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Toward a cloud-based manufacturing execution system for distributed manufacturing

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ABSTRACT

This paper illustrates the needs and challenges for the management of distributed manufacturing in a multi-company supply chain and processes these further as features of new IT systems. Requirements are collected from manufacturing companies and combined with insights from literature in the field of current ERP/MES system drawbacks, advantages, needs and challenges. The findings show that the needs and challenges in data integration inside SME networks are closely related to the limitations of current supply chain solutions. Current ERP-solutions lack extended enterprise support and a shared cloud-based approach. On the other hand, current MES solutions can operate the manufacturing process, but not for distributed manufacturing. As an answer to the requirements, we made a proposal for the core of architecture for next generation of MES solution in this position paper. Moreover, a pilot software tool has been developed to support the needs related to real time, cloud-based, light weight operation.

1. Introduction

Today's business supply chains for complex products are likely to involve a number of autonomous organizations. The competitive market requires that these supply chains are highly agile, effective and efficient. Agility and effectiveness are obtained by forming highly dynamic virtual enterprises (VE) within supplier networks [12]. All these highlight the importance of information technology in integrating suppliers and other partners' firms in a virtual enterprise and supply chain [11]. Interoperable enterprise systems are the key to enterprise integration [39].

Supply chain management (SCM) is a way of obtaining horizontal integration benefits without its formal ownership costs. SCM, the integration of key business processes among industry partners, adds value to customers, tightly links together several consecutive elements of the industry value chain, from upstream suppliers, to subassembly manufacturers, to final manufacturers, to distributors, to retailers, to end-customers, in order to make the processes more efficient and the products more differentiated [2]. The internet has brought forth numerous possibilities to increase this flow of information, and encouraged companies to form closer integration of their information services (IS). The adoption of the internet and turbulent market conditions have forced small and medium-sized enterprises (SMEs) to adapt their way of undertaking business, from traditional practice to e-business [4]. Arend and Wisner [2] suggest that many firms with 500 or fewer employees, i.e. SMEs choose to make SCM part of their strategy implementation, while other SMEs shun it.

The development of the enterprise resource planning (ERP) solution has created an opportunity to manage supply chains within and beyond the organizational scope [30]. This high value-oriented supply chain enables a high level of integration, improves communication within internal and external business networks, and enhances the decision-making process. In this way, the management of VE beyond different partners can be improved.

Current ERP technology provides an information-rich environment that is ripe for very intelligent planning and execution logic. Yet little has changed since the late 1970s in terms of the logic associated with such applications as forecasting, reorder point logic, MRP, production scheduling, etc. The current systems are now just executing the old logic much faster and in real-time. The area is ripe for innovative new approaches to these old problems [18].

Theoretically, ERP can solve the strategic problem at the upper level, and mainly handle internal and external relevant resource issues. Nevertheless, there are many limitations of ERP. It is precisely because of integration that the ERP system provides an industry standard for specific types of business. On the other hand, it also limits the flexibility and lowers the competitive advantage

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of an enterprise. ERP may also limit progress in SCM from the strategic perspective [1].

Particularly in the manufacturing industry, current ERP-solutions appear short in terms of supporting multiple plants, multiple suppliers, and lack functions such as inventory control, management planning and production order processing. Therefore, to manage the factories, manufacturing execution systems (MES) are designed to perform functions such as production control, maximize the workload of equipment, release unneeded machine tools, etc.

Nowadays, the problem is how to integrate all these applications and solutions in a single platform in order to bundle all virtual enterprises into one supply chain and manage them centrally. The research question addressed in this paper is: *what are the needs and challenges of integration for integrated supply chain coordination for distributed manufacturing networks?* The object of this paper is to present a new system based on current solutions to solve problems of integration of distributed manufacturing networks through VE form by using new technologies and new infrastructure.

Various system solutions are evaluated in this paper. After discovering the limitations and shortages of each solution, new requirements and challenges are summarized from real cases. In attempting to highlight the practical issues, Six cases are analyzed. Interviews and discussions with key managers and operators in these companies are used to collect and assess the information. Each of these companies contains a network of manufacturing supply chains. The case study reveals some important and unique requirements. Consequently, a new cloud-based solution with new infrastructure is proposed to fulfill these market requirements. This solution is named as NetMES.

Our paper has two major contributions. First, we discuss the limits of current software solutions as applied in distributed manufacturing. Second, we give guidelines on how to develop comprehensive software. This new solution integrates both the concept of ERP and MES. We report this empirical solution and provide a prototype to fulfill the gap between practices and academic research.

The rest of the paper is organized as follows. Section 2 introduces the current situation and approaches to managing virtual enterprises. Section 3 describes the method used in this paper to collect data. Section 4 performs an analysis and discusses the case studies. New challenges and requirements of distributed manufacturing networks integration are then summarized. Section 5 presents a solution and a prototype. Finally, Section 6 presents a brief summary and conclusion.

2. Current situation and approaches

2.1. Centralized ERP

The rapidly changing needs and opportunities of today's global market require a higher level of interoperability in data systems to integrate diverse information systems to share knowledge and collaboration among VEs. This includes partnership with the business partners which live in this dynamic environment on a day-to-day basis [35]. Although the core of VE is to effective exchange information, it is not an easy task due to the heterogeneity of information resources.

ERP provides a comprehensive transaction management system that integrates many kinds of information processing abilities and stores data in a single database [1]. In the era prior to ERP, information processing and data were typically spread across several separate locations.

The installation, re-programming and configuration in current ERP-solutions are very complicated processes that take too much time and planning resources. The solutions are usually hierarchical and centralized entities. ERP integrates all up-to-date information in a single application. Theoretically, this single major source ERP can feed SCM solutions. However, current ERP-solutions do not scale up very well to the whole networked supply chain. Indeed, the jointly agreed standards on data integration also delay the implementation of the next generation of SCM-solutions. Different kinds of SCM-solutions are not automatically interconnected, which makes data integration harder to achieve. One of the fundamental issues in networked supply chain coordination is that current solutions do not take manufacturing processes into consideration sufficiently so that lean production would be practically functional [47].

Akkermans et al. [1] highlight four limitations of ERP: (1) lack of extended enterprise functionality; (2) lack of flexibility in adapting to changing supply chain needs; (3) lack of advanced decision support capabilities; (4) lack of open, modular system architecture.

The needs of networked supply chain coordination are associated with innovative processes in which new materials and components are designed. There is a need for interfaces for intelligent applications that will transfer the information into knowledge that can be used in decision making. Employees must be integrated with user-based interfaces with intelligent devices and applications when there is a need for new education methods that will be used in fast information distribution [33]. Panetto and Molina [33] suggest that the future of SCM software lays in malleable and intuitively user friendly software tools that can become an integrating factor, rather than a barrier, to development. Jacobs and Weston [18] predict a greater focus on SMEs in the development path of ERP developers, something that may bring simpler and lighter commercial versions to the market and end up making this kind of solution more attractive.

Izza et al. [17] posit that the challenges of EAI-technologies lie in heterogeneity dissimilarities and lack of semantic interoperability. Different applications execute their own data and process models, which leads to different applications not being automatically interconnected. Primarily, supply chain coordination is based on the trust between different actors in a networked supply chain. This highlights the need for the secure data interchange and standardized services between the actors [39].

