Intelligent products for enhancing the utilization of tracking technology in transportation

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1 Introduction

In recent years, transportation companies have made considerable investments in information technology (Schumacher and Feurstein, 2010), including tracking technology such as GPS and RFID. These investments are typically made with the expectation that tracking technology will increase the visibility of on-going operations and, thereby, improve the ability to perform operational control. In that regard, an overview of operations management literature provided by Visich et al. (2009) shows broad empirical evidence that tracking technology can accurately capture operational information in real-time and at an unprecedented level of granularity. Nonetheless, other studies (see e.g., Dutta et al., 2007; Shu and Barton, 2012) have shown that it remains a fundamental challenge to transform the abundance of operational information into accurate and timely control decisions. Hence, the commonly held perception that tracking technology will improve the ability to perform operational control does not unequivocally stand up to empirical scrutiny. Consequently, many transportation companies struggle to effectively utilize the information provided by tracking technology for performing operational control (Crainic et al., 2009).

The in-depth case study presented in this paper aims to identify the problems underlying the inability to effectively utilize tracking technology within a transportation context. In addition to the empirical case study results, this paper contributes to solving the identified problems by proposing a novel set of information system design principles based on the concept of intelligent products. The intelligent products concept allows physical objects such as pallets and trucks to become aware of their local context through the information provided by tracking technology. Moreover, intelligent products have knowledge and reasoning capabilities which enables them to perform some of the repetitive tasks required for operational control. Based on these characteristics, it is argued that intelligent products are a suitable approach for enhancing the utilization of tracking technology. Accordingly, this paper provides a real case illustration of how intelligent products can support transportation companies in performing operational control by presenting operational information in a comprehensive way, detecting problems in plan execution, and allowing for more informed control decisions.

The remainder of this paper is organized as follows. Section 2 explains the need for the research presented in this paper based on an analysis of related work on the utilization of tracking technology and the concept of intelligent products. The research methodology, consisting of three phases, is discussed in Section 3. The results from each of those three research phases are discussed in the subsequent sections. That is, Section 4 presents the results of the case study that was performed as the problem identification phase of this research, Section 5 elaborates on the proposed design principles, and Section 6 provides a case example of how to apply the design principles for improving the utilization of tracking technology within a transportation company. Section 7 summarizes the main contributions of this paper, discusses the management implications, and proposes directions for future research.

2 Related work

2.1 Utilization of tracking technology

Tracking technology can be viewed from various research perspectives, such as economics, information systems, and operations management. Due to the focus of this paper on utilizing tracking technology for operational control, related work has been reviewed from an operations management perspective. Therefore, an analysis of recently published operations management research on tracking technology was performed to position the research presented in this paper and better frame its contribution. The search included papers published since 2005 in the most relevant journals in operations management, according to the journal evaluation of Theoharakis et al. (2007). Only papers presenting empirical studies about the utilization of tracking technology were selected, resulting in a list of 27 papers (see Table 1).

A first read of the selected papers indicated that most studies address, in explanatory terms, the widely used and well-established operations management practices related to the utilization of tracking technology. By contrast, the research in this paper aims to design novel ways to enhance the utilization of tracking technology and to study their effects on operational control. Therefore, an approach that structurally integrates design-oriented research with more conventional explanatory-oriented research is needed to position and frame the contribution of this paper. The framework presented in a recent guest editorial (Holmström and Romme, 2012) proved to be particularly useful in this context, due to the fact that it supports the integration of explanatory knowledge (theory) with technology development practices. Holmström and Romme (2012) argue that research can achieve this integration by explicitly formulating "the specific *Context*, the (set of) *Actions*, and the *Generative mechanisms* through which the actions are likely to produce particular *Outcomes*". The main result of the literature analysis is a classification of the selected papers according to these four terms. Each of the selected papers has been classified by assigning a specific descriptor for its:

- context – elaborating the domain in which the particular tracking technology is studied
- actions – detailing the tracking technology considered or applied
- generative mechanism – explaining the cause effect relation envisioned
- outcomes – reporting the effect that has been measured.

In addition to these four terms, a fifth one is used to classify the evidence of the outcomes. It is described according to the adopted research approach as distinguished by Meredith (1998), being *experiments or statistical methods* and *case or field studies*. Table 1 offers a structured overview of the papers by presenting their descriptors for each of the five terms used in the classification. A summary of the descriptors is presented in Table 2.

Table 1: Classification table.

(Table 1 about here)

Table 2: Summary of descriptors of papers from Table 1.

(Table 2 about here)

The papers numbered 1 to 14 report improved visibility as the outcome of utilizing tracking technology in a wide range of operations management contexts. Most of these papers (#1 to #9) address the deployment of either RFID or GPS, and consider tracking technology largely as a black box (i.e., simplifying it to the mere deployment of a specific technology, such as placing RFID tags on products). By contrast, papers #10 and #11 also consider an architecture which extends the tracking technology with intelligent means. The evidence of the outcomes in papers #1 to #10 is based on experimental or statistical methods – mostly simulation studies and statistical analysis of survey data. Papers #11 to #14 continue the same trend in terms of output, action, and context, but offer more in-depth empirical evidence for improved visibility – based on case and field studies.

The papers numbered 15 to 24 report improved control by the utilization of tracking technology in various contexts. Similar to the papers on visibility, the majority of papers focusing on operational control show results based on experimental and statistical methods (#15 to #21) and only few consider an intelligent architecture extending the tracking technology (#20 to #23). Papers #22 and #23 gathered evidence by means of a pilot study, which indicate that the utilization of RFID-enabled intelligence results in improved control in a real-world setting. Paper #24 is the single paper providing evidence for improved control from an in-depth case study.

The last three papers in the table (#25 to #27) do not deviate from the general trend of regarding tracking technology as a black box, but emphasize the fact that there is little in-depth empirical evidence of improved control. The experimental results presented in these three papers show that the utilization of tracking technology does not necessarily improve a firm's internal operations (#25), the resulting supply chain cost reductions are not significant (#26), and operational performance can in some cases even degrade (#27).

