Enabling ERP through Auto-ID Technology†

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In many respects MRP, the subsequent development of manufacturing resource planning (MRPII), and ERP, represents increasingly sophisticated databases that over time have improved tactical and strategic business planning. Essentially, ERP serves an “uncertainty absorption” function (Miles 1980). It is impossible to know with certainty all future outcomes that might occur for a business. However, with enough data and proper methods of analysis, reasonable projections of future outcomes become feasible. Having data allows for the possibility of calculating risk, where several different outcomes are possible, and a probability calculated from the data can be assigned to each outcome (for example see Allen and Schuster 2004).

The crowning achievement of ERP systems in practice is that business decision making has moved from an *uncertainty basis* where no comprehension of risk exists, to a *risk basis* where ERP serves the important function of mitigating uncertainty. The result; much more effective business decision-making based on rational analysis of data available rather than pure conjecture

With the established success of ERP in practice, it is realistic to begin thinking about what changes in information technology will further enhance ERP, thus reducing even more uncertainty within business planning. Since ERP is at its essence a data management tool, it is reasonable that any advancement in the way that data is obtained, organized, and employed will have a significant impact on the structure of ERP software.

This chapter examines the role of Auto-ID technology, a new way to capture input data for ERP systems. The implications of Auto-ID technology affect several important areas including data interfaces, bill of material structure, accounting, the treatment of capacity in material requirements planning, and the application of mathematical models to the analysis of data. All of these are new developments that will change the nature of ERP in the years to come.

RFID VS AUTO-ID TECHNOLOGY

A great deal of confusion exists concerning the meaning of two terms, radio frequency identification (RFID) and Auto-ID. While RFID has been in existence for more than 50 years, Auto-ID represents a new technological development (Sarma et al. 2000). Though both technologies share commonalities, several important differences exist.

Historically, the term RFID has applied to situations where an object identifies itself through the transmission of radio waves that are received by an antenna and processed into positional information. Transponders on commercial and military aircraft that use two-way communication are early examples of RFID technology. In these situations, a radio signal broadcast from a ground station or another aircraft activates the transponder, which then returns a signal containing important proximity information.

Other examples include the application of RFID tags to steamship containers and rail cars. Most of these applications involve different types of capital asset tracking and management. This type of two-way communication is tightly coupled with highly specific applications such as air traffic control, proximity warning, and shipyard management systems. Many in industry classify theses applications as “closed loop” to denote that direct feedback occurs between two objects coupled by RFID types of communication. Because most of these applications are highly specialized, RFID has evolved into mostly proprietary technology characterized by closed standards.

Though RFID has offered some highly innovative applications, the technology has never achieved mass use for supply chains because the cost of electronic tags powered with tiny batteries remained relatively expensive. Manufacturing breakthroughs during the past several years that include fluidic self-assembly and vibratory manufacturing methods offer significant potential to place individual transistors onto an integrated circuit at sharply lower cost (Sarma 2001). Projections show that the new generation of tags will reach a price that allows individual tagging of cases and pallets. At some time in the future, the price might be low enough to tag individual consumer goods on a large scale.

With these new manufacturing methods, production of the silicon chips needed for Auto-ID becomes a continuous manufacturing operation in contrast to the current batch method for producing the integrated circuits that make up silicone chips. This development opens the possibility of tag application to a large number of objects, such as individual units, cases and pallets of merchandise within the consumer goods supply chain.

Given the scale of retail supply chains that include billions of items, industry consortiums recognized very early the need for a comprehensive information technology infrastructure to manage the large amount of data potentially available from linking objects to the Internet. With such an infrastructure, the practical possibility exists of ERP systems having continuous, two-way communication with objects located anywhere within a supply chain. This *Internet of things* will create unprecedented interconnectivity, and have an important impact on the ERP systems of the future.

The infrastructure needed to manage the Internet of things is Auto-ID technology, an intricate yet robust system that utilizes RFID. An important feature of Auto-ID technology includes open standards and protocols for both tags and readers. This means that a tag produced by one manufacturer can be read using equipment produced by a different manufacturer. This type of interoperability between tags and readers is essential for wide-scale application within supply chains.

