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Performance Improvements based on RFID – Empirical Findings from a Cross-sectoral Study

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ABSTRACT

Based on a cross-sectoral survey among 114 RFID-using companies in Germany, the constitutive factors for performance improvement are evaluated. Analyzing realized target variables such as lead time or production downtime, we can show that the performance-enhancing impact of RFID can be ascribed to the three effects *automation*, *informatization*, and *transformation*. However, automation alone – i.e. a reduction of manual data acquisition activities through RFID – does not systematically contribute to performance enhancement. Rather, we found evidence indicating that it is necessary to exploit improved information about enterprise resources (*informatization*) and/or to re-engineer business processes (*transformation*) on the basis of RFID. No matter what sector an enterprise belongs to, investments in RFID technology that are exclusively aimed at an automated acquisition of information are inadvisable. This might be of special interest to companies who are facing a mandate in the near future.

Keywords

RFID, operating efficiency, evaluation.

1 INTRODUCTION

The enormous economic potential of RFID technology has been propagated for years. In recent time, the business success of RFID applications has been increasingly questioned. Main criticisms are aimed at high investment costs, hitherto unresolved technological limitations and organizational challenges (see for instance (Aberdeen Group, 2006; Clinton, 2007; Raghu, 2006; Strüker, Wonnemann, Kähler and Gille, 2007). Furthermore, most analyses that support the business success of RFID applications concentrate on measuring indicators in particular case studies. In some cases, these indicators are embedded in an overall financial assessment of the respective RFID investment (e.g. via net present value calculation), facilitating statements regarding business success (Laubacher, Kothari, Malone and Subirana, 2006; Subirana, Eckes, Herman, Sarma and Barrett, 2003). Mostly, however, individual non-financial performance indicators are subject to the evaluation (Gille and Strüker, 2008). For instance, Hardgrave, Waller and Miller (2005) state a decline of weekly out-of-stocks in RFID-enabled stores of a large retailer. Other performance indicators under consideration in the context of RFID pilot projects include labor utilization (Karagiannaki, Mourtos and Pramatari, 2007) and lead times (Holmqvist and Stefansson, 2006).

Even though analysis of these case studies delivers hints concerning the positive influence of RFID on performance, two major problems remain, namely the limited scope of the analysis (i.e. individual case studies) and the wide range of different metrics in use. In fact, there is so far little empirical indication concerning the influence of RFID technology on economic performance beyond anecdotal evidence. This contribution aims at closing this gap in two ways. First, the problem of limited scope will be overcome by presenting a cross-sectoral survey among 114 German RFID users. Moreover, as an extension to existing studies, several *universal* performance indicators will be subject to the analysis, taking into account the multitude of different RFID applications in different sectors as well as the necessity of applying comparable indicators. The objective of this analysis is to determine to what extent the operational application of RFID influences economic performance and to evaluate the influence of superordinate and non sector-specific factors.

The remainder of this contribution is organized as follows: Firstly, we present the methodical foundation for our analysis by characterizing the research design of the empirical study. Section 3 analyzes the extent of realized RFID-based performance improvements among 114 German RFID users. In this context, performance is defined as a given level of financial and non-financial characteristics of business processes. Consequently, performance improvement is defined as an increase (e.g. delivery reliability) or decrease (e.g. lead time) of at least one financial or non-financial process characteristic. In section 4, basic factors of RFID-based performance improvement are determined. For this purpose, we present an approach which ascribes the impact of RFID technology on economic performance to three effects, namely automation, informatization and transformation (“RFID performance effects”). Subsequently, it will be analyzed as to what extent automation, informatization and transformation can help in explaining the observed performance improvements (section 5). As a basic result, we find strong evidence that the effects have an important but highly variable influence on the realization of performance improvements. In particular, it can be shown that automation, i.e. substitution of manual data acquisition, has no significant impact on any of the performance indicators under consideration. The contribution closes with and recommendations for companies considering investing in RFID technology (section 6) and a summary and discussion of our findings (section 7).

