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ORIGINAL ARTICLE

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An RFID-based remote monitoring system for enterprise internal production management

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Abstract The disconnected flow of inventory and information will lead to a lack of real-time information and a build-up of excess inventory to buffer uncertainties in supply and demand. In this paper, a radio frequency identification (RFID) based remote monitoring system over the Internet is proposed to provide a transparent and visible information flow for supply chain and enterprise internal resource management. RFID technology has been a hot technology to replace barcodes in supply chain management in recent years. Actually, it has been successfully applied by the US Army in military logistics in 1991. Recently, the superman of the supermarket, Wal-Mart, mandates that its top 100 suppliers must equip RFID tags on their supplied items. However, RFID technology is still not a standard form acceptable for global use. The first big problem is to select a global universal radio frequency (RF) for active and passive RFID systems, but because of the advantages of RFID technology, it is unassailable that it will be popularly used in various fields very soon, such as supply chain management, enterprise resources planning (ERP), sales management, and so on. In this paper, the RFID-based monitoring system for enterprise internal production management is introduced. The RFID technology, Bluetooth, and Internet technology are employed to form a remote system for the monitoring of the production status of a factory. Based on this system, the management department can transparently master and control the status of the production line and supply chain, including raw materials and outsourcing supply/consumption status, production status of parts and components, production status of the finished products, etc. This system will be of benefit to greatly improve the productivity and reduce the cost for the enterprise.

Keywords Production management · RFID · Remote monitoring · Internet

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1 Introduction

Nowadays, companies have consistently tried to enhance their business efficiency and effectiveness by reassessing their internal business operations, such as purchasing, warehousing, materials management and distribution, and optimizing external supply chain management. The internal business operation processes commit huge time and financial resources and, therefore, companies are continually striving to make them more effective in order to improve their financial standing and market positions. This has involved manufacturers using techniques such as manufacturing resource planning (MRPII), just-in-time (JIT), and enterprise resource planning (ERP) [1]. ERP is an enterprise-wide computer management system. It is described as a commercial software package that promises the seamless integration of all of the information flowing through the company—financial, human resources, supply chain, and customer information [2]. It represents the application of the latest information technology (IT) to the manufacturing resources planning (MRP/MRPII) system [3].

For supply chain optimization, a supply chain is defined as a network of facilities and distribution options that performs the functions of materials procurement, transformation of these materials into intermediate and finished products, and product distribution to customers [4]. Every industry can be described by the combination of one or more supply chains. Despite their vital role in industry, supply chains have traditionally been fragmented, resulting

in slow and sequential material flow downstream and similar movement of data back upstream. In the past decade, considerable efforts on supply chain management have been expended in developing decision models for supply chain problems. These have been supported by the integration of these models into decision support systems. These models have adopted conventional techniques, including mathematical programming, simulation, heuristics, and statistical and probability tools [5].

However, whatever the reassessing of internal business operations or optimization of supply chain management, it severely depends on exact and real-time information flow. The system must know when, where, and what to give a reference for enterprise decision-making. If the information flow is not transparent and visible, the disconnected flow of inventory and information will lead to a lack of real-time information and a build-up of excess inventory to buffer uncertainties in supply and demand. Increased inventory carrying costs, longer order lead times, and difficulty in responding proactively to real-time changes have decreased profits and weakened customer goodwill. So, an accurate, exact, visible, real-time, and transparent information flow is vital to management, from enterprise internal business operation and production tracking, to local and global supply chain management. The accuracy of decision-making is totally dependent on exact and real-time information of the enterprise and the whole supply chain.

Radio frequency identification (RFID) technology as a contactless identification technique provides an effective measurement for items (raw materials, parts, components, products, etc) tracking [6]. It is helpful to realize visible and transparent information flow. When the tagged item goes through the gate, the configured RFID scanner can read the information on the tag of the item, consequently, identifying the tracking item. Configuring enough RFID scanners in the whole supply chain, combing robust remote data communication network, and information management system, a complete visible and transparent product and information flow will be shown on the monitors. Every nodes in the supply chain network can effectively make use of this visible and transparent information flow to achieve optimal business, reduce cost, save resources and labor, and improve efficiency greatly. When RFID is combined with a global positioning system (GPS) module equipped on items (e.g., vehicle, container, trailer, etc.), the monitoring center can even completely master the item's real-time information, including when, where, and what.

