The Paperless Factory: A Review of Issues and Technologies

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Summary
In this era of digital technology and network communications, paper-based data management can be a bottleneck, slowing factory-wide information transfer. This study explores the evolution of paperless communication in a factory environment and reviews some of the key technologies that contribute to the implementation of a paperless system including digital communication, the virtual factory, computer-integrated manufacturing, and web-centric information flow. The challenges facing users of a paperless information system are also discussed.

Key words:
Paperless factory, data security, computer integrated manufacturing Introduction

1. Introduction

In most situations the main objective of a firm is most likely not the elimination of paper. Their goal is to improve customer benefits through higher productivity. [1] described paperless operations as a by-product of the electronic (real-time) factory system. The operations were a response to customer needs the drive to improve quality and on-time deliveries, shrink manufacturing cycle time, and minimize waste. Over time a variety of technologies led to the development of an infrastructure that enabled the paperless factory. In support Louw and Yarberry [2] described the benefits of wireless communication systems in removing physical barriers inherent in paper-based systems. Yao [3] and Porter, et al. [4] further emphasized the effects of “wireless connectors” in manufacturing workstations to improve inventory control and the timeliness of real-time data. These changes enhanced the spectrum of activities of suppliers, sales and distribution personnel and customers to be performed with confidence and improved profitability. Earlier Debolt [5] emphasized a computer integrated manufacturing approach as a means for a paperless bi-directional data flow from shop floor to the business management systems. Li, et al. [6] described the application of some computer web-based technologies, such as Java and visualization techniques, to establish a seamless integration of product design with paperless concurrent engineering design. The advent of the internet combined with the world wide web [WWW] accelerated the demise of paper-based processes. Customers became accustomed to information at their fingertips while the market demands and expected their products to arrive quickly and with greater customization [7].

While numerous articles about paperless office systems have been published, few studies have been devoted to exploring true paperless information systems in a factory environment and related technologies. One article [8] describes how paperless production of machined parts has become a reality at the Westinghouse Electronic Systems Group. The systems designers can originate a concept, develop a three-dimensional solid model for the part, and electronically send the required information to the machine shop without generating a print. In our study, we review the evolution of paperless factories in integrating knowledge and information systems. We focus on the evolution of selected paperless technologies including digital communication, the virtual factory and web-centric information flow. We also examine the emerging trends drive the use of paperless information flow in factories, the development of integrated information systems, and the transition from paper-based to digital systems.

1.1 Trends from a paper-based to a paperless factory

Traditionally, data communication among various functional areas of a factory (Figure 1) has been through the exchange of blueprints, routing sheets, inventory lists, shop floor travelers and so forth. Often papers occupied too much space and cost too much to process. Doing business on paper slowed the pace of the enterprise to the speed at which paper traveled in the factory. To improve their systems, some companies required that their operations function without paper. They used workflow automation to define paths for electronic documents to travel automatically. They employed "smart" forms, which looked just like their paper analogs but could catch errors

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as data was entered and were able to route themselves to the right work stations [9].

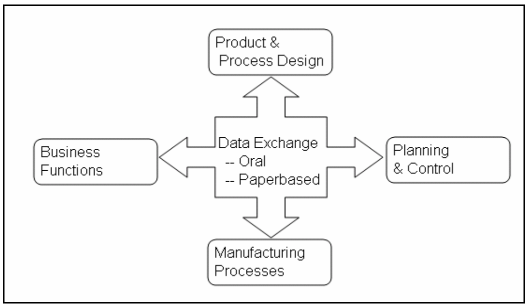

Figure 1. Data Communication in Traditional Paper-based Manufacturing Industry

1.2 The shop floor traveler

The creation, maintenance and tracking of paper documents on the shop floor can result in extensive work for manufacturing personnel. Following the release of a shop order, several hands are required to create the appropriate shop order documents, which may require photocopying of documents, drawings, instructions, lists, and so forth. Often routing sheets are placed in plastic sleeves and bundled in a thick file called a shop floor traveler. This file follows the job from station to station and becomes thicker as details of the work are recorded. Such a process is tenable but is fraught with potential control, accuracy and integrity problems. In this paper-based environment, manufacturing personnel must follow the status of the order, update the appropriate documents on the amount of time spent on the order, keep track of the quantities completed, and report the expected finish dates to a master scheduler. This is an inflexible system for releasing and tracking jobs on the shop floor in the sense that when a change is made, someone has to locate the paper packet, update it and verify that no product has gone out the door using old information.

