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RFID IN MANUFACTURING: THE INVESTMENT DECISION

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Abstract

RFID technology promises to improve a broad range of processes in logistics and manufacturing. However, market acceptance of RFID develops slower than anticipated. One likely reason is the difficulty to evaluate the resulting effects beforehand. A lot of research has already been conducted on how to assess costs and benefits of RFID investments. But until now the focus has mainly been on logistics applications. The manufacturing domain still lacks dedicated models for the costs and benefits of an RFID rollout, especially concerning the intangible, non-quantifiable aspects of such an investment. In this paper we suggest some guidelines assessing both the quantifiable and the non-quantifiable aspects of RFID in manufacturing. We present a structured model that guides decision makers along crucial trade-offs in this particular domain. Our work is based on case studies conducted at production plants in different industries.

Keywords: RFID, manufacturing, IT investment, intangible benefits, risk assessment.

1 INTRODUCTION

Over the last years, improvements in radio-frequency identification (RFID) technologies, such as increased data storage capabilities, reduced tag prices, and improved robustness of tags, have made RFID-based applications increasingly appealing to a wide range of industries. In logistics, RFID is already used in numerous applications. More recently, RFID applications on the shop floor have received increasing attention (Chappel et al. 2003). In this context, however, it is often unclear if and when RFID outperforms well-known alternatives, such as the barcode. Thus, when investing in RFID, managers face the classical IT investment dilemma: IT investments often do not have a “direct value in [their] own right”, they rather open up “a potential for derived value”, stemming from a reorganization of business processes supported by the new technology (Remenyi et al. 2000). As a result, it is often impossible to do reliable return-on-investment (ROI) calculations ex-ante. According to Lucas (1999), the likelihood that IT investments generate a positive ROI is 50% or even below for most investment types (infrastructure investments, investments focusing on indirect returns, strategic applications, transformational IT etc.).

However, does this really mean that such investments tend to be bad, or does the problem rather lie within the often short-term monetary focus of the chosen performance indicator? Many benefits - but also some risks - of RFID are hardly measurable in monetary terms in the first place. RFID investments might, for example, affect the company’s image, its relationships with customers and suppliers, or employees’ motivation. All these effects are hardly quantifiable (particularly beforehand). Consequently it is “not possible to cost the total impact of an IT project” (Costello et al. 2007). This also means that investment appraisal techniques alone are unsuitable to assess IT-investments reliably (see criticism by Millis and Mercken 2004). Instead, multi-dimensional evaluation models are needed to address the intangible aspects of such investments. This is particularly true for investments in RFID which is often regarded as an enabling technology and a strategic investment. However, as our in-depth interviews with practitioners revealed, managers mostly rely on rather primitive assessment methods during the investment decision-making process.

Managers prefer assessment methods that are clear, efficient and simple.With our decision model for RFID rollouts in manufacturing we address these three objectives. The model should be *clear* in order to make the decision process transparent. The demand for *efficiency* poses constraints on the resources used in the decision process. Furthermore, the effort to use a decision model must be kept reasonably low or otherwise it will not be accepted by the employees. Finally, a decision model should be *simple* and easy to understand for all involved parties. Simplicity is closely related to clarity and efficiency. A simple model makes the decision process comprehensible and keeps the overhead low.

With our decision model we present a holistic evaluation approach that takes into account both quantifiable (tangible, monetary) and non-quantifiable aspects of the investment. Our aim is to provide managers with means to estimate the benefits of RFID when making rollout decisions. We thus address the main obstacle that leads to decisions against RFID, viz., the inability to foresee concrete benefits (Schmitt and Michahelles 2008).

Note that we use the terms quantifiable, tangible, and monetary interchangeably, and as opposed to the terms non-quantifiable, intangible, or non-monetary. As we will discuss later, this taxonomy is independent of the taxonomy classifying certain measures into being operational vs. strategic. Figure 1 gives examples of all four possible cases. The boundaries between operational and strategic are somewhat fuzzy, as are the boundaries between quantifiable and non-quantifiable. Especially the latter classification should not be seen as a dichotomy but as a spectrum.

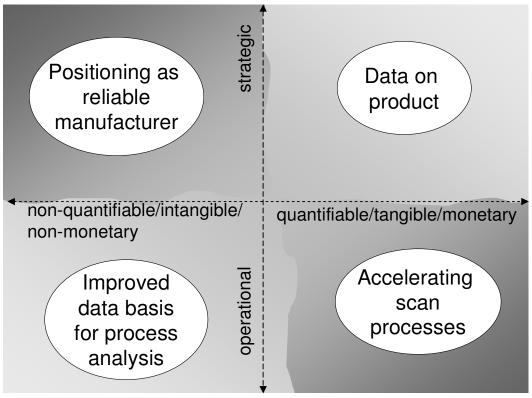

Figure 1. Aspects of an RFID rollout in manufacturing.