Currently, however, not everybody in a supply chain wants to share its private information selflessly, so it is very difficult to seamlessly integrate the whole supply chain nodes, including the warehousing management system, transportation management system, sales management system, enterprise production management system, etc. In this paper, we will only focus on enterprise internal production management to achieve a transparent and visible information flow. The hot technology, RFID, is employed to contactlessly track items over a short distance. Bluetooth is used to build a wireless data communication network in the middle range. Internet technology is employed to construct a boundless communication network for the system within the enterprise and as the interface to external systems. Combing RFID, Bluetooth, and the Internet, the system will be developed to provide a visible material flow, product flow, and information flow to enterprise management. The management department can base these transparent flows to make optimal production and marketing decisions, consequently, improving management efficiency and reducing manufacturing cost greatly.

2 RFID and the Internet

RFID is hotting up in recent years as a potent technology for the identification and tracking of assets. Basically, for asset tracking and identification, there are three general methods: paper and pencil or similar manual record-keeping techniques; bar code techniques using printed paper or plastic labels with laser readers and computers for record keeping; and RFID techniques featuring radio transponders and interrogators for reading and computers for record keeping. Manual methods are labor-intensive operations, which were the first methods to be used and are still in use today. With its superior accuracy and ease of use compared to manual methods, bar codes soon became the dominant method for asset identification, and is still in use today. As the use of bar codes grew, a significant characteristic began to limit the applications: the label is read using a light beam. The bar code was, thus, limited to clean environments with a direct line of sight from the reader, and the reader had to be close to the label. The development of radio frequency (RF) techniques promised to overcome these limitations, and with the introduction of the RFID products developed by Savi Technology, this promise became reality.

Generally, an RFID system is always made up of two components: the transponder, which is located on the object to be identified, and the detector or reader, which, depending upon the design and the technology used, may be a read or write/read device. A reader typically contains a high-frequency module (transmitter and receiver), a control unit, and a coupling element to the transponder. In addition, many readers are fitted with an additional interface (RS-232, RS-485,...) to enable it to forward the data received to another system (PC, robot control system,...). The transponder, which represents the actual data-carrying device of an RFID system, normally consists of a coupling element and an electronic microchip. When the transponder, which does not usually possess its own voltage supply (battery), is not within the response range of a reader, it is totally passive. The transponder is only activated when it is within the response range of a reader. The power required to activate the transponder is supplied to the transponder through the coupling unit (contactless), as is the timing pulse and the data.

RFID systems carry data in suitable transponders, generally known as tags, and retrieve data, by machine-readable means, at a suitable time and place to satisfy

particular application needs. Tags have a discrete memory capacity that varies from a small license plate to thousands of records. The data within a tag may provide any level of identification for an item during manufacture, in transit, in storage, or in use. With additional data, the tag may support applications that need item-specific information. For example, shipment consignee or destination ports can be readily accessed upon reading the tag. In addition to tags, an RFID system requires a means for reading or "interrogating" the tags to obtain the stored data, and then some means of communicating this tag data to a logistics information system.

Actually, early experience with RFID began when the US Army installed active, data-rich RFID technology at selected sites around the world to track containers through the logistics pipeline and to provide stand-off visibility of container contents. Fixed interrogators installed at key nodes read RFID tags attached to pallets or containers, and provided data to a regional server prior to passing the data to the global asset visibility systems. During the latest operation in Iraq, the use of active, data-rich RFID tags was mandated for all material entering the theater.

