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Smart Objects and Smart Finance for Supply Chain Management

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Logistic transport processes are highly distributed and often subject to disturbances, as they are embedded in dynamic environments that prohibit tight control, as many third-party actors and influences exist. Classical approaches for planning and controlling supply chains based on centralized architectures often encounter their limits managing processes at runtime, due to inherent latencies. Decentralized approaches promise a more robust and timely control. The project SOFiA strives to elevate the machines and objects themselves to smart objects, equipped with an understanding of processes and capable of independent decision-making, rather than a centralized server-based system. This paper discusses the project's decentralized control architecture and the integration of semantic process models with event-discrete simulations as well as smart payment technology to provide an integrated solution for planning, controlling, monitoring and accounting of logistic processes.

[Keywords: Smart Objects; Smart Finance; Supply Chain Management; Digitalization]

1 Introduction

Production and logistic networks – so called supply chains – require a large number of planning and control decisions. These include mid-term sales, production, procurement and distribution planning as well as short-term planning, control and monitoring of production and transportation orders.

With increasing globalization more and more companies become involved in production and logistics processes. Logistical decisions, which had earlier been made by one company at one location, need to be coordinated with many individual and distributed parties (suppliers, logistics service providers, customers, etc.). Complex decision-making problems - due to the large number of alternatives - and narrow response windows for determining the best possible solution, require the application of IT systems. Nevertheless, todays IT systems are not well-suited to this task: Classical ERP (Enterprise Resource Planning) and PPS/PPC (Production Planning and Control) systems as well as software for transportation management (TMS), warehouse management (WMS) and also APS (Advanced Planning and Scheduling) software, which had been introduced in the mid-90s, rely on centralized information storage of the company's data and make their planning decisions by considering only the company's perspective [Hom13]. This limits the effectiveness and quality of decisions, since companies hoard information about their respective network parts. For example, the orders and order planning of other network parties are vital to making quality decisions, but are often not available to all participants.

2 Related Work

For these reasons, different approaches for the overlapping business planning and control of material and information flows have been developed. The prototypical implementation and application of these approaches in the automotive industry have been successful [LBM13], [MPH14]. The implementation of overlapping business approaches results in strong interdependencies between the supply chain partners: so-called focal company aggregate all information relevant to planning in a central platform and use them during the decision-making processes. Such supply chains consequently have a hierarchical structure, which does not necessarily reflect the distributed and decentralized nature of supply chains.

Current developments aim for closer cooperation between suppliers and customers in a network. One limitation of this approach is that the suppliers in a supply chain are usually also connected to other focal companies. Therefore, the former cannot provide comprehensive information on their production capacities to other focal companies [GH07]. Decentralized approaches help to overcome such limitations and are useful in supporting effective planning and control.

Under the keyword Industry 4.0 or Logistic 4.0 so-called Cyber Physical Systems (CPS) have been developed for the decentralized planning and control of production tasks in companies [GH07], [BHV14]. These CPS consist of "smart" objects that are connected with each other [HK15]. Amongst other features, every Smart Object has a Decentralized Control Unit (DCU) for data processing as well as components to communicate with other Smart Objects and, if needed, also with centralized IT systems (cf. Fig. 1).

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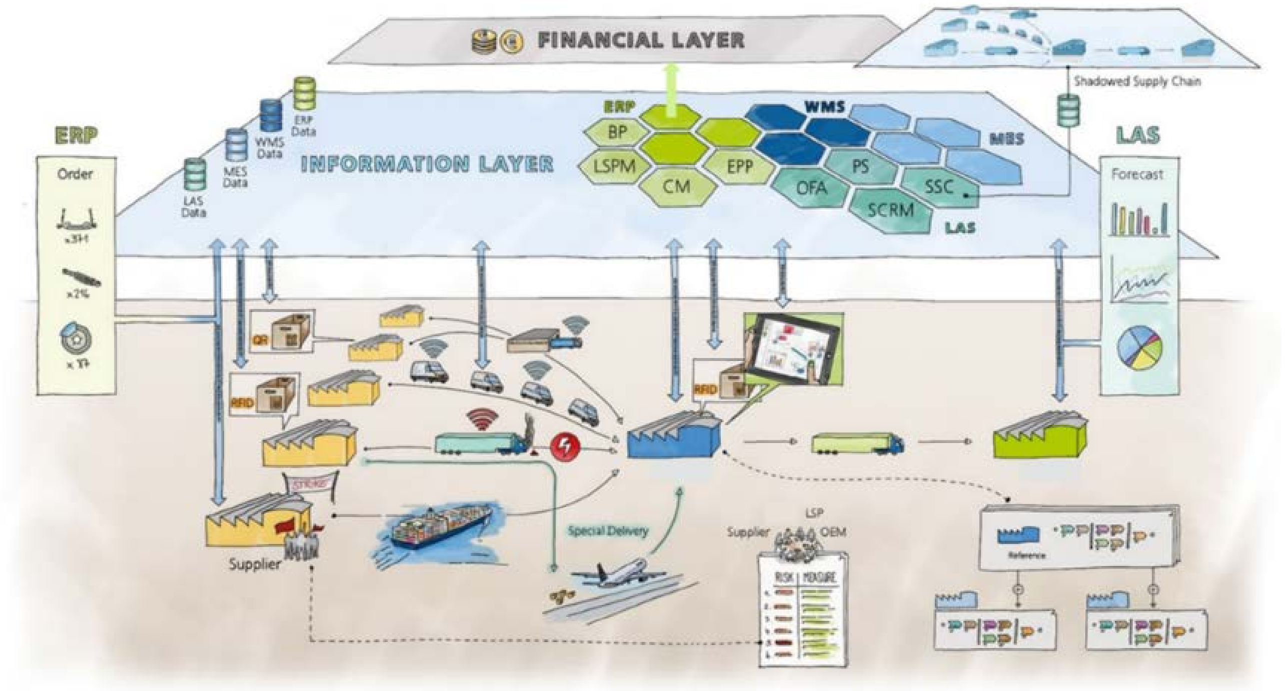