The remainder of this paper is organized as follows. The next section gives an overview of related work. Then we present derived objectives for applying RFID in manufacturing. Thereafter, we describe the peculiarities of RFID introduction in manufacturing, split into two sections. The first one deals with the assessment of quantifiable costs and benefits, the second one with non-quantifiable aspects of RFID introduction in manufacturing.

2 RELATED WORK

For decades, researchers have been working on the challenge to assess investments in IT. As a result, a large number of models and frameworks have been developed (see e.g. Pietsch 1999 or Costello et al. 2007). As RFID is an information technology, these general IT investment models are of interest for the assessment of RFID investments, even though they are often purely conceptional, arguing mostly on a meta-level. Thus they are not directly applicable to concrete investment decisions on the introduction of RFID in the manufacturing domain. One of the earliest models was Rockart's (1982) critical success factor approach. According to Rockart, there are four key factors determining the success of IT investments: quality of the system's service, communication between management and users, human resources in the company, and the new system's ability to reposition the information system's function from an "automated back office to a [...] ubiquitous function involved in all aspects of the business".

Although published almost 30 years ago, Rockart already identified the ubiquity of information systems as a key factor for IT investment success – a strong argument for the introduction of RFID throughout the company, including manufacturing processes. However, Rockart's set of factors also indicates that *ubiquity* alone is not sufficient and needs to be accompanied by other components, such as technology acceptance, intense communication, and management skills. A more recent model along those lines is the balanced scorecard approach developed by Kaplan and Norton (1992). The balanced scorecard was initially conceived as a general management tool, but was soon adapted to the specific needs of IT investments. Other popular IT investment evaluation approaches are Seddon et al.'s information systems effectiveness matrix (1999), DeLone and McLean's model of information systems success (2003), or Farbey et al.'s (1995) information system benefits evaluation ladder. However, all these approaches do not take into consideration the very specific challenges of RFID-related IT investments.

During the last years, more RFID-specific evaluation methods have been developed. One recent stream of research addresses the issues of imprecise and uncertain information by applying fuzzy logic to solve the underlying investment decision problems. Bozdağ et al. (2007), for example, propose a fuzzy analytic hierarchy process with a hierarchy of four main criteria (scientific and technological merit, potential benefits, project execution and project risk). However, such approaches include complex mathematical computations and therefore do not meet the simplicity and clarity criteria which we focus on. Although being very valuable for specialists, they are not ideally suited for applications in small and medium-sized enterprises where the management often has little decision-modeling experience. The same holds for proposals to apply option models from financial theory (e.g., Black and Scholes, 1973) to IT and RFID investment decisions (Lucas 1999, Curtin et al. 2006). In order to be applicable to a wide range of companies, less sophisticated approaches are needed, such as value benefit analyses, as discussed by Tellkamp (2005).

Other methods take a more fine-granular approach and focus on the effect that RFID has on atomic activities. Laubacher et al. (2005), for example, conduct an activity-based performance measurement. GS1 (2005) show the impact of RFID on logistic processes with an Excel-based calculation tool for cost benefit analysis of RFID rollouts in supply chains. The Auto-ID Center developed a web-based tool for estimating the impact of RFID (Tellkamp 2003). However, only the EPC Value Model (Lee et al. 2004) focuses more on the role of manufacturers. Unlike our work, this Excel-based tool targets mainly benefits in the manufacturers supply chain rather than on the shop floor.

Still, all these methods are not tailored for RFID rollouts in the manufacturing domain, and they strongly focus on financial issues, omitting to a large extent the unquantifiable benefits and risks that RFID may have. Specialized models for RFID rollouts in the manufacturing domain have rarely been discussed so far. For example Chappell et al. (2003) discuss potentials of RFID on the plant floor. However, they provide no concrete equations for calculating monetary effects, do not address strategic potentials of RFID nor do they propose a corresponding evaluation model.

In summary, to our knowledge existing RFID assessment approaches still do not provide a concrete method to assess the tangible and intangible aspects of RFID in manufacturing. This paper is going to address this problem by presenting a detailed guide for assessing monetary and non-monetary costs and benefits of RFID applications on the plant floor. We provide guidance to assess RFID potentials that go beyond purely operational improvements.