ERP-solutions should support other solutions and operating systems more extensively. This would lead to the easier execution of integration of different systems and applications [43]. Consolidation of the ERP-software providers will affect the development of ERP-solutions. ERP-solutions are equivalent in the needs of the biggest global companies, but they do not necessarily answer the needs of local SMEs. Universally applicable ERP-modules do not fit to the last detail the needs of local SMEs [18]. The increase of service-oriented solutions will enable the systems to be more easily configured. In the future it will be easier to bring the solutions into services because the modules will be tailored more specifically for certain branches of industries. Future solutions must become more intelligent. Data mining, intelligent tools and expert-systems will contribute to decision making. Simulation will be a significant element in integrated networked supply chain coordination [18].

2.2. Connection between upper level and lower level in the organization

Even though ERP is used to integrate dispersed information, manage all the centralized information and improve the management within the organization, it is more relevant to the upper level (management level) of the organization. However, in many organizations, the detailed and traceable data about production at lower level, such as the shop-floor control, are unavailable. And yet these data are precisely the key cost drivers in manufacturing environment. In today's complex manufacturing operations environment, it is necessary to find a new way to meet the changing production demands in real time.

Manufacturing execution systems (MES) are software packages used to manage factory floor material control and labor and machine capacity, and to track and trace components and orders, manage inventory, optimize production activities from order launch to finished goods, etc. Some of the larger ERP-solution providers have incorporated MES-related capabilities to offer this specialized functionality and fill the shortcomings of traditional ERP-solutions [9].

The integration of ERP and MES requires the easy sharing of information across the systems. MES systems typically take production orders from ERP systems and link quality control, scheduling and material information. Receipt of goods and some low level material handling functionality, including serial number generation for products may be supported as well. Performance dashboards and advanced statistics reporting may be included in the system to provide an overall view of production cells and lines [28]. It is an information bridge between planning systems and manufacturing shop-floor control systems.

Using MES provides benefits to SMEs in supporting different types of production and processes. It reduces manufacturing cycle time and data entry time; it optimizes the inventory and warehouse; it improves product quality and empowers the plant operation people; it improves customer services and quickly responds to unanticipated events [29].

The latest developments in MES systems have included building flexible workflows and applying the latest software technologies to support distributed manufacturing. Holonic MES is a non-hierarchical (hierarchical) system, and it supports flexible hierarchies, which can be formed dynamically through aggregation. It possesses the characteristics of MES and also the properties of failure recovery and security certification [6]. Cheng et al. [6] developed a system framework for computer-integrated MES to support integration. Later, Cheng et al. [6] continued integration work between multiple MES and ERP systems for interoperability. The concept of holonic manufacturing system in this context means building workflow-based protocols for flexible communication between ERPs and MES servers. Valckenaers and van Brussel [38] have also worked on the same theme. Their solution adopts hierarchical design and relies on agent technology on communication and decision-making which means orders, machines and product parts each are considered as a corresponding computing agent in the control system. This method is used to predict the workload of the machines and forecast routings of the products. For a near future solution, Valckenaers and van Brussel [38] suggest systems that are able to route and schedule themselves by taking into account any changes. Holonic systems are heterarchical when applied to a small system as discussed in this paper but have flexible hierarchical characteristics by using aggregation when larger. Component based software supports this type of architecture [10].

User interface development has also been discussed in the literature. User interface and general usability of MES software systems is a very important feature. For example, Cooper [7] has patented some transaction control features of a user interface. Later, when web technology has matured, web access systems and mobile terminal access have received increasing interest. There are patented solutions available on this side as well [8]. Lan et al. [22] propose an integrated manufacturing service system which is a Java-enabled solution, together with web techniques, employed for building such a networked service system.

However, existing MES lacks the capability of adaptability, reorganization and configuration. It is unable to adjust its architectures and functionalities following changes in enterprises, businesses and organizations, thus hindering the wide adoption of MES software [23].

Simply integrating ERP with MES not solves the potential issues, such as the time lag between the actual occurrence of shop-floor control data and its recognition in the front office ERP systems at the management level. Broadly speaking, a clear picture of the entire shop floor is not available in real-time. High level managers cannot see what issues exist on the floor and what inventory shortages might impact delivery to the customers.

One the other hand, the information from front office may not be communicated to the shop floor until the MES download the data from ERP. Changes in ERP have been made in real-time do imply the real-time in MES. This disconnection may cause other issues.

Due to the lack of capability of adaptability in current ERP systems and MES, new technologies are introduced to improve the capability.

2.3. Cloud-based solutions

Cloud computing represents a combination of various IT technologies: hardware virtualization, distributed computing (grid computing, utility computing), internet technology (service-oriented architecture, web services, Web 2.0, broad-band networks), system management (service level agreements, data center automation) and open source software [24,45,46]. Cloud-based solutions can be described as web-based applications that are stored on remote servers and accessed via internet by standard web browsers [24].

Cloud-based solutions run on a SaaS (software as a service) layer in the cloud architecture. They are demand-driven and charged by metered time, instances of use, or defined period [15]. The set of functionality provided by cloud-based solutions is richer than in-house counterparts [27], and it is faster, simpler and cheaper to use [3]. By adopting a cloud-based solution, the shortage of current ERP-solution can be covered.

The main benefit for companies in choosing a cloud-based solution is that almost no local IT resource investment is required [24,40]. Companies can utilize the flexibility of cloud resources dynamically to meet peak demand without investing in in-house resources [40]. Also, a cloud solution can handle the weaknesses of their current system regarding redundancy and high upgrade cost because Cloud is a virtualization of resources that maintains and manages itself [44].

Nevertheless, most of the challenges and risks are basically security concerns due to the migration from one business model to another. Besides, companies lose the governance over their valuable data and they have to accept that the cloud solution provider will control a quite large number of important issues and areas of their own business process [26]. Some relevant issues are vendor lock-in, compliance challenges, and cloud provider acquisition [19].

Cloud computing is already practical in many business applications. Nowadays the major application vendors are actively building cloud-based application infrastructures, exploring relationships with cloud hosting providers, and promoting SaaS based software [14].

Xu [42] raised the concept of smart manufacturing with cloud computing, which is cloud computing adoption in the manufacturing sector. It is interesting to know that with a cloud-based solution, manufacturing companies can eliminate the IT resources and outside support and maintenance, but in the meantime companies are able to develop better-integrated and more efficient processes [34]. Based on a particular case in the Elkay Manufacturing Company, which adopts a cloud-based solution, an average IT person's workload has shifted to higher level functions, and his or her skillset and knowledge base have evolved significantly in the process [34].

Based on Moad's observation [25], manufacturers were still new to cloud-based applications in 2011. But now, they are no more concerned with cloud in terms of its performance, uptime or security of the public networks, but rather they are much more interested in how and when vendors will continue to enhance the functionality of cloud-based systems, particularly with things like business intelligence and industry-specific capabilities.

For manufacturing companies, cloud-based MES solutions allow the standardization of manufacturing sub-processes across multiple plants in many countries. This concept is attractive because it acquires manufacturing assets around the world and leverage best practices internally within the entire organization [14].

