An Analysis of Data-on-Tag Concepts in Manufacturing

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Abstract: Over time various drivers affecting information technology architecture design have been proposed which favored more centralization or decentralization. The last major shift towards centralization started in the late 1990s and was motivated by standardization, integration, and cost issues. With the advent of ubiquitous computing, the next inflection point heading towards decentralization might arise. This paper aims to improve the understanding of the decentralization debate by investigating the drivers that influence the design decision on whether or not to store data on a transponder label ('tag'). The manufacturing domain is taken as an example for discussion from which key factors and management implications are derived. These form a model that can guide companies wishing to implement Radio Frequency Identification (RFID) on how to design their applications.

1 Practical Background

Of all discussions in information technology, few have been as contradictory as that of information technology and (de)centralization. The ultimate goal has been to determine an appropriate arrangement for information technology resources such as hardware, software, communication equipment, data, and people within an organization. In general, the (de)centralization debate has tended towards examining trade-offs, in which the organizational advantages of centralized control, standardized operations, and economies of scale have been balanced against individual user department requirements, responsiveness and flexibility. However, an appropriate answer to the (de)centralization issue has not been found yet and for information technology departments the dilemma whether to centralize or decentralize remains [AB91, BJZ92, BR96, KCS03, Ki83].

With the advent of ubiquitous computing and its vision of smart objects equipped with digital logic, sensors, and actuators, the complexity further increases due to the ability to store data and to execute functions on a large number of objects themselves. This and the ability of these objects to interconnect, significantly contribute to the problem of finding the appropriate level of (de)centralization. Surprisingly though, whereas in practice most discussions on this issue are dominated by a centralized approach, significant amount of research is done to understand and develop the alternative, decentralized solution.

This paper takes a rather narrow view on the (de)centralization topic by focusing on manufacturing applications which require storage of data on a tag. It aims to improve the understanding of the drivers that influence the decision whether or not to store data on tag. The reason for choosing the manufacturing domain is that the notion of (de)centralization includes the concept of distance, for instance, between different levels of hierarchy [Si65]. As one of the best known hierarchical systems is the production planning and control system [Sc03], applications in manufacturing seem to be a suitable area for analysis.

The rest of the paper is structured as follows: first, we give a short overview on materials and methods used. This is followed by a description of generic RFID applications in manufacturing to illustrate the scope of research. We then present five cases studies and extract drivers that have an influence on the distribution of data. In the discussion section we critically evaluate the identified drivers and derive managerial implications. The paper closes with a summary of our findings and an outlook on further research.

2 Research Methodology

Understanding the factors for the distribution of data is a context-bound issue. For this reason, a qualitative research approach was used [Yi03] and a multi-case research design was employed [Ei89]. All case studies refer to manufacturing companies that implemented RFID and stored data on tag. In our investigations, we analyzed cases in the following industries: automotive, aerospace, petrochemical, and semiconductor.

To further enhance validity, the research process additionally includes three other data sources: first, we analyzed the existing literature on RFID in manufacturing including case studies and surveys. Second, we conducted semi-structured interviews with executives having particular knowledge of the use of RFID in manufacturing processes. Third, we visited a factory with the aim to analyze existing manufacturing processes and to discuss the potential of RFID to improve these processes.

3 RFID in Manufacturing Applications

The use of RFID in manufacturing is still in its early stage. However, according to two surveys, it will gain momentum in the future: one study [Ar07] found that only 22% of 95 respondents have currently RFID applications installed and 80% are evaluating, planning or are in the process of installing such systems. A second report [Mc06] provides a similar picture. About 10% of the 275 companies surveyed had already implemented RFID and about 58% were in the process or were planning to implement RFID.

