Cost-Benefit Model for Smart Items in the Supply Chain

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Abstract. The Internet of Things aims to connect networked information systems and real-world business processes. Technologies, such as barcodes, radio transponders (RFID) and wireless sensor networks, which are directly attached to physical items and assets transform objects into Smart Items. These Smart Items deliver the data to realize the accurate real-time representation of 'things' within the information systems. In particular for supply chain applications this allows monitoring and control throughout the entire process involving suppliers, customers and shippers. However, the problem remains what Smart Item technology should be favored in a concrete application in order to implement the Internet of Things most suitably. This paper analyzes different types of Smart Item technology within a typical logistics scenario. We develop a quantification cost model for Smart Items in order to evaluate the different views of the supplier, customer and shipper. Finally, we conclude a criterion, which supports decision makers to estimate the benefit of the Smart Item. Our approach is justified using performance numbers from a supply chain case with perishable goods. Further, we investigate the model through a selection of model parameters, e.g. the technology price, fix costs and utility, and illustrate them in a second use case. We also provide guidelines how to estimate parameters for use in our cost formula to ensure practical applicability of the model. The overall results reveal that the model is highly adaptable to various use cases and practical.

1 Introduction

Supply chain scenarios in logistics are an interesting field to apply information and networking technology to objects or things. Here, embedding technology into the application results not only in qualitative improvement - e.g. user satisfaction - but also in quantitative improvement, e.g. process optimization. By implementation of quantitative improvements, the technology of things goes beyond general applicability into the business domain.

This paper is largely inspired by the fact that the use of technology, namely in wireless sensor networks, pervasive computing and ubiquitous computing, allows tighter coupling of information about the overall process and the actual process status itself. This is reflected in Figure 1 showing a status of the information world, and a status of the physical world (figure is adopted from Fleisch, Mattern [1]). More complex technology obviously provides closer matching of both

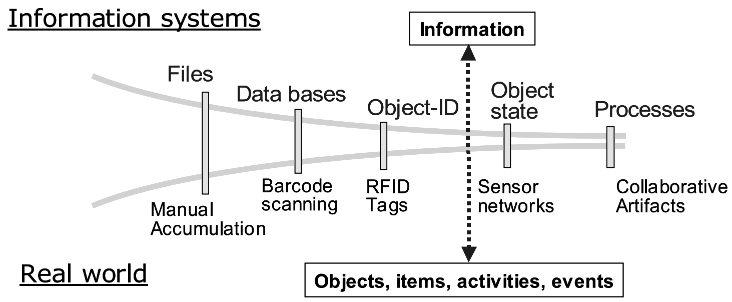

Fig. 1. Bridging the gap between the real world and information systems

worlds, while less complex technology means more fuzzy information. With today's barcode enabled business processes, mostly object-types are collected in databases. Such information offers performance measures for supervision on a process level.

This paper focuses on logistic processes, and the use of information technology in logistic processes. In this business area the use of electronics making objects and processes smart is already a concept used in some settings [2]. The use of RFID tags for example allows acquiring knowledge about an items location and activities through reading the objects identification. This information is used to accelerate supply chain throughput, thus enabling e.g. lower intermediate inventory stock [3].

A more advanced technology can be attained by the use of sensing technology. A sensing and networking unit is added to each item of a logistic process, e.g. to each container for a chemical good transportation process or to each box of vegetables in a food supply chain process. The electronic device continuously supervises the condition of the item, and reports this information. Reporting can either be carried out continuously or on dedicated synchronization points. The most advanced technology comprises the use of Collaborative Artefacts. Collaborative Artefacts add processing power and smart behavior to the smart sensor node that is attached to every good or item. They are able to operate independent from an infrastructure and allow spontaneous ad-hoc collaboration with other devices and computers within vicinity. Here, integration of technology allows close collaboration of items and of business processes. One example of such an application is the CoBIs project [4], where items not only deliver information. They also control the business application collaboratively together with business process systems.

1.1 Problem Statement

Such closer control is envisioned to dramatically improve the supply chain process quality. For example, perishable food commodities are prone to post harvest loss in the magnitude of 25% [5], mostly while transport. Sources from the US [6] even report that 40-50% of the products ready for harvest are never consumed - a total sum of several billion dollar per year. Application of Smart Items into supply chains may therefore be able to save costs in the magnitude of millions or even billions of dollars.

Although such numbers show sheer endless potential for the use of technology in a supply chain process, for any concrete logistic process, benefit has to outweigh cost to be economical feasible. To justify this we require a pre-calculation of cost and benefit. This paper will present a simple, but powerful cost model taking into account overall costs of a logistic process, including the cost for technology, but also the benefit cost when using the technology. The proposed model allows calculating and optimizing the usage of technology in logistic processes for decision makers. The model also enables decision makers to estimate benefits and to justify decisions. E.g., the model can find break-even points at what cost level technology pays-off, and it allows to find the appropriate density of technology usage for a given logistic process.

