joint vehicle routing, the customer orders are put together in such a way that efficient routes can be determined for the individual forwarders (Los et al., 2020). In this case, the information provided by the individual forwarders must be aggregated. After aggregation, planning can take place based on shared information, which achieves a higher benefit for the overall system than decentralized, independently planned processes (Gansterer and Hartl, 2020).

The examined platform of this study operates in the context of an open pallet exchange system to support collaboration in various circular supply chains. In this system, actors make use of their own pallets and can either exchange them with one another (Gnoni et al., 2011; Chen et al., 2019a) or sell them together with the transported goods (Accorsi et al., 2019; Roy et al., 2016). Since the exchange is not always carried out directly, due to time pressure or insufficient empty pallet capacities, the pallet claims and debts have to be recorded between the actors. Depending on whether the forwarder provides their own pallets or not and whether an exchange takes place directly or is postponed, different debt relationships arise between the actors (Table 8).

Table 8: Debt relationships.

Type of pallet management	Direct exchange	Postponed exchange
Selling pallets with product (*1*)	-	-
Double Exchange (*2*)	-	Forwarder/Consignee
Simple Exchange (*3*)	Forwarder/Shipper	Shipper/Consignee

In the first case (selling pallets with product), the shipper sells the pallets as part of the packaging. This does not result in any debt relationships, as ownership is simply transferred to the consignee. However, this simple type of pallet management makes a constant flow of new pallets into the system necessary, as the shipper always needs more pallets. Thus, it also leads to a waste of resources, which contradicts the principle of zero waste in CSCM.

With double exchange pallet management, the forwarder provides their own pallets. The forwarder collects the palletized goods from the shipper and hands over a corresponding number of empty pallets. When arriving at the consignee, the forwarder hands over the goods that are stored on the pallets and receives the corresponding number of empty pallets from the consignee. In this case, no debt relationship arises. However, if the consignee cannot hand over empty pallets directly, the consignee owes the forwarder the number of pallets that have been delivered.

In the case of *simple exchange* pallet management, the forwarder does not use their own pallets. This means that they hand over the palletized goods to the consignee and receive empty pallets for the shipper. This creates a debt relationship between forwarder and shipper. However, if the consignee does not hand over empty pallets to the forwarder on the spot, a debt relationship arises between the shipper and the consignee.

In common practice, digital pallet forms exist, in which different actors can record their pallet debts and receivables with one another. An example of this is a project by GS1, in which this is implemented via a blockchain application (GS1, 2018). There are also logistics service providers with various depots where the pallet debts and receivables of customers are aggregated across all depots (Elbert et al., 2020). In some cases, this type of netting is also carried out between partner companies (EUROLOG, 2016). However, the platform in this study goes beyond the existing concepts because debts and receivables are recorded multilaterally via a central platform, instead of bilaterally between the actors, as is usually the case. Figure 30 compares the commonly practiced concept with the new platform concept. On the left, the debts and receivables are recorded bilaterally, while on the right, the debts and receivables are transferred to the platform. As a result, the debts and receivables are cleared for the individual actors. In the figure, the forwarder owes the first company three pallets, while the second company owes the forwarder three pallets. In the scenario with the platform, these two positions are offset against each other, so that the forwarder has a balance of 0.

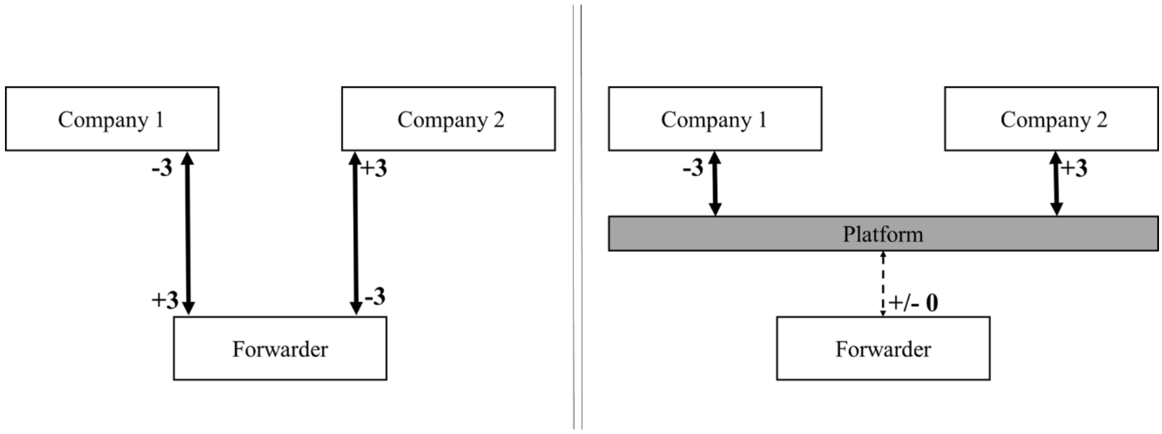

Figure 30: Pallet receivables and debt are recorded bilaterally between the actors (left) and multilaterally via a platform (right).

5.4 Mathematical Formulation for Planning the Commodity Flow of Empty Pallets

For supporting CSCM collaboration, the central planning instance of the pallet exchange platform aims to coordinate the commodity flow of empty pallets. Therefore, a corresponding commodity flow problem must be solved to determine at which stop of which tour additional empty pallets are to be collected or delivered by the trucks, with the aim of balancing the debts and claims of the individual actors in the network. In the previous combined consideration of forward and reverse flows, cost-optimal route planning was the objective (e.g., Iassinovskaia et al., 2017; Ranjbaran et al., 2020). The consideration of flows regarding empty RTIs based on existing tours and with the objective of balancing debts could not be identified.

In the mathematical formulation, the stops that are approached are modeled as nodes N. The trucks are implemented as J. To consider the empty pallet commodity flow, the individual actors participating in the platform have either debt toward or claims against the system. The debt relationship toward the system is defined in parameter a. A negative value signifies that the actor has claims against the system, a positive value signifies debts against the system. The optimization model is based on the planned routes of the trucks that are transmitted to the algorithm. The route is planned in advance and is not influenced by the mathematical modeling, because forward logistics has a high priority and the processes for RTI management do not have a value-creating character, but instead are support processes.

The tours made by the trucks (j) are passed on to the optimization model as a set of tours (S). To check the capacities for empty pallets, a list is transferred which records how many palletized goods are still in the truck at a certain location (derived from the order of the consignees). Also relevant for the empty pallet capacity in the truck is the stacking height of empty pallets h_{max}, which specifies as a parameter how many empty pallets can be stacked on top of each other in a storage space in the truck. The decision variable is x_{rs}. The variable indicates at which stop pallets are collected and at which stop pallets are delivered. In the model, a negative value means that pallets are collected at this stop, and a positive value means that pallets are delivered. The input parameters and notations are given below as well as the decision variable x_{rs}:

Notation:

N	Set of nodes
J	Set of trucks, for each truck $j \in J \exists! \ s \in S$
S	Set of tours, each tour $s \in S = (i_1, \dots i_n) \subset N$ is an ordered tuple of nodes to visit
S_{bs}	Set of all nodes of tour $s \in S$ visited so far at stop b of the tour
$\|s\|$	Number of stops in the tour $s \in S$
s_j	Tour of truck j
a_i^0	Pallet account balance at the beginning of the day at node i
a_i^1	Pallet account balance at the end of the day at node i
q_j	Pallet capacity in truck j
n_{max}	Maximum additional number of pallets picked up per stop
h_{max}	Stacking height of empty pallets in the trucks
y_{jb}	List of the full pallets of the truck j to the stop b

Decision variable:

x_{rs}	Additional pallets picked up or dropped off at the stop r in tour s

Based on the notation, the following mathematical model is formulated:

$$min \sum_i |a_i^1| \tag{1}$$

such that

$$a_i^1 = a_i^0 + \sum_{s \in S} \sum_{r=1...|s|} x_{rs} \quad \forall\, i \in N, if \;\; i = s(r) \tag{2}$$

$$\sum_{r=1...|s|} x_{rs} = 0 \quad \forall s \in S \tag{3}$$

$$\sum_{r \in S_{bs}} x_{rs} \leq 0 \quad \forall\, s \in S, b = 1, \dots, |s| \tag{4}$$

$$x_{rs} \geq n_{max} \quad \forall\, s \in S, \;\; r = 1, \dots, |s| \tag{5}$$

$$q_j \geq y_{jb} + \left\lceil \frac{-(\sum_{r \in S_{bs}} x_{rs})}{h_{max}} \right\rceil \forall\, j \in J, S_{bs}\, for\; b = 1, \dots, |s| \tag{6}$$

$$\begin{array}{lll} -a_i^0 \leq x_{rs} \leq 0 & if\; a_i^0 > 0 & \quad (7.1) \\ 0 \leq x_{rs} \leq -a_i^0 & if\; a_i^0 < 0 \quad \forall\, s \in S, r = 1, \dots, |s| & \quad (7.2) \\ x_{rs} = 0 & if\; a_i^0 = 0 & \quad (7.3) \end{array}$$

$$x_{rs} \in Z \tag{8}$$

The objective function (1) minimizes the total debts or receivables in the system. Since the debts in the system are negative and the corresponding receivables in the system are positive, the absolute values of the pallet account balances of the individual actors are added up. At this point, the pallet account balances at the end of the day are relevant, when all additional empty pallet flows between the actors have taken place.

Constraint (2) states the calculation of the pallet account balance at the end of the day for the individual actors i. For this calculation, the pallet account balance at the beginning of the day is noted and the additional inflows and outflows of pallets at each actor's node are added up over all tours of all forwarders of the day. Of importance here is the link between the actors and the tour stops: the stop of the tour must correspond to the node of actor i.

Constraint (3) ensures, that, at the end of a tour, the truck does not contain any pallets. For this, the sum of all inflows and outflows of a tour must equal 0 at the end. Constraint (4) ensures that the sum of inflows and outflows does not have a positive value at any time during a tour. The pallet accounts a_i are modeled such that a positive value represents debts toward the system (the actor has more exchange pallets at their disposal than they are entitled to). Therefore, x_{rs} has been defined so that a negative value means that a pallet will be picked up by the forwarder. If, at any point of the tour a positive value occurs within a truck, any empty pallet stock in the truck would have a negative value.

Constraint (5) limits the maximum number of additional pallets taken for debt settlement, whereby it is assumed that pallet exchange plays a subordinate role compared to forward logistics. To ensure that the processes for the distribution of empty pallets do not influence the traditional processes too much, we introduced an upper limit with constraint (5).

Constraint (6) takes the capacity of the truck into account by not exceeding the total amount of storage space for pallets in the truck. To achieve this, the number of full pallets which are still in the truck at the respective stops (from the transferred list y_{jb}) is added to the number of empty pallets which are in the truck at the same stop. While each full pallet requires one separate pallet space in the truck, up to h_{max} empty pallets can be stacked on top of each other in one space. Therefore, the sum of empty pallets is divided by the stacking height and rounded up. $\sum_{r \in S_{bs}} x_{rs}$ describes the total quantity of empty pallets that are in the truck at the time of each stop b. The loading and unloading of empty pallets at the previous stops are balanced up to stop b of the tour. Since negative values of x_{rs} indicate that pallets are being carried in the truck, the sum x_{rs} must be multiplied by -1 beforehand.

Constraints (7) set the value ranges of the decision variables. It is relevant here that additional pallets can only be taken from actors who still owe pallets. Likewise, pallets can only be given away by actors when they have open claims against the system. If an actor has no pallet debts or claims, they can deliver neither. The last constraint states the integer nature of the decision variable, as only whole pallets can be exchanged between the actors.

By predetermining the routes, the optimization problem is restricted in the solution space to such an extent that a heuristic algorithm for commodity flow determination is not necessary. The optimization problem can be solved accurately.

5.5 Simulation Study

Simulation modeling is widely used in research on logistics and transport issues. This is particularly true in the area of RTI management (Accorsi et al., 2019; Bottani and Casella, 2018). Since a cross-actor pallet exchange platform with claim transfer does not exist, an investigation using simulation modeling is a reasonable approach. An agent-based simulation was used which is applied when different actors interact with each other and with the environment (Law, 2013). This fits the investigated use case in RTI management with the main actors being forwarder, consignee, and shipper. The used simulation software is Anylogic (vs. 8.5.2), which is often applied for simulations in the field of transport and supply chains (e.g., Elbert and Friedrich, 2018) and specifically in RTI management (e.g., Elia and Gnoni, 2015). For the simulation study, the systematic approach of Manuj et al. (2009) was adopted.

In order to close the gap that often exists between scientific observation and practical implementation (Hellström and Johansson, 2010), all assumptions were discussed and validated in regular workshops with representatives from common practice. These were employees of forwarders, logistics service providers, manufacturing and trade companies, operators of an open pallet pool, as well as a pallet manufacturer and a platform provider for digital pallet accounts. Thus, we were able to assemble representatives of all relevant actors of the pallet exchange system into our project support team. All representatives operate in the German transport and logistics sector and use different types of pallet management in the open pallet pool (see Table 8). A detailed list of the participants of the project support committee, their companies, and a short statement about why the participants are suitable can be found in Table 9.

Table 9: Participants of the project support committee.

Number of the participant	Company type	Industry	Company size*[5]	Position of the participant	Suitability of the participant as member of the project support committee
1	Forwarder	Road freight transportation	SME	CEO	CEO of small company with an overview of all internal and inter-company processes
2	Forwarder	Road freight transportation	Large	Group manager packaging materials	Responsible for the management and organization of pallets
3	Forwarder	Road freight transportation	SME	Transport manager	Pallet exchange and organization of pallets as part of the daily business
4	Forwarder	Road freight transportation	Large	Project manager	Pallet exchange and organization of pallets as part of the daily business
5	Logistics service provider	Pharmaceutical industry	Large	CEO	Overview of pallet exchange processes and insight into forwarding division of the company
6	Logistics service provider	Air, sea and road freight transportation	SME	Transport manager	Pallet exchange and organization of pallets as part of the daily business
7	Logistics service provider	Road and rail freight transportation	Large	Project manager	Pallet exchange and organization of pallets as part of the daily business
8	Manufacturer	Automotive supplier	Large	Project manager logistics	Knowledge on pallet exchange and related internal processes in the company
9	Manufacturer	Detergents and cleaning products industry	SME	Head of logistics	Overview on pallet exchange and all internal and inter-company processes
10	Trading company	Building materials industry	SME	CEO	CEO of small company with overview of all internal and inter-company processes
11	Trading company	Toy industry	Large	Head of incoming goods department	Overview of pallet exchange and pallet account management processes
12	Trading company	Food industry	Large	Supply chain manager	Knowledge on inter-company processes, including pallet exchange
13	Pallet pool operator	Association		Business development manger	Knowledge on inter-company processes, including pallet exchange
14	Pallet pool operator	Association		Innovation manager	In-depth knowledge of pallet exchange processes, standards and current challenges
15	Pallet account provider	Software industry	SME	Business development manger	Knowledge on how a digital pallet account system works and operates
16	Pallet manufacturer	Lumber industry	SME	CEO	CEO of small company with an overview of technical specifications and characteristics of wooden pallets
17	Consulting	Transportation and logistics	Large	Research manager	Expertise in digital innovations in logistics and transport

[5] Small- and medium-sized enterprises (SMEs) are defined as less than 250 persons employed and less than 50 Mill. EUR annual turnover and/or an annual balance sheet total less than 43 million according to a recommendation of the Commission of the European Communities from 6 May 2003 (2003/361/EG) available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003H0361. Companies exceeding these variables are defined as large enterprises.