The use of RFID in the Department of Defense of the USA (DoD) supply chain has the potential to provide real benefits in inventory management, asset visibility, and interoperability in an end-to-end integrated environment. RFID encapsulates the data accuracy advantages inherent in all types of automatic identification technology (AIT). Additionally, RFID is a totally nonintrusive methodology for data capture (requires no human intervention), is a non-line-of-sight technology, and is a technology that may possess both read and write options within the same equipment item.

To take maximum advantage of the inherent life-cycle asset management efficiencies that can be realized with RFID, the Under Secretary of Defense for Acquisition, Technology, and Logistics issued a policy: (1) directing the use of high-data-capacity RFID used in the DoD operational environment and (2) requiring that suppliers put passive RFID tags on the lowest possible piece part/case/pallet packaging by January 2005. In this regard, the DoD is leveraging electronic product code (EPC) and compatible RFID tags. The Assistant Deputy Under Secretary of Defense, Supply Chain Integration, has taken the lead to facilitate the implementation of the RFID policy [7] .

For application of RFID, Wal-Mart is another powerful propellent. Over a decade ago, Wal-Mart required its suppliers to track inventories with bar codes, which revolutionized supply chain management practices. At the time, the goal of Wal-Mart's program was to track the flow of products from dock to stock automatically. With the company's recent announcement mandating the use of RFID by 2005, Wal-Mart is about to make history again.

Concurrently, efforts were underway to make it possible for computers to identify any object anywhere in the world instantly by utilizing passive RFID technology. The key was to create a universal, open standard for identifying products and sharing information. Part of that work was to develop the EPC, a unique number that identifies a specific item in the supply chain. EPCglobal Inc. is a joint venture between EAN International and the Uniform Code Council (UCC) Inc. It was formed on November 1 2003, and will administer the electronic product codes and develop EPC standards for RFID technology going forwards [8].

The new EPC specification will include an elaborate, multi-tiered architecture with elements covering data management, Web-based data addressing, and product data structures. It starts with Savant, a set of middleware standards specifying protocols for managing distributed networks that capture and filter EPCs picked up by RF scanners. Next, the object naming service (ONS) provides standards for specifying the Internet addresses where product attributes and related information are maintained, while the physical markup language (PML) will include an XML-based set of standards for structuring product data. On the horizon, additional standards will cover communications protocols for RF tags and readers. Another specification for RFID, Ubiquitous ID, is also taking active action to bring about the standardization of RFID and push its applications around the world, particularly in Japan [9].

Currently, a lot of supermen in the hardware and software field are involved in supplying devices and solutions for RFID applications, such as Alien Technology, Matrics, Intermec, Philips Semiconductor, Texas Instruments RFID, Accenture, Cap Gemini Ernst and Young, IBM Global Services, Microsoft, SUN, Oracle, and so on. A lot of vendors are introducing RFID tracking applications to appeal to Wal-Mart's suppliers. And large consulting and integration companies alike are partnering to offer big suppliers the hardware and software they need. Sun Technology Inc. is already applying RFID technology to its internal manufacturing and supply chain operations.

RFID is an effectual contactless automatic article identification and information acquisition measurement over a short distance. On the other hand, the Internet as a boundless data communication and media interaction network has drastically changed our way of doing business. Using the World Wide Web, any valuable business information can be easily accessed anywhere and at any time. The Internet has also changed the status of the market place. Product information can be exchanged instantly, and market competition is becoming global in scope [10]. The use of the Internet in the upstream supply chain, between suppliers and manufacturers, is impacting greatly on purchasing, as well as on the coordination, communication, and movement of goods and information from suppliers. It is a very effective medium, which is improving information flows. For example, General Electric uses the Internet to schedule shipments out of centrally located warehouses to allow the company to realize savings of time and money.

The Internet has enabled information exchange on an unprecedented scale. However, many companies are not equipped to make effective use of data from warehouse management systems—which contain information on supplier/customer warehouse inventory levels and key customer ordering patterns—and transportation management systems—within which, information pertaining to the location of important supply chain assets, such as products

or vehicles is typically stored. Yet, these systems are key factors in integrating the physical flow of goods along the supply chain [11].