Overall, related operations management literature provides ample evidence that tracking technology can be utilized to improve operational visibility. Whether and how the utilization of tracking technology will also improve operational control remains inconclusive, due to several reasons. Firstly, the majority of related work considers the utilization of tracking technology as a black box. Secondly, there is scarcely any attempt to reason why the utilization of tracking technology is expected to improve control. In terms of generative mechanisms, there is only one paper (#21) that starts to give such an explanation. This paper indicates that due to decentralization of control, a higher level of robustness is measured when uncertainty increases. Thirdly, existing empirical evidence for improved operational control is mostly based on experimental methods. Moreover, out of the few papers presenting case or field results, only one paper addresses a transportation context (#23). In conclusion, the above classification and analysis of literature shows a gap in operation management research regarding a lack of in-depth evidence that explains whether and how the utilization of tracking technology can improve operational control in a transportation context.

2.2 Intelligent products

An illustrative example (Anon, 2007) of how RFID-enabled visibility does *not* automatically improve operational control stems from a context where a big retailer deployed tracking technology in its distribution centers and stimulated the vendors in its supply chain to do the same. In this particular example, a seafood vendor, which already had the required tracking technology in place, was invoiced a huge penalty for sending a spoiled shipment of lobster tails to the retailer. However, the seafood vendor could provide posteriori evidence from the gathered RFID data that the mistake was actually made at the retailer's distribution center, where the handlers accidentally left the shipment of lobster defrosting for 7 hours. As a result, the retailer withdrew the penalty and absorbed the cost of the spoiled shipment. The spoilage could have been fully prevented, however, if an additional layer of intelligence would have been designed to utilize the tracking information for warning the handlers at the distribution center about this kind of mistakes. A promising means for adding this layer of intelligence to the visibility-oriented tracking technology currently in place would be the deployment of intelligent products.

Formally, an intelligent product can be defined as a physical and information-based representation of a product, which can retain or store data about itself and is capable of participating in or making decisions relevant to its own destiny (McFarlane et al., 2003). The intelligence of an intelligent product can be provided by a software agent, which is linked to a particular product, and is able to utilize the available information of that product (Wong et al., 2002). Figure 1 shows an example of such a product. In this figure, the pallet is the physical product, the information-based representation of the product is stored in the database, and the intelligence is provided by the decision making agent. The connection between the physical product and the information-based representation is made using tracking technology, such as an RFID tag and reader. By connecting the physical product to its information-based representation, the concept of intelligent products enables traditionally passive entities (e.g., trucks and pallets) to become active (Valckenaers et al., 2009).

(Figure 1 about here)

Figure 1: An intelligent product

The intelligent products approach is product-centric, referring to the fact that detailed product information and history are stored separately for each individual product. This approach strongly differs from traditional inventory-based approaches, which only store aggregated information, such as inventory levels of different product types at different warehouse locations (Rönkkö et al., 2007). Several case studies have shown the advantages of applying a product-centric approach as compared to the application of a traditional inventory-based approach. The reported advantages include the availability of more accurate product information (Holmqvist and Stefansson, 2006), the ability to track individual products (Holmström et al., 2010), and the ability to more accurately monitor inventory levels (Holmström et al., 2011). Other studies have shown promising results with respect to the application of intelligent products and decision making agents for improving operational control in various domains, such as manufacturing (Bussmann and Schild, 2000; Meyer et al., 2011; Vrba et al., 2011), supply chain management (Kärkkäinen et al., 2003; Wong et al., 2002; Woo et al., 2009), and product life-cycle management (Hribernik et al., 2006; Kiritsis, 2011; Marchetta et al., 2011).

The intelligent products research discussed above indicates the potential value of intelligent products in various applications. Accordingly, this paper presents the application of intelligent products to enhance the utilization of tracking technology for improving operational control in transportation companies. When performing operational control in a situation without the use of intelligent products, all trucks and pallets are passive entities, and only humans are active entities. The use of intelligent products enables the passive entities to become active to a certain extent. Currently, information systems used in transportation are typically grounded on the view that each truck has its own driver who can actively manage information related to that truck and who can control the progress of the truck's transport operations. If one considers an information system where each pallet is represented by a digital equivalent providing a certain amount of intelligence (i.e., by making it an intelligent product), each pallet would have its own active minder that is able to perform some of the repetitive tasks required for operational control. Hence, with respect to existing information systems, a system design based on intelligent products would allow for operational control to be performed at a much finer grained level of analysis.

3 Methodology

The main objectives of this research are to identify the problems faced by transportation companies when utilizing tracking technology for improving operational control and to develop a solution approach which contributes to solving these problems. Regarding this type of research objective, Simon (2002) argues that the design science research paradigm can not only be used to explain and predict the phenomenon of interest, but more importantly, it also allows shaping the phenomenon by the design of novel solutions. Due to its explicit focus on improving practice, design science research can complement theory-oriented research in operations management (van Aken, 2004; Holmström et al., 2009; Holmström and Romme, 2012). Therefore, the study as described in this paper adopts a design science research methodology. Accordingly, the three main phases of this research, *problem identification*, *solution design*, and *prototype development and evaluation*, are inspired on the design science guidelines and procedures provided by Hevner et al. (2004) and Peffers et al. (2007).

3.1 Problem identification

The problems associated with utilizing tracking technology for operational control are identified by studying the operational control activities at a transportation company. A typical medium-sized road freight transportation company was selected as the case company. The case company utilizes a state-of-the-art transportation tracking system, for which adequate support is provided. For a period of nearly two years, the researchers frequently visited the case company to collect empirical data by means of observations, interviews with the planners and management, as well as studies of formal documents and databases. In total, 75 hours of observing activities at the case company were documented. The observations were aimed at understanding the operational control activities, as well as what triggered the actors to perform these activities. Observations were corroborated by means of discussions with the involved planners. Moreover, frequent meetings with the head of planning and the IT manager took place to verify new insights or to answer unresolved questions. Over the time span of the research project, five semi-structured interviews were conducted at which the CEO, the head of planning, and the researchers involved were present. The aim of these interviews was to better understand the operational control activities at the case company and to verify intermediate research results.

