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The Promise of Auto-ID in the Automotive Industry

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ABSTRACT

RFID (Radio Frequency Identification) is the next evolutionary step in automatic identification (Auto-ID) technology. It makes it possible to synchronize the physical flow of goods and the related information flow without the need for human intervention. Managing physical resources will be as efficient as moving bits in the digital world of information systems. Efficiency gains arise from the avoidance of errors, from automation and from the ability to manage all kind of things individually. Such technologies provide benefits for a variety of applications across the automotive value chain. This paper evaluates the most promising applications for Auto-ID technology in the automotive industry. The paper considers:

– Current RFID applications and their costs and benefits;
– The business need for advanced Auto-ID technology in various areas of the automotive value chain;
– Likely scenarios for the adoption of Auto-ID technology;
– Drivers and challenges on the adoption path.

We find that there are many beneficial applications, with a focus on the supply chain, the product itself and the area of after-sales services. Today most applications are not based on standards or even a common infrastructure like that proposed by the Auto-ID Center. Although automotive makers expect significant benefits from RFID technology, they face three main challenges that need to be addressed for a breakthrough: the availability of industry wide standards, a drop in price and a model for solving the distribution of costs and benefits across the automotive value chain. These three challenges can be addressed by the work at the Auto-ID Center as further discussed in this paper.

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The Promise of Auto-ID in the Automotive Industry

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The Promise of Auto-ID in the Automotive Industry

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1. INTRODUCTION

1.1 Overview

This paper will evaluate Auto-ID technology that is based on RFID (Radio Frequency Identification) technology for the automotive industry. In such systems, small chips (tags) are used for identification. These chips store an unique identifier that can be read independent of line of sight. RFID enables automatic identification without the need of human intervention.

As a result of strong global competition the automotive industry has always held a leading position in the adoption of new technologies. By adopting new technologies the industry has improved their processes and products. Major initiatives in the automotive industry include just-in-time (JIT) manufacturing, mass customization, "zero error production", and reduced cycle time[1]. To accomplish such goals, automotive manufacturers increasingly rely on information technology to help manage processes. The Auto-ID Center at MIT has developed an approach to using low cost RFID technology for identifying and managing everyday items[2]. How this concept (following named as Auto-ID technology) might affect the automotive industry is the focus of this paper.

The automotive industry already uses RFID technology for a variety of applications. Sokymat, who is the market leader in transponder sales according to VDC, sold around 30 million RFID transponders (50% of their total sales) to the automotive industry in 2001[3]. Such applications include container and bin tracking, work-in-progress tracking, vehicle identification, access control, etc.

Auto-ID technology has the potential to enhance those applications by an ubiquitous infrastructure that provides standardization for automatic identification. Technology standards will significantly reduce hardware costs of RFID systems. E.g. where RFID today is only used with valuable goods (e.g. special racks) it soon will pay of for any kind of containers that are used for the transport of parts. Standards for data management and a middleware that integrates RFID systems with business software like ERP systems will enable RFID with nearly every part that is used for building cars. In those scenarios common standards are necessary that enable using RFID by all members that collaborate along the automotive supply chain, from the supplier to the end user.

The applications described in this paper demonstrate today's potential for Auto-ID technology. A variety of applications are possible and financially justifiable for certain product and market requirements. Based on the business needs of the automotive industry, statistical market data, and the projections of the Auto-ID Center, this paper examines the conditions such applications are feasible.

One major area where Auto-ID technology will have a large impact is the automotive supply chain, encompassing all tasks associated with moving goods from raw materials through to the consumer. This includes tasks such as sourcing and procurement, inventory management, assembly, order processing, distribution, transportation and warehousing[4]. Although the automotive supply chain has the reputation of being well organized compared to other industries, supply chain visibility and information accuracy are still far from perfect. Automotive manufacturers, referred to as Original Equipment Manufacturers (OEM) are dependent on their suppliers for a large number parts, components or modules. Because of this dependency supply chain visibility is more crucial. Some sources say that the automotive manufacturers spend roughly 60% of their IT budgets for the improvement of their supply chain management systems[5].

In addition to supply chain applications like inventory management, assembly automation and asset management, other beneficial applications are found in the area of after-sales service. Examples are maintenance support, recalls and recycling.

[1] VDA: Auto Jahresbericht 2002, http://vda.de

[2] Auto-ID Center Website: http://www.autoidcenter.org

[3] Venture Development Cooperation: http://www.vdc-corp.com

[4] SCOR: http://www.supply-chain.org

[5] See Supply Chain Systems Magazine: http://www.idsystems.com

We will further explore these applications in chapter two. Before doing so, we will introduce the concept of Auto-ID technology and review the automotive supply chain Chapter three summarizes the market opportunity for the applications identified based on the current and projected potential for Auto-ID technology. Tag requirements for each application can be found in the appendix. In chapter four the main adoption drivers and challenges are identified and in the final chapter discussed a possible adoption path for Auto-ID applications in the automotive industry.

1.2. About Auto-ID Technology

The technology discussed in this paper has been introduced by the Auto-ID Center. It is a visionary new concept for the unique automatic identification of individual physical objects. Like the barcode 25 years before, this is expected to have a large impact on supply chains, assembly processes, products and after sales service in various industries.

The concept involves several components:

1. **The Electronic Product Code™ (EPC™)** is a unique 64–96 bit identifier.

2. The **Smart Tag** is a low cost RFID based label that is attached to the physical object and stores its EPC™ code.

3. A **Reader Infrastructure** of RFID antennas is able to identify tagged objects without the need for a line of sight.

4. The **Physical Markup Language (PML)** is an XML format to describe all product related information.

5. The **Object Name Service (ONS)** returns for a specific EPC the address where the object data can be found.

6. The **Savant™** is a software tool that manages the data as it is collected and provides it in real-time to business software systems, e.g. ERP systems, or to the Internet.

Auto-ID technology can virtually connect physical objects and data via the Internet. Data about every product, e.g. its history or other product related information can be made available through a standardized infrastructure anywhere and anytime[6].

[6] For detailed information please see http://www.autoidcenter.org.

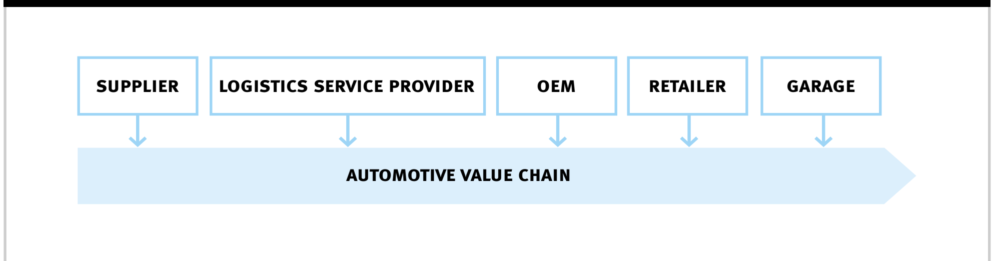
1.3. The Automotive Value Chain

A large number of different companies collaborate along the automotive supply chain including suppliers, logistics service providers, OEMs, dealers and garages. Accurate information about inventories at any point of the supply chain is required for Collaborative Forecasting Planning and Replenishment (CFPR) and supply chain efficiency.