While many manufacturers are adopting RFID in their supply chain operations by force of mandate imposed by the US Department of Defence as well as Wal-Mart, Metro and other major retailers, even more of them are seeking ways to use the technology to improve their production operations. In manufacturing, RFID can be implemented in three generic areas: (1) the inbound process, (2) the actual production process, and (3) the outbound process. According to [Be05, BT04, Le04, Mc06] and our own investigations, RFID's unique capabilities are enablers for gaining benefits in different areas:

Reusable Assets Management: Firms use physical assets such as tools, returnable containers, machinery, material, and other equipment in production and in the delivery of products and services. Knowing where such an item is and what state it is in, is crucial in a manufacturing process. Challenges faced by manufacturers that can be addressed by using RFID include low asset productivity, low asset visibility, absence of unique identification as well as theft and lost assets.

<u>Example</u>: Nordam Group, an aerospace company that manufactures aircraft parts, is using RFID to track high-cost molds, tools and parts. The system helps collect data for regulatory agencies, reduces data entry errors, saves labor time and lowers expenses since experienced, high-paid technicians no longer need to waste time looking for tools [Ba06].

Labor Tracking, Safety and Security: When worker badges are equipped with RFID tags that contain worker identification and authorizing data, three types of improvement become feasible: first, workers can use their RFID badge to open secure doors, portals, cages etc., based on authorized level of access. Second, value added by certain individuals can be captured. Third, attempts to utilize assets during the manufacturing process such as forklifts can be verified against the training record of the worker. These applications lead to improved security, worker safety, reduced risk, optimized warranty, and recording legal requirements.

<u>Example</u>: BP is piloting RFID in the area of health safety, security, and environment. Some of their envisioned applications are attaching RFID tags to safety equipment for unique identification and documentation of regular inspections. Other applications include the usage of tags on personnel to locate people in the event of an emergency, to immediately identify whether someone is missing, and to safely evacuate employees [Ro06].

Process Control: RFID technology has the potential of combining the efficiency of process automation with the flexibility of manual production. It leads to complete transparency in manufacturing processes that had been difficult to control until recently, enabling real-time performance monitoring of essential functions within process control. Examples of this are identifying incoming products, providing operators with critical information, monitoring and controlling operations during processes, determining pass / fail statuses, moving products to subsequent processes, and stopping further processing if products failed predefined quality limits.

Example: Infineon Technologies developed a real-time identification and localization system which combines RFID tags and ultrasound sensors to track plastic wafer boxes and wafer cassettes in the company's chip-manufacturing process. The implemented solution led to improved efficiency, decreased lead times, increased machine utilization, and made the entire production process visible and therefore controllable [TFD06].

Inventory Management: By placing tags on containers and pallets, information can be collected as those items move through the facility. The amount of idle inventory can be reduced and managers can be alerted to unscheduled movements that may indicate theft or other forms of shrinkage. Moreover, such a solution eliminates time and cost for stock counting by collecting the needed data automatically.

Example: Blommer Chocolate, a cocoa-processing company, implemented an inventory tracking system to improve inventory control and visibility. By using RFID, the company was able to make its warehouse operations more accurate and efficient. As a side-effect, the company could speed up its loading process and can now follow the best-practice model of first-expire-first-out sequencing for ingredients [Oc06a].

Receiving, Picking, and Shipping Processes: By using RFID, pallets can be automatically read when deliveries arrive at the warehouse. This allows immediate verification of contents of the load and real-time visibility to backend systems. It increases productivity, enables faster invoice settlement, eliminates manual and error-prone, time consuming handling, increases inventory accuracy, and leads to a reduction of inventory levels. Implementing RFID technology in a shipping process ensures proper and swifter shipment and enables the automatic validation of loading sequences. In the end, this decreases shipping delays and improves customer satisfaction. Using RFID in a picking process provides faster identification and location of objects which eliminates extra time for matching items.

Example: In 2004 Gardeur AG, a German clothing manufacturer, decided to deploy an RFID system to track garments from production to its warehouse. With this implementation, manual work and shrinkage could be reduced and efficiency of the underlying processes could be improved [We06].

Work-in-Progress Tracking: For build-to-order production and sequencing, manufacturing processes rely on item-level tagging to ensure that the correct base components and raw materials are used. In this context, RFID provides an easy way to verify objects and the data can be integrated with material handling and production-control systems. Consequently, items are more reliably routed to the appropriate assembly, testing, or packaging locations.

