Chapter 1
RFID in Manufacturing: From Shop Floor to Top Floor

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"As manufacturers gain control over inventory and grab accurate demand signals from their customers, the last blind spot in the global supply chain is the plant floor."
Rob Spiegel, Automation World

1.1 Architectural Perspectives

The vision of an enterprise information system comprising a complete virtual image of the enterprise is as old as information technology (IT) itself. IT architectural diagrams from the 1960s often take a pyramidal shape, thus capturing the hierarchical structure of most enterprises. Staff members were at the bottom of this pyramid, entering data into the IT system (Fig. 1.1). After undergoing various phases of filtering and aggregation, the data were compiled into a variety of tactical and strategic reports for decision makers positioned at higher levels of the hierarchy.

When this vision first appeared, several factors prevented it from being a great success. Data entry was usually manual and therefore costly, incomplete,

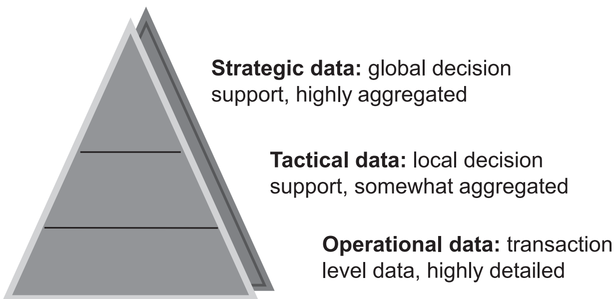

Fig. 1.1 Simple management information system pyramid architecture

O. Günther, W. Kletti, U. Kubach, *RFID in Manufacturing*
DOI: 10.1007/978-3-540-76454-0, © Springer 2008

and error prone. Filtering and aggregation algorithms were much less powerful than the technologies in use today. As a result, the quality of the reports delivered to senior staff was often questionable. Moreover, the only way to access this information was through printed reports. User-friendly online access via a PC was a distant possibility at best. Executives thus quickly learned not to rely on their corporate IT, and many preferred to follow traditional ways of decision making.

IT progress of the last decades, including the development of radio frequency identification (RFID) and other sensor technologies as an important component of enterprise computing, has led to a situation that is fundamentally different from the situation described above. This progress has already led to impressive productivity gains throughout the various functional areas of enterprises. Atkinson and McKay (2007) give a thorough overview of how IT has transformed our economies and led to tangible economic benefits. Niederman et al. (2007) present the potential of RFID in supply chain management. They use a data life-cycle framework to discuss the key issues involved when introducing RFID into an existing IT infrastructure.

Today, data capture has been automated along large parts of the supply chain. Algorithms for aggregation, search, and data mining have improved tremendously, both in terms of functionality and performance. The vision of a "digital shadow" or "virtual image" for each physical object seems closer than ever. This creates major privacy challenges and raises difficult questions concerning an integrated enterprise IT architecture. But it also opens up new perspectives for event and object tracking inside a corporation and for inter-enterprise cooperation, spanning the complete product life cycle starting with production, continuing through distribution, and finishing with aftersales services and possibly recycling.

Figure 1.2 illustrates the kind of information flow along the supply chain that is already possible. In the example pictured in the figure, only the objects

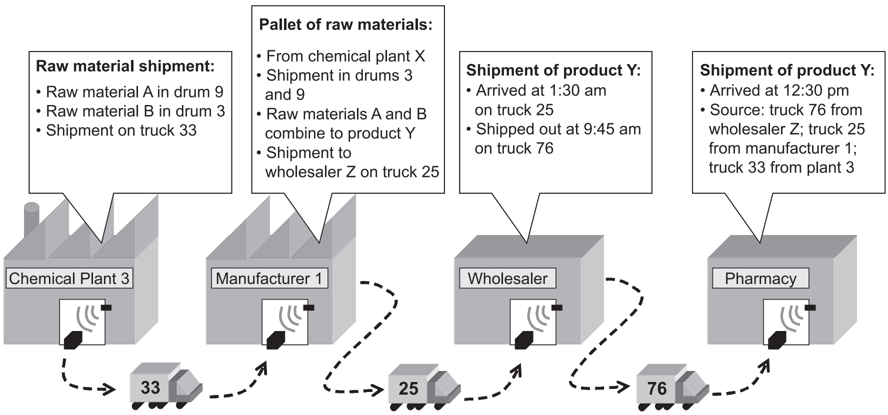

Fig. 1.2 Information flow along an RFID-enabled supply chain (source: GS1)

being produced are being tagged. Tagging could be extended to production machinery and tools, thus allowing even tighter control of the production process and improving inventory control. Even personnel could be tagged. Given the obvious concerns regarding privacy and loss of control, however, any potential benefits need to be carefully gauged against the considerable drawbacks.

The term “real-world awareness” is increasingly being used to characterize this convergence between physical and virtual worlds and the availability of timely and accurate information. Obvious advantages include the following:

- Optimized inbound and outbound logistics via more accurate visibility to production activities
- Efficiency gains by giving plant personnel access to up-to-date location information for materials, assets, and orders
- Increased responsiveness to unplanned events

In this book we present the results of a variety of case studies analyzing the benefits of RFID in manufacturing and supply chain management. Industries surveyed include automotive suppliers as well as companies from the electronics and packaging industries. The majority of the companies surveyed use SAP R/3 or some other kind of enterprise software [also called an enterprise resource planning (ERP) system]. Some are also using a manufacturing execution system (MES) such as MPDV’s HYDRA. If RFID and sensor technologies are added to such an architecture, various integration issues need to be addressed:

- Which of the RFID and sensor data need to be forwarded to the MES layer?
- Which of the RFID and sensor data need to be forwarded to the ERP layer?
- What kind of filtering needs to be applied and when?
- What kind of information should be exchanged with which partners in the supply chain?
- What kind of sensor technology is most cost efficient in a given situation? What about barcodes?

RFID applications are normally closely tied to the MES controlling the production process. The typical functionalities of an MES are described by the Manufacturing Enterprise Solutions Association:

- Operations scheduling and production control
- Labor management
- Maintenance management
- Document control
- Data collection
- Quality management
- Performance analysis

RFID technology may support most of these functionalities. In operations scheduling and production control, RFID can be used for guaranteeing process safety and interlocking. If materials or material containers are equipped with a unique ID (provided via barcode or RFID), the MES can ensure that all preceding process steps have been conducted successfully before starting the next manufacturing step. Furthermore, production order data and manufacturing parameters may be written to the RFID tag at the first manufacturing step and then read and updated locally, providing fast local data maintenance and redundancy for the MES.