The paper is driven by applicability, and the model is thus reduced to a set of parameters that are simple to estimate in a technology evaluation process. The paper is focused at supply chain processes and ensures simplicity of use through a black box approach. This allows to only model the most important parameters and views of a supply chain process, and the use of technology therein. The paper will take three different views on the process, which are independently modeled: The supplier, the shipper, and the customer. Each of them may independently optimize its cost function for the use of Smart Item technology. The cost formula developed within this paper will enable potential applicants to quantify costs and benefits of use of technology within logistic processes, and especially supply chains. It will also introduce a guideline how to approach the problem of finding parameters for the formula and describe the steps required.

1.2 Paper overview

The paper first analyzes an existing logistic scenario and discusses the use of technology in supply-chains. The scenario is used to develop the parameters used in a cost model for supply chains. In Section 3, six cost models are presented, two for each of the major stakeholders in a supply chain: the supplier, the shipper and the customer. The cost model is explained in Section 4 using a concrete example. Section 5 provides a short guideline how to estimate and calculate parameters for the cost model in an effective way.

2 Supply-Chain Scenario Analysis

A logistics process in a supply chain consists of planning, implementation and control of a cost efficient transport and storage of goods from a supplier to a customer according to the customer's requirements [7]. The main goal is an increase of the customer's utility while optimizing the performance of the logistics. The basic logistics functions are to transport *the right goods in the right quantity and right quality at the right time to the right place for the right price.* Information systems keep track of the logistics process and implement various techniques to enable the basic functions. Figure 2 associates the functions with the techniques used by information systems. Further it shows different Smart Item technologies and their coverage on the techniques. The information system requires to identify goods to link electronic processes to the real item. Tracing is necessary to let the system detect when an item gets lost. As a result, it ensures that the right amount of goods is delivered. Location tracking enables the information system to keep track on the transport itself. During the transport the good is not under the control of the supplier. In order to ensure the quality of the delivered goods, an appropriate monitoring of the goods' state is necessary. Having all these data within the information system, the overall logistics process can be observed in very detail. It allows real-time actions to unforeseen events, to determine bottlenecks and it provides the basis for optimization. Finally, this will affect the price accordingly.

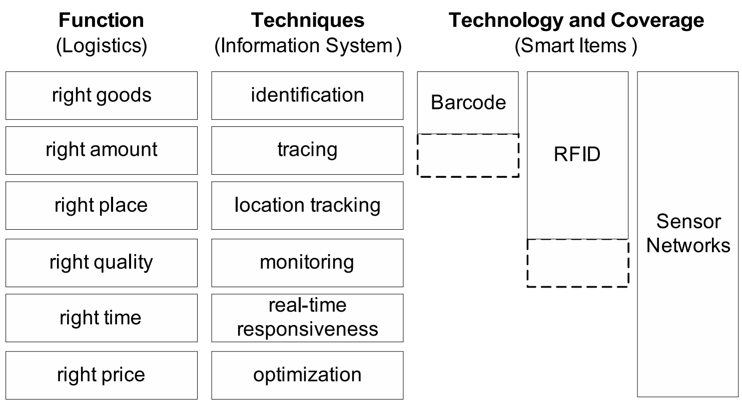

Fig. 2. Techniques of an information system to implement the logistics functions. It also shows how well three Smart Item technologies (barcode, RFID, sensor networks) cover the basic functions. Dashed areas indicate partial coverage.

Various technologies have been developed for acquiring logistics data electronically directly from the good and process and then delivered to the information system. We refer to this technology as Smart Items. Depending on the technical capabilities (basic to advanced) Smart Items cover different techniques.

Barcodes are a current state-of-the-art technology for electronic identification of goods. A barcode label is attached on the goods and then optically detected by a barcode reader. The reader de-ciphers the printed identification and sends it to the information system, which updates the good's record. Barcodes can support tracing only partly. The line-of-sight requirement makes it impossible to detect single items within a pallet of goods. Solution for in-transit inspections would require a complex infrastructure. As a consequence, barcodes can only be used in loading and unload processes at the ramp at a very coarse-grained scale.

Radio Frequency IDentification (RFID) [8] is a radio-based identification technology. Line-of-sight is not necessary. This allows identification of single items within a box of items. Location tracking and tracing is possible as far as the infrastructure of RFID readers is deployed [9]. A mobile infrastructure, e.g. GSM based readers, allows even a remote identification and tracing while the goods are in transit. Novel RFID transponders acquire sensor information of the goods, e.g. temperature or pressure or shock, during the transport and enable a monitoring of goods' state. However, those sensing capabilities are very limited.

Wireless sensor networks are an upcoming advanced Smart Item technology for logistics processes. Sensor nodes are tiny, embedded sensing and computing systems, which operate collaboratively in a network. In particular, they can be specifically tailored to the requirements of the transported goods. In contrast to previous technology, which delivers data to an information system, sensor networks can execute parts of the processes of an information system in-situ directly on the items. Goods become embedded logistics information systems. For instance, CoBIs [2] presents a sensor network example of storing and in-plant logistics of chemical goods, which covers all identification, tracing, location tracking, monitoring and real-time responsiveness at once.

2.1 A Smart Logistics Example

The following example of the logistics process is derived from previous experiences in [2], [10] and [11]. This example draws a picture of a supply chain process that uses most advanced Smart Item technology. We will first present the example and then analyze the example at the end of the section.