Example: Lawsgroup, a Chinese contract manufacturer that produces garments, uses RFID technology to automate the tracking of work-in-progress. Now the system provides information on how many pieces are completed and which pieces of an order have reached a certain working station. It also enables the company to produce more garments and react more quickly to changes than they were able under the manual system for tracking work-in-progress [Oc06b].

Replenishment: RFID can be used to provide timely replenishment of materials used in production. This brings just-in-time replenishment processes such as KANBAN to new levels of efficiency and responsiveness. As a consequence, manufacturers are able to lower their material stocks and thus reduce their operating expenses without the need to reengineer the underlying process.

<u>Example</u>: DaimlerChrysler added RFID to existing KANBAN parts-management cards and is now able to track whether parts are in storage or being used on a production line. The increased visibility eliminates the need for labor-intense, time-consuming manual stock counts and enables the automation of part orders [Co06].

Figure 1 illustrates the example of an existing manufacturing process for confectionary including the process steps in which RFID might be beneficial. In this process, unwrapped sweets arrive at the production lines where they are wrapped and poured in large bulk containers prior to being consumed on packing lines. Depending on the need of the packing lines, the full containers either go directly to packaging or are brought to the cold store and kept there until needed on the packing lines. Additionally, a container may be in need of washing. The management of the containers includes knowing their location, their contents and the quality state of the contents. There is also a need to efficiently manage empty containers.

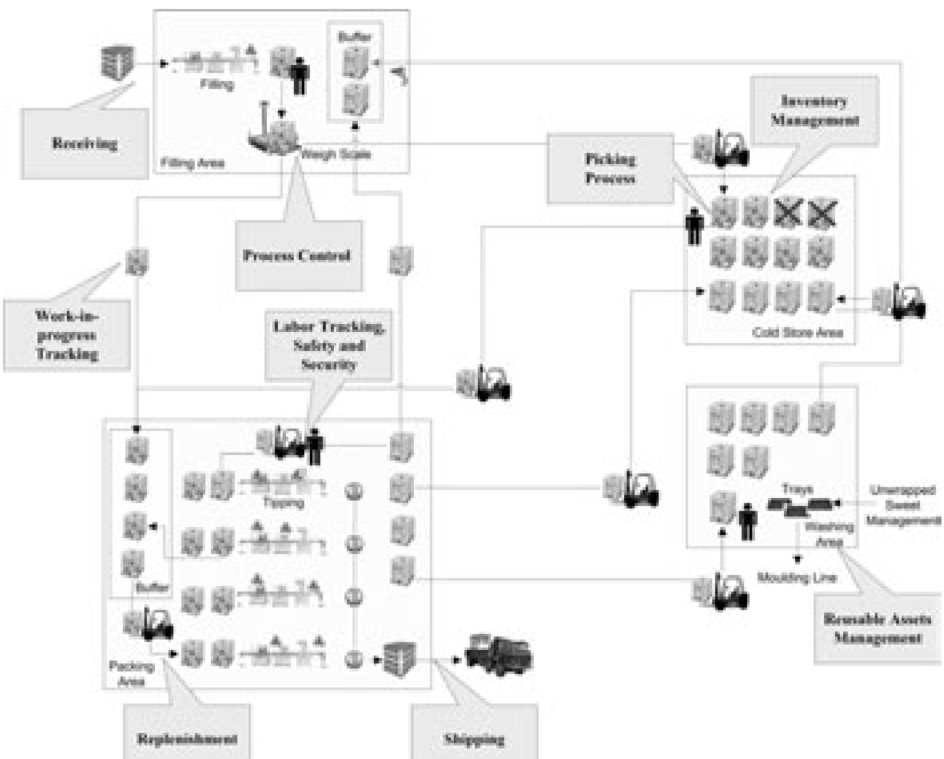

Figure 1: Generic RFID applications exemplified by a food manufacturing process

4 Factors influencing the Data-on-Tag Decision

In the former section, we presented generic RFID applications in manufacturing. Now, we concentrate on five specific cases of RFID implementations from different industries and give reasons why data are stored on the RFID tag versus only being stored centrally. The results are summarized in Table 1.

