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ENABLING PROCESS INNOVATION THROUGH SENSOR TECHNOLOGY: A MULTIPLE CASE STUDY OF RFID DEPLOYMENT

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Abstract

The advances in information technologies (IT) that we have witnessed in recent years has enabled organisations to digitise much of the work that previously was carried out manually or supported by analogue tools only. As this development continues, it is likely that IS in the future will have an even more profound impact on organisations and their capacity to innovate. In this paper, we make a contribution to the study of IT's effect on business process innovation by reporting from a multiple case study of five Swedish organisations using sensor technology. Understanding sensor technology as a boundary spanning technology, we have studied in particular the purpose of introducing Radio Frequency Identification (RFID), the intended effects on process innovation and what business processes were affected. We illustrate how business values are achieved as automational, informational, and transformational effects, and whilst the automational effects are easiest to detect and value, it is the transformational effects that are likely to have the strongest and most profound impact on the organization. In addition we identify three major inhibitors: insufficient integration with existing systems; lack of organisation adjustment; and uneven distribution of cost/benefits. Our work thereby offers contributions to both academia and practice.

Keywords: Sensor technology, business process innovation, boundary spanning, RFID

1. INTRODUCTION

In today's competitive business landscape, the need for organisations to innovate constantly is stressed by numerous commentators (*cf.* McAdam, 2000; Hult *et al.*, 2004; Barsh, 2008). Innovation literature suggests that the ability to acquire, assimilate, and make sense of peripheral information is crucial for an organisation's ability to stay competitive (Kogut & Zander, 1992; Cohen & Levinthal, 1990). Boundary spanning, i.e., the activity in which an organisation reaches beyond its border in order to link external information to its present knowledge, is thus essential to organisational renewal (Lindgren *et al.*, 2008). The advances in information technologies (IT) that we have witnessed in recent years has enabled organisation to "digitise" much of the work that previously was carried out manually or supported by analogue tools only (Yoo *et al.*, 2009). As the information being handled by organisations becomes increasingly digital, the activities of the boundary spanners can be greatly enhanced and facilitated by information technology (Yan & Lewis, 1999). For example, inter-organisational systems based on electronic data interchange (EDI) or XML standards allow organisations to share richer sets of information at a higher pace (Kumar & van Dissel, 1996; Jonsson *et al.*, 2009).

Recently, sensor technology has been suggested as a technology capable of providing a new perspective on boundary spanning. Being able automatically and in real time to collect and monitor digital representations of an external environment, this technology can act as the organisation's extended eyes and ears, allowing remote analysis and decision making (Fano & Gershman, 2002; Lindgren *et al.*, 2008; Jonsson *et al.*, 2009). If utilised appropriately, sensor technology could enable organisations to move towards a more proactive role in their ways of working. When linked to a firm's information infrastructure, and combined with existing and more traditional information systems, sensor data can enable unparalleled efficiency and effectiveness gains (Curtin *et al.*, 2007), which in turn stimulate and facilitate process innovation (Sharma & Vredenburg, 1998).

As the digitisation of work continues, it is likely that IS will continue to have a profound impact on organisations and their capacity to innovate. However, it is *the combination of technological and process innovation* that provides the best opportunity for an organisation to achieve dramatic performance improvements. It is thus not the use of an information system *per se* that generates sustainable performance gains, but the enhanced organisational process capabilities enabled by the integration of IS in the day-to-day operation (*cf.* Mooney *et al.*, 1996; Young *et al.*, 2008).

The particular technology used in this study is Radio Frequency Identification (RFID). Much academic work on RFID can be found in the areas of supply chain management and logistics, but Spiekermann and Ziekow (2005) assert that RFID is now becoming a hot topic also in the IS world, and claim that RFID represents a major building block of the intelligent infrastructure envisioned by IS researchers. We agree and believe that sensor technology deserves more attention from IS researchers since it can provide useful insights to both technology and process innovation. The research questions addressed in this paper are: a) What was the purpose of introducing sensor technology, b) What business processes were affected, and c) What type of business innovation could be seen? Answering these questions by reporting from a multiple case study of five Swedish organisations using RFID in railroad applications, our work makes a contribution to the study of sensor technology's effect on process innovation.