A customer orders chemical substances from a supplier. The supplier subcontracts a shipper for the transport of hazardous chemical substances. The orders and acceptances are recorded in an Enterprise Resource Planning (ERP) system. In this scenario it is important to note that all participants are permanently informed on the state of the transport during the complete process. This is because of legal issues since supplier and shipper are commonly responsible for the safety. This logistics process is very complex because it requires the management of goods in different, potentially unforeseen situations involving different participants. As a consequence, there is a need for smart technology enabling a continuous supervision at any time and place in order to implement this management.

The chemical containers are Smart Items using wireless sensor network technology. The sensor nodes are attached to the containers, identify the containers and constantly monitor their state, e.g. temperature. Further, they establish a network between Smart Items to trace the load of all containers to deliver. The shipper provides a mobile communication infrastructure for the Smart Items with an uplink to a wide area network, e.g. GSM. As a consequence, all participants can query the state and location of their delivery. Figure 3 illustrates the smart logistics process using Smart Items. Following the eSeal approach in [10], the

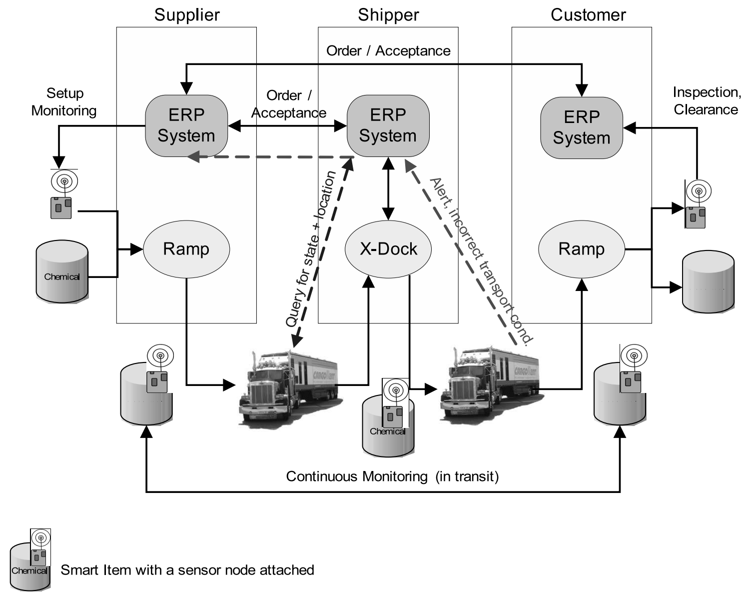

Fig. 3. Smart Items logistics process

supplier first setups and configures all Smart Items with basic transport information. It comprises container identification, destination, transport conditions, size of the delivery, and time to destination.

The shipper plans the routes separately. The different orders are summarized and re-organized in a cross-dock (X-Dock) in order to optimize the utilization of trucks. For instance, loads with the same destination are packed into one truck. Other parameters and real-time conditions can also be used for optimising the supply chain. E.g., the supplier and the shipper have to ensure that no hazardous material combination, e.g. flammable and oxidizing substances, is loaded into the truck. Instead of transporting all information to both (supplier and shipper) ERP systems, the Smart Items take care of this by checking the identification of surrounding containers and environment conditions (e.g. temperature). In case of an incompatibility, the items raise an alert.

During transport the Smart Items constantly supervise the transport conditions, e.g. temperature of the chemical containers. Using an uplink to a wide area network the state of Smart Items can directly be queried and checked by the process participants in order to fulfill the safety responsibility. Further, the location can be electronically tracked. Smart Items act proactively and will raise an alert and send out a notification to a participant, if some transport condition does not hold anymore. Appropriate actions can be triggered, e.g. the truck driver is notified immediately to check the load. The Smart Items also trace their packaging. In case that the delivery is accidentally split or a container is left behind, the Smart Items will raise an alert. As a result, Smart Items ensure that the right amount of goods is delivered. All alerts are locally logged for later revision in case that the person in charge is not reached or the alert is ignored.

When the delivery reaches the customer, the Smart Items automatically inform the ERP system on the delivery and the state. Identification and amount are inspected immediately and clearance is given accordingly. If the transport conditions are violated, then a retour process will be initiated and the participant in charge will be determined through the logging data.

Finally, the usage of advanced Smart Items such as wireless sensor networks helped to prevent losses and accidents during the transport. The example shows that Smart Items can accurately supervise the entire smart logistics process.

2.2 Benefits and Deduction of Parameters for a Smart Items based Supply Chain

We expect major improvements by the usage of Smart Items within the smart logistics process. Based on the benefits we will identify affected parameters for a Smart Items based supply chain model:

1. Reduction of critical situations for goods. Smart Items monitor the goods continuously and alert a person in charge when the transport conditions are not appropriate anymore. This leads to a prompt reaction, which prevents further damage or even loss. As a result, we expect a reduced ratio of defective or perished goods and a (positive) change in the
   (a) return costs
   (b) costs for removal of defective goods
   (c) lower transport costs due to lower reshipping rate and higher shipping throughput
2. Clear assignment of responsibilities. If the alert is ignored or the reaction is delayed, the Smart Items will determine and prove the damage or loss of goods. The shipper can accurately be taken into responsibility for the amount of defective goods. This allows for a transparent supply chain process and a clearer separation of costs between supplier and shipper.
3. Since the overall amount of defective and lost goods is known through Smart Items, the supplier is able to accurately conclude on the ratio of defective goods, which is inherent (and previously unknown) in his delivery. This is expected to raise consumer (customer) satisfaction.