3.2 Solution design

To provide a solution to the identified problems, this research presents a set of generic design principles for information system design, which are based on the concept of intelligent products. The design principles reported in this study have been supported by extensive research related to the concept of intelligent products, which comprises two main sources of knowledge. The first source is formed by state-of-the-art theories, frameworks, and application oriented knowledge in the field of intelligent products (see Section 2.2). The recent research trends, emerging architectural designs, and novel application domains in this field are surveyed in the work of Meyer et al. (2009), leading to the formulation of a classification model which can be used as a research framework. The design principles proposed in this research are theoretically anchored in that classification model. The second source of knowledge is based on application oriented experience of the researchers involved in this study. This experience was gained during the iterative development of an intelligent products architecture and the evaluation of that architecture by means of validating various prototypes (see e.g., Meyer et al., 2011). A thorough discussion on this architecture development process and its evaluation can be found in Meyer (2011).

3.3 Prototype development and evaluation

Based on the generic design principles, and using the intelligent products architecture proposed in Meyer (2011), a prototype system was developed to support the operational control activities at the case company. The purpose of this prototype development is to provide a case example of applying intelligent products for enhancing the utilization of readily available tracking technology in a transportation context, and thereby to evaluate the proposed design principles. To that end, this research adopts both experimental and observational evaluation methods. Firstly, experimental evaluation was conducted to demonstrate that the prototype is an appropriate instantiation of the design principles. Secondly, observational evaluation was conducted to examine the usefulness of the prototype at the case company. Finally, the evaluation results were used to reflect upon the validity of the set of design principles.

4 Problem identification

This section presents the results of the case study that was performed as the problem identification phase of this research. Although many aspects of the planning and control process were studied at the case company, this section is strongly focused on describing the process of operational control.

4.1 The case company

The case company ships temperature controlled, pallet based, products throughout Europe. Customer orders typically comprise a small number of pallets. In order to minimize the driving distance and maximize the effective use of truck capacity, the vast majority of pallets is consolidated and cross-docked at a central warehouse. To transport the pallets, the case company owns 80 trucks and uses the capacity of roughly 20 additional trucks chartered from outside the organization.

Ongoing transport operations frequently deviate from the plan due to unexpected events such as last-minute customer orders, truck break-downs, additional waiting times at pickup or delivery locations, and traffic congestions. During the execution of the transport operations, a team of nine full-time planners performs operational control aimed at mitigating the negative performance effects of these unexpected events.

4.2 Information available for operational control

Three state-of-the-art information systems are in place at the case company with the purpose to capture, analyze, and store information about the transport operations. An Enterprise Resource Planning (ERP) system is used to register and manage information on customer orders, including due dates, pickup and delivery locations, and size of the orders. A GPS-based transportation tracking system provides detailed and real-time information on truck locations as well as information on the progress of operations in terms of pallet pickups and deliveries. Information provided by the ERP and the transportation tracking system is automatically transferred to an Advanced Planning System (APS). The APS has a functionality to detect whether the actual progress of the trucks performing the transport operations is according to plan. Moreover, the APS can automatically notify the planners through pop-up messages about a delay in the execution of the planned operations.

Besides information from computer-based systems, it is observed that planners at the case company receive information about ongoing transport operations through conventional methods, such as phone calls with customers and on-route truck drivers. Moreover, visual checks are performed to determine whether pallets have accidentally been left at the warehouse, and to determine whether trucks have arrived at or departed from the warehouse.

4.3 Operational control at the case company

Observations at the case company were focused on understanding the process of operational control, including the triggers for control and the actual control activities performed. It was observed that the planners perform operational control in response to unexpected events. Hence, operational control is triggered when the planners get informed about unexpected events. The planners can get informed about unexpected events in three different ways:

- A truck driver notifying the planners through a phone call or text message, for instance about a traffic congestion.
- A customer informing the planners through a phone call or email, for instance about a last-minute order or about a pallet that has not arrived on time.
- A planner manually browsing through the information available in the case company's information systems, detecting for instance additional waiting time at pickup or delivery locations.

After being triggered, planners typically perform five subsequent control activities:

1. Confirm the existence of the unexpected event.
2. Evaluate the impact of that event on the ability to continue the execution of operations as planned.
3. Investigate potential control decisions.
4. Decide which control decision will be taken.
5. Inform the relevant stakeholders about this control decision.

It was observed that during each of the five control activities, the situation at hand is typically discussed internally among planners. Moreover, planners often manually analyze the information available in the company's information systems. In case customers are potentially affected by a control decision, they are contacted to negotiate the possibilities for alternative pickup or delivery times.

4.4 Problems identified

Observations at the case company identified three problems that hamper the utilization of the information provided by the transportation tracking system for improving operational control. The first problem is related to the inability of the planners to manually analyze the high amounts of information about the ongoing transport operations available in the information systems. The amount of information captured by means of conventional methods is rather limited and is provided to the planners when needed, for example, by a phone call from a driver in case of a truck delay. In contrast, the state-of-the-art information systems in place at the case company continuously capture detailed information about the progress of every pallet pickup and delivery, as well as detailed information about truck locations and movements, fuel consumption, temperature in the cargo space of trailers, driver hours, etc. The planners have to manually browse through all this information in order to retrieve the information they require. It is observed that retrieving all the required information from the information systems is a difficult and time-consuming task. First, the information systems in place only present the information of one truck or pallet at the time, while planners often need an overview of multiple trucks and pallets simultaneously for performing operational control. Second, the information systems present all the detailed information that has been captured for each truck or pallet, while planners often only require a small part of the captured information. Hence, manually analyzing the available information is too time-consuming and, therefore, unfeasible in practice, due to the high amounts of information available and the way in which that information is made available to the planners.

- *Identified problem #1*: Manually analyzing the available information is unfeasible.