2. A FRAMEWORK FOR ANALYSIS OF BUSINESS INNOVATION

Different categorisations of the effects of IS on process innovation exist and Davenport's (1993) is perhaps one of the most frequently used ones. In this paper we have chosen Mooney *et al.*'s (1996) framework since it a) covers all aspects of Davenport's categorisation while being more comprehensive, and b) has previously been successfully used in studies of RFID implementation and usage (e.g., Tellkamp, 2006; Gille & Strüker, 2008). Mooney *et al.*'s framework suggests that technology impacts business processes along three different dimensions; the *automational*, the *informational*, and the *transformational*. Further, the framework also suggests that business processes should analytically be separated into *operational processes* and *management processes*. Our work takes all these aspects into account. Previous applications of Mooney's work have not considered the process perspective and our work thus makes an empirical contribution to Mooney *et al.*'s original work.

2.1 Intended effects of process innovation

The automational effects refer to the gains achieved through the elimination or reduction of manual efforts in data acquisition (Mooney *et al.*, 1996). By replacing manual work with a sensor technology such as RFID, no real changes to the business processes are made, and the technology thus merely acts as an *implementer* of an already existing process (Davenport, 1993; Tellkamp, 2006). Potential value is primarily gained in terms of lower labour costs and organisations likely to benefit from the automational effects are thus those that have a relatively large number of manual data capturing activities (Gille & Strüker, 2008).

The informational effects refer to the benefits accomplished through the technology's ability to collect, store, process and disseminate information. Value within this dimension largely stems from improved decision making, employee empowerment, and enhanced effectiveness (Mooney *et al.*, 1996). Sensor technology such as RFID contributes to overall quality in terms of more accurate, objective, timely, and complete information, which, in turn, affects operational decisions positively. The tangible effects from the informational effects can be seen in lower out-of-stock ratio or improved customer satisfaction (Gille & Strüker, 2008).

The transformational effects, finally, refer to the value gained via process innovation and business transformation, manifested as shorter cycle times, improved responsiveness, and enhanced services and products (Mooney *et al.*, 1996). Sensor technology such as RFID here acts not merely as an implementer but as an enabler of process innovation (Tellkamp, 2006). The innovative aspects are however not limited to enhancing existing processes but to enable entirely new services and products and new corresponding processes (Gille & Strüker, 2008). These effects are difficult to foresee at the start and the value may be complex to assess due to it being realised indirectly.

2.2 A typology of business processes

Following Davenport (1993), Mooney *et al.* (1996) distinguish between *operational processes* and *management processes*. Management processes should not be understood to refer only to those processes that are carried out by managers, but to all activities associated with the information handling, coordination, and control processes required to ensure the efficiency and effectiveness of the everyday operations. These "everyday operations" constitute the operational processes, i.e., the carrying out of the tasks comprising the activities of an organisation. Although Mooney *et al.* (1996) stress that the management and the operational processes are tightly interrelated, they also point to the usefulness of separating the two for analytic reasons.

Operational processes, Mooney *et al.* (1996) suggest, are affected by information technologies such as robotics, workflow systems, and data capture devices. Typically, operational processes are improved by IT through the increased efficiency of automation, or by IT's capability to link different operational process together and thereby enhance their effectiveness and reliability. Management processes deal intrinsically with the handling of information, and these processes are thus enhanced by IT through the improved availability and communication of information that IT fosters (Mooney *et al.*, 1996).