Furthermore, we were able to draw on their empirical values and evaluations of practical data when determining the parameters. We received a report of a pallet account from a trading company with two anonymized customers (participant 11). Moreover, we received data sets from a pallet account provider (participant 15). We were able to use the pallet account data to compare to the reference model data that was generated in the simulation model. This comparison was used to validate the reference model, which represents the current system without the conceptualized pallet exchange platform with claim transfer.

The operator of the pallet accounts (participant 11) also provided us with analyses of the exchange behavior, based on bookings via the common system. Consequently, information could be obtained, such as the fact that pallets are usually either exchanged completely or not at all when the goods are unloaded at the consignee's premises. The exchange of partial quantities of pallets does not take place.

Further information, such as how often which type of pallet management is used (see Table 8), could not be derived from the data. In this case, we used the experience of forwarders (participants 1, 2). Due to their profession, they possess knowledge about the pallet management types of many different companies.

In addition to the data and the provided process knowledge, the practitioners were used to validate the created simulation model, as well as the concept of the platform that was developed with a claim transfer. Table 10 lists the topics of the individual project meetings, along with the participants. Since not all participants were able to attend all meetings, a summary of the last meeting was given at the beginning of each meeting, and protocols were made available to all project participants afterwards. With the help of the data and information from common practice, we were able to create a realistic model of the process of pallet exchange in Germany and examine our concept within it.

Table 10: Project meetings and participants.

Meeting	Topic	Numbers of participants (see Table AI)
1	Process analysis and problem description of the pallet exchange system	1, 4, 6, 8, 17
2	Demonstration of the simulation model (reference model) and validation as well as presentation of the concept of digital pallet exchange platform with claim transfer	1, 2, 5, 6, 11, 13, 16, 17
3	Demonstration of the interim status of the simulation model with a digital pallet exchange platform with claim transfer and validation	3, 5, 7, 10, 12, 13, 14, 17
4	Demonstration of simulation model for the platform and validation	1, 6, 9, 10, 11, 13, 17
5	Presentation of results and validation of results	1, 6, 10, 11, 13, 14, 15, 16, 17

Since no exchange network platform with pallet claim transfers is currently used in common practice, we used a simulation modelling approach and chose a network from scientific literature as the basis for our study, in order to achieve results which are as general and comparable as possible. The locations and the fixed order quantities for the actors were taken from Solomon (1987), which is often used in scientific literature (e.g., Chen and Shi, 2019). This data set is established and still used for comparability of results, e.g. in the field of tour planning (e.g., Chen and Shi, 2019). For the simulation model, a data set was used which provides a mix of random and clustered structures. This creates a network which includes urban and rural areas, and thus reflects a real network structure of business locations (Figure 31). The locations of the 50 companies were distributed in a field measuring 100 km by 100 km. In addition, five forwarders and three pallet shops were randomly selected from the dataset, and Euclidean distances were determined between the actors.

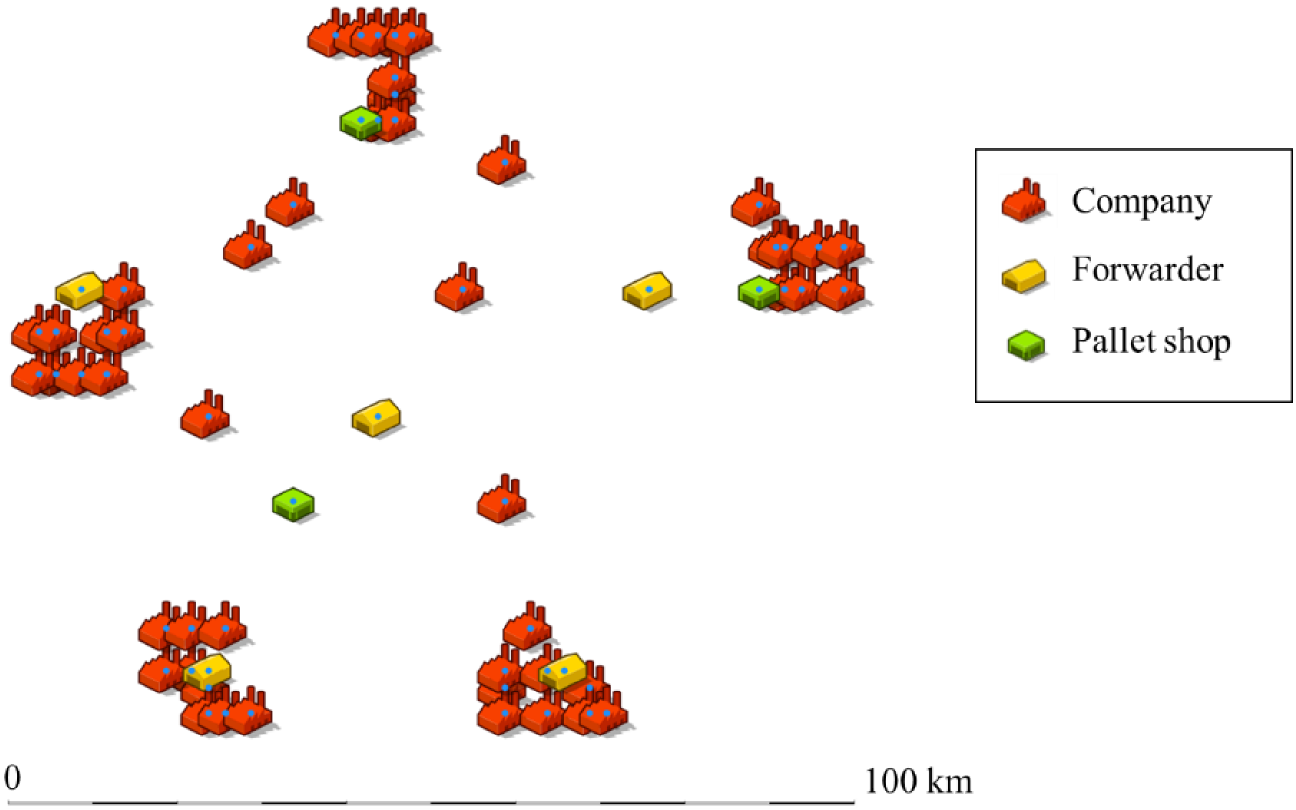

Figure 31: Network of the simulation model.

Preliminary analyses have shown that pallet debt builds up immediately. Furthermore, since the relevant output factors are evaluated and compared aggregated over the entire period of the simulation run for the individual scenarios, no transient phase was taken into account. Additionally, the preliminary investigations have shown that the output factors (debt, new pallet purchases, etc.) develop linearly for longer time frames. Thus, a limitation to three months could be chosen in order to limit the runtime and to be able to generate as many replications as considered practical.

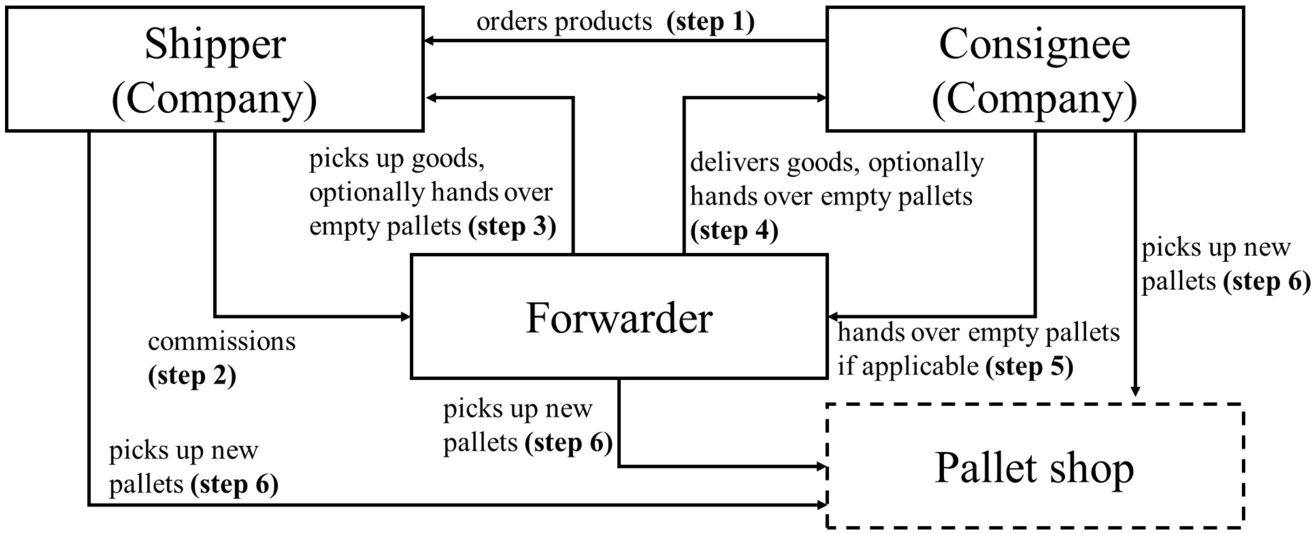

Figure 32: Main actors and their interactions.

The relevant actors and their basic interactions are illustrated in Figure 32. First, a company (consignee) orders goods from another company (shipper). The shipper then commissions a forwarder who collects the goods with a truck and delivers them to all recipients in a round trip. The actors can purchase new pallets in the pallet shop. The forwarder balances the pallets between the actors. The forwarder can transport empty pallets in the truck and deliver them to the various actors in the network. In the following section, the interactions are described in detail for the scenario without a platform (reference scenario) and for the scenario with a platform:

Scenario without a collaboration platform

At the start of the day, five companies, out of the 50 available, are randomly selected to act as shippers on that day. The other companies can order products from these randomly selected shippers (full pallets). The shippers have a daily production capacity of 34 pallets (a full truck load). As soon as all customer orders have been received, the shipper randomly commissions a forwarder to collect these pallets and distribute them to the customers on the next day. Thereby, the shippers specify the type of pallet management. Either (1) the pallets are sold along with the goods to the consignee as part of the packaging, or (2) the shipper requires the forwarder to provide their own pallets and receives empty pallets from the forwarder when the fully loaded pallets are picked up from the shipper or (3) the shipper opts to receive the pallets back from the consignee. If the forwarder is expected to provide their own pallets (type 2), the forwarder loads the truck with the corresponding number of empty pallets before driving to the shipper. There, the truck delivers the empty pallets (of which the number corresponds to the number of pallets that are to be transported). From the shipper, the forwarder drives to all customers in a round trip and delivers the palletized goods.

The route planning is carried out using the greedy algorithm developed by Schrimpf et al. (2000), as well as Pisinger and Ropke (2007). The open-source package jsprit was integrated for this purpose (e.g., Elbert and Friedrich, 2018). Once the palletized goods have arrived at the customer, they are handed over to the consignee. When all of the consignee's orders have been completed, the forwarder's truck drives back to the home depot.

Depending on which pallet management type the shipper desires and whether an exchange can be carried out on site, empty pallets are exchanged, or various debts are recorded. Using type 1 (sale as part of the packaging), no pallets are exchanged, and no debts are recorded after the full pallets have been delivered. In terms of pallet management, this is uncomplicated, but the shipper is forced to continuously buy new pallets and overstocks are built up at the recipients. Therefore, according to statements made from forwarders (participant 1 and 2), this procedure is not often used in common practice (approx. 1/3 of the time).

In the scenario with pallet management type 2, the consignee hands over the corresponding number of empty pallets after receiving the palletized goods. In this case, no debts arise between the actors, as all parties have the same number of pallets as at the beginning of the process. Since an exchange does not always happen due to lack of time or an insufficient number of empty pallets at the consignee's premises, the forwarder does not always receive empty pallets in return. This postpones the closing of the pallet circle, which leads to pallet debts between the forwarder and the consignee (the consignee owes the forwarder pallets).

In the scenario using pallet management type 3, pallet debts arise between the forwarder and the shipper when the consignee hands over the empty pallets to the forwarder on behalf the shipper. If the consignee has not handed over empty pallets to the forwarder, a bilateral debt relationship arises between the shipper and the consignee.

In order to ensure that the circular supply chains for the pallets closes, the pallets that are owed must be returned. The incurred pallet debts can be settled in different ways. If the forwarder owes debts to the shipper of the particular day, the forwarder loads the pallets that they owe into the truck (for type 2 in addition to the required empty pallets) and hands them over to the shipper. If the forwarder has claims against a consignee on that day, the truck will transport additional pallets on the condition that empty pallets are exchanged with the consignee. If the consignee has debts to the shipper, additional pallets that are intended for the shipper are also given to the forwarder. Since the forwarder thus receives additional pallets to send to the shipper, a new debt relationship arises, in which the forwarder now owes the shipper pallets. Therefore, the forwarder acts as an intermediary who facilitates the settlement of debts between the two companies.

If the actor's pallet stock falls below a minimum number of 60 pallets (approx. twice the amount required for the daily production capacity of a shipper), the actor needs to actively procure pallets. Various options are available to procure pallets, therefore, the actor may choose an option. The forwarder obtains new pallets, either by acquiring them at the pallet shop (60 pallets) or by claiming the pallet debt from a consignee. If they choose to do the latter, the forwarder creates a round trip and collects empty pallets from various consignees. The companies can also drive to the shop or claim pallet debts from the forwarder. The forwarder then drives to the company with the empty pallets. Generally, the actors try to obtain the pallets they need by collecting the debts before buying new pallets from a pallet shop.

Scenario with a collaboration platform

The concept with a cross-actor platform takes over the bilateral pallet debts of the participating actors and simultaneously acts as a central instance of commodity flows for debt settlement for CSCM. Regarding the three scenarios of pallet management types, the processes that are described above apply in almost the same way, the difference being that all claims (receivables/debts) are assigned to the central platform. If debts incur as a result of an exchange transaction, the debts of one actor and claims of the other are reduced or increased to the total balance of the respective actor. In addition to balancing debts and receivables, the platform also maintains the role of a central planning instance by organizing the commodity flow of additional empty pallets which are picked up and handed over by the forwarder on regular tours. The platform is used to plan the return of the pallets, thus closing the reverse cycle. The regular exchange of empty pallets for full pallets takes place independently from this. The forwarders hand over their respective tours as a list of nodes that are to be visited. The first and last nodes are always the forwarder's depot. Furthermore, a list with the full pallets currently in use is transferred, as well as the current balance of the pallet accounts from the individual actors on the platform.

In the simulation model, the Gurobi v.9.0.2 standard solver is implemented as a Java package. The Gurobi solver is often used as a standard solver for solving mathematical optimization models in scientific literature for logistical problems (e.g., Canca and Barrena, 2018; Wang and Qi, 2019).

If the participation rate is below 100%, a hybrid is created of both concepts described above. The incurred debts are netted between the participants in the platform, while the debts are held bilaterally, if an actor does not participate in the platform.

Modell assumptions

Various assumptions were made, and different parameters were chosen for the simulation model. These were defined and validated in accordance with practice partners. Table 11 lists the relevant parameters. The first input parameters (participation rate and max. additional pallets picked up per stop) vary in the experiments.

Table 11: Parameters of the simulation model.