As a consequence of the Smart Items usage, each participant in the logistics process can accurately determine his responsibility for the amount of defective goods and transport losses. This enables the potential for process optimization, but involves a complex interplay between the participants and the used technology. In the following section, we break down these relations and we quantify them based on the above analysis of the process.

3 Smart Items Quantification Cost Model

In this section we introduce our model for quantification of Smart Items usage in logistic processes. We describe a cost model of the logistics process and quantify the profit for different technological approaches ranging from simple Smart Items, e.g. barcodes, up to very complex Smart Items, e.g. wireless sensor nodes. In this investigation we adopt three different positions of the three stakeholders: supplier, shipper and customer. For all stakeholders the amount of defective and lost goods determines their profit. Therefore, our approach focuses on how Smart Items relate to lost and defective goods. Important in the model is the complexity of the different technologies from Section 2. We model it by the density ratio ρ. The more complex the technology gets, the larger is the density. Our model describes the shipment scenario in a simplified form and within an ideal environment, e.g. the error free functionality of the Smart Items, the supplier only produces one type of good and the parameters and variables are known or can be determined through a simulation or a field trial. In Table 1 the used variables and parameters are defined and explained.

3.1 Analysis from the Supplier's Point of View

First we define a simplified profit function (Equation 1) for a supplier who uses Smart Items (SI) with limited capabilities, e.g. barcode or passive RFID tags.

$$
\begin{aligned}
\prod\nolimits_{perShipment}^{SimpleSI,supplier} &= ((1-\omega)p_{good} - c_{production}) \cdot q_{sales} && \text{turnover} \\
&- \omega \cdot q_{sales} \cdot c_{retour} && \text{costs for processing defective good} \\
&+ \psi \cdot s \cdot q_{sales} && \text{penalty for shipper for loss} \\
&- C_{fix} && \text{fixed costs}
\end{aligned}
\tag{1}
$$

The profit $\prod$ (Equation 1) results from margins between the price of the good p_{good} and the costs of production $c_{production}$ per unit multiplied with the amount of sold units q_{sales} less the defective goods ω which were delivered to the customer. The defective goods which were delivered to the customer need to be manually addressed with costs c_{retour}. The shipper has to pay a fee s depending on the price of the good p_{good} for the ratio ψ of goods lost or not delivered in time. The fee is a compensation for costs of damage, customer dissatisfaction and loss of reputation. Additionally the fixed costs C_{fix} get deducted. The profit

p_{good}	price charged for good
$c_{production}$	variable costs of production per good
q_{sales}	amount of sold/distributed goods
c_{retour}	cost of manual processing of returned goods (defective or perished)
C_{fix}	fixed costs
$C_{fix,SI}$	additional fixed costs using Smart Items (infrastructure)
$c_{operation}$	variable operational costs per Smart Item and shipment (e.g. recharge battery, programming)
c_{SI}	acquisition costs of Smart Item
s	penalty depending on cost of goods (shipper ⇒ supplier)
$p_{transport}$	price of shipping per good (to be paid by the customer)
$c_{transport}$	variable transportation costs per good (for shipper)
$p_{special}$	additional shipping charge for usage of Smart Item per good
$c_{capacity}$	costs of capacity loss for reshipping
c_{GSM}	costs of message sent over GSM to ERP-System
F	fleet size of shipper
W	non quantifiable advantage through usage of Smart Items (consumer satisfaction, etc.)
$\rho \in (0, 1]$	factor of density, ratio of Smart Item quantity to quantity of goods
$\nu \in [0, 1]$	factor of maintenance: $\nu = 0$ all Smart Items get shipped back (reusable); $\nu = 1$ no Smart Item is returned
$\omega \in [0, 1]$	ratio of defective goods delivered to customer
$\phi \in [0, 1]$	ratio of triggered Smart Items, $0 \leq \phi \leq \omega \leq 1$
$\psi \in [0, 1]$	ratio of searched (potentially lost) goods during shipping
$\kappa \in [0, 1]$	ratio of recovered goods (previously lost)

Table 1. Variables and parameters for the Smart Items cost model

$\prod$ is interpreted as a profit per shipment. To model the profit under usage of advanced Smart Items (e.g. wireless sensor nodes) Equation 1 is extended to Equation 2.