In this paper, RFID, the Internet, and Bluetooth will be jointly employed to build the system for enterprise internal production management, integrating the transportation management system, warehouse management system, sales management system, and the production management system. This will lead to enterprise inventory visibility, which, in turn, leads to reduced costs and improved customer service by decreasing shipping and receiving cycle times, increasing shipment and inventory accuracy, and decreasing lead-time variability.

3 System structure

The RFID-based remote monitoring system for enterprise internal production management is shown as in Fig. 1. The system is built over the Internet for information interaction and data transmission among different local monitoring terminals within the factory. The items' automatic identification is achieved with RFID technology. In the workshop, Bluetooth technology is employed for wireless data transmission. The operation of the system is described as follows in this section.

The internal supply chain starts at the point of the warehouse of raw materials and outsourcings. When the raw materials and outsourcings have been delivered to the warehouse, the items offloaded from the trailer, container, tray, etc. will be attached with a passive RFID tag. Here, the item may be a part, component, steel roll (raw material), a package of bolts (small products), or even a container. In this paper, we do not make a distinction between product tag, package tag, item tag, and so on. We just call all them "item tags" for generality. What elements should be tagged with an RFID tag is dependent on the enterprise situation and application purpose. Before the item is stored in the warehouse, it will be equipped with a passive RFID tag. In this tag, the basic information related to the tagged item is stored in the memory of the tag, such as the item ID, item name, etc. When the tagged item goes through the entrance of the warehouse, the RFID reader in the gate will read the information stored in tags and transfer the message to a local monitoring terminal and central monitoring terminal. When the items are moved out from the warehouse, the reader on the exit door frame will