The second problem identified at the case company is related to the inability to timely detect unexpected events. Due to *Identified Problem #1*, the planners have to rely on automatic analysis to detect unexpected events. In principle, the APS in place at the case company provides the functionality to automatically analyze the available information for detecting unexpected events and to notify the planners. However, the case study revealed that the APS does not correctly detect unexpected events and it was observed that the notification functionality of the APS had been disabled.

During the planning of transport operations, the APS automatically generates a detailed transport plan based on many transport constraints set in the APS. In order to detect unexpected events, the APS compares this automatically generated transport plan with information provided by the transportation tracking system. When transport constraints set in the APS are incorrect or outdated, the automatically generated transport plan will not reflect the actual plan intended by the planners. Hence, the APS requires the planners to keep all transport constraints up-to-date to correctly detect unexpected events. However, the planners consider this unfeasible, due to the vast number of transport constraints and their constantly changing nature.

Planner: “The transport constraints are different for every customer, driver, truck, and pallet. In case of a truck delay, it is actually often not a problem to arrive a little late at the next pick up or delivery location. However, some customers impose more strict arrival times than others.”

Head of planning: “We consider it not useful to put a lot of effort in continuously keeping all the constraints up-to-date in the APS while we already know most of these constraints by heart.”

Observations confirmed that the majority of transport constraints is known by the planners as tacit knowledge and are typically not made explicit in the APS. Consequently, the APS does not correctly detect unexpected events and produces a high number of false alarms, as the detection is based on an incorrectly generated transport plan. Therefore, the management of the case company decided it was best to disable the notification functionality of the APS.

IT manager: “Subsequent to the APS implementation, the notification functionality was enabled for some time. At that time, the planners complained about the sheer number of notifications. Moreover, they argued that the vast majority of these notifications did not reflect the real situation of ongoing transport operations. As we did not manage to overcome this issue, we decided to disable the notification functionality.”

Due to the vast number of constantly changing transport constraints, using the APS for detecting unexpected events is unfeasible, which resulted in the notification functionality to be disabled. Therefore, despite the fact that a state-of-the-art APS is in place, unexpected events are often not timely detected.

- *Identified problem #2*: Unexpected events are often not timely detected.

The third problem identified at the case company is related to the inability of planners to take the many complex relations between pallets and trucks into account when making control decisions. In case an unexpected event is noticed, it is observed that planners manually analyze a small subset of the available information related to that unexpected event.

Head of planning: “In performing operational control we use information about the truck with a delay, the pallets it is transporting, as well as the planned sequence of pickups and deliveries.”

Due to the cross docking operations at the central warehouse, there are many complex relations between the pickups and deliveries of individual pallets. Observations confirmed that a delay of one truck can also affect the pickups and deliveries of pallets inside other trucks. However, the planners typically only focus on the impact of the unexpected event on the single truck and its unfinished pickups and deliveries.

Planner: “In the case of a truck delay, I first seek to determine which of its remaining pallet pickups and deliveries are affected by the delay. Afterward, I aim to solve the problems that are caused by these pickups and deliveries.”

Further comparison between observations of control activities and a study of the case company's databases confirmed that much of the information provided by the transportation tracking system is not utilized by the planners for performing operational control. The inability of planners to take the many complex relations between pallets and trucks into account when making control decisions is caused by two factors. First, the time available for making control decisions is limited. Second, the amount of relations is vast and the analysis of the information related to the unfinished pickups and deliveries of one truck alone already takes a considerable amount of the planners’ time. Consequently, the planners are not fully aware of the impact of the unexpected events and the effects of their control decisions on other parts of the ongoing transport operations.

- *Identified problem #3*: Many complex relations between pallets and trucks are not taken into account when making control decisions.

In conclusion, the planners at the case company are insufficiently supported in utilizing the information provided by the transportation tracking system for performing operational control.

5 Solution design

In order to overcome the identified problems above, a set of design principles for information system design is introduced in this section. The main goal of these principles is to support the development of information systems, which apply the concept of intelligent products to enhance the utilization of tracking technology with the purpose of improving operational control. The design principles are introduced next according to the three levels of intelligence for intelligent products as prescribed by the classification model of Meyer et al. (2009): information handling, problem detection, and decision support.

5.1 Information handling

According to *Identified Problem #1*, manually analyzing the available information is unfeasible. To utilize all the available information provided by tracking technology for operational control, the intelligent products should first of all be enabled to handle this information. For this purpose, two design principles for the behavior of intelligent products on the level of information handling are introduced next.

- *Design Principle #1*: Design for full information availability.

As discussed in Section 2.2, intelligent products can represent individual physical objects, such as pallets and trucks, and provide them with knowledge and reasoning capabilities. However, in order to do so, all information about these physical objects has to be made available to them. In line with the recent research findings discussed in Section 2.1, the basic assumption of this paper is that current tracking technology is able to accurately capture high amounts of detailed and real-time information about the state of the ongoing transport operations. Hence, every intelligent product should have access to all information provided by the tracking technology related to the physical object it represents. Moreover, other relevant information in information systems should also be made available to the intelligent products. For example, an intelligent product representing a pallet should have access to all tracking information related to that pallet, as well as other relevant information available in the information systems, such as pickup and delivery due dates, the status of relevant trucks, transport constraints, etc. In this way, an intelligent product is enabled to collect all relevant information related to the physical object it represents.

- *Design Principle #2*: Design for autonomous enrichment and presentation of information.

When all information of the physical objects is available to the intelligent products, every intelligent product should be enabled to autonomously enrich the information related to the physical object it is representing. For example, an intelligent product can add additional information based on analysis and aggregation of the available information. As a result of the full information availability and information enrichment, the amount of information related to the physical objects can be overwhelming. Presenting all this information to the planners will therefore not overcome *Identified Problem #1*. Hence, every intelligent product should also be enabled to autonomously determine which subset of the information it will present to the planners. In this way, an intelligent product representing a pallet can for example only show the planners whether the execution of its operations is still on schedule.

5.2 Problem detection

According to *Identified Problem #2*, unexpected events are often not timely detected. Therefore, the intelligent products should be enabled to timely detect the unexpected events for which operational control by the planners may be required. For this purpose, two design principles for the behavior of intelligent products on the level of problem detection are introduced next.