Beyond the sophisticated information technology, Auto-ID lays the groundwork for the intelligent value chain of the future (Brock 2000). Creating "smart products" that sense and respond with the physical world requires unique identification, which is an element of Auto-ID technology. With this capability, distributed control systems can interact and give instructions to a specific object.

For example, some time in the future smart objects within the consumer goods supply chain might dynamically change price based on sensing demand and communicate this information to ERP systems without human intervention. Because it offers much more than merely identifying objects using radio communication, Auto-ID technology holds the potential to drive rapid advances in commerce by providing the infrastructure for true automation across supply chains.

HOW AUTO-ID TECHNOLOGY WORKS

In addition to the advances in manufacturing technology for producing the integrated circuits, there are several other important advances worth noting that deal with the way tags are powered. Currently there are two basic types of tags used most often.

An *active* tag requires a small battery that provides electric power to continuously generate and transmit the radio frequency signal. Active tags can be read from a relatively long range—up to 30 meters. In general, these tags have significant amounts of memory to store information such as bill of lading details. In some cases, specialized readers called interrogators can not only read data from an active tag, but can also send signals to reprogram the tag with new information or instructions.

However, active tags have several drawbacks. Because these tags transmit signals significant distances, there is greater chance of a "frequency collision" with other radio waves such as those emitted by radios, transformers or cellular phones. This type of interference could cause the reader not to pick up the tag signal. In addition, with longer read distances, the opportunity of providing exact location information diminishes. The tiny batteries are moreover somewhat expensive, thus limiting widespread use. Common prices for active tags range from $2 or more per unit, depending on capability, memory and order size.

Beyond the expense, the other disadvantage of active tags is that the batteries sometimes wear out resulting in total loss of signal. This is disastrous if the tag fulfills a critical function such as providing data for a moving rail car. Battery life varies a great deal depending on many different factors, so it is difficult to predict in advance when a failure might occur.

Beginning in 1999, industry and academics undertook research to develop low cost passive tags. With this technology, each tag does not contain a battery. Rather, the energy needed to power the tag is drawn from electromagnetic fields created by readers that also serve a dual purpose of gathering the signals emanating from the passive tags. The read distance of a passive tag is usually no more than three meters.

Since no fixed power source is required, passive tags hold a great advantage over active tags in terms of lower cost per unit. This opens the possibility for the use of passive tags in a far greater number of applications. Gradually, as costs decrease, passive tags will challenge bar codes as a means of gathering information within supply chains.

A third type, the *semi-passive* tag, is a hybrid of both active and passive tags. It has a smaller battery that is partially recharged each time the tag enters the electromagnetic field of the reader. These tags are currently under commercial development and are not widely used in industrial applications though there is promise such technology might be an important factor in the near future.

Designed to operate at low energy levels, passive tags store relatively little information. Just enough memory exists to store a serial number that can reference an IP address on the Internet. Information is stored on the Internet, not on the tag. This provides a distributed means of holding information.

Table X-1 summarizes the capabilities of tags.

Table X-1, Comparison of Different Tags

	Active	Passive	Semi-Passive
Power Source	Battery	Induction from electromagnetic waves emitted by reader	Battery and Induction
Read Distance	Up to 30 meters	3 meters	Up to 30 meters
Proximity Information	Poor	Good	Poor
Frequency Collision	Hi	Medium	Hi
Information Storage	32 k or more. Read/Write	2 kb Read only	32 k or more. Read/Write
Cost/Tag	$2 - $100	25 ¢	Under Development, Some applications

Overall, passive tags hold the promise of ubiquitous application to objects within a supply chain. However, a comprehensive information technology infrastructure must also exist to organize and communicate the data gathered from passive tags. Auto-ID provides such an infrastructure.