2 RESEARCH DESIGN AND CHARACTERIZATION OF DATA SAMPLE

The following analysis is based on the data of a cross-sectoral survey on the deployment of RFID technology in German enterprises. The questionnaire was evaluated and improved based on several external pre-tests. The replies to the questionnaire took place between the beginning of April 2007 and the beginning of August 2007. The composition of the sample was attained through contacting intentionally as well as randomly selected enterprises. The aim of this proceeding was to attract as many RFID users as possible to participate in the survey. The selection of participants was carried out in several steps. Firstly, enterprises with realized or planned RFID applications were contacted via e-mail. Additionally, calls for participation were placed in numerous German industrial-related printed and online publications (e.g., Impulse newsletter, RFID im Blick) as well as widely read printed publications such as “VDI nachrichten”. Furthermore, based on a representative selection of 20000 companies from the German “Hoppenstedt”-databases for SMEs and large enterprises, calls for participation were sent via e-mail. A total of 278 enterprises could be included in the study. 114 of these enterprises could be identified as RFID users. An enterprise is defined as an RFID user if it deploys RFID technology either within the regular business, a pilot project or in the form of a prototype. 53.5% of the RFID users deploy RFID within their regular business, 31.6% within a pilot project and 14.9% within a prototype (n=114). The following analysis is based only on these RFID users because reliable statements concerning the achieved performance enhancing effect of RFID can only be expected of them (see table 1 for basic parameters of the study).

Research Approach	Explorative Study Quantitative Survey
Method of Collecting Data	Online Questionnaire
Period	April 1 st - August 1 st 2007
Sample Type	Combination of random and selected
Target Group	CEOs, CIOs, Heads of Logistics
Sample Number	N= 278 n= 114 (RFID user)

Table 1. Basic parameter of the study

With the industrial sector, logistics/services as well as retail being derived as the main application sectors for RFID technology from the review of current literature and case studies (Holmqvist and Stefansson, 2006; Hardgrave, Waller and Miller, 2005; Laubacher et al., 2006; Loebbecke, 2007; Subirana et al., 2003; Tellkamp, 2003; Wamba, Lefebvre and Lefebvre, 2006), these findings are well reflected by the respondents' sectoral distribution. The majority of firms belong to the logistics/services (43.0%) and industrial sector (35.1%), while about 10.5% of all companies represent retailers. Only about 11.4% could not be assigned to one of the three aforementioned sectors (n=104). Furthermore 37.5% of the enterprises in the sample survey can be classified as small or medium-sized enterprises (SMEs), and 62.5% as large enterprises (n=104).¹

3 EXTENT OF PERFORMANCE IMPROVEMENT BASED ON RFID TECHNOLOGY

Based on the concept of performance measurement (Neely, 1999) as the evaluation of financial as well as non-financial characteristics of firms, units, processes etc., *performance* is defined in the context of this contribution as a given level of financial and non-financial characteristics of business processes. Consequently, *performance improvement* is defined as an increase (e.g. delivery reliability) or decrease (e.g. lead time) of at least one financial or non-financial process characteristic.

Realized performance improvements were quantified in terms of *target variables*. Two aspects were considered relevant with respect to each target and therefore rated in separate questions, namely intended and realized improvement. In both instances, the respondents had to rate these targets on a scale between 1 (fully) and 5 (not at all). Based on interviews with experts and an extensive review of current literature², 14 financial and non-financial target variables were chosen, all of which can be related to RFID deployment in different sectors. A special focus lies on the application fields factory, logistics and process automation. Since determining universal and meaningful indicators for measuring absolute economic performance of companies with varying sectoral affiliation is a rather complex and ambiguous issue, this procedure seems adequate in the context of a cross-sectoral survey.³

Figure 1 shows that the target of *reduced production downtime* was realized most frequently. 70.0% of all enterprises with high ambition regarding this target realized this target either "fully" or "broadly" (n = 20). In contrast, only 27.3% of the respondents realized a *reduction in waste of material* (n = 30). On average about half of the enterprises achieved their intended targets.⁴

¹ The classification of small, medium-sized and large enterprises is made according to the employee numbers and financial thresholds specified for the definition of enterprise categories in the Official Journal L124 of 20.5.2003 of the European Commission.

