Software selection for using manufacturing shop-floor data in MPCS

-With focus on the Swedish market

by

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Abstract

One of the recent concerns for the western companies is the use of appropriate IT support for production planning and control in order to improve utilization of their resources. The offered integrated solutions should be able to cover business processes as well as manufacturing processes in the whole supply chain and to respond to changes in the companies' environment, strategy, and customer requirements.

According to The PPA studies of Swedish manufacturing companies, there is a significant gap between operation times in reality and in the planning systems. One reason for this problem is the operation times in the classical structure of MPCS are updated rarely.

This thesis work studies a modern level structure of MPCS that comprises three levels: business management level including ERP or APS systems, MES (Manufacturing Execution System) level, and production level. The integration of MES, as middle layer of MPCS, with the other levels provides real-time information and helps managers to make decision based on facts. Although specific functions are assigned to each level, there are no clear boundaries between these levels and the functions included in each level can be moved with respect to each company's circumstances. The term "MES" is examined from two aspects, first functions covered by the software and then the non-functional requirements that should be considered for implementing and operating MES solutions.
Furthermore, the study analyzes the capabilities and functionalities of software solutions introduced to the Swedish market in each level of MPCS as well as their performance with regards to the feedback from customers. The information collected is based on literature reviews, responses to a web- questionnaire and the study of IT vendors' websites.

Generally to select and implement a right MPCS package, some items should be considered. As an example, Industry type and size of the company that is interested to implement the package, number of users, functionality needed in each department of the company, the language requested, budget for the project, capabilities of the vendor all to be considered. Additionally, the functionalities of existing software solutions in the market should be evaluated with respect to the needs of the company. The implementation should be applied in several small control phases by a team which includes representatives of different sectors of the company and also an IT vendor.

Since this project is not able to investigate about the influence of 3-level structure of MPCS on the performance of Swedish companies, further studies must be done to confirm the capabilities of MES level.

Keywords: MPCS, MES solutions, Real-time information, IT vendors, and Swedish market

Acknowledgment

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I would like to express my gratitude to my family who always encourage me to do the best in my life.
I don't know how I can show my deepest gratitude to them.
Finally, thanks to someone who has supported me by developing a strong belief inside me.

Gothenburg, January 2011

Ashkan Mohajeri Naraghi

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- APS: Advanced Planning Systems
- ASMX: Active Server Methods (Microsoft filename extension)
- ASPX: Active Server Pages (Microsoft filename extension)
- BOMs: Bill Of Materials
- BPM: Business Process Management
- CNC: Computer Numeric Controllers
- CRM: Customer Relationship Management
- CSR: Corporate Social Responsibility
- DAC: Data Acquisition and Control
- DLL: Dynamic-Link Library
- EAM: Enterprise Asset Management
- ERP: Enterprise Resource Planning
- HCM: Human Capital Management
- HR: Human Resources
- ISA: Instrumentation, Systems, and Automation Society
- MDA: Machine Data Acquisition
- MDC: Machine Data Collection
- MES: Manufacturing Execution System
- MPCS: Manufacturing Planning and Control Systems
- MPL: Material and Production Logistics
- MRP: Material Requirement Planning
- MRP-II: Manufacturing Resource Planning
- NCM: Non-Conformance Management
- OCR: Optical Character Recognition
- PAT: Process Analytical Technology
- PDA: Production Data Acquisition
- PDP: Process Data Processing
- PIC: Product Innovation and Consulting
- PLC: Programmable logic Controller
- PPA: Productivity Potential Assessment
- QM: Quality Management
- R&D: Research and Development
- RFID: Radio Frequency Identification
- ROP: Reorder Point
- SFDAC: Shop Floor Data Acquisition and Collection
- SOA: Service Oriented Architecture

- SWP: Software Products
- SPC: Statistical Process Control
- SCM: Supply Chain Management
- TRM: Tool and Resource Management
- WIP: Work In Progress

1. Introduction

This chapter describes the background and problem description of the project work followed by the purpose and delimitations of the master thesis work.

1.1 Background

In today's world industry there is a fierce competition among companies, and productivity plays a major role in this competition. Western companies have faced challenges as result of low-wages countries in Eastern Europe and Eastern Asia. Therefore, optimization of manufacturing operations is vital for achieving a sustainable production system. The effective and suitable Manufacturing Planning and Control System (MPCS) is a key factor that helps a company to improve utilization of its existing resources (Almström, et al., 2009).

Manufacturing Planning and Control Systems which have been used since the earliest days of the industrial revolution (Rondeau, 2001) are designed to plan and control materials, labors, and equipments by developing feasible, time phased plans and monitoring their progress (Vollmann T. E., 2005). Six main steps can be considered for the evolution of MPCS: 1- Reorder Point (ROP) systems 2- Material Requirement Planning (MRP) systems 3- Manufacturing Resource Planning (MRP-II) systems 4- Enterprise Resource Planning (ERP) systems 5- Advanced Planning Systems (APS) that are related to the concept of supply chain management and provide functions for optimizing the production and logistics (Rondeau, 2001) 6- Integration of Manufacturing Execution System (MES) and ERP/APS (Kletti, 2007).

On a competitive world market, a company will be successful if decisions are based on facts. Thus, firms need to have MPC systems with the ability to constantly adapt and respond to changes in their company environment, strategy and customer needs. The Productivity Potential Assessment (PPA) studies of the Swedish manufacturing companies has shown that there is a significant gap between real operation times at shop floor level and the similar times in the manufacturing planning and control systems. Several causes for the gap have been investigated and have been found that management's unawareness is the root cause of these deficiencies (Almström, et al., 2009). This gap has an effect on scalability, reliability, stability, and flexibility of the companies. In order to reduce the severe consequences of this gap, a planning system is still a typically human domain in many companies.

There are several small software companies that have investigated the problem and have found solutions for collecting data on the shop floor, but few manufacturing companies were successful to optimize their production by using suggested methods. For instance, one German company (A first -tire supplier to the automotive industry) could manage to bridge the differences between operation times in the planning system and in reality. Although the company was mostly performing manual assembly, they had a well designed and very advanced system for automatic data gathering at shop floor level (Almström, et al., 2009).

1.2 Problem description

The master thesis is assigned by Chalmers University. Chalmers has been performing some research programs in a close collaboration with manufacturing, industrial software and consulting companies in order to find the main reasons for this mismatch and also give some suggestions for solving the gap.

Since the classical MPCS can just give a holistic view of company- wide business processes, they are not able to provide reliable and accurate data. Therefore, many manual corrections and intervention at the shop floor level are necessary and a lot of extra work must be done for re-planning and modifications of production schedules that are created by MPCS.

This mismatch has negative effects at different level of organization from lowest level to highest, for instance, wrong decisions at a strategic level for investment are caused by the mismatch. According to Almström, et al, there are three primary reasons for the gap: using inaccurate ways for setting operation times from beginning, adding allowances to the operation times and rarely updating the operations times in MPCS (The PPA studies have revealed that more than 75% of the manufacturing companies don't update the operation times in their planning systems). The first two causes will be taken into consideration and discussed in the future research.

Another research study was conducted across 440 firms from varied industries to figure out the primary goals for integration of ERP/APS and shop floor (Aberdeen Group, 2006). This study shows data flow from shop floor layer to ERP/APS layer is the strongest goal (figure1).

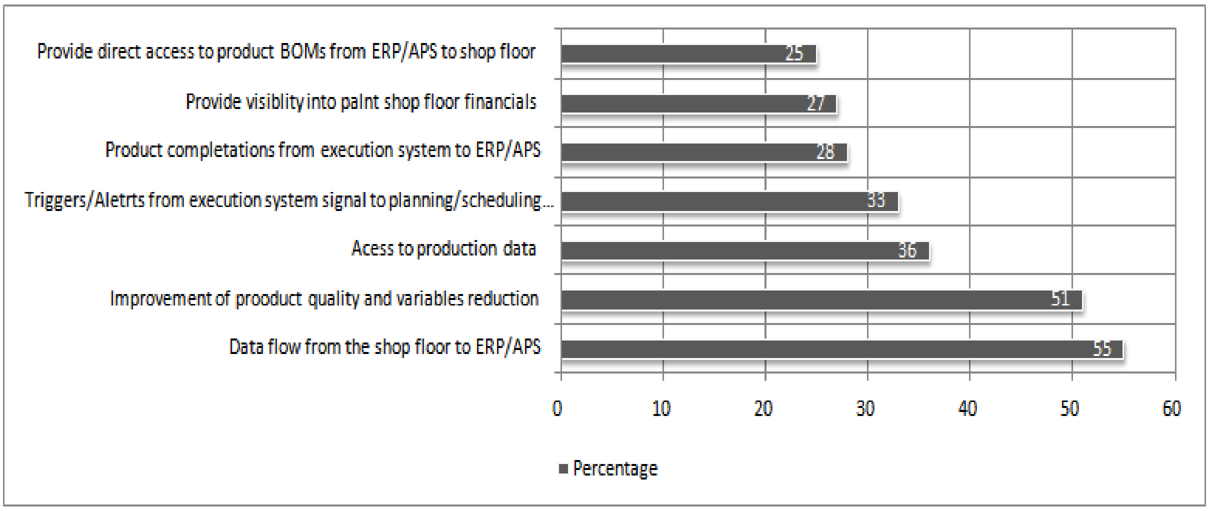

Figure 1 the goals for integration of enterprise applications and shop floor (Aberdeen Group, 2006)

Variations in manufacturing processes and also variations that depend on operator (motivation, skill level, habits and etc) make hard to update the planning systems especially for operations including manual tasks. So, a new category of information systems is necessary to support production planning and execution. Deductively meaning that the system must be capable to gather and analyze data (such as the status of production, personnel, and machine) on shop floor and then to update the data in higher level (ERP/APS).

This study analyzes the layers of MPCS as well as some common methods used for gathering data (machine and manual tasks) on the shop floor. In addition, it makes subjective conclusions about a suggestion, called Manufacturing Execution System (MES), to improve the gap between operation times in reality and in the planning system. In order to compare the performance of different planning systems, it is necessary to indicate specific criteria. The problem definition can be summarized by asking the following questions:

1. What is actually meant by the term “manufacturing planning and control systems“?
2. What are the functionalities of modern perspective of MPCS?
3. What are important items for choosing and implementing a right MPCS package?
4. What are advantages of MES implementation in the contemporary perspective of MPCS?
5. What is IT vendors’ viewpoint on MPCS and its functionalities in each layer?
6. What are the capabilities and functionalities of software solutions introduced to the Swedish market in each level of MPCS?

1.3 Purpose

Although some Swedish companies have started to develop their own solution for data retrieval, automatic data acquisition system for manual work is still a challenge for most of these companies and it needs more investigations.

The purpose of the master thesis work is to study a gap between operation times in reality and in the planning systems further and to discuss which data gathering method at shop floor level would be capable to eliminate this gap. In addition, compare different solutions packages that are used on the Swedish market for both planning and data collection functions. The aim is to use the result of the thesis work for larger research project in department of Materials and Manufacturing Technology- Chalmers University.

1.4 Delimitations

The focus of the project is to evaluate planning software packages and data gathering methods applied on the Swedish market. There are limitations regarding the technical evaluation since access to the planning systems is restricted and assessment is just based on the filled questionnaires from the related IT vendors and available information at the companies’ website. The thesis work doesn’t have the ability to confirm the validity of the recommendations.

Because the study is carried out by one person and within a timeframe, very detailed evaluation and investigation couldn’t be reached. In fact, this master thesis work is a pre-study of a research project that will be conducted by a number of researchers in Chalmers University and some Swedish companies.

2. Methodology

This chapter shortly demonstrates the differences between various research strategies and then explains how the thesis is conducted regarding the research questions that are supposed to be answered. The next section discusses the research methods used for gathering data, and then general information about participating IT vendors is presented. Finally, the research reliability and validity is briefly explained.

2.1 Research strategy

Research is an investigative process for evaluating and interpreting information that are gained by an observation or question (Waltz, et al., 1981) and research approaches can be categorized in different ways. One of the common classification methods is arranged in two clusters; primary and secondary research. Primary research investigates a subject according to original data and first hand observation but secondary research is based on previous studies that have been done by other researchers (CLarke, 2005). In most research writings like this project, both forms of research are used.

Bryman and Bell (2007) have suggested a classification for methods of research that called Quantitative and Qualitative research. Quantitative research which involves numerical data attempts to explain its observation by categorizing features and building statistical models. In this method, a researcher knows very well what is searching for and uses some tools such as questionnaires to gather data, and also the researcher remains objectively split from the subject issue. Quantitative research starts with existing theories and then formulates hypothesis, thus it is considered as a deductive approach (Dubios, et al., 2002). On the other hand, Qualitative research involves a complete and detailed description in which data is presented in the form of words, pictures or objects. A researcher doesn't know what he is exactly looking for and subjectively absorbed in the subject issue. Qualitative research which uses empirical data in order to formulate new or extended theories is considered as an inductive approach (Dubios, et al., 2002).

2.2 Thesis approach

Regarding the characteristics of this study and also the questions that are supposed to be answered, quantitative approach has been chosen to conduct the research. The main role of author during the project is to look at the problem from outside the boundaries of user and provider's circle in order to get a better understating of key subjects that have generated the problem. Preparing a questionnaire for planning software providers that are active on the Swedish market was done for the first step. In parallel, books, articles and companies websites that help to have in-depth analysis of the problem was studied. The first empirical findings specially after interviewing with a technical expert conducted a direction for further studies. It became clear, in the contrary of the classical MOCS, there would be another layer between ERP/APS and shop floor layers of MPCS that usually was not considered. Therefore, the focus of literature review was directed to this layer which is called MES (Manufacturing Execution System) layer. Understanding of the functionalities of the layers and also relationship between them was developed by reviewing and analyzing the results of the web-questionnaire. A framework which has been used in the thesis to answer the requested questions is described in figure 2.

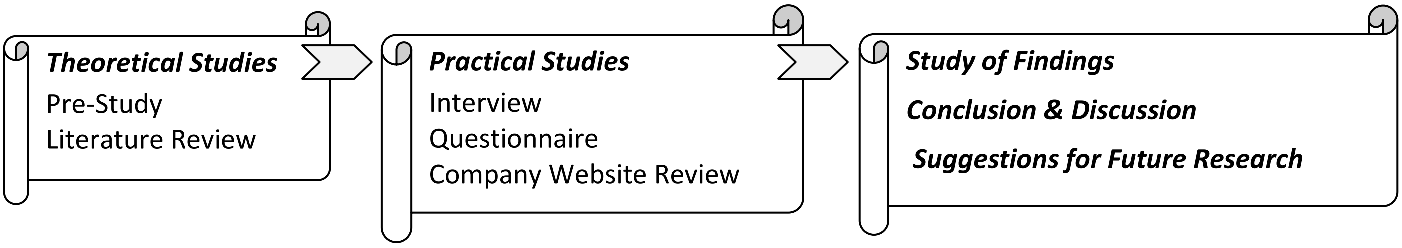

Figure 2 the procedure for master thesis work

2.3 Research methods

Various systematic ways can be used to collect information during a project work. A chosen method must be based on several considerations including a purpose of the technique, values, availability and cost (Bryman, et al., 2007). Three methods that have been used on the project are briefly explained below.

2.3.1 Literature review

A list of useful and related sources was used in order to get the basic and necessary background about the topic. Since limited investigations have been done about the subject, to get help from persons who are expert in the planning systems was necessary. In addition, available databases at Chalmers university library website were helpful to collect appropriate data. The main focus of literature studies was about the MES layer of planning system that integrates with other layers (ERP/APS and shop floor) and bridge the gap between these two layers. The studies were conducted from basic definition of each layer of the manufacturing planning and control system to design of conceptual framework that covers all details.

2.3.2 Interview

Interview technique is divided into three types: structured (predetermined questions), semi-structured and unstructured (unrestrained questions). Semi- structured interview which is used as a qualitative method for gathering data is combination of structured and unstructured interviews (Bryman, et al., 2007). It means this type of interview is held by a list of unbounded questions for a specific subject.

During the project work, one semi-structured interview was done with an expert from a company that has developed a solution in MES layer of the planning system. Interview started by describing the goal of the interview and then asked some flexible questions around desired subject and it took approximately one hour. The interview provided a good knowledge of the functionalities of MES software.