Figure 1.: *Supply Chain 4.0 – Network of Smart Objects and centralized IT systems of involved companies*

For example, containers can be turned into Smart Objects with the help of IT and communication systems. Each container in a supply chain can be equipped with a small, single-board computer (e.g. a Raspberry Pi) and modules for data communication via mobile radio networks and/or WLAN networks.

The following example of an intercontinental supply chain serves to illustrate the application of these Smart Objects. In this supply chain, the suppliers are located in Asia and ship products by container and sea freight to a recipient in Europe. The transport is intermodal: The parts that need to be delivered are transported in containers per truck to a port in Asia. From there a sea transport to a port in Europe takes place. After that, a train carries out the transport from the port to the plant of the receiver. Sometimes road congestion or construction works cause a container to miss the deadline at the port in Asia and missing the ship. The shortage of the transported material could then lead to a bottleneck and even production hold-up at the receiver. In order to eliminate such disturbances, dispatchers from the involved companies need to communicate tightly with each other and exchange data via globally distributed IT systems. A significant challenge is to detect delays early enough in order to take counteractions on time. A future scenario according to Supply Chain 4.0 could be as follows: The container "itself" detects that it will not reach the port on time, it "picks" a suitable transportation alternative and "chooses" a local carrier from a market place to conduct the transport. The container "pays upon collection" and reaches the destination punctually, while the financial transaction is being completed at the same time [HM14].

For such applications, respective Industry 4.0 based management approaches for self-management and self-organization of logistics and production as well as related tasks for payment processing and Supply Chain Finance solutions are developed and tested in the course of the ongoing project SOFiA (http://www.sofia-projekt.de). The project started in November 2015 and has an overall duration of three years. This paper presents an intermediary report on the selected use cases and our conceptual approach towards decentralizing the management of logistics chains.

3 Methodology

To develop strategies and methods for the decentralized management of logistic chains, we first needed to identify suitable use cases. To achieve our goal, we sought for supply chain use cases that greatly benefit from an Industry 4.0 approach towards logistics. The use cases had to allow for the incorporation of intelligent logistics objects, for example by equipping the transported goods (i.e. a container) or the transporting vehicles (i.e. a truck) with a control unit that combines process analysis and decision making capabilities. We solicited two use cases, one regarding classical supply chain management and one regarding the management of the harvesting logistics in an agricultural context (cf. Fig. 2). We identified the requirements of these use cases through expert interviews and the background knowledge of the respective project partners (EKOL Logistics & CLAAS). Both use cases will be described in the section below.