Suppliers provide raw materials, parts and components that are used for automotive assembly. (Today many suppliers not only need to consider their customer's needs but also their customers' customer's needs. This paper looks only at first tier suppliers that directly deliver to the OEM, also called 'tier one suppliers'.) Logistics service providers offer a variety of services that are related to transportation and warehousing along the whole supply chain. OEMs focus on building cars that customers will buy. As the last stage before the end customer, the OEMs generally have a stronger position than other members of the supply chain. Dealers sell cars, spare parts and complementary products like credit and insurance. Garages provide maintenance and repair services. All of these participants constitute the automotive value chain.

Figure 1

THE AUTOMOTIVE VALUE CHAIN



Auto-ID systems will only be efficient if they are used in a collaborative way. This means data will be shared along the supply chain based on standards. A basic scenario on how an Auto-ID system could work is source tagging, also referred to as direct part marking (DPM). In this scenario the supplier adds a RFID tag on each part manufactured.

In doing so the supplier will incur costs for the tag and for changing his production process in order to integrate the tagging procedure. On the other hand he may have some benefits in the management of his own warehouse and in faster distribution. The tagging costs are the dominant cost factor in this scenario. The automotive manufacturer will receive the most benefit. The only cost he faces is to implement an infrastructure of readers and to integrate them with the existing IT infrastructure. These benefits relate to inventory management, theft control, brand authentication, production, and recycling. The benefits and costs for suppliers, OEMS, Dealers and Garages are shown in table 1[7].

[7] Main costs and benefits are printed bold.

Table 1: The value chain for RFID source tagging in the automotive industry

	SUPPLIER	OEM	DEALER	GARAGE
COSTS	– **tagging** – changes in production process – reader infrastructure	– reader infrastructure – integration into existing IT infrastructure	– reader infrastructure	– reader infrastructure
BENEFITS	– distribution – theft control	– **inventory management** – theft control – **brand authentication** – assembly – distribution – support for recalls – recycling	– distribution – theft control – brand authentication	– maintenance – brand authentication

[8] autoid.org: http://www.autoid.org/GM1724/gm1724.htm

The question for this scenario is how the benefits and costs can be shared in an equitable way along the value chain. Historically it has always been the OEMs who were pushing the introduction of new standards for logistics applications. An example is the barcode based GM 1724 spec that has been introduced by GM to standardize shipping labels[8]. It has been released in 1999 and is mandatory for all GM suppliers since 2001. GM estimates that the system can save more than $100 million annually in shipping, mishandling and other expenses. This shipping label is the template for a common global shipping label for the entire automotive supply chain. Members of the AIAG, ODETTE and JAMA have signed a letter of understanding on this issue.

This example shows that new standards can be implemented quickly in the automotive industry if a benefit can be realized. The OEM provides leadership because he realizes the most benefit, has the power of being a large customer and has advantages in providing the technological know how. In order to push adoption of the technology, OEMs will have to offer some financial compensation to the suppliers. The value chain applies for most applications that are evaluated in the following chapter.

2. APPLICATIONS AND BENEFITS

The applications of Auto-ID technology can be grouped into three classes:

– Part-tracking
– Capital Asset Management
– Vehicle Related

Part-tracking can improve supply chain related tasks such as inventory management, brand authentication, theft control and assembly as well as after sales service tasks like maintenance, recalls and recycling. Part tracking provides the most benefits across the automotive value chain, but requires a standardized Auto-ID infrastructure for RFID tags that cannot be reused (an “open loop” scenario), and solutions for sharing costs and benefits are needed. The second class of applications, capital asset management, improves the management of resources that always stay within the company (“closed loop” scenario). Such working assets comprised of a variety of containers that are used in logistics, as well as tools used for production and maintenance. Standards are not necessary for such applications, however if in place would reduce implementation costs and facilitate the outsourcing of capital asset management to service providers. For example already today logistics service providers own and manage many of the containers that are used in the automotive industry. Once tracking and monitoring of capital assets supports accurate billing models for such services the concept could easy be applied to further capital assets, e.g. tools, or improve exiting services. In part tracking the technology will help to improve operational processes. Such applications can frequently be realized as closed loops where tags can be reused.

Finally, RFID technology also can be used to add functionality to the car itself. Such applications comprise car identification, access control and tire pressure monitoring. The reason for implementing such systems is to better serve customer needs. These applications don’t require standardization for sharing data, although standardization will almost certainly result in reduced costs.

Table 2 summarized the applications discussed thus far. The following sections will analyze each of the applications in more detail.

Talbe 2: Auto-ID applications in the automotive industry

PART TRACKING	CAPITAL ASSET MGT	VEHICLE RELATED
Inventory Management Assembly Theft Control Brand Authentification Maintenance Recall Recycling	Container Management Tool Management	Car Identification Access Control Tire Pressure Monitoring

2.1. Part Tracking

Insufficient supply chain visibility effects planning reliability in the automotive industry. According to A.T. Kearney, supply chain inefficiencies can waste up to 25 percent of a company's operating costs[9]. Insufficient coordination between material flow and information flow leads to the so-called bull-whip-effect[10]. The consequences are excess production or stock outs. For this reason, the majority of companies maintain costly safety stocks.

Auto-ID technology could be used to improve supply chain tracking. Auto-ID based tracking of parts leads to several benefits. It enables full supply chain visibility and as a consequence facilitates collaborative forecasting, planning and replenishment (CPFR) and just in time (JIT) production.

Part tracking can be achieved in two ways. Either the tag is attached to the part itself (direct part marking or DPM) or it is attached to the part's packaging or carrier. In the second case, one tag may be used for identifying more than a single item, which helps reduce costs, especially if the packaging is reusable. For example, part tracking can be accomplished by tracking the containers that are used for parts transportation. Doing so requires maintaining a database linkage between the RFID tag-equipped container and the parts in the container. This approach is called soft linkage or soft tracking and can be achieved at lower costs but offers less accuracy as errors can occur in associating the container ID to its contents.