2.3.3 Questionnaire

(See appendix 4 for a copy of the web research questionnaire)

2.3.3.1 Introduction

Since it was impossible to have interview with all related companies that are active on the Swedish market, data was collected by preparing a proper questionnaire. Therefore, a web questionnaire which is a combination of several types of question formats was designed and before sending, the aim and the structure of the questionnaire were explained to the IT companies. The web research questionnaire includes five parts. The first part is a covering letter to the respondents including the topic of the research, the name and contact information of the researcher as well as the name of the supervisor, the university and the department. This is followed by a briefly explanation of the research purpose and a deadline set as well.

Part 2 contains some questions about MPCS in general such as a rating of key business drivers that influence a customer's decision to select MPCS and also the difficulties for implementing this system. Part 3 covers the name of ERP/APS systems that companies have introduced on the Swedish market and also information about industry focus, industry size, number of implementations (worldwide and Sweden), and the functionalities. At the end of this part, a performance of the MPCS released on the market regarding the customers feedback is questioned in specific areas including simulation capabilities, ease of customizing, ease of creating/modifying report, speed of (re) planning, ease of integration with other applications, ease of maintenance, ability of optimization, and ease of operation. Part 4 comprises a rating of the main drivers that made a customer to choose a MES solution and also the name of MES solutions that are presented by IT vendors as well as industry focus, industry size, number of implementations and the functionalities. And then a performance of the MES solutions with regards to the feedback from the customers is queried in the following criteria ; adaptability and extensibility, operating reliability and robustness, usability and simplicity, integrability and connectivity, value (function/ cost), and central deployment. Part 5 asks technologies used by companies to provide their Shop floor Data Acquisition and Collection (SFDAC) systems and information that can be collected by these systems.

The web research questionnaire was open for 10 days on the web and after 5 days a reminder email was sent for those that had not filled it. The questionnaire were used to give better understanding of features and functionalities of planning system packages that already exist on the market and also to get a holistic view about users and providers of these packages.

2.3.3.2 Types of questions

According to (Merriam, 1998), there are different types of questionnaire that each one follows specific aspects, for instance, a questionnaire can be multiple choices, rating scale, matrix of choices and order list of items or it can be used in any combination of these types. The project web-questionnaire is made up of some questions that apply rating scale, some questions that require a short sentence and tick boxes are used for the questions relevant to the modules and the functions included in software. A type of questions is straight forward question, for instance, "What are the features of your MES software that has been released to the market?"And for the questions that respondents need to rate specific statements, numbers are used, for example, "Every software implementation faces difficulties that lead to delayed implementation. How do you rate the following problems?" No.1 counts for the most common problem and No.8 counts for the least common problem one.

2.3.3.3 Validation of Questionnaire

Before sending the web research questionnaire to IT vendors that are active on the Swedish market, the questionnaire was shown to the academic supervisor (Peter Almström) and the approval was received.

2.3.4 Company document review

Fortunately, the needed documents which contain their solutions, products and services of companies and also customer feedbacks are accessible on the companies' websites. The review of documents was started after providing a list of companies that are active in the Swedish market (appendix 1). Preparing the mentioned list was facilitated by knowledgeable person from a consulting company that is in connection with providers of Industrial IT and automation solutions.

2.4 Participating companies – general information

This section presents the general information of IT vendors that participated in the project work as well as the name of their software and solutions released to the Swedish market. In chapter 4, the vendors' solutions and products will be studied in detail.

Adductor is a Swedish company founded in 1987and the main office located in Ingelstad, Sweden. The company started its business by selling micro computers and sensors, but now they are working on ***MUR system*** (Maskintid Uppföljning Realtid) and also programs, systems related to MUR.

ARROW Engineering Oy is a Finnish company founded in 1993. The aim of the company is to provide Industrial IT solutions that are suitable for small and large companies. The company is based in Europe but it has clients in China and USA as well. The ARROW's products including ***ARROW Maint, and ARROW Machine Track*** have been delivered to more than 400 clients in 15 countries.

AXXOS is a Swedish company based in Jönköping. The company develops and implements IT solutions mostly for medium and large manufacturing companies such as Volvo, Ericsson, Electrolux, and Atlas Copco. The company was established as a private organization in 1980 and then was changed to a joint-stock firm in 1987. The products of the company are ***Axxos Production Downtime, and Axxos Calibration***.

Balthzar, located in Gislaved, is a Swedish company with 10 years history. The goal of the company is to develop real-time production monitoring systems for small and midsize companies. ***Balthzar,*** as a product, is a modular system that the modules can be added based on customer requests, Batlhzar system consists of ***Balthzar Client, Balthzar eTouch, Balthzar stopporsaker, Balthzar Alert, Balthzar Attention, and Balthzar coupling ERP***.

ComActivity, a global company with partners in over 15 countries, is established in 2001. The young Swedish company has implemented Service Oriented Architecture (SOA), Business Process Management (BPM), Web and model-based applications in more than 100 medium and large companies. The Products offered by the company are ***ComActivity Business Process Platform, and ComActivity Lean Software Solution***. The company based on Business Process Platform introduces three types of applications: ***Composite Applications*** (improvement of existing applications), ***Plug-in Applications*** (Advanced Planning and Scheduling, Customer Relationship Management, Intranet and Document Management, Product Development, and Incident Management) and also ***The Application suite*** (Warehouse Management, Product Data Management, Production Activity Control, Sales Order Processing, and Procurement Management).

Full Fact, founded in 2004, is a Dutch software developing firm. The company serves over 400 worldwide clients by introducing two products (***OEE Starterkit and OEE Toolkit***) which can be used in different industries or manufacturing processes.

Good Solutions is a young Swedish company located in Göteborg. The company has a strong partnership with Aretics, Tacticus and Prevas. With the help of its partners, Good solutions has introduced and implemented support systems for production monitoring. The company's products that are developed and sold are ***RS-Production, TAG Production Reporting System, and Tekla Collector.***

IBS, established in 1978, is a Swedish company with offices and subsidiaries in more than 40 locations. Around 1986, the company joined the Stockholm Stock exchange and also initiated close cooperation with IBM as one the main software suppliers of IBM. Now the company has over 5000 worldwide clients. IBS distribution resource management software that is built on the IBS Orchestrate architecture is provided for companies in various industries and sizes.

Number of employees	1,114
Annual revenue 2009 (SEK Million)	1,819
Number of offices and subsidiaries	>40 locations - Nordics, Europe, Americas and Asia Pacific
Name of products	IBS Enterprise 6.0 Suite : IBS Supply Management, IBS Logistics, Assembly and Services, IBS Demand Management, IBS Distribution Financials, IBS Distribution Intelligence, IBS Supply Chain Integration

Table 1 key figures of IBS

IFS is an international company that was established by five engineers graduated from Linkoping University, Sweden in 1983. The focus of the company is to develop solutions for the management of four core processes including Service & Asset, Manufacturing, Projects and Supply Chain. The company has over 79 offices and subsidiaries around the world and the IFS Applications are available in more than 20 languages. IFS Company, with 2,700 employees, serves more than 2000 customers and 800,000 end users. In order to develop its global presence, the company has a strong alliance with some companies such as BAE SYSTEMS CENTRIC, LOGICA, Microsoft, and ORACLE. IFS Applications which is component-based with open standards is a complete business suite of ERP software and customers can install the components needed according to requirements.

Number of employees	Around 2,700
Annual revenue 2009 (SEK Million)	2,605
Number of offices and subsidiaries	Over 79 offices and working with more than 40 distributors
Name of products	A complete suite of component-based ERP software

Table 2 key figures of IFS

JDA started its business in Alberta, Canada in 1978. The company was sold in 1985 and then moved to the US. JDA, headquartered in Scottsdale, Arizona, has around 3,000 employees that work in 14 U.S. offices and 23 international subsidiaries. JDA supply chain solutions have been implemented in over 6,000 companies worldwide including discrete and process manufacturers, retailers, distributors, and also service providers such as hospitals, banks. JDA is able to serve companies of all types and sizes. According to a strategic plan, JDA has started to expand its business since 2000 and during this period, JDA has acquired some companies such as i2 Technologies, Manugistics, E3 Intactix and Arthur.

Number of employees	Almost 3,000
Annual revenue 2009 ($ Million)	107.1
Number of offices and subsidiaries	14 U.S. offices and 23 international subsidiaries
Name of products	A complete supply and demand chain industry-specialized suite

Table 3 key figures of JDA

Lawson, founded in 1975, is a Swedish company that began its business as a logistics and production consulting company. Now the company provides software and IT solutions for more than 4,500 clients in 40 countries. Lawson, with 3,880 employees across the world, serves customers in the manufacturing, distribution, maintenance, and service industries. The company offers a various ERP solutions including distribution, maintenance, supply chain, finance, manufacturing, human capital management, business intelligence, corporate social responsibility, and customer relationship management (CRM). In addition, Lawson, with 1,700 professional consultants, helps the customers to get more value from Lawson solutions.

Number of employees	3,880 (1,700 professional consultants)
Annual revenue 2009 ($ Million)	757
Number of offices and subsidiaries	>40 offices and subsidiaries around the world
Name of products	Lawson M3 Business Process Management and Lawson S3 Business Process Management

Table 4 key figures of Lawson

NovoteK Group, headquartered in Malmo, Sweden, has more than 20 years experience in industrial IT and automation solutions. The company is one of the leading companies that have introduced various IT solutions in MES and automation layers of MPCS. Because of a close collaboration with GE Intelligent Platforms, CSENSE, and Kepware, the company is able to serve customers from automotive industry to petrochemical industry.

Number of employees	132
Annual revenue 2009 (SEK Million)	243
Number of offices and subsidiaries	>7 offices in Nordic and Benelux countries
Name of products	Proficy Plant Applications

Table 5 key figures of NovoteK Group

Oracle started its business as a provider of business software and hardware systems in more than thirty years ago. Oracle is the leading company that presented 100 % internet-enabled enterprise software. The company's solutions are used by more than 370,000 clients from over 145 countries and now Oracle technology is applied in the data centers of 100 of the Fortune Global 100 companies. Oracle applications are provided for companies of all sizes and industries.

Number of employees	105,000
Annual revenue 2009 ($ Billion)	26.82
Number of offices and subsidiaries	In more than 95 countries
Name of products	**Oracle Database** - with different editions **Oracle Fusion Middleware** including Beehive, Business Process Management, Content Management, Identity Management and etc. **Oracle Applications** including Oracle Fusion Applications, Oracle E-Business Suite, PeopleSoft Enterprise, Siebel and etc. **Related Technologies** including Optimized Solutions, RFID, Data Warehousing, Information Lifecycle Management and etc. **Oracle Enterprise Manager** **Sun Server and Storage Systems**

Table 6 key figures of Oracle

Prediktor, established in 1995, is a Norwegian company with office in more than 7 countries (Europe and Eastern Asia). The focus o f the company is on developing industrial IT software and solutions in the following business areas: MES systems, Process Analytical Technology (PAT), Software Products (SWP) and Product Innovation and Consulting (PIC). Predikotr's solutions that cover most types of industries including automotive, oil and gas, chemical, food and feed are ***APIS and On-line NIR***.

Rockwell Automation, headquartered in Milwaukee, USA was established in 1903.The company with more than 5,600 specialists, has provided industrial automation control and information solutions for its clients across 80 countries. Rockwell contains two segments; 1-*Architecture & Software* segment has introduced a complete suite of automation solutions to the market 2- *Control Products & Solution* part has provided intelligent motor control and components as well as worldwide manufacturing support services.

Number of employees	19,000
Annual revenue ($ Billion)	4.8
Number of offices and subsidiaries	In more than 80 countries
Name of products	Various products and services through every stage of the manufacturing cycle (Design, Installation, Operation and Maintenance) **Software** including FactoryTalk (Integrated Production and Performance Suite)

Table 7 key figures of Rockwell Automation

SAP, which is known for introducing business systems applications as well as products in processing, was established in 1972. The company, headquartered in Walldorf, Germany, serves over 100,000 customers of all sizes and industries in more than 120 countries. Although, the main focus of SAP is large and global companies, the company has provided some specific IT solutions for small and midsize companies as well.

Number of employees	52,921
Annual revenue (€ Billion)	10.67
Number of offices and subsidiaries	>50 countries worldwide
Name of products	**Enterprise Software** including SAP Business Suite, SAP Manufacturing, SAP Service and Asset Management and etc. **Solutions for Small Businesses and Midsize Companies On-Demand Solutions including** SAP Business Objects BI On Demand, **S**AP Business By Design, SAP Carbon Impact and etc. **Rapid Deployment Solutions** including Rapid deployment of SAP Business Communications Management Rapid deployment of SAP CRM

Table 8 key figures of SAP

SDA is a Swedish company with more than 25 years experience in control and automation solutions. The company's services and applications are used in different sectors including Oil & Gas, Energy, Transport and Marine. Xcon, known as MES software, is provided based on the ISA-95 standard featuring client-server system.

Siemens started as a small back building workshop in 1847, Berlin, Germany. Now, Siemens is one of the leading companies in energy efficiency, industrial productivity and intelligent infrastructure solutions. The company provides fast, local and tailor-made solutions for clients in more than 190 countries.

Number of employees	Around 405,000
Annual revenue (€ Billion)	76.651
Number of offices and subsidiaries	>1,640 (including 176 R&D facilities)
Name of products	**Automation** including Automation and Control Systems, Logistics Systems (such as MES and Product Lifecycle Management Software), **Building Technologies, Communication Networks and Consumer Products**

Table 9 key figures of Siemens

Supply Chain Consultants, founded in 1993, is American company that provides an end-to-end, Microsoft solution for supply chain planning. The APS software solution, called Zemeter can help both process and discrete manufactures to optimize their supply chain. Zemeter is used in more than 150 large corporations such as Hexion Chemicals, Akzo-Nobel, Terra Industries and Sunsweet Grower.

Syncron, a Swedish company with more than 15 years experience in the supply chain business, provides process-centric and service-oriented SAP software for multinational manufacturing and distribution companies. Syncron software solutions can improve supply management processes and streamline the flow of materials and products among the whole supply chain. The company, headquartered in Stockholm, has offices and subsidiaries in more than 14 countries.

SYSteam Group is a Swedish Company established in 1984 and its main office is in Huskvarna, Sweden. In 2007, SYSteam became a company in ErgoGroup (Norwegian IT Company), generating a revenue of more than 5,214 NOK million (2009). The SYSteam Group Company has approximately 1,250 employees with offices and subsidiaries at more than 40 locations in the Nordic region.

Number of employees	1,250
Annual revenue 2009 (NOK Million)	5,214
Number of offices and subsidiaries	>40 locations – Nordic region
Name of products	Microsoft Dynamics AX , Dynamics NAV , Garp , Jeeves Selected , Jeeves Universal , Movex , Oracle Business System , Pyramid , Spektra , STYR/400 , Bygg GT

Table 10 key figures of SYSteam Group

System Andesson is a Swedish company established nearly 30 years ago. The head office of the company is located in Jönköping and it has some schools in Stockholm, Göteborg, Malmö, and Växjö. Training programs are held in these schools for companies that have installed Andersson's products. Unlike most IT solution vendors that usually focus on large organizations, Andersson Company has strived to develop accounting and payroll systems for small manufacturing companies. Around 25,000 users work with Andersson's products daily. Now the company is working on a new product called "Andersson manufacturing". The current products of System Andersson are ***Qwick Touch, Qwick MPS, Handterminal, Andersson Moblie, EDI & E-Handel, and Andersson Produktion***.

2.5 Reliability and validity

The quality of the chosen research approach is necessary to be examined with regard to reliability and validity. According to (Winter, 2000) "Reliability and validity are tools of an essentially positivist epistemology." Reliability shows the consistency of study results and its aim is to minimize errors during a study (Garson, 2002). Because the interview and the web-questionnaire can be influenced by a subjective opinion and attitude, the reliability of data can't be assessed high enough. Moreover the investigation and research about the subject studied are mostly in a conceptual phase and they have never been tested. Validity is about the integrity of the case study results and also the applicability to generalize the findings (Garson, 2002). Since a direct observation that shows how the IT solutions work in reality was impossible, there is not strong consistency between the reality and theoretical ideas have been developed by author. The study was not done for a specific company and all vendors on the Swedish market that work in industrial IT solutions was considered; therefore the analysis and recommendations can be generalized.