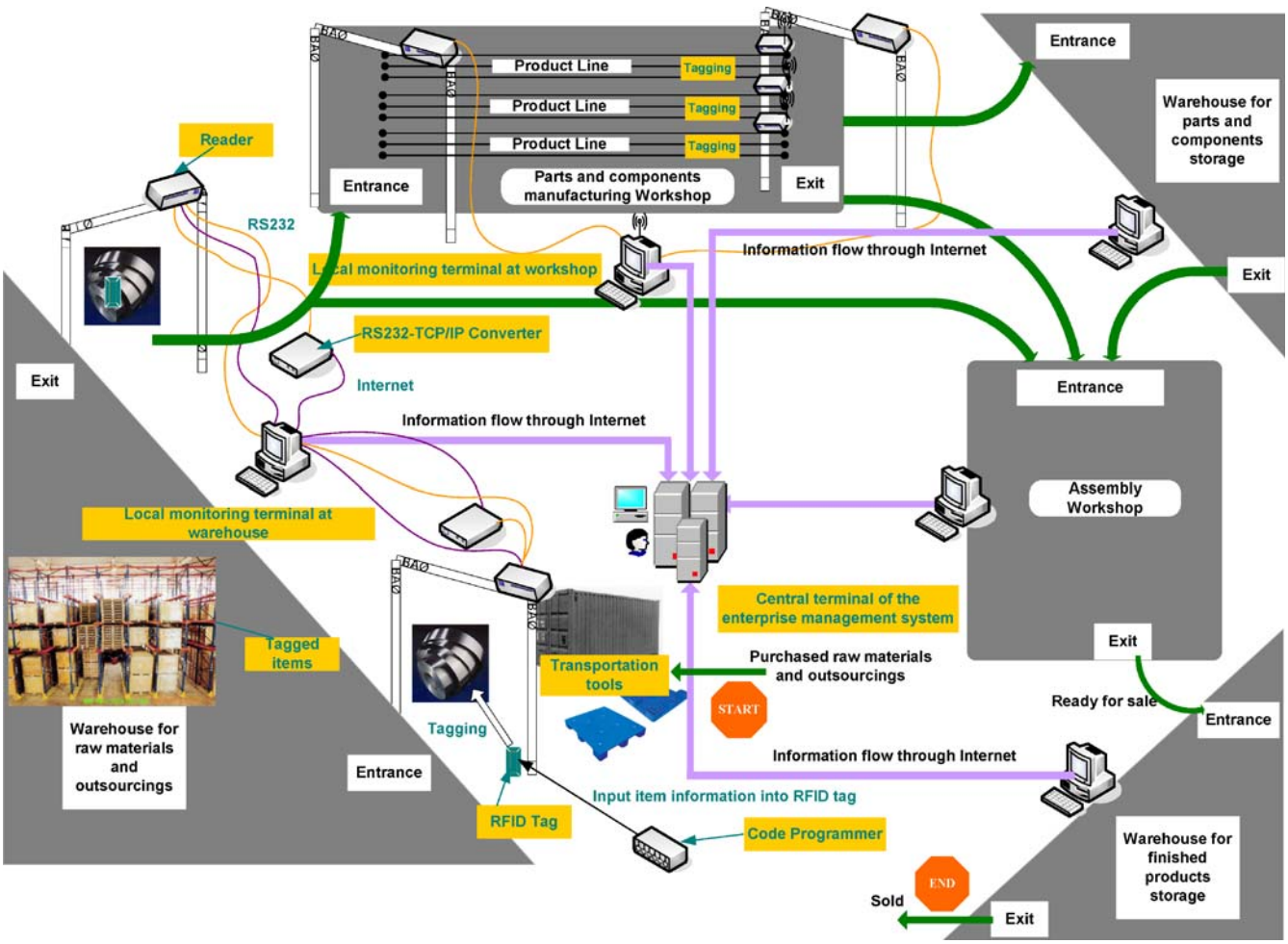

Fig. 1 A remote monitoring system for enterprise internal production management

acquire the tag information and transfer the message to the local and central monitoring terminals too. So, the status of raw materials and outsourcings is transparent to the management department of the enterprise. It provides timely and visible inventory in the warehouse, consequently, benefitting the task of making an optimal raw materials and outsourcings purchase plan.

Similarly, at the entrance and exit of the manufacturing workshop, RFID readers are also installed to read the in and out items. On the end of every production line, an additional working procedure will be added to attach the passive RFID tag on produced parts or components. The code programmer is employed to input basic information of products into tags to identify ready parts and components. The reader on the end of every production line will read the tagged products and send messages to the monitoring terminals. In the workshop, Bluetooth technology is used to transfer messages from the reader at the end of production line to a local monitoring terminal, since it is often difficult to renovate current enterprises to an Internet-connected network layout in workshops. The production line reader and the reader on the exit of the workshop can help the management of an enterprise to master the production status of all workshops and product lines.

The RFID systems in the warehouse of parts and components and the assembly workshop have similar functions. In the assembly workshop, all imported items and the finished products (e.g., an engine, a machine, a container, etc.) are transparent to the management of the enterprise through RFID systems at the entrance and exit of the workshop. The ready products will be also attached with an RFID tag. When the tagging has finished, the product is moved out from the exit of the warehouse and to the storage for completed products. Basically, it means that the product is sold out and that the internal production management system is over at this point. The following actions will refer to the whole supply chain management. It is out of the scope of discussion of this paper.

As stated above, based on the RFID-based monitoring system, the material flow, information flow, and product flow are totally transparent to the management department of the enterprise. The management can efficiently master the enterprise production status and make optimal action plans for raw materials purchase, production progress, sales order processing, and even financial flow management. The great benefit of the system is that it has achieved completed transparency of the enterprise to the management, including material flow, production flow, information flow, and even financial flow. Based on this system, the productivity can be improved and the cost of manufacturing a product can be reduced greatly.