The three dimensions of intended effects of process innovation can be combined with the typology of business processes to string out a framework that can be used to analyse the business value impacts of IT in general and sensor technology in our case (see Table 1). Mooney *et al.* (1996) claim that the business value effects of the three dimensions of process innovations are primarily visible in either operational processes or management processes. Starting with automational, first order effects are primarily associated with operational processes, whereas first order informational effects emerge primarily on management processes such as information processing for decision making, coordination, communication and control. First order transformational effects apply to operation and management processes simultaneously since it results in the merging of these two processes. This transformation also gives rise to second order effects. The automational effects on operational processes increases the information content in these processes and make them susceptible to the informative effects previously associated with management processes. Analogously, the informative effects on management processes decrease information content and open the management processes to automotive effects. These primary and secondary effects are illustrated in Table 1. Finally, third order value is created from the new ways of conducting business (i.e., the combined changes in operational *and* management processes) created by the transformational effect (Mooney *et al*., 1996).

	Intended effects of process innovation		
Business processes	Automational	Informational	Transformational
Operations	Primary	Secondary	Primary
Management	Secondary	Primary	

Table 1. Primary and secondary value effects of various process innovation efforts on different business processes (Adopted from Mooney et al., 1996).

3. RESEARCH METHOD

Yin (1994, p. 13) describes a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". The above captures eloquently the characteristics of our study, which can be described as a multiple case study involving five different organisations currently engaged in RFID technology deployment. Qualitative data has been captured through semi-structured, in-depth interviews with 20 individuals from the five different organisations. In total, the data collection process has covered six month starting in October 2008. The respondents have been selected to represent both operational and managerial levels in the organisations. The interviews have lasted an average of 49 minutes and were all recorded at the respondents' sites and later transcribed. Table 2 illustrates the respondents and their position within the organisations.

Data collection and data analysis have partly been carried out in parallel, as advocated by Miles and Huberman (1994). These authors further describe the analytic phase as consisting of three concurrent flows of activity: *data reduction*, *data display*, and *conclusion drawing*. Although being intertwined, these three flows are now described separately for clarity.

Data reduction refers to the process of selecting, simplifying, and abstracting the raw data that the researcher has in forms of field notes and transcribed interviews. For this paper, we have explicitly analysed the material along the two dimensions presented in table 1 above. Looking first for the rationale for engaging in RFID adoption, we mapped the respondents' utterances towards the automational, the informational, or the transformational dimension. Thereafter, we analysed whether RFID development had had an impact on the operational or managerial processes. Using theory in this way helped us narrow down the empirical data. *Data display* is an organised spatial way of presenting the data systematically in a form that helps the researcher see what is happening. In our work, we used the two theoretical dimensions to form Table 1. Using post-it notes with respondents' statements, the empirical data filtered out in the data reduction process was placed in Table 1, forming clusters of notes in certain cells. This visual displaying of our data helped noticing both differences and similarities between and amongst the organisations, which thereafter could be further analysed in more detail. *Conclusion drawing*, finally, is perhaps the most obvious part of the analysis. Conclusions first appear as vague hunches (often already during data collection, data reduction and data display) that subsequently are validated as the work proceeds in an iterative way (Miles & Huberman, 1994). We have compared and contrasted our tentative results with the literature until we have reached a plausible understanding that encompasses all our findings.

Organisations	**Respondents' positions**	**Duration of interviews**
MiningCo Industry: Mining	1 IS/IT manager, 1 developer, 2 technicians	29-66 mins, average 41 mins
SteelCo Industry: Steel manufacturing	1 general manager, 1 operation staff member, 1 technician	39-65 mins, average 50 mins
RepairCo Industry: Train maintenance	1 IS/IT manager, 1 middle manager, 1 operation staff member, 1 technician	45-55 mins, average 50 mins
PaperCo Industry: Paper manufacturing	1 logistics manager, 1 operations manager, 3 operation staff members	38-75 mins, average 60 mins
TrainCo Industry: Transport	1 IS/IT manager, 1 strategist, 1 project manager, 1 technician	45-78 mins, average 57 mins
Summary: 5 organisations	*20 respondents*	*29-78 mins, average 49 mins*