1.2 Shop floor display terminal

To reduce the amount of paper circulation, many manufacturing firms replaced the shop floor travelers with display terminals. Each terminal was part of a local area network and displayed relevant information as work moved though the various stages of assembly. Systems contained text, diagrams, blueprints and photographs. The terminals allowed the operator to interactively respond and enter product/task data. These electronic records created a trail of accountability.

1.3 Hybrid paperless system

A transitional approach to a true paperless system is the hybrid paperless factory system, which includes a combination of digital communication, bulletin boards at each work center and traveler data packets (Figure 2). The bulletin boards typically display shop floor control data such as work-in-progress, quality control charts and other production data. The traveler packets accompany the parts and materials during inter-work center moves. Typically, a packet contains parts specifications, coding and routing information. While this hybrid paperless system has the potential to achieve a leaner operation in comparison to traditional paper trails, it cannot offer the full benefits of a true paperless system in a factory.

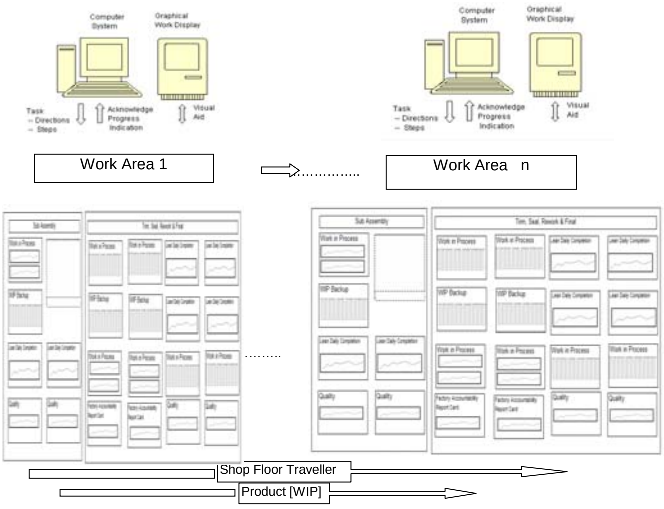

Figure 2. Configuration of a hybrid paperless system

2. Enabling technologies

In this section, the building blocks of enabling technologies for moving toward a true paperless information system in a factory environment are examined. These include manufacturing executive systems, RFID, electronic collaboration, and web-centric data exchange.

2.1 Manufacturing executive systems

A manufacturing executive systems (MES) is an information system designed to replace traditional paper-based communication. MES systems typically include modules for the factory workstation, time critical manufacturing packages that track work-in-process (WIP) and other features that enable the paperless factory. Longenwalter [10] defined MES as "an on-line, integrated, computerized system that is the accumulation of methods and tools used to accomplish production." MES systems can collect data from the machines to continually monitor and improve the manufacturing processes leading to increased productivity. It tracks and manages all aspects of a job on the factory floor in real-time.

2.2 RFID in data management

The use of automatic identification (Auto ID) technology can be part of a larger MES solution. A most recent technology involves the use of radio frequency identification (RFID) tags. RFID is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is **an object** that can be attached to or incorporated into a product for the purpose of identification using radio waves. These tags can store, transmit and receive various shop floor and product data. They lend themselves well to a factory-wide digital communication system by using the tagged entity as a mobile, intelligent, communicating component of the organization's overall information infrastructure.
The combination of RFID with other factory data management systems (MES, CIM) offers opportunities for smoother integration with the overall corporate information system and a true paperless factory. In addition to tags, RFID systems include middleware software that resides on a server between readers and enterprise applications (Figure 3). To optimize most from RFID, there is a need for an advanced enterprise-wide information management infrastructure. RFID data collection is only the front-end for this total solution.