The Components of Auto-ID Technology

In conjunction with advances by tag and equipment manufacturers, the objective of Auto-ID technology is to create infrastructure and set open standards that will make it possible for wide adoption of passive RFID technology (Dinning and Schuster 2003, Schuster et al. 2004). The four components that make up Auto-ID Technology include:

- EPC (electronic product code)
- ONS (object naming service)
- PML (physical markup language)
- Savant (data handling)

The EPC is a numbering system that contains enough combinations to identify trillions of objects. This is necessary because the ultimate goal is to provide a structure for low cost identification at the item level, meaning every single product will have its unique code. The PML is the communication format for the data and it is based on XML (extensible markup language) that is gaining popularity in eCommerce transactions. PML represents a hierarchal data format to store information. By having a standardized means of describing physical objects and processes, PML will facilitate inter- and intra-company commercial transactions and data transfer.

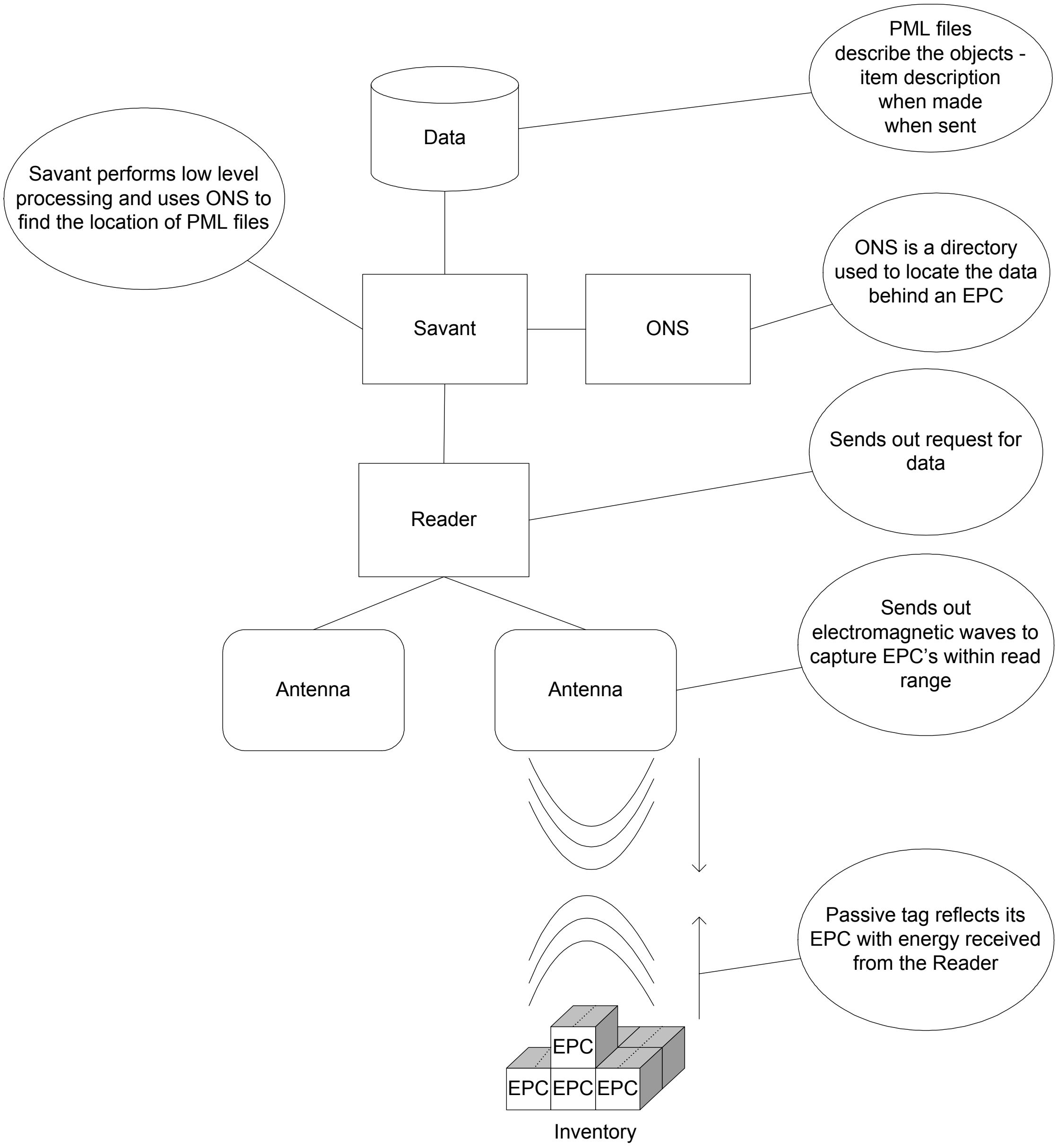
The ONS acts as a pointer to connect the EPC to the PML file stored on a network, either a local area network or over the Internet. It performs a similar function to the Domain Naming Service (DNS) of the Internet, which connects a text web address to an underlying IP address. An IP address is comprised of a 32-bit numeric address written as four numbers separated by periods, to find resources over the Internet. However, with the EPC, we start with a number and use ONS to find the product information linked to that number.