3 RFID ROLLOUT IN MANUFACTURING: CASE STUDIES

In order to be able to identify tangible and intangible cost and benefits we first analyze objectives for applying RFID technology on the shop floor. For this we choose the case study approach. We visited companies producing sliding clutches (case 1), airbags (case 2), engine-cooling modules (case 3), cast parts (case 4), electronic connectors (case 5), and packaging (case 6). For a detailed description see (Ivantysynova et al. 2008). From these studies we have derived common RFID use cases that we found repetitively in our investigations of the manufacturing domain. These are: accelerating scan processes, extending scan processes, improving data management, automating asset tracking, reducing backend interactions, and unifying labels. Our findings are in line with elaborations in (Chappell et al. 2003) and show the practical relevance of RFID in manufacturing.

A	Cost for reusable RFID tags	a	Frequency that assets are missing without RFID based tracking
$B_{...}$	Used to denote various types of benefits		
$C_{...}$	Used to denote various types of costs	b	labour time for making a data entry without RFID support
D	Cost of removing the RFID tags from an item	$c_{...}$	Used to denote various costs resulting from false or missing data entries
E	Cost of applying required RFID tags to an item		
F	Cost for training staff	d	Frequency that assets are missing with RFID-based tracking
G	Cost for transporting tags associated with an item		
I	Integration cost in the introduction phase of RFID	e	number of manual label scans per service hour
J	Cost per non-reusable RFID tags attached to an item	f	number of forgotten data entries per service hour
K	Cost savings per item to cost sharing models or Discounts	g	Number of production tasks affected by a back-end system failure
L	Number of items per hour labeled with RFID tags	i	number of unreadable barcode labels per service hour
M	total maintenance costs	j	number of unreadable RFID tags per service hour
N	Cost for network technology	k	average number of back-end system failures per service hour
O	Cost for terminal computers	m	number of data mix-ups per service hour
P	Labor cost per hour for scanning personnel	n	Cost for recalling an item
Q	Number of identifiers scanned per hour	o	Opportunity costs resulting from downtimes of the production
R	Cost of required RFID readers		
S	Cost for additionally needed software	p	Penalties for delays resulting from downtimes of the production
T	Expected lifetime of the application in hours		

U	Time which is needed for scanning identifiers with RFID alternatives	*r*	labour time for making a data entry with RFID support
W	Time for scanning an RFID tag	*s*	Penalty per unreadable label
X	Number of batches per hour that need to be recalled due to errors	*t*	number of wrong data entries per service hour
Y	Tracked batch sizes without RFID	*u*	Cost for printing and transporting a barcode label from the printer to a packing station
Z	Tracked batch sizes with RFID	*v*	Number of labels applied per hour

Table 1. Variables.

Accelerating scan processes takes advantages of the fact that RFID works without line of sight. This enables a higher degree of automation in data capturing and can also speed up manual scan transactions. *Extending scan processes* refers to additional read points and increased visibility, as the readability of tags is not affected by dirt or mechanical influences. Thus, RFID can make data capturing feasible at more points than alternative solutions do. *Improving data management* refers to the data storage capabilities of tags. This allows storing production related information right at the corresponding products, thus coupling information flows with material flows. Storage capabilities also *reduce backend interactions* because the logic for controlling production operations can be moved to devices on the plant floor. Thereby IT systems and production processes can increase their level of autarky. *Unifying labels* refers to the ability of RFID to provide different information on the same type of label. Unlike for paper based labels, tags support different data formats.

4 QUANTIFIABLE COSTS AND BENEFITS

In this section we first discuss quantifiable costs and benefits of RFID investments along the identified objectives. We structure this discussion along three parts: general fixed costs, general variable costs, and a quantification of the RFID objectives presented above. One part of the fixed costs arises only in the first period T_0. These are for instance costs of an RFID reader *R* or costs for additionally needed software *S*. Assuming constant equipment utilization over time, another part of the fixed costs is uniformly distributed *from* T_1 to T_n. This are in particular maintenance costs *M*. Variable costs and benefits are basically uniformly distributed between T_1 and T_n. If the proportion of the fixed costs in comparison to the total costs in T_0, is low then a calculation of one period is sufficient otherwise not. When conducting the calculation for more than one period the amount for each T_i with $T_0 < T_i <= T_n$ must be discounted with an appropriate discount rate. However, in the following, we focus on the simplest case where the equipment is used precisely one period.