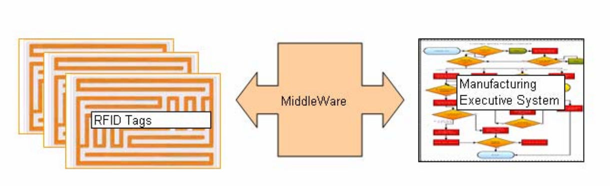

Figure 3. An integrated RFID data management

architecture

3. Electronic collaboration

For many firms the decision to go paperless was accompanied by the use of electronic data interchange systems enabling their suppliers, manufacturers, and customers to directly communicate with the firm. Instead of sending a paper form to order new supplies (and waiting days for the paperwork), the manufacturer's computer automatically entered the computer order and simultaneously alerted the warehouse, the factory, the accounting department, the billing department, and the shipping department. Most industries have found, and continue to find the task of creating seamless electronic networks of lean, agile computer-integrated manufacturing operations frustrating and difficult. Managers, in their drive for flexibility, need to determine how to extend their network to their partners without significantly increasing costs and overhead. There are three basic demands on these networks:

- The network must be able to accommodate the variety and variability of work roles and work assignments and the range of computer know-how on the factory floor.
- While maintaining a high level of security, the system must be able to cope with a changing pool of suppliers and customers whose relationships vary in intimacy and scope; and,
- Networks must give their members functionality, including the capacity to transfer files between computers, the power to access common pools of information, and the capability to access and utilize programs on remote computers.

RFID facilitates the collection and use of performance metrics to assess on-time deliveries and in-transit time by case/item. This information can be shared among supply chain partners to improve overall efficiency and effectiveness.

3.1 Web-centric data exchange

The web-centric manufacturing software platform [11] prepares product data in the factory office for controlled dissemination throughout the factory, delivers paperless documentation to the factory floor through browsers, and tracks products while collecting quality information. Large amounts of information are developed and archived during these activities.

Web services technology is being deployed approach as part of distributed software systems to enable business-to-business and business-to-consumer interactions across internet environment [12] [13]. Developing techniques to cope with the volatile and open nature of the web during execution of composite services at the service platform is essential for delivering reliable and acceptable performance in this new process delivery framework.

Competitive advantages can be derived from these web-centric technologies used within the factory as well as those extended through the enterprise. Such technology gives line operators, engineers, and managers a clear view of the performance and capability of their processes in a user-friendly fashion. Other parts of the technology improve communications beyond the factory by granting parties in the extended enterprise, such as customers and suppliers, web access to specific product and production information. Web-centric enterprise monitoring technology affords several levels of manufacturing information about machine activities and performance not available through other means. Together they join the real-time data flow from machinery to information from other points in the routing such as quality collection and rework areas.

Line operators monitor machine and line conditions to correct problems before they become serious. Process and quality engineers have the information to identify the root cause of problems, and localize the areas of the factory needing the most attention. Access to external feedback and machine performance data permits factory workers to determine problems rooted in machine activities. At the management level business leaders have access to summary views of multiple factories, and organized, directed diagnostics for real-time evaluation of the performance of the factories.

3.2 The virtual factory

The term "virtual factory" is frequently used to describe the electronic model for executing factory systems including virtual physical systems and virtual information systems [15]. A virtual information system is implicitly a paperless system, providing data access capabilities and the ability to share common pools of information in sophisticated ways. By creating virtual bulletin boards and file cabinets authorized users can verify that all participants in a product development project are on the same schedule, that updated CAD files are available to suppliers, and that regulators can monitor emissions levels.