- *Design Principle #3*: Design for learnability of problems.

The planner should be enabled to train intelligent products by providing them the perceived status of the physical objects they represent. A perceived status indicates whether the physical object currently has a problem according to the planners. When such a perceived status is provided to an intelligent product, this intelligent product should generate and store a training instance based on the planner-provided status as well as on all the available information of the physical object it represents. For example, if a planner informs an intelligent product representing a pallet that its current status is perceived to be problematic, the intelligent product should generate and store a training instance based on the provided problematic status as well as on all the available information, such as tracking information, pickup and delivery due dates, transport constraints, etc.

- *Design Principle #4*: Design for autonomous detection and notification of problems.

Every intelligent product should be enabled to autonomously determine whether its current status is problematic according to the training instances provided by the planners. As providing sufficient training instances for each individual intelligent product would be unfeasible, training instances should be shared among all intelligent products representing the same type of physical object. For example, training instances should be shared among all intelligent products representing pallets. The use of a machine learning classifier (see e.g., Mitchell, 1997) is recommended for providing the most appropriate status. The machine learning classifier enables the intelligent product to learn which part of the available information is important for determining whether it has a problematic status, and enables the intelligent product to determine its current status. For example, an intelligent product representing a pallet can learn which of the collected transport constraints are important for determining its current status. When the current status is determined to be problematic, the planners should be informed. Hence, every intelligent product should also be enabled to autonomously notify the planner when their status becomes problematic, for example by means of emails or text messages. In this way, the planners are directly triggered about physical objects which require operational control.

5.3 Decision support

According to *Identified Problem #3*, many complex relations between pallets and trucks are not taken into account when making control decisions. Therefore, it is important that the intelligent products are enabled to analyze and present the available information in such a way that planners can make informed control decisions, taking into account their impact on the related parts of the operations. Hence, *Design Principles #1* to *#4* already support planners in making more informed control decisions and thereby contribute to mitigating *Identified Problem #3*. Further improvements in making more informed control decisions can be achieved by the formulation of design principles that enable autonomous discovery of potential control decisions. This more advanced form of decision support is not discussed in the subsequent sections of this paper and the formulation of corresponding design principles is deferred to future work. When solving the detected problems, planners in this study are, therefore, expected to use the readily available information systems as well as the information handling and problem detection capabilities of the intelligent products-based system.

6 Prototype development and evaluation

As discussed in the methodology section, a prototype has been developed based on the proposed design principles, in order to provide a case example of applying intelligent products for enhancing the utilization of tracking technology in a transportation context. First, this section describes how a prototype was developed based on the design principles. Next, this section presents the results of the experimental evaluation to demonstrate that the prototype is an appropriate instantiation of the design principles. Afterward, the results of the observational evaluation are presented, which demonstrate the usefulness of the prototype in a real-world transportation company. Based on these evaluation results, a reflection is provided upon the validity of the design principles.

6.1 Prototype development

During the period of six months in which the researchers had unrestricted access to all information, documents, and operations of the case company, a prototype was built through multiple iterations of incremental software development. In this prototype, intelligent products represent the physical objects which require operational control due to unexpected events. The databases of the case company were used to identify the objects which require operational control as well as the corresponding information that is provided by the currently available tracking technology. The identified objects including their available information are:

- *Truck* objects, including information on the driver, the trailer, the pallets on board as well as its current and past locations.
- *Pallet* objects, including information on the source and destination location, the pickup and delivery due date, and the transport constraints.

Unexpected events typically happen to individual pallets or trucks. By including all individual trucks and pallets as intelligent products in the prototype, analysis of available information on this low level of granularity is enabled through the instantiation of the design principles.

Information handling

To instantiate *Design Principle #1*, every intelligent product is provided access to the information available in the databases of the existing information systems, being the ERP system, the transportation tracking system, and the APS. The intelligent products are developed to continuously collect the required information from these databases. Moreover, in line with *Design Principle #2*, the intelligent products are developed to autonomously enrich this information where needed. An intelligent product representing a pallet object will for example enrich the information it has collected by continuously determining the estimated delivery time, based on analysis of information about its current location, whether it is loaded in a truck, and what the distance to the delivery location is. Furthermore, the intelligent products are developed to autonomously determine which information it will present to the planners, based on what information is considered useful for performing operational control. For this prototype, the intelligent product presents information about its planned operations combined with the actual progress of those operations.

Problem detection

To instantiate *Design Principle #3*, the prototype enables the planners to teach every intelligent product at any moment in time whether their current status is perceived problematic or not. Every time this happens, the respective intelligent product will directly generate a training instance based on its collected information and the status provided by the planner. This training instance is shared among all other intelligent products of the same type (i.e., among all trucks or pallets). Moreover, the intelligent products are developed to autonomously determine whether the object it is representing has a problematic status, as required by *Design Principle #4*. To determine this status, a machine learning classifier provided by the WEKA library is used (Hall et al., 2009). Moreover, the intelligent products are developed to directly and autonomously notify the planners by means of an email message when their status becomes problematic.

6.2 Experimental Evaluation

Two different kinds of experiments have been conducted. Firstly, it was evaluated whether the prototype is able to handle the information available in the databases of the aforementioned information systems in place at the case company. Secondly, it was evaluated whether the prototype is able to perform the activities required for problem detection. The results of the experiments are presented next.

Information handling experiment

Information about approximately 10,000 pallet objects, together with the related truck objects, was captured from the databases of the case company and provided to the prototype. This amount of objects represents approximately three times the amount of objects which the prototype has to handle during the normal operational control process at the case company.

The experiment showed that every intelligent product was able to collect the information it requires out of all the available information. Next to that, the experiment showed that all intelligent products were able to autonomously enrich the information of the objects they represent in real-time. Accordingly, all the intelligent products were able to correctly add additional information, such as the estimated delivery time in case of intelligent products representing pallet objects. Finally, all intelligent products were able to correctly determine which information to present, namely the planned operations they are involved in together with the actual progress of those operations.

