Traceability and Data Support in SME Manufacturing

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Abstract

Appropriate description and implementation of internal part traceability in manufacturing is a complex task. Accurate and real-time traceability from a part to a manufacture, storage, or transport issue is essential to efficient and high-quality operations. With the increasing amount of machine status and product quality information coming from the manufacturing lines, a question arises. When there is a problem with the process or product quality what information can be utilized to enable effective traceability to the foundry batch lot? In this paper a systems-based approach is applied in a participating SME foundry. The literature is almost non-existing in traceability supporting foundry manufacturing and hence the novelty of this paper.

Keywords: *Foundry Traceability, Foundry Automation Integration*

1. Introduction

Similar to foundry related *flexibility* [1][3]; *traceability* in literature also results in a number of definitions and its types and its applications being in areas ranging from part recall, part-liability-prevention, process improvement, logistic applications etc. Traceability in the foundry context, described in this work, can be defined as the ability to retain and trace the identification of the part, its originating melt batch and value added operations [2]. The discussed industrial implementation discussed relates to the traceability in a passive sense. Traceability in the passive sense helps in providing visibility to which melt batch do the parts come from, where the items are and their respective dispositions. [4]

Globalization has created an environment of similar opportunities for manufacturing competitors around the world. It has created a world market driven by fierce competition among companies that are located in different parts of the world but produce similar products. Organizations both large and small, require a set of reconfigurable equipment to meet customer demands of one of kind, or small batch quantities of customized products. Client demands for small volumes of customizable product leads to a paradigm shift in how effectively a SME (less than 250 employees and less than €50 million annual turnover: European Commission 2010); would operate to satisfy varying customer demands.

Flexible automation allows rapid reconfigurability of the production system in order to manufacture several different products, achieving high degree of machine utilization, reduction of in-process inventory, as well as decrease in response times to meet the changing customer preferences. Automation is the force behind the rationalization of manufacturing processes to increase competitiveness and productivity. Manufacturing is of high importance to Europe, with a huge potential to generate wealth, jobs and a better quality of life. Manufacturing activity in Europe represents approximately 21% of the EU GDP and provides about 20% of all jobs (more than 30 mi) in 25 different industrial sectors, largely dominated by SMEs.

The ability to respond efficiently to the changing demands of the customer and is different in SMEs (Small-to-Medium manufacturing Enterprises) than the traditional OEMs (Original Equipment Manufacturers). Literature shows that the central distinction between large and small firms is the greater external uncertainty of the environment in which the small firm operates, together with the greater internal consistency of its motivations and actions. It has been observed that identifying best practices is a tricky process difficult to implement, which is more noticeable when the companies are small- to medium-sized enterprises (SMEs). Typically, SMEs have severe resource constraints and limited knowledge of manufacturing automation methodologies.

From the perspective of SME foundry traceability there has been very limited academic literature published in the area. Vedel-Smith et al. presented a methodology for enabling traceability cast iron foundries by part number marking on individual castings [4]. Arabatzis et al. described the issue of traceability in aluminium foundry [5]. The literature is almost non-existing in traceability related to data collection supporting manufacturing control plan, and hence the novelty of this paper. This paper aims to provide the most comprehensive compilation of general flexible manufacturing parameters that could be applicable to SMEs industries with demonstration in the metalcasting industry. A limitation of the study is the number of SME foundries (nine national foundries). A detailed analysis of results based on such small sample of participants is not practical, nevertheless this number is representative of the total foundry businesses in the country. The paper helps in the development of further studies in the addressing the automation needs of the industry in which the number of published studies is limited.

The structure of the paper is as follows : Section 2 describes the importance of traceability, followed by the usage requirements of internal traceability system for an iron foundry. Section 3 describes the SME industrial background. Section 4 describes the data collection activity procedure for supporting traceability control plan documentation. The methodology and procedure were applied to an iron foundry business described as case study Section 5 presents the conclusions.