4 Some details

In this section, we will discuss some issues related to the construction of the system. As stated in the previous section, the RFID-based monitoring system for enterprise internal production management is composed of three key components: RFID-based data acquisition device, data communication network, and the information management and data processing platform (shown as in Fig. 2). The RFID data acquisition device is used to read the item's tag and acquire the information from it. The data communication network then transfers the acquired data of the RFID tag from the RFID Reader to the local monitoring terminal, which the transfers the data from the local monitoring terminal to the remote central monitoring terminal. The information management and data processing platform then processes the received data on the local and central monitoring terminals. Three communication technologies have been employed in this system to build a robust data communication network: RFID, Bluetooth, and TCP/IP. Basically, the RFID reader can just reach a passive RFID tag at a distance of 5–10 m at a frequency of 915 MHz. So, RFID technology is employed just for short distance item identification. Most of the RFID commercial readers provide RS-232 ports to connect to computers (local monitoring terminal). But RS-232 is only good for about 10-m wireless data transmission. If the reader is far away from the local monitoring terminal, an RS-232–TCP/IP converter should be provided to convert the RS-232 protocol data to TCP/IP protocol data, and then the data can be sent to the local computer through the Internet unboundedly.

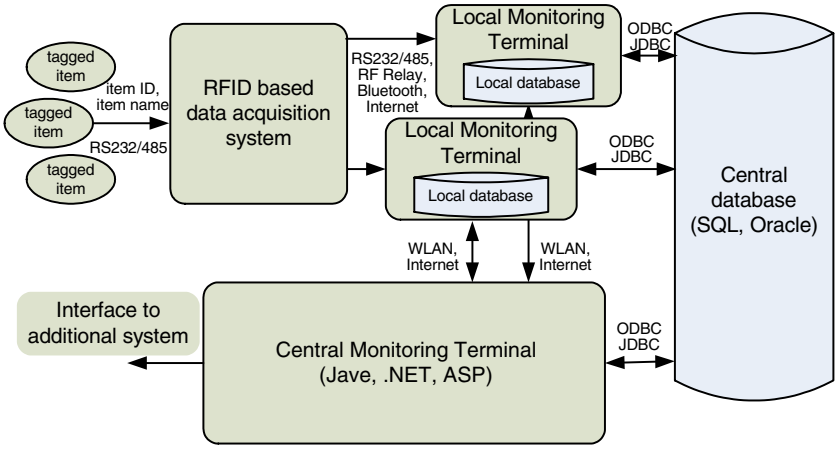

Fig. 2 Information flow over the remote monitoring system

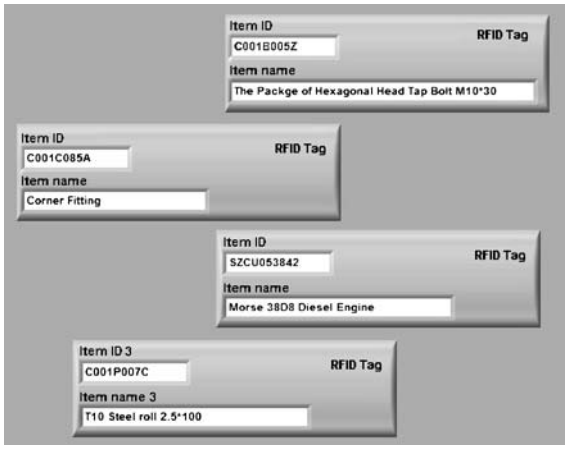

Fig. 3 User-customized information of the item within the tags

In the workshop, it is difficult, sometimes, to renovate the plant layout to build an infrastructure of Internet-connectivity for every product line. Since Bluetooth can transmit data over 1–2 Km, in this situation, a Bluetooth sending module will be additional to the RFID reader for wirelessly transferring data to the Bluetooth receiving module, and then the data will be saved on the local monitoring terminal via the Bluetooth interface or the TCP/IP interface. The communication between the local monitoring terminal and the central monitoring terminal will be built over the Internet. The information management and data processing platform will be running on the Web. The management on the local and central monitoring terminals can easily log into the platform to find out the current status of warehouses, workshops, and product lines, and master the production and sales status of the whole enterprise.