Savant is a lower level software application that processes the data and performs error checking and de-duplication procedures in the event that more than one reader receives a signal from the same tag. It handles the scalability problem associated with the massive amount of data captured by Auto-ID. To summarize, the EPC identifies the product, PML describes the product, and ONS links them together.

To make the system work, products are tagged with passive RFID chips containing the EPC. The tags are placed on surface areas of pallets, cartons or contained within item packaging. Readers are positioned at strategic points throughout the supply chain where companies need to capture data. Readers constantly emit an electromagnetic field that is received by the tags through a small antenna. This energy activates the tag, and in turn, a signal is generated and transmitted to the reader. Through this process, readers capture the EPC and interact with a Savant to look up the information on the product using ONS.

The position of the reader receiving the EPC signal provides important information on location, and environmental conditions such as temperature, vibration and humidity, which is then linked through databases to the EPC. All this information is housed and written to corporate databases using the PML format. (See figure 1 – Technology Overview)

Figure 1 – Technology Overview



Advantages of Auto-ID Technology Relative to Bar Codes

Few other inventions developed during the 20th century have had as wide an impact on everyday life as the bar code (Haberman 2001). First implemented in 1974, the bar code has drastically reduced the amount of labor needed to operate retail stores, improved pricing accuracy, and shortened countless checkout lines saving great amounts of time.

Beyond retail stores, bar codes have been applied in many other situations to provide important information such as the coordination of production within manufacturing plants or tracking data for overnight packages in transit. Bar codes transmit a small amount of information that identifies the manufacturer and links to a description of the object. Non-profit standards groups such as GS1 administer the numbering system used for the bar code ensuring a unique identification without duplication by other firms.

New research efforts have led to the development of the two-dimensional bar code that is able to carry more data about an object. This opens possibilities to attach important information such as billing details directly to the object as it passes through the supply chain.

A basic characteristic of bar codes is that all information travels with the object. In the case of a two-dimensional bar code, more information travels with the object as compared to a regular bar code. This is a common attribute shared with active RFID tags, although in most cases active tags contain much more information than two-dimensional bar codes.

Though two-dimensional bar codes do provide much more information beyond product identification, all bar codes have limitations including:

- The need for a direct line of sight from the scanner to the bar code,
- The ability to read only one code at time
- Bar codes often require human intervention to capture data or to orient packages in the case of overhead bar code readers.

In addition, bar codes provide only one-way communication and seldom provide real time information or Internet connectivity to the data. There is always a chance the bar code will be missed or in other cases, read twice. As well, bar codes can be damaged or compromised in a way that makes them impossible to read. Auto-ID technology is designed to overcome all of these limitations and make it possible to automate the scanning process, providing real-time data.

With all the advantages of Auto-ID, it is natural to begin thinking about how this new identification technology will affect the overall design and operation of ERP systems. At its core, ERP is essentially a large database. As increasing amounts of data become available through Auto-ID technology, the nature of ERP and the infrastructure needed to support the system will change dramatically opening new possibilities to do things previously thought impossible to achieve in practice.