2. Manufacturing traceability

Traceability is defined as 'the ability to trace the history, application or location of an entity by means of recorded identifications'. (ISO 8402). This definition is also mentioned in ISO 9001:2008 quality management systems requirements which states that 'where traceability is a requirement, the organization shall control the unique identification of the product and maintain records.' The standard suggests incorporating traceability into the quality control plan 'retrieval, retention and disposition' to meet the compliance to standard.

2.1 Traceability levels

The concept of traceable unit (TU) was first introduced by Kim where it was defined as a batch of any resource. In SME manufacturing, a traceable unit could relate to an individual part; a batch of parts originating from a specific raw material/input; or relate to the shift operating to produce parts for example, during a certain day or week etc. The nature of the discrete batch product determines the definition of traceable unit, its importance and level. Some of the variables that determine the relative importance of are product value, criticality, customer requirements etc.

There are a few reference models mentioned in the literature, suggested for batch level and individual part level traceability control in the manufacturing. [8][10] Van Dorp presented a reference data model for batch traceability. [11] For example, part traceability to assure product quality is mandatory requirement from automotive part suppliers and OEMs. [12] This is to ensure passenger safety by compliance to automotive safety standards. [13]

The method of implementing traceability systems can affect acceptance of the system users. Sohal [12] stresses the importance of adequate employee training. As the technical setting affects the usefulness of traceability data, the main impacts of the organizational setting seem to be in the overall success and acceptance of the system. The utility of data can be realized only when the opportunities for the use of data are perceived and the data is used.

A number of day to day applications of traceability can be found in logistics, legal, quality etc. related activities. Cheng et al.[14] state that traceability refers specifically to the ability to retrace steps and verify that certain events have taken place. The information required from the tracing functions at different points in the history of events and at different levels in the manufacturing system is the next step in the traceability cycle.

Traceability has different defintions in literature: *Internal Traceability*, that is the traceability inside the factory and the production system and *External* that follows the product into his relations with customers, maintainers, suppliers, etc. [14]. Another definition proposed has been *Backward* and *Forward Traceability* [15] (Figure 1). *Backward Traceability* records information and data on the past history of the product. *Forward traceability* explains what will happen to a certain product, all the processes and output that the product in question went into. These information are written before the product production begins and aims to give all the information that are needed to the production. This kind of traceability could be very useful in automated manufactures [16].

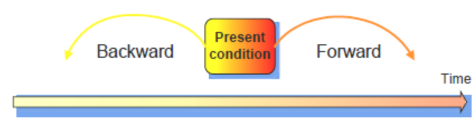

Figure 1. Backward and forward traceability

Cheng and Simmons provide examples of traced information operations, design and strategy levels of manufacturing systems [14] Similar levels of manufacturing systems have been proposed in literature. [17][18] According to Cheng, traced information available at the operations level would be batch size, machine availability, machine reliability information such as machine uptime and downtime etc. Examples of information at the planning level have been proposed as product cost, rework and scrap level, new product introduction, exploiting new technology etc. The strategy level concerns government regulations, company expertise, growth etc.

2.2 Traceability data

Batch traceability is defined by APICS as ‘the ability to identify the batch numbers of consumption and/or composition for manufactured, purchased or shipped items.’ [19] With batch tracing, one can identify suspect products or processes. Three models describe the requirements needed to create a traceability system.

First, Caplan identified five techniques to employ for traceability with the primary purpose of cost savings in case of part recall: [8]

- Lot integrity control: Identification of lots and prevention of strayed parts from parent lots.
- Processing control: Unique identification assigned to each part or group of parts.
- Build control: Identification of processing and assembly information to depict which components were combined to manufacture the final assembled product.
- Inspection and test: Recording results of evaluation initiatives.
- Field activity and modification control: Recording installation processes, services and engineering changes.

Second, Steele identified two types of data, batch and process, to define the full scope of batch traceability. [9] Batch traceability data records the occurrence of movement into processing the parts and mixing of different batches. The process data records important statistical or quality process related information. Steele identified three ways of correlating process material to batch lots, namely, recording batch identification number; tracing raw material by batch number and linking batches and processes by date and time. Four OEMs were evaluated to determine a good benchmark for the proposed traceability scope. How well the resolution of the batch traceability is maintained determines the resolution of the traceability system.