Table 2. Details of studied organisations and the respondents

4. FIVE CASES OF RFID DEPLOYMENT

4.1 MiningCo

MiningCo started using RFID technology in 1996 primarily in order to gain control of the car maintenance. With all of their 4,000 cars and 20-30 locomotives tagged, the organisation knows how many kilometres each vehicle travels and is able to base their planned service on this information. In addition, the organisation knows exactly where every car is positioned along the track and is thus able to plan their operation more effectively. Previously, MiningCo had a time-based maintenance process where cars were serviced every 10 weeks. The problem was that one car could have been unused for 9 weeks and thus not in need of service while another car could have travelled many kilometres and been in need of service much earlier. Further, in order to know approximately where the cars were, employees had manually to go out once a months and count and record all the cars they could see. This process was both time consuming and imprecise.

RFID technology has enabled MiningCo to switch from a time-based to a mileage-based maintenance process. The RFID information is integrated with their own systems so that the yard operators can graphically see that this train has three "red" cars, indicating that the mileage threshold has been reached. They can also see that "Okay, there are two yellow (i.e., soon to reach the threshold) cars in between. Let's switch out all these five cars". This has enabled the organisation to reduce stand-still and thus saved money. All key indicators for car maintenance such as number of kilometres between service, total number of car stops, and total number of reported errors have improved radically, and our respondent estimates the payback time to 3-4 years.

However, MiningCo would like to go to condition-based maintenance. Information pertaining to car condition is collected by the Swedish Railroad Administration (SRA) via discrete detection stations along the railroad. SRA can detect and report that a bearing on axletree 278 on a particular train is warmer than normal and fax this information to MiningCo. To be useful, though, this detector information has to be paired with the RFID information from the car, or MiningCo will not be able to single out which car generated the alarm. This requires a level of coordination currently not in place. In addition, to enable proactive maintenance, MiningCo must receive information on a continuous basis and not only when a problem has occurred, which is currently the case.

> *"No, we don't get it [the information]. We only get it when there is an alarm. Then it's really too late, because then we have to stop the train and block the track, and that is obviously a disadvantage to everyone." (IS/IT manager)*

Also inside their own plants there is room for improvements. Had they known what was inside each car, the cars could have been automatically sent to an unloading station where the same material just had been unloaded. That would have eliminated the need to clean the transport belt. This matching procedure is now handled manually, with more manpower needed, longer handling times, and less precision. This lack of integration is according to one respondent due to the lack of a shared vision for the organisation.

> *"They don't see the benefits. Even if we are one company, there are different units and we operate in different ways. This requires a more holistic vision." (IS/IT manager)*

4.2 SteelCo

SteelCo started using RFID technology in 2001 with the aim of changing the way they handled the shipping of their raw material from their supplier to their own plant. The material comes on specially designed railway cars where every car has an RFID tag that identifies the car and how it is positioned. Knowing the order of the cars in the train set, SteelCo has been able to plan and optimise their unloading and storing processes. The vision for SteelCo is to be in full control and to know at every moment where everything is located and to be able to manage the resources needed to move the goods around.

When material previously was shipped from the supplier, information was manually entered into the warehouse system saying that this material was now in store. This created a discrepancy between the physical warehouse (where the slot was empty) and the logical warehouse (the system, where the slot was recorded as occupied). Due to this, there were delays as material had to be relocated and trucks and cranes had to be moved. In addition, SteelCo had to rely on manually assembled lists of railroad cars from the train operator and they had manually to verify that the specification and the actual order of the cars matched.

With RFID technology in place, the system knew what material was on its way when the train passed a reader station a few miles from the plant and an optimal warehouse placement could be calculated. A warehouse has physical limitations so being able to store material as short period of time as possible is important. Being able to rely on the information regarding the cars position in the train has enabled the organisation to see the train as part of their moving warehouse facility. SteelCo has integrated RFID data with their other information systems. For example, the RFID data identifying the cars is combined with the shipping information saying what material is loaded onto which car. This is then used to create a graphical image that the forklift drivers use to unload the material and repack it in the right order. Eliminating the need for manual reading and data entering, the organisation no longer needs staff working nights and has been able to reduce a whole shift. Asked whether the benefits have justified the costs, one of our respondents calculates the payback time of the investment to 1.6 year.