Problem detection experiment

In this experiment, the intelligent products were trained. Intelligent products representing pallets were trained based on their expected delay. In this context, the expected delay was defined as the estimated arrival time minus the planned arrival time. When the expected delay of a pallet was more than one hour, the intelligent product representing the pallet was informed that its status is perceived to be problematic. Intelligent products representing trucks were trained based on the pallets they were transporting at that moment. When a truck was transporting a pallet with a problematic status, the intelligent product representing the truck was informed that its status is perceived to be problematic. Accordingly, fifty intelligent products representing pallets and fifty intelligent products representing trucks were trained in this way.

The experiment showed that all the intelligent products were able to determine their status correctly and in real-time. Therefore, it was concluded that the intelligent products were sufficiently capable of learning whether their status is problematic. Moreover, all intelligent products were correctly providing notifications when their status was changing to problematic.

6.3 Observational Evaluation

The observational evaluation conducted at the case company was performed in two phases: applying the prototype and discussing the results of applying the prototype with the management. The results of these two phases of observational evaluation are presented next.

Phase 1: Applying the prototype

In the first phase, one of the researchers involved in this project used the prototype during execution of operations at the case company, and directly informed the head of planning about the notifications provided by the prototype. As illustrated by the following example, the prototype showed to be able to collect and analyze all available information required for detecting problems in time.

Example #1: At 11 A.M., the prototype notified the researcher about an unexpected event. This notification was provided by an intelligent product representing a pallet with an expected delay of more than 1 hour. According to the plan, the involved truck had to first deliver two other pallets before the problematic one. The prototype detected the problematic pallet delivery, notified the collaborating researcher, and provided the information that was required for understanding that specific problem. The head of planning mitigated the negative impact of the expected delay by directly altering the sequence of pallet deliveries for the involved truck. In case the problem would not have been detected by the prototype, the head of planning would not have been able to alter the sequence of deliveries in time. In this specific case, the pallet was planned to be delivered just before closing time of a customer warehouse. Due to the delay of that pallet and the closing time of the warehouse, the specific pallet delivery would have to be postponed to the next day. This would also have affected the truck's schedule for the next day, which in turn could have led to additional delays.

Some problems that were detected by the prototype were not perceived as problematic by the head of the planning department, typically due to incorrect or incomplete information in the ERP system of the case company. Due to the presentation of information provided by the prototype, the collaborating researcher could often directly determine whether a detected problem was based on incorrect or incomplete information, as is illustrated by the following example:

Example #2: At 9 A.M., the collaborating researcher was notified about a problem detected by the prototype. A product had to be delivered before 6 P.M. on the previous day. Because all related information on the particular product is presented in a comprehensive way, the collaborating researcher directly observed that the product was in fact planned for delivery before 6 P.M. on the present day. Therefore, the collaborating researcher concluded that the delay of 15 hours was due to a changed sequence of deliveries by a planner. However, as the planner did not change the delivery due date of the pallet in the ERP system, the detection was based on incorrect information.

In total, the prototype notified the collaborating researcher 13 times about problems during the two day observational evaluation period at the case company. Out of the 13 notifications, 4 cases led to direct action by the planners to mitigate severity the problem, such as in *Example #1*. In 9 out of the 13 cases, the detection was based on incorrect information, such as in *Example #2*, and the notification led to planners changing the incorrect information. However, from a system perspective, the problem detection was correct in all cases, as the prototype is dependent on the information collected from the company's existing information systems.

Phase 2: Discussions with the management

In phase two, discussions with the management have been conducted. Both the head of planning and the CEO articulated that an information system introduced for supporting their operational control activities should, in the first place, be able to select and present relevant information from the vast amounts of information available.

Head of planning: “Providing relevant information is the most important functionality for an information system supporting operational control. Based on such information, we can more easily make an informed control decision ourselves. The prototype has shown to be useful for providing such information.”

The prototype is designed to support the planners in performing operational control, by presenting the information relevant for performing control activities in a comprehensive way. By contrast, the APS currently in place at the case company provides the planners with all the available information about the ongoing operations. Moreover, as discussed in Section 4.4, the APS frequently provided the planners with false notifications. The notifications generated by the prototype, on the other hand, were often triggering control activities.

Head of planning: “Several notifications resulted in immediate phone calls to customers, negotiating the possibilities to change arrival times of pallets.”

The management responded highly positive and was willing to take further steps in the implementation of the prototype, as they confirmed the positive influence of the prototype on their ability to perform operational control.

CEO: “One major advantage of the prototype over our existing information systems is that, for detecting delays, the prototype requires a relatively limited information input from the planners. This would simplify further adoption of the prototype.”

6.4 Reflecting upon the set of design principles

As the final part of the evaluation process, a reflection upon the validity of the set of design principles is provided. This validity is analyzed by determining to what extent the principles enable the development of an information system to overcome the identified problems as presented in Section 4. The reflection includes a summary of how the design principles contribute in solving these problems (i.e., presenting their generative mechanism).

According to *Identified Problem #1*, manually analyzing the available information is unfeasible. Through the instantiation of *Design Principle #1* and *#2*, the experimental evaluation showed that the intelligent products are able to collect and enrich all related information provided by the existing information systems. Moreover, the observational evaluation showed that the intelligent products are able to select and present the relevant information in a comprehensible way. This enables a level of understanding about unexpected events, including their impact on the ongoing operations, which could not be achieved by the information systems already in place at the case company.

According to *Identified Problem #2*, unexpected events are often not timely detected. In order to overcome this problem, *Design Principle #3* postulates that problems should be learnable for intelligent products. The evaluation showed that due to the learnability of problems, the intelligent products are able to determine which existing information is the most important for detecting problematic unexpected events. Consequently, the planners did not need to keep a vast number of changing transport constraints up-to-date, as only the information that is important to the intelligent products had to be provided. Therefore, the amount of information to be provided is significantly reduced compared to the amount of information to be provided when using the company's APS for detecting problems.