Parameter	Value
Participation rate of the companies	0-100 %
Max. additional pallets picked up per stop	5-25
Probability of no direct pallet exchange	50 %
Order size	Dataset Solomon 1995
Pallets at the start (per actor)	200
Probability of selling pallets with product	33,3%
Probability of double exchange	50%
Probability of simple exchange	17,7%
Pallet capacity in the truck	34
Stacking height of empty pallets in the trucks	15

The pallets are subject to wear and have a life span of 15 cycles (Carrano et al., 2015). After that, the pallets are no longer usable. In the model, it is assumed that the actors behave fairly and that the exchanged pallets have the same quality level, and thus the pallets are selected randomly from the stack. This assumption was made because, even in current practice, the actors in the pallet exchange with deliberate misconduct can create their own advantage in such a system by giving, as far as possible, only poor-quality pallets to the exchange partners (Elbert and Lehner, 2019; Prataviera et al., 2021). At this point, the implementation of the presented platform would not result in any changes for the time being. The extent to which the platform has the potential to alleviate this problem will be addressed again in section 5.6.

Other relevant assumptions are summarized as followed:

1. Pallets are defect after 15 runs and are sorted out by the current owner;
2. No errors are made, e.g. in the booking of pallet debts or in the issuing of pallet quantities, and no pallets disappear;
3. The consignees order randomly from the shippers; thus, no regular business relationships are modeled;
4. The forwarders always participate in the platform, as they benefit from it the most (see section 5.6);
5. The truck of the forwarder can drive to a maximum of eight actors on their tours to ensure that all tours can be completed within an 8-h shift;
6. The pallet collections and deliveries planned through the platform can always be carried out accordingly.

5.6 Analysis and Discussion

This section presents the results of the analyzed scenarios. As previously described in section 5, the simulation study was developed with the help of practical partners. In addition to providing data, process knowledge and validating the simulation and conceptual model, the practitioners were also consulted in order to validate the results. The results were presented to the practice partners, checked for plausibility and discussed.

For each scenario, 30 replications were executed. With 30 replications, the half-width of 95% confidence intervals are usually at a level of about ±5% of the sampled means (see Kelton, 2016). In some scenarios, the variations around the mean value are larger, meaning that this level cannot always be maintained. The test that was increased to 40 replications for one scenario did not lead to a significant reduction of the confidence intervals. Due to the complexity of the model and the resulting computing time, we could not significantly increase the number of replications any further.

First, an analysis is presented of how the use of the digital platform affects the amount of debt between the actors. Figure 33 (left) shows the debt as a function of participant rate for the scenario, in which a maximum of 15 additional pallets can be picked up at each stop. The mean value of the total debts is shown with a confidence interval of 95%. The total debt in the system decreases as the participant rate increases. However, the effect differs between the forwarders and the companies (shippers and consignees).

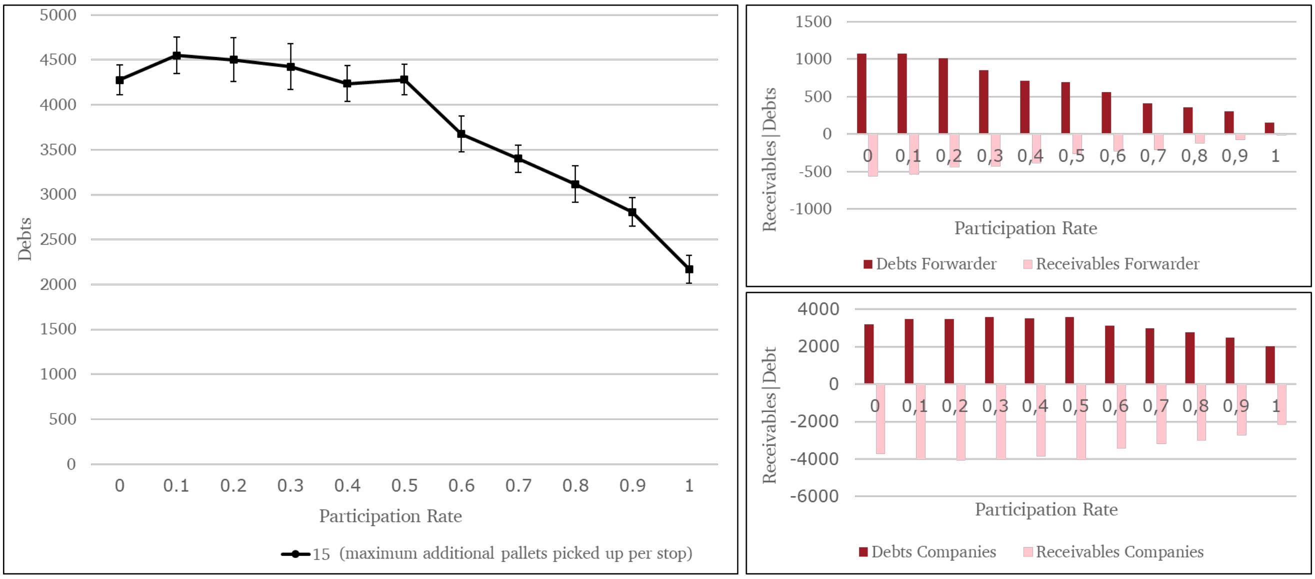

Figure 33: Debts in the overall system in the scenario with 15 maximum additional pallets with a confidence interval of 95 % (left), debts and receivables of the forwarder (right, above) and companies (right, below) in scenario with 15 maximum additional pallets.

On the right-hand side of Figure 33, a significantly higher reduction can be observed in the debts and receivables of the forwarders, compared to those of the companies. This can be explained by the fact that the forwarder acts as an intermediary in the regular system and is involved in most of the resulting debt contracts (see Table 8). In the scenario containing the platform, this role is carried out by the platform, which has a relieving effect on the forwarder. In the discussion, the greater relief for forwarders was considered to be realistic (participants 3, 5, 10, 13, 17). Since forwarders had the greatest challenges in the current open exchange pool system (participants 2, 4, 5), this circumstance was evaluated positively by shippers and recipients as well (participants 5, 6, 11).

For companies at low platform participation rates, the debts increase slightly at first. The reason for this is that it takes longer to settle the debts in the platform scenario, because the pallets owed to the companies are not requested at short notice by the contracted forwarder. This results in a slight increase in total debts in the system at low participation rates.

Figure 34 shows the total number of debts in the system, depending on the participation rates in the cross-actor platform and different maxima of additional pallets that are picked up per stop (5, 15, 25). The more pallets that are picked up at the individual stops, the more debts can be offset, which results in a reduction of the total debts in the system as a whole. It should be noted that this effect becomes significant at a participation rate of 30 %. A maximum of 15 additional pallets picked up per stop leads to a significant reduction of the total debt, compared to just 5 additional pallets. The difference between 15 and 25, however, is only marginal.

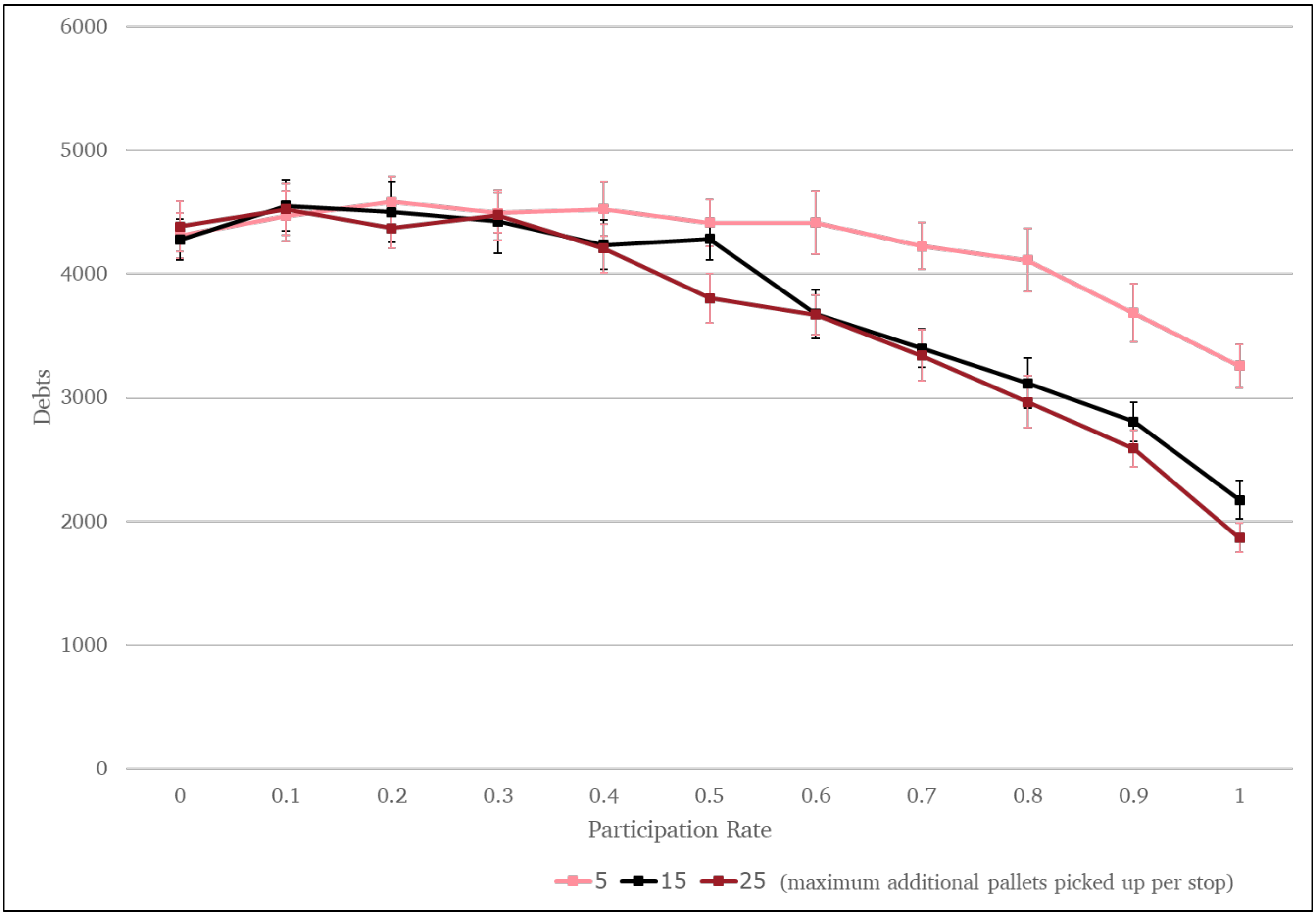

Figure 34: Debts in the overall system.

In the discussion, the practitioners emphasized that the reduction of pallet debts through the transfer and balancing via the platform would also lead to less administrative effort (participant 1, 10, 11). Another advantage from the practice partner's point of view was the use of a common system for suppliers and customers instead of individual bilateral solutions (participant 1, 2, 11).

The number of additional pallets that are transported between the actors is responsible for balancing, and thus reducing the total amount of debts and receivables (see Table 12). The higher the number of pallets that can be collected by the individual actors, the more pallets will be transported. Approximately half of the pallets are transported from the forwarder to the current shipper, a quarter from the companies to the forwarder and a quarter between the different companies.

Table 12: Additional pallets transported between actors with a confidence interval of 95%.

Participation rate	Number of transported pallets (for different max. additional pallets per stop)		
	5	**15**	**25**
0	0	0	0
0.1	296 [±72]	453 [±102]	538 [±128]
0.2	701 [±105]	951 [±134]	983 [±145]
0.3	1,010 [±83]	1,447 [±160]	1,654 [±162]
0.4	1,211 [±135]	1,861 [±159]	2,143 [±219]
0.5	1,413[±88]	2,209 [±157]	2,465 [±157]
0.6	1,667 [±101]	2,717 [±167]	2,911 [±209]
0.7	1,764 [±88]	2,954 [±133]	3,414 [±192]
0.8	1,927 [±81]	3,287 [±161]	3,780 [±204]
0.9	2,080 [±113]	3,550 [±112]	4,230 [±125]
1	2,126 [±66]	3,907 [±142]	4,432 [±206]

According to the practitioners (participants 1, 3, 11, 15), the preparation of additional pallets for other platform participants would involve an additional amount of effort.

Since the planning is also partly taken over by the platform, and additional pallets are only made available if pallets are also exchanged during the regular deliveries, the additional effort is estimated to be low. The difference in effort to provide and load up to 5, 15 or 25 additional pallets is only minor (participants 1, 10, 11).

In addition to the reduction of debts and receivables, the implementation of the platform also leads to a reduction in the additional distances which must be driven for pallet management (Figure 35). These include the distance the truck travels to collect empty pallets from companies which are in debt with the forwarder, as well as the trips the forwarder makes when the shippers, who are the customers in this case, reclaim pallets owed to them. Finally, the additional distances that are travelled for RTI management include trips made by the actors (both forwarders and companies) to the pallet shop, where they buy new pallets. For the additional distances that are covered, it also appears that the effect becomes stronger with higher participation rates and with an increase in the maximum number of additional pallets that are to be collected from an actor. It should also be noted that even with a low participation rate, there is a high potential of saving resources, compared to the reference scenario (0% participation rate). Thus, even small collaborations have a high savings potential with respect to reducing transport routes. This facilitates the initial implementation of a corresponding platform.

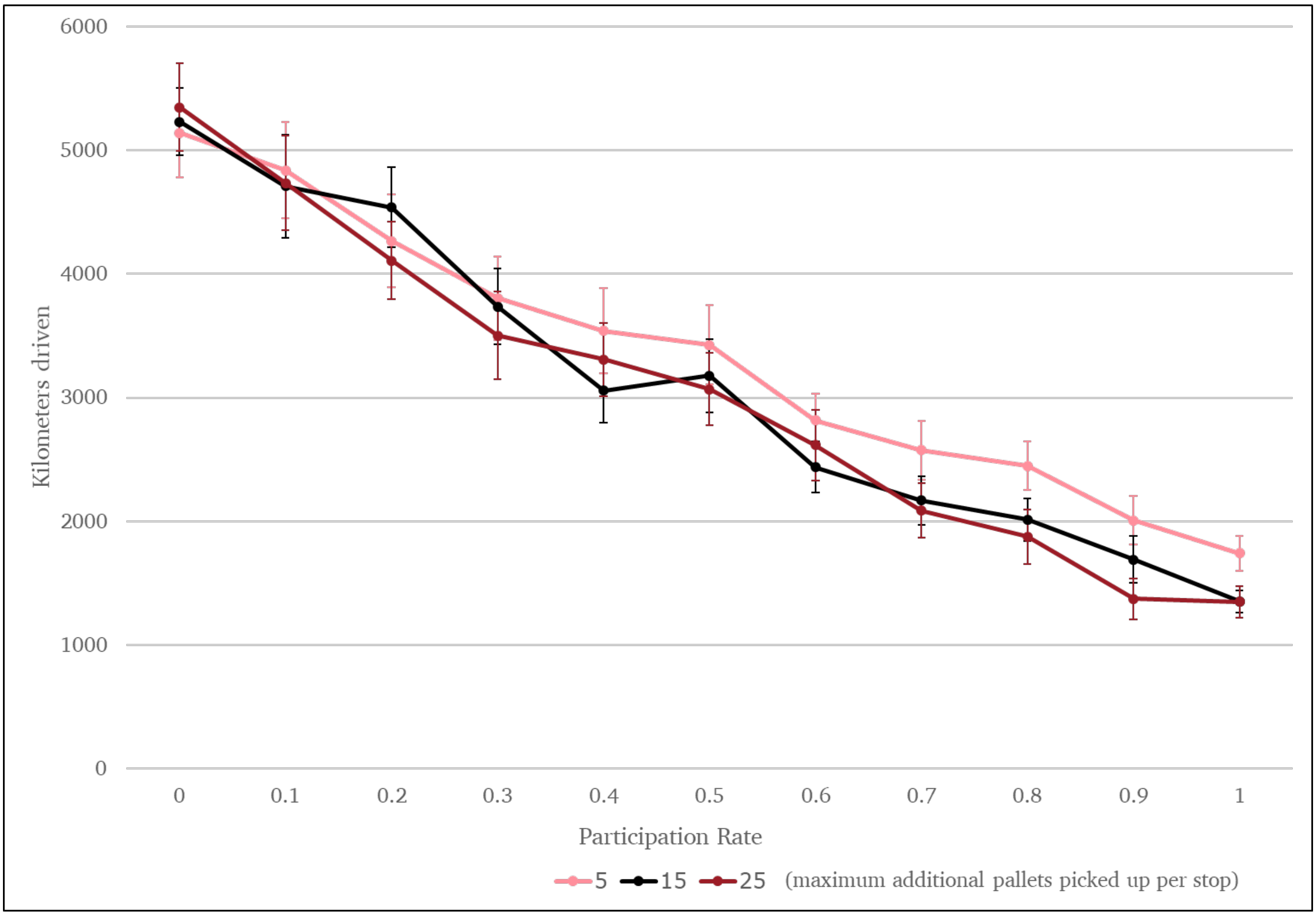

Figure 35: Additional distances travelled for RTI management with a confidence interval of 95 %.