Concerning labor management, plant personnel could automatically be registered via appropriate sensor technologies. Also, location tracking of plant personnel could potentially be enabled. Once again, privacy concerns would need to be taken into account when considering such measures. In maintenance management, data may be stored locally at the resource in an RFID tag. This may reduce the required paperwork for performing maintenance and updating associated records. Regarding data collection, RFID can help automate the tracking and tracing of materials, work in process (WIP), the location of mobile resources, etc. For quality management, data about the quality targets may be stored locally at the material within an RFID tag.

Sensor gates and RFID readers collect data from the shop floor. They pass this data on to "edge servers." This term refers to computers that are directly connected to the RFID readers and sensor gates. Edge servers belong to the back-end system. The back-end system comprises the edge server software, the ERP system, and the MES. Figure 1.3 visualizes the basic functionalities of the resulting three-tier architecture integrating sensor data into an existing ERP/MES installation. It also shows the possibility of opening up an IT architecture to customers, suppliers, and other business partners in the supply chain.

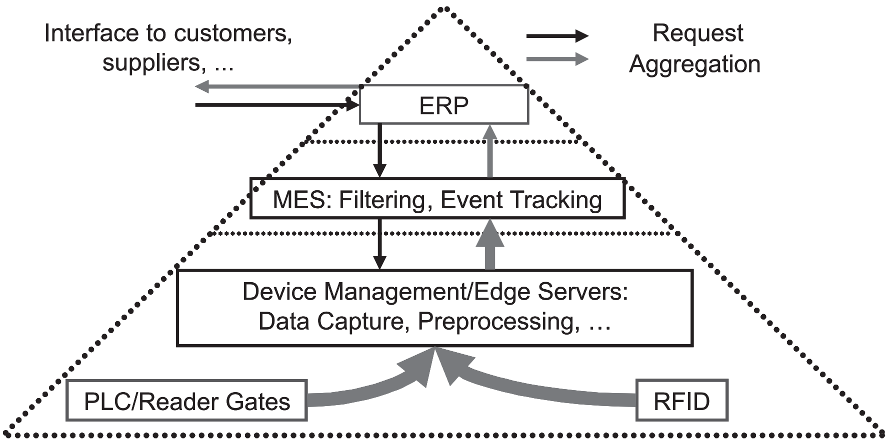

Fig. 1.3 A modern pyramid architecture integrating sensor/radio frequency identification data, a manufacturing execution system, and an enterprise resource planning system

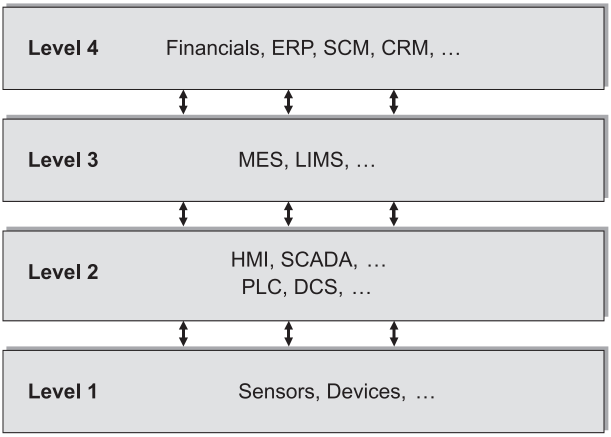

Fig. 1.4 ISA-95 functional reference model based on the Purdue reference model, showing connectivity from shop floor to top floor for adaptive manufacturing

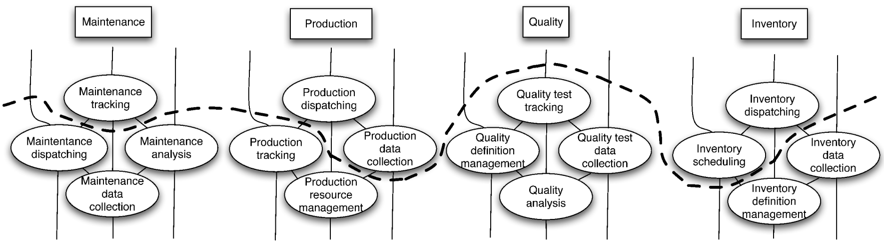

Fig. 1.5 Fuzzy borders between different tiers of the architecture (source: ISA S-95 standard)

A more detailed distribution of the different functionalities has been proposed in the ISA-95 functional reference model (Fig. 1.4), but this should not convey a false impression of accuracy. For many functionalities, one has several choices regarding how to assign them to tiers. The border between hardware controllers and MES is equally fuzzy, as is the border between MES and ERP (Fig. 1.5).

Moreover, some enterprises prefer not to use an MES, connecting the hardware controllers directly to the ERP system. This is only possible, of course, if the ERP system is equipped to do this by containing modules that accept the controller output as input and that perform the necessary modeling and filtering. The SAP Auto-ID Infrastructure (see Chap. 2) provides such functionality. Moreover, vendors such as Infosys (Deshpande and Singh 2006) and PEAK (Schultz 2007) offer middleware components that serve as interfaces between the hardware on the shop floor and the ERP software. Often, however, this includes only a technical interface without any application or process support, as is provided, for example, by an MES (Kletti 2006).

Currently, RFID and sensor technologies are mainly used to automate logistics processes. However, there are many other ways these technologies can be employed to make manufacturing more efficient. To evaluate the feasibility and cost efficiency of an RFID solution, one needs to address the following issues:

- Continuous or other inline processes may not allow the tagging of "discrete" entities and thus will dramatically increase the complexity of the tracking and tracing problem.
- High-volume, low-cost goods rarely justify the cost of unique identifiers.
- The small physical size of critical components cannot support a tag.
- Complex and frequent transformations of the physical goods may make it difficult to maintain up-to-date identity.
- The combination of RFID and sensor technology within the walls of the manufacturing plant or distribution center often requires substantially higher granularity than tracking unit loads across the supply chain.
- In the context of combined RFID and location sensing, a substantial amount of time and resources may be required to locate and expedite materials and orders within a location. The combination of RFID and global positioning system (GPS) location tracking is not typically suitable or accurate enough for in-plant tracking. Other "smart-tag" technologies, which may include three-dimensional position tracking, may be required.
- Concerning deployment strategies, it may be preferable from a cost and operational perspective to tag carrier devices (carriers, pallets, bins) instead of individual items and to maintain a dynamic association of specific items and orders with these devices.