$$\begin{aligned}
\prod\nolimits_{perShipment}^{Adv.SI,supplier} = {} & ((1-\omega)p_{good} - c_{production} - \rho \cdot (c_{SI} \cdot \nu + c_{operation})) \cdot q_{sales} \\
& - (\omega - \phi) \cdot q_{sales} \cdot c_{retour} && \text{costs for processing defective goods} \\
& + \phi \cdot q_{sales} \cdot s && \text{penalty for shipper for damage} \\
& + (1-\kappa) \cdot \psi \cdot s \cdot q_{sales} && \text{penalty for shipper for loss} \\
& + W && \text{not quantifiable advantage} \\
& - (C_{fix} + C_{fix,SI}) && \text{fixed costs plus SI invest}
\end{aligned} \tag{2}$$

An important parameter is the density factor ρ which describes the ratio of goods with Smart Items to the amount of goods without. If every good is equipped with a Smart Item, the density factor will be $\rho = 1$. The density factor is proportionally reduced the higher the number of goods per group which are equipped with a Smart Item. E.g. if there is a pallet with 20 boxes containing each 16 TFTs the resulting density factor would be $\rho = \frac{1}{320}$ if there is only one Smart Item per pallet or $\rho = \frac{1}{20}$ for one Smart Item per box. The assumption is, of course, that the goods are equally grouped and the Smart Items are also equally distributed.

The density factor directly influences the profit, as can be seen in Equation 2. Depending on the density of Smart Items, additional costs for operation, acquisition and maintenance arise. If a Smart Item is not reused, its costs will have to be paid for each shipment, which results in a maintenance factor of $\nu = 1$. In the best case of reuse the maintenance factor is $\nu = 0$, i.e. there is no abrasion or loss. Also new in Equation 2 is the parameter ϕ, which indicates the fraction of Smart Items which trigger at least one alert, i.e. at least one detection of violation of the shipment agreements. So the ratio of defective goods due to improper shipment is expressed through ϕ. The supplier does not adhere for the return costs c_{retour} and gets a penalty s per alerted good paid by the shipper. If only a small amount of goods are equipped with a Smart Item, the penalty for the shipper is high since he needs to cover the whole amount of damaged goods. Through the possibility of locating Smart Items, the ratio of shipment loss is reduced by the parameter κ and accordingly the amount of penalty s. The variable W indicates the not quantifiable advantage resulting of the use of Smart Items, e.g. customer satisfaction, positive reputation as a result of fast deliveries, optimization of the shipment process, etc.

The fixed costs C_{fix} include along the original costs the costs for acquisition of the Smart Items and the equipment for programming and reading them.

3.2 Analysis from the Shipper's Point of View

We model the profit function for the usage of low-performance Smart Items, e.g. barcode and passive RFID tags, as follows:

$$\begin{aligned}\prod\nolimits_{perShipment}^{SimpleSI,shipper} &= ((1-\phi)p_{transport} - c_{transport} && \text{penalty paid to the producer}\\ &- \psi \cdot (s + c_{capacity})) \cdot q_{sales} && \text{for loss and loss of capacity for reshipment}\\ &- C_{fix} && \text{fixed costs}\end{aligned} \quad (3)$$

The profit $\prod$ per shipment results out of the shipment price $p_{transport}$ the customer has to pay, less the shipment costs $c_{transport}$ and the ratio ψ. Again, the ratio ψ indicates the loss of goods during shipment, which gets multiplied with the penalty s. In addition, the shipper has to do a subsequent delivery of the lost goods, which results in a capacity loss of $c_{capacity}$.

If advanced Smart Items are used, the resulting profit function is modeled as follows:

$$\prod\nolimits_{perShipment}^{Adv.SI,shipper} = ((1-\phi)(p_{special} + p_{transport}) - c_{transport}) \cdot q_{sales} \quad \text{turnover}$$

$$
\begin{aligned}
&- c_{GSM} \cdot (\phi + \psi \cdot 2 \cdot F) \cdot q_{sales} && \text{penalty for loss} \\
&- \phi \cdot q_{sales} \cdot s && \text{penalty for damage} \\
&- (1 - \kappa) \cdot \psi \cdot (s + c_{capacity}) \cdot q_{sales} && \text{comm. costs} \\
&+ W && \text{not quantifiable adv.} \\
&- (C_{fix} + C_{fix,SI}) && \text{fixed costs including SI investment}
\end{aligned} \tag{4}
$$

Because of specialization and higher effort the shipper needs or can demand a higher price $p_{transport} + p_{special}$. The reduction of shipment loss through tracking of lost goods reduces the payments for penalties by a factor of $1-\kappa$. For detected shipment damage ϕ the penalty s needs to be paid to the supplier. Additionally, the costs c_{GSM} arise for transmitting alerts and tracking ψ of goods. Here the worst case costs are denoted, i.e. all alerts arise outside the reach of an access point at the cross dock stations and for tracking the complete fleet needs to be addressed. The fixed costs C_{fix} comprehend the acquisition of the readers, communication infrastructure and the original fixed costs per shipment. The variable W also indicates the not quantifiable advantage, e.g. customer satisfaction.