In Figure 36, the ratio of the debts and the reduced kilometers is once more considered, if no additional empty pallet flows are organized. Here, we see that the total debts remain constant, while the number of participants increases. However, the kilometers that must be driven decrease, which is why it could be said that the physical pallet flows are replaced by virtual ones. In terms of CSCM, we could speak of a circle being digitally closed. In the model, only the driven kilometers are evaluated. Employee costs or the number of trucks that are required are not taken into account. Practitioners from the field have emphasized that reducing the distances to be covered, would also have a positive effect on these aspects (1, 6, 17).

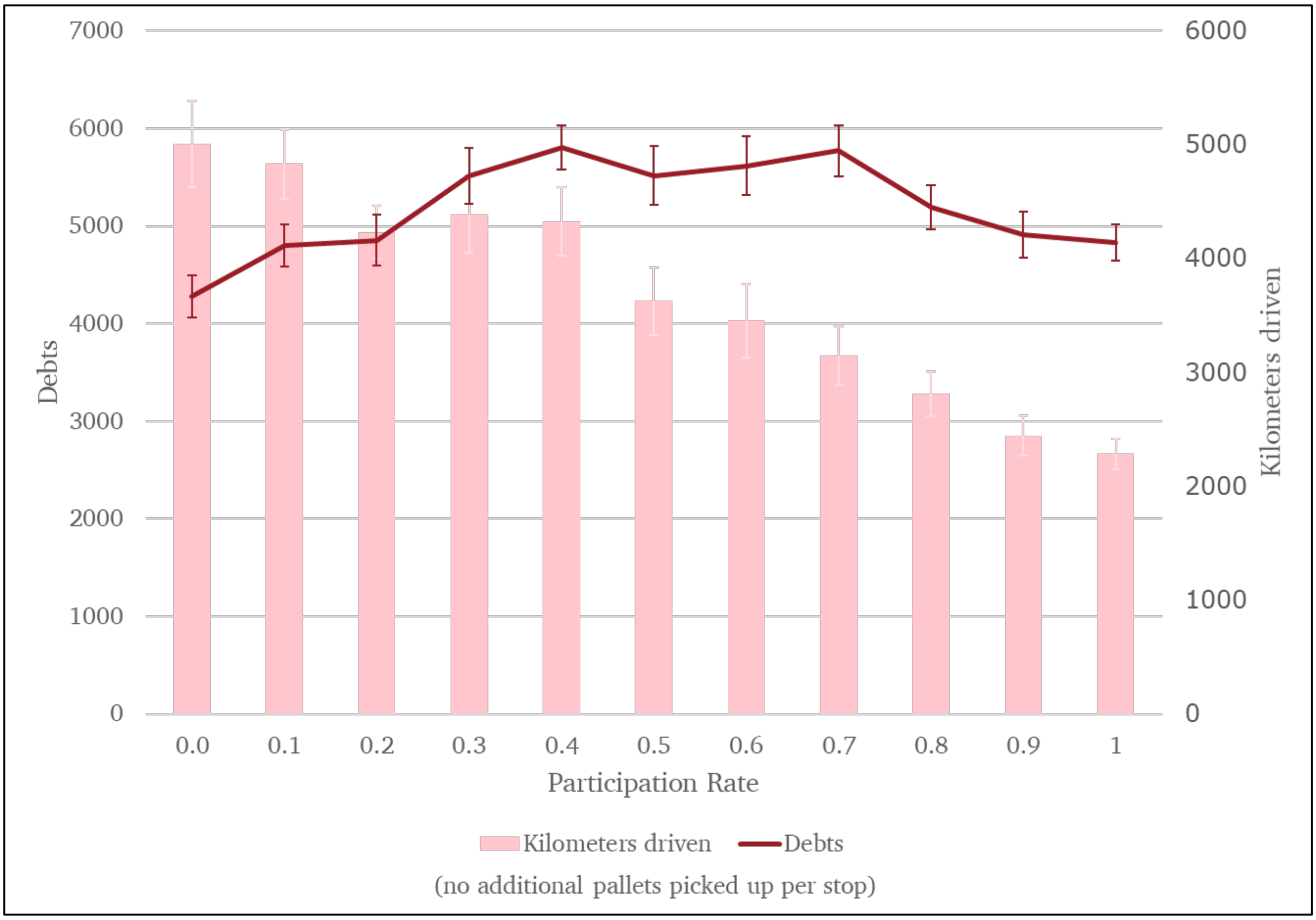

Figure 36: Debts in the overall system in the scenario with no maximum additional pallets with a confidence interval of 95% and additional distances travelled for RTI management with a confidence interval of 95%.

The impact of a digital platform with claim transfer and a central planning function must be considered in a differentiated manner regarding the purchase of new pallets (see Figure 37). If the number of pallets which can be taken per stop is high, the number of new pallets to be purchased decreases, as the participation rate increases. With a participation rate of 100% and a maximum number of 25 pallets which can be taken along per stop, the number of new pallets to be purchased decreases by approx. 10% compared to the reference scenario.

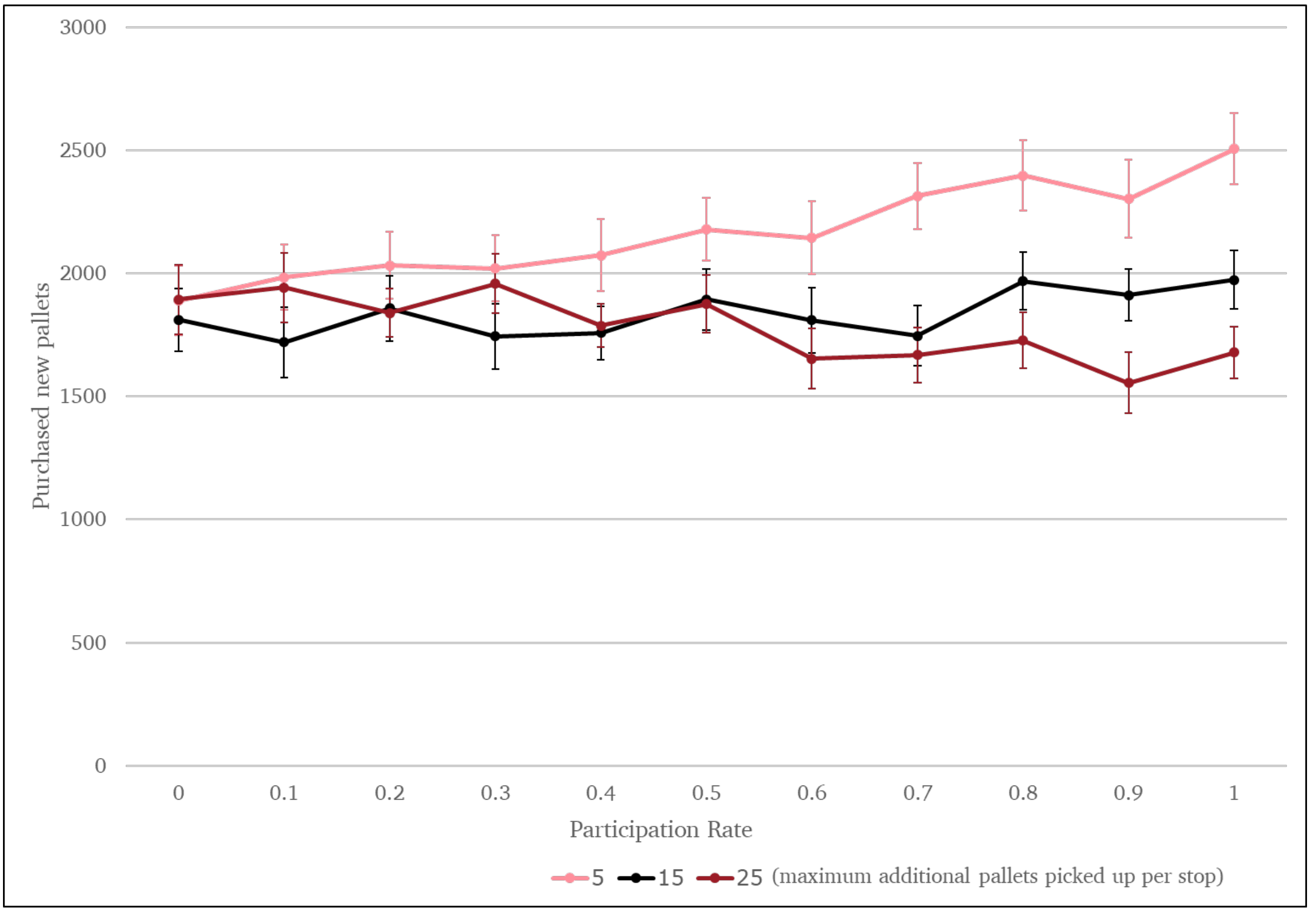

Figure 37: Purchased pallets with a confidence interval of 95 %.

However, if only 5 pallets can be taken per stop, the number of new pallets that must be procured increases along with the number of participants. This can be explained by the fact that the balancing is carried out more slowly by the platform, due to the restrictions and irregular deliveries. Therefore, new pallets must be procured or purchased elsewhere for short-term needs. At 15 pallets, the effects balance out, and the number of pallets remains relatively consistent, as the number of participants increases. Platform operators should therefore aim to set the number of additional pallets as high as possible.

Other mechanisms of the platform can also help to reduce the number of pallets that are needed in the overall system. For example, in addition to controlling the balancing of debts, the platform can also balance the over- and undercapacities. Actors who require more pallets can inform the platform, as can actors who have more pallets than they need. This can then be taken into account in the platform, when planning the flow of empty pallets. Additionally, financial incentives and compensation can encourage companies to provide additional pallets for other actors. It was important to the practitioners (participants 10 and 11) that the number of pallets which are required should not increase when using the new platform concept. However, they also see the opportunity to reduce the number of pallets under the right circumstances, as an incentive to use the system as effectively as possible.

Overall, the forwarders benefit the most from this platform concept, considering that in the current system without a platform they are usually the actor who suffers the most disadvantages (Elbert and Lehner, 2019). The cross-actor pallet exchange platform manages to distribute the difficulties of pallet exchange more fairly among all actors. Additionally, the reduction in transport distances for the forwarder also indirectly benefits the other actors because it reduces the costs of the forwarder, which in turn enables the forwarder to offer their services more cost effectively.

As is currently the case in the open pallet exchange system, it is still important to check the quality of the pallets at the transfer points during direct exchange, and to document it in case of doubt. In the case of a postponed exchange, corresponding functions could be implemented so that the documentation runs via the platform, e.g. by taking photos. The advantage of the platform is also that the actors are directly connected. This is a benefit because the forwarder usually has no contractual relationship with the consignee, and when using subcontractors, in some cases not even a direct contractual relationship is established with the shipper. For certain actors who only provide low-quality pallets toward additional pallets that are distributed by the forwarder to other actors, this could be recorded and sanctioned via the platform. For example, the actor could be penalized with decreased options in the distribution of the empty pallets which is planned through the platform or being required to pay penalty fees.

In addition to the practical implications, our work also makes a theoretical contribution. The work expands the literature on pallet management by addressing the cross-actor and cross-supply chain potentials of an open exchange pool for the first time. In this regard, we take into account a dynamic system, in which new customer–supplier relationships are constantly emerging instead of long-term supply chain partnerships.

Furthermore, the benefits of using digital platforms in the area of pallet management have so far only been considered conceptually on the scientific side (see section 2). With this study, our concept was now able to provide empirical evidence. At the same time, we were able to show that, in addition to vertical collaboration, horizontal collaboration should be given greater consideration in the area of pallet management in particular. We would extend the statement of Ren et al. (2019) that pallet management should not be viewed from the actor level but rather from the supply chain level: if possible, pallet management should even be viewed across the supply chain, in order to make the overall system more efficient, from which each individual actor would benefit.

Additionally, we can contribute to the CE literature in a theoretical way. The implementation of open-loop circularity supply chains in the field of pallet management is already established, and the CE principles have progressed. Thus, we were able to show an area in which open-loop circularity is also indirectly addressed in science. We demonstrate how the advantages of an existing CSCM system can be further improved with the help of information sharing, platform technologies, and both horizontal and vertical collaboration, regarding both economic and ecological factors. In doing so, we were able to empirically prove the potentials for our platform concept, which are attributed to collaboration in CSCM literature.

5.7 Conclusion

The pallet exchange principle is already strongly developed with regards to CE since the pallets are used multiple times as shared resources. With the help of an innovative central instance and the balancing of pallet receivables and debts, additional trips which are necessary for RTI management can be reduced significantly by simply using the forwarder's regular tours. Furthermore, the number of new pallet purchases can be slightly reduced using such a platform (under the condition of a high participation rate and the existence of many distributed empty pallets). RTI management is only a small part of CE, i.e. the entire supply chain (CE considered from the creation of products to new use). However, looking at the extent to which RTI is used in the various supply chains, collaborations can make a significant contribution to CE in general. The study shows that platform technology enables closer collaboration, leading to more efficient processes and less waste of resources. The use of the platform brings together actors from different sectors, which creates the possibility of collaboration across different supply chains. This is in accordance with the idea of circular supply chains.

On the one hand, we used literature instances to describe a comprehensible procedure and to achieve results, which are as generally valid as possible. On the other hand, we determined the relevant parameters and simulated processes together with practitioners, so that the results have a high relation to common practice. Nevertheless, the present simulation study has limitations. The number of actors is restricted to 50 companies and five forwarders, in order to limit the computing time to a reasonable level. Even though the system is designed for cross-sector use, no sector-specific requirements have been taken into account in the model, e.g. the need for high pallet qualities in the pharmaceutical industry, as compared to the building materials industry. In addition to that, the selection of forwarders and the decision where to order products, are random.