Direct Part Marking could increasingly be used at the component level. Safety issues, and the increasing need for management of liability, might require each part of a vehicle to be tied to the vehicle identification number (VIN). One example that might be break ground for other safety-related components is tire tracking. As more parts are marked directly by the supplier, more benefits can be achieved in inventory management, assembly, brand authentication, theft control, maintenance, and recall actions. The identification technology to be used for part tracking will largely depend on the part itself. Factors supporting the use of DPM are high part value, safety requirements, and the ease with which similar but incorrect parts may be substituted.

Today traditional barcode based shipping labels are used for identifying parts in the supply chain. The use of linear or 2D barcodes has already enhanced transport accuracy, reduced misrouting, and increased the accuracy of information about part location through the supply chain. Examples of such to allow supplier and routing information to be read everywhere without need to download the electronic waybill that is transmitted via EDI. Still, an estimated 20% of all deliveries are delayed because the electronic waybill cannot be downloaded immediately[11]. A more advanced infrastructure like that provided by Auto-ID technology would be able to address these shortcomings.

[9] S. Mayer: Erfolgsfaktoren für das Supply Chain Management nach der Jahrtausendwende.

[10] H. L. Lee, V. Padmanabhan, S. Whang: The Bullwhip Effect in Supply Chains, Sloan Management Review, Spring 1997

[11] Interview with OEM.

There are some cases where barcodes are simply not appropriate and where improperly read barcodes produce errors. RFID readers are cheaper and more reliable than 2-D barcode readers. Collaboration between the members of the value chain in setting up standards and sharing data are essential for to fully realize the benefits of these applications. Source tagging or DPM will provide the most benefit, but requires the supplier to tag his products. On the other hand, manufacturers, dealers and garages will realize the largest benefits. A common infrastructure like that provided through the Auto-ID Center's approach would be facilitate these applications.

The following sections discuss how tasks along the automotive value chain can be improved by part tracking. Benefits can be found for inventory management, assembly, brand authentication, theft control and in the after sales area. Finally, tire tracking is presented as an example application.

2.1.1. Inventory Management

The goal of high quality inventory management is to keep stocks as low as possible without running out of needed parts. Large warehouses in the automotive industry can store up to 250,000 different parts[12]. This requires careful planning based on production plans, on-hand stocks and parts in transit, and also calls for short replenishment times.

Automotive manufacturers' production sites are often large (e.g. 75,000 square feets[13]). It is essential not only to know what is in inventory but also what is in transit. Especially in just in time scenarios, the last few meters are the most important. In the automotive industry more and more products are delivered just in time. Today at a typical OEM ca. 30% of all parts are delivered just in time[14]. A load of parts can easily be moved to the wrong assembly station, so detailed information about material flow is needed in advance. In this context, inventory management indeed means replenishment management.

Auto-ID technology can help to provide reliable information about parts in transit and parts in inventory. How Auto-ID is implemented depends on how part tracking is handled (i.e., at the item or packaging level). For a base scenario, it should be sufficient to update the tracking information whenever parts enter or leave warehouses/terminals or assembly stations (automatic check-in and check-out). This is already done in today's barcode based applications. An OEM uses on average around 50 scanners per factory for check-ins and check-outs[15]. The expected need for RFID readers will be similar, but with RFID technology check-ins and check-outs can be done much faster, more reliable and nearly without human intervention.

For soft tracking scenarios, where containers are tracked, active transponders with more range can pay off and enable localization. If the parts are also tagged, the errors that can occur in associating parts with their container can be avoided. Readers mounted at entry and exit portals can be used for automatically assigning part and container IDs, or the containers themselves could be equipped with RFID readers and wireless LAN connections, making truly real-time tracking possible.

Benefits

- Reduced safety stock
- Prevention of material outages
- More accurate and faster flow of parts
- Fewer high-cost emergency orders
- No lost inventory (lost inventory consumes space in the warehouse and can be discovered only during stocktaking)
- No manual stocktaking required
- No search for misplaced parts (if tags are used in combination with a Real-time Locating System (RTLS), or with full-coverage networks of many readers)
- Check-in and check-out processes can be automated (vs. today's manual processes)
- Supports vendor managed inventories (VMI)

[12] Interview with OEM.

[13] Ford's Van Dyke facility in Sterling Heights, MI

[14] Interview with OEM.

[15] Interview with OEM.

Examples

– **Ford** uses a soft tracking based RTLS on some of their production sites[16].

[16] Wherenet: http://www.wherenet.com.

Summary Comments

If DPM is used the tag price is the main cost factor in this application. In order to minimize costs, soft tracking approaches will most likely be adopted first for part tracking on the production site. DPM for accurate inventory management will only make sense if a large number of different parts are marked. This would require very cheap RFID labels (<$0.05) that are able to work in a metallic environment. Once these requirements are met the potential of RFID will be enormous. These requirements can potentially be met by Auto-ID technology. It provides the standards that are necessary for the availability of cheap RFID tags and a software infrastructure. Independent of parts tracking, some parts like tires will be tagged earlier but for other reasons (theft control, build-to-order-management, legal/safety requirements)[17].

[17] According to VDA.

Within the next five years RFID labels could also replace the 2D barcodes that are used as shipping labels today. The advantage over barcode is in higher data capacity, greater durability and automated readability without line of sight. One smart label can easily store a whole waybill. The Auto-ID infrastructure could eliminate problems like delayed waybills that exist with EDI today.

2.1.2. Brand Authentication

Counterfeiting has a large impact on the automotive spare parts business, a segment that contributes significantly to manufacturers' overall profit. According to DaimlerChrysler 10% of all car parts sold are counterfeits. This equals a loss of $12 billion every year[18].

[18] B. Lalk-Menzel, DaimlerChrysler.

There are two types of counterfeits. The first type is by companies that simply copy the original product without license. The quality of those products can vary. Good counterfeits can hardly be distinguished from originals; even by trained mechanics. Still, failures of such products may have a negative impact on the image of the automotive manufacturer and even can lead to lawsuits. Most parts are produced in Asia and Eastern Europe and are also sold in those markets.

A second type of counterfeit comes from approved manufacturers. These manufacturers are official suppliers of spare parts for the OEM. They have an agreement with the OEM to produce and sell an agreed number of parts. But the OEMS believe that some suppliers are over producing and selling parts on their own through unauthorized channels. In this case, checking a serial number, if one exists, is the only way to identify the counterfeits. This procedure is time consuming and not supported by dealers.

Auto-ID technology could solve this problem if suppliers tag their products with at least a serial number stored on the tag. At a minimum, suppliers and OEMs must agree on common standards for the identification of parts and data sharing. To achieve optimum brand protection, dealers should also participate. Readers could be installed wherever parts are sold or used (distribution centers, garages and retail stores) with dealers agreeing to validate every part they sell. OEMs could require the dealers to adopt this procedure for parts that are sold under their brand.