The virtual factory [16] benefits from several specific enhancements in the move to eliminate paper from the manufacturing floor:

- A digital and electronics-assembly-specific routing backbone (wide area network) allows for the intuitive access and organization of assembly data from the beginning to the end of the process, while providing uniformity to all outputs.
- The plant floor viewing systems are integrated with the data preparation system and the product data management system for electronic verification and revision control through the use of linked local area networks connected to a wide area network.

It enables the use of the Intranet/Internet, multimedia instruction, and third-party software integration with the computer-integrated manufacturing and manufacturing execution system along with a security system and firewalls to protect the integrity of the organization.

4. Paperless systems in CIM environment

In or search we were not able to locate an explicit definition of the ideal paperless factory. One software developer, Reveille Technology [17] defines the paperless factory as a system that addresses the management of manufacturing operations including the directing, monitoring, and control of individual entities of work; the delivery of component material to work-in-process; the collection and control of data relevant to all resources used in the process; and the integration of manufacturing control data with manufacturing planning, general business, and engineering data. Most mentions of the paperless factory are accompaniments to the discussion of Computer Integrated Manufacturing [CIM][18,19] [20].

Many enterprises have experienced strong competition for many years in an environment dominated by emerging technologies and a changing market place. To survive in this competitive environment companies have been driven to deliver their products and services at lower cost, with higher quality/reliability and lower product development cycle time. To achieve these goals a number of approaches have been taken including factory automation and computer-integrated manufacturing (CIM). This evolution began with the introduction of digital computers in the 1950s, robotics in the 1960s, computer numerical control (CNC) in the 1970s, CIM in the 1980s, and continued by the emergence of the internet, wireless communication and e-manufacturing in the 1990s. While eliminating paper was not the main goal of any enterprise, the evolution of these electronic-based technologies made a significant contribution to the development of a paperless factory. Anjard states that paperless systems are an inherent part of CIM systems [21]. CIM networks the factory and support systems used hierarchical computer architecture. Manufacturing requirements planning (MRP) systems were designed to centralize and serve the hierarchical information needs for corporate management to the shop floor. Some software on the factory floor was developed to serve various engineering requirements from the bottom up in a decentralized fashion.

Figure 4 depicts a CIM model for enterprise-wide paperless operations. It encompasses a vertical integration of a shop-floor information system including MES, supports information systems including design, process planning, accounting, and internet-enabled businesses including suppliers and customers. Such a seamless integrated information system is particularly powerful in meeting the new challenges that many enterprises are facing including lower production cost, higher quality and short product-to-market time. Among the capabilities that such true paperless systems can bring to a factory are:

- Low inventories and quick order execution;
- The ability to direct, monitor and control work activities at processing positions in an integrated manner and in a real-time data processing mode;
- The ability to access real-time data for the location, quantity, and process status of individual work units in the factory;
- The ability to account for all inventory in work-in-process as well as in main stores and finished goods;
- The ability to "see" the material, labor, machine and tool utilization expended throughout the entire production process; and,
- The flexibility to react quickly to changes in the manufacturing environment. For example, the ability to change schedules, routings, material, bills, and product mix in a real-time mode.

In figure 4 the various parts of the organization are linked in a web-like fashion. Each functional unit operates in a semi-autonomous fashion to fulfill their part of the mission. LAN systems are specifically tailored to their needs and requirements. Each LAN communicates to other functional LAN-based units and provides information in a continuous stream to the corporate data base. All of the LANs within the organization are part of an Intranet system. A filtering router and firewall serve as the passage point to the customer-supplier interface, commonly called the Extranet. The Extranet consists of those customers and suppliers that have special, defined relationships with the firm. This part of the network is often called the DMZ – a place where trust is implicit but still held at arms length. From the extranet there is another passage to the internet through some internet service provider [ISP] to the business world at large.

5. Data security concerns

Despite the benefits promised by a paperless environment, all industries, particularly aerospace or defense industries face extensive data security challenges. There is currently no consensus on how to handle sensitive data. One solution requires all internal networks connected to the internet to be protected by firewalls to block unauthorized access.