Third, Jansen et al. specified core requirements for any traceability system.[15] Recording data for any operation on batches to attain the final product, the need for ‘upstream’ and ‘downstream process’ investigation such as ‘where used’ and ‘where from’ for batches, and also easy identification of batches; were perceived as the core requirement for traceability system.

2.3 RFID in manufacturing traceability

Recently, Chongwatpol et al. presented an RFID based information traceability approach demonstrating its application in a job shop SME. [20] The study provides an analysis on the development of an RFID based system that tracks work-in-progress. Delen et al. presented a case study exploring the benefits of RFID in supply chain management. [21] Lee and Park proposed a model to trace the end product and its subcomponents in the Bill of Materials (BOMs). [22] Sari presented the impact of RFID on supply chain performance. [23]

Both RFID and barcodes are identification and data collection technologies. They do have some differences in many aspects. RFIDs have a longer reading range of over a 100 m. [24] [25] RFIDs can read tags at a fast speed of 100 tags/s. RFID tags have memory capabilities for passive (4 kB) and active tags (1 MB). [27] Barcodes, on the other hand, can only be read individually. [White et al] The increasing applications of RFID (radio frequency identification) technology, which has been extensively applied in the fields of logistic, supply chain, warehousing, retailing and transportation. However, due to relatively low cost, some companies still prefer to use barcodes.[29]

2.4 Traceability information distribution in batch production

The literature related to trends of information distribution system design when moving from mass customization to batch production using flexible manufacturing technology and its relationship to traceability is suggested.

The advantages of mass production come from economies of scale and system design. [30][31] The dedicated manufacturing production line is an ideal solution when a part is designed and manufactured in mass quantities.[31] The typical information adopted by mass production OEMs includes company product numbers listed in their catalogues. The companies use standard bill of materials, resource planning, inventory, purchasing and delivery functions. Within the mass production process islands of CNC and robot equipment evolve, often working in isolation producing inventories of semi-finished components.

The advantages of economies of scale by producing in mass quantities are transferrable to batch production using flexible manufacturing systems (FMS). [31] The subject is also closely connected with the evolution in the microprocessor technology which has enabled new methods of production planning and machine control as pointed out by Sethi and Sethi [32]. These new methods have enabled developers and manufacturers to build features into their systems that make new, flexible manufacturing solutions possible. A flexible manufacturing system although more expensive than dedicated manufacturing production line enables production of new incoming batches of products on the same existing system, thus expanding its life.

Analyzing a batch manufacturing system with integrated automated elements we realize that it is actually a combination of several components. This realization leads us to believe that to be able to analyze the flexibility of automated manufacturing systems we need to look at the flexibility of the components that the system is made up of. For example, an automated production line is usually made up of some sort of transportation system, handling devices, feeders, robots, sensor systems, computers and human resources for operating and maintaining the system. This holistic view of the system leads to believe that the best way to measure the flexibility of the automated system is to use some kind of aggregate measure combining measures of several dimensions of flexibility.

Flexibility comes with the use of computer controlled CNC machines used in processes such as finishing. These machines have the advantage of resetting themselves according to the product/product family being processed. This helps reducing the setup time enabling changeover capability for batch production environment and hence provides an advantage over the dedicated production lines of mass production system. Availability of instructions, for each individual batch, enables the production system to work effectively.

Each manufacturing line in a company is designed differently according to their specific requirements. Information may or may not be required at each process. There are a number of different methods for distributing information to various manufacturing process work centers, machines and sub-processes. These include download able files, bar codes, display monitors. The process of downloading data to individual machines or workstations automates the process while saving operator time and error.