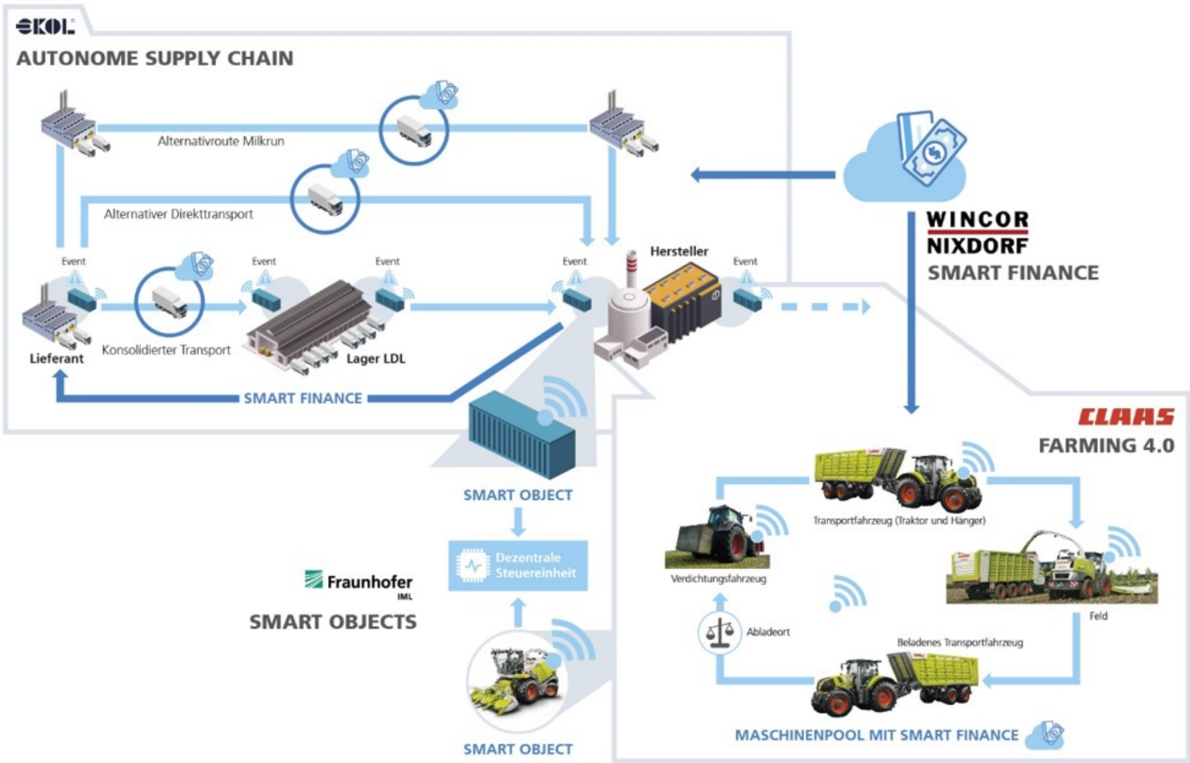

Figure 2.: *Supply Chain 4.0 and Farming 4.0 in the SOFiA project [Wit16]*

Next we derived a formal description of the underlying logistical model, that covers the requirements of the given use cases. Based on this model we created a conceptual description of a software architecture capable of decentralized decision-making. This architecture is currently under development and its system design will be discussed below.

We are currently recording sets of telemetry data from different transport vehicle fleets (e.g., during a harvesting campaign) to test our software architecture in realistic deployment scenarios.

4 Use Cases

4.1 Supply Chain Management

For the considered supply chain the companies can be divided into three roles (cf. Fig. 3):

- The shippers produce and distribute parts for the recipients. They coordinate their production planning with the part requirements of each recipient and its production capacity.
- The recipients are manufacturing companies, which produce finished products from the parts delivered from the shippers. The production planning on the recipient side results in the part demand for each supplier and the related transportation demand.
- Logistics service providers are responsible for the transport, handling and, if needed, storage of the parts that need to be transported. In the SOFiA project, the transport is carried out with curtain trailers, which are transported by truck, ship or train.

An important aspect of this application case is that all companies participating in the supply chain pursue their own objectives sometimes causing business conflicts concerning these objectives. For example, a short-term increase in the part demand of a recipient may require the corresponding shipper to provide buffer stocks or allocate additional production capacities. This normally results in higher costs. The solutions of these conflicts of objectives are usually achieved through contractual agreements (framework agreements). For decentralized planning and control, an important consequence can be derived from their framework agreements: The supply chain is a non-hierarchical decision-making framework in which the decisions to be made as well as the communication mechanisms between the involved parties need to be modeled.

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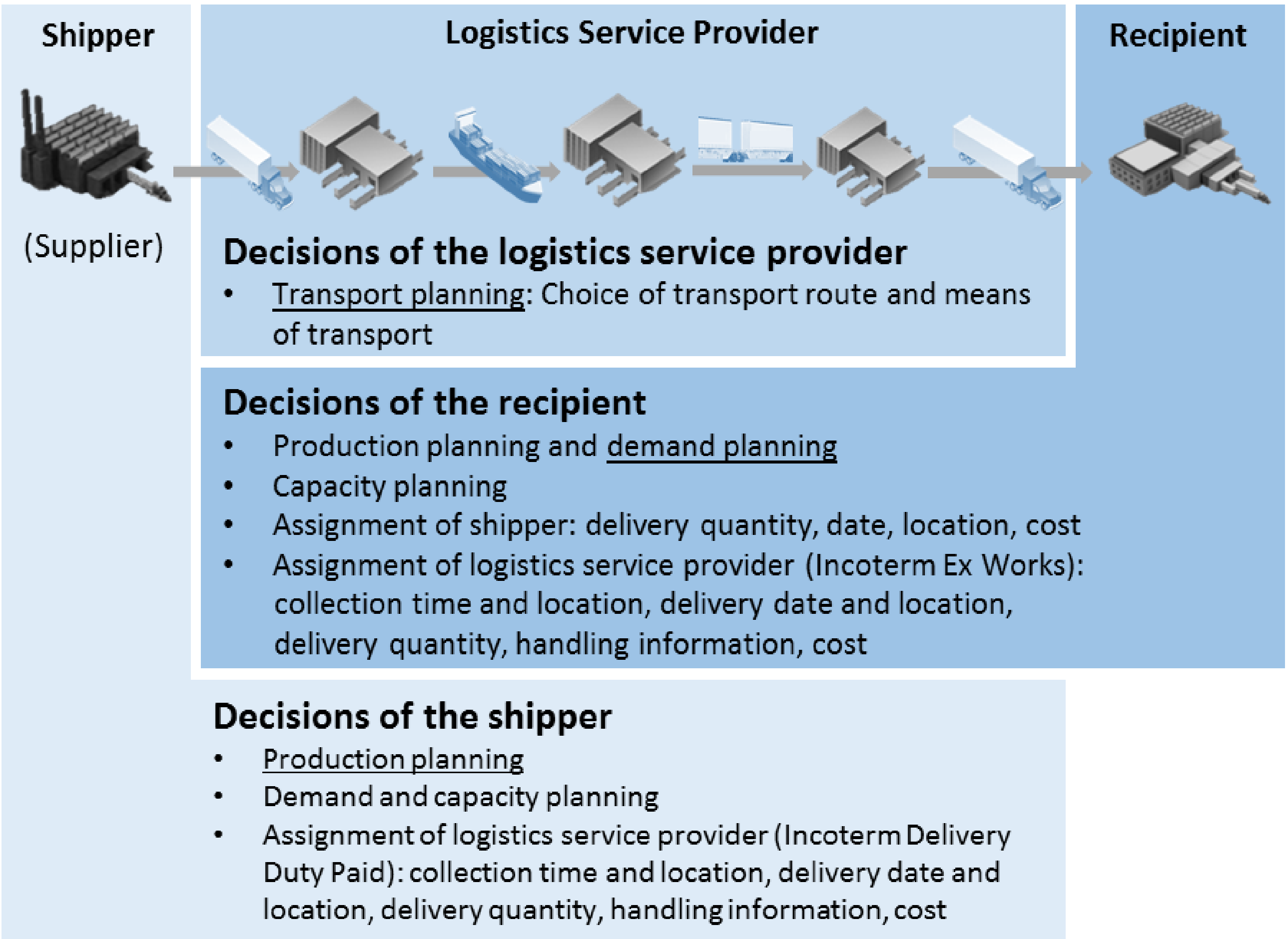