Information about parts sold could be forwarded immediately to the manufacturers who can base their production plans on this information. Such an application could benefit greatly from an infrastructure like that proposed by the Auto-ID Center. It would provide cheap tags and readers and would make real-time data about part sales available to the OEM.

Benefits

- Ensures that only parts from licensed production are sold
- Refusal of guarantee if counterfeit was used
- Better chance to identify producers of counterfeits and to close gray markets
- Real-time information about sold parts

Summary Comments

The automotive industry has a pressing need for a solution to the counterfeit problem, as a simple cost/benefit calculation can illustrate. For example, it is not uncommon for 10% of sales of a particular part type to be counterfeit. In such a case source tagging will be justified if the profit per genuine part is 10 times higher than the tag price. If tags cost 5 cents this means tagging is advised if the profit per part is above 50 cents. This should be the case for most parts sold for more than a few dollars.

A challenge in this application will be the need for dealers to participate. But even if some dealers are not equipped with a reader infrastructure, manufacturers could still identify counterfeits when needed – e.g., in case of a lawsuit. Another way to fight counterfeiting could be to conduct random inspections of dealer stocks.

As the benefits for dealers are debatable, it will probably be necessary for manufacturers to bear the infrastructure costs. The risk of voided warranties or legal action if a counterfeit part is used might be a reason for customers and garages to favor tagging.

As with other applications spanning the automotive supply chain, being able to access the data that needs to be available about every single part will require a powerful infrastructure like that proposed by the Auto-ID Center.

2.1.3. Theft Control

Theft is a major problem for all kinds of supply chains. Things that get stolen from the shelf at the retail store contribute only marginally to the total theft of automotive parts. More commonly, automotive part theft occurs during transport, distribution (external theft) and from the inventory of the manufacturer (internal theft). Later, parts may also be stolen from the dealer. Data breaking down theft losses by location in the supply chain is not available for the automotive industry. In general, theft is a major issue for electronic parts.

As with authentication, theft control calls for source tagging, with suppliers, OEMs and dealers agreeing on common standards. Every part should have an identified owner, with necessary tracking information shared between suppliers, manufacturers and dealers. Readers must be installed where parts are distributed, for example at warehouse exits. For some electronic parts it may also be possible to verify IDs with a reader integrated into the car’s electronic system.

Benefits

- Reduced shrinkage
- Rapid notification of theft, helping to identify weak points in the supply chain
- Increased difficulty in reselling of stolen parts

Summary Comments

As with brand authentication, the business need for theft control is significant. This application could use the same infrastructure as brand authentication, and similar cost/benefit calculations can be made.

To be effective, dealers and garages must cooperate in preventing stolen parts from being resold through legitimate channels. It may not be possible to prevent theft completely but Auto-ID will at least help identify when and where it happens. This will also make it more complicated to resell stolen parts. In addition to the technical infrastructure, Auto-ID technology will deliver the necessary common standards and data management capability to make this application work.

2.1.4. Assembly Automation

Auto-ID technology can be used to improve assembly in several ways. Three scenarios are discussed below. In the first, RFID enables full automation of the production process. An average car is made from around 13,000 parts. This scenario would employ tags on all of them. The second scenario uses tags on all parts whose application varies with customer orders. It is called build-to-order management. The third scenario is being implemented today in some plants referred to as Work-in-progress tracking. Here, one tag identifies the car during the entire production process and allows work-in-progress tracking. The increasingly tag-intensive scenarios can be considered enhancements building from today's best practices.

2.1.4.1. FULLY AUTOMATED ASSEMBLY

Today' s automotive production is highly automated. Building a car takes less than two days on average. Automatic identification of parts could enable an even higher level of automation and more flexibility. Machines could be programmed to process parts according to the information that is available about the specific part. As the machines automatically check which parts fit together, errors in production could be avoided.

This application requires source tagging, with common standards for suppliers and car manufacturers. Every production station in the assembly operation must be equipped with a reader, and must have the intelligence to act on the data gleaned from interrogating parts. This application has the potential to transform the car factory in a "black box" where parts enter one end and finished cars come out the other, with no human intervention.

Benefits

- Integrated total quality control
- Complete real-time information about work-in-progress supports exact output planning
- Supports continuous improvement of production process
- Flexible use of machines
- Elimination of manual tasks/labor and human error

Summary Comments

Even if all parts could be tagged this scenario won't develop very fast. Key roadblocks include the development of suitable production machines and the dramatic reduction of tag costs to allow such universal part tagging. The path to this kind of full automation might proceed step by step, but this application will not be an early driver for Auto-ID technology.

2.1.4.2. BUILD-TO-ORDER (BTO) MANAGEMENT

Ordering a new car can be like ordering a PC from Dell. Many cars are built individually for customers who can choose from different components (e.g. different engines or audio systems). This increases the number of specific components that have to be available and the potential for incorrect assemblies. Automatic identification of components can help to prevent such mistakes if smart labels are attached to components that are typically different from car to car.

This application is a preliminary stage to the previous scenario. It is based on the assumption that the pay off is higher for error-prone parts. The number of components per car relevant to this application is estimated to 100–150[19]. For this application it is preferable that suppliers affix smart labels on their products, but the automotive manufacturer could also affix the tags if necessary. Readers are needed at each assembly station.

[19] Interview with OEM.

Benefits
– Avoidance of errors in configuration
– Faster assembly with automatic quality checks

Summary Comments
This application could be realized within the next five years. Source tagging and common standards will help to increase efficiency. At least 20–30 parts and components might be tagged within the next three years for safety reasons, e.g. tires. This application will profit from the cheaper tags and readers that come out of the Auto-ID Center initiative.

2.1.4.3. WORK-IN-PROGRESS TRACKING
Knowing the status of each product in the assembly process can help in planning output, improving capacity utilization and enhancing product quality. Information about the time spent by a product in each process step can help to better determine product costs. In addition, some steps in the production process (e.g. painting and drying) require a predefined amount of time. RFID technology can help machines to control those times automatically.

This application requires one smart label attached to the car or to its carrier. Attaching the tag only to the carrier might cause problems during painting. During this step the car is taken from its carrier. After painting the car is replaced on the carrier. Of course, if a car were put on the wrong carrier it would cause problems during later assembly, because the further processing steps are linked to the carrier. In most cases active transponders are used for this application.

For this application, readers must be installed at each assembly station. As it is a closed loop application, standards are not a major issue. The tags can be reused.

Benefits
– More exact planning of output
– Better capacity utilization of assembly stations and reduced cycle times
– Enhanced quality control for some steps in the production process (e.g. painting)

Examples
– **BMW** uses active RFID transponders for identifying the car during production[20].
– **Ford** uses active transponders for identifying engines during production. Data is stored on the transponder because the large amount of data that is communicated would require a higher speed wireless network than is currently available[21].