However, there are still many challenges connected with bringing MES to cloud. MES tends to be highly industry and process-specific, which means highly customized for a specific process running at specific plants. It needs to be able to quickly change when processes or requirements change [25]. However, customization is still a limitation for cloud-based solutions.

3. Methodology

Due to the nature of the research question addressed in this study, it is appropriate to conduct qualitative research. That is, qualitative research is employed to understand people and their social and cultural context [31]. In this paper, it is important to understand, from the case companies' perspective, what are the new requirements and challenges they perceive when using new technology to manage the organization. Quantitative research, on the other hand, is intended to obtain numerical outputs and the meaning they represent [36].

To collect the needs and requirements for distributed manufacturing, interviews were conducted at six different small and medium sized companies, which all have their own products and manage suppliers as a focal point in the manufacturing chain. From a manufacturing point of view, all the companies have organized their production processes as flow shop type organization. Different products follow very similar routings and use similar resources. The company products at each case company included manufacturing of the following products:

- Electrical appliances,
- HVAC pumps,
- Boats,
- Customized metal profile products,
- Heating equipment,
- Electronics control systems.

The interviews were conducted with several stakeholders in each company during 2010 and the results were recorded in the form of requirements specification. We search for patterns in these companies and summarize the consistent requirements. This is not a typical approach for case study research, but commonly used in software engineering when building common understanding of the required features for a system. These six case companies are in different phase of enterprise systems development. So there are different levels of expectations. Although the number of companies studied is small, for a requirements specification phase the companies cover a reasonably wide range of manufacturing characteristics and the key requirements are captured. Therefore, these six cases are sufficient for the purpose of our analysis. Certainly, for wider generalizations, a survey type of research method, probably with industry specific questions, should be conducted.

4. Requirements analysis

The result of the requirements collection from six companies was organized as common requirements specification document. Initially, the collected data set was recorded, which was then consolidated in a requirement document for further refinement.

4.1. Functional requirements

From the interviews, it was noticed that most of the companies base their IT-architecture in several heterogeneous applications. The whole SCM system is comprised of several applications, services and sources of information. Many different kinds of ERP-solutions, SCM-applications, electronic business applications, portals and transactions between companies in the network will make the whole architecture a complicated entity. This leads to even more complicated data flow and systems integration, especially in the manufacturing related activities.

The specified requirements from each case company were collected individually. There are four important requirements that need particular illustration:

- Company A would like to increase transparency in the supply chain by automatizing stock and sales information gathering. In addition, it wants to create an electronic insurance registry and update all the insurance information into this database, Company B would like to create a practice that will show a production schedule to suppliers on a weekly basis. With utilizing such a system the supplier will be able to supply components more accurately.
- Company C has trained its employees to use the current ERP-system more effectively. Their ERP-system includes a feature that enables different partners to coordinate and supervise information in the supply chain. The information includes, for example, ordering information and status updates. The company would also like to determine the development of the ERP-system from the customer point of view. In addition, there is a need to optimize call-off stock.
- Company D would need transparency of quality data in multi-factory environment. The purpose is to increase ramp-up performance.

In order to systematically analyze the requirements, eight general requirements for distributed MES system design are summarized in Table 1. This table illustrates the collected requirements and the frequency of their appearance in all case companies.

4.2. Real-time requirements

Being able to show real-time information from production is an important feature for any MES system. In context of distributed cloud-based MES, Real-time information exchange between companies is both functional and non-functional requirement at

Table 1
Requirements for distributed MES.

ID	Requirement	Freq
1	Order tracking in supply chains	5
2	Real time view on work queue	5
3	Capacity view	4
4	Materials traceability, serial numbers	3
5	Test records	1
6	Sales order – EDI connection	2
7	Purchase orders – EDI connection	2
8	Product information – work instructions for suppliers	2

the same time. It is a functional requirement in a sense that user interfaces are needed to see production status at suppliers and other parts of the supply chain. It is a non-functional requirement in the sense that the information synchronization should be transparent between suppliers, manufacturers and sales units.

The reliability of real time manufacturing data is important when the information flow is being automated. The message receiver must have trust that the transferred information is authentic. It would be ideal if all the counterparts had the same cloud based system and the data model in use, but in practice that goal would be impossible to reach. Companies have different types of ERP and MES systems which need open interfaces for integration. Open interface definitions are in a central position in order that the integration can be executed using the best technology with the most cost effective partners.

4.3. Analysis

The following features were proposed as critical to such a program: (1) the system should be easy to change: when the business changes, the system should evolve as well, not hinder; (2) a production employee should be able to change the production flow related fundamentals of the program without aid from an IT-professionals; (3) supply chain information sharing should lie at the very base of the program (accessible through the Internet); (4) the system should be based on open source code for legal sharing of modules and solutions; (5) the system's user interface should be the internet, (6) the system should be made entire new, without old remnants of source code, as in today's ERPs; (7) the software should always be up-to-date: if the system is light and internet based, it will be; (8) the system should support flexible and lean production options; (9) the information database should contain highly detailed data; (10) the electronic accountancy and inventory should be closely tied to the physical dimension (by efficient tracking systems). Furthermore, users require access of this system via the internet without restrict of location. Simultaneously, the protections of users' sensitive data and information are required.

To summarize the results of the analysis from cloud technology point of view we can see that the mentioned requirements have some features, which are not part of standard MES systems and where cloud technology could offer some solution.

- Routing of manufacturing operations may change within the supply chain and the companies that need to access the data may vary from time to time.
- Transparency between operation steps occurring at different locations has traditionally seen as supply chain or purchasing management issue, but in distributed production, a common view on production schedule helps planning.
- Quality and test data need to be shared between manufacturing partners along the routing.
- The participating companies of manufacturing network may vary from project to project and ability to reconfigure the access should not require IT projects.

Current EPR and MES systems are not very good at this type of fast structural change. Information sharing between partners working together in common projects is actually a typical feature for cloud based social media sites rather than operational manufacturing systems. The concept of linking and sharing data between entities in a similar way would have novelty.

5. Prototyping a solution – NetMES

5.1. Concept and objectives

To fulfill the requirement and challenges presented in the results part, a software tool was designed to illustrate a potential solution. Although this solution has focused on key requirements, it includes new business process and planning, sequencing algorithms, and a new infrastructure based on existing MES technology. If successfully implemented, such a software solution could prove very beneficial to multi-company SME-intensive networks (Fig. 1).

The NetMES system was eventually implemented in one of the interviewed companies and its network. In this solution, the cloud plays a role as a platform in the evolution of MES. Since cloud computing is already practical at the business application level, it is very reasonable to build MES based on web services and provide a standard for information sharing/transferring environments. Cloud technology will be adopted in order to support monitoring, information exchange and also other real-time interactions.