Figure 3.: *Network structure, involved parties and decisions in the use case supply chain*

4.2 Harvest Campaign Control

The project's second use case examines the harvesting of silage maize, i.e. the process of cutting and chopping full maize plants and transporting it to a silo facility where it is compacted and stored for fermentation, such that is can be used as animal food or substrate for bio gas plants. It is a use case well-suited for the study and development of a decentralized planning and control system for logistic networks, as the agricultural activities involved are heavily dependent on tightly controlled logistics processes. The major logistical challenge when harvesting silage maize is the sheer volume of chopped plants produced in the field. With yield rates of several hundred tons per hour and no bunker on-board of the forage harvester, it is essential to provide a transport vehicle for overloading the harvested crops at any time. Otherwise the process comes to a complete halt, which is costly and problematic, due to the short and weather-dependent time windows of the harvesting season.

The goals in SOFiA regarding the process of silage maize harvesting are twofold: Firstly we are concerned with digitizing the contract between a farmer and an agricultural contractor. Secondly, we aim to utilize the smart objects for the cooperative control of the involved machines that is adapting the transport vehicles schedule, the harvester's production rate, as well as the working rate of the compactor vehicle.

By deploying smart object technology for decentralized decision making on board of agricultural machines, it is possible to address problems when and where they arise. This is particularly beneficial, since agricultural processes are often located in rural areas lacking broad band connectivity, which makes data transfer to and from a centralized planning and control architecture brittle if not impossible.

Next, we will present our approach towards the decentralized planning and control of logistic chains. For brevity, we hereby concentrate on the use case of supply chain management. The agricultural use case is based on the same principles and architecture. For a detailed discussion of this use case, see [DKS17].