[20] Control Design Magazine: http://www.controldesignmag.com/Web_First/cd.nsf/ArticleID/JFEY-4MNVEG/

[21] Escort Memory Systems: http://www.ems-rfid.com

Summary Comments
Work-in-progress tracking using RFID technology is state of the art today. As there are no mature standards, nearly every system works differently. Efficiency gains through standards would be marginal for this application, although system costs for standardized tags and readers would presumably be lower. Advantages over bar coding in this application include data storage on the transponders, automated reads without line of sight, and the tolerance of RF tags to dirt and extreme conditions (e.g. the heat encountered in the painting process.)

2.1.5. After Sales Services
Auto-ID technology is also able to provide benefits after the sale. Improvements can be realized in maintenance, recalls and recycling.

2.1.5.1. MAINTENANCE

Knowing the history of the parts used in a car can help in making maintenance decisions. The goal is to manage the configuration of each car. If all major parts are tagged, the technician can see what parts were used (original parts, replacements, etc.) without disassembly. Additional information on the parts can help in providing the appropriate maintenance. Parts approaching end-of-life can be more easily identified and proactively replaced.

This application requires source tagging of key parts. For maintaining the history in a central database it is sufficient that only a serial number is stored on the parts. However, common standards will be needed for suppliers and car manufacturers. Readers must be available at garages wishing to take advantage of the data, and data about the parts and maintenance history need to be shared in a common database or stored somewhere in the car's electronic system. The garage could retrieve information about what parts exactly are used in the car, whether they are original parts or spare parts. Knowing the configuration of a car and its maintenance history can help to speed up and improve maintenance and repair.

Benefits:

– Automatic documentation of executed repairs
– Avoidance of errors in maintenance
– Preventive maintenance
– Product information on spare parts

Summary Comments

For at least some components, e.g. brakes or sparking plugs, that frequently need maintenance, it would be beneficial to have tag based maintenance records. For the next five years this may only affect a few components. Until a common infrastructure – like that developed by the Auto-ID Center – is adopted, data will need to be stored on the tags or otherwise carried with the car. This requires more expensive kinds of RFID tags. Only low cost RFID could tagging make available for nearly all parts of a car. For many electronic components that are wired into the car's systems, automatic identification and self-checking will be integrated features.

2.1.5.2. RECALL

The number of automotive recalls has increased over the last few years, probably as a result of the pressure to reduce design cycle times. Public recalls are expensive and affect the image of the car manufacturer. In some cases it is necessary to recall a whole product line because traceable parts information is unavailable. A well-known example is the recall of 14.4 million Firestone tires in 2000. The recall caused Ford a loss of approx. $ 2.6 billion, or $ 1.70 a share. Being able to say exactly on what cars the tires are used would have made the recall faster, more precise and more "silent". Most recall actions are less spectacular, but the cumulative effect is still significant. In 2000, for example, 94 recalls were registered in Germany[22].

For some products, like aircraft engines, manufacturers are required to keep detailed records, with the ID of every part logged to a database. There are about 20automotive parts for which safety concerns might justify tagging[23].

As with other parts tracking applications, this will require suppliers to affix smart labels to several mechanical parts. Again, there must be a common standard for suppliers and car manufacturers, such as that proposed by the Auto-ID Center. Readers must be available at assembly stations, and a shared database must be maintained for authorized users.

[22] ADAC: http://www.adac.de

[23] Interview with OEM.

Benefits

- Well directed recalls
- Compliance to laws

Summary Comments

Tracking of tires will be required in the USA by law[24]. It is estimated that another 20–30 parts per car could be tagged for the same reason within the next three years[25]. For recalls it is important that information is available about the parts installed in a specific car. The Auto-ID infrastructure is well suited to manage that data and would allow rapid and efficient access and notification in the event of a recall.

[24] Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act

[25] Interview with OEM.

2.1.5.3. RECYCLING

Every year over 11 million vehicles are recycled. This process involves tearing the car down into parts and sorting them. Each part must be classified to be sold or to be recycled. If the latter, it must be sorted by material composition. In the EU automotive manufacturers will soon (2006) be required to take back old cars. This means that they will be responsible for the recycling process. The law also says that at least 85% of all car parts must be recycled in the EU.

Today the sorting is done manually. For both tasks Auto-ID technology can help provide reliable information about each part. For parts that can be sold, the value can be better determined if its history is known.

This application would require each part or at least those parts that might be resold to be tagged, meaning up to 13,000 tags per car. Readers would need to be installed at recycling plants.

Benefits

- Automatic sorting of parts
- Part value determination

Summary Comments

This application could benefit from laws that require OEMs to take their cars back for recycling. As sorting is generally a manual process today, a higher level of automation will increase efficiency.

Most OEMs do not consider this to be a high-priority problem. But legislation could make recycling an important incentive for tagging within the next five years. As with the other part tracking applications, it will be important that low cost RFID technology is available and that there is a common data infrastructure.

2.1.6. Example Case: Tire Tracking

The first large part tracking application in the automotive industry may be tire tracking. Recently, a standard for labeling of tires (B-11) with 2D-barcodes or RFID has been released by the Automotive Industry Action Group (AIAG). This is the first automotive RFID standard for item level tagging.

The labels are placed on the outside wall of the vehicle's five tires. The information could be stored in a database and shared between automakers and suppliers. In the case of a recall, this data can be used to pinpoint affected tires quickly and efficiently.

For the barcode solution a 12-character code is used:

Figure 2

B-11 DATA STRUCTURE FOR 2D BARCODE

MANUFACTURING PLANT	MANUFACTURING DATE	TIRE SIZE	UNIQUE SERIAL NUMBER

The UHF (915 kHz) RFID solution will allow 128 bytes of data to be stored on the chip:

Figure 3

B-11 DATA STRUCTURE FOR 2D BARCODE

MANUFACTURING PLANT	MANUFACTURING DATE	TIRE SIZE	TIRE SIZEUNIQUE SERIAL NUMBER	VEHICLE ID	...

RFID tire tags will initially be affixed to the outside of the tire. Later they may be embedded in the tire itself. At the moment Intermec is the only supplier claiming to have a chip compliant to B-11, but others including Philips and Sokymat are also working on solutions.

In Europe the German Association of the Automotive Industry (VDA) is also working on a standard for tire tracking. The focus there is more on logistics than on safety aspects. The release of a proposal is scheduled for October 2003. Like B11, this standard will call for writeable data storage on the tag. Currently it is not clear whether the group will propose 13.56 MHz or UHF as the carrier frequency.