Andon systems are core elements in this NetMES. They are used when a problem occurs in the production lines. "Andon" is a visual

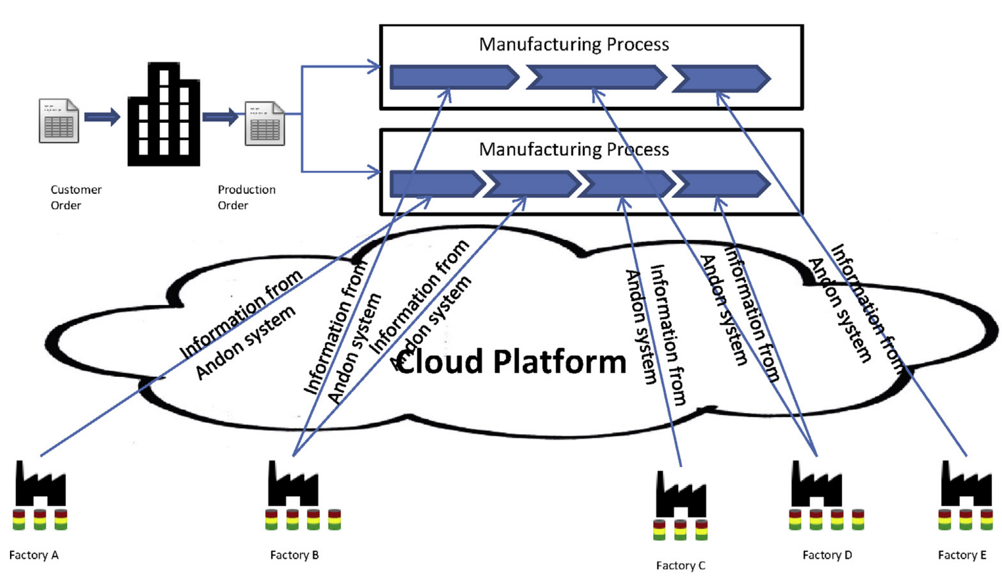

Fig. 1. Integrating ERP systems with MES systems.

control that is used to notify the status of machines and manufacturing line in the manufacturing process. This concept was first invented by the Japanese for Jidoka (automation in English) and refers to the principle of stopping work immediately when a problem occurs [37]. Andons are used by Toyota and quickly adopted by many Japanese and American manufacturing companies [21]. They can be used to control the quality of production and improve the defect detecting processes.

Andon comes with an alarm to alert workers when there is a change in status. When the alarm is activated, it directly indicates a problem on a particular production line. A worker can stop the production line to call for help to adjust a machine or fix a quality defect [21]. Then workers study the problem and solve it together. Although productivity is lost due to line stop page, the overall system performance is improved [21].

In this NetMES solution, the Andon systems will recode all the production line problems and send the real time status of each production line back to NetMES. In this way, high level decision makers can provide a critical response to problems and avoid costly downtime.

This solution is based on the concept of virtual enterprises, which combines the power of several independent enterprises to achieve complex manufacturing processes. When an organization receives a new order from a customer, the order can be converted to production orders, and different factories will be selected and assigned to the manufacturing processes. Conversely, this MES can be used to collect real-time information from the Andon system and transform this information to the higher level organization.

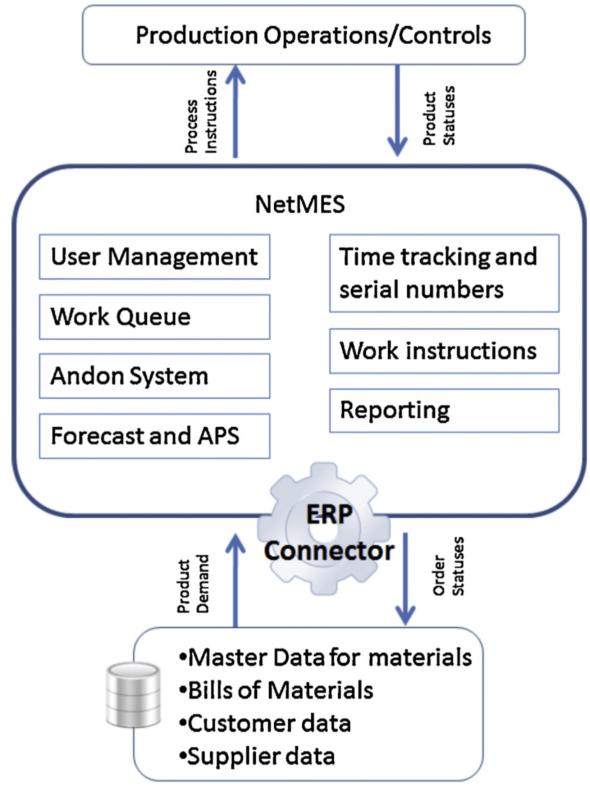

Fig. 2. NetMES key functionality blocks.

5.2. NetMES functionality set

Most manufacturing companies use ERP or an equivalent system to determine product manufacturing and the production planning process. NetMES is used herein to translate this plan into work instruction, and elaborate the method of dealing with real resources and real plant floor execution. The NetMES system is a web browser based MES system for distributed (multi-site) production planning and control system. The key features of the system include:

- Support for multi-site manufacturing,
- No installation required – a web based system,
- Connections to external systems such as ERP,
- Tracking and tracing within the entire extended enterprise,
- Providing KPI data master for production.

From the theory point of view, the NetMES application is a shared production view for managing the extended enterprise. The term "extended enterprise" represents the concept that a company is made up not just of its employees and its managers, but also its business partners, its suppliers, and even its customers. The extended enterprise can only be successful if all of the component groups and individuals have the information they need in order to do business effectively.

The NetMES concept relies on external master data for materials, bills-of-materials, customers, suppliers, which all should be stored in the ERP system. The system focuses on capacity management, work queue, and traceability information within the extended enterprise.

NetMES occupies a very important technical position. In attempting to connect the factory floor to the executive levels of the enterprise, it occupies the space between low-level control automation systems and high-level ERP system. It acquires product orders from the ERP system, and converts this product demand into an execution order and passes process instruction to the control automation system. After product operation and execution is done, the product status is updated and information is sent back to NetMES. Later on, the order status will be fed into the ERP system.

The positioning of NetMES is presented in Fig. 2. This figure also shows the main functionalities provided by NetMES. The NetMES system should offer functionality for managing the order flow similarly for people within the company as well as the suppliers, retailers, etc. The planned key functionality blocks in the NetMES software package include: (1) user management, (2) work queue, (3) Andon system, (4), forecast and APS, (5) time tracking and serial numbers, (6) work instructions, (7) reporting, and last but not least, (8) ERP connectors.

5.2.1. ERP connector

The NetMES should be directly coupled to the planning system to retrieve production orders from the ERP system and also all other inputs; in this way the NetMES can provide upload information as necessary. This ERP connector acts as an information gateway, without significant information processing. The communications should be two ways so the MES can keep the planning system properly informed about plant activities such as labor data, inventory changes, and work order progress. Other methods of data entry and reporting can easily be accommodated.

While the planning system has the aggregate data on inventory, the detail can easily reside at the local level—the MES. "Dock To Stock" operations are accomplished here with regular updates to the planning system. A current map of all inventory and storage locations, including WIP, is maintained.