2.5 Data Modeling

Data model is a visual plan for building a database. [39] A data model may be one of three types: conceptual, logical or physical. There are generally four data modelling methods; the Richard Barker methodology [40], the IDEFX1 [41], the entity-relationship model (ERM) [42] and the unified modelling language (UML). [43]

The Barker methodology is a style of visual language to draw entity relationship diagrams which is used by Oracle case modelling tool. The methodology shows how the data modelling technique can be applied to develop quality integrated information systems. Many favoured the readability and efficient use of drawing space and variation of the 'crow's foot' style of data modelling in this methodology. IDEF1x is a federal information processing standard used to support the management of data as a resource, the integration of information systems and building computer databases. It is used to produce a graphical information model which represents the structure and semantics of information within an environment or system. Basic constructs of an IDEF1x are: Box (to keep the objects), lines (to connect the boxes) and attribute names (describes the characteristics within the boxes). The ERM is the meta model ANSI standard in information resource directory systems (IRDS). It can be used for unification of different views of data, relational and the entity set model. The UML is a graphical language for visualizing, specifying, constructing and documenting artefacts of a software-intensive system. The UML diagram represents three different views of a system model: functional view, static structural view and the dynamic behaviour view.

The ERM is adopted for the case study in this paper as it was found well suitable for the level of data definition and proven application features that the SME detailed as a case study in this paper required.

3. SME Industrial Background

Small and medium enterprises (SMEs) are very dynamic, innovative and from a manufacturing point of view, face many demanding customers and intense competition. What is interesting is the fact that the size and complexity of the systems that need to be developed for SME competitiveness are comparable to the systems developed by large companies. An advantage though is that small and medium sized manufacturing companies are usually more entrepreneurial and willing to experiment and innovate in terms of manufacturing operations than larger companies with established hierarchies. Thus, governmental initiatives aimed at increasing the manufacturing readiness of SMEs can result in a higher level of national and international competitiveness in this important sector.

3.1 SMEs in European Union

The importance of SMEs in the EU clear by the most recent annual report. The SMEs represent 99% of the businesses and more than 66% of the total employment. [44] Some of the challenges identified facing the SMEs in the above survey are as

- Limited access to finance- SMEs could be limited by the financial ability to purchase and implement modern robotic automation and flexible manufacturing technologies.
- Skilled Labor-The shortage of skilled automation specialists could be prominent in small medium enterprises. This slows down the application of latest technologies.

- Administrative regulations- SMEs tend to have a personalized style of management and lack formal management structures like the OEMs.
- Infrastructure- SMEs don't have the necessary knowledge base or infrastructure to test various flexible frameworks.

The last point has a heightened importance for SMEs [44]. SMEs present three economic impacts mentioned below

- The presence of SMEs increases the competition in the market by the growth of new ideas, specialized know-how and labor.
- SMEs increase the diversity in the market which increases with their growth.
- They serve as a medium of knowledge transfer which OEMs can access via company acquisitions through IP transfer or technology acquisition. Van der Linde [45] identified 833 industrial consortium clusters in his study, whereas the [44] identified this number as 900. Some notable characteristics that could be identified from the EC are:
- Connecting new technologies for regional SME networks
- The need for improving the innovation capability between the SMEs.

One could observe that the European regional alliances show a better performance than the national average of their respective industries. The European Commission had the following main conclusions in its study related to the cooperation between SMEs:

- Cooperation and Performance - More than 75% of the SMEs interviewed stated that cooperative practices helped them improve their competitive advantage
- Main obstacles – The SMEs desire to maintain their independence and fear to open up the strategic information that they thrive on.
- Reasons for motivation for cooperation- The main reason is the common cultural basis that was mostly observed in the Nordic countries. The motivating factor for cooperation was to develop technology to compensate for high labor cost and meet global competition.
- Existence of cooperation practices- In general, approximately half of the European SMEs present cooperation practices formal/informal. The Nordic countries Norway, Finland and Sweden stood out in this study.

Government efforts and programs that support partnerships involving SMEs can help ensure that this critical growth sector is not left behind in manufacturing competitiveness. Most governments play a mobilizing role in facilitating partnerships amongst private businesses, industrial research partners, universities and educational institutions and industrial associations as a strategic means of supporting SME manufacturing development. The focus on SME collaboration for innovation is motivated by the fact that the more the cross organizational and cross disciplinary the competencies that are involved in an innovation, the harder it is for the competitors to break in. The results of the efforts from one such foundry SME consortium during an academia collaboration project for flexible automation supporting plantwide traceability has been described as a case study for this paper.