According to Texas Instruments the market for tire tags could rise to at least 20 million units per year in the short run. Once all tires are tracked it will enable all the benefits described for the preceding applications to be realized. The most important benefits of tire tracking named by the AIAG and the VDA are listed below.

Benefits

- Affected tires can be identified in case of a recall
- Attempts to mount the wrong tires will be detected and flagged
- Automatic sorting of tires in distribution
- Compliance to law in the USA

Summary Comments

According to the TREAD (Transportation, Recall, Enhancements, Accountability, and Documentation) Act the automotive industry is mandated to develop a mechanism to trace tire recalls for the USA. RFID technology seems best suited as it is more durable than easily defaced bar code labels. The price for a tag is small compared to the price of a tire. If this application proves successful it will break ground for a large number of further RFID applications in the automotive supply chain. The automakers have recognized the need for an open standard in their development of the B-11 specification; ultimately, their costs could be even lower if they migrate toward Auto-ID technology.

2.2. Capital Asset Tracking

It was found that in general, the potential for early adoption of RFID is higher in those applications where the tag is attached to the packaging or in closed loop scenarios – assets like tools, vehicles, etc. are examples of closed loop applications. In the automotive industry there are many examples where transponders (often active tags) are used for identifying and locating pallets, containers and other movable assets.

2.2.1. Container Tracking

Containers mostly are used in closed loop scenarios. There are a large variety of containers used in the automotive industry, e.g. shipping containers, plastic totes, pallets, etc.

Some of them are specialized for transport of specific automotive parts (e.g. engine racks). Bad container management leads to misplaced or lost containers and parts. Examinations with RFID pilots have shown that container pools could be reduced by at least 5%[26]. Tagging of containers also enables tracking of the parts that are in the container (soft tracking). The number of reusable plastic containers that are used in logistics applications by the German automotive industry alone is estimated at 60 million units[27]. This number can be projected to a number of over 200 million units worldwide. The number of reusable metal boxes (including special racks and large containers) that are used by DaimlerChrysler is estimated at 12 million units. This number can be projected to 50 million units worldwide. There are also a number of other types of containers like recycle bins, transport packaging and non-standard bins that are not included in these numbers.

Tracking of these containers requires transponders attached to each of them, communicating with an infrastructure of readers. For larger containers active transponders may be appropriate. If the containers are owned by the manufacturer, no special standards are needed, although standardized equipment will generally be less expensive. However, the manufacturer does not typically own shipping containers, so a standard will be important. The VDA is working on a standard for the use of transponders on containers[28].

Benefits

- Reduce misrouted containers
- Faster handling of containers at cargo terminals
- More efficient use of resources
- Tracking of parts (that are in the container)
- Containers are available faster for reuse
- Storing of waybills on the tag
- Higher durability than bar codes

Examples

- **Eurostar** uses active transponders to track containers (pilot)[29].
- **Ford** uses active transponders for container tracking[30].
- **Volkswagen** uses active transponders to track engine racks[31].
- **Volkswagen** uses passive transponders on some of its recycle bins[32].

Summary Comments

Many application examples can already be found. For most containers (especially larger ones) the price of a transponder is small compared to the value of the container. Volkswagen achieved a positive ROI using RFID based rack tracking in less than a year.

In the near future, smart labels could replace the bar codes that are used today on smaller plastic containers. The additional cost per container is small, and in many cases smart labels will eliminate the

26 Interview with OEM

27 VDA: http://www.vda.de

28 VDA: http://www.vda.de

29 Institute of Information Management: http://elogistics.iwi.unisg.ch.

30 Wherenet: http://www.wherenet.com

31 Identec Solutions: www.identecsolutions.com

32 Interview with OEM.

need to relabel containers again and again with fresh bar codes. Once there are recommendations from the automotive associations implementation will follow very fast. Open-standard Auto-ID technology, with its lower costs, would also make tagging profitable for smaller containers. All kinds of containers could be managed using one database/communications infrastructure.

2.2.2. Tool Management

In car manufacturing many moveable tools are used, some of them on a shared basis. The resulting problems are similar to what happens in a library. Workers return some tools late, while others are misplaced or returned incomplete. Regular inventories are necessary to support operations.

Today laser marking is the most common technology for tool marking, although in a few cases 125 kHz RFID technology is used. More comprehensive RFID tagging of tools could help to automate and control tool circulation. As this application only is used locally data sharing isn't required. As the application is sensitive to the costs it would benefit from low cost RFID systems that only can be achieved with standardized Auto-ID technology. In implementations, readers would be installed at tool stores exits and/or integrated into the shelves where tools are stored.

Benefits

– Self check-out
– Automatic stock taking
– Automatic checking to verify that toolkits are complete
– Ability to find misplaced tools
– Tracking of tool usage

Summary Comments

The marking of tools is common in the automotive industry, but there are two problems with using RFID technology. First, it is often difficult to integrate an RFID tag into a tool, so tagging may be practical only if done by the supplier. Second, most tools are metal, which is still a challenge for RFID technology[33].

33 Metal as background material can drastically reduce the read range of a RFID.

For larger tools or electronic devices RFID tagging is already in use. For most smaller tools, source tagging based on common standards will be the likely long-term solution. For cost reasons the tag should be integrated by the manufacturer of those tools. This probably won't happen in the next five years for most tools.

2.3. Vehicle Related Applications

There are a number of applications where RFID technology is being used to add functionality to the car itself. In most cases they enhance safety and convenience for the customer. The need for standards will be very specific to the applications, but a common infrastructure for data management would enable a variety of additional services to the customer.

2.3.1. Identification

Unique car identification can be used for many purposes. For example, the electronic number plate allows identification of each vehicle by a unique vehicle identification number (VIN). This number can be written on a RFID label that gets attached to the car.

This application can be realized as a closed loop scenario, for example if there is the need to identify and locate cars on the factory site to facilitate customer pickup. This solution requires a reader infrastructure on the factory site, and will probably call for active tags if locating capability is needed. The label could also be used to store any information required by the vehicle licensing authority (traditional number plate).

Benefits
– Localization of cars
– Theft control
– Could be used for toll payment systems

Examples
– **BMW** stores personalized data of the car owner on a RFID tag that is integrated into the key[34].
– **Electronic number plate** is being discussed as a replacement for the traditional number plate.
– **Electronic toll collection** based on RFID is used at many toll roads in the USA, Europe and Asia.
– **Volkswagen** uses active transponders to locate finished cars. The transponder gets removed when a purchaser picks up the car[35].

[34] BMW : http://www.bmw.com

[35] Identec Solutions: http://www.identecsolutions.com

Summary Comments: There are many related applications that an identification chip could be used for. The examples listed above demonstrate only some possibilities. In the near future every car will likely have at least one identification chip, possibly required by law. Data that is needed for toll collection or other personalized services need not necessarily be stored on the tag; it could alternatively be managed by the Auto-ID infrastructure linking all additional data to the Vehicle ID.