² Cp. for instance (Fleisch, Ringbeck, Stroh, Plenge, Dittmann and Strassner, 2004; Tellkamp, 2006). Expert interviews were conducted with Metro Group and SAP among others.

³ To support this procedure, it should be stated that *originally intended* target improvements vary only slightly between different sectors. No empirically significant relationship (5% significance level) to sectoral affiliation (industrial sector, logistics/services, retail) could be ascertained (Kruskall-Wallis test).

⁴ Following a study of the Standish Group, which is often cited in the regarded context (cp. for instance (Nelson, 2007)), on average two out of three IT projects fail.

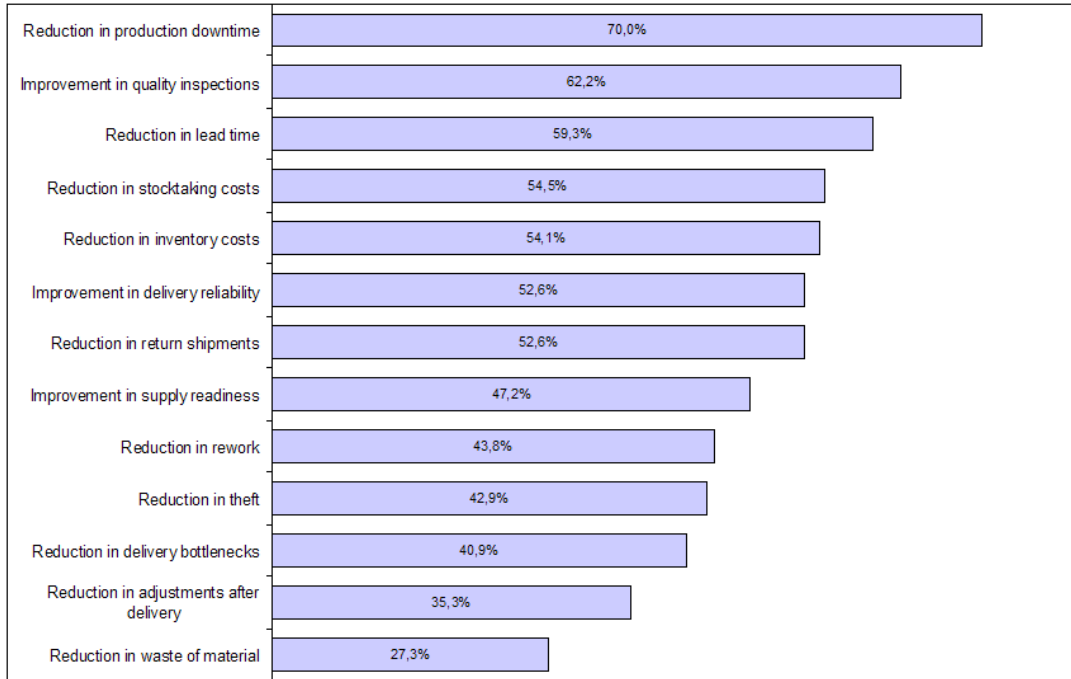


Figure 1: Realization of Financial and Non-financial Target Improvements based on RFID Deployment (sum “fully realized” and “broadly realized”; n = 54-20)

(Remark: Only enterprises for which target improvement intentions apply “fully” and “rather” were included)

Additionally, it becomes obvious that realized target improvement is independent of sectoral affiliation. No empirically significant relationship (5% significance level) to sectoral affiliation (industrial sector, logistics/services, retail) could be ascertained (Kruskall-Wallis test)⁵. One possible explanation is that performance improvements based on RFID can be ascribed to superordinate and non sector-specific categories. Such an approach will be presented and evaluated in the following section.