Note that the implementation of RFID has a lot in common with any generic IT project: the IT project's costs for integration, support, training, and maintenance are much higher than the actual purchase price of the required hardware and software. Therefore the costs should be calculated with the Total Cost of Ownership (TCO) analysis. A complete TCO analysis spans over a specific period of time (such as 5 years) and includes expectation values for all costs to be encountered by the specific company in question. Therefore a TCO analysis cannot be done at a general level, it has to be case-specific. In this section we restrict the discussion to general aspects that apply to any manufacturer. Table 1 explains the relevant variables.

4.1 Fixed Costs

Some fixed costs are common to practically all RFID applications in manufacturing. Equation 1 captures these costs by summing up the cost for software (*S*), hardware (*R, N, A, O*), training (*F*), maintenance (*M*), and system integration (*I*):

$$C_{Fixed} = S + R + N + A + O + M + I + \mathrm{F} \quad (1)$$

If RFID is used as a replacement for an existing barcode solution, C_{Fixed} needs to include write-offs for the already existing solution which is prematurely phased out.

4.2 Variable Costs

Here we have to distinguish closed loop and open loop scenarios. In closed loop applications, RFID tags do not remain on the product post-sale. They are recycled and reused in future production cycles. We can compute the variable costs as the product of the expected lifetime of the application (*T*), the number of items labeled per time unit (*L*), and the cost per item of applying and later recycling the necessary RFID tags (*E* + *D* + *G*):

$$C_{VarClosed} = T \cdot L \cdot (E + D + G) \qquad (2)$$

In many use cases, RFID tags could be applied to transportation units which cycle on the plant floor (e.g., material carriers). In such cases, tags are applied only once. However, the data written on the tag (or associated with the tag) must be changed in each cycle. Depending on the particular setup, this task may require manual intervention which results in variable labor costs. *E* refers to costs of applying tags to an item. *D* refers to costs per tagged item which occur if RFID tags are removed at the end of the production process. Removing tags accounts for additional labor costs. However, no removal is necessary if tags cycle on transportation units on the plant floor. *G* refers to the cost per object for transporting reusable RFID tags between the points of application and removal. Tags may just be transported within the plant floor in applications that are restricted to one plant. Yet, advanced RFID applications may span several production steps in the supply chain and tags may need to be transported between different plants.

In open loop applications, the RFID tags are used throughout several parts of the supply chain and subsequently discarded (or left with the customer). In this case we need to adapt the calculation of variable costs as follows:

$$C_{VarOpen} = T \cdot L \cdot (E + J - K) \qquad (3)$$

Here *J* stands for the costs per non-reusable RFID tags attached to an item. Note that *K* represents cost discounts per item due to cost sharing models or discounts. Cost sharing models are typical of complex supply chains where RFID tags are used by several supply chain partners at once, which then share the related expenses.

4.3 Benefits

In the following we specify expected benefits for all but the objective extending scan processes for quality and efficiency. This is because here the monetary effects cannot be quantified easily.

Accelerating scan processes: One reason for applying RFID is to accelerate or to completely automate the scanning of identifiers. This allows reducing labor costs. Resulting total benefits can be quantified as the product of the expected application lifetime (*T*), the number of identifiers scanned per hour (*Q*), the time saved by RFID (*U* - *W*), and the relevant labor costs (*P*):

$$B_{AcceleratingScanProcesses} = T \cdot Q \cdot (U - W) \cdot P \qquad (4)$$

Extending scan processes for narrowing recalls: Equation 5 estimates the monetary benefits of reducing the batch size for tracking. In the considered case, errors occur at a known single point in time and only affect a single item. Total benefits are the product of the expected application lifetime (*T*), the error frequency (*X*), the improvement in batch sizes (*Y*-*Z*), and the cost for recalling an item (*n*):

$$B_{NarrowingRecalls} = T \cdot X \cdot (Y - Z) \cdot n \qquad (5)$$

Reducing paper based data management: As described above, improving data maintenance by RFID may reduce costs which result from errors in collected production data. This is because RFID can help to automate data maintenance in some applications and thereby reduce the impact of human mistakes. Equation 6 captures the potential savings due to improved data maintenance, taking into account various types of data maintenance errors and related costs. For instance, wrongly configured machines may produce waste ($m \cdot c_m$), forgotten bookings of finished steps may delay the production ($f \cdot c_f$), or manual data entries can be error prone ($t \cdot c_t$). Furthermore, RFID may accelerate or automate data maintenance tasks, thus saving labor costs ($e \cdot (b - r) \cdot P$).

$$B_{ReducingPaperBasedDataManagement} = T \cdot (m \cdot c_m + f \cdot c_f + t \cdot c_t + e \cdot (b - r) \cdot P) \quad (6)$$