2.3.2. Access Control

Today many vehicles are equipped with remote entry and access control systems. The key typically employs an encrypted transponder and controller chip. The transponder is verified when the key is put into the ignition lock. The car will start only if the correct code is read.

According to Gartner, in 1999 more than 50 % of sub-128 kHz RFID chips were used for this application[36]. In 2001 ca. 60 million transponders were sold for this application by Philips Semiconductors, Sokymat and Texas Instruments. In the future there will be a shift to passive keyless entry (PKE) systems. Such systems use a RFID transponder that is read when the owner touches the door handle.

[36] Gartner: Identifying the Market for RFID Transponders, 2000

Benefits
– Theft control
– Convenience

Examples
– **Philips Semiconductors, Sokymat and Texas Instruments** are the main suppliers for access control systems for the automotive industry[37].
– **DaimlerChryslers** Mercedes S-class model is equipped with a PKE system[38].

[37] Interviews with tag suppliers.

[38] http://www.daimlerchrysler.com

Summary Comments

RFID based immobilizers are required by law in Europe. Today they are also used in many new cars sold in the US and Japan. Customers have accepted remote entry systems for convenience reasons, although they have been more expensive. The same will happen with PKE systems. This application only requires a local infrastructure.

2.3.3. Tire Pressure Monitoring

A new Federal Motor Vehicle Safety Standard in the USA that requires the installation of tire pressure monitoring systems (TPMSs) for passenger cars, trucks, multipurpose passenger vehicles, and buses will go into effect in November 2003. Transponders are typically placed in each wheel well; each carries a unique ID necessary to distinguish between the four tires.

Benefits
– Compliance with law
– Safety
– Longer tire life because of proper inflation
– Fuel savings
– Convenience

Examples

– **Philips Semiconductors and Smart Tire** (among others) offer transponder based TPM systems that are compliant to the Federal Motor Vehicle Standard[39].

[39] Philips Semiconductors: http://www.semiconductors.philips.com, SmartTire: http://www.smartire.com

Summary Comments

TPMSs will be found on most cars within the next five years. Customers that are not required by law to use such a system will choose it for safety and convenience reasons. As this is a new application it will increase the tag demand for the automotive industry, although the application will be largely independent of any standards activity.

3. MARKET OPPORTUNITY

3.1. Product Requirements

The requirements for RFID products differ from application to application. The following table describes some of the key requirements for each application. Detailed estimates of the tag quantities required for each application can be found in the appendix.

3.1.1. Tag Styles and Special Characteristics

For many applications a basic passive tag with read range of 50 cm or 1.5 feet will be sufficient. In most automotive applications, however, the tag has to work in a metallic environment, sometimes even mounted directly on metal. Applications where metal mounting and long distance reads are required will likely call for active transponders.

Table 3: Requirements for RFID tags in automotive applications

APPLICATION	READ RANGE	METALLIC RESISTANCE
Part tracking (item) – Inventory management – Brand authentication – Theft control – Recall – Maintenance – Tire tracking	1.5 ft	mount on metal for ca. 50% of parts, must work in metallic environment
Part tracking (packaging) – Inventory management	1.5 ft	metal might be present
Assembly – BTO management – Work-in-progress tracking	1.5 ft	mount on metal for some components, must work in metallic environment
Container management – small plastic containers – metal boxes	>3 ft preferred	must work in metallic environment
Tool management	1.5 ft	Mount on metal for ca. 70% of tools
Product related applications	>3 ft preferred	must work in metallic environment

3.1.2. Reader/Tag Performance

Tracking all the items in the automotive supply chain would sometimes result in very large numbers (hundreds or thousands) of tags being in the field of a single reader at a given time. Today's systems can distinguish on the order of 50–100 tags per second, meaning that systems will need to be designed to allow adequate reading time where tag densities are expected to be high. There will also be some significant mechanical/environmental requirements imposed by automotive applications – both tags and readers will need to be designed into unusual form factors and/or ruggedized for many applications.

Because of the potential volume of data being transferred, the database and communications infrastructure will also need to be carefully designed. The communications burden will vary depending on the amount of data stored locally on the tag: if the tag carries data with it, tag reads will be slower but less burden will be placed on the factory network; conversely, a "license plate" tag will offer the fastest reads but demand more of the network infrastructure.

3.1.3. Systems Solutions

The automotive industry uses a variety of systems for supply chain management, production planning and production control (e.g. ERP or PPS). The reader infrastructure has to be integrated into existing systems. Software vendors like SAP are already working on appropriate middleware[40]. Most applications should not require more effort than a barcode-based solution.

[40] SAP is also a sponsor of the M-Lab and the Auto-ID Center.

4. ADOPTION FACTORS

4.1. Drivers

The supply chain of an automotive manufacturer handles approx. 200,000 different parts. **Identification technology is necessary for keeping track of parts** in stock or in transit, for preventing misrouting and for minimizing safety stock requirements. Full automation is the only way to keep identification free of errors. A highly JIT-optimized supply chain can easily be jeopardized if errors occur.

The automotive industry comprises relatively few market players that participate in **associations like AIAG, ODETTE, JAMA/JAPIA, and VDA**. Standards are discussed in those groups. The AIAG has monitored the development of RFID for several years and is the initiator of the B-11 tire label spec. The success of this standard may be the driver of RFID in the automotive industry.

Sustainable **advantages for RFID over barcodes** in most automotive applications include resistance to harsh conditions, the ability to read without a line of sight, and the near elimination of the need for human intervention.

The automotive industry has always been an early adopter of new technologies to streamline logistics and manufacturing. They have a proven ability to implement new systems, even those of high complexity. Some experience in using RFID technology has already been gathered; successful examples are mentioned in this report. Such examples, if accompanied by positive business case analyses, can dramatically speed adoption.

4.2. Challenges

One major hindrance to the use of smart labels in the automotive supply chain is the **lack of an industrial (and retail) standard**. As long as everyone has to attach tags for their own purposes, the costs will outweigh the benefits for many applications. However, if suppliers began to source-tag their products and data sharing were made practical, the cost per user could be minimized. This challenge is addressed by the Auto-ID Center's approach to RFID.

Technical drawbacks in RFID are **the interference of RFID with metallic objects** and collision problems in reading more than 100 tags at once. In automotive applications, many parts in the supply chain are made of metal. Current techniques for reading passive smart labels on metal are relatively expensive and cumbersome. However there are some solutions based on active transponders and novel passive tag designs that show promise[41].