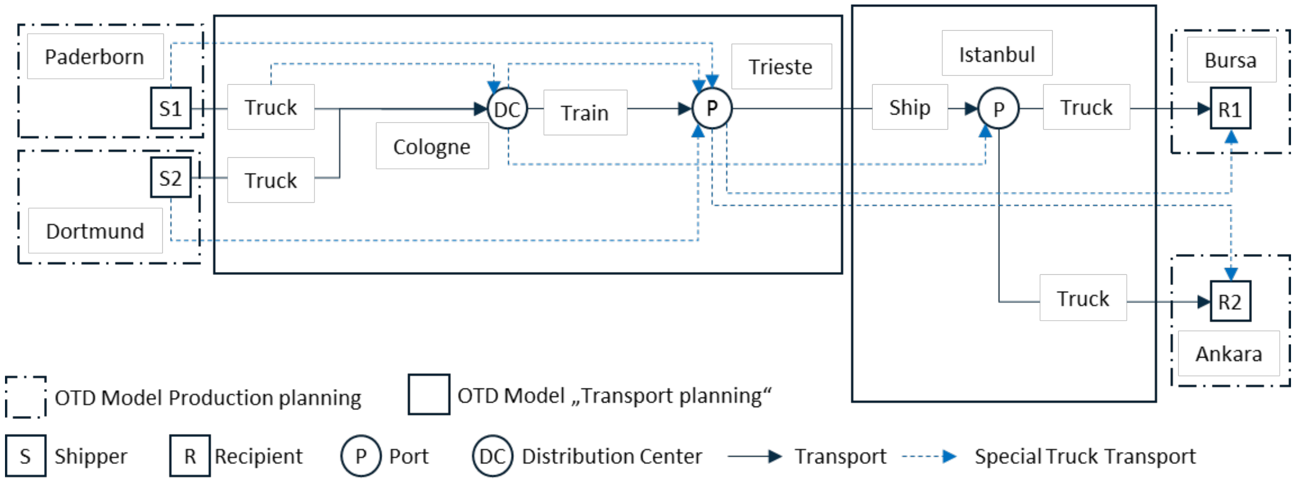

Figure 4.: *SOFiA network model for a sample supply chain*

5 Decentralized Planning and Control of Supply Chains

For the decentralized planning and control of supply chains with Smart Objects the SOFiA project relies on a model-based approach. Here, a supply chain is modeled as a network of nodes (shipper, hubs of the logistics service provider, recipient) and edges (routes between the nodes) (cf. Fig. 4). In the network the parts will be transported in transport equipment (curtain trailers) according to the transport order from one shipper to one recipient. Different means of transport (truck, ship, train) move the transportation equipment. The means of transport can be changed at the hubs. Therefore, the transport order can be divided into so-called route section orders. Every route section is operated by one means of transport (truck, ship, train). The transport demand is determined by the production and distribution planning of the shipper and the production and procurement planning of the recipient.

For the planning and control of activities in individual hubs, the simulator OTD-Net [LBM13] is used. This results in three classes of OTD-Net models: models for the shipper, models for the logistics service provider or individual hubs of the logistics service provider (LSP) and models for the recipient. Figure 5 shows the conceptual interfaces of the models with local systems of the parties involved in the supply chain. These models perform the following planning and control tasks:

- In LSP models, the planning of incoming and outgoing transports per hub is made. In addition to the transport capacities of the different means of transport, handling resources and available empty transport equipment are also considered. Apart from a standard route for a transport section from one hub to the next, a LSP can also choose alternative transport route sections to react to events (breakdown of a machine, missed ships and trains, but also changes of the plan at the shipper or recipient).
- A shipper is the source (start location and time) for a transportation request and provides resources for the loading and, if needed, the buffering of transportation equipment. Shippers can submit a transport demand plan to the LSP based on their production and/or distribution planning (if the shipper is responsible for the transport) and inform the LSP about the goods to be picked up (pick-up advice).
- A recipient is the sink (location and time) for a transportation request and provides resources for the unloading and, if needed, the buffering of transportation equipment. Recipients can submit a transport demand plan to the LSP based on their procurement planning (if the recipient is the customer) and inform the LSP about incoming transport goods (delivery advice).

Transport orders, planned receipts and issues of transport goods are the main results of the planning process on the shipper, LSP and recipient side respectively. The corresponding transport orders – or rather route section orders – are transmitted to the means of transport via WLAN and/or mobile radio by the respective transaction system (ERP and transport management systems). A route section order specifies the transport of transport equipment from a start to a target node (shipper, hub, recipient). For the order control, the start location and a collection window as well as a target location and a delivery window are relevant. In coordination with the respective means of transport, the Smart Object of the transport equipment can permanently monitor its order status and inform the next hub about expected delays (cf. Fig. 6).

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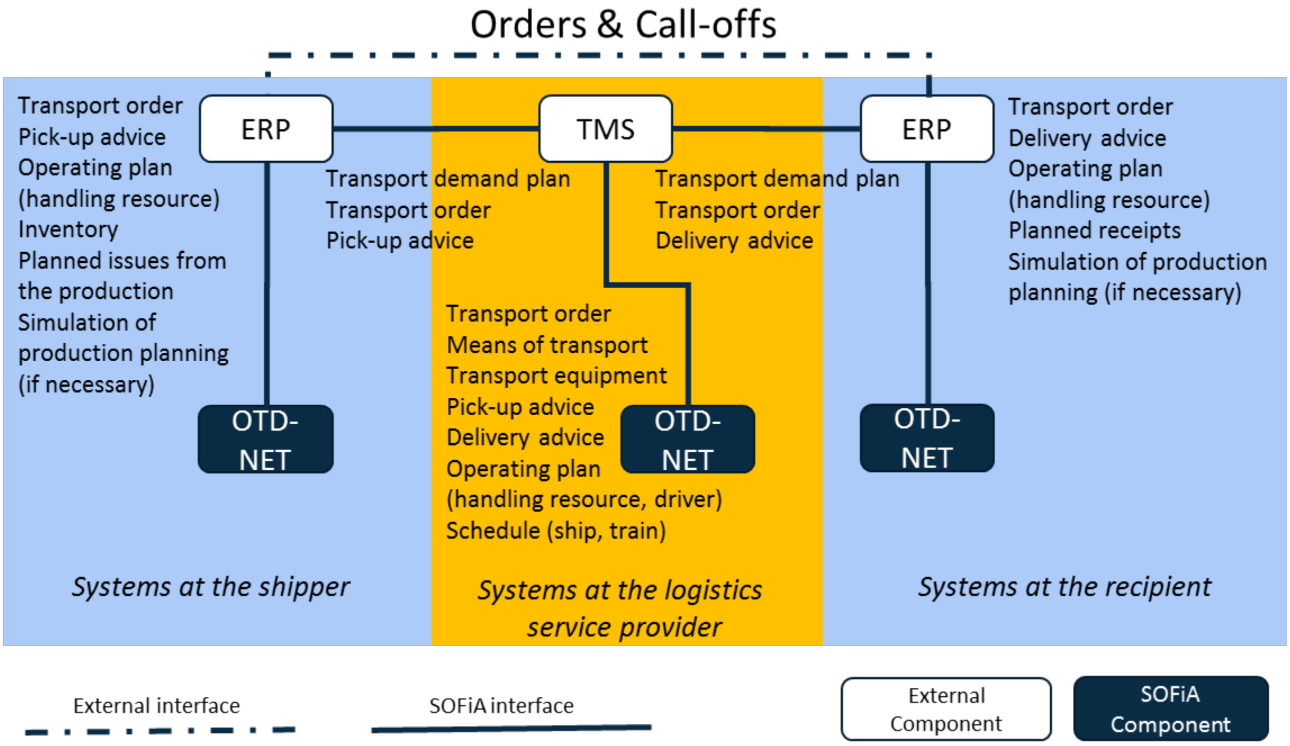