In 1998 thirty percent of internet sites that reported security breaches had firewalls in place [22]. Today that figured has changed to over ninety percent. Firewalls are vulnerable to an intruder who uses a legitimate IP address or some form of authentication to pass through the firewall's defense. A firewall configuration that is much preferred to a simple perimeter packet filter is known as a "dual-homed gateway" or "DMZ." DMZ is a military acronym for "demilitarized zone," an area free from combat. A company's Web server, and other servers that may be exposed to attack, are sandwiched between these two firewalls. This arrangement is shown in Figure 4. A robust firewall is placed between the web server and the company's network. This firewall protects the network from attacks initiated from the web server. The company's database and other sensitive data are better protected, and there is an added benefit: the firewall can prevent disgruntled employees from attacking the web server from inside the company. Social engineering accounts for two-thirds of all security breaches.

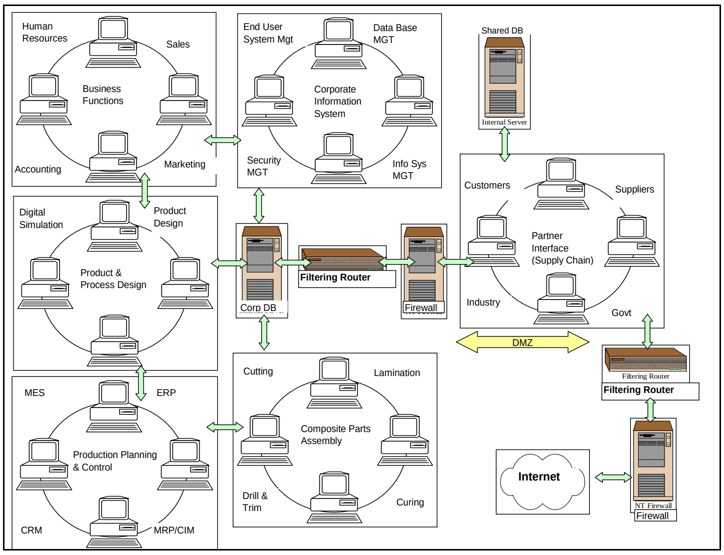

Figure 4. Configuration of a seamless integrated information system

While data security and integrity in a web-centric information system is well-publicized, other factory-based technologies are not immune to similar problems. For instance, RFID technology brings its own challenges in data integrity. This can be an since radio signals in RFID system are sensitive to heat, RF interference and the presence of certain materials. Another concern is the need to insure compatibility of middleware software to integrate RFID to an existing paperless network system. Data security challenges also arise from the RFID environment connecting everything. That is, it is possible to read RFID tags without authorized physical access to the item.

6. Summary

The next generation of factories will be part of digital enterprises that collaborate seamlessly around the world with their systems and business processes [23]. It is under such conditions that manufacturers will be leaner, more agile, responsive, productive, profitable, and humane than companies are today. In a computer-integrated system, processes, manufacturing, and management personnel work collaboratively to prepare and release information to the factory floor. Simultaneously, factory floor operators have simplified access to dynamic documentation that helps them do their job effectively, while eliminating the overhead normally associated with managing such a large volume of information. The web-centric system combines the functions collaboratively while making the information accessible to the factory, its suppliers and its customers [24].

Clearly, "paper" has not been eliminated. Instead, there are paper substitutes or representations prevailing throughout the factories. Bulletin boards provide the shop floor with operational status, and production control data such as work-in-progress and quality control charts. Shop floor traveler packets follow the job from station to station. The trend from a paper-based to a paperless factory has gained momentum over time enabled by the application of the existing technology of wireless communication on the factory floor and the introduction of new technologies and concepts such as RFID and web-centric systems. However, implementing a true paperless factory is not without its challenges. It requires improvement in data security, integrity and evolution of existing technologies to allow factory operations to be seamlessly integrated. It is under such an environment where a piece of paper will become a rare sight.

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