For supply chain and production management, a passive RFID tag is more appropriate than an active tag because the active tag is a time bomb, since it is very difficult to exactly know the remaining life of the battery. If the battery runs out, the items cannot be read when they go through the gate. In addition, it is very time and labor-consuming if it is required to check the capacity of the battery regularly and periodically. The disadvantage of passive tags is their short reading distance and small data capacity.

For the distribution of information storage, in this paper, only the item ID and item name as the user-customized information is stored in the memory of the tag (as shown in Fig. 3). All other information related to the items is stored in the background database of the system. The reasons for this distribution are: (1) the code programmer is operated by a worker or technician at the warehouse, production line, or workshop, the operation should be easy and brief; (2) the tag is a passive tag, its capacity limits information storage in its memory, some passive tags have only 64 bits, 96 bits, or 128 bits, only very limited bits are reserved for the user; (3) to improve the scanning speed of the RFID reader for a tag and efficiency of the system, the information acquired through the RFID device should be brief and simple, so, in this project, all data except the item ID and item name will be stored and run on the background database, the item ID and item name will be mapped with the additional information of the item through the product database over the Internet.

5 Background management system

RFID and the Internet play integrated roles for information acquisition and data transmission. The core of the system is on the background management expert system, including data processing and decision-making. Basically, if the system is only acting for information flow monitoring purposes, the background data processing system is relatively simple. But if the system acts as more than just a monitor, it must also provide functions of decision-making based on the acquired information to management for rapidly responding marketing. The background management system then is complicated and must be developed based on the application case. Different fields, applications, and enterprises have totally different decision models. An accurate and exact decision model is the base of a

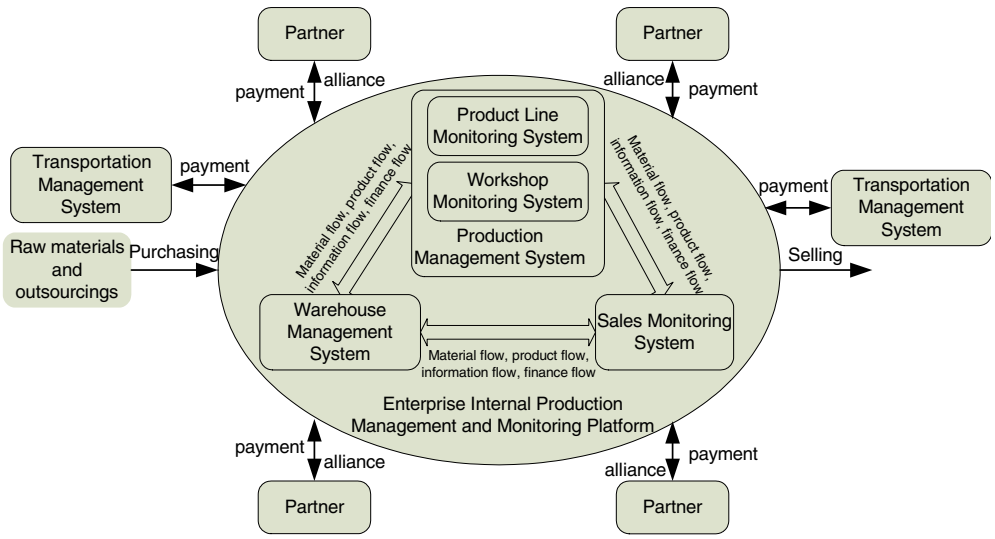

Fig. 4 Supply chain framework focusing on enterprise internal production monitoring

background management system. In this paper, we will only focus on achieving visible and transparent information flow for enterprise internal production management.