3.2 Automation in SME manufacturing

It is becoming increasingly evident over the past few years that one of the major possible ways to improve the production rate and reduce labour costs is to automate the process of handling of handling of parts accompanied by tools to plan the varying production rate with production lines having imperfect machines, work in progress and product handling. The above view is consistent with the literature and is justified because of the following observations

- A review of the current manufacturing processes in most SME industries reveals that over 65% of the total manufacturing time is spent in manual handling of the material by human operators.
- It was also found that the cost of manufacturing a product is roughly between 30%-40% of total manufacturing cost, which increases with increased labour cost.

3.3 Foundry SMEs

Foundry SMEs in particular are in need help from automation technology, and some of the reasons are listed below

1. Intensive in manual labour
2. Have high variation in parts, due to multiple environmental variables such as temperature of molten metal, metal solidification defects etc. which is a huge detriment to automation
3. The extreme environmental working conditions of foundries necessitates the need for automation
4. Health and safety issues in foundries are an important driver for automation in the foundry as well.

From above we notice that the first, third and fourth drivers are the main reasons supporting automation of foundries. The second diver is a deterrent to flexible automation from a foundry perspective. Flexible automation is key to the future development of foundries, with more operations being carried out by robots. Global competitive pressures, along with increased demand from major customers are the two primary factors fueling this trend.

4.Supporting data collection activity for documenting traceability control plan

Depending on the customer requirements of traceability data must be recorded from raw material input until shipment to the customer. The concept of traceable unit (TU) was first introduced by Kim at al. [6] where it was defined as a batch of any resource. In foundry practice, a traceable unit could relate to an individual part; a melt used to cast a batch of parts; or relate to the shift operating to produce parts for example, during a certain day or week etc. The level of traceability is usually agreed with the customer.

The start of the casting process when iron is melted the oven number and raw material delivery number can be recorded. Depending on the molten metal delivery technology used at the casting facility, the holding oven numbers used to hold the molten metal are the next in step supporting process traceability. The casting process traceability data such as the sand mold cycle number, batch number, internal job number can be provided for the downstream processes when the parts are put on the cooling tunnel to the cast part cleaning and fettling process. After a visual check, the cast parts could follow an automated finishing process or a manual finishing process. The part batch number dictates how the part would be handled during transfer operations and the sequence of finishing operations that would be performed in order to process the part successfully. After this process it is advised to check the part to ensure that it was processed successfully and does not contain any non-conformances. In case of observed non-conformance a decision needs to be made as to whether the part can be reworked, needs to be scrapped or can move to the next process downstream which is assembly. After sub-assembly process the product could go into a safety stock or move to the downstream assembly and inspection process before final packing, storage and shipping. The parts can obtain the disposition for scrap or re-melting if a non-conformance occurs at any process stage.

4.1 Industrial Implementation

A series of IDEF diagrams were created to support the implementation of part traceability at an automated cell at the company (a commercial product cast iron foundry manufacturer). The foundry wanted to look into automating traceability data collection at the CNC finishing and thereby reducing the manual handling of heavy parts with flash on its edges.

Figure 2. Cast iron parts with flash on the edges

A series of standard IDEF0 functional model diagrams for the system elements in sand casting flexible automation cell were developed which were suitable to the manufacturing needs. The manufacturing automation installation consists of the following modules: (1) the vision module, (2) the robot module (3) the robot end effecter part handling module (4) the automated storage lift, (5) the CNC machine (6) RFID tags placed on the (7) part family fixtures. When there is an order from ERP system to meet a request downstream, the HMI requests the bin selection from storage lift. When the requested bin is available at the exit of the lift the robot receives a signal notifying that the bin is in place under the vision system, and notifies the camera through PLC, to take the picture. The position and orientation of the part/fixture is transferred to the robot via the PLC, which then proceeds to orient the gripper accordingly to pick the part. Different grippers and configuration for part pick-up and delivery position to the basket were programmed by the foundry engineers to make them available for possible use. After the part is loaded by the robot on the CNC the delivery of the part on the fixture is confirmed by the inductive sensors located on the fixture. The part is located on the fixture via rotation and sliding locators. A sliding locator ensures that the variation in part linear dimensions during the casting process is properly compensated. If the part is in the correct position the clamps are activated and the machining starts.