Finally, one word about terminology: Note that the terms "manufacturing" and "production" are often used interchangeably in the literature, even though the term production typically signifies a broader range of activities than the term manufacturing does. Wikipedia defines manufacturing as "processing raw materials into finished goods" and regards it as a "specific use" of production. Production, on the other hand, is defined in a microeconomic sense as "the act of making things." This involves "decisions…on what goods to produce, how to produce them, the costs of producing them, and optimizing the mix of resource inputs used in their production." This latter definition goes somewhat beyond what is commonly meant by the term manufacturing. Nevertheless, for this book we opted for better readability and decided to use the two terms synonymously, unless noted specifically.

1.2 RFID Basics and Standards

For our discussion of the various standards, we use a reference RFID environment consisting of four elements:

- *RFID tags:* The tags (also called RFID chips) are attached to physical objects and store at least a unique identifier of the object that they are attached to. In addition, they might store some other user data.
- *RFID readers:* These are the hardware devices that directly interact with the RFID tags. Higher-level applications can access RFID readers through a well-defined protocol. RFID readers provide at least reading and in some cases also writing functionality. In addition, they might offer functionalities for aggregating or filtering read operations and for disabling RFID tags either temporarily (e.g., via locking) or permanently ("kill").
- *RFID middleware:* The middleware is software that can run centrally on a single server or be distributed over different machines. Its major role is to coordinate a number of RFID readers that are usually located close to each other, for example within a single plant or production line. The middleware buffers, aggregates, and filters data coming in from the readers to reduce the load for the applications.
- *Applications:* The RFID data may be used by a great variety of software systems. In a manufacturing environment, the applications are typically part of the MES or ERP system.

After introducing some technical foundations, we present three families of standards that cover various aspects of an RFID environment. The only standards that have been designed especially for RFID environments are the *EPCglobal*™ standards. These standards cover all aspects from tag to application. The *OPC/OPC-UA* standards family primarily addresses communication with systems close to the shop floor, such as programmable logic controllers (PLCs) or plant historians. In an RFID scenario, OPC/OPC-UA would be most suitable for the communication between the middleware and the readers. As of today, OPC is not broadly accepted for this purpose. However, it is an important standard for shop floor integration with IT systems in general and is used when RFID readers and shop floor equipment must be used in combination. The third standards family that we consider is the *ISA S-95* family, for plant-to-business integration with a special focus on manufacturing.

1.2.1 Technical Foundations

Currently, the following recognition systems are used in manufacturing:

- *Visual recognition:* Different colors and shapes are used for identification.
- *Contact recognition:* Systems with, for example, reed relay belong to this category. Such systems have the disadvantage of mechanical wear and low identification depth, in most cases between only 6 and 8 bits.
- *Optical recognition:* Barcode and other visual systems have the disadvantage of depending on a line of sight between object and reader. (See Fig. 1.6.) Dirt, vapor, refraction, scratches, and even vibrations can interfere with the automatic recognition. In particular, the traditional one-dimensional bar-

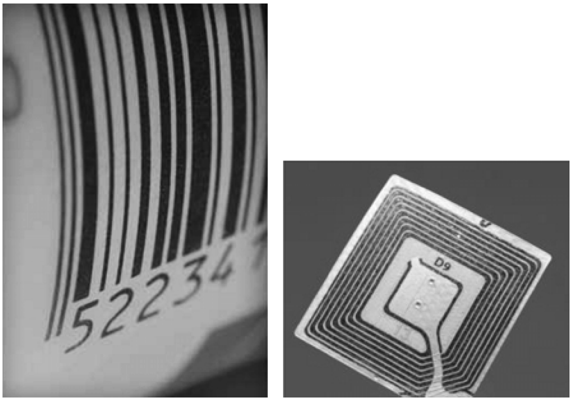

Fig. 1.6 Example of a barcode label and an RFID chip

codes are rather sensitive to disturbances. Two-dimensional barcodes are able to store much more information but, in turn, require more space. Matrix codes mitigate this problem somewhat, but they require a more sophisticated logic in the evaluating software.

- *Radio frequency identification:* RFID solves many of the problems discussed above. In particular, it works over a certain distance and even through non-metallic materials. We will now discuss RFID in more detail.

An antenna emits radio waves generating voltage in the inductor of the passive transponder or triggering the active transponder to send data (Fig. 1.7). The transponder chip starts working with this voltage, uses the inductor as antenna, and sends its ID to the reader antenna in bit-serial form (00101111100…). The transponder signal is evaluated in the decoder, checked for errors, converted into a code (000F5A3B1C…), and forwarded for further processing.

Low frequency (LF; 125 kHz): Low-frequency systems have proven sufficient in many contexts even though their range is limited to 1–2 m. Successful implementations exist in manufacturing, assembly, logistics, and access control. The transponders are not very expensive and work even when embedded in metal. However, transponders are not protected against collision; bulk reading of many transponders at once is not possible.

High frequency (HF; 13.56 MHz): This higher frequency enables thin and inexpensive write/read transponders with anticollision technology, thus enabling the reading of several transponders at the same time. This technology represents a good compromise between cost and benefit even though it is still too expensive to lead to the "disposable transponder." Moreover, the transponders are not very resistant to adverse mechanical and thermal conditions, and they do not work very well in environments with lots of metal.

Active ultrahigh frequency (UHF; 868 MHz): This technology based on ultrahigh frequencies allows read distances of up to 100 m at high transport

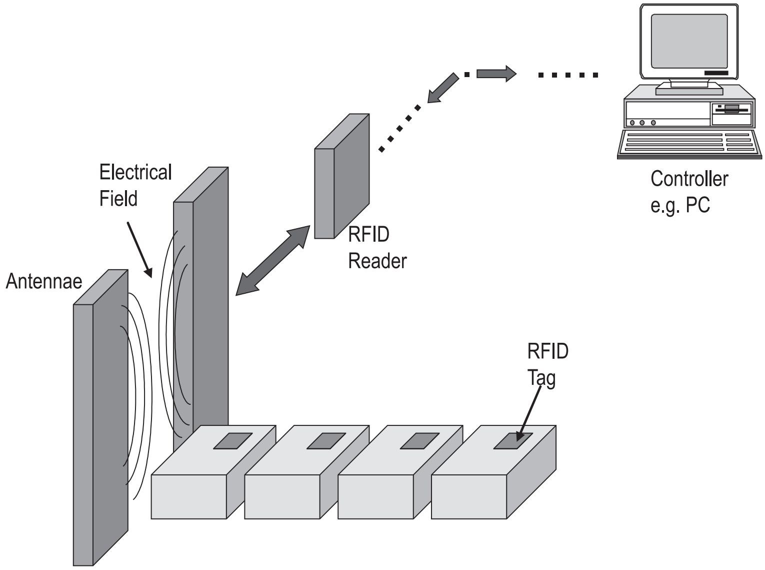

Fig. 1.7 A typical architecture for RFID data capture

rates, provided directional radiation or an antenna field. As these data carriers dispose of a separate energy source, multifunctional transponders are possible, registering via light-emitting diode (LED) or disposing of an integrated temperature logger. In this case, multiple transponders can also be read simultaneously via anticollision technologies that can manage up to 2,000 tags in the reading area. Yet the high costs for the transponders and readers as well as the limitations of the temperature range due to the battery must be considered disadvantages. Metal reflections may also prevent the position from being assigned uniquely.