One of the most important inputs to ERP is data about objects such as raw materials, work in process, and finished goods. The next section addresses this issue providing a blueprint for gaining the most from Auto-ID technology.

DATA AND ERP SYSTEMS

Since the inception of ERP, accuracy of data has been an important goal for long-term success. Early efforts focused on improving the accuracy of the bill of material (BOM), an important part of MRP. In the past, popular management programs such as Class A MRP II were important in helping practitioners get the most benefit from these systems.

With the perfection of the BOM approach, emphasis has shifted to raw data accuracy as a means of further improving the overall results of planning. Though data accuracy has been an important issue for many years, it continues to attract the interest of practitioners.

A recent online survey conducted by APICS supports this observation. When polled about relevance and main goal Auto-ID technology, 55% of respondents indicated improved inventory accuracy was the most important objective. The total results of the poll are as follows:

Auto-ID Poll (spring 2004)

What is your main goal in implementing an Auto-ID solution?

Improve inventory accuracy	55%
Trading partner requirement	13%
Increase inventory turns	10%
Reduce out-of-stock situation	9%
Enhance supplier relationship	9%
Improve fill rates	4%

Sample size 658 respondents

The goal of tracking items through an entire supply chain with 100% inventory accuracy remains elusive. This type of effort represents a huge challenge to current information technology infrastructures that are a critical part of ERP. In the future, automated methods of planning and control within manufacturing and service operations, and entire supply chains, will depend on accurate, real time information and unique identification of individual objects. Because manufacturing systems are in constant flux, data accuracy is not just a function of having the correct value, but of having the correct value at the correct time to reflect the proper state of the system. Accurate data that is old is of no use in a dynamic system.

Thinking beyond the utilization of real-time data, Auto-ID offers other opportunities to capture detailed data about objects within a supply chain on a scale never before experienced in commerce. However, organizing EPCs represents a challenge requiring significant changes to ERP systems.

Organizing Data from the EPC

Though it is early in the development of Auto-ID technology, it appears ERP will hold an important role in managing the EPC data needed for supply chain wide visibility. The EPC, a fundamental tenet of Auto-ID Technology, provides the capability for unique identification of trillions of objects. Unique identification on this scale results in useful information for track and trace (Koh et al. 2003a; Schuster and Koh 2004), and the authentication of objects located anywhere in a supply chain (Koh et al. 2003b). However, managing serial numbers for trillions of objects presents a difficult challenge for current ERP systems to handle. As a result, there will be a measured transition from lot control, currently available in some ERP systems, to serial number control enabled by new software concepts such as the Transactional Bill of Material (T-BOM^{TM}).[a]

With the T-BOM approach, serial numbers contained in the EPC are organized to provide the history of movement for an item (pedigree information), a schematic of the serial numbers for all components contained in the finished item, and a mechanism to allow a query for authentication by any party within a particular supply chain (Bostwick 2004). This is accomplished through sophisticated database technology that utilizes EPC information gathered from the middleware interface to Auto-ID.

The T-BOM represents a new generation of software intended to enhance system integration as Auto-ID technology begins to take hold in industry. Since current ERP systems use only lot control for tracking and tracing, it is important to add capabilities that handle EPC data so that that it can be queried and communicated as needed. Without these types of new structures to enhance ERP, there will be much less effectiveness in using data from Auto-ID technology.

Besides tracking, tracing, and authentication, serial data on components opens new possibilities to gain insight into complex operations. There are many situations where lack of detailed information leads to ineffective supply chain management. For example, difficulties with management of versions is a common problem in the capital asset industries where service parts for long life cycle items such as aircraft frequently undergo modification and redesign midway through the life of the asset (Engels et al. 2004). With most part numbering systems, different versions of a service part cannot be identified, inventoried, traced or tracked. In situations where there are large networks that do maintenance of deployed assets, such as airbases in support of combat aircraft,