Automating asset tracking: Having the right assets available at the right time is crucial for seamless operation of a production plant. The expected monetary benefits can be computed as the product of the expected application lifetime (T), the improvement regarding missing assets ($a - d$), and the related costs ($o + p$):

$$B_{AutomatingAssetTracking} = T \cdot (a - d) \cdot (o + p) \quad (7)$$

Reducing back-end interactions: RFID allows storing data with the corresponding object rather than in back-end databases. Applications that work on data from RFID tags are less vulnerable to system failures than centralized solutions (no single point of failure). Using data from RFID tags, the production can at least temporary continue in case of a back-end failure. We estimate the monetary value of this effect as the product of the expected application lifetime (T), the improvement regarding back-end system failures ($k \cdot g$), and the related costs ($o + p$):

$$B_{ReducingBack\text{-}EndInteractions} = T \cdot (k \cdot g) \cdot (o + p) \quad (8)$$

Unifying labels: One cost driver for printing labels are specialized multi format printers. Another cost factor that is related to label handling, concerns the penalties for labels which can not be read by the customers. We estimate the monetary effect as the product of the expected application lifetime (T) and the improvement regarding unreadable labels ($(i - j) \cdot s$), plus some label transportation costs ($u \cdot v$):

$$B_{UnifyingLabels} = T \cdot ((i - j) \cdot s + u \cdot v) \quad (9)$$

5 NON-QUANTIFIABLE COSTS AND BENEFITS

Despite the advantages of RFID discussed in Section 3, adoption by the marketplace proceeds slower than expected. Among the main reasons for not implementing RFID are the high implementation costs, and the lack of foreseeable benefits. Taken together, this often leads to a negative expected return on investment in the short and medium term. It is, however, necessary to consider not only quantifiable (tangible, monetary) aspects but also non-quantifiable, intangible benefits (and costs). In this section, we analyze potential intangible risks and benefits manufacturers have to take into account.

5.1 Operational Benefits

The case studies show that operational benefits are the main driver in most RFID projects. They provide short-term positive returns on investment, which should convince every controller. However, some RFID applications can leverage additional intangible benefits on top, which may tip the scale in favor of adoption, even though the short-term ROI may be negative. We have observed the potential for such effects regarding improved *production planning*, *process optimization*, and *IT management*.

1. *Production planning* requires accurate information on the availability of resources. RFID enables better control of assets and materials through its tracking functionality, thus reducing loss and search times. The direct effect of this is easy to quantify. However, these applications open up new opportunities by enabling the introduction of more flexible planning methods, such as switching to shorter planning periods (case 4). The same applies to RFID-enhanced methods for material tracking and inventory management. In combination with these methods, RFID can reduce uncertainty in planning (case 6). However, the resulting benefits are rarely quantifiable beforehand.

2. *Process optimization* is often a driver for RFID introduction; e.g. manufacturers exploit properties of RFID (like reads without line of sight) to increase process automation and speed up manual scanning tasks (case 1, 2, 5). This kind of process optimization does not necessarily lead to intangible benefits. However, RFID can also facilitate more detailed data capturing (cases 2, 5, 6). This

enhanced business intelligence might enable data analysts to get more insight into the processes and potentially reveal unexpected potentials for improvements.

3. *IT management* in a plant is certainly affected by RFID introduction. Introducing RFID components into an existing IT landscape allows for a novel distribution of data and logic as well as for new means of data exchange. For instance RFID-based architectures improve the autonomy of system components (case 6). Manufacturer can use the memory on RFID tags to store routing data and to log production data right at the product. This enables system components on the plant floor to operate autonomously. Production stations can operate directly using data from RFID tags and become independent from back-end systems and network connections. Furthermore, RFID can help encapsulating data management tasks (case 3), and support a system's scalability (case 1). As a result, RFID may improve the robustness and availability of the production system. However, the degree of improvement is often unknown before an actual implementation takes place, thus making this benefit very hard to quantify ex-ante.

5.2 Strategic Benefits

The decision whether or not a manufacturer should adopt RFID has impacts beyond the operations on the plant floor. Depending on the specific industry, RFID may be a distinctive factor in a company's strategy. Strategic potentials of RFID may concern *improving quality and customers' service*, *increasing reputation*, and *improving inter-organizational collaboration*.