Passive UHF (868 MHz): Passive label transponders using 868 MHz technology also have the advantage of combining write/read transponders with anticollision technology at an attractive cost–benefit ratio. They are especially well suited for label and track pallets and cartons. By means of directional radiation, ranges of up to 6 m can be reached at high transport rates. However, these transponders are typically not very robust with respect to adverse mechanical and thermal conditions. Location problems in the presence of metal as well as the relatively high costs for readers constitute other disadvantages.

In recent years the barcode has been established in many areas, including manufacturing. To identify goods or objects within manufacturing, this code carrier has become absolutely indispensable. Careful analysis is therefore required to see where an existing barcode solution should be replaced by RFID or whether a combination of barcode and RFID may be advisable. This is often a cost–benefit issue. RFID solutions are mostly more expensive, but they may well be worth the price. Sometimes, however, the benefits of an RFID solution do not occur at the same site where the costs occur. In a supply chain, the investments of one participant may benefit other participants, and special measures may have to be taken to assure fairness and avoid free-riding.

In general, one has to consider the total system costs, not just the price of the code carriers. If only a few code carriers but many readers are needed, the price of the readers and IT infrastructure tip the scales. If, on the other hand, in a high-rack warehouse thousands of spare parts or goods and only a few goods movements are to be covered, the price of the single code carrier determines the expenses. The basic technical advantage of RFID compared with barcodes or other code carriers is that the code carrier may store many pieces of information on very little space and that this information can be modified, extended, or exchanged automatically, without requiring any contact and without having to exchange the code carrier. Moreover, there are environmental conditions in which the benefits of RFID chips clearly prevail.

Over the past years, processes associated with creating, changing, applying, and removing labels have been playing a decisive role in logistic production processes. Relevant applications include material tracking, the identification of WIP materials, random storage, and the identification of products and their use (such as in the automotive sector for the delivery of spare parts to automotive manufacturers). This demand involves the increasing transition to flexible production processes and also the individualization of products as described beforehand.

This transition is accelerated by decreasing lot sizes, smaller production and packing units and thus an increasing number of operations. Because nearly all pieces of information saved on a paper or plastic label can be put on an RFID tag, this will become an interesting application in the future to reduce manual interventions as well as the number of needed label printers, materials (labels), and administration of this infrastructure (for example, printer maintenance and networking). Certainly, similar equipment and IT infrastructure are also required for RFID chips, namely the use of write/read devices to add information or to read it on RFID tags. However, it is, of course, much more cost efficient to write RFID tags than to administer label printers.

A major disadvantage of RFID for the identification of products is that, along with barcodes, labels also contain information in plain text that employees can read and recognize without other technical tools. If information is saved on RFID tags, only stationary or mobile readers can render them visible.

1.2.2 EPCglobal™

EPCglobal™ is a nonprofit organization founded in 2003 by the global standardization consortium GS1. Its goal is to define global standards for the use of RFID technology. Like GS1, EPCglobal™ has members around the world. Its technical roots lie in research conducted by the Auto-ID Center, a global research network driven by the Massachusetts Institute of Technology with locations in Adelaide, Cambridge, Fudan, Keio, Shanghai, and St. Gallen. In 2003 the Auto-ID Center handed over its administrative functions to EPCglobal™ and continued as a pure research organization, now known as the Auto-ID Labs.

EPCglobal™ envisions an "Internet of Things" as an information network, also called the EPCglobal™ Network, that will allow producers, retailers, and consumers to easily access and exchange information about products. The information access is based on the Electronic Product Code (EPC), a globally unique identifier that unambiguously identifies each product and can be used as a reference to information stored in the EPCglobal™ Network. In contrast to barcodes, the EPC identifies each product instance rather than only product categories. To ensure the uniqueness of each product code, only so-called EPC managers are allowed to assign product codes to physical objects, and they can assign only codes from code blocks that are under their responsibility. The code blocks are assigned to the EPC managers by an issuing agency.

EPCglobal™ has defined and is still in the process of defining a number of standards that come together under the umbrella of the EPCglobal™ Architecture Framework. This architecture describes how the different components and standards suggested by EPCglobal™ will fit together to form the EPCglobal Network. Two key components of this architecture are the Object Name Service (ONS) and the EPC Information Services (EPCIS).

The EPCIS store the information that can be referenced through the product codes and is potentially exchanged between trading partners. These services are run by EPCglobal™ subscribers or EPC managers. The stored information includes static data about the products that does not change over a product's life cycle, e.g., expiration date, as well as transactional data, e.g., business transactions or product sightings.

The ONS is a look-up service that maps an EPC to the address of one or more EPCIS that hold information about the EPC. Each EPC manager runs a local ONS service that holds, for each EPC under his or her management, the address of an EPCIS service holding information for that EPC. Moreover, EPCglobal™ controls a Root ONS service. To look up an EPCIS for a specific EPC, an EPCglobal™ subscriber first addresses this Root ONS service. This service returns the address of the local ONS of the EPC manager responsible for the requested EPC. Finally, the subscriber uses this address to contact the local ONS and gets the EPCIS in question as a response. To ensure scalability, the ONS is implemented as an application of the Domain Name Service (DNS) used in the World Wide Web to map domain names to Internet Protocol (IP) addresses.

Besides these decentralized services, the EPCglobal™ Architecture Framework covers the components that each EPCglobal™ subscriber needs to read EPC tag data and participate in the EPCglobal™ Network. Actually, most of the EPCglobal™ standards finalized up to today refer to these local components. Figure 1.8 gives an overview of these components and the standards specifying the communication between them.