Also, the NetMES provides the workflow visibility and event notification required to ensure that manufacturing meets the enterprise information demands. ERP and NetMES offer varying types of functions and features. The functionality of this part includes:

- Selecting and importing production orders from ERP,

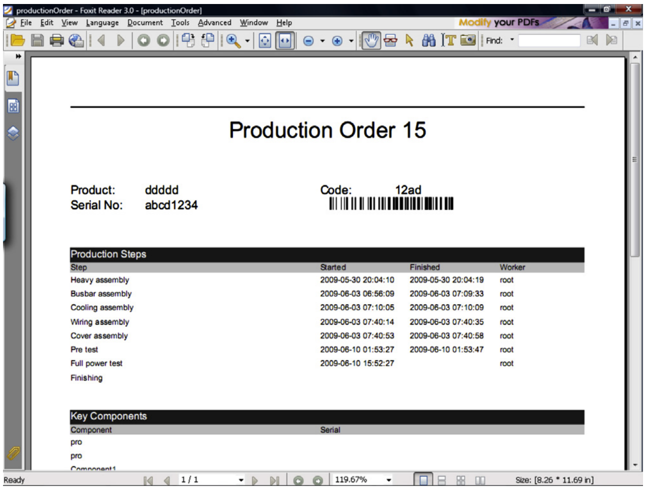

Fig. 3. Production orders with planned assembly timings.

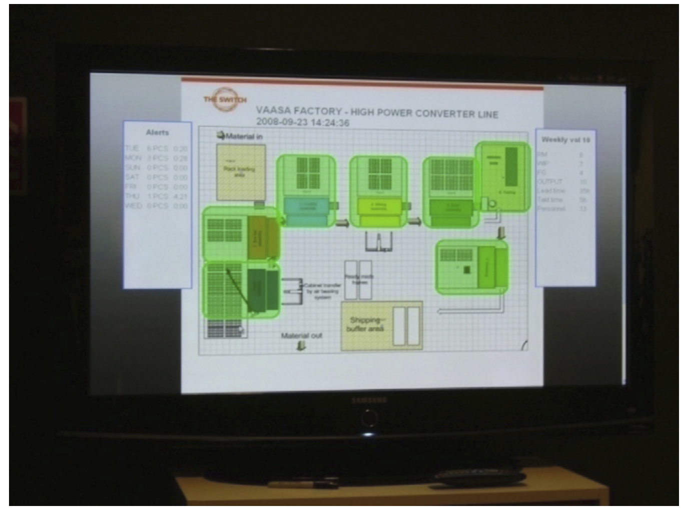

Fig. 4. Andon status displayed on NetMES.

- Importing BOM and key components,
- Importing referred materials from ERP,
- Building a link to work instructions in the PDM system.

5.2.2. Work queues

A work queue screen displays prioritized job operations scheduled in each factory and the status of production orders. This work queues screen is presented in Fig. 3 as an example. This view can be used at production line level or to present a multi-factory production queue for production managers and line managers. The functionality of this part includes

- Viewing all orders for factory and sort the view,
- Adding a new production order,
- Connecting BOM, routings, work instructions for production orders – applying localized routings and components for each production line,
- Viewing status for each factory – capacity, lead-time, etc.,
- Printing production order documents for tracking,
- Toggling between key components view and production steps view,
- Production scheduling: optimizing the production queues,
- Printing friendly view.

5.2.3. Andon system

The Andon system supports quality control especially in volume ramp-up situations and continuous improvement. Each production line has an Andon system to present its working status and to collect data about the product line as shown in Fig. 4. If problems occur, the workers can active the alarm, and the alarm indicators will be displayed on the NetMES. By using Andon functionality the workers on the production lines can record Andon cases and report issues to a centralized database. It provides a critical response to workflow problems in order to help avoid costly downtime by immediately alerting the maintenance and quality teams at the first sign of trouble. Factories producing the same products can compare practices and learn from each other. High level managers can monitor the real time situation in the factories. The functionality of this part includes:

- New cases and descriptions,
- Processing of cases according to workflow (R&D, supplier etc.),
- Controlling Andon “traffic lights” according to status (Red: production downtime required; Yellow: the problem is under process; Green: OK),
- Connecting cases with production orders in the database.

5.2.4. Worker screen – time tracking and serial numbers

Because NetMES directly interacts with the execution and operation on the factory floor, it should provide a direct view for workers. This easy to use interface is developed for workers working on the factory floor. It includes touch screen monitors as well as bar code readers to simplify data entry while reducing mistakes. This worker screen includes a list of work to be performed, specific instructions and requirements to execute the work, quality inspections of the work, and sign offs indicating the work is complete. The worker can also report working status through this worker screen. For instance in Fig. 5, it depicts the user interface for worker screen.

The workers’ view in NetMES is based on work instruction, which is controlled by the user ticking each part completed and recording components. The system also maintains work time calculation and notifies if the planned time is exceeded. The key features for this functionality include:

- Recording operation time stamps,
- Recording S/N for components,
- Providing tact time reports based on recorded information,
- Including test records for FPY calculation,

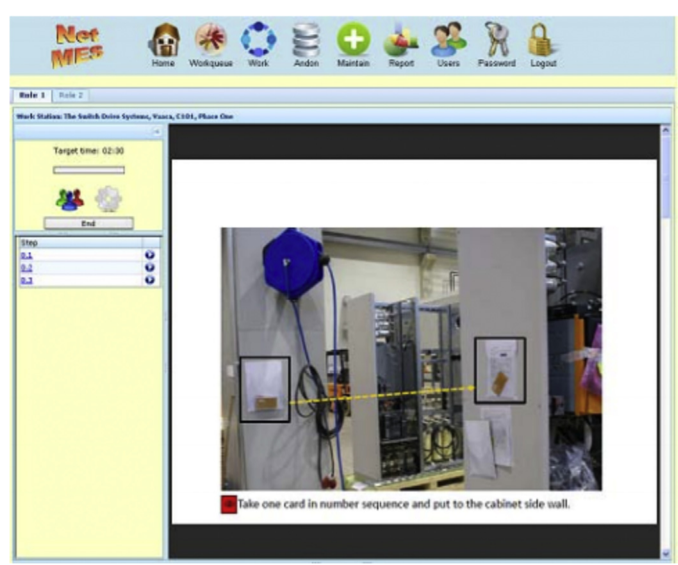

Fig. 5. Area elements in operator screen.

- Work instructions – viewing current work instruction for each stage by connecting bar code readings with instructions,
- Maintaining work instructions for each plant.

5.2.5. Dashboard

Production planning and control reports are presented as dashboards. These provide real time analytical information of various activities. Dashboards may be designed for wall displays or small embedded web-applications that can be used in corporate intranets and supplier extranets. Typically, the reporting and dashboard system may include the following features.

- KPI report for FPY per line/factory based on throughput,
- Production order report,
- Reporting progress of production,
- Current capacity report,
- Test reports.

This personalized, role-based dashboard displays production information from a summary level to a detailed level. The dashboard delivers real-time information to speed up decision making and improve business processes. These screens are simple and easy to handle.

5.3. Technical implementation

The overall architecture of the system will be based on a three-tier model: user interface, business logic and data layer. Fig. 6 illustrates the architecture overview. This architecture is developed to overcome the drawbacks of client-server architecture. These three layers stay separated at the time of deployment for this cloud-based NetMES. The system uses enterprise beans in the business logic level and hibernate system for data layer access. The data layer includes all the integrated data and centralized database. The business logic layer acts as the connection between the users and the database. The user interface layer is responsible for receiving the user's input data and results display. The users can switch interface views according to their needs and keep them exactly the same under data models. It is based on a Struts framework. The WAR/EAR packages should be installable on a JBoss application server system. The system should support Java EE clustering also Microsoft.Net and other equivalent technologies. User authentication is based on Java EE security provided by the application server software.