SteelCo never did a pilot test of the technology. They studied other organisations using RFID technology and decided that if it worked for others it should work for them, too. Nor did they wait for an international or European RFID standard to be established. They felt that they needed to get started and in stage one settle for their internal flow. This limited context made it possible to make autonomous decisions about the tags and to make an early move. Different sites within the organisation have their own systems for handling the RFID information but our respondent does not see this as a problem as long as the interfaces are well-defined.

> *"We have agreed upon the definitions and we have defined the communication interfaces. Then it's not a problem. We don't need to have the same system everywhere." (General Manager)*

Tagging the cars presented some problems and turned out to be a bottleneck since SteelCo did not want to take the cars out of service but attach the tags during planned service. Not being able to bring in other cars (without tags) when needed has created tensions within the organisation. The logistics planners were not happy having to wait for cars being tagged while untagged cars were readily available.

4.3 RepairCo

RepairCo started working with RFID technology in 2006, in order to move from mileage-based to condition-based maintenance of the cars and trains they service. RepairCo receives detector information both from their own detector stations and from the SRA's stations. By adding RFID tags to the vehicles, they were able to identify exactly the individual car associated with an alarm and were thus able to target their service to the correct vehicle. This greatly improved the turn-around time in the repair shops and minimised stand-still for the operators.

Before using RFID, SRA sent reports of detected errors to the train operator, who in turn contacted RepairCo to schedule the required service. However, the report could state that a bearing had shown too high temperature but it would not indicate on what axletree. By the time the train arrived at the repair shop, the faulty bearing had already cooled down and it was impossible for the maintenance technicians to know what to fix. In addition, much of the repair work was related to the acute fixing of problems that had already occurred. Some errors were also written down by hand by the engine driver on an error report form placed in the driver's compartment. When the train was due for service, the technician would read the form and find that this problem was already two weeks old and that the spare part needed to fix the problem was not in stock.

Attaching RFID tags to the vehicles enabled RepairCo to match the incoming alarms with the actual car and thus being able to reduce the manual labour used in the identification process. By automating this part of the process, maintenance personnel could be freed to do more qualified tasks. Receiving the error information through the detector stations also enabled RepairCo to optimise service and repair by ordering spare parts in advance and schedule trains for maintenance based on actual needs, thus assuming a more proactive role.

Now, RepairCo is adjusting one of their repair shops to become a model shop that is to receive information automatically via the train crew and have a service vehicle meet the train during the next longer station stop. There, they would fix the problem or write a precise work order so that the technicians know what to do when the trains enters the shop half an hour later. However, the entire process is not yet re-engineered. One challenge is that the repair shops are fully occupied and do not have room or time for new experiments. Introducing new routines causes disturbances during the transformation phase and since this temporarily has a negative effect on performance, there is resistance.

Our respondents were positive that the benefits outweighed the cost but maintained that cost still was a factor. The problem they noted was that even though all parties benefitted to certain extents, the fact that many different organisations were involved made it difficult to agree upon how to split the cost. Typically, one actor had to make the first move and invest in the technology.

> *"Who wants to do that? Hardly the car vendor! Not without getting paid. And from whom? Perhaps the SRA, perhaps the car owner, perhaps the train operator, perhaps us… As a maintenance entrepreneur, we can't be sure we get the service deal so we don't want to pay…" (IS/IT manager)*

RepairCo primarily saw RFID information as a decision making enhancer. Being able to better plan the service, the more effective their technicians can be and the quicker the car is back in operation.