Furthermore, the chosen parameters and assumptions regarding processes for pallet exchange are related to Germany. Without an examination of the general settings, the results are not directly transferable to pallet exchange systems in other countries. The simulation model refers to the reuse phase, but with the help of the platform, it is also possible to integrate other phases, e.g. repair, so that pallets can be picked up by different actors from the forwarder and be brought in for repair. Further research is necessary before an exchange platform, such as the one outlined in this paper, can be adopted into common practice. Drivers and barriers should be identified, and relevant features should be taken into account. The technology in use and possible platform operators should also be considered.

Furthermore, the quality of the pallets in the exchange and the additional flows of empty pallets were not taken into account in the examined scenarios. As individual actors can transfer costs to other actors, in case of an unfair exchange (Chen et al., 2019a; Elbert and Lehner, 2019), the platform needs to have corresponding safeguards. An example of this is the submission of ratings for the exchange behavior, combined with sanctions.

6 Study 3: Trust-Building Effects of Blockchain Features[6]

Alongside the hype regarding the cryptocurrency Bitcoin, the underlying blockchain technology is growing in popularity as well. The potential of this technology has been acknowledged by academic researchers and practitioners alike. Although research on blockchain technology has increased tremendously in recent years, scholars paid only a little attention to the crucial topic of trust in blockchain technology. To investigate trust in blockchain technology, previous research has predominantly used qualitative or design-oriented research approaches. Yet, empirical investigations of individual blockchain features have received only minimal attention so far. To fill this research gap, we conducted a scenario-based experimental study with 455 participants. We analyzed the trust-building effect of three technological features (immutability and traceability of information as well as an anonymous use of the technology) which can be found in current blockchain implementations. Our results show that immutability and traceability positively and anonymity negatively influence trust in technology. Moreover, anonymity moderates the effect of immutability, showing that in highly anonymous blockchains, the immutability of information is more relevant. By revealing the interplay between blockchain features and trust in technology, we broaden the discussion concerning the impact of trust in blockchain technology and open various new avenues for future research.

6.1 Introduction

Blockchain technology first attracted attention in 2008, when Bitcoin, a decentralized digital payment system, was introduced as peer-to-peer cryptocurrency (Yin et al., 2019). Thanks to Bitcoin, the blockchain technology has attracted much attention in both mainstream media and industry over the past ten years (Avital et al., 2016), particularly in the financial sector (Nærland et al., 2017). The considerable interest of the financial sector is due, among others, to the enormous price increases and the incomparable market capitalisation of Bitcoin. According to Yin et al. (2019), for example, Bitcoin's market capitalisation in 2018 was approximately more than 100 billion USD. But, more importantly, the rapid growth of Bitcoin led also to the rise of an ecosystem of innovative ideas and services that stretches far beyond the financial sector (Tapscott and Tapscott, 2018). For instance, scholars state that blockchain technology has the potential to shake up supply chains or to prevent fraudulent tax returns (Du et al., 2019; Durach et al., 2021; Hyvärinen et al., 2017). Meanwhile, prototypical applications are increasingly

[6] The content of this study is similar with only slight modifications to the paper Wallbach, S.; Lehner, R.; Röthke, K.; Elbert, R.; Benlian, A. (2020): "Trust-Building Effects of Blockchain Features – An Empirical Analysis of Immutability, Traceability and Anonymity.", in: European Conference on Information Systems (ECIS). Thus, in section the pronoun "we" refers to the authors of the paper.

being found in these areas as well. In the transportation sector, for instance, Maersk and IBM have developed the blockchain-based platform "TradeLense" to reduce bureaucracy within this sector, improve supply chain visibility and eliminate inefficiencies through paper-based processes (Scott, 2018).

According to Beck et al. (2017, p. 381), a blockchain is "a distributed ledger technology in the form of a distributed transactional database, secured by cryptography, and governed by a consensus mechanism". In comparison to traditional centralized database architecture, the blockchain technology offers unique features such as immutability of transactions, traceability of all entries and anonymity of actors (Hughes et al., 2019; Wickboldt and Kliewer, 2019). These features contribute to the fact that the blockchain is often regarded as a trust-free technology (Beck et al., 2016). However, other views argue, for example, that instead of an emergence of an actual trust-free technology, a shift from an institution-based trust to trust in technology occurs (e.g., Lustig and Nardi, 2015).

Until today, theoretical issues such as adoption have been scrutinized to some extent (Abramova and Böhme, 2016). However, the significance of trust in the blockchain context is yet to be analyzed in-depth, either conceptually or empirically (Sadhya et al., 2018). For example, nascent research results are the two-sided trust framework model by Ostern (2018), which illustrates how factors foster or impede the formation of trust in blockchains or the work of Beck et al. (2016), which shows how a trust-based centralized system can be replaced by distributed and trust-free transaction systems. Previous work, however, does not address the influence on trust that emanates from three main features of blockchain technology, i.e., immutability, traceability and anonymity. In an interview-based study, Sas and Khairuddin (2017) were able to gain first insights and revealed that these features are related to trust in blockchain technology. However, scholars were not yet able to provide empirical evidence for this critical relationship. The empirical investigation of these features is essential since they are unique facets of the blockchain technology and occur in this specific constellation exclusively in blockchain technology. Unfortunately, previous results from traditional centralized database architecture cannot be transferred to blockchain research. One reason for this is that conventional systems with centralized storage of data do not possess the unique trust-related features (i.e., immutability, traceability and anonymity) of blockchain technology. Various calls for research underline the importance of empirical investigation of the influence of these blockchain features on trust. Rossi et al. (2019b), for instance, calls for a more granular, theory-driven and empirically investigation of the relationship between trust and blockchain. Despite these calls for research, neither direct nor moderating influences of these blockchain features on trust in technology have been empirically investigated so far. This research gap leads to our research questions:

RQ 3.1: What is the impact of the blockchain technology features immutability, traceability and anonymity on trust in technology?

RQ 3.2: How does anonymity interact with immutability and traceability?

To answer these research questions, we develop five hypotheses, which were tested in a scenario-based online experiment with 455 participants. For the operationalization of our features, we were guided by existing blockchain applications and ensured that these features are perceived similarly by our participants. In doing so, we were able to demonstrate that the blockchain features immutability and traceability have a positive impact on trust in technology. In contrast, an anonymous usage of technology decreases trust in technology. However, even more, noteworthy is that by investigating the interactive effects of these blockchain features, we unveiled that immutability interacts with anonymity: If individuals perceive that they are more identifiable, the feature immutability seems to be less relevant. In contrast, we found no empirical evidence for an interactive effect between anonymity and traceability.

By doing so, we contribute to existing research in several important ways: Firstly, our study is one of the first empirical studies which investigates the isolated as well as the combined effect of specific features of blockchain technology. In particular, we heed calls for research from Rossi et al. (2019b) and Beck et al. (2017) and extend the scarce literature on blockchain research by providing empirical evidence that specific blockchain features, namely immutability, traceability and anonymity affect trust in technology. Secondly, in contrast to previous design science approaches used in research, we have decomposed the blockchain features and demonstrated their separate and moderating effect on trust in technology. The revealed interactive effect between these features (i.e., anonymity and immutability), indicates a substituting effect between primarily technological and social mechanisms mediated through technology regarding their impact on trust in technology. This insight contributes to a more nuanced and fine-grained understanding of trust-building in technologies in general and in the context of blockchains in particular. Our results provide vast opportunities for further research on blockchain protocols, as they can specifically strengthen features that increase trust in the technology. Thirdly, our results highlight the importance of considering the distinct features of technology regarding their effect on trust in that technology and thus provide insights on how other industries (e.g., supply chain management) can leverage these features to build trust in further industry-specific technologies.

The remainder of this paper is structured as follows. In the next section, we present the theoretical background with regards to users' perception of blockchain features and trust in technology. Afterwards, we develop our hypotheses, followed by a description of our research methodology. Subsequently, we present our results. Finally, we discuss the results, draw theoretical and practical implications and present avenues for future research.

6.2 Theoretical Foundation

6.2.1 Trust-Building Features of Blockchain Technology

A blockchain is a distributed peer to peer ledger, which contains an ordered set of connected and replicated data blocks (Risius and Spohrer, 2017). Thanks to the technological design, a blockchain exhibits unique key features, such as immutability of transactions, traceability of all entries and anonymity of the actors (Ølnes et al., 2017). Each data blocks in a blockchain contain multiple transactions, a timestamp, the hash value of the previous block ("parent"), and a nonce, which is a random number for verifying the hash (Nofer et al., 2017). Hash values are unique, and fraud can be effectively prevented since changes of a block in the chain would immediately change the respective hash value (Nofer et al., 2017).

Moreover, new blocks can only be added at the end of the existing chain, if the majority of nodes in the network agree on both, the validity of transactions in a block and the validity of the block itself (Notheisen et al., 2017b). Thus, the integrity of the entire chain up to the first block (genesis block) is facilitated by hash value verification (Nofer et al., 2017). Therefore, once a block of data has been validated by the consensus mechanism and appended to the end of the blockchain, the containing transactions are nearly unchangeable.

However, there is no single specific form of blockchain technology. The technology exists in many different types, with various properties. The main variants are either private or public closed blockchains (called private/public permissioned blockchain) versus private or public open blockchains (called permissionless blockchain) (Ølnes et al., 2017; Mainelli and Smith, 2015). Whether a ledger is public or private determines who has access to copies of the ledger, whereas the attribute of permissioned versus permissionless determines who maintains the ledger. Permissioned blockchains are controlled only by the owners, and they exclusively have the authority to provide access and assign new nodes to the blockchain architecture (Rossi et al., 2019a). It is important to note that these characteristics directly affect the perceived anonymity of users. In particular, when users are required to register and authenticate themselves to the owner of the blockchain (e.g., through a registration process in which the user's data is validated against their identity card), these users are very likely to assume that their actions can be traced back to them and that they cannot act anonymously when using the system. In contrast, when no identification is required, users probably presume that they remain anonymously while using technology.

In practice, the degree of anonymity varies when using blockchain systems. On the one hand, there are systems where users can act completely anonymously, e.g., payment systems such as ZCash or Monero (Rossi et al., 2019a; Siegfried et al., 2020). Besides, there are also systems such as the well-known payment system Bitcoin allowing users to act pseudo-anonymously (Sas and Khairuddin, 2017). Pseudo-anonymity means that user's numeric wallet address is publicly available, but the owner's information is not available (Scott and Orlikowski, 2014). On the other hand, there are also systems where the identity of the user is verified during registration, and therefore users are completely identifiable, e.g., applications for digital storage of patients' health records (McGhin et al., 2019; Roehrs et al., 2017).

The different designs of the technological properties affect not only the user's degree of anonymity but as well the degree of immutability and traceability of information from the user's perspective. The immutability of the transactions is visualized to the user in several ways. Firstly, for example, in Bitcoin transactions, users receive a post-purchase confirmation when the transaction is confirmed, and the block is successfully added to the chain. This status switches from unconfirmed to confirmed and is also visible to the user through various blockchain explorers (e.g., blockchain.com). In detail, the status unconfirmed indicates that the transaction has not yet been confirmed by the consensus mechanism meaning that no new block has been added at the end of the chain. In this case, the transaction can be replaced, for example, by using "replace by fee" or "double spending" (Risius and Spohrer, 2017; Pérez-Solà et al., 2019).

In contrast, if the status is confirmed, the transaction and the block have been confirmed by the consensus mechanism and added at the end of the chain. Thus, this visualization provides a signal to the user that the data is nearly immutable stored in the blockchain. Secondly, in case of subsequent modification of the transaction data, the hash value of the block changes immediately, which is visible to the user (Nofer et al., 2017). This protection against subsequent modifications of information (i.e., immutability) is strengthened by the consensus mechanism as well as by the distribution of data storage.

The traceability of transaction data is supported by the included time stamps and the hash-link to the previous "parent" block. However, the possibility for users to perceive traceability is influenced by the chosen type of implementation (e.g., private vs public). For example, in public blockchains, users can view the transaction data of each transaction (in the case of Bitcoin, for example, the sender, the recipient and the amount) by using blockchain explorer software. Also, based on a single transaction, users can identify the corresponding block and trace back all previous transactions (including transaction data) up to the genesis block (Nofer et al., 2017). In contrast, in private or permissioned blockchains users' perception of the traceability feature is limited or even not possible at all.

6.2.2 Trust in Blockchain Technology

Trust is widely defined as “the willingness of a party to be vulnerable to the actions of another based on the expectation that the other party will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party“ (Mayer et al., 1995, p. 712). By investigating trust between individuals and technology, IS researches have applied this general notion of trust relationships to the technological domain (e.g., McKnight et al., 2002). In the course of this investigation, trust in technology has been identified as a crucial factor influencing the adoption of several technologies, which has been studied extensively (e.g., Benbasat and Wang, 2005; McKnight et al., 2002).

Trust in technology is primarily built similarly to trust in people (McKnight, 2005). Both, a person as well as a technology, have the quality of competence in terms of what they can do. The perception of the quality of competence of another person or technology can be described as trusting belief (McKnight, 2005). In detail, trusting belief in a person’s competence means that the person is perceived as capable of performing a task or assuming responsibility. For the conceptualization of trust in technology, IS researcher distinguishes between two streams (e.g., Lankton et al., 2015; Ostern, 2018). In the first stream, trust in technology is perceived as human-like, and computers are seen as social actors (Nass and Moon, 2000). The measures use attributes that are also used for the evaluation of trust between individuals – typically the trusting belief dimensions integrity, competence, and benevolence (Li et al., 2008; Vance et al., 2008). Integrity is the trustor’s perception that the trustee adheres to a set of principles that the trustor finds acceptable (Mayer et al., 1995). Competence is understood as the set of skills, competencies and characteristics that enable a party to influence within a specific domain (Mayer et al., 1995). Benevolence means that the trustee is caring and acts in the interest of the trustor (Li et al., 2006). These measures are mainly used when the addressed technology has anthropomorphic properties or interactive functions, such as online recommendation systems with human characteristics or social media websites (Benbasat and Wang, 2005; Benlian et al., 2019; Lankton and McKnight, 2011).

In the second stream, trust in technology is conceptualized as machine-like trust and measured with modified attributes. In this context, McKnight et al. (2011) developed the measures reliability, functionality and helpfulness. These measures are derived from the trusting belief dimensions integrity, competence and benevolence. They are transferred into the technological environment by mapping these three dimensions to the modified dimensions of reliability, functionality and helpfulness (Lankton and McKnight, 2011). According to McKnight (2005), reliability corresponds to integrity and is characterized by error-free and proper service of technology. Functionality (corresponding to competence) describes the perception of the technology to have the necessary functionality to perform a task that the trustor wants to be done (McKnight, 2005). Helpfulness (corresponding to benevolence) is used to evaluate adequate help provided by the technology or the system (McKnight et al., 2011). The measures of this stream are appropriate when the technology has merely technical features, such as in the case of knowledge management systems (Thatcher et al., 2011). However, depending on the subject under investigation, it must be examined which approach is appropriate. In the case of blockchain, Ostern (2018) recommends using elements of both streams to measure trust in technology, as the technology allows interactive functions between individuals which are mediated through the blockchain technology. In detail, Bitcoin transactions, for example, are based strictly on technical features such as immutability or traceability of information, but also include components of human interaction. To capture both, machine-like and human-like trust in technology, IS researcher combined trusting belief dimension of both domains, mainly when the technology provides human and technological characteristics (e.g., Lankton et al., 2015; Lankton and McKnight, 2008; Lee and Turban, 2001). By doing so, Lee and Turban (2001), for instance, have captured the trust dimension competence in the human-like domain alongside reliability in the machine-like domain. With this approach, they measure both, trust in the seller mediated by the technology (i.e. the e-commerce website) and trust in the technology itself. Both, the interaction with the blockchain technology as well as trading in e-commerce represents an interaction between humans, which is mediated by technology. Thus, the established procedures can be adapted to this new context.