4. *Improving quality and customer service* are important strategic means to gain an advantage over one's competitors. The introduction of RFID possibly affects the quality and the range of customer services that a manufacturer can provide to its clients. As a side effect of operational improvements, better control of plant floor processes can improve the quality of a manufactures output. For instance, RFID-based process monitoring could enhance the detection and correction of production errors before products are shipped (case 2). Moreover, RFID can improve production quality by helping to ensure that shipments are complete, consistently documented, and that all products passed through the production process correctly. As an additional service, the manufacturer may share the captured RFID data with its clients (case 3). This could streamline operations and leverage benefits at the client side (e.g., better planning due to updates on the production status). Another potential for additional services is to leave RFID tags on the shipped products (case 1). This leverages RFID applications at the client side. For instance, clients could benefit from RFID at their material intake. Manufacturers may also store production data on the RFID tags. This service could help clients routing products through their production and facilitate consistency checks on the plant floor (case 2, 6).

5. *Increasing reputation* is another strategic benefit that RFID can contribute to. A company's reputation can profit from new technology advancements - such as RFID - because the company is perceived as innovative by its business partners (case 1, 3). Additionally, RFID enables narrowing and avoiding recalls for some products (case 2), thus limiting adverse reputation effects associated with production problems.

6. *Improving inter-organizational collaboration* can leverage optimization across value chains and strengthen the position of partner networks. Depending on the market structure, good positioning in such a partner network is a crucial strategic issue. RFID is more and more developing into a technology for inter-organizational collaboration. Collaboration infrastructures – such as the EPCglobal network – are increasingly based on RFID technology. An RFID rollout provides the strategic option to opt into RFID-based collaboration networks and become part of RFID enabled value chains. Examples from the retail industry show that dominant players in a value chain may even force their suppliers into RFID adoption (RFID Journal 2003). These market forces influence manufacturers as well. Thus, getting ready for RFID is of strategic importance for many manufacturers (case 1, 2, 3).

5.3 Risks and Costs

Any IT project bears intangible risks with associated costs that decision makers must weigh against expected benefits. Following we discuss specific intangible risks that are related to RFID technology. We identified three major risk categories concerning *technology integration*, *privacy and security*, and *standardization*. While these general risk categories also exist in supply chain processes, manufacturing shows different particularities within these categories. Specifically the importance of concrete risks differs from supply chain applications.

1. *Technology integration* for RFID systems comprises two levels: (i) the software level for back-end integration, and (ii) the hardware level for physical integration in the process. Properties of the manufacturing environment are crucial for the latter. Solid objects (especially metal) can absorb and reflect RFID signals. Thus, tags may be missed or captured at positions outside the intended reader scope (e.g., at a different process step). At the software level it is necessary to connect RFID middleware to other systems (e.g., an ERP or MES). Like in any IT integration project this poses challenges: e.g., in finding suitable interfaces and organizing the migration to new solutions. A special challenge of RFID data integration is data quality. It is important to understand that raw RFID data can include false positive and false negative reads. It is therefore crucial to define the required data quality and to implement appropriate cleaning mechanisms. Achieving the required data quality can be a serious obstacle in some projects and may pose the risk of failure. It is hardly possible to quantify all these aspects of the technology integration in advance.

2. *Security* continues to be a controversial aspect of RFID applications. The (in-)security of RFID data potentially jeopardize the confidentiality of business operations. The possibility to read out tags without line of sight exposes RFID data to anyone who can come close to the tag (e.g. staff of logistic service providers). It is therefore important to assess the confidentiality of data on RFID tags, to weigh the risks, and to possibly implement counter measures. It may be advisable, for example, to remove or even destroy the tags at the end of the production line. Beyond protecting information on RFID tags, security analysts must carefully evaluate network based exchange of RFID data. Again, one must trade the confidentiality of RFID data against the security risks of the technology used. However, compared to risks regarding technology integration and technology development the risks related to security are less important in the manufacturing domain.

3. *Standardization* is essential for the sustainability of an application and for leveraging network effects. Even though GS1 has released the well known standard Gen2 for UHF tags, still unsolved standardization questions exist. The authorized frequency spectra for RFID must still be harmonized and dominating standards for HF technology are still missing. Even though the standardization situation is improving, there remains a degree of uncertainty for some solutions.

5.4 Assessment

In previous sections we have evaluated non-quantifiable, intangible aspects of RFID in manufacturing. As the reader could see, not all aspects occur in each RFID rollout. Moreover, if they occur, their importance may differ substantially. In order to assess non-quantifiable costs and benefits, we suggest a lightweight multidimensional decision model where one assigns weights to the different aspects, specific to each case. Aspects and weights are represented by a tree whose root represents the specific RFID rollout (Figure 2). The nodes and leaves of the tree correspond to the intangible factors discussed above. Note that on a coarse grained level some – yet not all – factors are also known from RFID applications in supply chain management. Furthermore, some effects in supply chain management (like improved demand forecast) cannot be achieved by using RFID on the shop floor. Therefore, the relative importance of the various aspects is domain specific. Even though in manufacturing each aspect weighs differently depending on the case, we found some general trends in our case studies. In Figure 2, these tendencies are denoted as "++" (for very important) "+" (for important), and "–" (for less important). The tree should be traversed top-down and then bottom-up, while each node is assigned with a relative importance and a score respectively.