And basically, that is what all this is about - the vehicles should be in traffic as much as possible since that is when they generate profit

4.4 PaperCo

PaperCo started using RFID technology in 2007 in a pilot project to tag the railway cars transporting their goods in order to improve predictability in goods delivery. They needed to know what goods were coming in, when, and in what order. Knowing that there are ten incoming cars of which cars 2, 3, and 5 have special cargo bound for the ship that is currently loading would mean that unloading could be optimised so that the goods sooner reach the customer.

Before introducing RFID, one site could have reported in that ten cars were loaded and ready for transport and this information would then be entered into the computer systems as if it was already in place. Thereafter, a train operator picked up the cars and many things could happen before the car arrived at the destination. The operator may have decided that there was only room for 7 cars. In addition, the order of these cars could have been rearranged multiple times. The operator would send a fax to PaperCo informing them about the number and order of the cars in the train set but this information can be delayed since the operator does not always report this right away.

> *"We don't know if there are seven cars arriving and not whether it's the seven high priority cars. So we need to have margins and think like, well if they're not with this train, they're probably with the next one. Perhaps arriving tomorrow." (Operation manager)*

PaperCo wanted to run a small scale project to address the problems of not knowing where their cars were, so they tagged their approximately 150 cars and the SRA set up reader stations along the tracks. However, the project had low priority and a small budget. SRA placed the readers where it was convenient and not were they would be most useful. As a result, the cars had plenty of time to be re-arranged between the time they passed the last reader until they arrived at the destination. Further, the technology used was low-technology left-overs, such as old PCs, and PaperCo experienced many problems with reader stations being unavailable. The tags were read properly but the information was not communicated further due to technical problems. There were also bugs in the logic of the computer systems handling the RFID information and although these bugs were noticed and reported, they remained uncorrected.

> *"This is a 3-year project and you think you have plenty of time but after a while you notice that things tend to take a long time… Two months after a decision and nothing has happened, then you start to feel that this project will end before we're halfway through…" (Logistics manager)*

Due to the RFID readers being unavailable at times, there were often discrepancies between the data reported by the operator, and the information received from the two reader stations. The train operator is obliged to report to the SRA the number and order of cars in a train set, but this information is sometimes lacking or is not entered until a few hours after the train has left the station. In addition, when the information is entered, it is done so manually, and with the car-ID being a ten digit number, there is the risk of human error. In addition, the RFID information that PaperCo has access to today is handled in a separate system and not integrated with their other operational systems. This means that the operator has to switch between systems to get the information needed. In this situation it is easier to have the information on paper and since the train operator faxes this information, the print-out is readily available when the operator clocks in.

> *"Well, it's just that… They [the faxes] lay on my table when I come in the morning. It's easier to use them than to start up the computer [laughs]. So I do it that way…, instead of waiting for the computer… […]. I don't think we will use it [the RFID information] much. But when we get the [RFID] information in our systems, then we will benefit from it. Then we can see it straight away. But I don't know when that will happen." (Operation staff member)*

A train is rather long and had PaperCo been able to control the order of the cars and had the information been correctly communicated to the unloading personnel at the terminal, this could have been used to optimise the process. As of now, the fork lifts have to go all over the place and often search several cars to find the cargo they are looking for.

4.5 TrainCo

TrainCo started experimenting with RFID technology in 2008. The purpose was twofold; to keep better track of their vehicles in order to plan maintenance more efficiently, and to increase the precision in the calculated arrival time that they communicate to their passengers. With RFID tags on their cars, the organisation is able to match detector information with car IDs and thus be able to service the exact individual that caused the alarm rather than to manually scan the whole train set. As for passenger information, the RFID tags are read along the tracks and fed into the system that estimates time of arrival at the next stop. Updated information with high precision can thus be sent to the monitors at the upcoming train station, thereby enhancing customer satisfaction.

Previously, TrainCo received alarms from the SRA that a bearing on axletree 8 was running warm when passing a certain detection station at a particular time. TrainCo had then to consult their time tables to find what train was supposed to be there at that time and then to schedule a manual check of that train at an appropriate point - a complex and error prone process.