In many applications **barcodes seem to be sufficient**, especially with industry efforts to improve barcode technologies (e.g., the 2D barcode). For these applications it is necessary that the price of RF tags comes down. For example, GM requires its suppliers to design their shipping labels according to the new 2D bar code standard (GM 1724). Although only RFID could provide full automation and high reliability, the price premium for RFID tags will need to decrease before the tags will become widely used.

There is still **little integration of RFID technology in standard software**. A middleware tool used for connecting RFID (called "Savant") is under development by the Auto-ID Center. A Savant based infrastructure could be useful for the automotive industry. Software vendors like SAP are working on providing interfaces to Savant and on integrating RFID support directly into their mainstream products.

As Auto-ID is quite a new approach, at least for commercial applications, there is **little information available** about practical experiences. In particular, there are no proven, business cases publicly available. This gap can only be closed by the publication and discussion of real industry experience. The Auto-ID Center's Business Case Action Group is working to address this issue.

Finally, **benefits and costs are distributed unequally** between the members of the value chain. For most applications, source tagging will be optimum, but the source will not usually be the main recipient of the tag's benefits. This issue will require the beneficiaries to find some way to compensate others in the supply chain for additional costs that are incurred.

[41] E.g. Marconi Infochain: http://www.marconi-infochain.com

5. CONCLUSION

This report describes the great potential that Auto-ID technology has for the automotive industry. An infrastructure like that being developed at the Auto-ID Center is well suited for applications where:

– A large number of items needs to be identified individually;
– Additional data about the item needs to be managed.

Such applications include inventory management, assembly automation, brand authentication, theft control, recalls, maintenance, and recycling. These applications will deliver the most benefits if all or at least most parts in the supply chain are tagged and there are common standards used by all members including suppliers, automotive manufacturers, and dealers. OEMs, who receive the most benefits in the automotive value chain, will need to take action in planning and advocating such applications.

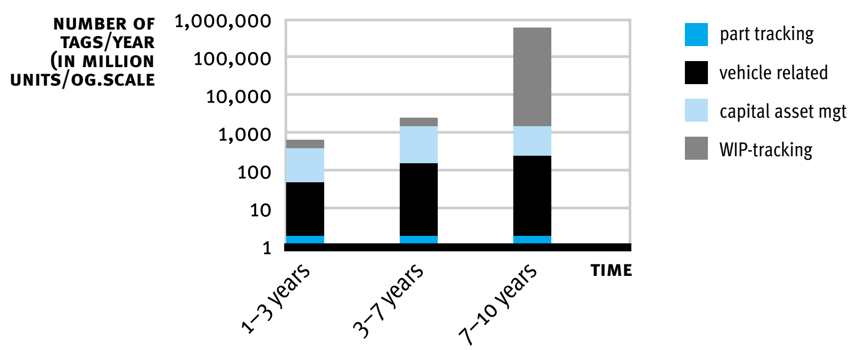
Applications like container management, WIP-tracking and end-product identification can pay off without industry wide standards for identification and data management, although they too would benefit from the lower costs and outsourcing possibilities that standardized systems offer.

There is always a trade off between application scenarios that are based on item level tagging and those that use packaging tags or "soft tracking". In the first case much higher benefits can be achieved, but the costs are also much higher. Today, the second scenario will tend be more profitable. This will change as Auto-ID technology takes hold. The availability of standardized systems will lead to a drop in prices of all components.

Tagging only those parts that are delivered from the first tier suppliers to the automotive manufacturers would require approx. 650 billion RFID tags per year. The numbers would be several times as high if all tiers of suppliers were included in the calculation. According to the application scenarios that are described in chapter 2 and the assumptions that are presented in chapter 3 the adoption path of RFID technology in the automotive industry could be as shown in figure 4.

Figure 4

RFID ADOPTION IN THE AUTOMOTIVE INDUSTRY



We will continue to investigate the uses of Auto-ID technology in the automotive arena. Further work will focus on deeper analysis of single application scenarios. The costs and benefits of those applications that are expected to drive Auto-ID adoption in the automotive industry will be analyzed in detail. Specific areas planned for further study may include:

– Replenishment Management
– Brand Authentication and Theft Control
– Support for Recalls
– Container Management

6. ACKNOWLEDGEMENTS

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7. APPENDIX

7.1 Assumed Numbers

The potential demand for RFID tags depends on the number of cars that are produced and the number of tags that are needed for each application. The following numbers are based on publicly available statistics and the applications that are described in chapter 2.

7.1.1 Numbers of Automobiles Produced

Table 5: Number of produced/sold automobiles [43]

[42] South Common Market of countries in South America: Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay.

[43] VDA: Auto Jahresbericht 2002, http://vda.de

REGION	2000	2001 (EST)
EUROPE	19,713,206	19,767,115
NAFTA	17,668,296	15,815,396
ASIA	17,926,524	17,484,000
MERCOSUR[43]	1,935,874	1,890,677
REST OF THE WORLD	685,966	696,300
TOTAL	**57,929,866**	**55,653,488**

7.1.2 Numbers of Tags Needed

The following tables estimate tag usage in applications in the near term (up to three years), medium term (3–10 years) and future (later than 10 years). The basic assumptions are for passive tags with a read range of 1.5 ft cm:

Table 6: Assumptions about development of RFID technology

CRITERIA	NEAR	MEDIUM	FUTURE
PRICE	$ 1.00	$ 0.10	$ 0.02
STANDARDS	very few, only industry specific	some, mainly industry specific	many, some global
METALLIC ENVIRONMENT	mount on metal reduces read range to 0.1 ft	mount on metal feasible, but higher costs	mount on metal feasible

Table 7: Number of tags per car

APPLICATION	NEAR	MEDIUM	FUTURE
Part tracking (item)	10	500	13,000
– Tire tracking	5	5	5
– BTO management	0	100	150
Part tracking (packaging, not reusable)	100	10,000	10,000
Vehicle related	12	20	20

The following numbers are based on the assumption that 50 million cars are produced per year.

Table 8: Number of tags total in million units

APPLICATION	NEAR	MEDIUM	FUTURE
Part tracking (item)	500	25,000	50,000,000
– Tire tracking	250	250	250
– BTO management	0	5,000	7,500
Part tracking (packaging, not reusable)	5,000	500,000	500,000
Vehicle related	600	10,000	10,000

For the following applications there is a one-time supply and replacements. The replacements are based on the assumption of a tag life of 10 years.

Table 9: Number of tags in one-time supply applications in million units

APPLICATION	NEAR	MEDIUM	YEARLY REPLACEMENTS
Work-in-progress tracking	0.1	0.1	0.01
Container management	90	180	12
– small plastic containers	60	120	6
– metal boxes	24	50	5

Designed and produced by Foxner. www.foxner.com