Although scholars attest the blockchain technology an enormous potential (e.g., Beck et al., 2018; Ølnes et al., 2017; Zachariadis et al., 2019), research on blockchain and especially on trust in blockchain is still in its infancy. Until today, the AIS Senior Scholars' Basket contains only a few publications investigating blockchain technology. Moreover, these publications date back only a couple of years and are thematically broadly diversified. In more detail, Mai et al. (2018) for example, focused on the impact of social media on the Bitcoin stock value and Ingram Bogusz and Morisse (2018) have investigated the conflict arising from the commercialization of open source technologies in the example of blockchain technology. Furthermore, Du et al. (2019) conducted a case study about a successful blockchain implementation and Beck et al. (2018) as well as Yin et al. (2019), for instance, developed a research agenda for future directions of blockchain research. None of the publications we identified from the basket examined a direct relationship between the features of blockchain technology and trust in technology. However, the high relevance of investigating this relationship for the IS research community is evident from several calls for research contained in these publications (e.g., Beck et al., 2018; Mai et al., 2018; Rossi et al., 2019b). Besides this, leading IS conferences (e.g., European Conference on Information Systems or International Conference on Information Systems) have dealt with this topic for some time. Thematically many publications are practically motivated and investigate challenges associated with conceivable use cases, improvements of the implementation of blockchain protocols, smart contracts, as well as of security, privacy and usability of blockchain applications (e.g., Beck et al., 2016; Egelund-Müller et al., 2017; Notheisen et al., 2017a; Risius and Spohrer, 2017). Furthermore, several publications consider financial issues such as Bitcoins (e.g., Abramova and Böhme, 2016), Initial Coin Offerings (e.g., Chanson et al., 2018) or challenges for governance and organizations arising from that technology (e.g., Seebacher and Schüritz, 2019).

In addition to the topics above, trust in blockchain technology is recently getting increased attention at these conferences. Jahanbin et al. (2019), for instance, investigated the individual trust requirements and priorities of supply chain participants using blockchain technology. Moreover, Beck et al. (2016), illustrate how a trust-based centralized system can be replaced by a distributed and trust-free transaction system. Methodically, many projects in blockchain research pursued a design science approach and developed extensive prototypes (e.g., Jahanbin et al., 2019). In these design-oriented studies, requirements for the application were defined during the development phase, but individual technological features of the blockchain technology were not experimentally varied and evaluated. Moreover, other projects have pursued qualitative approaches and discussed, for example, the influence of trust in blockchain on blockchain adoption (e.g., Sadhya and Sadhya, 2018; Sas and Khairuddin, 2015). An experimental and empirical investigation of the influences of specific blockchain features on trust in technology has, to the best of our knowledge, been overlooked so far in previous research.

6.3 Hypotheses Development

According to McKnight (2005), individuals trusting beliefs in another person will be increased if they consider the characteristics of the other person as beneficial for the performance of a task. Transferred to a technology, favourable characteristics of technology (for the performance of the task) will influence trusting beliefs in this technology. Such a beneficial characteristic of technology is the preservation of data integrity resulting from the technological design (Nicolaou and McKnight, 2006). A facet of data integrity is the prevention of unauthorized changes in information (Birgisson et al., 2010). The characteristics of blockchain technology prevent a subsequent change of data due to the design of the technology. In previous IS literature, data integrity is integrated into the concept of information quality. The positive relationship between trust in technology and (perceived) information quality has already been demonstrated, for example, in the case of supply chain information systems (e.g., Nicolaou and McKnight, 2006). Traditional supply chain information systems serve, among other things, for the exchange of information (McKnight et al., 2017; Nicolaou et al., 2013). Unlike blockchain technology, these systems cannot guarantee comprehensive protection against subsequent or malicious alteration of information based on their technological basis.

Nevertheless, these traditional information exchange systems are able to provide a certain degree of information quality that is sufficient to build trust in the technology. The blockchain technology prevents a subsequent or malicious manipulation of information due to the technological design. Therefore, we assume that if users perceive that the technology does not allow information to be changed afterwards, this will further increase trust in the technology. This leads to our first hypothesis:

H1: The stronger users perceive that blockchain technology enables immutability of information, the higher is their trust in that technology.

Traceability refers to the ability to track the history of entities (Aiello et al., 2015; Moe, 1998; Olsen and Borit, 2013). Entities can be physical goods such as food (Gellynck and Verbeke, 2001) or high-value products such as diamonds (Maurer, 2017) or pharmaceuticals (Rotunno et al., 2014). Nevertheless, entities can also be non-physical objects such as processes (Olsen and Borit, 2013), transactions of cryptocurrencies (Vasek et al., 2014) or information changes (Khattak et al., 2008). Usually, traceability is managed by traceability systems (Moe, 1998; Olsen and Borit, 2013). These systems have already been extensively investigated in IS research with a focus on reducing user uncertainty (e.g., Chen and Huang, 2013; Choe et al., 2009). In particular, the results of Liang et al. (2005) indicate that reducing perceived uncertainty is a way to build trust. Moreover, according to Chang and Chen (2008) and Pavlou (2003), low behavioural or environmental uncertainty leads to higher trust. Taken together, since traceability has been demonstrated to reduce uncertainty and reduced uncertainty leads to higher trust, traceability should lead to higher trust. Due to its technological properties, the blockchain is considered as a suitable technology for traceability systems (e.g., Hald and Kinra, 2019; Helo and Hao, 2019; Lacity, 2018). Scholars point out that the blockchain technology should generate trust due to the traceability of all transactions (Abeyratne and Monfared, 2016; Wickboldt and Kliewer, 2019). However, these statements have not yet been empirically investigated. Based on these reasonings, we hypothesize:

H2: The stronger users perceive that blockchain technology enables traceability of information, the higher is their trust in that technology.

Public blockchains, such as Bitcoin's, enables an almost anonymous use of technology. On the one hand, anonymous use of technology offers advantages, such as privacy protection by protecting confidential information from untrusted platforms and parties (Brazier et al., 2004). On the other hand, anonymous use of technology also enables malicious or criminal actions. In the case of Bitcoin, recently, various alarming or criminal actions have been reported. For example, Bitcoin was used for transaction processing on the website Silk Road, a website that facilitates the sale of illicit drugs (Martin, 2014). Some other publications report that Bitcoin has been used for terror financing, thefts, scams, and ransomware (Foley et al., 2018; Hyvärinen et al., 2017; Martin, 2014).

Crime, made possible by the anonymous use of technology, is not only an issue for law enforcement authorities but also prompts users to perceive the technology as less trustworthy (Yin et al., 2019). Furthermore, in the context of social media, for example, anonymity is often misused to create an environment for hate speech and defamatory remarks from people who behave with impunity and irresponsibility (Scott and Orlikowski, 2014). Davenport (2002) reports that anonymous communications on the Internet in forms of criminal and anti-social behaviour causes loss of trust and annual damages in billions of USD. In contrast, Mesch (2012) was able to show that online trust increases when personally identifiable information is disclosed. In addition, Sas and Khairuddin (2017) point out that the regulated online exchange is the preferred form of transaction, as the regulation promotes users' trust. They point out that Bitcoin users prefer transactions with identifiable authorized traders which implies that identifiability constitutes a critical factor in establishing credibility and trust.

These results are in line with the accountability theory. According to Vance et al. (2015, p. 350), the "theory explains how the perceived need to justify one's behaviours to another party causes one to consider and feel accountable for the process by which decisions and judgments have been reached". Furthermore, Fandt and Ferris (1990) point out that the accountability theory also explains how to increase prosocial behaviours, which, for example, facilitate trust (Ammeter et al., 2004; Tetlock, 1985). A core requirement of the accountability theory is the identifiability of persons (Vance et al., 2015). When people are identifiable, they feel the need to consider the possible outcome in a decision-making process. This need increases the likelihood that a person will think deeply and systematically about his or her procedural behaviours to consider his or her actions (Vance et al., 2013). This is an explanation that if individuals are identifiable, they are less prone to criminal activity or deviant behaviour. However, this also means that if persons are not identifiable, these mechanisms are not available and thus, the likelihood of inappropriate actions or socially undesirable and deviant behaviour increases. Based on these reasons, we assume that if a technology does not allow the identification of individuals, the likelihood of inappropriate actions increases and therefore, the technology will be considered as less trustworthy. Thus, we hypothesize:

H3: The stronger users perceive that blockchain technology allows them to remain anonymous during use, the lower is their trust in that technology.

Furthermore, we assume that if technology allows an almost anonymous use, technical characteristics of this technology gain in importance. Therefore, we assume an interaction between an anonymous use of technology and the protection against information alteration by the technology. Vance et al. (2013) demonstrated that an increasing degree of identifiability reduces the violation of IS access policies by users. Identifiability causes that an individual knows that his or her actions can be traced back to him or her (Vance et al., 2013). Thus, an individual knows that he or she can be made responsible for those actions (Lerner and Tetlock, 1999). When individuals perform identifiable behaviours, it is more likely that they will only perform behaviours for which they are willing to assume responsibility (Vance et al., 2013). Transferred to alterations of information, this means that if individuals are identifiable, they will not subsequently change any information unauthorized, as they could be held responsible for this access violating behaviour. Thus, when technology requires identification, the likelihood of individuals altering information without authorization is lower, resulting in a loss of relevance of protection against subsequent alterations of information. In contrast, if the technology allows anonymous use, users' relevance of protection against subsequent alterations of information increases which influence its effect on trust in the technology.

H4: The stronger users perceive that blockchain technology allows them to remain anonymous during use, the higher is the trust-building effect of immutability.

Finally, we also assume an interaction effect between anonymous technology use and the traceability of information. When technology allows users to remain anonymous, the potential risk increases that these or other users will make unauthorized changes to information. This also implies that the probability of incorrect information being contained in the application increases. To track possible errors in the information, individuals are dependent on detailed and traceable information (Choe et al., 2009). Since the probability of changed information is higher in the case of anonymous technology use, the relevance of traceability of information increases. This leads to our last hypothesis:

H5: The stronger users perceive that blockchain technology allows them to remain anonymous during use, the higher is the trust-building effect of traceability.

To generate a clear picture of our postulated effects, we summarize our hypothesis in Figure 38.

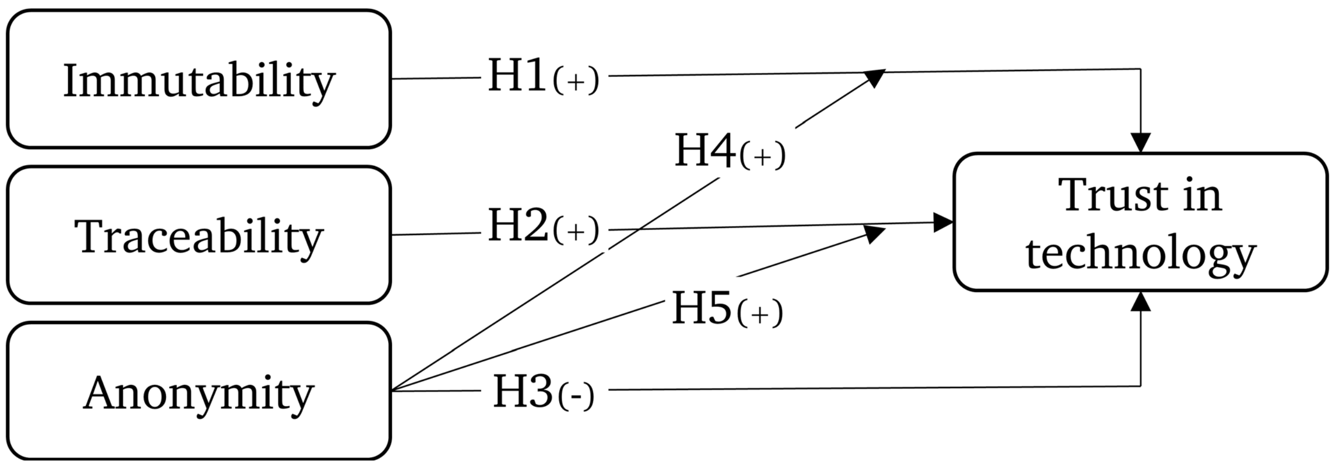

Figure 38: Research model.

6.4 Research Methodology

6.4.1 Experimental Design and Treatments

Following previous scenario-based experimental research (e.g., Klumpe et al., 2022; Schneider et al., 2020), we performed a 2 (immutability: absent vs present) x 2 (traceability: absent vs present) x 2 (anonymity: absent vs present) full factorial, scenario-based experiment to investigate the effects of blockchain features. The design results in eight different groups. We randomly assigned our participants to one of these eight groups. We chose the management of language certificate as suitable scenario because it constitutes an uncomplicated and comprehensible use case, which fulfils the requirements for a suitable blockchain use case - decentralized environments and limited trust (Lindman et al., 2017; Ølnes et al., 2017). Since the term blockchain is strongly hyped as "trust machine" (Betzwieser et al., 2019), we deliberately did not mention the term in our experiment. In doing so, we avoided that the term blockchain causes signalling effects similar to security certificates on websites (e.g., Wells et al., 2011).

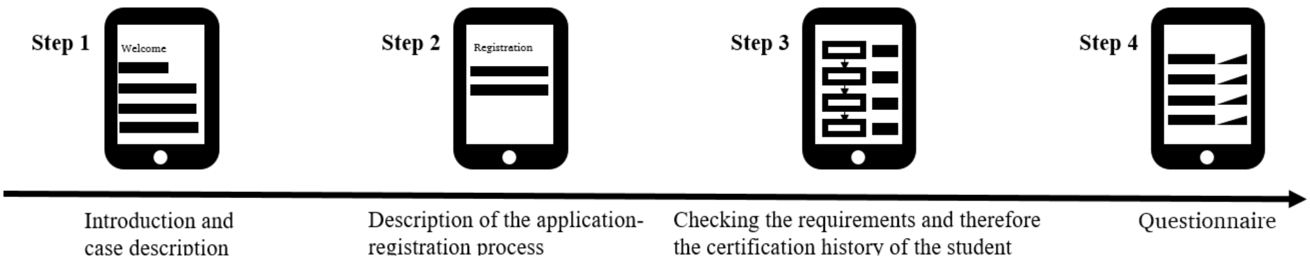

Figure 39: Experimental sequence.