Traversing top-down: Managers proceed top-down using their corporate knowledge when assigning weights for the relative importance of each node. For example, production planning may be considered more important than IT management or process optimization. During the top-down traversal, managers assign weights to all descendant nodes in relative importance to each other by using Value Benefit Analysis (VBA), a common scoring model (Bernroider and Koch 1999). The goal of the pair wise comparison method is to create a rank table among the children for each node.

Traversing bottom-up: Subsequently, domain experts traverse the tree bottom-up and give each node a score for an expected improvement or occurring risk. We assign positive scores for benefits and negative scores for risks and their associated expected cost. They start by analyzing all leaves of the tree and assigning each leaf a score. The score denotes the impact of RFID on this particular aspect. We use a standard equidistant scale for the scores. After completing all scores for the leaves, we use the ranking data (the relative importance) created by the management. We calculate a weighted average score for each leaf. Then we assess the final score of the analyzed investment by recursively calculating the scores bottom-up. I.e., for all interior nodes we multiply each child node's score with its relative importance, add the scores of all children, and pass the total score to the parent.

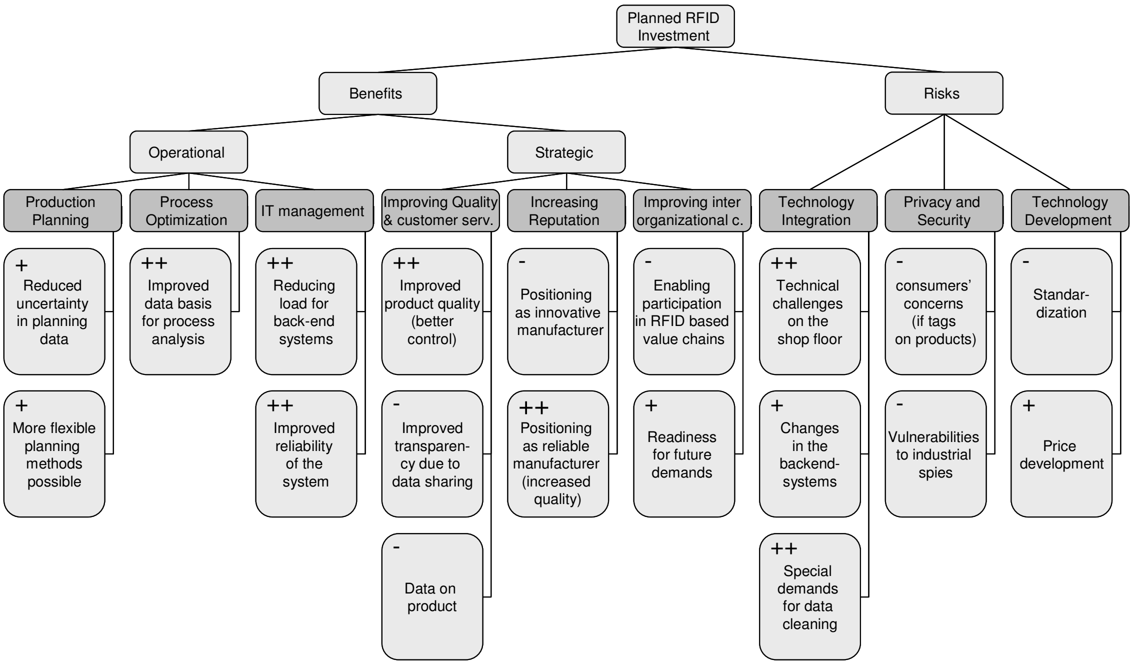

Figure 2. Tree classifying the non-quantifiable, intangible aspects of RFID in manufacturing.

After traversing the tree both ways, we have calculated the overall score for the planed RFID rollout. An analogous approach can be used to evaluate possible alternatives, such as barcode-based solutions. Hereby it is irrelevant whether the competing technology is already in use. If the competing technology is barcode, then the tree can be used as it is. If the RFID rollout should be compared with some other technology, like OCR, the tree would need to be adjusted accordingly.