Figure 5.: *Conceptual architecture of the main components at shipper, logistics service provider and recipient*

6 SYSTEM DESIGN

The IT infrastructure developed in SOFiA consists of a cloud-based central component and a network of decentralized control units (DCU).

The cloud-based component connects the multiple stakeholders involved in a supply chain via a smart contracting service. This service bridges the gap between financial and material flows in the supply chain. It also provides security, fraud tolerance and serves as the enabling connector to run smart payment methods (automated and invoice-independent transactions) between smart objects and smart finance services based on smart contracts. The service is based on a Blockchain, since the underlying technology is not only a perfect place to store cryptocurrencies like bitcoins, but also an appropriate solution to save and share contract relevant data in a secure and tamper resistant way [WFN16]. A private Blockchain guarantees a shared and trusted ledger of transactions that every consortium partner can inspect, but no one can control or change a later point in time [SSU16]. If a certified partner or a qualified system puts value in it, the decrypted data will be stored irreversibly.

Based on this technology the partners of the SOFiA-project design smart processes in logistics and farming. The smart contract services, which are implemented as web applications, connect the contracting parties, so they are able to negotiate contract details and create digital agreements, which are placed transparently for every contract partner on the Blockchain.

The smart contract service is able to analyze, monitor and verify all these events in terms of examining whether all contract components and requirements are fulfilled or not. Additionally, the smart contract is empowered to automatically trigger a financial transaction after an on-time delivery with no discrepancies. To connect the smart contract service with the payment cloud write-and-read-permissions are assigned by open source technologies such as the MultiChain.

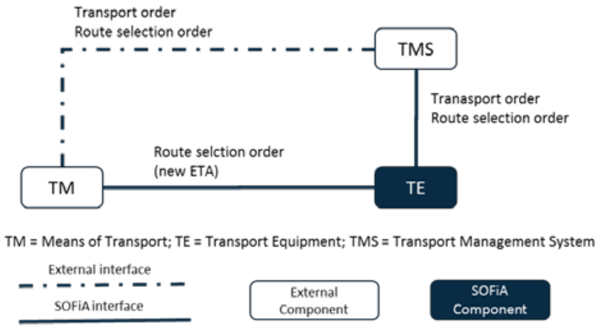

Figure 6.: *Conceptual architecture of Smart Objects*

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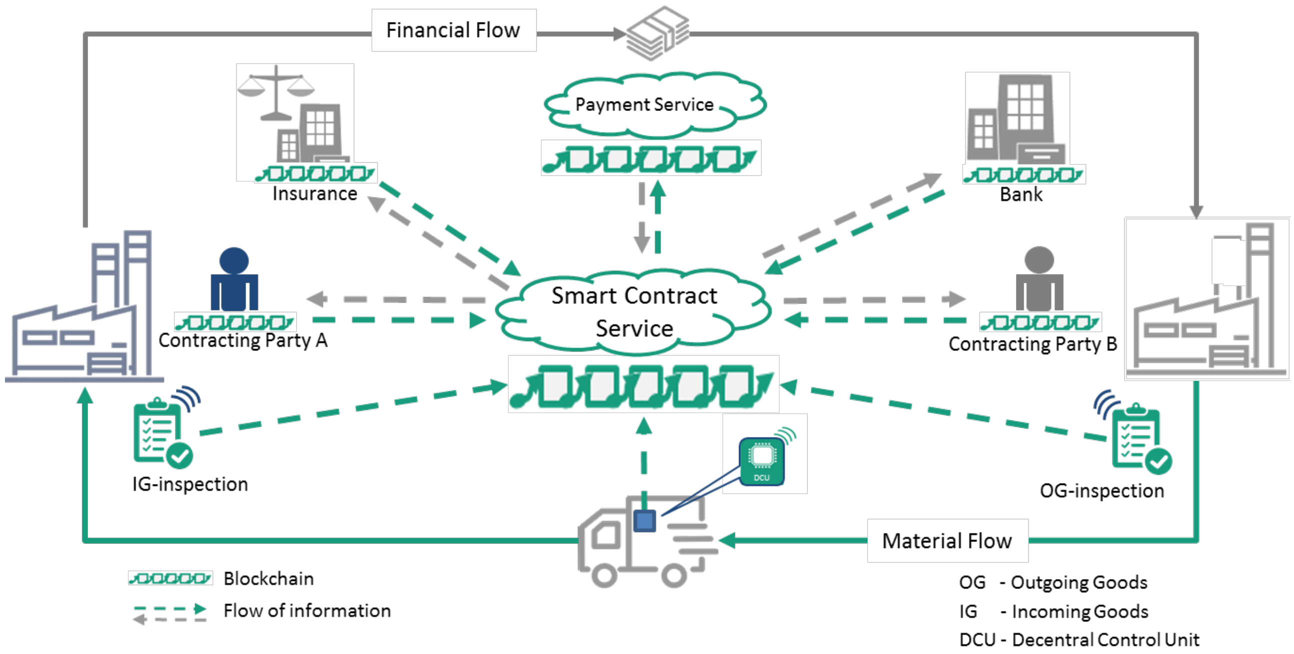