3. Theoretical framework

This chapter reviews the related literature which helped the author to construct the study of findings part. The first section introduces the general definition of Manufacturing Planning and Control Systems (MPCS) and then the different levels of planning system as well as the conceptual design for each level is described. The most part of literature review is assigned to Manufacturing Execution System (MES) and is tried to clarify this term in detail.

3.1 Context of manufacturing planning and control systems

Manufacturing planning and control systems (MPCS) is traditionally developed to plan and monitor manufacturing plant performance and is considered as a significant element for plant performance improvement (Vollmann T. E., 2005).

In the past, 2-level structure was defined for MPCS (ERP/APS and shop floor), but at end of 1990s, a new structure was developed by introducing the term "Manufacturing Execution Systems (MES)". According to the ISA S 95 standard, 3-level structure, known as ISA level model, is offered for planning systems (ISA S 95 standard is defined by a committee that consists of 200 users and manufacturers and will be discussed later). Each level that includes some modules operates within indicated time horizon (Kletti, 2007). The upper level (3rd level) is business management (ERP/APS) .It contains these function modules; Human Resource Management (HRM), Finance Management (FIM) and Supply Chain Management (CHM), Supplier Relationship Management (SRM) and Customer Relationship Management (CRM). Although these modules are separate from each other, there are points of contact between them. Some of them like CRM and SCM modules can be used as integrated part of ERP or APS systems or as an independent function. ERP and APS systems comprise a planning period that generally is considered for a medium and long term period. The 2nd level which is production management level or Manufacturing Execution System (MES) is developed by Manufacturing Enterprise Solution Association (MESA) at the end of 1990s when the need for accurate data in production information systems became necessary (Meyer, et al., 2009). The term "MES" contains 11 following functions that makes possible the integration between automation level and enterprise scheduling level (Meyer, et al., 2009). A time horizon that is specified in MES level is short term and real-time.
1- Operations / detailed sequencing 2- Dispatching production units 3- Product and tracking genealogy 4- Labor management 5- Quality management 6- Maintenance management 7-Data collection and acquisition 8-Process management 9-Performance analysis 10-Document control 11-Resource allocation and status
The 1st level, called production (automation) level, is relevant to shop floor data acquisition and collection. Regarding the complexity of the products and tasks, a type of systems that are needed in this level is varied. It can be used programmable logic controller (PLC) systems, Supervisory Control and Data acquisition (SCADA) systems, Radio Frequency Identification (RFID), bar code technology, robots and etc.

There are no exact boundaries between these three levels and as shown in the figure 3, they have overlap areas. It can be said that MES functionalities are in real time with a technological orientation and ERP functionalities are in a medium and long term with a commercial orientation. In addition, there is an unclear border between MES level and automation level and because of some functions like data acquisition and the transfer of machine settings; a tight connection between two levels is generated.

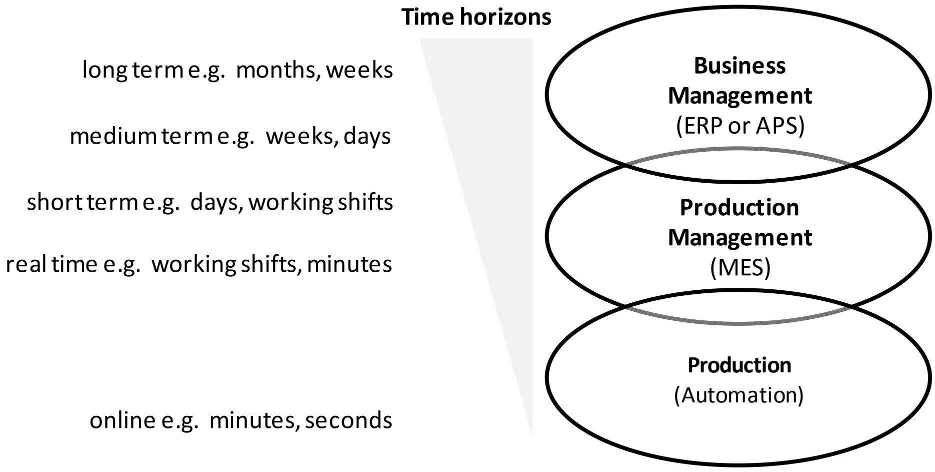

Figure 3 three- level architecture (Kletti, 2007)

In order to support the companies' needs and goals, the MPCS design and technology have to be changed and improved over time. The figure 4 demonstrates how MPCS design is influenced by market requirements and manufacturing task which are tagged as business specifications. Since market requirements are constantly changing, a way that the chosen markets can be satisfied is to redefine manufacturing task continually.

The interaction between MPCS design and manufacturing process design and manufacturing task is shown in the figure. In the MPCS design, sometimes improvements in existing MPCS are enough and in some cases, the new design that is based on the desired MPCS is required.

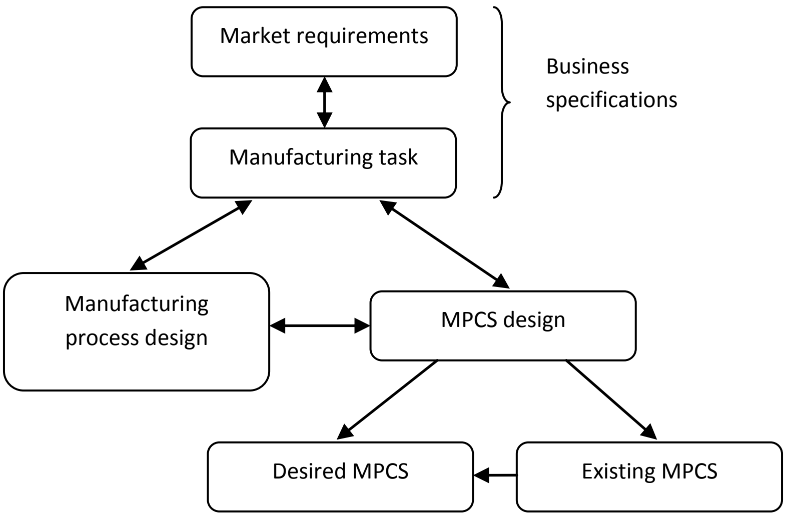

Figure 4 MPCS design (Kletti, 2007)

3.1.1 Business drivers impacting MPCS

MPCS that are based on information and communication technology make possible to get accurate information for the decision making processes. Therefore they can lead to lower utilization of resources including machines, personnel, raw material, and also money resources. For successful implementation of MPCS, IT vendors must be aware of the business objectives. There are many variables that could act as business drivers impacting on MPCS (Dembla, 1999). The following list that shows the top business drivers effecting MPCS was prepared based on literature reviews.

1- Reduce costs 2- Improve overall customer experience 3- Manage growth 4-Improve customer response time 5- Increase interoperability across multiple operating locations 6-Innovate to deliver more value 7-Improve decision-making by planning in real time

"Reduce costs": The MPCS implemented should reduce costs and these costs can be divided into two types (hard and soft). By reducing the hard costs including warehouse cost, transportation cost, procurement cost and etc., the production throughput and productivity increase. On the other hand, the reduction of the soft costs provides growth of revenue, profits and sales (Jutras, 2010).

"Improve overall customer experience": The MPCS should enable the companies to control and improve of theirs business and help them to increase the value of their products and services based on the customers' needs. (Jutras, 2010).

"Manage growth": Customers' demands to the new products and services are dramatically increased therefore MPCS should provide a structure including multi-site management capabilities and centralized/decentralized functions for companies to control and monitor the growth expectations (Jutras, 2010).

"Improve customer response time": MPCS must be able to develop and streamline the interaction between different departments of organization such as production, sales, planning, and maintenance departments in order to improve customer response time (Yapp, 2009).

"Increase interoperability across geographically dispersed units": Since sources, manufacturers and distributors of Companies especially international organizations are shifted based on the supply and demand patterns; MPCS must have the capability to facilitate coordination between multiple operating locations (Dembla, 1999).

"Innovate to deliver more value": More and more companies becoming multinational organizations and if they want to stay competitive in the years ahead, they need to implement MPCS that are able to deliver innovative value to customers.

"Improve decision-making by planning in real time": This item discussed earlier.

3.1.2 Choosing the right MPCS package

After management commitment about the implementation of planning system, choosing the right planning software package is the next step. In order to select the right one, the following issues should be considered in advance of an in-depth evaluation (Gyampah, 2004), (Baki, et al., 2005) and (Ross, et al., 2002).

- Identify which industry type mostly applies to a firm that wants to implement planning system? (For instance, aerospace, oil and gas, food and beverage, finance and banking, mining, business services, chemical, warehousing, transportation, telecommunication, automotive). Since Software providers usually develop their products with regard to the requirements of each industry, firms can take advantage of this vendor's focus for choosing the right software package.

- Indicate which departments and sectors within the organization will use the software? such as accounting and finance, administration, engineering and design, human resources (HR), maintenance, marketing, sales, purchasing, quality control, production, research and development (R&D), planning and warehouse.
- Specify the specific types of functionality needed in each department and sector? For example, auditing, benefits management, billing, cash management , change management, call center, business process management, contract management, customer service and support, data mining, financial and accounting, fixed assets, employee self-service, electronic records management, demand-based replenishment, forecasting, health and safety, inventory management, logistics and distribution management, manufacturing execution systems (MES)/plant automation, , order management, payroll, training and development, personnel management, payroll management, purchasing management, and scheduling.
- Indicate the regions as well as the languages that the software must support?
- Identify the total number of employees and also the number of software users in the organization.
- The other considerations can be listed as follow: a time frame for a decision and project start, annual revenue of the organization and a budget for the project and also types of professional assistance that the organization will need to get from a vendor e.g. customization, hardware and infrastructure, integration and customization issues, implementation and training.

3.1.3 Problems for implementing MPCS

While there are many reasons for implementing MPCS, there are also some risks and problems associated with their implementation. These difficulties may indicate why some or more implementations of MPCS are not successful as expected. The problems are not just technical or financial factors and it can be soft issues as well, for example, lack of management commitment (Spathis, et al., 2003). After reviewing several studies, the following list including some common and important difficulties that lead to delayed implementation was prepared.

1- Users resistance to change 2- Employees Training (no time for training) 3- Employees Training (learning ability) 3- Employees Training (hard to learn software) 4- Difficulties in data transformation from previous applications 5- Difficulties in adjusting applications to the MPCS environment 6- Difficulties in integrating existing systems with the MPCS 7-Lack of management commitment

According to the list, problems for employees training is divided into three categories; 1- when the employees are very busy and it is hard to find free time in their working schedule and to plan for training and learning the MPCS 2- when the employees don’t have enough abilities and skills for learning 3- when the MPCS implemented are very complex and complicated.

As shown in the list above, the problems can come up from organizational aspects like resistance to any kind of change, or from technical aspects such as difficulties in integration of current systems with the MPCS implemented and problems for transforming data from previous applications to a new system. There are also other important factors that are not in the list because the aim of this project is to understand the difficulties after agreeing to implement MPCS. For instance, the implementation of these manufacturing planning and control systems can be expensive for small companies and also some midsize companies.

3.2 Conceptual framework for the entire manufacturing enterprise

This section reviews ISAM model as one example about the application of intelligent systems to the entire manufacturing enterprise that is developed by National Institute of Standards and Technology (NIST, 2002). ISAM model has a hierarchical structure that includes all kind of manufacturing operations and activities. In each level, nodes (functional units) categorized as a nested series of control loops. Nodes get the missions and goals from a level above and also monitor situations in a level below. In functional units, duties are distributed, plans regarding planning horizon on that level are generated, and feedback from sensors is analyzed. Units in high levels deal with business management (ERP/APS) and in low levels deal with shop floor data collection systems. ISAM node includes five primary processes:

1- ***Sensory Processing (SP)*** is to indentify acceptable signals from sensors and measure observed properties of external world and compare with internal models and also calculate the features of events and entities.
2- ***World Modeling (WM)*** is based on four functions; to simulate the results of possible future plans, to forecast sensory observations by estimating the state of the world, to maintain the knowledge Database (KD) by comparing sensory observations and world model predictions and to act as data server in support of the other processes (BG,VJ and SP).
3- ***Behavior Generation (BG)*** is responsible to receive goals and priorities and then generates action plans and controls. Behavior generation manages the selected assignments by correcting the mistakes.
4- ***Value Judgment (VJ)*** contains algorithms for knowing the expected costs, risks and advantages of plans and actions. It makes easier to select goals and to set priorities by estimating the value of objects, situations and events. VJ process evaluates the reliability of information based on the difference between sensory observations and world model predictions. VJ also calculates the important items for attention or rewarding/punishing items for learning.
5- ***Knowledge Database (KD)*** collects information with symbolic and iconic structures related to the world including variables, entities, attributes, events, objects, structures, rules, frames, lists, graphs and etc. KD contains the three types of memory; immediate (sensor signals and current values), short term (iconic and symbolic representations) and long term (symbolic representations).

The mentioned processes can have bidirectional connection to an operator interface therefore any changes and modifications are possible to do by a human supervisor. The relation between these processes is indicated in the figure 5. The arrows show the flow information between processes. Observed input and commanded actions are in a reactive response control loop that starts from SP through world modeling to BG. Another loop between SP and WM facilitates knowledge acquisition and learning. The pathway that begins from behavior generation and after passing world modeling and value judgment comes back again to behavior generation enables planning evaluation for future actions. The pathway between SP and WM through value judgment makes possible to understand and evaluate situations.
The second part of the figure shows that the behavior generation unit of ISAM node receives commanded tasks (goals) from an executer in an upper level and then each commanded task is

divided into some tentative plans for subordinate BG units. According to these plans, the world modeling simulator/predictor gives the expected results. Then the task decomposition planner chooses the best tentative plans when the cost and benefit of the tentative plans are evaluated by the value judgment unit. And finally the chosen plans are given to Executors for implementation. The executors revise each step in their plan with getting feedback from KD which is updated by sensory processing information.

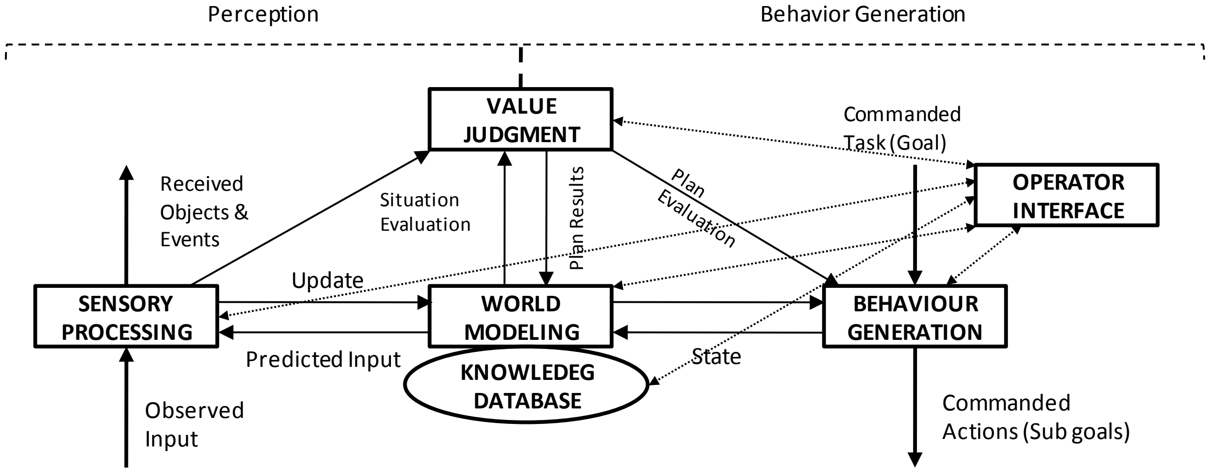

Figure 5 the relation between processes in a node of ISAM model (NIST, 2002)

Since planning within ISAM model has various planning horizons at different levels, it makes possible to support real-time (re)planning of demands that continually and dramatically change overtime. Thus the number of levels needed in a model is approximately based on the logarithm of the ratio between the highest planning horizon and the lowest one. With regard to a place of node in ISAM architecture, the node acts as an intelligent controller for a set of sensors, a machine, a workstation, a cell, a shop, factory, or upper levels in the manufacturing enterprise. Each level of ISAM architecture has specific spatial and temporal characteristics which cover the processing needs of that level. At each level, SP processes receive sensory observations from SP processes at lower level nodes and then dispatch perceived objects and events to higher levels. In all levels, SP processes evaluate the difference between estimations that are kept in the internal KD and the real observations from external world in order to update data. A connection between the ISAM model and the external world environment is made by a set of sensors and actuators at the bottom of the ISAM hierarchy like PLCs (figure 6). Each level of the ISAM architecture shown in the figure 6 is responsible for a specific planning horizon and includes particular functional characteristics. The high levels support business management and low levels support shop floor data collection systems.