4 FACTORS OF PERFORMANCE IMPROVEMENT BASED ON RFID TECHNOLOGY

4.1 RFID Performance Effects

Following (Mooney, Gurbaxani and Kraemer, 1996; Tellkamp, 2006), performance improvements based on RFID technology can be assigned to three bottom-up and non-exclusive categories (effects), thereby affecting financial as well as non-financial process characteristics:

⁵ Reduction in production downtime (n=16, $\chi^2=3.17$, sig.=17.2%); Improvement in quality inspections (n=32, $\chi^2=0.12$, sig.=73.6%); Reduction in lead time (n=31, $\chi^2=0.42$, sig.=80.8%); Reduction in stocktaking costs (n=19, $\chi^2=3.29$, sig.=19.3%); Reduction in inventory costs (n=31, $\chi^2=4.55$, sig.=10.3%); Improvement in delivery reliability (n=29, $\chi^2=0.54$, sig.=76.2%); Reduction in return shipments (n=16, $\chi^2=4.13$, sig.=12.7%); Improvement in supply readiness (n=31, $\chi^2=2.87$, sig.=23.8%); Reduction in rework (n=14, $\chi^2=2.90$, sig.=8.8%); Reduction in theft (n=26, $\chi^2=1.09$, sig.=58.1%); Reduction in delivery bottlenecks (n=20, $\chi^2=2.60$, sig.=27.2%); Reduction in adjustments after delivery (n=15, $\chi^2=2.08$, sig.=35.3%); Reduction in waste of material (n=8, $\chi^2=2.28$, sig.=13.1%).

- 1.) *Automated acquisition of information (“Automation”)*: Former manual activities of data acquisition and transmission can be automated via the deployment of RFID technology. For example, RFID gates at a goods receipt can eliminate the need for employees to capture data of incoming pallets manually by applying mobile barcode scanners. Potential economic benefits occur in terms of decreasing labor costs and a faster processing of activities. The extent of cost and time savings is dependent on the frequency of data acquisition activities (Laubacher, Kothari, Malone and Subirana, 2006; Subirana et al., 2003).
- 2.) *Increased information quality (“Informatization”)*: The deployment of RFID enables additional or qualitatively improved information about business resources to be gathered. The improvement of information quality can refer to accuracy, completeness, timeliness and objectivity (Tellkamp, 2006). Hence, suboptimal coordination decisions due to poor information (for instance resulting from human failure during data acquisition) can be avoided. For instance, an accurate sales floor control in retail can ensure an optimal replenishment and therefore avoid out-of-stock situations. (Hardgrave, Waller and Miller, 2005).
- 3.) *Re-engineered and new business processes (“Transformation”)*: In a next step, improved information can also enable further performance improvements by re-engineering of existing business processes (Malone, 1987). Real-time information about customers material needs can result in a profitability of just-in-time production for instance. First studies suggest that in many cases the full benefits and thus the generation of a positive net present value (NPV) of RFID investments will be only achieved by re-engineering of processes (Dighero, Kellso, Merizon, Murphy-Hoye and Tyo, 2005). In many cases, process adjustments in terms of modified workflows and job specifications will be indispensable in order to avoid a degradation compared to the status quo (process adjustments as complementary investments of technology deployment (Tellkamp, 2006)). As a final consequence, increased information quality due to RFID enables the provision of completely *new services and products* (e.g., tracking and tracing services for customers).

The empirical analysis of this approach in the following section promises to attain insights into whether the three effects can explain the attainment of performance enhancements.

4.2 Realization of RFID Performance Effects

Figure 2 shows that all three performance-enhancing effects are realized relatively frequently in the surveyed enterprises. Currently, an automated acquisition of information represents the most frequently realized effect (87.7%, n=107). The possibility of improved information about enterprise resources and the possibility of re-engineering processes are so far exploited in 72.1% respectively 64.8% of the enterprises (n=105) yet. The relatively frequent utilization of all three effects appears surprising, since current literature states that distant benefits from improved information quality and re-engineered business processes require higher level of organization and cooperation than “localized benefits” from automation (Laubacher et al., 2006).