> *"This procedure created a long chain of events that eventually often resulted in us losing track of the vehicle anyway." (IS/IT manager)*

As for the passenger information, monitors were typically turned off until the train almost reached the station. Then the indicators in the track recognised the train and lit up the monitors saying that the train was now coming in to platform 5 with a delay of 8 minutes. At that point, the passengers waiting already knew the train was late.

RFID technology is today used to complement the manual measurements that the maintenance personnel carry out. The vision is to be able to rely entirely on automatic error detection and thus be able to reduce the manual labour. The gain is the increased security aspect and the possibility to follow individual vehicles over time. It is good to get an acute alarm saying that this train has to be stopped but it would be even better to be able to detect such problems before they become acute, so that no traffic disturbance ever occurs. Having worked with this technology little over a year, TrainCo has not yet adjusted their organisation to handle real-time information.

> *"There must be a receiver of all this massive amount of information. It is of no use if nobody is reading it. Most of the data we get is totally unused, partly because of some initial problems we're experiencing, but then again - we'll never get rid of those problems unless we start to use the system so that they can be identified…" (Strategist)*

Apart from maintenance, being able to know exactly where every train is located is an important aspect of TrainCo's operation. This applies in particularly to rail bound transportations, since a delay or a stop creates cascade effects that affect many other actors. The RFID data received is today integrated with the internal systems and used to generate more accurate predictions. Our respondent stresses that it is still predictions and an absolute certainty cannot be obtained, but that this is not necessarily a problem. Just the fact that information is communicated to the passengers has an important positive effect.

> *"You must realise that when there is a stand-still or when something big happens, then there is a complete chaos. Nothing can be predicted! So you can improve the algorithms somewhat but it has only marginal effects. The big gain comes from the psychological effects that the passengers feel they "know" when the train is due, that creates a sense of safety…" (Project manager)*

5. DISCUSSION

5.1 The purpose of introducing sensor technology

We can see from our cases that the purpose of introducing RFID varies considerably. All five organisations show interest in automational effects although only PaperCo and TrainCo mentioned it as a primary objective. The other three organisations saw the automational effect as a means to a higher end. RepairCo needed to automatically identify faulty cars but only as a first step towards achieving shorter turn-around times and reduced manual labour in their repair shops. Similarly, both SteelCo and MiningCo wanted to automatically identify their cars but only to allow for the planning of a more efficient operation. The business value sought through automation was cost savings.

All five organisations expressed strong interests in informational effects. TrainCo, RepairCo and MiningCo wanted to manage their maintenance processes more effectively, whereas PaperCo aimed at optimising their load/unload process based on knowledge of the goods' position. SteelCo needed reliable information in order to control and manage their resources more efficiently. Business value here would stem from increased control, leading to improved effectiveness and higher quality.

Finally, three organisations were explicitly aiming for transformational effects, wanting to re-engineer their car maintenance processes, or radically change the way they handled shipped material. The business values here were expected to be radical cost savings and increased competitiveness. PaperCo and TrainCo were the two organisations not showing any explicit interest in transformational effects. Interestingly enough, these two organisations show the least benefits from their projects; PaperCo in particular being a failure. At the other end, SteelCo and MiningCo were the two most successful organisations and also those who most actively strove towards transformational effects.

5.2 The business processes affected

The business processes affected by the introduction of the new technology could be classified as both operational and management processes. The two organisations seeking automational effects aimed at the operational level for improvement of car handling routines. This was however only realised at TrainCo, resulting in increased business value through higher customer satisfaction. The remaining three organisations also improved their operational processes; in particular SteelCo and MiningCo who could provide their fork lift drivers and yard personnel with more sophisticated IT equipment and thus improve their efficiency. At management level, all five organisations expected to see informational effects and all but PaperCo also managed to realise such effects. TrainCo, RepairCo and MiningCo were all able to improve their car maintenance planning and SteelCo could better utilise their storage facilities due to access to real-time information.