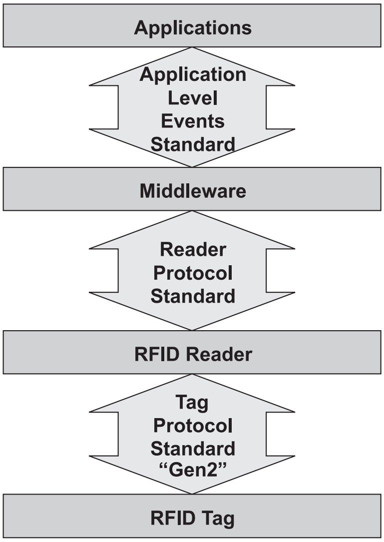

Fig. 1.8 Local components and protocols between them

The RFID tag holds the EPC and perhaps some additional user data. It might support features such as locking, access control, or killing of the tag for privacy reasons. Details are specified in the EPC Tag Data Standard, a ratified EPCglobal™ Standard. The description of this and also the following described standards can be downloaded from the EPCglobal 2005 Web site (EPCglobal 2005).

The physical communication between a reader (sometimes called the interrogator) and the tags is specified in another EPCglobal standard, the Gen 2 standard (EPCglobal 2005). Besides sending commands from a reader to a tag and receiving the answer from the tag, this standard addresses how to deal with multiple tags within a reader's range and how to minimize interference between different readers and tags.

The Reader Protocol Standard (EPCglobal 2005) describes how software applications including the middleware interact with the RFID reader. It provides a standardized way for host applications to ask RFID readers for the EPC codes in their reading range or for the additional user data on the tags. It also describes how to use additional functionality provided by the readers, such as writing to tags.

The Application Level Events (ALE) standard (EPCglobal 2005) describes how client applications can access the middleware in order to read EPC data from various sources. The ALE interface allows client applications to be completely agnostic of the reader infrastructure (e.g., the number of readers or their make and model). In addition, it provides a means for client applications to specify what to do with EPC data, such as how to filter or aggregate it.

Although the EPCglobal™ standards are so far not broadly accepted within the manufacturing domain, there are strong indications that this might change in the near future. A number of RFID tag and reader producers support the EPCglobal™ standards, and application vendors also have first products that support the EPCglobal™ standards—SAP with its Auto-ID Infrastructure, for example.

1.2.3 OPC and OPC-UA

Like EPCglobal™, OPC is also a family of different standards. The goal is to ensure the interoperability of different shop floor devices with each other as well as to provide a standardized way for applications to communicate with shop floor devices including sensors, PLCs, and historians. The OPC Foundation (OPC Foundation 2007) is the organization responsible for the OPC standards. It offers free tools for its members to test OPC compliance. Initiated in 1996 by a task force of a handful of companies from the automation industry, today the organization has more than 300 members. Originally, the OPC standard was based on Microsoft's Object Linking and Embedding (Distributed) Component Object Model (OLE COM/DCOM) technology, and therefore the name stood for "OLE for Production Control". But now the OPC standards are no longer restricted to COM/DCOM technology; therefore, the name has been changed to stand for "Openness, Productivity and Collaboration."

The first standard in the OPC family was the OPC Data Access Specification. It is still the most important standard within the family and rules the acquisition of data from shop floor devices through production control stations, MES, and even ERP systems. An OPC server running on a shop floor device or industrial PC close to the shop floor communicates via field buses with the data sources and exposes the data in a standardized way to higher-level applications, the OPC clients. With the new OPC XML-DA standard, a Web-service-based data access standard is provided. It allows running of OPC components on non-Microsoft systems.

The OPC Alarm & Events Specification provides a means for OPC clients to register for certain events or alarm conditions. The clients receive messages only when something happens that is of interest to them instead of having to read data streams continuously, as would be necessary if OPC Data Access were used.

OPC Batch specifies interfaces for the exchange of information about equipment capabilities and operating conditions, with a special focus on batch processes. OPC Data exchange specifies the communication between OPC servers via field buses. In contrast to the OPC Data Access standard, which deals with real-time data only, the OPC Historical Data Access standard specifies how data that is already stored in a system, such as a plant historian, can be accessed. OPC Security defines how the sensitive data on OPC servers can be protected against accidental or intentional manipulation.

OPC Unified Architecture (OPC-UA) is the latest specification from the OPC foundation. The first parts of this new specification were finalized in June

2006. OPC-UA provides uniform Web-service-based access to the various, formerly separated functionalities, including OPC Data Access, OPC Alarm & Events, and OPC Historical Data Access. It also overcomes the dependence on Microsoft COM/DCOM with the specification of its own communication stack. This provides the ability to run OPC-UA on non-Microsoft systems, including embedded systems, which are becoming more and more important as OPC servers.

Although the OPC standards are not very common so far for communication with RFID readers, they could provide a comfortable way to integrate RFID readers with existing plant IT infrastructures.

1.2.4 ISA-95

ANSI/ISA-95 (internationally standardized under ISO/IEC-62246) is the most prominent plant-to-business (P2B) integration standard relevant for manufacturing. The description of the standard is divided into five parts:

- ANSI/ISA–95.00.01 Models and Terminology, published in 2000 (Brandl 2000)
- ANSI/ISA–95.00.02 Object Model, published in 2001 (Brandl 2001)
- ANSI/ISA–95.00.03 Activity Models of Manufacturing Operations, published in 2005 (Brandl 2005)
- ANSI/ISA–95.00.04 Object Model of Activity Models from Part 3, unpublished draft
- ANSI/ISA–95.00.05 Business to Manufacturing Transactions, unpublished draft

The first part of this standard defines a terminology and concepts to structure manufacturing systems and operations. It builds on the Purdue reference model for computer-integrated manufacturing (Williams 1992) to define a multilevel functional reference model for manufacturing systems. Figure 1.4 illustrates how the functionality within a manufacturing system is distributed across different levels. Each of these comprises manufacturing functionality on a particular level of abstraction. In particular, the following areas are addressed:

- *Level 0:* Physical processes (machines); location of the actual production processes.
- *Level 1:* Sensing and manipulating of physical processes (sensors, actuators, RFID readers)
- Level 2: Monitoring and controlling of physical processes (PLC, human–machine interface)
- *Level 3:* Manufacturing operations and control: dispatching production, detailed production scheduling, reliability assurance, etc.; maintenance of records and optimization of the production process. Relevant time frame: seconds to days

- *Level 4:* Business planning and logistics: plant production scheduling, production, material use, delivery and shipping, inventory management. Relevant time frame: days to months

A complete RFID solution always spans multiple levels as defined in ISA-95. RFID tags are typically attached to material or material containers that are tracked through the process. Machine tools, inventory locations, and even workers may also be identified through RFID tags. The RFID tags themselves correspond to ISA-95 level 0. Hardware such as RFID readers offers level 1 functionality by reading from or writing information to RFID tags. Plant-local control devices such as a PLC or terminal PCs with an RFID device controller aggregate RFID read events and provide the interface to higher-level control systems such as an MES or ERP system. MESs are classified as level 3 systems and are responsible for orchestrating the manufacturing processes in the factory. This includes responsibilities such as operations scheduling, production control, and labor management. Level 4 functionality is typically provided by ERP systems such as the SAP ERP application.