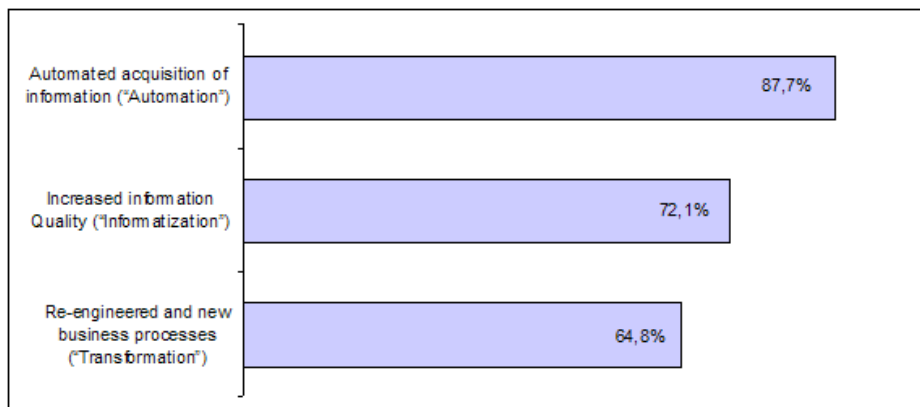


Figure 2: Realization of RFID Performance Effects (n=107-105)

The purpose of the following section is to analyze as to what extent the realization of the three effects has an influence on achieved performance improvements.

5 IMPACT OF THE RFID EFFECTS ON PERFORMANCE

In order to analyze the relationship between the three RFID performance effects (“Automation”, “Informatization”, “Transformation”) and the respective target variables, as a first step a selection has to be conducted with regard to target variables that can be influenced by all three effects. Accordingly, the targets "reduction in stocktaking costs", "improvement in quality inspections", "improvement in delivery reliability", "reduction in lead time" and "reduction in production downtime" were chosen in order to test the influence of all three effects. For each of these five targets, the reduction in manual activities, improved information about enterprise resources as well as transformation of processes can have an impact on realized target improvement. Examples as to how the RFID performance effects automation, informatization and transformation (which are sequentially based upon each other) may have an impact on these targets can be found in table 2. In addition, figure 1 shows that these five targets are among the most frequently realized targets.

RFID Performance Effect Target	Automation	Informatization	Transformation
Reduction in stocktaking costs	Substitution of manual stock counting in physical inventory processes Result: Avoiding manual inventory counts	Accurate stock counting in error-prone physical inventory processes Result: Avoiding recounts	Substitution of existing physical inventory processes by a (automated) continuous inventory Result: Avoiding plant closures (annual inventory count)
Improvement in quality inspections	Substitution of manual inspection of products or processes (such as temperature control, verification of authenticity) Result: Cheaper quality inspections	Increase in inspection frequency Result: Enhanced quality inspection (such as comprehensive verification of product authenticity instead of random checks)	Implementation of <i>additional</i> inspection processes Result: Ascertainment of new quality characteristics (such as inspection of correct composition of packed consignments)
Improvement in delivery reliability	Substitution of manual documentation (e. g. for financial controlling) Result: Enhanced delivery date accuracy (by means of faster order processing)	Complete acquisition of outgoing shipments Result: Enhanced delivery quantity accuracy	Implementation of automated decisions about re-ordering Result: Avoiding missing materials leads to a further enhancement of delivery reliability
Reduction in lead time	Substitution of manual goods receipt Result: Accelerated processing	Real-time information on processing status Result: Reduced idle period through precisely timed setting-up of downstream production stages	Implementation of just-in-time production due to real-time information about customers material needs Result: Stock reduction leads to further reduction of shelf life
Reduction in production downtime	Substitution of manual goods receipt Result: Accelerated processing leads to the avoidance of missing materials at the production line	Real-time information on processing status Result: Faster transmission of replenishment requirements leads to the avoidance of missing materials	Implementation of tracking & tracing services Result: Early detection of upstream delivery bottlenecks leads to the opportunity of short-term rescheduling of production

Table 2: Examples for the Impact of RFID Performance Effects on Selected Targets.