Automotive Industry: Production of Engine Cooling Modules

A first-tier automotive supplier uses RFID in two assembly lines for tracking cooling modules during the production process [Iv07]. In total up to 32 different variants can be produced in the factory. For the production, a module is placed on a carrier and moved along the production line from work station to work station. At each work station a worker performs a number of tasks on the module. Primary reasons for introducing RFID technology were a customer demand for improved process documentation and traceability as well as quality issues.

The variant type and job parameters are stored on the tag for each engine cooling module to be produced. This information is used at the work station to perform the required tasks. Once a job has been completed, information on whether the task was performed correctly, production errors, and the identification of the work station on which the task was performed are written back onto the tag. When the production process is finished, the information recorded on the tag is transferred to the backend system. There, it is used for quality assurance and planning. The carrier and the RFID tag can then be reused for production of the next module.

Major reasons for distributing data are *implementation costs* and *difficulty to adapt legacy systems*. Basically, there are two options for providing workers with the information about the next tasks to be performed: a) writing data on the tag and b) retrieving the data from the backend system at the time they are needed. In this application it was cheaper and easier to store the data on the tag than to implement and maintain a connection between the work stations and a central manufacturing execution system (MES). During the project, it was also mentioned that it might be possible to *exchange data* among supply chain partners using RFID tags rather than integrating backend systems of the different partners. This would ensure an easy and consistent access of product data across its lifetime.

Petrochemical Industry: Managing Hazardous Goods and Workplace Safety

The project 'Collaborative Business Items (CoBIs)' [NOS05] is taking a step beyond existing RFID applications by shifting business logic from resource-intensive backend systems to systems embedded in the object itself. Using sensors, wireless communication and computing components, chemical drums will warn operators when the storage limit in a warehouse is reached, if a leak occurs and if a drum is placed in the wrong location.

In contrast to traditional architectures, the sensed information is not collected in a central database from where decisions are made. Instead, data is stored and functions are performed locally. Stored data on the drum describes the physical nature of the object, such as content, reactivity, and mass as well as its location and proximity to other drums. In addition, rules that express the situation that must be true to trigger an action are defined in the backend system but stored and applied locally.

Key factors for distributing data are *response time* and *process flexibility*. As industrial work places at chemical plants pose enormous risk for workers, the slightest mistakes could lead to a disaster. Hence, manual processes need to be supported and problems need to be handled in real-time. Furthermore, by distributing data and logic the application will be highly scaleable and flexible. Introducing additional drums will not degrade the performance of the overall system.

Semiconductor Industry: Production of Silicon Chips

Like other companies in the semiconductor industry, Infineon seeks to reduce stock and to improve efficiency by increasing automation in production [TFD06]. Particularly, the company has a strong customer orientation which requires a flexible, operator-centric automation approach to handle the large number of varying production processes and frequent rearrangements of machinery and other technical equipment. Against this background, Infineon implemented a real-time localization system which combines active RFID tags, passive RFID tags, and ultrasound sensors to precisely locate and track plastic wafer boxes and cassettes in the manufacturing process. As a result, the company was able to decrease lead times, eliminate handling errors, and reduce non-value-added activities.

At the beginning of the production process, an operator attaches a battery-powered RFID device onto a lot box. This device is also equipped with an ultrasound sensor for localizing, a two-colored LED for signaling, a mechanical flipdot for reserving a box as well as a no-power display and four keys for user interaction. Within the box, there is a wafer cassette equipped with a passive tag. After selecting the next lot on a screen, the operator picks up the box, brings it to a machine indicated by the display, takes the cassette out of the box, puts it into the machine, and starts the processing. A reader on the machine identifies the passive tag attached to the cassette to make sure that no duplicate or missed process step occurs. After processing, the operator takes the cassette out of the machine, puts it back into the box and stores the box on a shelf waiting for the next operation.