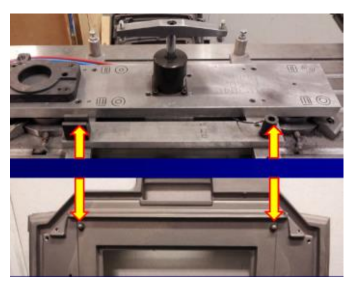

Figure 3. Part locators

Step2 and Step 3
The entity-relationship (E-R) technique was used to develop the internal traceability database model for the automation cell. The E-R model is represented in terms of entities in the manufacturing environment, the relationship among the entities and their attributes. [16] The implementation of the database, the human-machine software interface and its performance testing was conducted by an external vendor and is proprietary on request.

A control plan was developed for use at the automation cell by the manufacturing engineers under the supervision of the Quality director at the company. Initial validation of the installed automation cell was done internally in the company. Due to company's reorganization and facility layout restructuring, any further validation of the cell could not be conducted.

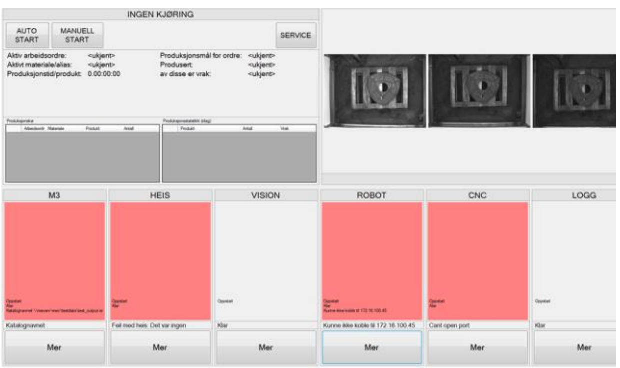

Figure 4. HMI Interface

5. Conclusion

In From the literature it is apparent that the use of traceability data is not limited to crisis situations, where defective products need to be identified and recalled, and situations where evidence needs to be provided. It is very clear to many authors that the necessity for traceability exists throughout a variety of manufacturing businesses whether it is a foundry or an aerospace manufacturer. The methodology could be generalized and applied to the case of an aerospace manufacturer, as the data collection process supporting traceability remains the same but the regulatory requirements on data storage may be longer, for example 50-60 years or longer, as compared to the short term requirements in commercial product manufacturing foundries. There is a wealth of data present in the new automated systems and it can be used to provide the status of each component in the system as well as the condition of the systems components. From the business side of the organization the data can be fed to an internal database and determine if the performance of the manufacturing operations is in line with the planed output and to know the quality of the parts as they come off the end of the line. The data is valuable and can be utilized for as many of the process indicators that are possible. As the processes are developed, the traceability element will need to be part of the design. This type of innovation will keep the organization on the leading edge of the competition.