The influence of RFID performance effects on realized target improvements will be analyzed by deploying regression analysis. To do so, a linear relationship between effects and realization of target variable improvement is assumed (linear multiple regression). The objective of the regression analysis is to elicit whether and to what extent the realization of the five selected targets can be explained with RFID performance effects (see figure 3).

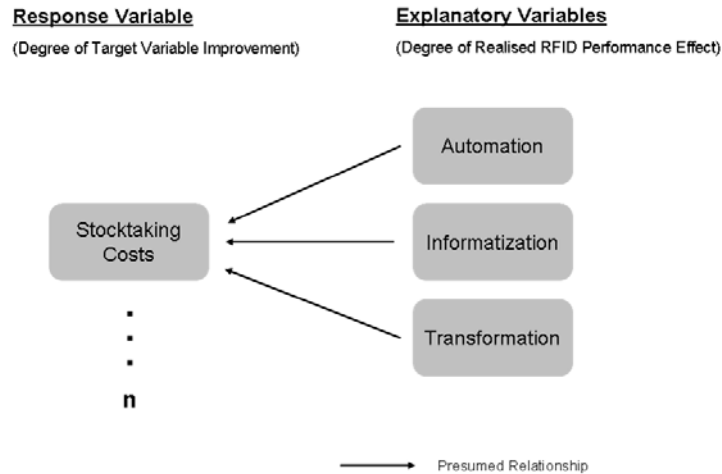


Figure 3: Scope of the Regression Analysis.

Hence, the degree of realized target variable improvement (Y_{target_n}) constitutes the dependent variable in our regression model (response variable), while the characteristics of the RFID performance effects (X_{Auto} , X_{Info} , X_{Trans}) are independent variables (explanatory variables)⁶. Values in our regression model are calculated based on ordinary least squares analysis (Cohen, Cohen, West and Aiken, 2003). The necessary assumptions have been verified and can be assessed as adequate⁷, yielding our regression model as follows:

$$Y_{target_n} = b_0 + b_1X_{Auto} + b_2X_{Info} + b_3 X_{Trans}$$

with

- Y_{target_n} = degree of realized target variable improvement
- X_{Auto} = degree of realized RFID performance effect „Automation“
- X_{Info} = degree of realized RFID performance effect „Informatization“
- X_{Trans} = degree of realized RFID performance effect „Transformation“
- b_0 = constant term
- $b_{1,2,3}$ = regression coefficients of explanatory variables

A summary of the regression results is presented in table 3.

⁶ The strength of the respective effects was rated on a scale between 1 (“not at all”) and 4 (“fully”). The distances between the characteristic values of this four-point scale are assumed to be equal (assumption of interval scale). The same holds for the variable Y_{target_n} (degree of target variable improvement). In order to derive the overall measure (Y_{target_n}) for performance improvements, each target’s associated two questions (intended vs. realized improvement) were joined in a single 10-point scale (0 = no success; 9 = complete success). With respect to using ordinal Likert scale items instead of interval data for regression analysis, Jaccard and Wan (1996) state, “for many statistical tests, rather severe departures (from intervalness) do not seem to affect Type I and Type II errors dramatically.”

⁷ The variance inflation factor reveals that linear dependency between the independent variables is not too strong for any of the regressions (no multicollinearity). Furthermore, the Durbin-Watson test confirms that the assumption of uncorrelated residuals is met for all regressions (no autocorrelation). Yet, homoscedasticity tests reveal that this assumption is not met for the regressions “reduction in stocktaking costs” and “reduction in lead time”. The heteroscedasticity causes an inefficiency in ordinary least squares calculation. However, the overall model estimation remains correct. Nevertheless, the regression coefficients can be biased (Cohen et al., 2003).