The distributed data serve as a *backup* if network connection is not available. As shown in the automotive case illustrating the production of engine cooling modules, one reason for distributing data is that a worker needs to know about the next task to be performed. In this application at Infinion, two usage scenarios are implemented. On the one hand, data can be retrieved from the backend system when needed. On the other hand, data about the production steps is stored on the tag. The decentralized stored data is needed for displaying information to the operator and is accessed if the network connection fails so that production does not need to be stopped.

Automotive Industry: Production of Car Keys

Huf Tools is a technology company, which specializes in the construction of machines for automation and the development of RFID systems. The company also develops and produces start-stop-buttons for major car manufacturers. For the fabrication of 14 different variants of car keys, they use RFID to control the manufacturing process. The production line consists of several work stations and the production of a key can start at different work stations.

Not the products themselves, but rather for production the container which holds them is equipped with an RFID tag. It contains information about job parameters, production progress, production errors, and product parameters such as color and frequency of the RFID enabled car key. At each switch and work station this data is used to determine the next work station and the next production step, respectively. Furthermore, in case of an error, the product is automatically taken off the line and sent to the repair station where corrective tasks can be performed before putting the product back onto the line.

Factors that influence the storage of data on the tag are *response time*, *implementation costs*, *difficulty to adapt legacy systems*, and *process flexibility*. By storing data on the tag the production system is faster because data does not need to be sent to a backend system to retrieve the next production step. In addition, the production is more flexible. There is no need for stopping the production line if new variants are introduced or if errors occur. In addition, designing the system in such a way that integration with the backend system is limited, the solution is less costly and less complex. Besides, it was mentioned during the interview that if production information is stored on the product itself, this can be used to *exchange data* between supply chain partners. This would streamline subsequent service processes.

Aerospace Industry: Usage of RFID in the Internal and External Supply Chain

Building an airplane is one of the most complex manufacturing processes. Not only does each plane consist of tens of thousands of parts that must be assembled in a highly orchestrated way, but most parts also have to be tracked separately to comply with regulations [Al03]. One of the major issues in the aerospace sector is the tracking and tracing of a part during its entire lifetime even after the plane has been manufactured and is in operation. In this stage maintenance and usage information must be shared among parts manufacturers, plane manufacturer, service centers, and the airline according to international requirements.

In this context, the major reason for storing data on the RFID tag is that decisions have to be made and data have to be captured by different parties without the existence of a *network connection*. Apart from storing maintenance data on the tag, companies in the aerospace industry require storing configuration and manufacturing data as well as information about part failure and the conditions under which the failure happened. This data is used by several parties for service and maintenance. Another reason given is that the tags can be used to *exchange data* among business partners without the need for integrating backend systems [Ke06].

Company	Application	Data on Tag	Reason	Source
Engine Cooling Modules Producer	Using RFID for transferring data between work stations for production control	Product parameters, Job parameters, Production progress and errors	Implementation costs, Difficulty to adapt legacy systems, External data exchange	[Iv07]
BP	Distribution of business logic and data to real-world items for hazardous goods and safety management	Product parameters, Business rules, Condition data	Response time, Process flexibility	[NOS05] Company Interview Factory visit
Infineon	Using RFID and ultrasound sensors to improve production in a wafer fabrication	Job parameters	Backup	[TFD06] Company Interview
Huf Tools	Using RFID for transferring data between work stations for production control	Product parameters, Job parameters, Production and errors	Response time, Implementation costs, Difficulty to adapt legacy systems, Process flexibility, External data exchange	Company Interview
Aerospace industry	Usage of RFID in the internal and external supply chain	Configuration, Manufacturing, Maintenance data, Part failure and condition data	Data access / capturing without network connection, External data exchange	[Ke06]

Table 1: Factors influencing the data-on-tag decision

5 Discussion

By analyzing five case examples, we identified drivers that have an influence on the decision whether or not to store data on tag in manufacturing. Given these factors, we can now discuss and provide implications for managers who wish to implement RFID applications in manufacturing.