Acknowledgments

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References

[1] Wadhwa R, Towards Modeling Changeovers for flexible foundry manufacturing, IJCSI, 2012.
[2] Bradford, J. 2002. A non-linear redesign methodology for manufacturing systems in SMEs. Computers in Industry. vol:49 iss:1 pg:9.
[3] Wadhwa R, Electromagnetic gripping in iron foundry automation Part III: Practice, IJCSI, 2012.
[4] Vedel-Smith NK & Lenau TA, Casting traceability with direct part marking using reconfigurable pin-type tooling based on paraffin-graphite actuators, Journal of Manufacturing Systems, 2012
[5] Aarbatzia T, Elval pilot aluminum casting traceability supported by CIMOSA, Computers in Industry, 1995
[6] Kim, H.M., Fox, M.S., Grüninger, M., 1999. An ontology for quality management enabling quality problem identification and tracing. BT Technology Journal , 17(4), 131-140.
[7] Juran JM, Gryna FM, 1988, Quality Control Handbook, Mc Graw Hill Inc.
[8] Caplan F, 1989, the quality system, Pennsylvania: Chilton Book Company.
[9] Steele DC; 1995, A structure for lot-tracing design, Production and inventory management journal, 36 (1), 53-59.
[10] Toyryla, I, 1999, Realising the potential of traceability, PhD thesis, Helsinki University of Technology, Finland.
[11] Van Dorp, CA, 2004, Reference data modeling for tracking and tracing, PhD thesis, Wageningen Agricultural University, The Netherlands.
[12] Sohal AS, Computerized parts traceability: An implementation case study, Technovation, Vol 17, No 10, 1997, pp 583-591.
[13] Aerospace First Article Inspection Requirement, 2004, SAE AS 9102, G-14 Americas Aerospace Quality Standards Committee (Aaqsc).
[14] Cheng, MJ & Simmons JEL, 1994, Traceability in Manufacturing systems, International journal of operations and production management, Vol 14, No. 10, 4-16.
[15] Jansen-Vullers J., A. van Dorp, B. Beulens, 2003, Managing Traceability information in manufacture, 2003, International Journal Of Information Management 23 : 395-413
[16] McFarlane D., J. Sarma, G. Chirn, J. Wong, A. Ashton, 2003, Auto-ID systems and intelligent manufacturing control, Journal of Engineering Applications of Artificial Intelligence, 16 : 365 – 376
[17] Vollmann, T, Berry W, Whybark D, Manufacturing planning and control systems, 2 nd edition, Dow Jones Irwin, Homewood, IL, 1988.