Response Variable: Target achievement (Y_{target_n})	Overall model		Explanatory Variable:								n
			Automation (X_{Auto})		Informatization (X_{Info})		Transformation (X_{Trans})		Constant term		
	adj. R ²	sig. (F-test)	b ₁	sig.	b ₂	sig.	b ₃	sig.	b ₀	sig.	
Stocktaking costs	21,0%	0,00**	-0,18	0,74	0,78	0,04**	0,82	0,03**	7,85	0,00	48
Quality inspection	48,7%	0,00**	0,03	0,93	1,90	0,00**	0,02	0,94	10,39	0,00	47
Delivery reliability	15,8%	0,01**	0,40	0,39	0,41	0,25	0,77	0,03**	8,17	0,00	48
Lead time	32,2%	0,00**	0,69	0,10	0,98	0,00**	0,24	0,43	10,70	0,00	52
Production downtime	28,1%	0,00**	0,40	0,42	1,33	0,00**	0,03	0,94	7,98	0,00	50

Table 3: Influence of the Effects on the Realized Performance Enhancements (5% significance level – different from zero)**

As a first and most fundamental result, realized target variable improvement can be explained by RFID performance effects (see table 3, column "Overall model"). Hence, the proposed overall relationship between response and explanatory variables is significant for each of the five selected targets (significance level: 5%). The coefficient of determination (adjusted R²) lies between 21.0% and 48.7%. Thus, there are strong indicators for an existing overall impact of RFID performance effects. Nonetheless, there appear to be further factors that are not subject to the regression model (e.g., company-specific factors such as firm size, worker qualification or degree of automation before RFID implementation).

Analyzing the regression coefficients' significance⁸ reveals that a systematic influence of reduced manual data acquisition (automation) on realized target variable improvement cannot be verified. Thus, as a second fundamental result, it has to be stated that the impact of RFID-based automation on economic performance is unverifiable on an empirical basis, indicating a low overall relative importance. In contrast, informatization and transformation exhibit a significant yet target-specific impact on economic performance, therefore constituting our third fundamental finding: Depending on specific target variables, informatization and transformation influence the economic performance of RFID-supported processes.

In detail, the presented results indicate that the main factor for a reduction in *stocktaking costs* among the RFID users of our survey are not labor cost savings, but rather the utilization of improved information and a re-engineering of inventory processes. More accurate information facilitates failure cost savings, for example by avoidance of recounts. Furthermore, RFID-enabled informatization is the only significant factor with respect to an improvement in *quality inspections* (e.g. implementing continuous instead of discrete temperature control of foods). According to our results, these improvements are currently realized without any re-engineering of quality inspection processes. In contrast, RFID does not facilitate an improvement in *delivery reliability* as long as processes are not re-engineered. For instance, inventory management that is enhanced by automated reorder may enable an avoidance of delivery bottlenecks, leading to increased delivery reliability. On the other hand, the results indicate that *lead time* reductions can be solely realized on the basis of improved information. For instance, real-time information concerning progress on a particular production stage may enable precise periodic change-over of downstream production stages and thus contribute to reductions in wait time (as part of lead time). However, automation (e.g., process acceleration due to eliminated manual data acquisition) has no significant impact on lead times. The same holds true for transformation (e.g., introduction of just-in-time production). Similar findings can be derived with respect to *production downtime* reductions, a major cause of long lead times.

6 IMPLICATIONS FOR AN OPERATIONAL USE OF RFID

This contribution explains the impact of RFID deployment on economic performance with a three-layered approach, consisting of the RFID performance effects of "automation", "informatization" and "transformation". Testing the approach empirically based on experiences of 114 RFID users shows that performance improvements can be explained with these effects: The presumed overall relationship is significant for all of the five selected targets (stocktaking costs, delivery reliability, lead times, production downtimes and quality inspections). However, a highly varying influence of RFID

⁸ The constants cannot be interpreted without a centering of the data, i.e. the mean has to be subtracted from every independent variable (Cohen et al., 2003). The regression was done without such a centering, because it does not matter to what degree a target was achieved if none of the effects were realized.

performance effects on target realization becomes apparent. In particular, substitution of manual information acquisition (automation), the effect to be realized with the lowest effort (Laubacher et al., 2006), has no significant influence on target variable improvement.