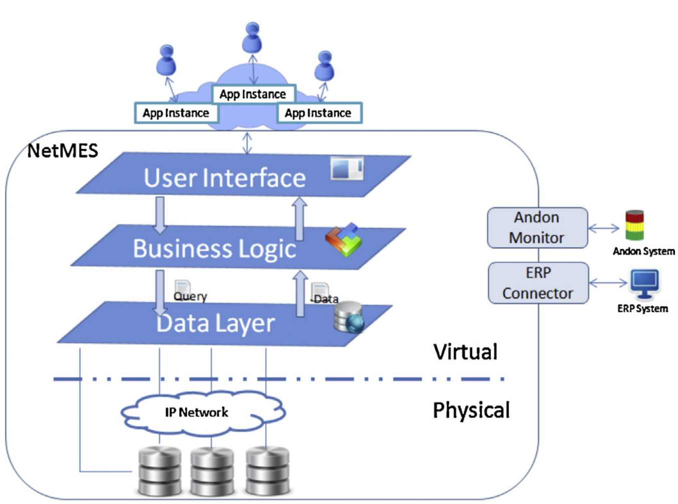

Fig. 6. NetMES architecture overview.

This NetMES is a high-performance and easily expandable information system with a centralized cloud server synchronizing local server databases and serves multiple factories at the same time. The open architecture enables easy system integration with a specific supply chain and manufacturing execution.

As mentioned earlier, this NetMES is designed as an information system that interacts with the ERP system. It acts as a messenger between the factory floor and the ERP. The ERP system focuses on global planning and business process across the whole enterprise and is an intra-enterprise system. On the other hand, NetMES responds to collecting data from the factory floor and transacting in real time to ERP.

The Andon system is a specific component integrated into NetMES to monitor wireless Andon system signals in the environment and send a record of all signals to the NetMES centralized database. NetMES enables monitoring over the entire Andon environment status on one screen. More importantly, the data transmitted from the Andon system and communicated to NetMES via the cloud is real-time, so the specified recipients will know the moment that an Andon alert is triggered.

The NetMES supports multi-factories with different instances. Each factory with its dedicated application instance over a shared NetMES platform in a hosting cloud environment has access to different factory floors and physical control over the manufacturing processes. The control data will be sent back to the ERP system. This cloud-based NetMES can provide an effective collaboration environment with employee agility and transparency.

5.4. Database construction

The NetMES is composed of several functional models that handle products, production lines and projects. Fig. 7 demonstrates the high level data structure of NetMES. The diagram depicts the relationship of distributed manufacturing. The multiplicity is shown to help understand the system better.

This model has a high level of abstraction. It is illustrated by a top-level representation where the taxonomy has been captured in nine key base classes. Each of these top-level classes is detailed with its attributes. The main classes are described as follows:

Project: once the customer order is coming, it is considered as a project. The project includes control over the production planning, and cost analysis. It enables the manufacturing for a specific requirement. The project lifecycle and status information are available to users.

ProductionLine: in a factory, many production lines are operated at the same time. Each production line has one Andon system to monitor the events occurring on that production line. The Andon system is a signboard incorporating signal lights to indicate which production line has a problem.

WorkQueue: a production line of the manufacturing plant consists of several production works. WorkQueue is used to arrange the working sequences in that production line.

AndonCase: when an event occurs during the production, an alert will be activated on the Andon signal board. The production stops and the issue should be recorded and reported to high level management. Each event is reported as one case and includes one serial-number.

Inventory: the maintenance of item inventories is very important. Inventory control supports a number of business processes, such as continuously monitoring stock level and automatically reordering.

WorkOrder: it contains the manufacturing process for production work orders. This includes creating work orders from production orders.

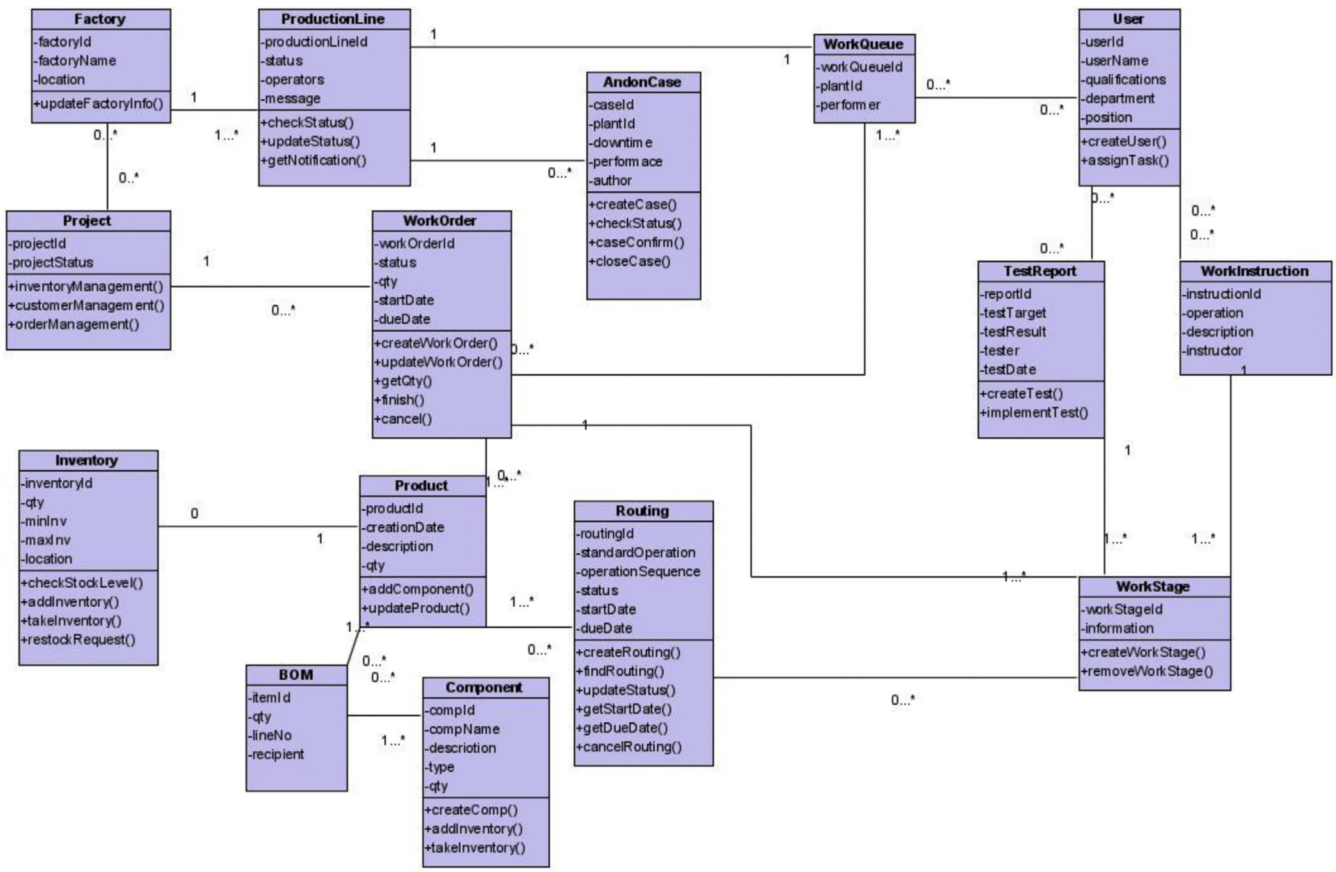

Fig. 7. NetMES class diagram of data structure elements.