Similar to previous experimental procedures (Adam et al., 2021; Koch and Benlian, 2017; Roethke et al., 2020), our study was carried out in multiple consecutive steps (Figure 39). First, in the introduction, we described our scenario. We asked our participants to put themselves in the shoes of an English teacher. Their job was to check whether an unknown student named Tom meets the requirements to participate in the language course “English level 4”. To fulfil this task, our participants had to register in the fictitious mobile application “MyLanguageCertification” and afterwards check the certificates with it. In step 2, we performed our first manipulation in which our participants had to register in the mobile application. For this purpose, we first showed our participants a typical registration page of a mobile application. Subsequently, depending on the assigned group, we informed our participants that either their registration information would be verified by a third party (i.e., by a Video-Ident-Provider) before using the app (anonymity absent), or that no verification of the registration information would take place (anonymity present). The two different processes serve for the operationalization of anonymity and representing a login to a private blockchain (a central authority decides about participation and knows the user) or to a public blockchain (everyone can participate anonymously). Afterwards, in step 3, we performed our next manipulations. Also depending on the initially assigned group, we presented our participants one of the four different representations of the app. We operationalized the immutability of information by displaying the student's certificates as not editable ("Certificate not editable") or editable ("Edit certificate") (compare Figure 40, screenshots 3 and 4). We have operationalized the traceability by showing the status "completed" or "unknown" in the student's certificates Level 1 and Level 2 (compare Figure 40, screenshots 1 and 2). Also, we again showed our participants their task next to the illustration. Their task was to verify that the student Tom has completed all previous language courses (Level 1 to 3). In step 4, the last step, our participants had to complete a survey.

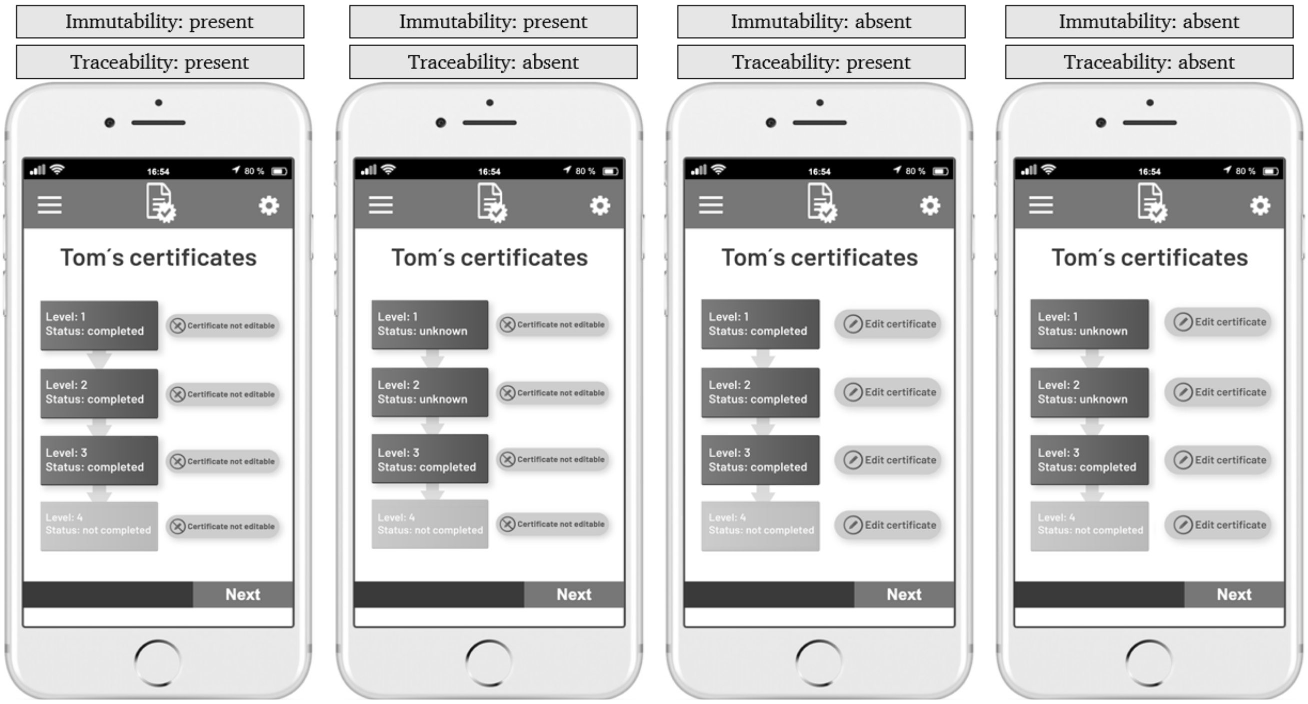

Figure 40: Certification screens for the different groups.

6.4.2 Manipulation Checks and Measurement Validation

The dependent variable, trust in technology, was measured by using reliability and competence constructs from Lankton et al. (2015). We did not consider the third dimension of human-like (benevolence) respectively machine-like (helpfulness) trust, as the application has no help function. However, the participants were supported by the instruction description in their tasks. Furthermore, the manipulations were tested by measuring perceived immutability (Flavián and Guinalíu, 2006), perceived traceability (self-developed) and perceived anonymity (Ayyagari et al., 2011) in different groups. To preserve the realism of the study, we have slightly adjusted our items (Table 13) and adapted them to the context of the study (e.g., replacing the original application name "Excel" with "MyLanguageCertification").

Table 13: Items used for the experiment.

Trusting Belief-Specific Technology—Reliability (Lankton et al. 2015)
MyLanguageCertification is a very reliable piece of software.
MyLanguageCertification is extremely dependable.
MyLanguageCertification does not malfunction for me.
Trusting Belief-Specific Technology—Competence (Lankton et al. 2015)
MyLanguageCertification is competent and effective in managing language certificates.
MyLanguageCertification performs its role of managing language certificates very well.
Overall, MyLanguageCertification is a capable and proficient service for managing language certificates.
Immutability (Flavián and Guinalíu 2006) "I think the app has sufficient technical capacity to ensure that the certificate details cannot be …"
… easily modified by the user (Tom).
… easily modified by any other user.
… easily modified by a third party (e.g., by another teacher, provider).
Traceability (Self-developed)
MyLanguageCertification offers a complete and seamless documentation of language certificates.
I can easily check Tom's complete and seamless certification level in the application.
I can easily verify Tom's entire certificate history.
Anonymity (Ayyagari 2011)
I can remain completely anonymous when using MyLanguageCertification.
I can use fictitious personal data (not my true personal data) when registering in MyLanguageCertification.
The personal data (e.g., name, driving licence number) provided by users when registering in MyLanguageCertification is consistent with their real personal data. (reverse)
We measured our Items by using 7-point Likert scales from strongly disagree (1) to strongly agree (7).

By evaluating our manipulation checks, we confirm that perceived anonymity was higher when our anonymity manipulation was present (M = 5.64; SD = 1.96) than when it was absent (M = 3.99; SD = 2.15; F(1,453) = 150.33; p < .001). Similarly, our manipulation check for immutability demonstrated that the perceived immutability was higher when the displayed certificate was immutable (M = 5.39; SD = 2.09) compared to when it was mutable (M = 3.57; SD = 3.17; F(1,453) = 143.77; p < .001). Further, we could validate that perceived traceability was higher when our traceability manipulation was present (M = 5.24; SD = 1.79) compared to when it was absent (M =4.48; SD = 2.34; F(1,453) = 32.62; p < .001). In addition to the measurements listed so far, we have included age, gender, job, education, institution-based trust (Vance et al., 2008), disposition to trust (Gefen and Straub, 2004) and product knowledge (Qiu and Benbasat, 2010) as control variables. For our constructs, the reliability was measured by using Cronbach's alpha, composite reliability (CR) and average variance extracted (AVE). The alphas of the constructs had a value above 0.7, which is a proper value. The CR of all constructs was above 0.5, which is also a satisfying value. The AVE met the requirements for a suitable level of reliability as well (Fornell and Larcker, 1981). To address common method bias, we followed the recommendations of Podsakoff et al. (2003): Firstly, we noted that participants should answer honestly and that there are no right and wrong answers. Secondly, we guaranteed anonymity for the evaluation. Thirdly, we used different answer formats.

6.5 Analysis and Results

6.5.1 Descriptive Statistics

We acquired our participants via the panel provider Prolific. Prolific participants received 0.99 euro as compensation for their effort. In contrast to Amazon M-Turk, Prolific offers services that explicitly targeted to researchers. Prolific participants know that they will be recruited to participate in the research. They are informed about the expected payments, treatments (e.g., exclusion due to faulty manipulation checks), rights and obligations in such an environment (Palan and Schitter, 2018). Furthermore, Prolific offers a comprehensive pre-filtering service, so that we were able to limit the group of possible participants to English native speakers from Great Britain.

To evaluate our research design, we conducted a pretest with 80 participants prior to the final experiment. The results revealed that participants considered our scenario as realistic, our manipulation checks, as well as participants' feedback, indicated that the treatment worked as we intended. Thus, we left our experimental design unchanged for the final experiment. In sum, 477 participants completed our study, and 455 participants were considered in the final analysis. We excluded 22 participants due to incomplete information or failed attention checks. The average age of our participants was 35.1 years, and 64 % were female, 34 % male and 2 % reported others. 44 % have a university degree as the highest education level, 16 % an A level and 40 % reported other educational qualifications. The distribution of the current job-activities showed that 71 % of all participants were employed or self-employed, 9 % were students and 20 % reported another activity. Moreover, our dependent and control variables show the following values: Trust in Technology (M = 4.83, SD = 1.69); Product Knowledge (M = 3.99, SD = 0.39); Disposition to Trust (M = 4.81, SD = 1.69); Institution-based Trust situational normality: Competence (M = 5.02, SD = 1.20), Benevolence (M = 4.64, SD = 1.56), Integrity (M = 4.67, SD = 1.49).

6.5.2 Main and Moderation Effects

To test our hypotheses, we conducted a two-stage hierarchical linear regression on our dependent variable trust in technology (see Table 14). We coded the manipulations immutability, traceability and anonymity as dummy variables (respective manipulation is present =1 / is absent = 0).

Table 14: Two stages hierarchical OLS regression on trust in technology.

	Stage 1		Stage 2	
	Coef.	SE.	Coef.	SE.
Intercept	-2.27***	.53	2.73***	.53
Manipulations				
Anonymity	-.53***	.11	-.79***	.16
Immutability	.23*	.11	.02	.15
Traceability	.56***	.11	.55***	.14
Immutability x Anonymity	-	-	.46*	.22
Traceability x Anonymity	-	-	.04	.22
Controls				
Product Knowledge	.10	.09	.10	.09
Disposition to Trust	.02	.04	.01	.04
Institution-based Trust Situational Normality				
- Competence	.15	.09	.16	.09
- Benevolence	.16	.09	.15	.09
- Integrity	.09	.08	.10	.08
Demographics				
Age	-.09	.05	-.08	.05
Gender (male)	-.06	.05	-.04	.11
Job	-.02	.03	-.03	.03
Education	-.05	.04	-.04	.03
Model Fit				
R^2		.266		.274
Adjusted R^2		.246		.250

Note: * p < .05; ** p < .01; *** p < .001; N = 455; Coef. = Coefficient; SE. = Standard Error

In stage 1, we entered all control variables as well as our independent variables anonymity, immutability and traceability. In stage 2, we added the interaction term of immutability and anonymity. R^2 and adjusted R^2 were computed to test the fit of both stages. By adding our manipulations into the measurement model, the share of explained variance increases from 15 % to 25 %. Regarding the controls, none of these variables had a significant effect on trust in technology.

The results of stage 1 demonstrate significant positive main effects of immutability ($b = .23$; t-statistic $= 2.1$; $p < .05$) and traceability ($b = .56$; t-statistic $= 5.2$; $p < .001$) on trust in technology and a significant negative main effect of anonymity ($b = -.52$; t-statistic $= -4.7$; $p < .001$) on trust in technology. Furthermore, supporting H1, in the condition where the displayed certificate was not editable and thus immutable, participants exhibited a higher level of trust in technology than when the certificate was mutable ($M = 4.98$ vs 4.64; $SD = 1.83$ vs 1.53; $F(1,453) = 7.86$; $p < 0.01$). Likewise, in treatments where the history of information was traceable, participants exhibited a higher level of trust in technology than when the history was not traceable, supporting H2 ($M = 5.11$ vs 4.53; $SD = 1.42$ vs 1.81; $F(1,453) = 23.76$; $p < 0.001$). Additionally, supporting H3, in the condition where the app could be used anonymously participants exhibited a lower level of trust in technology than in the condition with mandatory identification ($M = 4.49$ vs 5.09; $SD = 1.41$ vs 1.85; $F(1,453) = 25.09$; $p < 0.001$). Thus, all hypotheses (H1- H3) for the distinct effects of the blockchain features (i.e., immutability, traceability and anonymity) are supported empirically. The analysis in stage 2 unveils a significant two-way interaction of immutability and anonymity ($b = .46$; t-statistic $= 2.1$; $p < .05$) on trust in technology. In support of H4, the positive interaction term suggests that the effect of immutability on trust in technology is augmented when users perceive an anonymous usage of the technology.

As depicted in Figure 41, our results highlight that when users remain anonymous, users exhibited an increased trust in technology when the information was also immutable ($M = 4.75$; $SD = 1.60$). Yet, when the information was mutable the values were significantly lower ($M = 4.24$; $SD = 1.97$; $F(1,200) = 7.33$; $p < .001$). However, a significant difference in trust in technology between the treatments immutable and mutable does not emerge when app users perceive an identifiable use of the technology ($M = 5.13$ vs 5.04; $SD = 1.44$ vs 1.37; $F(1,251) = .31$; $p > .05$). Based on these results, we accept H4.

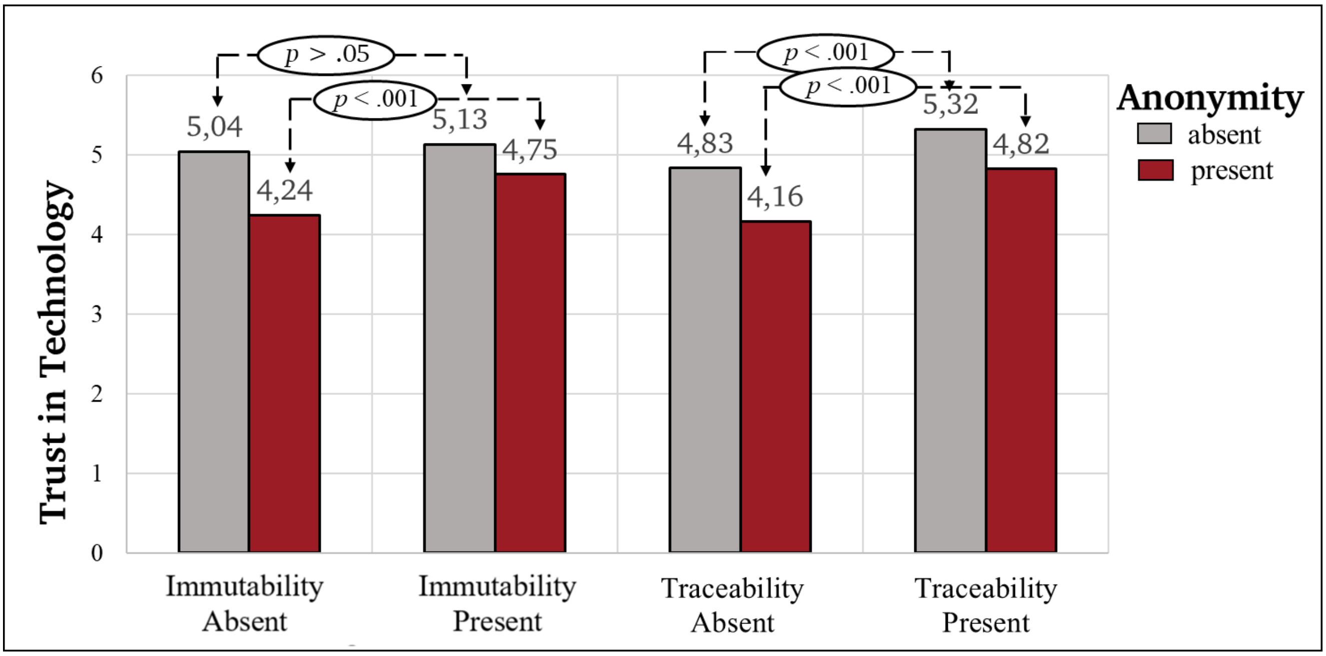

Figure 41: Contrast analysis for the different groups.