Legacy systems: From the cases of Huf Tools and the Engine Cooling Modules Producer, we extracted the factors *implementation costs* and *difficulty to adapt legacy systems*. Our investigations show that companies are reluctant to change their existing systems. Those systems are of high importance to operations and their implementation has been costly in terms of time and money. Against this background, companies seem to prefer loosely coupled and rather independent systems. Thus, storing data on tag is an option for manufacturers seeking to limit the changes to be made on legacy systems.

Network connection: In the aerospace case, major reason for storing data on the tag is a missing *network connection*. Yet, it can be argued that mobile telecommunication technologies could be used for transferring data. Then, however, network coverage and availability, communication costs as well as security becomes an issue. Hence, storing data on tag is an option for manufacturers that require access to object-related data if either no network is available or a network is available but the connection is unreliable or communication costs are prohibitive.

Backup: In the case of Infineon, data is stored on the tag as a *backup* for centrally stored data. The necessity to distribute data will be required in the future unless the network connection guarantees permanent connectivity. However, as uncertainty is always an issue with regard to performance, we have reasons to believe that the factor backup will still be of importance in the future. Therefore, storing data on tag is an option for manufacturers seeking to provide a backup for centrally stored information used in production critical processes in the case of system failure or an unreliable network connection.

Response time: Even if network connection is available, there might be problems with the *response time* which was mentioned in the cases of BP and Huf Tools. Response time or latency is the time for data to be sent from one application to another, the processing time, and the time that is needed for sending the results back. For instance, in the case of BP response time was a problem when more than 20 drums were in the system, which is a low number compared to the total number of drums in use. As a result, storing data on tag is an option for manufacturers if a time critical process or task relies on data stored in a central database and the response time for retrieving this data cannot be guaranteed or is higher than the time available for distributed decision making.

Data exchange: The possibility to *exchange data* between partners using tags was mentioned three times as a potential use case. However, there are major issues that make such a solution less feasible. First, companies only want to share data with certain partners. This requires authorization and security functionality on the tag unless data is unimportant. However, if data is unimportant then this data does not need to be exchanged. On the other hand, this additional functionality increases complexity and cost of the solution. Second, if the tag gets lost or destroyed, information is lost. In this case a backup of the lost data is needed in the backend system and data need to be shared between the backend systems. Yet, this would make the exchange of data using a tag obsolete. Consequently, storing data on tag for exchanging data between partners could be an option between trusted parties or for non-critical information. However cost and security aspects as well as the consequences of lost and destroyed tags need to be weighed carefully.

Flexibility is frequently mentioned in theory and practice as one major driver for decentralization. This concept usually characterizes the capability of a system to adapt to new, different, or changing requirements posed by disturbances such as machine breakdowns or rush orders. Although in our case studies *process flexibility* is mentioned as one factor that requires the distribution of data, it seems that flexibility is not the actual reason. Instead, implementation costs, difficulty to adapt legacy systems, network connectivity, and response time have more weight and need to be taken into account. For instance, in the case of Huf Tools it was argued that no production standstills occur in case of errors in production if data are stored on the tag. By having all necessary data distributed, the company is able to remove a semi-finished product from the line, take corrective actions and put it back onto the line. However, the same solution is achievable if required information is gathered from the backend system using a network connection with proper response time. Thus, process flexibility is not the ultimate factor for distributing data. Rather, it is implementation cost, difficulty to adapt legacy systems, network connectivity, and response time.

Figure 2 summarizes our findings in a decision tree. Only if a business case for an RFID implementation is positive, will the RFID application be designed. In the design phase, it is to be determined whether data should be stored on an RFID tag or in a backend system. When using the decision tree, each identified implication is to be tested against pre-definite conditions. This finally leads to the conclusion where to locate data.