BOM: BOM enables a list of required components and the routing of assemblies for the demand products.

WorkInstructions: this is included in BOM since every build process requires a bill of materials that outlines what components are required to successfully build the finished goods.

WorkStage: there are several stages to produce one product. The manufacturing process encompasses a variety of activities. WorkStage is used to organize the execution of a production.

5.5. Cloud security issues

In cloud-based environment, the physical database is replaced by a virtual database. Data are transferred throughout the cloud. Consequently, security issues regarding data storage and privacy can arise.

One approach suitable for manufacturing contexts is to store data locally in the factory level server and then synchronize with the centralized cloud database.

Users do not know the exact location of their data, and they can hardly prevent unexpected risk to the data storage due to their lack of rights to manage the data. It is a question of trust when users accept cloud-based NetMES as public cloud. The pilot implementations have been done by using a private cloud approach.

In order to ensure data confidentiality, integrity and availability, the NetMES capabilities have been extended. A tested encryption schema should be used to ensure that the shared storage environment safeguards all the data. Moreover, access controls will be adopted to prevent unauthorized access to the data [16], such as providing strong authorization, authentication based on the user's role, monitoring user activity, and single sign-on (SSO) [20].

Furthermore, privacy issues in the cloud environment need to be addressed. Therefore, standard procedures such as service level agreements (SLA) should be required [32].

6. Discussion

A cloud-based new MES infrastructure to integrate information exchange between companies has been proposed for distributed manufacturing. The proposed system has been designed to operate in situations where suppliers need to input significant manufacturing related information and provide this to other participants of the delivery along the supply chain.

The technical solution is a centralized system, where companies can link each other's data without heavy IT integration. The system is based on a layered architecture. The top layer supplies various kinds of flexible user interfaces so the clients can access this integrated system remotely. The middle layer is used to receive requests from users, manipulate the data, then convert them to useful information and present them back to users. The bottom layer is a collection of data from different sources. In this data layer, storage devices are consolidated by using storage virtualization techniques. It is very interesting that the logical representation that an application on a server uses to access data, which is called the business logic layer, is abstracted from this data layer as an independent layer. It is responsible for maintaining the mapping tables and presents logical entities to the users. For instance, when the business logic layer sends a request to access the data, the data layer will address resolution and access to the correct physical storage device. Subsequently, read and write instructions go directly to the business logic layer, and are ready to be presented to users.

This particular three-tier model is supported by a cloud-based infrastructure. It is different from the traditional deployment methods. Before cloud computing taxonomy was well defined, it was common for companies to have their own local files and application servers, as well as local storage devices. But now, the cloud infrastructure relocates resources and provides a centralized data center and virtualized server.

From the technical perspective, this cloud-based infrastructure provides direct data access for multi-factory management. This infrastructure can also reduce the constraints on an organization's ability to quickly adapt to evolving business needs. At the same time, it can rapidly respond to the provisioning of new services or other applications to this existing platform. Because of the cloud-based platform, each instance of this architecture is adapted to specificities of each application case.

Based on preliminary experiences, the advantages of this solution can be summarized as follows:

- Users only need to install web browsers to use this cloud-based system. It minimizes technical complexities and infrastructure.
- It provides an easier way for supply chain and manufacturing execution and control and it maximizes the benefits of IT systems.
- It provides a flexible platform to integrate different applications.
- It effectively constructs the connection of information from different factory floors.
- It provides a platform to share experiences of the cooperative team.
- Different users can have different customized views to monitor different information.
- It supports the decision making process and simplifies the business processes.

7. Conclusions and future work

The first ERP-like application was developed in the early 1960s. With the idea of controlling the business information flow within companies, ERP is limited to fulfilling functions outside companies, namely the entire supply chain. Especially in a global market business environment, ERP-solutions lack flexibility in adapting to the changing needs of the supply chain.

Considering this situation, today's standard product tracking and ERP-solutions seem ill-fitted to answer these needs. A first step toward greater supply chain integration seems to be product centric, light-weight product tracking systems, aimed at securing a greater degree of delivery reliability and automatic delivery failure detection. Cloud-based technologies present opportunities to respond the new needs of flexible information exchange between different partners. For further informational supply chain integration (developing the aspects of material and production planning from the point of view of the supply chain), a comprehensive system is needed. While current supply chain management (SCM) systems are cumbersome for the average SME to implement and maintain, a new generation of internet-based, light-weight, easy-to-use-and-edit MES systems could become the answer for such companies. We believe that the requirements collected for the prototype development as well as the NetMES system present some insight about what near future manufacturing execution systems should include. To support the claims put forth in this position paper, NetMES has been developed to support different factories with different production layouts and process types. From a technology point of view, this new infrastructure can be seen as the next evolution of migration of different applications on one platform.

There are several items on the future research agenda. Firstly, network level standardization work on product identification numbers, locations, factories, revisions, should be done. Companies need to develop master data to support working in distributed production. Secondly, practical experiences on cloud-based systems and portals combining manufacturing information need to be collected. What are the benefits observed in the long run and what are the concerns? From a technology point of view, further work is needed on developing smart systems for data synchronization between factory level databases and cloud level databases. Data security remains an important research area related to use of cloud.

References

[1] H.A. Akkermans, et al., The impact of ERP on supply chain management: exploratory findings from a European Delphi study/European, Journal of Operational Research 146 (2003) 284–301.

[2] R.J. Arend, J.D. Wisner, Small business and supply chain management: is there a fit? Journal of Business Venturing 20 (3) (2005).

[3] W. Voorsluys, J. Broberg, R. Buyya, Introduction to cloud computing, in: R. Buyya, J. Broberg, A.M. Goscinski (Eds.), Cloud Computing: Principles and Paradigms, John Wiley & Sons, 2010, pp. 1–14.

[4] C.M. Chituc, A. Americo, T. Cesar, A framework proposal for seamless interoperability in a collaborative networked environment, Computers in Industry 60 (5) (2009).

[6] F.T. Cheng, C.F. Chang, S.L. Wu, Development of holonic manufacturing execution systems, Journal of Intelligent Manufacturing 15 (2) (2004) 253–267.

[7] D.H. Cooper, Interface for controlling transactions in a manufacturing execution system, US Patent 5,367,624, 1994.

[8] H.I. Cohen, J.V. McCusker, Web access for a manufacturing execution system, US Patent 5,847,957, 1998.

[9] B. Crowley, Manufacturing execution systems vs. ERP/MRP: the myths and realities of coexistence in today's electronics manufacturing environment, Global SMT & Packaging 11 (9) (2011, September) 10–16.