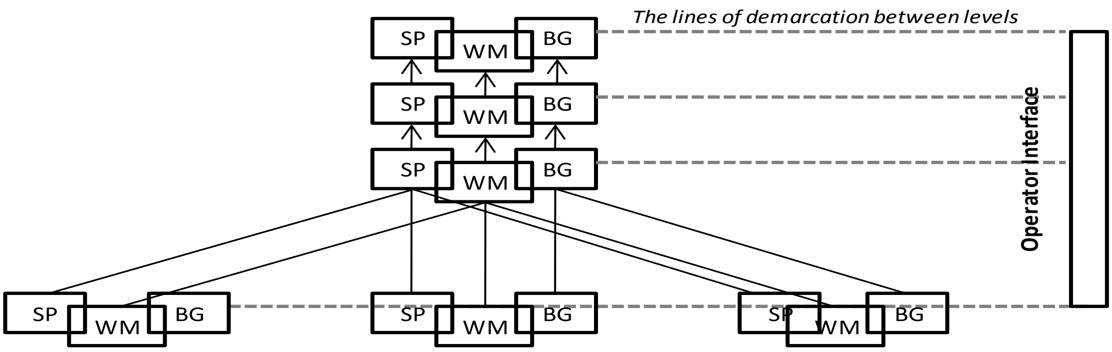

Figure 6 the hierarchical structure of the ISAM model

3.3 Enterprise Resource Planning

In the 1970s, early software packages that are known as Material Requirements Planning (MRP) were limited to the shop floor. Since the complexity of business activities was increased, MRP was developed to support more indirect firm's resources and functions and became known as Manufacturing Resource Planning (MRP II). Although the efficiency of business enterprise was improved, the main focus of MRP II was on the planning and scheduling of internal resources. The term "ERP (Enterprise Resource Planning)" was used during the 1990s to introduce new software that also is able to plan and schedule for outside resources as well (Sherif, 2010). The explanation of ERP term is dependent on interpreter's viewpoint. For example managers usually focus on the planning part and in opposite, the information technology community describes ERP as a system that integrates all functions in the company such as finance, sale, marketing and data processing applications (Vollmann T. E., 2005).

In fact, the next generation of MRP and MRP II is ERP that its basic structure is the same as MRP II. Enterprise resource planning that contains an enterprise –wide set of management tools (forecasting, planning and scheduling) links customers and suppliers and helps to predict and balance demand and supply. The figure 7 has shown the schematic view of ERP system.

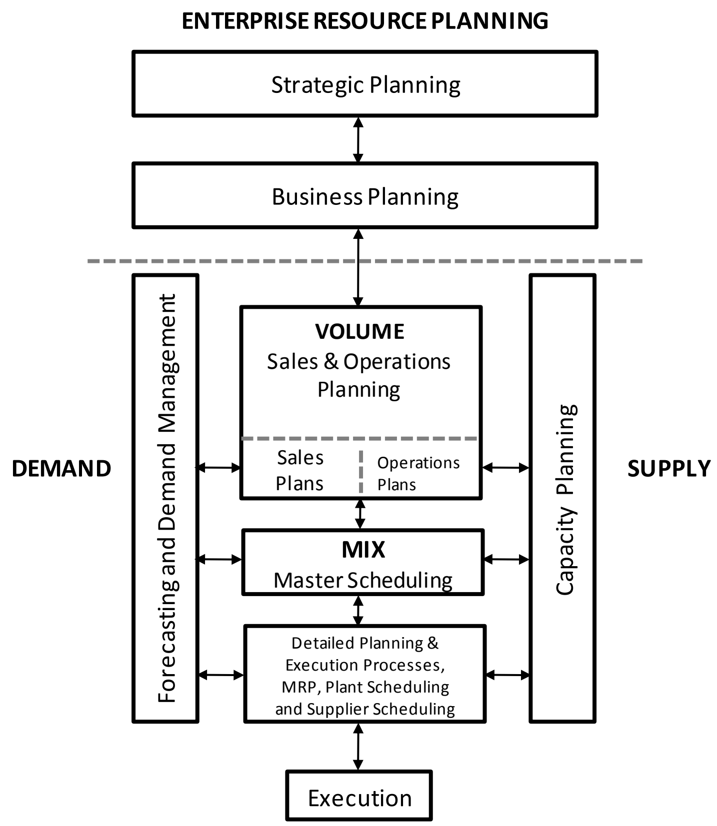

Figure 7 the schematic view of enterprise resource planning system (Wallace, et al., 2001)

Since ERP as a business system mostly has attention to the operational level including operational planning and execution, it supports short term planning and execution (Chopra, et al., 2002). The planning has two steps in ERP system; first the material requirements are calculated and then they are compared with the available capacity. ERP is a transaction-oriented system that keeps all information from different modules in one database and it facilities to take decision by showing what is happening in a whole supply chain. In fact, the ERP system can show the current situations but it can't support to determine the correct one (Chopra, et al., 2002).

ERP provides reliable integration between different parts of firm (sales, marketing, manufacturing, finance, logistics and etc.) therefore it makes possible to do the business with high level of customer satisfaction and at the same time lower costs and inventories (Wallace, et al., 2001). The quality of an ERP system can be found out regarding these factors:

- The system should be able to provide results closely related to daily staff requirements. It means the system can track diverse results and activities in the different units of business (multifunctional in scope).
- The system needs to be integrated. When any change is done in the system, the related data is modified as well without the need for reworking.
- The ERP must be able to join into a single system or connect with other applications (modular in structure)
- The system should facilitate the basic activities that generally have done by MRP and MRPII; production planning, material requirement planning, master scheduling.

The ERP software suite comprises eight primary modules that each of them includes sub modules and supports a specific area of business; finance, human resource, sales & marketing, engineering, projects, manufacturing and logistics, maintenance and business enablers. The ERP modules can be bought from a single vendor or each module can be purchased from a vendor that is the best in a requested module. The aspects that must be considered for evaluating an ERP software system are; a complexity and a size of business, a scope of functionality required, a type of manufacturing (discrete or process), unique requirements of business's processes, an available budget for implementing the system and finally available computer hardware and telecommunications (Vollmann T. E., 2005). During the evolution of ERP system, usually the fundamental platform has not been changed dramatically and it is tried to improve the functionality of software by adding new features. The core ERP software modules have been briefly described below (Vollmann T. E., 2005):

- ***Finance module*** can automatically collect any financial transaction from different functional departments of business and creates financial reports such as general ledger, invoices, time billing and balance sheet.
- ***Human resource module*** supports the capabilities required to manage the human resources and human capitals. It records various information of employees including contact information, shift allocations, attendances, trainings, travel expenses, performance analysis and payroll reports.
- ***Sales & marketing module*** performs functions of forecasting, order placement and scheduling, export controls, shipping, distribution and invoicing. Some ERP providers also present online storefront as a new feature of this module.
- ***Engineering module*** supports engineering design, processes and it facilities to access the related documents of design elements, products and facilities for everyone in the company.
- ***Projects module*** is applied to businesses that supervise their work by project principles, it includes project management, project budgeting, project planning, risk management, sales contract management and project reporting.
- ***Manufacturing and logistics module*** which is the largest and complicated ERP module supports the various planning efforts (human resource planning, financial planning, sales planning and

operation planning), execution (purchasing, inventory management and invoice management) , monitoring (quality control and assurance) and analysis of manufacturing process in all phases for all staff.

- ***Maintenance module*** contains the functionalities that are needed for day to day maintenance, preventive maintenance planning and also continuous improvement in equipment performance.
- ***Business enabler components*** help to provide customized applications for the unique characteristics of a company, for instance, Oil and Gas Company or hospital or banking.

3.4 Advanced Planning System

Since there are different definitions for Advanced Planning System (APS) as well as some mixed concepts between APS and ERP, it is difficult to have a clear view of APS functionalities and features. According to most APS vendors and consultants, APS in comparison to ERP has more capabilities in the planning and scheduling functionalities because APS is able to simulate various planning scenarios before implementation. In addition, APS is able to do planning with consideration of finite resource capacity and based on an optimization algorithm. Thus, APS software facilitates daily operative decisions by utilizing finite-based planning as well as simulation and optimization tools (Hvolby, et al., 2010).

In 2000s, some ERP system providers like Oracle and SAP decided to integrate APS to their ERP business suites and they supposed APS as updated version of ERP systems with new features and capabilities. The APS and the ERP systems can be integrated in different ways including standard middleware systems, Service-Oriented Architecture (SOA), and vendor specific integration methods. This new version for ERP suites can support daily activities for decision making as well as the primary activities and transaction such sales, finance and marketing and etc (Hvolby, et al., 2010). According to Shapiro, two overlapping motivations among managers are the main reasons for growing interest in APS systems; 1- The need for business systems that support fact-based decision making. 2- The need for integrating decisions in the entire supply chain (Shapiro, 2001).

Areas	**ERP**	**APS**
Planning philosophy	Planning material and capacity in order Goal: Feasible plan	Planning material and capacity at the same time Goal: optimal plan
Scope	Mainly discrete manufacturing industries	All industries such discrete and process manufacturing industries
Functional focus	Manufacturing, finance, controlling distribution, human resource	Planning processes including demand, logistics, manufacturing
Decision phase	Operational planning	Strategic, tactical and operational planning
Simulation capability	Low	High
Optimization capability	No	Yes
Lead times	Approx static	Dynamic
Data storage	Central database	PC's memory
Speed or (re)planning	Low	High

Table 11 the contrast between ERP and APS systems (Entrup, 2005)

According to (Stadtler, et al., 2005), APS typically contains the following seven modules: 1- ***Strategic network planning (SNP)*** covers all long term planning tasks including supplier selection, collaborations, materials program, selection of plant location and also production system, design of physical distribution structure, products program, and strategic sales planning. In this module, the design of a supply chain and information flow among customers and suppliers are established. 2- ***Demand planning (DP)*** supports most tasks in the strategic and mid-term sales planning. 3- ***Demand fulfillment and ATP (DF&ATP)*** covers short-term sale planning e.g. fulfillment of delivery promises from stocks in "*make to stock environments*". 4- ***Master planning (MP)*** supports mid term planning level in procurement, production and distribution sections including personal planning, material requirements planning , contracts, master production scheduling, capacity planning and distribution planning. 5- ***Production planning and scheduling (PP&S)*** is responsible for processes such as machine scheduling, shop floor control and lot-sizing. 6- ***Transport planning and distribution planning (TP&DP)*** is used in mid- and short-term distribution processes e.g. warehouse replenishment, distribution planning and transport planning. 7- ***Purchasing and material requirements planning (P&MRP)*** supports mid- and short-term procurement processes that traditionally are covered by ERP. But purchasing planning with consideration of alternative suppliers, quantity discounts, lower and upper quantity constraints are not supported by ERP systems. A typical module of APS with its functionalities in different time horizons is shown in the figure 8.

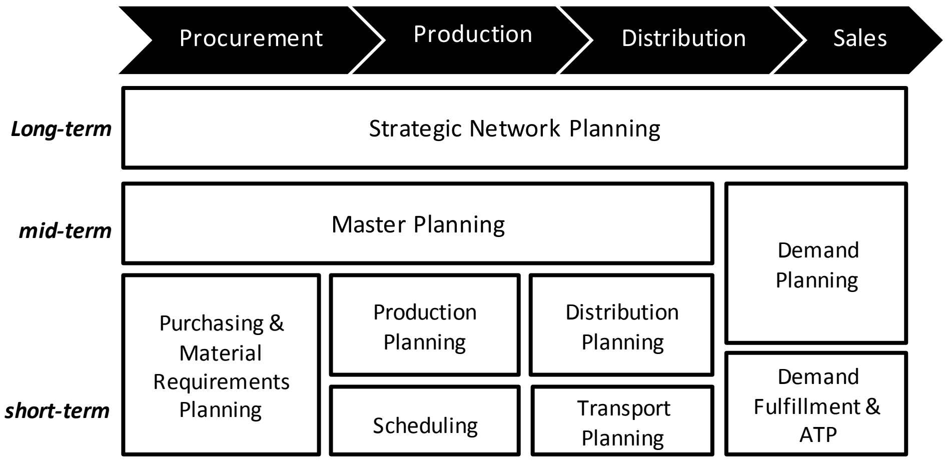

Figure 8 planning processes covered by APS (Stadtler, et al., 2005)

3.5 Manufacturing Execution System

As discussed earlier, the weakness of business planning systems such as ERP and APS is the method of collecting and updating data. In order to avoid of manual adjustments that lead to missing accuracy of data and also losing the functionality of these systems, it is necessary to introduce a solution for integrating ERP/APS systems with shop floor data acquisition and collection systems (Huang, 2002). The integration of Manufacturing Execution System (MES) with plant needs is a matter that has been emphasized by researchers from 1990s (David, et al., 1995), (Hori, et al., 1999), (Chung, S. L.; Jeng, M. D., 2002) and (Sieberg, et al., 2003). This integration helps manufacturing managers to get real-time information about production schedules, financial issues and operation performance data. Moreover, it supports to make decision based on production problems that are addressed (appendix 2).

The important question is how to design and to implement a MES system with respect to the plant requirements that it is able to report on and respond to plant activities in a real time? (Deuel, 1994).

3.5.1 Standards and guidelines

Before indicating the functionality of manufacturing execution system in more detail, some existing standards and guidelines relevant to MES are described below.

ISA

ISA, founded in 1945, has more than 28,000 members from 100 countries. ISA is the abbreviation of Instrumentation, Systems, and Automation Society. The ISA has developed a guideline relevant to MES, called ISA S95 (Meyer, et al., 2009). The ISA S95 presents a model that integrates ERP/APS systems with automation systems on the shop floor. A last version of ISA S95 model, published in 2005, provides detailed information about interfaces between functions in business management level and production management level (figure 9). According to this model, the following tasks are included in the 4^{th} level: providing master data for raw materials and substituted parts, supporting personal master data for human resources department, supervising energy utilization, controlling and managing warehouse master data, establishing optimal stocks, determining a rough plan for production and revising it according to the material constraints and the resources availability. Tasks assigned to the 3^{rd} level are: managing and evaluating of data associated with inventory, production, raw materials, substituted parts, energy and personnel, providing optimal planning for every division, managing the reservation and substitution of resources related to orders, providing monitoring functions for maintenance management and quality management e.g. alarm.

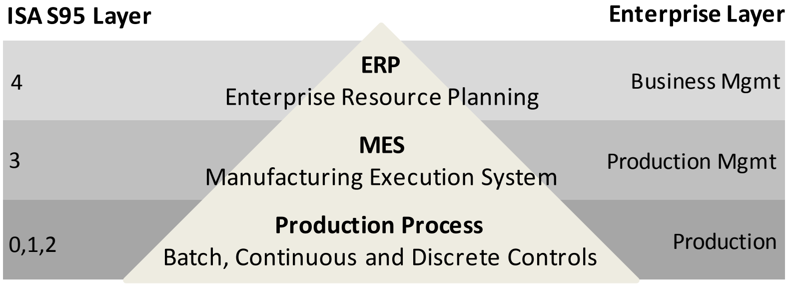

Figure 9 ISA S95 layers (Meyer, et al., 2009)

NAMUR

NAMUR, founded in 1949 - Germany, is International User Association of Automation Technology in Process Industries. The members of the organization are users from the process management technology sector. The following functions are described by NAMUR as MES functions: production management, quality management, warehouse management & material flow management, operations-neutral production planning, detailed production scheduling and production documentation. A model presented by NA 94 recommendation includes the primary terminology and forms for indentifying interfaces between business management and production management levels. In this model, solutions for Machine Data Acquisition (MDA) at business management level are described (Meyer, et al., 2009).

MESA

MESA as an American industrial association introduced the term “MES” for the first time. MESA is an acronym for the Manufacturing Enterprise Solutions Association. This association makes an effort to improve business planning processes by optimization of information flow systems. According to this standard, MES consists of 11 functions; 1- Optimal sequence planning of workflow 2- Management and control of the resources (machines, staff, tools and etc.) 3- Management and monitoring of the flow of production units 4- Personnel management 5- Quality management 6- Maintenance management 7-Process management 8- Management and control of information flow through the production processes 9- Lot traceability (to ensure that manufactured goods are traceable based on the recorded production data) 10- Operating (manual or automatic) data logging 11- Performance analysis (Meyer, et al., 2009).