Figure 7.: *Blockchain-based supply chain network*

The MultiChain consists of different streams whereby every stream provides particular information related to the entire contracting process. Underlying the principles of the Blockchain each stream stores its data on various servers to secure the inviolability of important process data. The extent of the permissions given to the contracting parties is defined by the business community and varies between full access on data, reading-permission only or the complete refusal of all information. This procedure ensures that only a verified party can add data or change status. It also simplifies the traceability in case of data abuse. When a contract component or requirement is fulfilled the DCU transfers the information of completion to one of the related Blockchains. Subsequently, the smart contract triggers the determined payment (cf. Fig. 8).

As well as the payment cloud, further smart B2B services like financing or insurance service can be integrated easily into the cloud-based system.

Similarly, the ERP systems of the participating parties are bridged by the central component of the SOFiA architecture. These systems provide the initial plans on how to execute the negotiated logistical services - either by using a manual disposition process or utilizing an OTD-Net based simulation of the supply chain to come up with a suitable set of actions and schedules for all involved parties and objects.

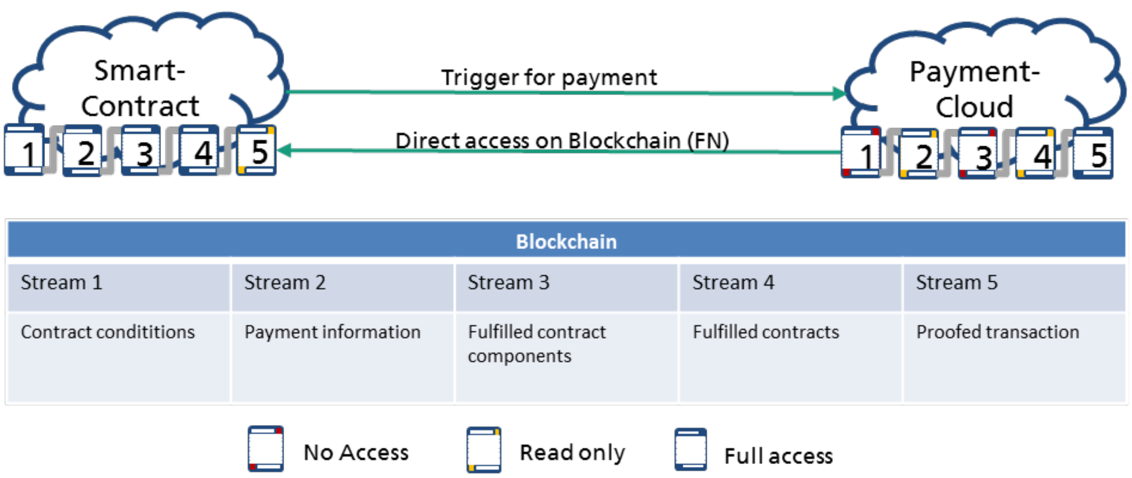

Figure 8.: *Interaction between smart services*

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These plans are then handed down to the individual process participants and evaluated on the respective DCUs to measure the process progress at run-time. To enable the on-going tracking of service contract components directly on-board the transport vehicle or cargo units, it is important that the DCU is able to understand the process chain and the associated tasks for this particular unit. It is essential that a DCU can measure its own progress, in order to report to the smart contracting system, as well as to re-plan its own activities to better fulfill its assigned tasks. To implement process monitoring and self-organization, consider the DCU as an agent and the logistical network as a multi-agent system [Woo09]. This reflects in the DCU's underlying architecture concept, depicted in Fig. 9.

Each DCU is equipped with a formal model of the supply chain and maintains knowledge about the process in knowledge bases using this model. We use semantic web technology standards (e.g. RDF/S and OWL) [BHL01] to represent the supply chains model, as described in the previous section.

To capture process data, we based our model on an existing ontological conceptualization of logistical processes [DF13]. This model consists of three interconnected ontologies: The logistics core ontology (LogiCo) defines the basic vocabulary for describing movable resources involved in a supply chains, e.g. trucks, containers, as well as relevant facilities, i.e. ports, airports and railway stations. The logistics service ontology (LogiServ) describes logistical activities, e.g. consolidation, transport and transshipment, as well as roles and actor classes, which can be used to model logistical services and their stakeholders. Finally, the transport ontology (LogiTrans) explicitly describes the communication between a customer and a LSP for organizing logistical transport. It provides a transport request which is specified by the customer. It denotes the loading and unloading locations, the required delivery times, as well as the cargo and its properties. As a response the provider issues a transport plan detailing how the request will be handled.