[10] R. Füricht, H. Prähofer, T. Hofinger, J. Altmann, A component-based application framework for manufacturing execution systems in C# and .NET, in: 40th International Conference on Technology of Object Oriented Languages and Systems (TOOLS Pacific 2002), Sidney, Australia, (2002), pp. 169–178.

[11] A. Gunasekaran, E.W.T. Ngai, Information systems in supply chain integration and management, European Journal of Operational Research 159 (2004) 269–295.

[12] P. Grefen, et al., Dynamic business network process management in instant virtual enterprises, Computers in Industry 60 (2) (2009).

[14] G. Halse, Manufacturing Execution Systems in the Cloud, MD ApplyIT, 2011 http://www.instrumentation.co.za/news.aspx?pklnewsid=37607 (accessed August 2012).

[15] J.J. Hwang, H.K. Chuang, Y.C. Hsu, C.H. Wu, A business model for cloud computing based on a separate encryption and decryption service, in: ICISA, 2011 International Conference on Information Science and Applications, 2011, 1–7.

[16] J. Harauz, et al., Data security in the world of cloud computing, IEEE Security & Privacy (2009) 61–64.

[17] S. Izza, L. Vincent, P. Burlat, Exploiting semantic web services in achieving flexible application integration in the microelectronics field, Computers in Industry 59 (7) (2008).

[18] R.F. Jacobs, F.C. Weston, Enterprise resource planning (ERP) – a brief history, Journal of Operations Management 25 (2) (2006).

[19] A. Khajeh-Hosseini, I. Sommerville, I. Sriram, Research challenges for enterprise cloud computing, in: 1st ACM Symposium on Cloud Computing, SOCC 2010, 2010.

[20] G. Kulkarni, et al., Cloud security challenges, in: Proceedings of Conference on Telecommunication Systems, Services, and Applications (TSSA), 2012.

[21] J. Li, D. Blumenfeld, Implementing an Andon, Industrial Engineer: IE 38 (10) (2006, October) 52–53.

[22] H. Lan, et al., A web-based manufacturing service system for rapid product development, Computers in Industry 54 (1) (2003, May) 51–67.

[23] Z. Li, Y. Chen, L. Shen, A component based reconfigurable manufacturing execution system, Advances in information Sciences and Service Sciences (AISS) 3 (10) (2011, November), http://dx.doi.org/10.4156/AISS.vol3.issue10.21.

[24] A. Lenart, ERP in the cloud – benefits and challenges, Lecture Notes in Business Information Processing 93 (Part II) (2011) 39–50. , http://dx.doi.org/10.1007/978-3-642-25676-9_4.

[25] J. Moad, MES in the Cloud: Is it Time? Manufacturing Executive: The Global Community for Manufacturing Leadership, 2012 http://www.manufacturing-executive.com/thread/1753 (accessed August 2012).

[26] D.M. Mangiuc, Enterprise 2.0 – is the market ready? Journal of Accounting and Management Information Systems 10 (4) (2011) 516–534.

[27] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, A. Ghalsasi, Cloud computing – the business perspective, Decision Support Systems (2010), http://dx.doi.org/10.1016/j.dss.2010.12.006.
[28] M. McClellan, Applying Manufacturing Execution Systems, St. Lucie Press, Florida, 1997.
[29] M. McClellan, Introduction to manufacturing execution systems, in: MES Conference & Exposition, Baltimore, MD, June 4–6, 2001.
[30] A. Majed, Z. Mohamed, Supply-chain re-engineering using enterprise resource planning (ERP) systems: an analysis of a SAP R/3 implementation case, International Journal of Physical Distribution & Logistics Management 30 (3/4) (2000) 296–313.
[31] M.D. Myers, Qualitative research in information systems, MIS Quarterly 21 (2) (1997, June) 241–242.
[32] E.I. Neaga, A.V. Gheorghe, A 'system-of-systems' standardised architectural approach driven by cloud computing paradigm, International Journal of Systems Engineering 3 (2) (2011) 103–116.
[33] H. Panetto, A. Molina, Enterprise integration and interoperability in manufacturing systems: trends and issues, Computers in Industry 59 (2008) 641–646.
[34] S. Shalini, Smart Manufacturing with Cloud Computing, Sraman Mitra, 2010 http://www.sramanamitra.com/2010/12/03/smart-manufacturing-with-cloud-computing-part-1/ (accessed August 2012).
[35] W. Shen, Q. Hao, S. Wang, Y. Li, G. Hamada, An agent-based service-oriented integration architecture for collaborative intelligent manufacturing, Robotics and Computer-Integrated Manufacturing 23 (3) (2007).
[36] D.W. Straub, D. Gefen, M.C. Boudreau, Quantitative research, in: D. Avison, J. Pries-Heje (Eds.), Research in Information Systems: A Handbook for Research Supervisors and their Students, Elsevier, Amsterdam, 2005, pp. 221–238.
[37] S.K. Subramaniam, S.H. Husin, R.S.S. Singh, A.H. Hamidon, Production monitoring system for monitoring the industrial shop floor performance, International Journal of Systems Applications, Engineering & Development 3 (1) (2009) 28–35.
[38] P.H. Valckenaers, V. Brussel, Holonic manufacturing execution systems, CIRP Annals – Manufacturing Technology 54 (1) (2005) 427–432.
[39] F.B. Vernadat, Interoperable enterprise systems: principles, concepts and methods, Annual Reviews in Control 31 (1) (2007).
[40] T. Wood, P. Shenoy, A. Gerber, K.K. Ramakrishnan, J.V.D. Merwe, The case for enterprise-ready virtual private clouds, in: HotCloud'09 Proceedings of the 2009 Conference on Hot Topics in Cloud Computing, 2009.
[42] X. Xu, From cloud computing to cloud manufacturing, Robotics and Computer-Integrated Manufacturing 28 (2012) 75–86.
[43] D. Yen, D. Chou, J. Chang, A synergic analysis for web-based enterprise resource planning systems, Computer Standards & Interfaces 24 (4) (2002).
[44] K. Zhang, B. Ma, P. Dong, B. Tang, H. Cai, Research on producer service innovation in home-textile industrial cluster based on cloud computing platform, in: 2010 IEEE International Conference on Service Operations and Logistics and Informatics (SOLI), 2010, 155–160. , http://dx.doi.org/10.1109/SOLI.2010.5551590.
[45] B.P. Rimal, A. Jukan, D. Katsaros, Y. Goeleven, Architectural requirements for cloud computing systems: an enterprise cloud approach, Journal of Grid Computing 9 (1) (2011) 3–26.
[46] L. Zhang, Q. Zhou, CCOA: Cloud computing open architecture, in: IEEE International Conference on Web Services, 2009. ICWS 2009, 2009, 607–616.
[47] G. Candido, J. Barata, A.W. Colombo, F. Jammes, SOA in reconfigurable supply chain: A research roadmap, Engineering Applications of Artificial Intelligence 22 (2009) 939–949.

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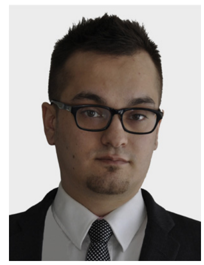

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