An integration framework of production management and monitoring platform is shown as in Fig. 4. It involves the warehouse management system, production line monitoring system, workshop management system, and the sales monitoring system. The external interaction includes the interface to the transportation management system, the partner collaborating management system. Every subsystem is a local monitoring terminal, as depicted in Fig. 2. The enterprise internal production management and monitoring platform is the central monitoring terminal to be in charge of monitoring the production status within the enterprise. A GUI (graphical user interface) of the local and central monitoring systems is shown in Figs. 5 and 6, respectively. Since the whole system is running over the Internet, a network-enabled database (SQL) is employed in this paper. The GUI is developed using VC++ and Java. The connection between the monitoring platform and the background database is achieved through open database connectivity (ODBC) and Java database connectivity (JDBC). Active server pages (ASP) technology is employed to develop XML and HTML-based Web GUIs. The Web GUI will interact with the background database through ASP controls. Rule-based reasoning, case-based reasoning, and artificial neural networks are used for data processing and decision-making. From Fig. 5, the monitor can clearly see the status of materials in the warehouse, including which item is full, supplement required, urgent to supplement, or empty. From Fig. 6, the monitor at the headquarters can master the whole production status of the enterprise. The enterprise material flow, production flow, and information flow is totally transparently displayed. Combining with additional systems, the management department can send instructions to subterminals and make decisions for consequent actions.

6 Conclusions

The disconnected flow of inventory and information will lead to a lack of real-time information and a build-up of excess inventory to buffer uncertainties in supply and demand. An accurate, exact, visible, real-time, and transparent information flow is vital to management, from enterprise internal business operations and production tracking, to local and global supply chain management.

In this paper, a radio frequency identification (RFID) based remote monitoring system over the Internet is proposed to provide a transparent and visible information flow for supply chain management and enterprise internal resource production management. The system structure is introduced and some details are discussed. A demonstration of the background management system is developed finally.

Employing RFID, Bluetooth, and Internet technologies, the developed system provides a complete transparent and visible information flow to the management. The monitoring terminal can clearly know the status of materials in the warehouse, production line, and workshop, including what items are full, supplement required, urgent to supplement, or empty. The monitoring center can master the whole production status of the enterprise, including material flow, production flow, and information flow. The management department can base these transparent flows to make optimal production and marketing decisions, consequently, improving the management efficiency and reducing manufacturing costs greatly.

The developed system will lead to enterprise inventory visibility, which, in turn, leads to reduced costs, improved customer service, increase of inventory accuracy, and decrease of lead-time variability.

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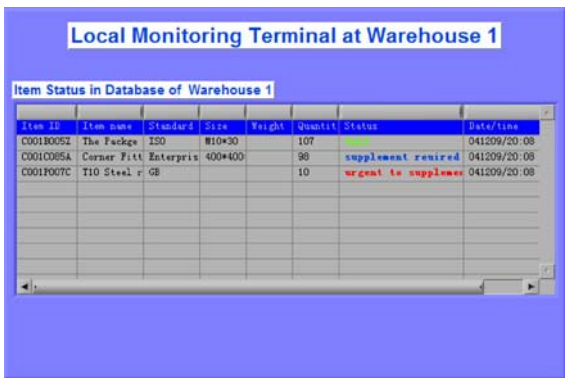

Fig. 5 Graphical user interface (GUI) of the local monitoring terminal

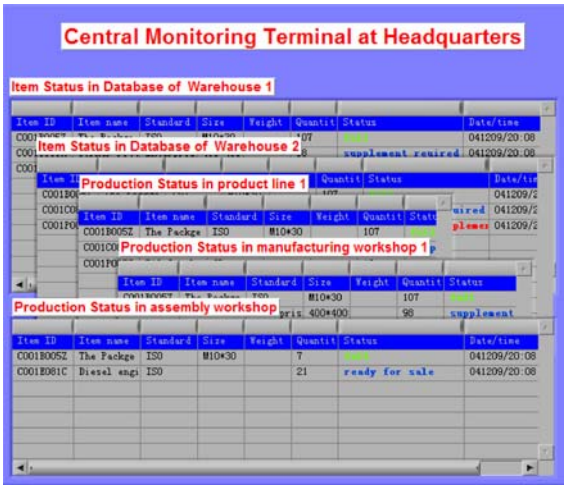

Fig. 6 GUI of the central monitoring terminal

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