Besides learnability, *Design Principle #4* states that problems have to be autonomously detected and notifications have to be provided to the planners. The evaluation showed that the intelligent products are able to detect problems caused by unexpected events, as *Design Principle #4* enables the analysis of the available information on a low level of granularity. Every intelligent product representing a truck or pallet can collect and enrich relevant information, and due to the learnability of problems, it can learn which information is important for detecting whether its current status will be perceived as problematic. This resulted in notifications about unexpected events not yet observed by the planners, but nevertheless required immediate control decisions. Moreover, only a small number of notifications were incorrect compared to the amount of false notifications when using the company's APS for detecting problems.

According to *Identified Problem #3*, many complex relations between pallets and trucks are not taken into account when making control decisions. Although there are no design principles postulated yet about the behavior of intelligent products on the level of decision support, the observational evaluation showed that the prototype instantiating the design principles on the level of information handling and problem detection assisted in solving this problem in two ways. First, the prototype presents the available and enriched information from the existing information systems in a more comprehensive way. Second, the prototype provides the planners with timely notifications about problematic unexpected events. Hence, the planners are provided with more time for performing control activities and gained a better understanding of the problem that needs to be solved.

Overall, it can be concluded that the proposed set of design principles together enable the development of an information system which overcomes *Identified Problem #1* and *#2*, and contributes to overcoming *Identified Problem #3*. This confirms the validity of the proposed set of design principles.

7 Discussion and Conclusions

7.1 Main research contributions

Many transportation companies struggle to effectively utilize the information provided by tracking technology for the control of their operations. Moreover, a review of recent operations management literature shows inconclusive research results on whether and how the utilization of tracking technology will lead to improved operation control. In order to highlight the main theoretical contributions of this paper, this section discusses how the proposed design principles address the gap in related literature, as it was identified by using the framework of Holmström and Romme (2012). Related to the *context*, a first theoretical contribution of this paper is an in-depth explanation of the problems currently encountered when utilizing tracking technology for operational control in a typical transportation company. In response, a set of design principles has been proposed with the aim to support the development of information systems that solve these problems by adding a layer of intelligence to the tracking technology available in contemporary transportation companies. The theoretical contribution of the set of design principles stems from a thorough explanation of how (i.e., the *action*) and why (i.e., the *generative mechanism*) intelligent products can enhance the utilization of readily available tracking technology, and thereby, complements theory provided by the on-going research program of Holmström et al. (2010), where the focus is on the transition from inventory-based to product-centric tracking technology. Based on the design principles, a prototype system was developed and evaluated in practice, providing a case example of how the application of intelligent products has a positive *outcome* in terms of enhancing the utilization of tracking technology for improved operational control.

7.2 Limitations and directions for future work

This research has four main limitations to be taken into consideration when interpreting the research findings described above. Firstly, to evaluate the design principles, a collaborating role for the researcher was created, due to the request of the management to disturb operations at the case company as little as possible. As only the collaborating researcher was using the prototype, and all feedback of the planners on the prototype was gained via the researcher, certain feedback from the planners about the prototype might not have been taken into account. Secondly, the research as presented in this paper was focused on design principles for information handling and problem detection. Thirdly, the empirical evidence gathered for the evaluation of the design principles was largely qualitative in nature. In addition to these qualitative findings, managers considering the implementation of intelligent products would need more quantitatively expressed performance improvement in order to justify a potential investment. Finally, in line with extant design science research in information systems, the problems and design principles have been identified and evaluated at the same case company. Therefore, while this design study provides insights in specific problems and solutions with respect to utilizing tracking technology, the generalizability of these insights is yet to be confirmed.

In accordance to the above research limitations, future work should focus on investigating and evaluating additional design principles for decision support. Next to that, confirmatory work should be conducted to increase the generalizability of the identified problems and the proposed design principles. Such research efforts should include additional, potentially more quantitative-oriented, performance metrics. One interesting suggestion for a quantitative performance metric follows from the qualitative measures used in this study. The design principles proposed in this paper primarily aim to solve issues that arise when planner notice problems with ongoing operations only when little can still be done to avoid a big impact on the ability to continue the execution of operations as planned. Future work could include a quantitative metric to determine the potential costs of this impact compared to the situation where intelligent products would have provided rapid problem detection and decision support. Finally, exploratory research in other organizational contexts could reveal similar problems with utilizing tracking technology for improving operational control, for which the design principles may also apply.

7.3 Managerial implications

As an increasing number of transportation companies is collecting information for operational control by means of tracking technology, it is expected that many companies will face problems similar to the ones identified in this paper. Therefore, two managerial implications can be gleaned from this study. First, investments in tracking technology are not likely to directly improve operational control. This is mainly due to the fact that manually analyzing the information provided by tracking technology is unfeasible, state-of-the-art information systems are often not be able to timely detect unexpected events, and many complex relations between pallets and trucks cannot be taken into account when making control decisions.

Second, the proposed set of design principles as presented in this paper can be applied to overcome this problem. The design principles aim to guide the development of information systems that add a layer of intelligence to the tracking technology readily available in most contemporary transportation companies. Due to the generic nature of the proposed design principles, it is expected that information systems similar to the prototype presented in this study can be easily developed for other transportation companies. Rapid development of future systems based on the proposed design principles can be enhanced by the use of a generic intelligent product system, such as the Smart Object System (Meyer et al., 2012), which is a by-product of the prototype development in this research. Future information systems developers can primarily focus on customizing the interface between the tracking technology currently in place and the intelligent products software offered by this generic system. In addition, this study provides a thorough explanation of the problem context and solution approach. Therefore, transportation companies facing similar problems when utilizing tracking technology for improving operational control are likely to benefit from the proposed principles as well.