The distinction of clearly separated levels constitutes a reference model but often does not correspond to reality. The functionality of certain levels may be combined into an integrated system. For example, an ERP system may include an RFID integration component, such as SAP Auto-ID Infrastructure, which enables it to communicate directly with manufacturing or logistics processes. In the future, the strict separation into levels and system boundaries is likely to disappear in favor of a more modular and flexible service-oriented architecture as described in Chap. 3.

ISA-95 addresses the interfaces between levels 3 and 4, describing the information that is communicated between the MES and the back-end ERP system. In part 2, the standard provides abstract definitions of information models, describing a production order, the equipment to be used for the execution, personnel, material, and other production-related entities. The ISA-95 standard defines these information models but does not offer an implementation or syntax. The business-to-manufacturing markup language, or B2MML, fills that void and fully implements ISA-95 as a set of XML schemas, with one schema per information model.

RFID itself is not explicitly considered within ISA-95. However, many of the ISA-95 information models include identification information such as data to identify a particular material or personnel. These data may be contained on an RFID tag attached to a material or carried by plant-floor personnel.

Other P2B integration standards are RosettaNet (RosettaNet 2007) and OAGIS (Open Applications Group 2007). In contrast to these standards, ISA-95 focuses solely on the integration of ERP and MES. Both RosettaNet and OAGIS go far beyond P2B integration in an attempt to model every class of business-to-business (B2B) transaction. The cost of this approach is the lack of depth for P2B integration. However, a recently started cooperation between ISA and OAGIS is likely to further harmonize the currently competing standards. ISA-95, although still far from being mainstream, has already been deployed successfully by a number of businesses and is currently the leading standard for P2B data exchange.

1.3 RFID Potentials

Judging from the case studies presented later in this book, many companies consider the introduction of RFID without a clearly defined business case. This is not altogether irrational. Many enterprises realize the potential of this technology and want to get a head start in turning this potential into a competitive advantage. Moreover, they want to be prepared in case their business partners or customers make corresponding demands. The situation of the retail industry in 2004/2005, when large retailers such as Wal-Mart and Metro put unexpected demands on their suppliers, serves as a warning to many smaller and midsize manufacturers in particular.

Despite the usual lack of a clear business case, the companies we surveyed focus on a few application areas where RFID and sensor technologies are very likely to create a solid return on investment. The following—partly overlapping—objectives were particularly prevalent in our case studies:

- More reliable scanning
- Better tracking
- Better tracing
- Integrated metadata management
- Reduced back-end communication
- More efficient label management
- Improved cooperation along the supply chain

We now discuss these areas in turn.

1.3.1 Scanning

A comparison between RFID and a conceivable or existing barcode solution is typical for many situations. RFID technology, while often more expensive than barcode solutions, offers a number of substantial advantages that make it worthwhile to consider a switch. First, RFID tags can be read without obtaining a line of sight. This may make it much easier, especially in a manufacturing environment, to implement an efficient scanning process. Some objects in the manufacturing plant may be shaped in a way that makes it hard for barcodes to be attached so that they are always readable. Optical barriers occur frequently on the shop floor. This always leads to requirements for manual interaction, while RFID reading can be automated completely. Second, RFID tags allow for bulk reading. Large numbers of objects can be scanned virtually at once, whereas barcode scanning works only on an object-per-object basis. Third, plant floors of manufacturing companies are often hostile environments with extreme conditions. Dirt, heat, the presence of metal, as well as limited space pose challenges that may be impossible to match by barcode- and network-based solutions. RFID tags have the advantage that they can be covered in protective casings and may thus be more reliable than barcodes. Moreover, writable tags do not depend on a network (see Sect. 1.2.6).

1.3.2 Tracking

As experiences from the retail industry have shown, the RFID-based tracking of parts, devices, and containers can lead to improved shipment and inventory management. With the availability of high-quality comprehensive data about the production process, labor costs can be reduced, and the overall process can be accelerated.

Cost depends on the hardware implementation. To ensure tracking on a shop floor, reader gates would be required at waypoints on the transportation routes. Additionally, RFID tags would be needed to label the model parts. Alternatively, a company could install mobile readers and position tags on the plant floor. Higher-class RFID tags can collect sensor data about physical conditions of the production environment. The autonomous energy supply and the ability of sensor tags to form ad hoc mesh networks allows for easy deployment in production environments.

Better tracking helps ensure accurate and real-time reporting about production status. Achieving compliance, narrowing recalls, addressing liability issues, and receiving better data about the production processes are among the possible motivations (see Sects. 4.4–4.6).

Typically, a production step is booked into the MES after the processing is completed. Information about the process status is thereby fed into the backend system. This information may also be required in future consistency checks and used for later process analysis. During the case studies, it was common for manual booking to be sometimes forgotten or not conducted in a timely fashion (see Sects. 4.2 and 4.5). Possible consequences are inaccurate data tracks, wrong status information, and even interruptions in the production process. These problems can be overcome if RFID tags are applied on the materials or on the internal transportation units. In such setups, RFID readers could automatically detect whether materials are transported to the next process step, and consistency would thus be ensured.

Improved tracking also allows for more thorough process analysis, which may help reduce production errors and improve product quality. This could particularly be achieved by automating the production-related data management and thereby avoid errors in manual data maintenance. The frequency of errors and the related costs determine the potential savings for this use case. Furthermore, improvements in data accuracy may help in analyzing the processes better and identify potentials for improvements. Event tracking may also lead to a swifter response to problems and emergencies, thus minimizing downtimes. Realizing an emergency system with RFID would require rewritable tags with a few kilobytes of memory as well as one reader per workstation. These investments must be compared to the probability of downtimes of the backend system multiplied by the average cost of such an incident.

Some customers of the companies we surveyed require process reliability and process documentation (for instance, consistency checks to ensure that no process step is skipped). In an example from the case studies, a company scanned its products after every processing step in order to be compliant with customers' demands (see Sect. 4.1). RFID can help meet such demands considerably.