We use this conceptualization to capture the individual tasks for every logistical object, as provided by the ERP system in the DCU's internal memory. However, the model was not designed to include information about an on-going logistics process, hence we extended the model to also capture the current state of the task. We update this state continuously using sensor data input (e.g. the cargo's current position measured by the DCU's GPS) and utilize rule-based reasoning and logical inference to evaluate relevant key performance indicators on this state. For transportation tasks, for example, we measure the remaining travel time and match it against the planned time of arrival.

If the DCU detects any major deviations from the initial plan, we extract data from the process model to generate a set of simulation models and use the latter to determine possible alternative activities, e.g. comparing a street-based transport with a railway connection. We feed this data to OTD-Net, to simulate the effects of the different scenarios on the individual object, as well as the entire supply chain. Depending on the results, the DCU's implemented process logic chooses the most suitable set of actions. This logic may vary depending on the kind of logistical object involved and the given service level agreements.

Once a suitable alternative set of action is determined it updates the tasks for the respective logistic object. Via a human-computer interface the DCU notifies the driver of the truck or the dispatcher of the unit about the changes. Note that resolving deviations from previously calculated plans requires the synchronization and data exchange between multiple DCUs. Similarly, many situations can only be resolved by making decisions for a set of logistical objects at once. We envision our architecture to allow for joint decision making, at least for B2B parties that explicitly agreed for their DCUs to cooperate, rather than compete. The latter feature is subject to future development.

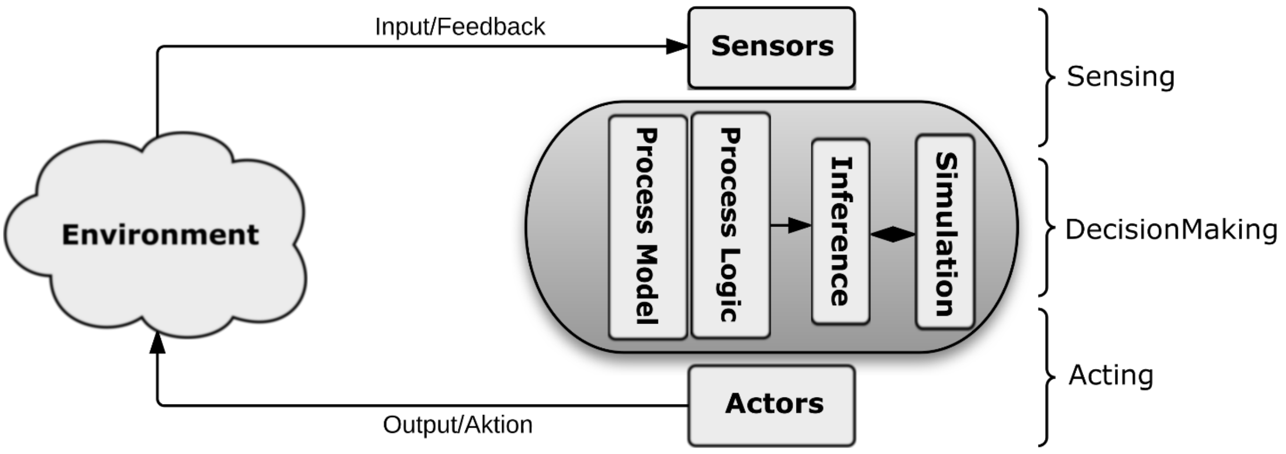

Figure 9.: *Conceptual architecture of an agent-based decentralized control unit*

7 Conclusion and Outlook

Logistic transport processes are often subject to disturbances of different kind due to their highly distributed nature. Resolving issues in complex dynamic environments such as supply chains can be challenging and often require significant efforts and comprehensive information base. The presented concept utilized in SOFiA combines centralized decision-making systems with OTD-Net simulation models and a decentralized control unit to enable automated on-demand simulation and evaluation of planning scenarios. With the help of the supply chain management use case a possible integration of Smart Objects in an interdependent intermodal network was examined. The harvest campaign control use case addressed the digitalization of the contracting process between a farmer and an agricultural contractor as well as the cooperative control of the involved machines. To bridge the gap between financial and material flows in a supply chain, a smart contracting service based on a Blockchain was introduced. The former is fundamental to the described event based mechanism for interaction between smart B2B services such as payment, insurance and financing.

The planning quality and stability is one of major challenges in SOFiA. Due to the interdependent environment in the supply chain management use case, a re-planning of the transport order by a hub of a LSP may under circumstances lead to the re-computation of the production planning at the recipient side, which will lead to a change in the delivery window of the transport order. A renewed planning at the LSP could be the result. These problems also occur in today's practice, but due to the manual disposition there are no "planning iterations". The approach in SOFiA enables the simulation and evaluation of new planning scenarios in the case of a disturbance by using automated information sharing. Protocols for the decision-making in non-hierarchical networks are currently being developed and tested in the SOFiA project.

8 Acknowledgements

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