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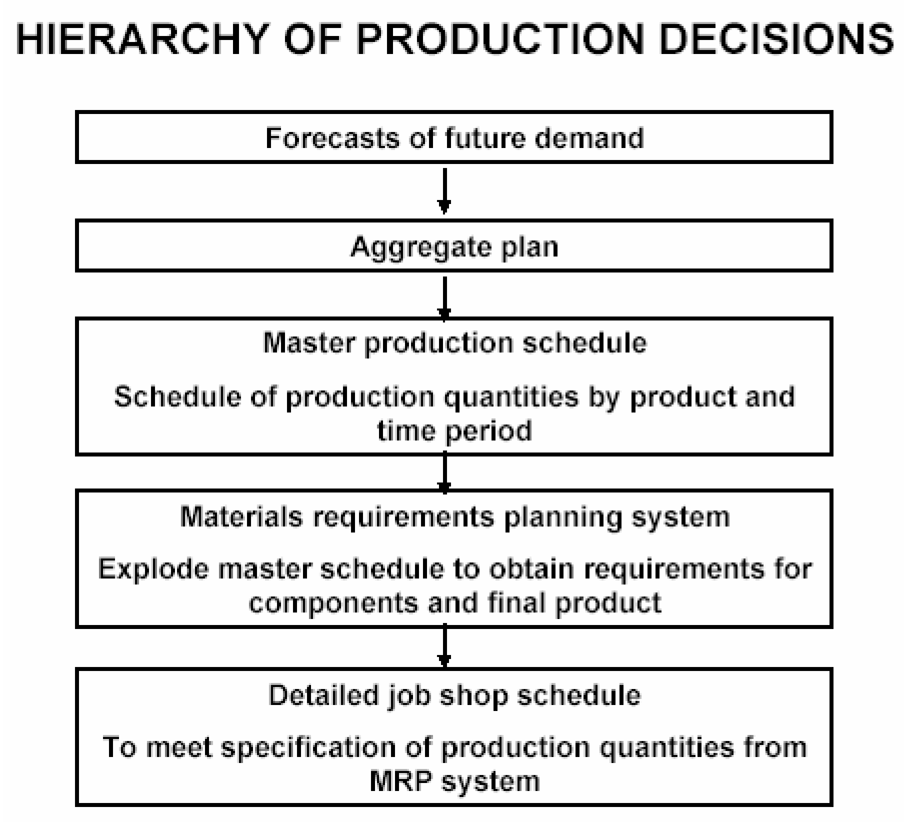
[a] General research information about T-BOM can be found at www.ed-w.info/tbom.htm

knowing the exact version of a service part in inventory is essential to providing high levels of service and readiness. In addition, the ability to track failure rates by serial number (version) is also critical to understanding overall reliability as service parts move from manufacture, to distribution and finally to installation and use (Kar et al. 2003).

There is no question that Auto-ID has great potential to provide detailed data about objects within a supply chain. The data capabilities of the technology also allow other possibilities such as a change in the algorithmic structure of ERP. The next section explores just a few of these possibilities.

CAPACITATED PLANNING AND AUTOMATED SCHEDULING

One of the most basic processes of ERP is planning and scheduling. The following diagram provides a conceptual overview of the various planning and scheduling functions common to all ERP systems.



Adapted from Nahmias (1993)

Two aspects of Auto-ID technology have the potential to change the way that practitioners use ERP for planning and scheduling.

First, the ability to have manufacturing plant and supply chain wide visibility of objects identified with the EPC allows for large amounts of information and executable instructions to be assigned to an object. An example that has been in application for several years involves attaching an electronic tag to a component that is work in process (WIP). As the component moves through different manufacturing stages, the tagged item is scanned and instructions are downloaded from databases into computer numeric control (CNC) milling machines that automatically cut the component to exact specifications. As the component moves to the next stage of manufacturing, another scan takes place and a new set of instructions are loaded into processing machines. It is even feasible that a queue of tagged parts for an individual work center could be scanned simultaneously to identify important information for adjusting work center priorities. In this manner, detailed day-to-day shop scheduling and management of instructions become automated processes.

With this level of control, there are almost unlimited opportunities to improve information handling and automation within manufacturing plants. The opportunity also exists to increase the level of automation across entire supply chains so that a component manufactured at one plant can be transferred to another with the knowledge that all relevant information and manufacturing instructions are attached to the component and can be processed automatically. The open standards and protocols are an important feature of Auto-ID technology that allow for this type of information transfer and communication within the supply chain.