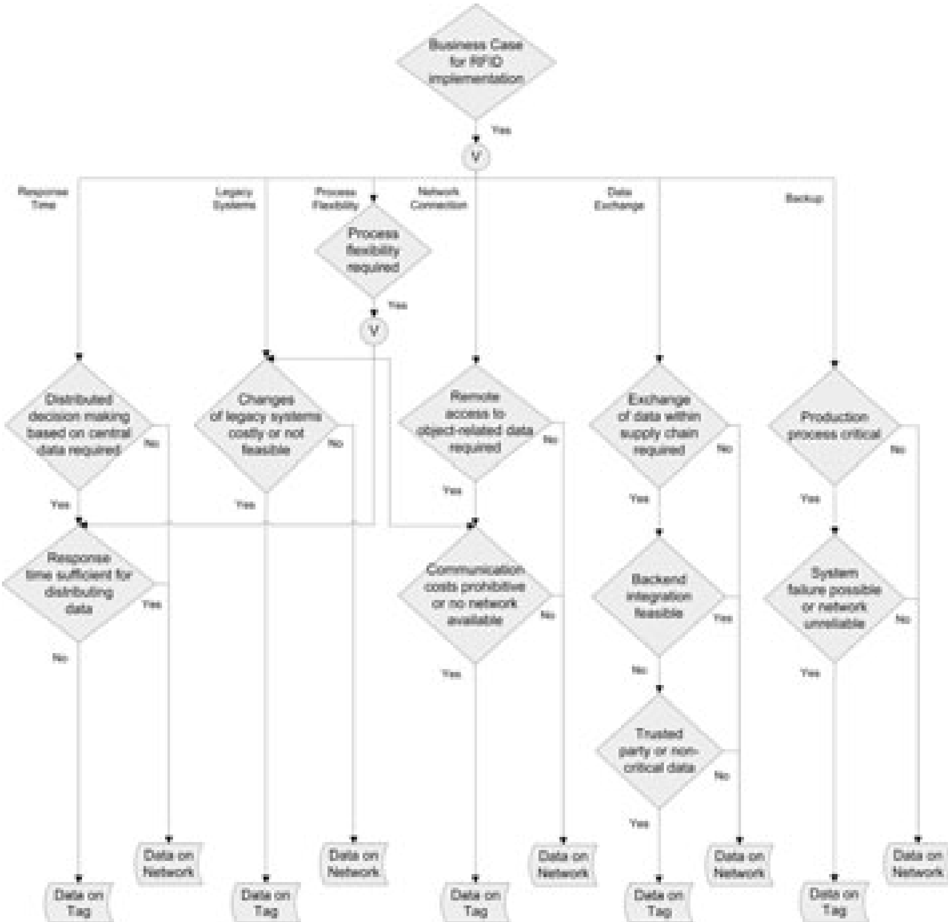

Figure 2: Decision tree

6 Summary and Conclusion

The aim of this paper was to improve the understanding of the (de)centralization debate in information technology research by investigating drivers that influence the design decision on whether or not to store data on tag. By analyzing five case studies supplemented with the participation in an RFID project, a factory visit, and semi-structured interviews, five drivers were extracted that influence the decision whether or not to store data on tag. Identified drivers are legacy systems, network connection, backup, response time, and data exchange.

The explanation of the drivers and the resulting implications form a model that can support software providers and managers wishing to implement an RFID application in manufacturing on how to design the application. From a theoretical perspective, this paper fills the existing gap in literature on the data-on-tag approach in manufacturing. Based on our typology of specific drivers, researchers can benefit from the theoretical work conducted and transfer the results to other domains, where especially related fields such as transportation and trade might benefit most.

As with any study, this research is not without its limitations. First, it is based on a relatively small number of case examples, owing to the early stage of technology adoption in manufacturing. Therefore, the validity of future research would benefit from insights obtained from quantitative data. In addition, the study is limited by the fact that it concentrates on cases in which data are stored on the tag and these cases come from only four industries. Including cases in which data are not stored on the tag, analyzing other industries, and looking beyond manufacturing could both reveal additional drivers and further enhance the transferability of the results. Finally, additional research could focus on problems that arise by distributing data such as synchronization problems and the distribution of business logic. For this, establishing a comprehensive view on the (de)centralization debate in the era of ubiquitous computing in manufacturing requires a critical review of related work in the fields of ubiquitous computing, information systems research, distributed systems, organizational science as well as production planning and control.

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