6 COMBINING TANGIBLE AND INTANGIBLE COSTS AND BENEFITS

Integrating intangible and monetary assessments has always been a challenging task, due to the heterogeneity of decision-relevant factors, as well as the diversity of possible investment scenarios. In general, it is hardly possible to use one type of approach for all types of investment (Andresen 2001). Therefore, we propose to apply different decision techniques, depending on the investment's main focus and motivation. The following investment types (adapted from Lucas 1999) can be distinguished in the manufacturing domain:

Direct returns as the main investment focus: In the manufacturing domain, this is, for example, the case if RFID is implemented to accelerate scan processes. In such a case, the financial assessment is the key for the management's investment decision. Out of several proposed solutions, the one with the highest calculated return is selected. The intangible assessment is secondary and mainly focuses on the assessment of risks, which must not exceed risk limits predefined in the company's policy. The risk assessment can be performed by using the risk-branch of the decision tree presented in section 5.4.

Indirect returns as the main investment focus: Here, the ROI is not quantifiable reliably beforehand. Examples include the implementation of RFID in manufacturing to improve the data accuracy due to more scanning points. This may help to analyze and streamline processes more effectively, which could improve a company's reputation and trust versus its suppliers and customers. In this type of investment, the management should allocate a budget for the envisaged implementation, look for implementations meeting these budget constraints, and then select the implementation with the maximum intangible evaluation score as determined by the decision tree in section 5.4.

Strategic investments that open up new opportunities: As strategic aspects are of utmost relevance, the key factor for the investment decision is the strategy score determined in the intangible assessment (see Figure 2). Preferably, the alternative with the best score is selected, as long as the investment meets budgetary constraints and the risks identified are deemed as manageable. If alternative solutions have significantly different risk scores, the management is advised to do a trade-off analysis between strategic impact and risk.

Transformational RFID investments: These are RFID investments that facilitate a complete reorganization of manufacturing processes. In such investments, all tangible and intangible parameters may be relevant. As a result, the management needs to define minimum thresholds for all criteria. In a first step, all investment alternatives not meeting the thresholds are discarded from further evaluation. For the assessment of remaining solutions, decision makers may use a modified balanced scorecard approach combining the financial perspective, the operational perspective, the strategic perspective and the risks perspective.

RFID as unique solution to implement a functionality: RFID may be the only possible solution to achieve a certain functionality (e.g., to identify products reliably in dirty environments). Here, the key issue is how much the management is willing to pay for the RFID-enabled functionality. Therefore, in a first step, the management defines target costs not to be exceeded. In a second step, all RFID implementations meeting the defined thresholds are assessed from an intangible perspective using the assessment model in Figure 2. Finally, the management performs a trade-off analysis between the remaining solutions' intangible scores and their calculated financial returns.

Mandatory RFID investments: required by law or contracts, e.g., if suppliers have to meet contractual requirements of the original equipment manufacturer. If the investment is mandatory, intangible aspects play a secondary role (as the investment is required anyway) and the focus of managers will be on cost reduction. In terms of the intangibles, managers will primarily look at the risks of the proposed solution and make sure that these do not exceed predefined, critical values. Out of the solutions that meet intangible risk requirements, the cheapest one is selected, unless very large differences in the intangible score have been determined.

7 CONCLUSION

Building upon experiences from a variety of case studies, we have outlined the most crucial tangible and intangible risks and benefits for RFID in manufacturing. Moreover, we presented an easy-to-use assessment scheme for intangible aspects of the decision problem, using value benefit analysis. In order to reflect tangible costs and benefits, a detailed calculation model was proposed that provides the management with an in-depth view of all relevant tangible effects. Another goal of our work was to develop a guideline for RFID adoption that can be applied by managers and experts in the field without lengthy training and within a limited amount of time. Our approach meets this goal

- by drawing attention to all relevant aspects to be considered during the decision-making process,
- by assigning confined tasks to both managers and evaluation experts, so that each group can focus on their field of expertise,
- by providing clear recommendations on how to combine tangible and intangible assessments, and
- by drawing attention to potential risks that are inherent to the introduction of RFID on the shop floor.

However, despite this structured evaluation approach, using our model is not a guarantee for a successful introduction of RFID. This is not a drawback of the model itself but inherent in the underlying investment decision problem. Little available experience with the technologies and related organizational solutions, as well as the heterogeneity of application scenarios, make a reliable assessment of all intangible risks and benefits impossible. However, by guiding managers and experts through the decision process, and by performing the risk assessment outlined in Figure 2, our approach assures that the decision will be as accurate as possible given the limited available resources for the decision-making process, As a result, the remaining degree of uncertainty is reduced. In the future, when more experience with RFID applications in manufacturing becomes available, the remaining uncertainties may be reduced further, thus making RFID investments a less risky venture.

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