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#	Paper	Context	Action	Generative Mechanism	Outcome	Evidence of outcomes
#1	Heim et al. (2009)	Serv. Ind. Appl.	RFID/GPS only	None	Visibility +	Exp./stat.
#2	Comert and Cetin (2009)	Log. & Transp.	RFID/GPS only	None	Visibility +	Exp./stat.
#3	Kang and Gershwin (2005)	SCM	RFID/GPS only	None	Visibility +	Exp./stat.
#4	Soroor et al. (2009)	SCM	RFID/GPS only	None	Visibility +	Exp./stat.
#5	Rekik and Sahin (2012)	SCM	RFID/GPS only	None	Visibility +	Exp./stat.
#6	Zhou (2009)	Man. Ass. & Rep.	RFID/GPS only	None	Visibility +	Exp./stat.
#7	Shu and Barton (2012)	SCM	RFID/GPS only	None	Visibility +	Exp./stat.
#8	Delen et al. (2007)	SCM	RFID/GPS only	None	Visibility +	Exp./stat.
#9	Zhang et al. (2011)	Man. Ass. & Rep.	RFID/GPS only	None	Visibility +	Exp./stat.
#10	Cheng et al. (2010)	SCM	RFID-enabled intelligence	None	Visibility +	Exp./stat.
#11	Xu (2011)	SCM	RFID-enabled intelligence	None	Visibility +	Both
#12	Brintrup et al. (2010)	SCM	RFID/GPS only	None	Visibility +	Case/field
#13	Kumar and Schmitz (2011)	SCM	RFID/GPS only	None	Visibility +	Case/field
#14	Ngai et al. (2007)	Man. Ass. & Rep.	RFID/GPS only	None	Visibility +	Case/field
#15	Gaukler and Hausman (2008)	Man. Ass. & Rep.	RFID/GPS only	None	Control +	Exp./stat.
#16	Heese (2007)	SCM	RFID/GPS only	None	Control +	Exp./stat.
#17	Schmid and Doerner (2010)	Log. & Transp.	RFID/GPS only	None	Control +	Exp./stat.
#18	Xu et al. (2012)	SCM	RFID/GPS only	None	Control +	Exp./stat.
#19	Zelbst et al. (2012)	Man. Ass. & Rep.	RFID/GPS only	None	Control +	Exp./stat.
#20	Hong et al. (2010)	SCM	RFID-enabled intelligence	None	Control +	Exp./stat.
#21	Meyer et al. (2011)	SCM	RFID-enabled intelligence	Decentralization	Control +	Exp./stat.
#22	Fang et al. (2012)	Man. Ass. & Rep.	RFID-enabled intelligence	None	Control +	Case/field
#23	Ngai et al. (2011)	Log. & Transp.	RFID-enabled intelligence	None	Control +	Both
#24	Wang et al. (2010)	SCM	RFID/GPS only	None	Control +	Case/field
#25	Dehning et al. (2007)	SCM	RFID/GPS only	None	Control +/-	Exp./stat.
#26	Sari (2010)	SCM	RFID/GPS only	None	Control +/-	Exp./stat.
#27	Guo and Zipkin (2009)	Log. & Transp.	RFID/GPS only	None	Control +/-	Exp./stat.

Table 1: Classification table.

Context			Action		Generative Mechanism		Outcome		Specification of outcome		
SCM	Supply Chain Management	16	RFID/GPS only	21	None	26	Visibility +	14	Exp./ stat.	Experiments or Statistical Methods	20
Man. Ass. & Rep.	Manufacturing, Assembly and Repair	6	RFID-enabled intelligence	6	Decentralization	1	Control +	10	Case/ field	Case studies or Field Studies	5
Log. & Transp.	Logistics and Transportation	4					Control +/-	3	Both	Both of the above	2
Serv. Ind. Appl.	Service Industry Applications	1									

Table 2: Summary of descriptors of papers from Table 1.

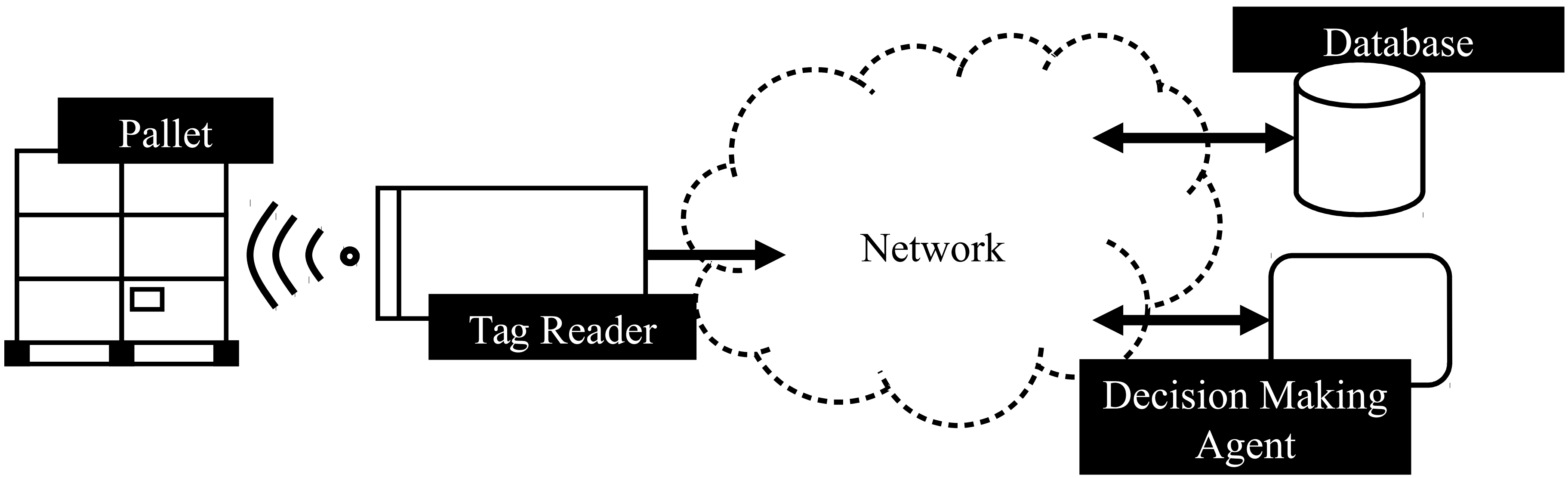

Figure 1: An intelligent product