3.5.2 The Ideal MES

Unlike traditional shop floor control systems that focus mostly on the scheduling and dispatching operations and their functionalities usually overlap with the responsibilities of ERP/APS systems, MES makes an effort to monitor and summarize the status of resources on the shop floor and focuses less on the scheduling (Jones, et al., 2001). Since MES has an extensive operational area (large working area with different time levels), recognition of an ideal MES is better to be studied in the following three areas (Kletti, 2007): the functionalities of MES, communication with higher level (ERP/APS), and communication with lower level (automation).

3.5.2.1 The functionalities of MES

According to Kletti (2007), the functionalities of MES can be divided into three groups that each group includes some modules; the function groups are production, quality and staff allocation (figure 10). The modules in the function group “production” are: ***Production Data Acquisition (PDA)***, production information including times and quantities relevant to order and also workers are recorded here. In this module, the information about confirmed items is kept separately from scrap items data. In addition, materials consumption, wear and tear is possible to be recorded. This information after accumulating over shifts, days or weeks are available to use by the 3rd level (business management) applications. ***Machine Data Collection (MDC)***, the data related to machines and other operational resources are collected here (manually or automatically) and then they are made available as the detailed forms for the 3rd level. ***Control station and planning table***, this module provides technologically feasible plans which are based on current situations. The detailed plans within MES support simulation, optimization and also fully-automated loading. ***Tool and Resource Management (TRM)***, this module manages and controls tools and equipment with respect to current availabilities as well as compatibility with machines and the technical state of operating resources. ***Material and Production Logistics (MPL)***, this module makes possible to keep an overview about the work in progress (WIP) materials and also those are kept in the temporary storages. Because MPL focuses only on the materials that are in circulation or in interim storages, the functionality of this module is different from warehouse management function.

Unlike quality management system that is offered by ERP and focuses mostly on planning and administrative work, the quality function group in MES should be considered as an operating quality assurance system. ***Statistical Process Control (SPC)***, it contains statistical techniques to measure values in processes and then to compare them against a set-point value. The aim of SPC is to monitor and maintain the consistency of processes and keep them under control. ***Non-Conformance Management (NCM)***, products which are returned back are managed and monitored based on manufacturing conditions, raw materials and technical issues and then new countermeasures against this kind of problems are introduced. ***Incoming goods***, delivered goods and dispatched goods are traced via a monitoring system. ***Inspection equipment management***, its functionalities is similar to TRM. Measuring and inspection techniques are controlled on the basis of the required standards. ***Process Data Processing (PDP)***, this module makes possible to process values directly and to compare them with tolerance and whenever it is necessary to introduce countermeasures against errors.

The human resources function group is very close to the business management level and it consist of the following modules: ***Staff work time logging***, this module keeps clocking in/out data and absence times and then it calculates them in month. ***Incentive wages,*** the module helps to implement bonus system and to establish an efficient connection between order times and absence times. ***Short-term manpower planning***, it has the same functionalities with "planning table" in the production function group. By getting help from automatic functions, it provides staff schedules based on the loading situations on departmental or company or plant level. ***Access control***, it provides the implementation of access control in a production facility when "staff work time logging" has been attached to the MES. ***Escalation management***, this module manages and monitors the production processes by responding to faults and errors in a shorter time.

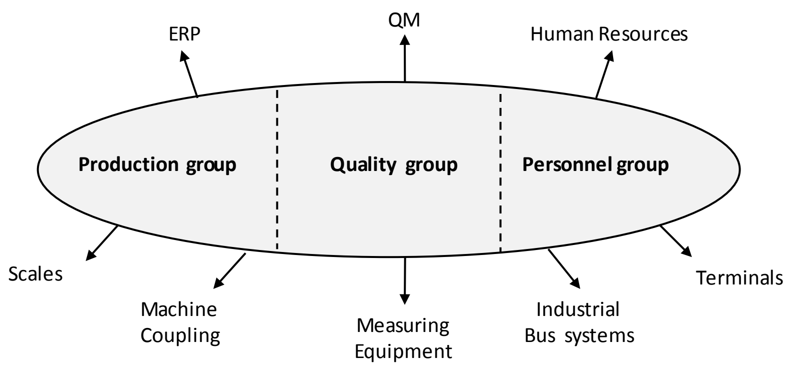

Figure 10 MES function groups (Kletti, 2007)

3.5.2.2 Information flow between business management level and MES level

According to figure11, there is bidirectional information flow between MES level and ERP/APS level. Work orders (including due dates, required processes and part numbers) as well as staff off/on-duty plans that are provided by business management level are used as input data in the MES level. The information keep in MES data storage and whenever it is necessary, the detailed work orders with respect to equipments, tools, manpower in the production level are planned. On the other hand, the event massages such as alarm messages that may result of shortage of raw materials or a machine break down are sent from production management level to business management level. These messages support real time (re) planning of activities in the ERP/APS level. Attendance reports for preparing payroll are sent to ERP/APS level as well (Huang, 2002).

3.5.2.3 Information flow between MES level and automation level

As shown in figure 11, MES can transmit detailed work orders including daily work schedule for each machine and employee to production level. In addition, maintenance timetables are sent to maintenance staff in order to carry out equipment maintenance in a right time. In the other direction, shop floor facts including job status, operation status, operator status, machine status, tool Status, material status, and material handling system status, are transmitted from production level to MES level. For data collecting on the shop floor, electronic devices such as barcode reader, magnetic strip reader and RFID are used. More information about data collector systems on the shop floor is discussed in section 3.6.

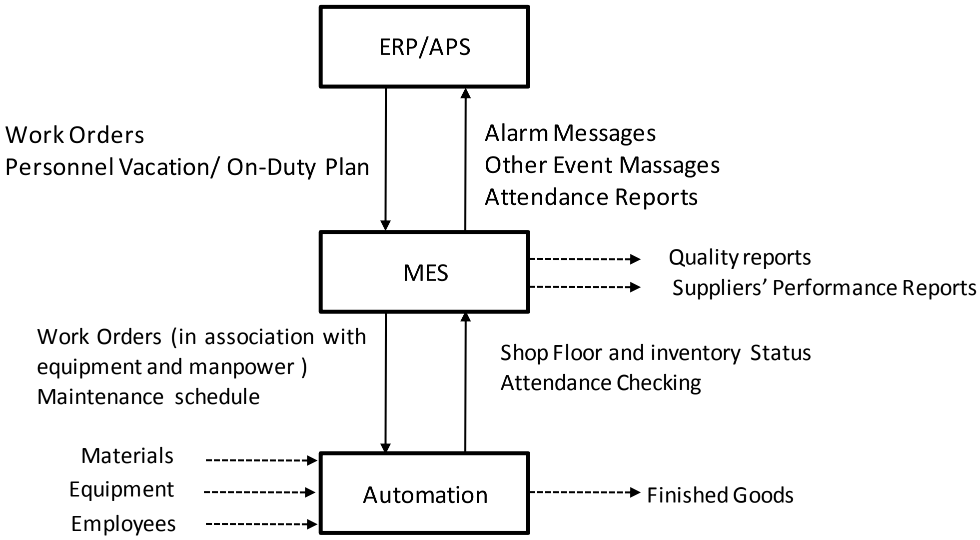

Figure 11 Information flow between different levels of MPCS (Huang, 2002)

3.5.2.4 Functional MES Reference Architecture

A functional MES reference architecture developed by Schmidt, et al. (2009) is based on a literature review of MES articles published in related journals and conferences as well as analyzing white papers from established MES standards. The reference model shown in figure 12 contains the three layers (APS/ERP, MES and shop floor) and each layer includes some processes and functions (the detailed description of each MES function is provided in appendix 3).

In MES layer, the functionalities indicated by dark grey color are core MES functionalities and boxes with light gray color are potentially redundant functionalities that they are located between layers and their position based on company circumstances can be changed.

According to Schmidt, et al. (2009) and Brocke (2007), the following parameters could influence the MES functions and change a layer of light grey functionalities;

- ***Plant Type***: MES functions would be different based on the plant type. For example, the MES functions needed in a component manufacturing plant differ from an assembly plant. Moreover, it must be distinguished between different types of component manufacturing plant or assembly plant with regard to MES functions requested.
- ***Number of Production Process Variants***: some plants such as component manufacturing plants usually comprise different types of production process (batch and flow production, individual and series production) therefore more complex functionalities are needed to adapt flexible production process or to install manufacturing equipment.
- ***Production Quantity***: total items produced can also influence the functional MES reference architecture.
- ***Vertical Range of Manufacturing***: a proportion of value added created by manufacturer itself is another influencing item, for example, a percentage of in –house production.

- ***Location***: It must be distinguished between plants in developing countries and plants in developed countries with respect to the level of automation. Since main parts of manufacturing process in developing countries is carried out by manual activities, requirements to support the MES functions is less compared to highly automated plants in the developed countries.
- ***Production Worker Autonomy***: staff empowerment on the shop floor in order to make decision freely during manufacturing process is another influencing factor.
- Allocation of MES functions to new plants is easier and more accurate than old plants in which applications have developed during years.

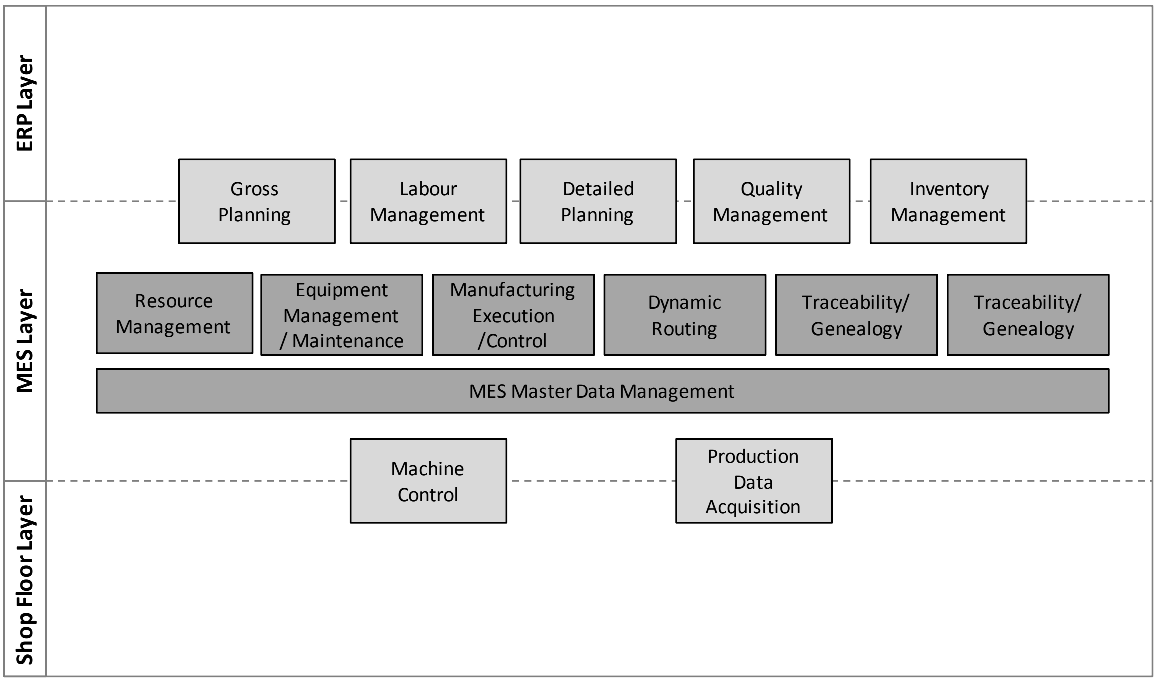

Figure 12 the MES reference model (Schmidt, et al., 2009)

3.5.3 MES database system

A MES database system designed should be able to support all kinds of MES functions. According to (Zhou, et al., 2005), subject's structures for MES database can be categorized in the following four structures; *1- **System Resource Subject's Structure (SRSS)*** describes the geometry characteristics and performance parameters of resource objects that are used in production activities as well as interrelation between them. Resource objects in SRSS are classified into six types, including work piece class, text class, program class, tools class, pallet class and fixture class. Each class also can be divided into sub-classes, for instance text class can consist of drawing class, test method class, technique specifications class, standard class and etc. Moreover, SRSS defines characteristics and attributes of all resource objects involved in maintenance activities. Since RSS has classified structure , it can be expanded or lessened according to specified applications *2- **Detail Executable Plan Subject's Structure (DEPSS)*** explains objects relevant to different planning processes including production plan, tools plan, equipments plan , vehicles plan as well as interaction information between them. When an order is received by production system, tasks related to order will be divided into sub tasks, and then the needed resources for these tasks are provided by DEPSS. In fact, DEPSS supports to make accurate and feasible production plan according to the updated data about the resources needed and also the interaction information between them. *3- **System Status***

Subject's Structure (SSSS) describes system status at a specified time and mostly the status of objects involved in the production activities such as object states and object locations. Since the production activities change dynamically, providing the real-time information of resources in the whole production system helps production activities to be carried in an effective and timely manner *4- **System Configuration Subject's Structure (SCSS)*** defines the configuration of the production system. It identifies the resources objects and the interrelation among them as well as their features and attributes in the production system. SCSS indicates material flow and vehicles route in the sub systems. Moreover, SCSS clarifies the performance of vehicles and the number of workpiece loaded for each vehicle. SCSS makes possible to show the location and the performance of equipment in the production system that it is helpful for maintenance management.

3.5.4 Non- Functional criteria

The functions that must be covered by MES solutions discussed in the previous sections. Some non-functional requirements that should be considered are summarized as follow (Schmidt, et al., 2009);

Adaptability and Extensibility: The MES solutions must have the capability to be modified with regard to customers' specifications and needs. In other words, a company that has implemented MES software should be able to change the source code of MES software easily and without getting external help.

Operating Reliability and Robustness: the probability of failure-free operation for MES solutions should be near zero percent in order to avoid any problem in production and service processes.

Usability and Simplicity: Since MES tools usually are located on the shop floor, near the machines. Since the operators are the main users, the use of MES software should be easy for operators.

Integrability and Connectivity: MPCS consist of three layers and the MES as the middle layer bridge the gap between two other parts. In order to create a planning system with accurate and instant information, the connectivity of MES solutions to interfaces provided by *,1- Existing ERP/APS systems 2- Existing applications for MES functions 3- Existing shop floor data collection system,* is very important.

Value (function/cost): The function/cost analysis that is applied to asses the cost of buying and implementing of MES solutions in relation to the value as perceived by clients should be considered as well.

Central Deployment: MES software must be centrally deployable. Deductively meaning that the MES solutions should provide "automatic distribution of system updates and also changes instead of applying multiple individual adaptations" (Schmidt, et al., 2009).

3.5.5 MES implementation

Mostly Companies show their interest towards implementing MES solutions when they understand the need for improvement in manufacturing performances and their business plans. The MES implementation like ERP/APS implementation must be done in several phases and an implementation team decides how to design these phases. The team should include representatives of different departments of a company as well as a software vendor. An approach that is used to implement a MES solution depends on the requirements of an industry or industries which need to be supported as well as the complexity of architecture of a production IT environment. A method that all the MES functionalities are implemented simultaneously maybe is not the right approach. In opposite, a method that MES implementation is carried out in small controllable phases and with involving the end users is a more reliable approach. Validation of each step of implementation is very important that can be done by using the vendor's tools and the internal quality system (Knight, et al., 2006).