The second important aspect of Auto-ID technology that will change the way planning and scheduling is performed within ERP involves the continuous flow of data. A well designed Auto-ID system is always "on." With this improved sensing capability, critical subsystems of ERP will have accessibility to more data for scheduling calculations. Given real-time data, new possibilities exist to apply advanced algorithms such as math programming and heuristics in every practical aspect of planning and scheduling.

One of the most important goals of manufacturing is the management of capacity utilization. Several ERP subsystems are crucial in achieving this short and medium term goal. The master production schedule, the MRP system, and the detailed shop schedule all visualized in Figure 2 are the current tools within ERP to manage capacity. For many years, all of these systems assumed infinite capacity when doing planning and scheduling.

This assumption, though widely recognized as an important weakness, reflected the reality that in many cases data did not exist to support advanced finite planning and scheduling. Planners have spent untold hours manually balancing production to meet available capacity. When the problem could not be solved manually, due dates were not met and customer service suffered.

Beginning in the mid 1980's, the advent of microcomputers resulted in the introduction of master scheduling software that accomplished capacitated planning and scheduling for end items. These software packages existed outside of ERP systems and required significant integration to achieve operability. During this time computer spreadsheets began to be used as a powerful means to build models and do finite capacity scheduling for end items (Schuster and Finch 1990; Allen and Schuster 1994; Allen et al. 1997; D'Itri et. al. 1999).

However, achieving capacitated planning and scheduling for a single level, finished good, is far easier than achieving the same task for dependent demand (MRP). In this case, the consideration of capacity constraints and cost optimization must take place through multiple levels for the BOM. Manufacturing multiple complex end items at a single facility adds to this complexity.

MRP has been singled out by managers and academics alike for the lack of consideration of capacity constraints when planning lots sizes. As Billington, et al.

(1983) write, “MRP systems in their basic form assume that there are no capacity constraints. That is, they perform ‘infinite loading’ in that any amount of production is presumed possible…”

For some types of industries, like heavy manufacturing, this limitation is an annoying inconvenience. With finished items requiring high labor inputs, the primary capacity constraint is often availability of skilled workers to do the job. If high production levels press the capacity of available trained labor, more workers can be hired or existing workers can be retrained. In other situations, such as the process industries, lack of capacitated planning and scheduling is a much more serious matter.

The process industries are asset intensive with huge investments in long lead-time equipment. In this case, adding additional capacity is not a short-term managerial prerogative so it becomes imperative to get the greatest amount of capacity utilization possible through scheduling methods that find the optimal solution and consider dynamic capacity constraints. The lack of capacitated MRP is such a serious issue that some leading companies have declined to use MRP for planning and scheduling (Taylor and Bolander 1994).

While the algorithms to do aspects of capacitated MRP (CMRP) are available, the drawback to implementation is partially dependent on lack of real-time data needed for a meaningful solution. To deal with dynamic demand for end items, manufacturers must account for capacity constraints at all levels of the supply chain. This ambitious goal remains elusive for most firms.

Auto-ID technology overcomes one barrier to the implementation of advanced algorithms for capacitated MRP by providing a continuous stream of data for mathematical programming models to achieve CMRP in practice. Although there are a number of complicating factors that limit the widespread use of advanced models, a major drawback appears to be schedule stability (Unahabhokha 2003). Because of a lack of continuous data, replanning often occurs less frequently than needed. In addition, small changes inventory and production values caused by inaccurate counts or poor execution to plan (for production and the sales forecast) also contribute to the schedule stability problem. The combination of these two factors can create large changes in out-front schedules and a great amount of instability within CMRP.

Having a continuous stream of data allows quick adjustment to variances and frequent updates. If the proper buffers exist, a stable schedule results with only minor changes occurring over the time horizon with each new planning run.