These empirical findings largely confirm Mooney *et al*.'s (1996) predictions that automational effects primarily should impact operational processes whereas the informational effects would first and foremost affect the management processes. The more substantiated business values, Mooney *et al*.'s (1996) model predicts, should come from the transformational effects as management and operational processes merge, as the automational effects extends to management processes and the informational effects extends to operational processes.

5.3 The type of business innovation seen

The transformational effects that resulted in business innovation we identified in this study included the improved passenger information as a result of combining automated train identification/positioning with arrival prediction routines at TrainCo. Further this organisation also innovated their service process through the combination of identification and error detection technology and thus being able to monitor individual vehicles over time. Similar gains were seen also at RepairCo who were able to have the needed spare parts readily available when a car came in for service. At SteelCo the real-time information enabled improved warehouse routines and enhanced loading/unloading processes. It also enabled a shift in mindset at SteelCo who begun to see the cars as part of their storage facility. MiningCo, finally, was able to improve the way the yard operators handled the cars by providing them with better decision support and could thus save money by reducing stand-still. Business values would here be expressed in terms of reduced cycles, competitive flexibility and new organising.

5.4 Implications for research and practice

Although RFID technology was successfully deployed in most of our five cases, the expected business values were often not fully achieved. Analysing the root causes for this, we were able to identify three major inhibitors; *Insufficient integration with existing systems*, *Lack of organisation adjustment* and *Uneven distribution of cost/benefit*s.

PaperCo failed to integrate the RFID information with their ordinary operational information, which led to underutilisation of the real-time data. The other four organisations made efforts - although they were not always successful - to leverage RFID data by combining it with data from existing applications. Our results suggest that the organisations that have experienced the least benefits from their RFID projects are those who have been least willing to commit themselves to the new technology and where RFID data has been handled separate from the main business.

Not only must RFID technology be integrated with existing systems, the organisation has to be adjusted to receive and use the data generated before it can be useful. This was typically often not the case. PaperCo were not able to re-engineer the load/unload process at their ports and most of TrainCo's RFID information remained unused since the organisation has not been updated to handle it. Similarly, MiningCo could have benefitted from integrating RFID information and detector information but the organisational adjustments needed to enable such integration were not in place.

Finally, business value that arises in one part of the organisation due to process innovation can cause problems elsewhere. If those problems outweigh the benefits, the innovation was a bad idea. A general problem is thus to know who to assess the overall business value. How can one compare gain in one area with a loss in another? Short term economic outcomes are often used but such measures fail to assess the long term effects of the innovation.

Our case study suggests that the whole process has to be integrated before a realistic evaluation can be performed, and this raises the question of whether a pilot project is at all feasible. An important issue to study further is how organisations should be able to do small scale proof of concept of sensor technology. A related question is how far along the value chain a sensor technology project needs to go. Is it sufficient to study the host organisation alone when many of the real business values are realised at the customer or at the customer's customer?

6. CONCLUSIONS

In this paper we have successfully used Mooney *et al*.'s (1996) theoretical framework and showed its usefulness when applied to empirical data. We have illustrated how business values from sensor technology are realised as automational, informational, and transformational effects and that they affect both operational and management processes. Whilst the automational effects are easiest to detect and valuate, it is the transformational effects that are likely to have the strongest and most profound impact on the organisation. However, such impact is seldom immediately realised partly due to the three major inhibitors we have identified; Insufficient integration with existing systems, Lack of organisation adjustment and Uneven distribution of cost/benefits. All these aspects require further academic work to be fully understood.

The implications for practitioners are that sensor technology is difficult to valuate properly as a stand-alone project; it has to be integrated with existing business systems and processes to add real value, and this requires a certain level of commitment from the organisation. Further, whilst automational effects (which are relatively easy to achieve) may provide good starting points for a business case, it is the transformational effects that will generate the most profound innovative changes. Our study of PaperCo has shown that there is an apparent risk in aiming too low - apparently, one has to dare to win.

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