1.3.3 Tracing

A key driver for implementing RFID is expected savings from improving the traceability of products, especially in case of failure. If a production error is detected, all potentially affected parts must be checked manually. For faulty and already shipped products, checks must even take place at the customers' plants. This results in additional costs for sending workers to the customers. Costs for recalls are even higher for parts that where already used in a customer's production process; in this case, the manufacturer may have to pay penalties. Therefore, improving traceability and thereby narrowing recalls can account for significant savings.

Our case studies confirmed that recalls can be a major cost factor for production plants. Consequently, narrowing recalls to the products that were actually affected is desired, so detailed data tracks and process information are necessary. Exact information about which object was manufactured out of which components and materials is required to identify all products that include potentially flawed parts.

In addition, fine-grained and reliable data records can be important in legal disputes (see Sect. 4.1). A company may be sued if malfunctioning products cause damage. In this case, data records are important to prove that the production was conducted correctly. Here, sensor data can help detect the cause of failure and further narrow the scope of potentially affected products. Evaluating this data can provide additional insights into performance measures such as cycle times. It can even help identify the cause of quality changes.

1.3.4 Metadata Management

Accompanying documents are currently a frequently used way to maintain data in the production line. These paper documents are transported along with their corresponding materials and are used to record (meta-) data about the production process. Additionally, these documents can hold information about how to conduct subsequent processing steps. The accompanying documents are usually only loosely coupled with the objects they belong to. That is, documents move along with the corresponding objects but are physically separated from them while data are written on the paper. This may cause a mix-up of documents and lead to incorrect data maintenance.

RFID tags with writable memory can be used to store metadata about relevant events and processes right on the corresponding object. This way, information cannot get lost or accidentally mixed up. This solution may also be leveraged to automate some of the manual data maintenance. For instance, records of the conducted processing steps can automatically be written from machines to the tags. Automatic data maintenance would account for time savings and a reduction in mistakes.

Users should be aware that information could also be stored automatically in the back-end system. An identifier on the corresponding object would be needed, such as a barcode label or an RFID tag. Exchanging such data with the back-end system requires an appropriate network infrastructure and software system. The investment in such an infrastructure must be traded against the investment in RFID tags and readers, and the resulting network load must be considered carefully.

1.3.5 Back-End Communication

In contrast to barcodes, RFID tags can store up to several megabytes of data. More complex tags even have processing capabilities and programmable logic. These technical properties enable a novel distribution of processing logic in the IT infrastructure. Specifically, it is possible to shift the execution of business logic from monolithic back-end systems to the edge computers or even the tags themselves, thereby decoupling the processing logic from the back-end system. However, tags that store more than just identifiers are relatively expensive and may therefore be primarily applied in cases where they can be reused.

Some of the investigated companies expressed the demand to reduce interaction with the back-end system. In one case, the network infrastructure and the back-end database were perceived as unreliable (see Sect. 4.6). Consequently, IT support for production should work without the back-end system (at least in an emergency in case the back-end system fails). In another case, the company's network and back-end computers were hardly able to serve the demanded response time (see Sect. 4.1), and the IT staff has predicted significant bottlenecks when data volumes increase in the future. In both cases, RFID tags with writable memory could help decouple the processing of business logic from the back-end system. Currently, interaction with the core back-end system is needed to retrieve task-related data at each processing step. These data could also be stored at the object of interest if RFID were used. In this setup, edge servers that read the RFID data may execute business logic without consulting the back-end system. As a result, data retrieval would speed up, and the back end would no longer be a single point of failure.

1.3.6 Label Management

The case studies confirmed that manufacturers face challenges in handling labels at the outbound shipment; different customers demand different barcode solutions for labeling transportation units and packages. These differences can be in the demanded label format, coding scheme, or information on the label. Another challenge is that customers may claim financial compensation from the manufacturer if barcode labels are unreadable. In a specific example from the case studies, a customer's production line stops if a barcode happens to be unreadable (see Sect. 4.1). The resulting costs must be reimbursed by the manufacturer that printed the barcode.

RFID tags with writable memory can hold data in arbitrary coding schemes. RFID may thus be leveraged to abstract from the physical level. Different data amounts and coding schemes would no longer require different label formats. That is, one kind of RFID tag could be used for all customers. Label handling could be further improved by increasing the labels' readability. This could at least be done in environments where dirt or mechanical influence can affect the barcode. However, for this use case, all customers would need to accept the RFID tag protocol being used.

If RFID readers are in place, they can be used to write customer-specific information on tags in the outbound. In this case, expensive, specialized printers for labels would no longer be necessary. Label printing is currently done centrally to reduce the number of costly printers. If RFID readers could be used instead, central printing could be avoided, and the process could be organized more efficiently. This would result in savings on hardware costs and increased productivity.

1.3.7 Inter-Enterprise Collaboration

Partly as a result of the potential improvements described above, the introduction of RFID in manufacturing may improve the cooperation of enterprises along the supply chain. The key for successful collaboration is a controlled sharing of information that works to everybody's advantage ("optimal transparency"). The information can be transferred on the RFID tags that traverse the supply chain, or it can be held in one or several back-end repositories. More important than the technical realization, however, is the question of how to ensure that the efficiency gains are fairly distributed among the various participants. If this cannot be achieved, some enterprises may oppose the introduction of RFID simply because the cost outweighs the benefits. In this case, partner companies may want to establish compensation payments in order to avoid a "prisoner's dilemma" in which the efficiency of the supply chain remains suboptimal because of the opposition of only a few participants. We will discuss this in more detail in the following section.

1.4 Cost–Benefit Considerations and Adoption Decision

The RFID application areas discussed in the previous section can be categorized along two dimensions, as visualized in Fig. 1.9. We distinguish between operational use and strategic use on the one hand and between intra-enterprise and inter-enterprise applications on the other hand.

The term *operational use* refers to improvements that impact processes and productivity directly. That is, the RFID technology is applied to make processes faster, more secure, and so on. Furthermore, improved activity planning and better resource allocation due to RFID falls into this category. The term *strategic use* refers to use cases in which RFID is introduced for long-term strategic purposes. For instance, RFID may allow a company to provide additional services or quality guarantees to customers, thus changing the market positioning of the enterprise as a whole. Strategic decisions have a long-term impact, whereas operational decisions focus on immediate results.