In this context, the target *reduction in stocktaking costs* takes an exceptional position. While the costs of an RFID investment do not directly influence *delivery reliability*, *lead time* and *production downtime*, there surely is an immediate impact on stocktaking costs. Hence, the finding that automation has no influence on stocktaking costs might be incorrect. For instance, one might imagine a situation where a reduction in stocktaking costs was realized that was not sufficient to offset the initial costs of the RFID investment. Nevertheless, according to our results, reductions in stocktaking costs can be sufficiently large to offset the initial RFID investment costs when RFID-enabled *improved information* is utilized.

With respect to the remaining targets that are not directly affected by RFID investment costs, we have found strong evidence that pure automation will not be sufficient in order to realize performance improvements across the vast majority of RFID users. There might be sporadic performance improvements based on automation in companies where extreme economies of scale are in place. For instance, large retailers might be able to speed up processes and reduce process costs significantly due to the sheer number of manual processing activities that can be replaced by RFID. However, such particular cases are not expected to add up to a significant impact across the entirety of RFID users. Furthermore, our results indicate that an *improvement in delivery reliability* will be realized only if additional investments regarding the re-engineering of processes are conducted (cp. section 2). With respect to an *improvement in quality inspections* and *reduction in lead time / production downtime*, the need for process re-engineering cannot be detected.

Overall, a restriction to pure automation cannot be recommended, regardless of sectoral affiliation. The exclusive aim of replacing manual information acquisition activities should not be the main focus of RFID investment decisions. Our results suggest that RFID technology unfolds its full impact on economic performance only if improved information quality is utilized, being flanked by process re-engineering in some cases. A successful deployment of RFID requires considerable complementary investments in order to realize informatization and transformation. Enterprises with RFID ambitions are therefore advised to budget follow-up costs of their RFID investment decisions.

7 SUMMARY AND PERSPECTIVES

The results of the empirical study among 114 RFID users in Germany shows that, on average, about half of the enterprises achieved their intended targets. This result does not allow conclusions regarding the overall profitability of RFID applications due to the non-consideration of investment costs. Nevertheless, it can be established that the operational application of RFID in Germany has a perceivable influence on economic performance. To determine the basic factors of RFID-based performance improvement, it was analyzed to what extent the performance improving impact can be ascribed to three effects, namely automation, informatization and transformation. The study shows that the three effects as a whole can explain target achievement to a considerable degree. Further, it could be shown that an RFID-based reduction of manual data acquisition does not systematically contribute to performance improvements. Rather our results suggest, it is necessary to exploit the possibility of improved information about enterprise resources or to re-engineer business processes on the basis of RFID. This finding can be compared to observations of the adoption of the Universal Product Code (UPC) and the international article number code EAN (originally European Article Number, EAN) in the 1970s. The most substantial economic gains were reached by the exploitation of improved information or by a re-engineering of existing business processes in the case of UPC and EAN as well (Garg, Jones and Sheedy, 1999).

Although the analyzed model contributes toward explaining the performance improving impact of RFID usage, the results have to be interpreted with necessary caution. There are further factors which appear to have an influence on performance enhancements.⁹ For example enterprise specific factors such as firm size can be of considerable importance. SMEs typically exhibit lower financial resources for instance. This raises the question as to what extent SMEs are able to procure the necessary complementary investments for a successful deployment of RFID. On the other hand, since SMEs usual exhibit greater level of organizational flexibility, this might be an important issue especially for SMEs that are facing RFID mandates e.g. by retail companies (Strüker and Gille, 2008).

⁹ The coefficient of determination lies only between 15.8% and 48.7%.

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