[18] Bilberg A, Alting L, When simulation takes control, Journal of Manufacturing Systems, Vol 10 No 3, 1991, 179-93.
[19] APICS Dictionary. 7th Ed. Falls Church VA: American Production and Inventory Control Society, 1992: 27.
[20] Chongwatpol J, Sharda R, 2013, RFID enables track and traceability in job shop scheduling environment, European journal of operations research, 227, 453-463.
[21] Delen D, Hardgrave BC, Sharda R, 2007. RFID for better supply chain management through enhanced information visibility. Production and operations management 16(5), 613-624.
[22] Lee D, Park J. 2008. RFID based traceability in supply chain. Industrial Management and Data Systems. 108(6), 713-725.
[23] Sari K, 2010. Exploring the impacts of radio frequency identification technology on supply chain performance. European Journal of Operations Research. 207(1), 174-183.
[24] Jedermann R, Ruiz-Garcia L, Lang W, 2009, Special temperature profiling by semi-passive RFID loggers for perishable food transportation. Comput. Electr. Agric., 65 (2), 145-154.
[25] Ruiz-Garcia L, Lunadei L, 2011, The role of RFID in agriculture: Applications, limitations and challenges. Comput. Elec. Agric. 79(1) 42-50.
[26] Finkenzeller K, 2004, RFID Handbook Radio-Frequency Identification Fundamentals and Applications, second ed. John Wiley & Sons, England.
[27] EPC Global , 2008, EPC Radio Frequency Identity Protocols Class-1 Generation-2 UHF RFID. Protocols for communication at 860-960MHz.
[28] White G, Gardiner G, Prabhakar G, Abd Razak A, 2007, A comparison of barcoding and RFID technologies in practice. Journal of Inform. Technology, 119- 132.
[29] Inlogic. RFID vs barcodes comparison. 2011. (http://www.inlogic.com/rfid/rfid_vs_barcodes.aspx)
[30] Pine BJ, 1999, Mass customization: the new frontier in business competition, Harvard Business School Press, Boston, MA.
[31] Koren Y, Ceryan O, 2009, Manufacturing capacity planning strategies, Annals of the CIRP, 58/1.
[32] Sethi, S.K., Sethi, S.P., (1990) Flexibility in manufacturing: a survey. International Journal of flexible manufacturing systems.2:289-328.
[33] De Toni , A., Tonchia, S. (2002), New production models: a strategic view. In International Journal of Production Research. 40:4721-41.
[34] Gerwin, D.,1993. Manufacturing Flexibility: A Strategic Perspective. Management Science , 39/4:395-410
[35] Grubbstrom R.W., Olhanger, J. (1997) Productivity and flexibility: fundamental relations between two major properties and performance measure of the production system. International Journal of Production Economics 52:73- 82.
[36] Lee, J., Hu, J., Ward,A. 1999. Workspace synthesis for flexible fixturing of stampings, Transactions of the ASME , 478/Vol. 121.
[37] ElMaraghy, H.A. (2005) Flexible and reconfigurable manufacturing systems paradigm. International Journal of Flexible Manufacturing Systems, 17:261-276.
[38] Zhang, Q., Vonderembse, M.A., Lim,J-S., (2003) Manufacturing flexibility: defining and analyzing relationships among competence, capability and customer satisfaction. Journal of Operation Management ,21:173-191.
[39] Khabbazi MR, Ismail N, Ismail MY, 2009, Data Modeling of traceability information for manufacturing control system, International conference on information management and engineering.
[40] Barker R, 1990. Case Method. Entity Relationship Modeling. Addison-Wesley.
[41] IDEF1x, 1993, Announcing the standard for integration definition for information modeling (IDEF1x) Federal Information Processing Standards Publication 184, vol. 2008.
[42] Chen PPS, 1976. The entity relationship model toward a unified view of data. ACM transactions on database systems, TODS, 1(1), 9-36.
[43] Booch G, Jacobsen I, Rumbaugh J, 2000. OMG Unified Modeling Language Specification. Rational Software Corporation, Version 1.3, First Edition [online] (http://www.omg.org/docs/formal/00-03-01.pdf)
[44] European Commission (EC) (2004b) 'Observatory of European SMEs, 2003, No.8 Highlights from 2003 observatory',
[45] VanDerLinde, C. (2003), The demography of clusters-findings from cluster meta study, Innovation Clusters and Interregional Competition, Berlin, Heidelberg, New York: Springer-Verlag, pp. 130-149.
[46] Jenkins, H. 2006. Small Business Champions for Corporate Social Responsibility. Journal of Business Ethics. 67: 241-256.
[47] Bolton R, Tyler S, 2008, PQLI engineering controls and automation strategy, Journal of Pharmaceutical Innovation, 3, 88-94.
[48] ANSI/ISA-95.00.01-2000, Enterprise-Control System Integration, Part I: Models and Terminology
[49] Campos JG, Miguez LR, 2011. Standard process monitoring and traceability programming in collaborative CAD/CAM/CNC manufacturing scenarios, Computers in Industry, 62, 311-322.
[50] Rolstadås, A, 1997, Enterprise performance measurement, International journal of operation and production management (Special issue on BPR & M) .
[51] ISO 10303-1 1994, Industrial automation systems and integration - Product data representation and exchange - Part 1: Overview and fundamental principles.
[52] ISO 10303-223, 2008, Industrial automation systems and integration – Product data representation and exchange – Exchange of design and manufacturing product information for cast parts.
[53] ISO 10303-203, Industrial automation systems and integration- Product Data Representation and Exchange- Part 203: Application Protocol: Configuration controlled 3D design of mechanical parts and assemblies (modular version), International organization for standardization (ISO), Geneva, Switzerland, 2005.
[54] ISO 10303-224, Industrial Automation Systems and Integration – Product Data Representation and Exchange- Part 224: Application Protocol: Mechanical product definition for process planning using machining features, International organization for standardization (ISO), Geneva, Switzerland, 2006.
[55] ISO 10303-240, Industrial automation systems and integration- Product data representation and exchange

– Part 240. Application protocol: Process plans for machined products, International organization for standardization (ISO), Geneva, Switzerland, 2005.

[56] I SO 10303-228: 2007, Industrial automation systems and integration - Product data representation and exchange- Part 238: Application Protocol: Application interpreted model for computerized numerical controllers, ISO TC 184/SC 4, Geneva, Switzerland, 2002.

[57] ISO 6983-1, 2009, Automation systems and integration- Numerical control of machines- Program format and definitions of address words- Part 1: Data format for positioning, line motion and contouring control systems.