3.3 Analysis from the Customer's Point of View

The perspective of the customer is modeled as a profit function with two dimensions, quality and completeness of a shipment aggregating the profit level u. Further values influencing the profit level, e.g. speed of delivery, are omitted for reasons of simplicity. For further extension of the profit function several additional factors can easily be included. The highest profit level is reached at the best case, when the delivery is complete and without defective goods reaching the customer. According to the previous modeling this case occurs when $\psi = 0$ and $\omega = 0$. The result is a normalized Cobb-Douglas function [12] (Equation 5) with its saturation defined in point $u(0,0) = 1$.

$$
u(\psi, \omega) = (1 - \psi)^2 \cdot (1 - \omega)^2 \tag{5}
$$

The Cobb-Douglas function can be seen from two different perspectives in Figure 4. We assume that the improved amount converges into point $(0,0)$. Presumably, the assignment of the budget (allocation) utilizing basic Smart Items, e.g. barcode, is (ψ', ω') and the customer pays the price $m' = (p_{good} + p_{transport}) \cdot q_{sales}$. The amount of defective goods ω can be reduced by a ratio ϕ through the use of more complex Smart Items. This relationship is shown in Figure 5. Besides, the shipment loss can be reduced through tracking by Smart Items in average by $-\kappa \cdot \psi'$, which is also apparent in Figure 5. The allocation is improved from (ψ', ω') to (ψ^*, ω^*). In return, the customer has to pay the increased price $p_{special}$. In sum the costs for the new allocation are $m^* = (p_{good} + p_{transport} + p_{special}) \cdot q_{sales}$.

If the gain of profit through improved allocation is bigger than the loss of usefulness through raised prices, then the customer will have a direct advantage of the use of advanced Smart Items. Let $\widetilde{u}$ be the utility function according to the preferences of the customer that maps monetary units onto a scale comparable

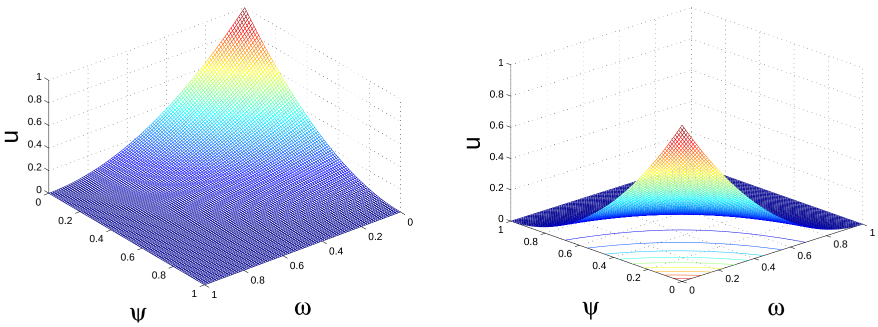

Fig. 4. Gain function $u(\psi, \omega)$ from two perspectives

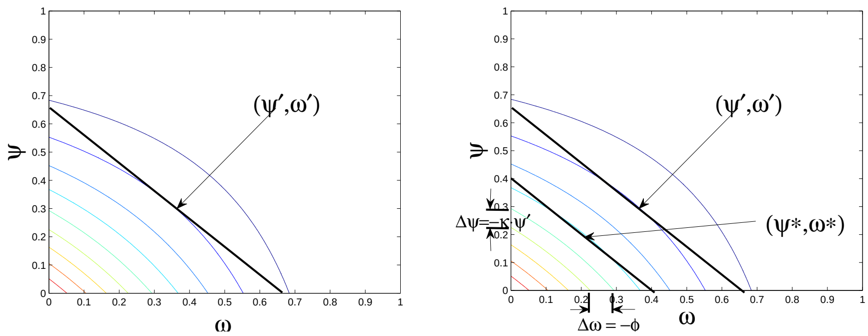

Fig. 5. Indifference curves of $u(\psi, \omega)$

with u. If the following inequality evaluates to true, the customer considers the use of advanced Smart Items as beneficial compared to a technology like barcode.

$$\widetilde{u}(m^* - m^{'}) < u(\psi^*, \omega^*) - u(\psi^{'}, \omega^{'}) \quad (6)$$

4 Use Case for our Model

In this section we will present a simple use case to exemplify the usage of our model. A supplier is selling apples to a customer, which are transported by a shipper. The parameters (e.g. costs) from the model are derived from real world data.

One box of apples holds 18 pounds. In July 2007 a box of apples cost an average of $c_{production} = 5.27\$$ [13] and could be sold for an average of $p_{good} = 17.14\$$ [14] in the United States. We will consider one shipment to be $q_{sales} = 400$ boxes of apples, which is the amount a small truck can transport. From all boxes that arrive at the customer, $\omega^{'} = 20\%$ are rotten. The customer does not pay for boxes with rotten apples and further requires the supplier to pay $c_{retour} = 2\$$ for their disposal. Using Equation (1) we can calculate the supplier's profit when using barcodes for each delivery:

$$\prod_{perShipment}^{barcode,supplier} = 5,484.80\$ - 2,108.00\$ - 160\$ - C_{fix} = 3,216.80\$ - C_{fix} \quad (7)$$

Notice that the supplier looses 20% of his income because of rotten apples. It is also not clear at which point they got rotten (during transport or already at the supplier). To cope with this problem, the supplier decides to track the temperature of the apples during delivery using Smart Items. Every fourth box ($\rho = 25\%$) is equipped with an expensive Smart Item which costs $c_{SI} = 50\$$. The Smart Items are reusable ($\nu = 0$), so the supplier only has to buy them once. Maintenance costs for each Smart Item are $c_{operation} = 0.50\$$ per shipment, e.g. for charging batteries and programming.