One simple example of MES IT environment:

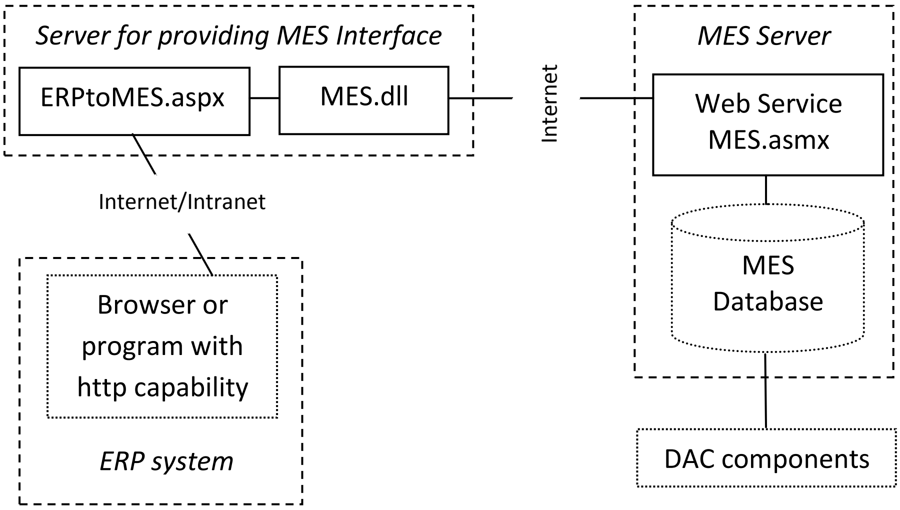

Figure 13 the connections between MES, ERP and DAC components (Huang, 2002)

Figure 13 shows the connection between MES and ERP through .NET framework (Platt, 2003). The information that is collected from shop floor Data Acquisition and Control (DAC) components store in the MES database. The web service MES.asmx that is connected with the MES database in the MES server cannot be executed without getting help from MES.dll (as agent program) that is located in the same server as ERP to MES.aspx. Data collected is transferred from ERPtoMES.aspx to ERP system by a browser or a program with http capability. On the other hand, MES can use the same method to retrieve information that is kept in ERP database.

Unlike old MES solutions that were based on to database-centered approach and mainframe technologies, the architecture of this web based application follow the patterns of Service Oriented Architecture (SOA). Thus it can support agility and changing requirements.

3.5.6 Performance advantage of MES

A study (between 1998-2002) about the performance advantages of MES was carried out by Industry Directions Company and Rockwell Automation Company among 106 top-performing plants in North America (58 use MES and 48 do not). Data collected from those plants indicated that plants using MES had more success in main scopes such as profitability, process improvement, productivity and staff performance, regardless of size, process type and industry. Furthermore, MES provided extra benefits when it was integrated to other planning software systems or improvement methodologies and philosophies like ERP, APS, Six Sigma, and Lean (Co., 2004).

According to the study, the productivity of companies that used MES increased more than those not using MES based on the following measures; revenue/square foot (84% higher), value-add/ employee (32% higher) and sales/employee (10% higher). About another terms of productivity including the reduction of costs and energy consumption, the plants with MES solutions had dramatic gains over three years (reduction of costs was 34% greater than companies not using MES and reducing energy consumption was 7% more). In process performance aspect, the study showed that plants with MES have greater process capability (11% better Cpk) and for larger companies (15% better Cpk). Scrap and rework costs decreased 46.3% for MES adopters over three years and just 39.8% for companies that not using MES. Manufacturing cycle times decreased 53% in plants with MES compared to 38.8% in plants without MES. Moreover, MES adopters achieved 49.6% reduction in order-to-ship cycle times and those not using MES gained 40.4% reduction.

Since employees in plants with MES solutions work according to accurate data that are achieved directly from MES, overtime hours needed per week are less than those not using MES. The survey also found hours of staff training in plants with MES is quite less and these firms mostly focus on training on the shop floor instead of classroom. Finally, it is claimed, MES adopters can improve faster on most key measures than plant not using MES. The reasons behind this claim;

- MES provides accurate and real time data about production processes and issues,
- increases the system abilities for having wide visibility ,
- supports employees' empowerment.

According to McClellean (1997), MES implementation in some firms was not successful owing to wrong and poor definition of MES. Moreover, Extensive customization of MES software can cause some errors in the system as well as other systems that have been integrated with the software. The performance advantages of MES have mostly mentioned in MESA case studies and because the MES vendors don't like the failed projects to be made available to public, there aren't any statistics about unsuccessful MES implementations.

3.6 Shop Floor Data Acquisition and Collection (SFDAC)

The first step is to know what information is needed to be gathered from shop floor in order to support management planning, monitoring, and decision making. The primary information required can be listed as follow (Berrya, et al., 1983); 1- What is the current status of resources (personnel, machines, material handling systems and tools) that are used on the shop floor? 2- What is the current status of jobs that are defined on the shop floor? 3- What is the current status of raw materials and parts that are used on the shop floor? 4- What is the status of operations and controls that are planned on the shop floor? 5-What is the current status of material handling systems on the shop floor? 6- What is the current performance of shop floor with regard to resources, operations, materials, jobs, controls and material movements? 7-What is the status of maintenance and services that are scheduled on the shop floor such as machine services, tools services and staff training?

Varied technologies and methodologies can be used to collect data on the shop floor and to transform the collected data from shop floor to higher level (MES) with respect to the information required which has mentioned above and also the circumstances of each company including size, annual revenue, type of business, complexity of operations, company policies and etc . Some typical technologies have been briefly explained below.

3.6.1 Barcode system

Barcode system is one of the first technologies, used to collect different information from shop floor. A one-dimensional (1D) barcode consists of several rectangular bars with varied width that are located beside each other in different distances (figure 14). Barcode format depends on symbology standard used, some of them are fully alphanumeric e.g. code 39 or partially alphanumeric, but most of them are just numeric. 1D barcode labels usually have a serial number that is used to provide extra information about product such as name or price. 1D Barcode system is a simple, accurate and reliable technique that its implementation cost is low. This technology can be upgraded easily and it can record shop floor data with high rate. On the other hand, this technology has some negative points, for instance, inclement environment can damage barcode labels or data capacity of barcodes are usually less than 20 characters. In addition, distance limitation for the scanning process is also another disadvantage (Cecelja, 2002). Two -dimensional (2D) barcodes are the new generation of barcodes that have more data representation capability compared to 1D barcodes. 2D barcode is capable of covering 1D barcode disadvantages, for example, one type of 2D barcode (PDF417) has ability to encode around 1850 characters and to make correction for lost data because of damaged label (Arendarenko, 2009).

Barcode reader can get the data automatically or manually, and by contact or at a distance. Light pen, laser hand-held reader and mobile phone with camera as well as decoding software installed are examples of barcode reader that are usually used by operators (Cecelja, 2002).

Barcode system can be used to gather simple data as well as complex information, for instance, it can be applied to automatically recognize the products that pass a specific point on the production line or can be applied to record utilization of resources e.g. Equipment and staff (Cecelja, 2002).

Figure 14 1D barcode (left) and 2D barcode (right) (Arendarenko, 2009)

3.6.2 Radio Frequency Identification (RFID)

RFID is a technology that allows information is transferred between identified objects. These objects can be products, people, production materials and etc. The RFID system usually contains three parts; a tag including one or more electronic chips/labels, a reader (interrogator with antenna) and a data processing system (figure 15). In some cases a RFID reader and a data processing unit are the same such as mobile phones with RFID reader. The RFID function can be explained as follow: In a transmission field, the tag that is powered up by the RF (for a passive tag) or by its own power (for an active tag) responds to a radio signal received and sends all own encoded data. And then the data will be decoded by the reader itself or by the data processing unit (Cecelja, 2002).

There are different types of RFID tags that can be classified by frequency range or working mode (readable/readable and writable) or power type (active/passive), memory capacity and etc. According to the requirements, the proper RFID tag can be chosen, for example, system just needs to know something is there or requires to detect something is there and what it is or needs further updated information (Arendarenko, 2009).

The RFID reader provides a bidirectional communication with the RFID tag. On the one hand, it gets the stored data in the RFID tag and sends the received data to the further processing and on the other hand, the reader writes the data into the RFID tag. Regarding needs, readers can be processing unit as well. The passive or semi passive RFID tags are powered up by radio waves that are emitted from the readers' antenna (Arendarenko, 2009).

The primary feature of RFID technology is to allow updating the object information during the processing. Generally, this technology is reliable, accurate and resistant to most environments. On the other hand, this technology is expensive compared to barcode system and needs special systems for writing and reading to the electronic tags. In addition, the radio waves that are caused by RFID system are another disadvantage (Cecelja, 2002).

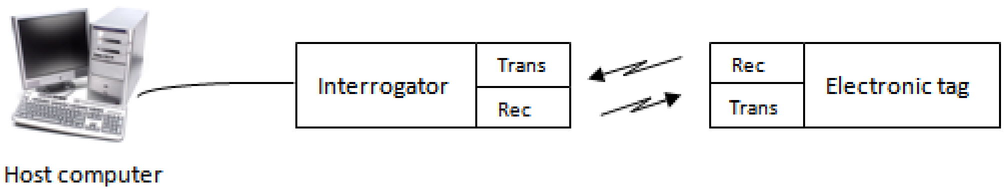

Figure 15 an example of RFID system

3.6.3 Optical Character Recognition (OCR)

Data encoded in OCR, in opposite of barcode technology, is machine- readable as well as human readable. The function of this technology is based on recognition of patterns which include letters, numbers and some s symbols e.g. commas and question marks. Because of high error rate during recognition process, this technology is not reliable compared to barcode system. In addition, application of this system in manufacturing companies is still restricted (Cecelja, 2002).

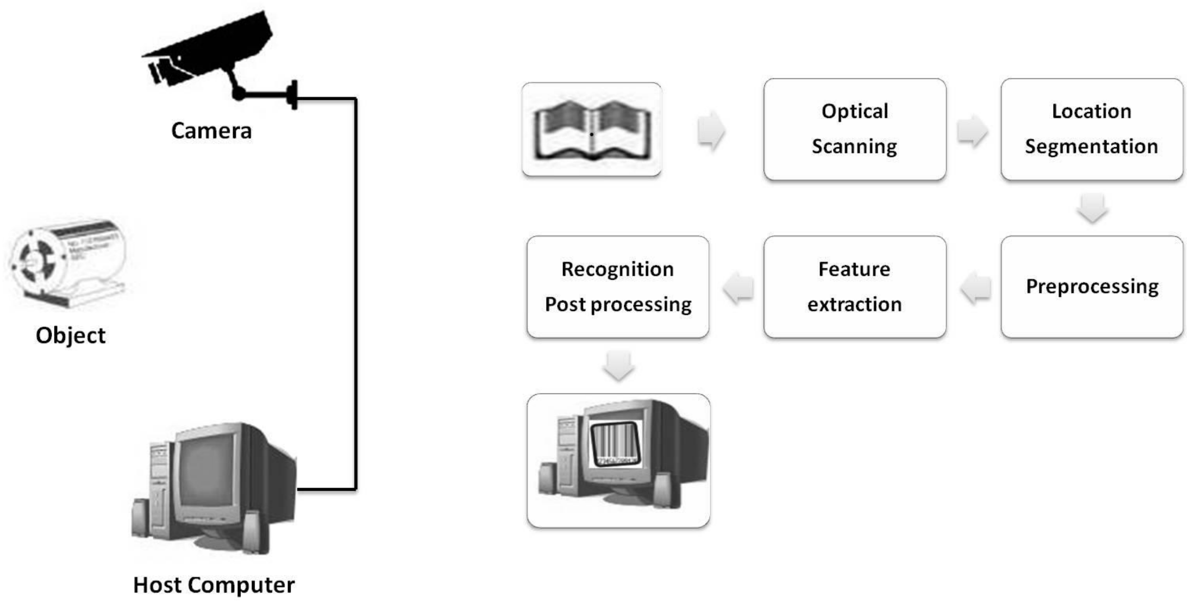

Figure 16 OCR systems used in a supply chain (left) and components of an OCR system (right)

Figure 16 shows components of typical OCR system. First, analog documents are transformed to digital format by optical scanner and the next process is to locate and segment the components of an image. A part of the scanned document that consists of data must be located and distinguished from graphics and figures. Segmentation for text is isolating of letters and words in order to be recognized separately. And then the extracted symbols that may contain some defects due to scanning process are preprocessed to eliminate noise from the digitized characters. To identify the essential characteristics of the symbols that usually are the most difficult part of the OCR process is the next step. The identification process is done by comparing to the symbol classes kept in an archive. Finally, the words and numbers of the original text are rebuilt by contextual data (Eikvil, 1993).

3.6.4 Programmable Logic Controller (PLC)

Direct communication with process control devices like the programmable logic controllers is another way to collect data on shop floor. PLC is a kind of microprocessor-based controller that applies programmable memory to record process parameters such as temperature and pressure and in order to manage and control machine operations and material loading, some functions including timing, sequencing, counting are implemented by PLC (Bolton, 2009). Since programming in PLCs is based on logic and switching from one operation to another operation, the term *logic* is used, for instance, if X or Y happens switch on Z, if X and Y happen switch on W. As shown in figure 17, some devices like sensors (switches) are as input to the PLC and output devices are applied to control and monitor motors, regulators, valves and also to record related data. All information that is available in the PLC can be transformed to a host computer and used for updating data in MES level. PLCs are robust and also are able to be implemented in severe environments e.g. high temperatures. The main problem of using this technology is the difference between what is actually happening and what PLCS think is happening. In order to avoid this problem, using proper sensors in place is necessary (Amunrud, 2002).

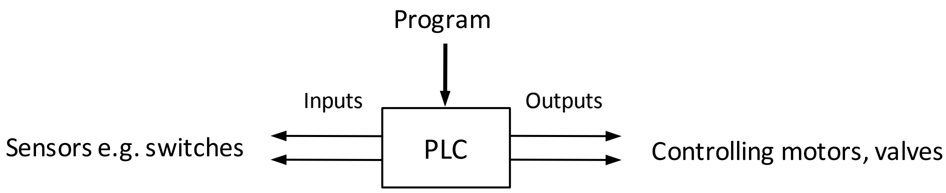

Figure 17 a programmable Logic controller (Bolton, 2009)

3.6.5 Other types of SFDC system

There are also more technologies that can be applied to collect data on the shop floor. One patent registered by (Ishida, et al., 2010) is illustrated below.

The purpose of this invention is to identify an ID data, a position, and a direction of an operator on the shop floor and to provide a proper operation structure for operator as well (figure 18). This system consists of an optical ID including a pair of LEDs, cameras, a monocle display, a RFID reader-writer, and controller .The optical ID that is attached to a headset of each operator sends light emission signals to the cameras located in different places a long a pathway of operator. Regarding these signals, an ID, a position and a direction of each operator is determined by controller. A proper operation instruction based on these received data is also provided and the monocle display is used to show this instruction to the operator. In addition, an RFID reader-writer is applied by the operator

in order to read RFID of picked articles and also to write his ID in the RFID tags. The collected RFID is transmitted to the controller by a portable communication device like a cellular phone. All information gathered in the controller can be used as input data for higher level in the planning system (MES level or ERP/APS level).
The problem of the invention is that it can only be used when an operator works in the specific areas, For instance, when the operator moves a cart in a predetermined way through racks for getting articles.

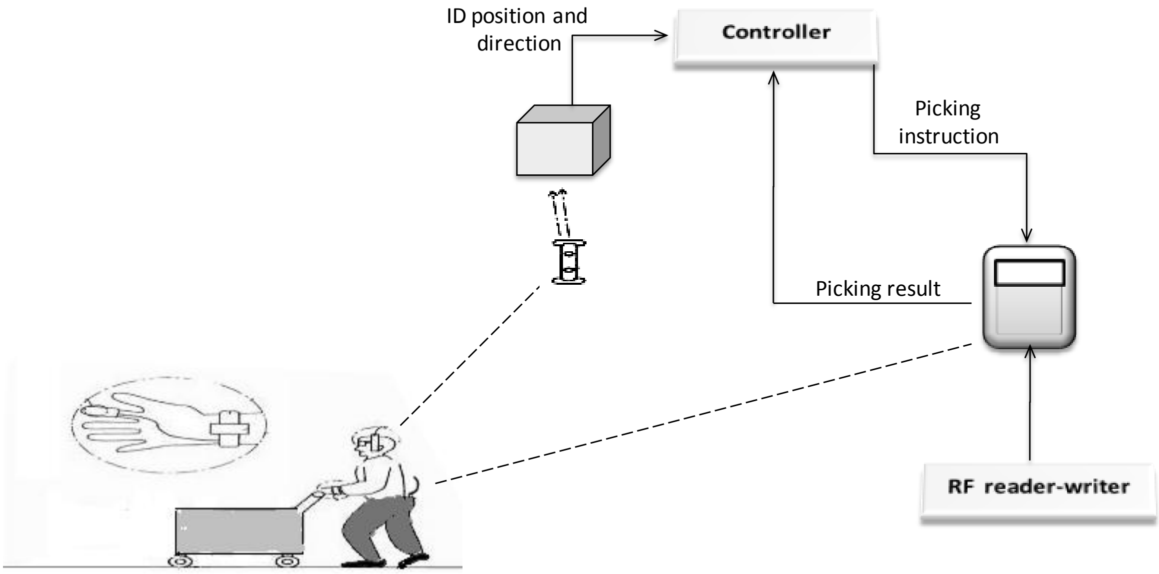

Figure 18 a schematic view of the system

3.7 Summary of the theoretical framework

In the theoretical part, a model of manufacturing planning and control systems that leads to fill the gap between operation times in reality and in the planning systems was explained. According to this model, MPCS consists of three layers with different time horizons and functionalities (ERP/APS, MES and shop floor). There are no clear boundaries between these layers and the functionalities assigned to each layer can be changed based on companies circumstances. Some parameters that could influence the functions of each layer and change their level on 3-level structure of MPCS were mentioned, for instance, plan type, production quantity, number of production process variants. This chapter also explained about conceptual framework for the entire manufacturing enterprise, called ISAM model, and shown how an ideal planning system must work based on this model. ISAM model with a hierarchical structure and various planning horizons is able to cover all kind of manufacturing operations and activities and to support real-time (re)planning of demands that continually and dramatically change over time. This model is used as a reference for developing manufacturing planning and control systems.