There are several documented examples of the application of CMRP in industry (Schuster and Allen 1998; Schuster et al. 2000). Most notable is the work of Leachman et al. (1996). This article provides a comprehensive report on the successful application of CMRP for a semiconductor company. The approach uses large-scale linear programming (LP) to accomplish CMRP with the goal of improving on-time delivery. The authors note that before implementing the LP approach, sector-wide planning took place only once per month because of the poor quality and availability of data on demand, work in process and inventory. Essentially, planners always had incomplete information.

A large part of the project included design of databases to feed the LP planning model and the development of standard ways to represent data. In the end, the authors state that data accuracy, availability and timeliness were significant factors in the overall success of their efforts to implement CMRP as a management tool.

These are just a few examples of how Auto-ID technology will change the nature of ERP systems in practice. However, the concepts of Auto-ID do not just apply to supply chains. The final section of this chapter explores the application of Auto-ID concepts beyond the Internet of things. In many ways, this is Auto-ID Part II. This effort will have a long-term impact on ERP system design.

SEMANTIC MODELING

The underlying aspects of Auto-ID technology will form the bedrock for international commerce in the years to come. Unique identification, interoperability, standards, and automated Internet based systems to track, trace, and control physical objects all are important elements of Auto-ID technology that are moving out of the laboratory and into practical application. There will be new applications that can only be dreamed about today, and other applications that are beyond what currently can be conceptualized.

Though there is a long road to full implementation of Auto-ID technology in business, the merging of data with physical objects opens so many new opportunities that it is important for all firms that use or create ERP systems to plan for future operations by learning as much as possible about the technology. One of the most frequent questions managers have about the future of Auto-ID involves improved ways to analyze the data generated by the technology. As a result, there is a renewed research effort to examine ways to make sense out of data gathered using Auto-ID technology.

The new initiative, termed Semantic Modeling, examines how various types of mathematical models can be applied quickly to the volumes of data produced by Auto-ID (Brock 2003a; Brock 2003b, Brock et al. 2004). Using the principles of computer languages, protocols, standards, interoperability and unique identification refined during the development of Auto-ID technology, the research initiative focuses on new ways to connect mathematical models with data. This will substantially increase the Clockspeed (Fine 1998) of modeling, and the computational efficiency of applying models to perform the functions of "sense," "understand," and "do," that comprise the underpinning of creating smart objects within supply chains.

In many ways, this effort is a step beyond linking the physical world, the underlying concept that has made Auto-ID technology successful. Networks, of physical objects or abstractions like models, share the premise that leaps in productivity arise from the free flow of information. Creating an *Intelligent Modeling Network* will accelerate the flow of information to the great advantage of many practitioners who apply Auto-ID technology.

Semantic Modeling also has important implications for ERP systems. One of the significant achievements of ERP is the delivery of software to firms in a standard package that includes numerous modules. A firm has the freedom to choose which modules to implement, although once in place, the firm has no flexibility in making rapid switches. For all the economic efficiency of standardized packaged software, there also exists a rigidity that often means the business processes of the firm do not match precisely with the requirements of individual software modules. This results in the need for substantial adaptation of business processes to fit the capabilities of the software, which are sometimes limited. Many managers are unwilling to make adaptations to business processes that have withstood the test of time. In some cases, firms initially implemented select ERP modules only to remove them latter because of a mismatch with business processes. This has been known to occur in many firms.

Semantic Modeling may offer a powerful alternative to traditional packaged software employed by ERP vendors. In essence, the approach provides a means of establishing a repository of model elements located on the Internet that can be searched, recombined, and employed as needed. The primary search criteria are precise semantic definitions that describe data inputs for a particular model. In this way, a model can be matched exactly to a stream of data within a firm. As well, the outputs of one model can become the inputs of another model.

For example, there are hundreds of models that deal with all types of master production scheduling problems. Many of these models are long forgotten or have never been applied to more than one scheduling problem in practice. Using Semantic Modeling, it is possible to build an Internet-based repository of master scheduling models that are interoperable and easily applied to the available data within firms. This would facilitate the rapid interchange of models allowing for a better chance of finding an exact match to business processes.

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