Now, the shipper can be held responsible if apples get rotten because of wrong shipping and handling conditions. The tracking with Smart Items further allows the shipper to monitor the apples temperature. Therefore we assume the total amount of rotten apples will fall to $\omega^{*} = 10\%$. Now, only $\phi = 1\%$ of all apples get rotten because of the shipper, so he has to refund the supplier and pay a penalty making a total of $s = 20\$$ to supplier per rotten apple box.

If we consider the fixed costs to stay unchanged ($C_{fix,SI} = 0$), then Equation (2) will show the supplier's profit when using Smart Items as follows:

$$\prod_{perShipment}^{SI,supplier} = 6,170.40\$ - 2,158.00\$ - 72.00\$ + 80.00\$ - C_{fix} = 4,020.40\$ - C_{fix}. \quad (8)$$

The supplier's profit will increase by 803.60$ per shipping. The one time investment of 5,000$ for buying 100 Smart Items amortizes after 7 shipments. Now let us see how the use of Smart Items influences the shipper's business. The shipper charges the customer $p_{transport} = 4\$$ for each box shipped. His costs are $c_{transport} = 2\$$. Through Equation (3) we get the shipper's profit for each delivery with a simple Smart Item technology, such as barcode:

$$\prod_{perShipment}^{barcode,shipper} = 800\$ - C_{fix} \quad (9)$$

When using advanced Smart Items, the supplier will charge $p_{special} = 0.50\$$ extra since he also has to sustain a Smart Items infrastructure. But he will also have to refund the supplier and pay a penalty making a total of $s = 20\$$ for damaged products. The shipper's profit calculated through Equation (4) is

$$\prod_{perShipment}^{SI,shipper} = 900.00\$ - 80.00\$ - C_{fix} = 820 - C_{fix}. \quad (10)$$

The shipper's profit will increase by 20$. Even though he is responsible for the goods he damages during transportation, he will also be earning more money.

Now let us consider how the use of Smart Items influences the customer. We expect him to profit from the smaller amount of rotten apples, even though he will be paying higher transport costs. When using barcodes, we get $m^{'} = (17.14 + 4.00) * 400 = 8,456.00$ and $u(\psi^{'}, \omega^{'}) = (1 - 0.20)^2 = 0.64$. And the use of Smart Items results in $m^* = (17.14 + 4.50) * 400 = 8,656.00$ and $u(\psi^*, \omega^*) = (1 - 0.10)^2 = 0.81$. We assume the following model structure for the customer's utility function: $\widetilde{u}(x) = 1 - e^{-kx}$. This utility denotes the normalized value of an additional (financial) effort x for the customer. The scalar k expresses the slope of the value of the additional effort. In this example, an additional financial effort of $m^* - m^{'} = 200\$$ for more powerful Smart Items leads to 10% less rotten apples. This makes the delivery more valuable for the customer. However, this has to be compared with the value of an additional investment of 200$ per shipment. Inserting the above values into Equation (6) and assuming $k = 0.9‰$ results in the following equation

$$\widetilde{u}(m^* - m^{'}) = 0.16 < u(\psi^*, \omega^*) - u(\psi^{'}, \omega^{'}) = 0.81 - 0.64 = 0.17, \tag{11}$$

The right side of the inequality evaluates to 0.17 and denotes how much more the delivery becomes valuable for the customer. This is due to the reduction of the amount of rotten apples. The customer's additional financial effort has a value of 0.16 according to his utility function. The inequality evaluates to true. The delivery becomes more valuable than the additional effort spent by customer. Hence, the use of more powerful Smart Items pays off.

5 Guidelines for Parameter Estimation

One of the cornerstones of our model is the use of simple abstract parameters that estimate certain values within one type of supply chain. This allows us to compare various types of supply chains, e.g. traditional vs. Smart Items supported supply chains. The major problem for doing so is how to obtain these parameters in a practicable way.

We proposed to estimate the parameters using a black-box approach, as we see it difficult to measure detailed values or to uncover complex interplay within a supply chain. This approach is less sophisticated than a full-blown analysis and may be more error prone. On the other hand, the proposed method is faster and can be carried out at lower costs. Furthermore, it can be applied to supply chains where it is impossible to retrieve a detailed understanding, e.g. because not all participants in the supply chain are willing to participate. The model we present here requires only three stakeholders to work together: The supplier, the customer and the shipper. In the simplest form of the model, we consider only one instance of these stakeholders within the process.