In business management level, the similarities and differences between ERP and APS were studied. It was explained that the quality of ERP/APS depends on several factors, for instance, the capability of integration especially with applications from lower level (MES) as well as providing results closely related to daily staff requirements.

The main part of theoretical chapter was assigned to MES level and the term “MES” was explained from different aspects. Despite the integration MES with planning systems has been emphasized from since the end of 1990s, the studies about MES and its functionalities is still not very comprehensive. Some organizations such as ISA, NAMUR, MESA, are heading organizations in developing guidelines and standards relevant to MES. A well known classification of MES which has been provided by MESA defines MES based on 11 functions. MES as the middle layer of MPCS, bridge the gap between business management level and shop floor. In order to develop an ideal MES, the following areas must be considered by IT vendors: the functions that are covered by MES and the degree of information flow between MES with others levels (ERP/APS and shop floor). Moreover, if the IT vendors want to remain competitive in the market, their MES solutions introduced must also cover some non-functional requirements, for example, integrability and connectivity with other applications from the same level as well as upper/lower level. Accurate and real-time information in the planning systems depend on the degree of connectivity of the MPCS layers. Increasing information flow between the layers helps to have more reliable planning systems. Old MES solutions are based on database-centered architecture and they are unable to support changing requirements. But using Service-Oriented Architecture (SOA) can increase the capabilities of MES solutions to support agility.

At the end, some methods and technologies that are applied to collect data on the shop floor (e.g. job status, operation status, operator status, machine status, and material status) and to transform them to higher levels (ERP/ASP, MES) was described.

4. Study findings

The aim of this project work is not to introduce the best software provider and software product, it is tried to show how to select the right long-term business partner. Chapter 3 explained the research studies that have been done in different layers of MPCS including APS/ERP, MES, and automation (figure 3). It also discussed the key concepts of each layer specifically the MES layer. Chapter 5 discusses about the products of IT vendors that already are used on the Swedish market and explains their functionalities based on the subjects discussed in the theoretical part. The data about these IT solutions was mainly gathered from the companies' website and also from answered questionnaires. In addition, this chapter analyses the responses of IT solution vendors on the Swedish market to the web questionnaire. Studying the answers helps the author to understand the IT vendors' capability to bridge the gap between operation times in reality and in the planning system.

4.1 Respondents to the web questionnaire

Table 12 shows the statistics of the respondents to the web questionnaire that was emailed to 22 IT solution vendors on the Swedish market. 16 companies opened the questionnaire but only 10 of them answered to the questions. It means less than half of the questionnaires were returned. There are different reasons why the response to the web research questionnaire is weak such as the questionnaire was designed in English. Although most of the companies are international companies, some companies had problem to answer the questionnaire due to English version. The other reason could be a time that the questionnaire was available for the companies (from 28 October 2010 to 6 November 2010). Since this period is usually a busy time for companies, the deadline for answering the questionnaire was short. As could be expected only small/midsize IT vendors as well as consulting companies answered the web-questionnaire.

Total number of companies	22
Opened questionnaire	16 (72.7%)
Answered e questionnaire	10 (45.5%)

Table 12 analysis of web questionnaire responses

4.2 Business drivers impacting selection of MPCS

As described in the previous chapter, In order to meet sustainable future business growth, MPCS is a required infrastructure for companies. In addition, it is a potential source of cost savings and operational improvements. While growth of income, profits and also remaining competitive are the main goals of companies, accurate rating of the following business drivers which influence customers' decision to choose one MPCS package is necessary.

Introduction to table 13: This table shows the detailed analysis of the responses to the first question of the web-questionnaire; "How do you rate the following business drivers that impact a customer's decision to select MPCS?" No. 1 counts for the most important item and No.7 counts for the least important one.

The table 13 indicates that IT companies have different opinions about the rating of the following business drivers. Each company has done the ranking according to the feedback from customers as well as the company policies. For instance, more than 50 % of the respondents believe that "Reduce costs" can get the number 1, it means the first priority. Almost 30% of them see it as the second item and the rest respondents (14%) have a completely different idea and put it as the last priority.

Business drivers	1	2	3	4	5	6	7
Reduce costs	57%	29%					14%
Improve overall customer experience			14%	14%	43%	14%	14%
Manage growth		29%	14%	43%		14%	
Improve customer response time		29%	29%	29%		14%	
Increase interoperability across multiple operating locations	14%		14%	14%	14%	29%	14%
Innovate to deliver more value	14%	14%				29%	43%
Improve decision-making by planning in real time	14%		29%		43%		14%

Table 13 business drivers impacting MPCS

Introduction to Figure 19: This vertical bar graph compares the answers about the business drivers impacting MPCS in order to figure out the priorities.

The graph shows that "Reduce costs" is the most important business driver. For the second priority, "Mange growth" and "Improve customer response time" have the same percentage. Since "Manage growth" has the highest percentage in the fourth priority, "Improve customer response time" can be considered as the second important issue and "Mange growth" as the fourth one. The other priorities have been identified by the same method and the results are summarized as follow:

1- Reduce costs 2- Improve customer response time 3- Improve decision-making by planning in real time 4- Manage growth 5- Improve overall customer experience 6- Increase interoperability across multiple operating locations 7- Innovate to deliver more value

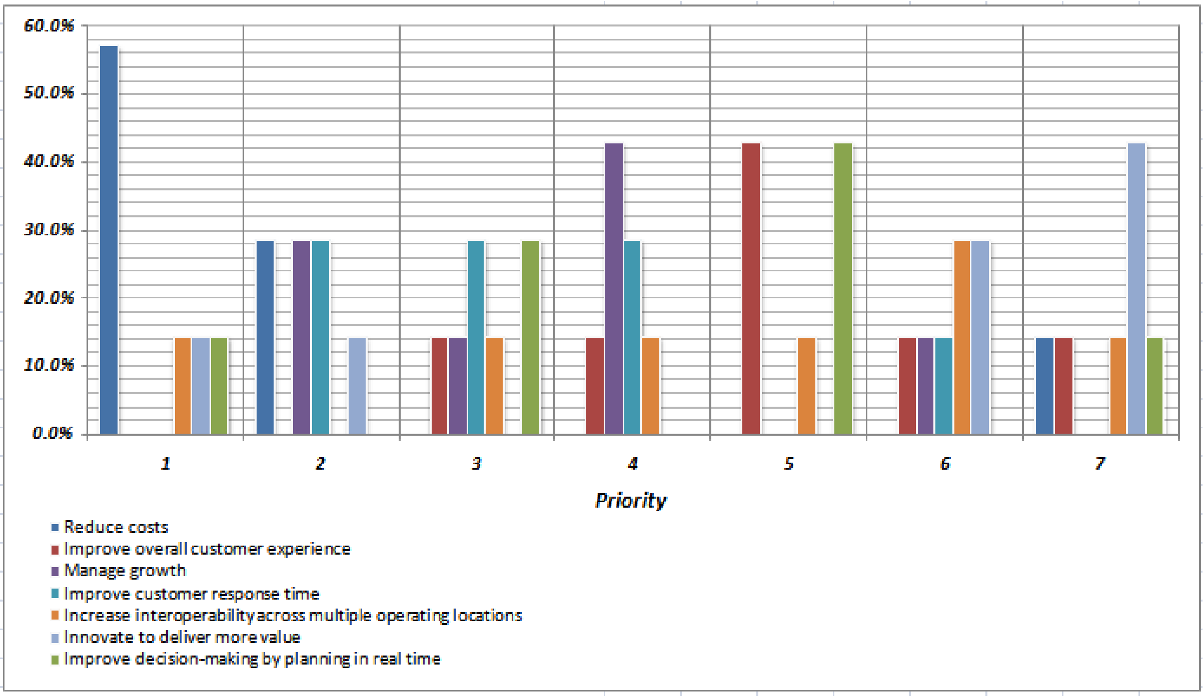

Figure 19 comparison between business drivers impacting MPCS

4.3 Difficulties of MPCS implementation

According to the industry statistics, each software implementation faces difficulties that lead to delayed implementation. Knowing the problems in advance and also the severity of them help the companies to increase the success of MPCS implementation and the adoption of the applications. Based on the literature reviewed, the following list of common problems was collected and sent to IT vendors as well as IT consulting companies.

Introduction to table 14: This table describes the breakdown of answers to the second question of the web-questionnaire; “MPCS providers usually face with the following problems when they want to implement MPCS software, how do you rate these problems?” No. 1 counts for the most important item and No.7 counts for the least important one.

Like the previous table, table 14 shows that companies have different experiences about difficulties of MPCS implementation as well. “Users resistance to change” is a factor that related employees’ attitudes and behaviors. Staff usually resist against changes which modify the way of their work especially when a new technology or system needs to be adopted. As shown in the table, the lack of time for training is the major problem between three categories of “employees training”.

Problems	1	2	3	4	5	6	7	8
Users resistance to change	29%	14%	29%	29%				
Employees Training (no time for training)		29%	29%	14%		14%	14%	
Employees Training (learning ability)					14%	29%	29%	29%
Employees Training (hard to learn software)					29%		43%	29%
Difficulties in data transformation from previous applications	14%	14%	14%	14%	14%	29%		
Difficulties in adjusting applications to the MPCS environment		14%	14%	14%		29%	14%	14%
Difficulties in integrating existing systems with the MPCS		14%	14%	29%	29%			14%
Lack of management commitment		14%	14%	29%	29%			14%

Table 14 problems for MPCS implementation

Introduction to Figure 20: This vertical bar graph compares the responses about the problems of vendors for implementing MPCS in order to indicate the priorities.

According to the figure, most of the vendors believe that “Users resistance to change” is the major problem when they implement MPCS for their clients. And the second one is the lack of time for training. Although training and education of employees is a vital factor that reduces the risk of poor performance throughout implementation, it is very difficult to find a free time in staff working hours and to create a training program. Since there are various opinions about the other factors, indicating their priorities doesn’t give a proper pattern. For example, “Difficulties in data transformation from previous applications”, “Difficulties in adjusting applications to the MPC environment”, “Difficulties in integrating existing systems with the MPC system” and “Lack of management commitment” are the factors that vendors consider them as problems with variable priorities (between 3 and 6). And also “Employees Training (learning ability)” can have a priority between 6 and 8.

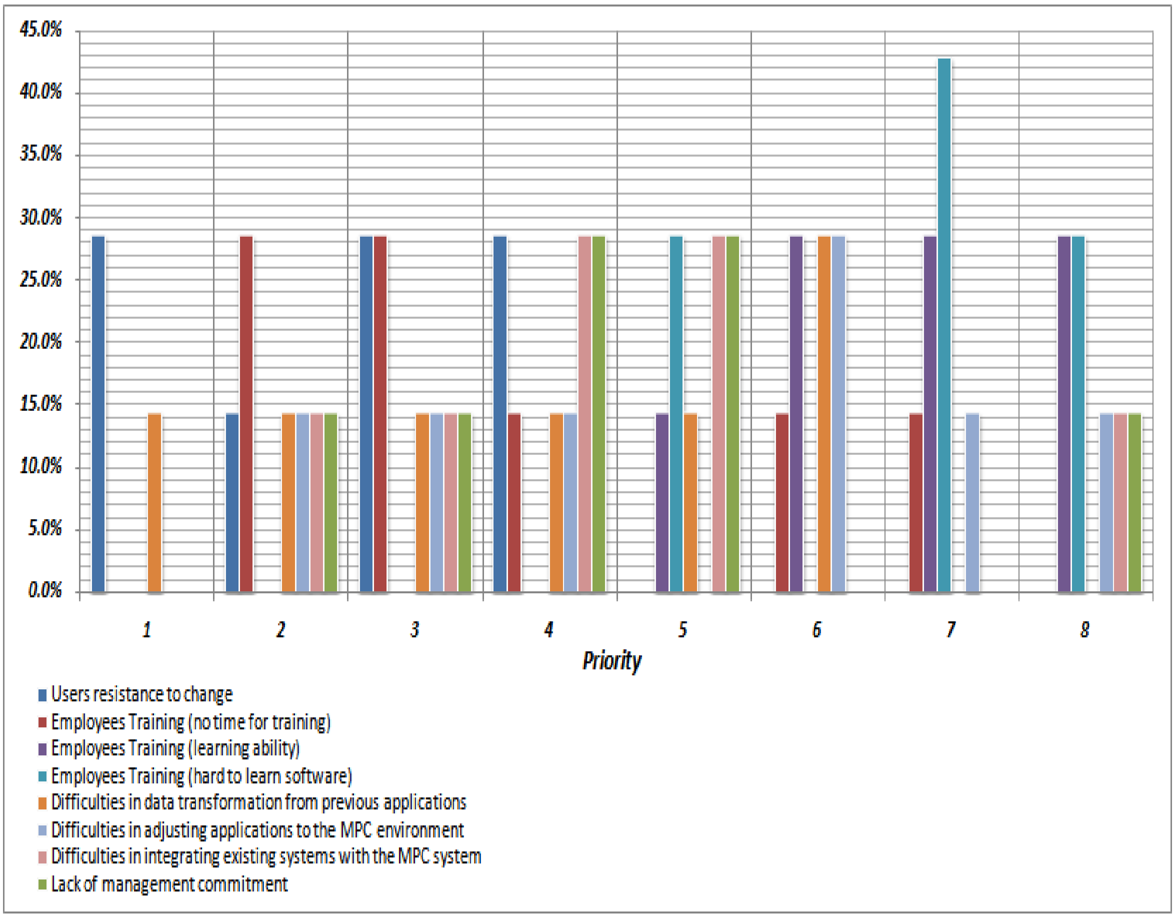

Figure 20 comparison between the difficulties of implementing MPCS

4.4 ERP solutions

Although the companies mentioned before (section 2.4) have various industrial IT solutions and software, only the products that can be situated in the 3-level structure of MPCS (ERP/APS, MES and automation) will be discussed in this and the next sections.

The capabilities of ERP software solutions which are introduced by the companies are summarized as below (table 15). The following information was collected based on the responses to the web-questionnaire and also the companies' website.

Table 15 indicates the similarities and differences between the ERP systems offered on the Swedish market. In order to get an objective and a helpful comparison, The ERP solutions were studied according to the following criteria; *1- Industry focus 2- For which industry size (small, midsize, large) 3- Number of implementation (Worldwide, Sweden) 4- The modules and functions included.*

As mentioned in the theoretical chapter, the core ERP software modules are finance, human resource, sales & marketing, engineering, projects, manufacturing and logistics, maintenance. In addition, each module which consists of sub modules supports some functionality. In the table 16, the primary modules are revised and classified based on 4 main groups including financials, sales & marketing, operations & logistics, and human resources that they provide all functionality needed.

Most of the ERP packages studied are complete suites that include almost all ERP modules and functions. The industries are covered by the ERP solutions are different, some ERP systems have capability to use in any industry and some of them like Garp or Lawson S3 are just provided for a specific industry. Although some ERP vendors such as SAP and SYSteam have introduced ERP software solutions for small and midsize companies, the main focus of the vendors is supporting large multinational corporations. Since there wasn't any accurate statistics about the number of implementations of the software in Sweden, worldwide implementations are mentioned for most of the products.