In contrast, our results do not indicate any significant interaction between traceability and anonymity (b = .04; t-statistic = .17; p > .1). As exhibited in Figure 4 too, when users remain anonymous, users exhibited an increased trust in technology when the information was also traceable (M = 4.82; SD = 1.55). However, when the information was not traceable the values were also significantly lower (M = 4.16; SD = 1.94; F(1,200) = 12.53; p < .001). Regarding H5, the difference in trust in technology between the treatments traceable and untraceable were significant, when app users were identifiable (M = 5.32 vs 4.83; SD = 1.22 vs 1.51; F(1,251)= 11.19; p < .001). Thus, we reject H5. Finally, we performed further robustness checks by replacing all treatment variables with the measured manipulation check constructs. The results yield the same signs for all regression coefficients, including the interaction effect.

6.6 Discussion, Implications and Future Research

This study aimed to examine and reveal how specific features of blockchain technology, namely immutability, traceability and anonymity affect users trust in technology. The features immutability and traceability can be seen as blockchain specific trust-building features, comparable to trust-building features such as third party certificates for websites (Kim and Benbasat, 2003) or restricted access rights for smart products (Michler et al., 2020). In contrast, a higher perceived degree of the anonymous use of blockchain technology impacts negatively trust in technology. Besides, we were able to demonstrate that anonymity interacts with immutability. If users perceive that technology allows anonymous usage, the immutability of information is more critical. In contrast, when technology requires an identification of the user, the importance of immutability of information will be less relevant. As a result, the trust-building effect of immutability is no longer supported by our analysis. However, our data showed no interaction between the traceability of information and the anonymous use of technology. This indicates that the trust-building influence of traceability exists independently of the perceived degree of the anonymous use of blockchain technology. Besides, it is notable that our model fit is rather low. However, considering the improvement between model 1 and 2, our models explain a significant portion of the total variance of our dependent variable trust in technology.

With our results, we contribute to research in several ways. Our study is one of the first empirical studies in blockchain research which investigate the effects of selected blockchain features in an isolated manner. We have built on previous results from qualitative research and have empirically demonstrated the impact of the blockchain features immutability, traceability and anonymity on trust in technology. Our results show that the designation of the blockchain technology as "trust-free-technology" is misleading and more specifically that these three blockchain features are capable to influence trust in technology. It is well known from various other IS research areas that trust in technology is an important factor influencing the success of IS or the adoption of IS (e.g., Lee and See, 2004; Moore and Benbasat, 1991). Our results indicate that the role of trust must also be considered in future blockchain studies.

In addition, we decomposed the blockchain features and empirically investigated their individual influence on trust in technology. Besides qualitative studies, previous research in the field of blockchain has often used design-oriented approaches. With this, individual blockchain features were not considered separately, but often the prototypical development as a whole. Our decomposed analysis of blockchain features allowed us to gain granular insights into the extent to which of the three features considered to promote or inhibit trust in technology. These findings are essential for further research on blockchain protocols, as they can specifically strengthen features that increase trust in technology.

Moreover, we were able to show that different blockchain features interact with each other and their trust-building influence changes. In particular, we revealed an interaction between an anonymous use of technology and the immutability of information. The moderating influence of anonymity is relevant for two reasons: Firstly, when users perceive that they are identifiable when using technology, moderation becomes evident, and the immutability of information loses importance. This means that the existing research on blockchains, especially those where users perceive that they do not act anonymously while using the technology, should be re-evaluated concerning this aspect and further research in this stream should take this moderating effect into account. Secondly, this effect shows an interplay between technological and social control. When users perceive that they remain anonymous in their use of technology, it seems that users tend to rely on technological measures, such as the immutability of information, to build trust. In contrast, if users perceive that they are identifiable when using technology, the immutability of information seems to be less relevant. Thus, during the use of technology, users seem to be subject to a kind of social control, which is also in line with the accountability theory.

Furthermore, our results stimulate additional research areas, such as supply chain management. Traceability of information or objects is a central function in supply chain management. We were able to demonstrate that traceability is an essential part of trust-building in technology. This knowledge can be applied by researchers in the area of supply chain management, and additional specific features can be investigated which promote or inhibit trust in technology in this area. Finally, we heed various calls for research in the field of blockchain research. This includes calls for research from various research agendas such as Rossi et al. (2019b) or Beck et al. (2018) as well as from publications such as Hughes et al. (2019) who claim that, for example, questions on the legality of transactions or trust in technology should be investigated.

In addition to the theoretical contributions, our study also offers significant contributions to practitioners. Our results indicate that our considered blockchain features can influence users' trust in technology. Therefore, practitioners should ensure that users perceive features such as traceability or immutability of information, even if this is not necessary for the technical function of the application. Furthermore, we have shown that anonymity reduces trust in technology. Since the specific implementation of the technology can influence the degree of anonymity, practitioners should consider this aspect when choosing which type of blockchain to implement.

Our study offers broad avenues for further research but is also subject to some limitations. First of all, our study is a scenario-based experiment in which the manipulations were carried out using a textual description and exemplary illustrations. Although the used method was appropriate for the context of our study and our postulated hypotheses could be demonstrated empirically, some limitations of the scenario method should be explained in more detail. In our study, we asked the participants to take the perspective of a fictitious person and to perform a task from this point of view. This procedure is often used in IS research (e.g., Lowry et al., 2013; Vance et al., 2013; Wallbach and Haag, 2018) but there may still be a difference between the real behaviour of the participants and the given behaviour in the role of the fictional person. During the study, we recorded an open feedback field in which many participants wrote that the study was very realistic. Based on these, we deem our scenarios and manipulations as realistic. However, we recommend validating the results in future, especially in the field or with a more heterogeneous and global distribution of the sample. Moreover, in our scenario, we have operationalized the technical features of blockchain technology via the user interface. This type of visualization is also found in various blockchain applications but is not always mandatory. Therefore, it should be noted that our results describe the effect of the perceived technical features on users trust in technology. Besides, we only investigated three blockchain-specific features in our study. Further research is needed to investigate to what extent additional blockchain features such as the distributed ledger property, consensus mechanism or open-source availability also influence trust in blockchain technology. Finally, depending on the specific implementation of blockchain technology, different levels of anonymity between the two extreme “anonymous” and “identifiable” will occur. Thus, the question arises, to which “degree of anonymity” the interaction effects between anonymity and immutability can be observed and whether linear or non-linear relationships can be expected. Furthermore, the question arises which of the above-mentioned blockchain features interact with anonymity or with other blockchain features, too.

7 Conclusion

The three studies in this thesis were able to answer the three research questions that were derived in section 1.3, regarding the potential of a conceptualized digital platform for pallet exchange and a suitable technological implementation. The first research question was:

RQ1: Is the developed platform concept with claim transfer for pallet management in an open exchange pool advantageous for the forwarders?

This question was examined in Study 1 and answered in 2 sub-questions:

> **RQ 1.1: How high are potential transport savings in RTI management for the freight forwarder when using a cross-actor pallet exchange platform?**

The results of the first simulation study show that the proposed concept of a pallet exchange platform with claim transfer can considerably improve the conditions for the forwarder, who can save more than 70 % of the additional routes that need to be driven for the RTI management.

> **RQ 1.2: What is the minimum participation rate of consignees for a freight forwarder in order to implement transport savings?**

Study 1 shows that savings of around 20 % can be achieved at the lowest considered participation rate of 10% (with a network size of 37 consignees and 5 shippers). With a higher number of participants, the savings increase further, but to a lesser extent.

Based on the answers of the two sub-questions, the superordinate question can also be answered: The designed pallet platform with claim transfer for the open pallet exchange is advantageous for the forwarder. In fact, the forwarder is able to reduce transports for the RTI management by using such a platform. This is economically advantageous for the forwarder, but also ecologically, since fewer emissions are caused. It is especially worth mentioning that high savings (approx. 20%) are possible, even with a small number of participants. This means that even smaller collaborations make sense. This can be especially advantageous during the start-up phase of such a platform. It is not necessary to reach a high number of participants to achieve significant improvements for the participating forwarders.

The second research question is related to the first research question. Here, the focus no longer lies on the forwarders alone, but also on all the shippers and consignees of palletized goods. The platform is extended and takes on the role of a central planning instance. The platform uses the information of the actors' account balances, as well as the information of the planned routes of the forwarders, to organize empty pallet flows between the platform participants in an open-pallet-pool context.

RQ 2: What effects does a collaboration platform with central planning instance have on the overall system of the open pallet pool?

The second research question is also answered by two sub-questions:

> **RQ 2.1: How high is the savings potential of a pallet exchange platform with "claim transfer", which acts as a central instance for planning the commodity flow of additional pallets that are distributed by the forwarder, compared to the current reference situation?**

The results of the second simulation study show that the platform has a great potential to significantly reduce trips for RTI management. The total trips for RTI management that are taken by all actors (companies and forwarders) can be significantly reduced by up to about 70%. Also, the debts in the total system can be reduced by almost 50 % using the considered platform. Under optimal conditions, the number of pallets in the overall system can also slightly be reduced (by up to 10%).

> **RQ2: How much does the number of platform participants and the number of additional transported pallets affect savings?**

Regarding the transportation distances that can be saved, there is a linear relationship between the participation rates. The number of empty pallets that are additionally distributed by the forwarders has hardly any effects on this. However, the number of pallets that are distributed has an influence on the number of pallets that are required in the overall system. If a higher number of pallets can be distributed between the actors, the required amount of pallets in the system is reduced. However, if only a small amount can be distributed, the number of pallets in the system may increase. Furthermore, starting from a participation rate of 30%, debt reductions in the overall system can still be measured.

Overall, the second simulation study also shows that a digital platform which acts as a central planning instance for pallet management in the open-pallet pool has a great potential. By increasing the collaboration of independent participants, substantial gains in efficiency can be achieved. Compared to the first study, in which only the savings of the forwarders were considered, the savings are not as high in the second study when the number of participants is small. However, even here, savings of more than 10% % are achieved for routes that need to be traveled when the number of participants exceeds 10%.

The third research question relates to the technical implementation of the platform using blockchain technology. The focus lies on the trust of the users in the platform generated by the blockchain, which should enable collaborations in an environment with unknown participants.

RQ 3: Can the use of blockchain technology build trust among users of a collaboration platform where anonymous participants interact with one another?

To answer RQ3, the two sub-questions are decomposed and operationalized:

> **RQ 1: What is the impact of the blockchain technology features immutability, traceability and anonymity on trust in technology?**

The results of study 3 show that immutably and traceability in an application increase trust in technology. Highly perceived anonymity, on the other hand, reduces trust in the application.

> **RQ 2: How does anonymity interact with immutability and traceability?**

While no interaction can be observed between anonymity and traceability, anonymity moderates the relationship between immutability and trust in technology. The stronger users perceive anonymity, the higher is the trust-building effect of immutability.

By answering the two sub-questions, the overarching RQ3 can be answered as well. Blockchain technology can increase user trust in the technology by implementing and visualizing the features immutability and traceability. Furthermore, it has been shown that the immutability of data is particularly relevant when users are in an anonymous environment. This is also valid for the actors of the designed platform. The special feature of the platform is that, through it, different actors are linked and have interactions with one another, who have previously not had a business relationship with one another and thus are unfamiliar with each other. Since anonymity has a negative influence on trust, an attempt should be made to ensure that the users are as easily identifiable as possible when the platform is implemented.

Implications

With the research work that was conducted, it was possible to quantify the potential for a specific use case, which is attributed in the scientific literature to cross-supply chain, or horizontal and vertical collaboration. For the use case at hand, it can be confirmed that such a collaboration can lead to substantial efficiency gains.

Furthermore, a contribution could be provided, in order to bring the system of open-pallet pools more into the focus of the scientific literature. It could be used as an example for the implementation of closed-loop supply chains with open circularity, according to the concept of CSCM. Additionally, using an open-pallet pool and exchange pallets also presents a possible alternative to the renting of pallets, the sale together with the goods, and the return to the owner.

Moreover, it was possible to contribute to the blockchain research by empirically demonstrating the influence that various key features of the blockchain have on trust in the technology, and also how these features interact with one another.

In addition to the implications for scientific research, this thesis has the potential to also contribute to common practice. This work proves that the designed platform concept has a high savings potential. Platform operators can use the presented mechanisms to enable more efficient pallet management for their users, and thus achieve further added value for them. Since savings are already being achieved with a small number of participants, consortiums of companies, for example, can also adopt the approaches and implement them in their communities.

For blockchain applications, the technological features such as immutability or traceability should be presented visually to users to increase trust in the application. This is recommended, regardless of whether this is technically relevant.

7.1 Limitations

The conducted studies are restricted by certain limitations. Firstly, the investigation of the potential of the designed collaboration platform is based on the general conditions that are prevailing in the open pallet pool in Germany. Therefore, the obtained results cannot be transferred to other countries without further consideration.

Furthermore, concerning the study on blockchain, the scenario designed for the test participants was kept generic. Although this enabled many participants to be recruited and for the questions to be answered in a general context, there was no longer any reference in the experiment to the topic of logistics or the designed pallet exchange platform.

Only key features of the blockchain were considered in terms of trust-generating or inhibiting factors. However, in addition to the presentation of blockchain features, there are other factors that can generate trust in such a platform. For instance, user ratings and reviews of transactions could be used. The operator of the platform could also generate trust if, for example, it is considered as an independent third party (e.g., EPAL).

Moreover, as an enabler for a collaboration platform, trust is placed in the spotlight as a factor. Even though trust has been proven to be a decisive factor for the adoption of technology in general and platforms in particular, other factors are important as well. Whether a platform succeeds or fails depends on the specific conditions and on more factors than trust.

7.2 Further research opportunities

The thesis offers starting points for further research. Further mechanisms for the platform could be considered, such as jointly arranged repair, recycling, or even the organization of new purchase processes.

Moreover, the quality of the pallets could also be taken into account. For example, pallets with poorer quality can be made more accessible to operators from industries that do not have high demands for pallet qualities, e.g. for construction materials. As a result, pallets can be allocated reasonably, and thus be kept in circulation for a longer amount of time before their disposal (or their recycling).

In the next step, a corresponding platform concept could be implemented and tested on a small scale. To achieve this, the technical implementation would have to be further substantiated, such as the question whether the pallet account balances should be stored on the blockchain, in order to use the immutability and traceability of the transactions.

With regard to the blockchain, further features can be empirically investigated. For this purpose, the distributed-ledger property or various consensus mechanisms could be considered.

All in all, this thesis could demonstrate the potential of a cross-supply chain collaboration platform for pallemet management. In the future, the platform concept that was developed and evaulated should be further explored to improve the processes for all actors in a pallets exchange system.

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