Our proposal for the black-box oriented approach is to estimate parameters based on small trial-runs of the technology. Here, the technology is brought into the supply chain for selected items only, and parameters are continuously measured. In a first run, parameters will not be used for improving the process, but used for quantification of the factors ω and ψ. Additionally, from the calculation model of the supply chains other parameters are derived (p_{good}, $c_{production}$, q_{sales}, c_{retour}, s, C_{fix}, $c_{capacity}$). In a second run, Smart Item technology is used to additionally quantify parameters ν, ω, ϕ and ψ. From the cost calculation for the introduction of the Smart Item technology we finally project the total cost of a full-blown application of technology, and their parameter $C_{fix,SI}$, $c_{operation}$, c_{SI}, c_{GSM}, plus additional known and estimated parameters (F, W).

6 Discussion

The derived cost model is mainly linear. This may be considered as an over-simplification. However, an iterative approach for the parameter estimation could compensate this and reflect a close to the real-world model. If one of the parameters changes, we will initiate a re-investigation of the other parameters according to the method described in section 5. If any two or more parameters depend on each other, this re-investigation will figure out a new parameter set. This accounts for the non-linearity in real-world processes. One has to be aware that this approach increases significantly the effort to work with the Smart Items cost model.

Another point of discussion is the usage of the Cobb-Douglas function introduced in section 3.3. This function structure is neither derived, nor does it have its fundament in a larger theory of logistics processes. However, it has attractive mathematical features and introduces a non-linear behavior which is inherent in real-world processes, but on the other side very hard to model. In our opinion, the non-linearity accounts for the effects that some ranges of parameters have less influence on the overall result than others. In our example a decreasing ratio of loss and defective goods will contribute to the overall utility. The utility gets largest, when approaching zero-loss. However, this is quite hard as the non-linear slope of the Cobb-Douglas function illustrates.

Related to Cobb-Douglas is the customer utility $\widetilde{u}$. It is difficult to determine and may involve many parameters which may require a broader study. The selection of the function and its parametrization may partially depend on psychological factors, e.g. previous experiences in a business domain or personal risk assessment. The utility function is very open to an adaptation according to the specific needs of a concrete domain.

Another point of criticism is the simplifications in the model. We assumed an ideal environment, where the supplier only produces one type of good and Smart Items operate error-free. However, experiences from field trials involving Smart Items, e.g. CoBIs [2], revealed a variety of errors. For logistics applications, the most crucial are RF shielding, i.e. the Smart Items cannot communicate to each other anymore, and the power supply of the electronics. Latter adds significantly to the operation costs.

A deeper investigation on the effects of our design decisions is clearly a task for future work.

7 Related Work

The research on RFID and related technologies for supply chains of specific business and market contexts is well established. In many cases the research is driven by applications or scenarios where technological solutions for specific market segments (e.g. grocery stores) are developed or evaluated [15][16][17]. Examples can be found in various areas, e.g. livestock tracking [18], military [19] and evaluations of pilot projects of retailers such as Gillette [20], Tesco, Wal-Mart [21], Metro AG [22], and Smart Packaging of Hewlett-Packard [23]. The main discussions of RFID driven applications is currently appearing in whitepapers of technology consultants or magazines (e.g. RFID Journal, Information Week or Infoworld.com) and are facing the challenges of poor forecasting accuracy, low effectiveness and responsiveness, high inventory, high returns processing cost and the presence of counterfeit products in their value chain [24].

Many researchers concentrate on technical aspects of RFID applications which are emphasized in several engineering and computer science publications outlining the system architecture and circuit design. The replacement of barcodes to automatically tag and inventory goods in real-time situations, including the whole process chain is just seen as the beginning. The real benefits come from high level uses like theft and loss prevention, reduced turnaround times, avoidance of unnecessary handling and streamlined inventories [25][26]. The main focus of many consulting-oriented and management-related publications is the integration of new technology in ERP systems to provide managerial insights. They offer an in-depth technological overview of state-of-the-art developments and outline different aspects of e-business and supply chain management [27][28][29]. From the general technological and integration approaches analytic models have been derived to show the benefits and costs resulting from the usage of the RFID in supply chains. In [30] item-level RFID usage for decentralized supply chains is discussed by means of two scenarios for one manufacturer and retailer. Within these particular scenarios they capture important benefits reflecting real-world cost considerations in a model based on RFID.

8 Conclusion and Outlook

The proposed cost model for supply chain management is a first step towards estimating the benefits of introducing Smart Items into a logistic process. We presented separate cost models for supplier, shipper and customer. This allows for split benefit calculation, which is often required in supply chain management processes where mixed calculation is not possible or not attractive.

The proposed model can be used to maximize profit according to different types of technologies for Smart Items. It also incorporates different granularities of technology applications. We have shown in this paper, that there are three classes of technology to be distinguished: the use of barcode, the use of RFID tags and the use of (smart) sensor systems and networks. Each of these options require a set of parameters to calculate their costs. To simplify estimation and calculation of these parameters we introduced guidelines to increase practical applicability of our model.

Our ongoing and future research has two directions. Firstly, we try to evaluate the model on further trial runs and collect experiences regarding the applicability of the guidelines and the cost model. Secondly, we seek to identify parameters that can be used for standard settings, and different technology options. This requires to define standard procedures for various types of supply chain applications, and to perform test runs on the same process using various technology options. Although we have experienced, that this will be very restricted to the specific application case, we envision to commence such parameter and data collection based on our approach on a case by case basis.

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