Use cases for RFID in which the technology as well as the captured data are used only within one organization fall into the category of intra-enterprise applications. However, RFID holds potential for applications that span several steps in the supply chain. For instance, enterprises may exchange data that are obtained using RFID. Also, RFID labels may remain on products and could be reused by several companies downstream in the supply chain. Such use cases are categorized as inter-enterprise applications.

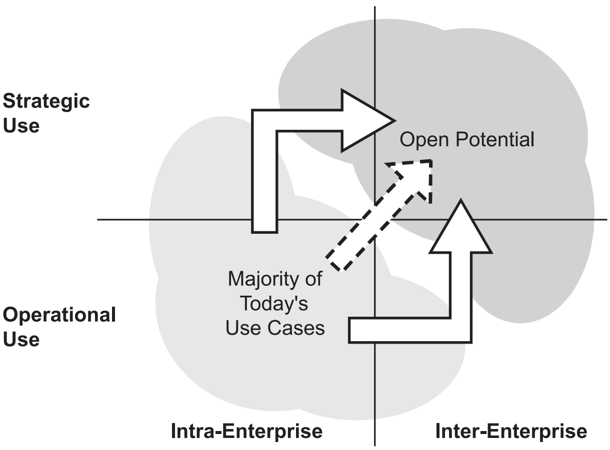

Fig. 1.9 Taxonomy of motives for RFID adoption

During our case studies we found that most RFID use cases today fall into the category of operational, intra-enterprise use. That is, the technology helps improve processes and productivity on the plant floor. Use cases in which RFID is used as a strategic enabler are found much less frequently. With regard to planning, RFID-enabled decisions are also mainly of local scope. In most cases, only locally obtained RFID data are used, and decisions are made for local processes.

The current focus on operational, intra-enterprise applications neglects the potential for RFID technology to be used in many steps of the supply chain. Operational use across enterprises can be enabled by the reuse of RFID tags. One option is to permanently leave RFID tags on the products as they move through the supply chain. Another option is to reuse the tags in a closed loop but extend the loop across several enterprises. This not only supports seamless integration of processes but also enables cost-sharing models for hardware expenses. Beyond this, RFID use across enterprises may strengthen the strategic position of the supply chain as a whole. For instance, cooperating partners can use the technology to provide fine-grained product traceability and quality assurances across the whole supply chain. Moving toward this opportunity can become a distinguishing factor and competitive advantage for innovative manufacturers in the near future.

We anticipate for the near future that manufacturing companies will introduce RFID with the expectation of realizing short-term benefits in the lower left quadrant of Fig. 1.9—that is, through operational, intra-enterprise measures. From there, we expect many companies to move gradually to the upper right quadrant, often by traversing the lower right quadrant or the upper left quadrant first.

RFID holds considerable potential for improving relevant business indicators. The cost of an RFID implementation includes some costs for hardware and software that are relatively easy to measure. Depending on the required functionalities, tag prices may range from about 5 cents to several euros. Reader prices range from a few hundred to several thousand euros. Tags may be reused (closed-loop applications) or remain attached to objects. However, there are costs that are notoriously difficult to measure, including system integration costs and costs of adapting business processes. In particular, as our case studies have shown, a successful RFID introduction greatly depends on the IT infrastructure already in place. This affects important architectural and functional aspects such as integration with other systems (S95 level 3 functionality), paradigms for data and event stream processing, distribution of logic and data, and support for heterogeneous data sources.

Concerning benefits, RFID may lead to increased automation, especially in data capture, and therefore to a reduction of labor costs. More important, the introduction of RFID may lead to a qualitative improvement of the relevant business processes. Improved tracking and tracing may lead to a more stable manufacturing process, with interruptions in the production process becoming less frequent. Tracing faulty parts and processes in the wake of a complaint or an accident is becoming much easier, and given the increasing demands regarding product liability, this is likely to create major competitive advantages for early adopters. In container management, RFID can reduce the overall cost of purchasing and renting containers. Tracing containers would allow reduction in the safety stock of containers, and fewer containers would need to be rented. Furthermore, loss of containers could be reduced, or external partners could be held responsible for losses at their sites. Using RFID for the uniform labeling of shipments (label management) could also lead to considerable savings in labor and hardware. Concerning process safety, production waste could be reduced by avoiding false machine settings. The resulting savings of this use case depends on the value of the wasted material and the cost of processing it.

As discussed above, a major problem when considering RFID introduction in a supply chain is that costs and benefits are not always correlated. Some participating companies may incur considerable costs that outweigh the local benefits, and vice versa. This can lead to a classic prisoner's dilemma: It could well be possible that an existing supply chain could gain considerably from introducing RFID technology. These gains, however, are never realized because some participants would need to incur costs that are not justifiable in comparison to their local benefits. As a result, these participants decide—for completely rational reasons—not to adopt the new technology. One way to break this deadlock is to negotiate compensation payments between different participants in the supply chain, with the objective of distributing the global benefits fairly among the participants. These compensation payments do not have to be monetary; in the retail domain, certain types of data, such as sales data about one's own products or the products of one's competitors, are also common currency.

1.5 Summary

The purpose of this chapter was to lay the foundations for the upcoming discussion of RFID in manufacturing. A key observation concerns the fact that RFID develops its full potential only if it is tightly integrated with any existing IT infrastructures. A tight integration with existing ERP and MES systems makes it particularly more likely that RFID will lead to concrete and local productivity improvements in the short and medium terms. Such concrete improvements—especially if they are purely intra-enterprise, i.e., independent of any coordination with supply chain partners—facilitate the adoption decision considerably. Cost–benefit calculations are less complex, and there is less uncertainty about the medium-term profitability of an investment in RFID technology.

We suspect that many enterprises will first focus on operational, intra-enterprise applications of RFID. Several examples of such applications were given in this chapter. We also pointed out the importance of working standards for both hardware and software. Even intra-enterprise applications rely on well-accepted standards to integrate hardware and software from different vendors.

Once an enterprise has introduced RFID on the shop floor and obtained tangible productivity improvements as a result, we expect more and more companies to look at the strategic potential of the technology. Inter-enterprise applications will become increasingly popular, even though they require close cooperation of the supply chain partners. In many cases, detailed negotiations will be necessary in order to distribute the costs and benefits fairly.

In the following chapters we continue with a presentation of the salient features of MES and ERP systems and show how RFID technology can be integrated into existing ERP- and MES-based IT infrastructures.

http://www.springer.com/978-3-540-76453-3

RFID in Manufacturing
Günther, O.P.; Kletti, W.; Kubach, U.
2008, XVI, 163 p. 47 illus., Hardcover
ISBN: 978-3-540-76453-3