4.5 APS solutions

The research is based on the data collected from companies' website. Although in some cases it was difficult to understand that software is categorized as ERP or APS, finally the following table (table 16) was prepared. The APS solutions were examined according to: *1- Ability of optimization 2- Planning process covered, called functional criteria 3- Integration method 4- Integration mode*

Regarding the section 3.4, functional criteria that is covered by APS includes 7 modules with different time horizons; strategic network planning, demand planning, demand fulfillment & ATP, master planning, production planning & scheduling, transport planning & distribution planning, and purchasing & material requirements planning.

As shown in the table 16, the majority of ERP vendors also offer APS packages that use complex mathematical algorithms to analyze supply chain constraints and limitations to develop optimal or near optimal solutions. APS software don't generate their own data and ERP systems are usually limited in planning and decision supporting capabilities, thus the integration of APS with ERP can bring a more powerful planning system. The APS can be integrated by other applications in different ways, for example, using standard middleware techniques or vendor specific integration systems. An advantage of standard middleware system compared to vendor specific middleware techniques is that this method is supported by more applications. Another item that was studied is to know how the data transfer from ERP to APS. The transformation is done by two methods; 1-*Online system* means data is updated constantly 2-*Batch system* means data is gathered for a period of time and then information is transferred as a batch.

JDA, Lawson, Oracle and SAP as ERP vendors offer APS solutions that cover all planning processes but all of them don't use commercial optimization tools, for example, some of them provide their own optimization software with some limitations compared to commercial one like JDA solution and in some of them such as SAP software, this capability is not applicable. Supply Chain Consultants, Syncron and System Andersson are not ERP vendors and they just provide APS solutions.

	Product	*ComActivity Supply Chain Suite*	*IBS Enterprise*	*IFS Applications*	*JDA Supply Chain Suite*	*Lawson M3*	*Lawson S3*	*Oracle Applications*	*SAP Business Suite*
	Vendor	ComActvity	IBS	IFS	JDA	Lawson		Oracle	SAP
	Industry Focus	Process Manufacturing, Heavy Maintenance and MRO Distribution	Wholesale & Distribution	All	All	Manufacturing & Distribution	Service Industries	All	All
	Industry Size	Midsize & Large	Midsize & Large	Midsize & Large	All	Midsize & Large		All	All
	Number of Implementation ***Worldwide (W) - Sweden (S)***	W: 100	W: 5000	W:2200	W: 6000	W: 4500		W:370000	W:43400
	Modules and Functions Included								
1. Financials	*Accounts Receivable &payable*		✓	✓	✓	✓	✓	✓	✓
	Asset Accounting		✓	✓	✓	✓	✓	✓	✓
	Cash Management & Forecasting		✓	✓	✓	✓	✓	✓	✓
	General Ledger		✓	✓	✓	✓	✓	✓	✓
	Product – Cost Accounting		✓	✓	✓	✓	✓	✓	✓
	Profitability Analysis		✓	✓	✓	✓	✓	✓	✓
	Cost-Element & Cost-Center Accounting		✓	✓	✓	✓	✓	✓	✓
	Profit-Center Accounting		✓	✓	✓	✓	✓	✓	✓
	Standard & Period-Related Costing		✓	✓	✓	✓	✓	✓	✓
	Financial Consolidation		✓	✓	✓	✓	✓	✓	✓
	Executive Information System		✓	✓	✓	✓	✓	✓	✓
2. Sales & Marketing	*Order Management*	✓	✓	✓	✓	✓		✓	✓
	Sales Management	✓	✓	✓	✓	✓		✓	✓
	Sales Planning	✓	✓	✓	✓	✓		✓	✓
	Pricing	✓	✓	✓	✓	✓		✓	✓
	After-Sales Service	✓	✓	✓	✓	✓		✓	✓
3. Operations & Logistics	*Inventory Management*	✓	✓	✓	✓	✓		✓	✓
	Material Requirements Planning (MRP)	✓	✓	✓	✓	✓		✓	✓
	Materials Management	✓	✓	✓	✓	✓		✓	✓
	Production Planning	✓	✓	✓	✓	✓		✓	✓
	Plant Maintenance	✓	✓	✓	✓	✓		✓	✓
	Project Management	✓	✓	✓	✓	✓	✓	✓	✓
	Quality Management	✓	✓	✓	✓			✓	✓
	Purchasing	✓	✓	✓	✓	✓		✓	✓
	Routing Management	✓	✓	✓	✓	✓		✓	✓
	Shipping	✓	✓	✓	✓	✓		✓	✓
	Vendor/ Supplier Evaluation	✓	✓	✓	✓	✓		✓	✓
4. Human Resources	*Payroll*		✓	✓	✓		✓	✓	✓
	Personnel Planning		✓	✓	✓		✓	✓	✓
	Travel Expenses		✓	✓	✓		✓	✓	✓
	HR Time Accounting		✓	✓	✓		✓	✓	✓
	Training			✓			✓	✓	✓

Table 15 comparison between ERP systems (Part I)

	Product	*Jeeves*	*Garp*	*J D Edwards*	*Microsoft Dynamics AX*	*Microsoft Dynamics NAV*	*Movex*
	Vendor	SYSteam	SYSteam	SYSteam	SYSteam	SYSteam	SYSteam
	Industry Focus	Manufacturing	Textile & Fashion	Manufacturing, Food and beverage, Financial Institutions	All	All	manufacturing & distribution
	Industry Size	Midsize	Small & Midsize	Midsize & Large	Midsize & Large	Midsize	
	Number of Implementation ***Worldwide (W) - Sweden (S)***	S: 2000	S:1500	W:6000 S:100	W:4000	W:50000	W:3000
	Modules and Functions Included						
1. Financials	*Accounts Receivable &payable*	✓	✓	✓	✓	✓	✓
	Asset Accounting	✓	✓	✓	✓	✓	✓
	Cash Management & Forecasting	✓	✓	✓	✓	✓	✓
	General Ledger	✓	✓	✓	✓	✓	✓
	Product – Cost Accounting	✓	✓	✓	✓	✓	✓
	Profitability Analysis	✓	✓	✓	✓	✓	✓
	Cost-Element & Cost-Center Accounting	✓	✓	✓	✓	✓	✓
	Profit-Center Accounting	✓	✓	✓	✓	✓	✓
	Standard & Period-Related Costing	✓	✓	✓	✓	✓	✓
	Financial Consolidation			✓	✓	✓	✓
	Executive Information System	✓		✓	✓		✓
2. Sales & Marketing	*Order Management*	✓	✓	✓	✓	✓	✓
	Sales Management	✓	✓	✓	✓	✓	✓
	Sales Planning	✓	✓	✓	✓	✓	✓
	Pricing	✓	✓	✓	✓	✓	✓
	After-Sales Service	✓		✓	✓	✓	✓
3. Operations & Logistics	*Inventory Management*	✓	✓	✓	✓	✓	✓
	Material Requirements Planning (MRP)	✓	✓	✓	✓	✓	✓
	Materials Management	✓	✓	✓	✓	✓	✓
	Production Planning	✓	✓	✓	✓	✓	✓
	Plant Maintenance	✓		✓			✓
	Project Management	✓	✓	✓	✓	✓	✓
	Quality Management	✓		✓			✓
	Purchasing	✓	✓	✓	✓	✓	✓
	Routing Management	✓		✓	✓	✓	✓
	Shipping	✓		✓	✓	✓	✓
	Vendor/ Supplier Evaluation	✓		✓	✓	✓	✓
4. Human Resources	*Payroll*				✓		
	Personnel Planning				✓	✓	
	Travel Expenses			✓	✓	✓	✓
	HR Time Accounting			✓	✓	✓	✓
	Training		✓		✓		

Table 15 comparison between ERP systems (Part II)

Product	*ComActivity APS*	*IBS APS*	*IFS APS*	*JDA / i2 Technologies*	*Lawson APS*	*Oracle APS*	*mySAP Supply Chain Management*	*Zemeter*	*SCM*	*Andersson Qwick MPS*
Vendor	ComActivity	IBS	IFS	JDA	Laswson	Oracle	SAP	Supply Chain Consultants	Syncron	System Andersson
Ability of Optimization	In-house developed	N/A	In-house developed	In-house developed	Commercial	Commercial	N/A	Commercial	In-house developed	N/A
Integration Method	Specific & SOA	Specific & Standard	SOA	Specific & Standard	Specific & Standard	Specific & SOA	Specific & Standard	Standard & SOA	Standard & SOA	Standard & SOA
Integration Mode	*Online*	*Online*	*Online & Batch*	*Online & Batch*	*Online & Batch*	*Online & Batch*	*Online & Batch*	*Online & Batch*	*Online & Batch*	*Online & Batch*
Planning Processes Covered										
Strategic Network Planning				✓	✓	✓	✓			
Demand Planning	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Demand Fulfillment and ATP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Master Planning	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Production Planning and Scheduling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Transport Planning and Distribution Planning	✓	✓	✓	✓	✓	✓	✓			✓
Purchasing and Material Requirements Planning	✓	✓	✓	✓	✓	✓	✓	✓		✓

Table 16 comparison between APS packages

4.6 Performance of ERP/APS software

Although various methods as well as different indicators can be applied to evaluate the performance of the ERP/APS software, this study chose some common technical factors that are usually questioned about IT solutions. The software was evaluated based on these factors by using the experience of vendors and the perspective of users. In order to have a success software performance assessment, first three main classifications were determined and as the second step, each of them broke down to more detailed indicators; 1- *User friendliness*: Ease of operation 2- *Flexibility*: Ease of integration with other applications, Ease of maintenance, Speed of (re)planning, Ease of customizing and Ease of creating/modifying report 3- *Functionally:* Simulation capabilities and Ability of optimization.

Introduction to table 17: This table shows the responses to the sixth question of the web-questionnaire; "How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers?" The performance indicators were evaluated based on three headings "Very High, High and Medium"

According to the table, most of the software has very high or high performance on indicators selected. Neither vendors that use commercial optimization tools nor vendors with their own optimization tools have the optimization ability as very high. In around 86 % of software studied, the integration capability with other applications (the same layer or other layers of MPCS) is very high or high. The table indicates that most of the vendors have a very good capability in developing user friendliness factors (71% as very high).

Performance Indicators	Very High	High	Medium
Ease of customizing	57%	43%	0%
Simulation capabilities	14%	57%	29%
Ease of creating/modifying report	57%	43%	0%
Speed of(re)planning	43%	57%	0%
Ease of integration with other applications	43%	43%	14%
Ability of optimization (for APS system)	0%	80%	20%
Ease of maintenance	57%	29%	14%
Ease of operation	71%	29%	0%

Table 17 performance of ERP/APS software

4.6 MES solutions

As discussed in the previous chapter, MES software that fills the communication gap between ERP/APS layer of MPCS and shop floor is better to be studied from two aspects 1 –Functional requirements that should be covered by software 2- Non- functional requirements.

Introduction to figure 21: The purpose of the figure is to show the perspective of IT vendors which provide MES solutions about the fifteenth question of the web-questionnaire; “How do you rate the importance of the following criteria for evaluation of MES solutions?” No. 1 counts for the most important item and No.6 counts for the least important one.

According to the figure, the majority of vendors believe that “Value” which means the functions of a MES solution in relation to the costs for buying and implementing the software must be considered as the most important non functional requirement. Contrary to the author’s expectation, sufficient integration of MES software with existing applications on other layers is not the first priority and IT vendors identify it as the second one or even lower priority. As explained in the theoretical chapter, some functions are provided by applications from different layers, for example, regarding a time horizon, some tasks are provided by ERP/APS software as well as MES applications. Thus a proper integration of MES solutions with applications of higher or lower layers is necessary.

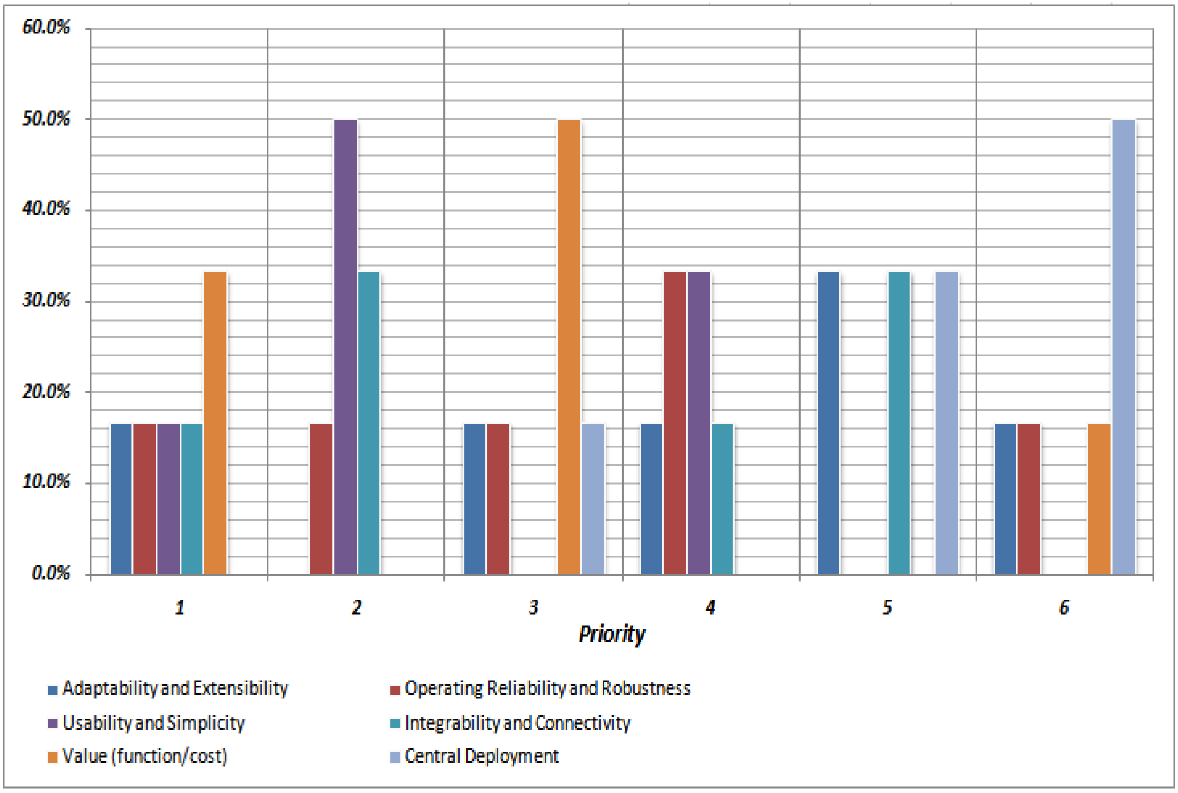

Figure 21 non-functional criteria on MES solutions

Table 18 shows the performance of MES software in non-functional criteria. Since the purpose of the study is not to compare the performance of software based on the following items, only the average of responses is presented. In all cases, MES solutions have very high or high performance. Around 80 % of software is able to connect to interfaces provided by applications on other layers (ERP/APS, shop floor) as well as existing applications that support MES functionalities. The capability of modification in software according to the company requirements is not very strong in all MES software studied (Just 40 % Very high).

Non-functional Criteria	Very High	High	Medium
Adaptability and Extensibility	40%	60%	0%
Operating Reliability and Robustness	60%	40%	0%
Usability and Simplicity	80%	20%	0%
Integrability and Connectivity	80%	20%	0%
Value (function/cost)	60%	40%	0%
Central Deployment	40%	60%	0%

Table 18 performance of MES software in non-functional criteria

Since the MES, Manufacturing Execution System, market is almost new, there is no comprehensive information about the vendors that provide MES solutions, especially for the Swedish market. This market has grown very fast during recent years, thus it is vital to do a complete investigation about the name of MES solutions on the market as well as their functionalities, number of implementations, industry focus and size.

Table 19 presents the MES solutions on the Swedish market. Unfortunately, accurate statistics about the number of implementations of software (worldwide, Sweden) couldn't be collected. According to the MES reference model presented in the theoretical chapter, the functionalities of the solutions are divided into three groups; the core functionalities that are only assigned to the MES level, common functionalities with ERP/APS systems and common functions with shop floor layers. The main focus of MES solutions studied is manufacturing industry (process, discrete), but some software can only be used for specific industries, for example, "Xcon" is provided for the following industries; oil and gas, food and all types of bulk handling.

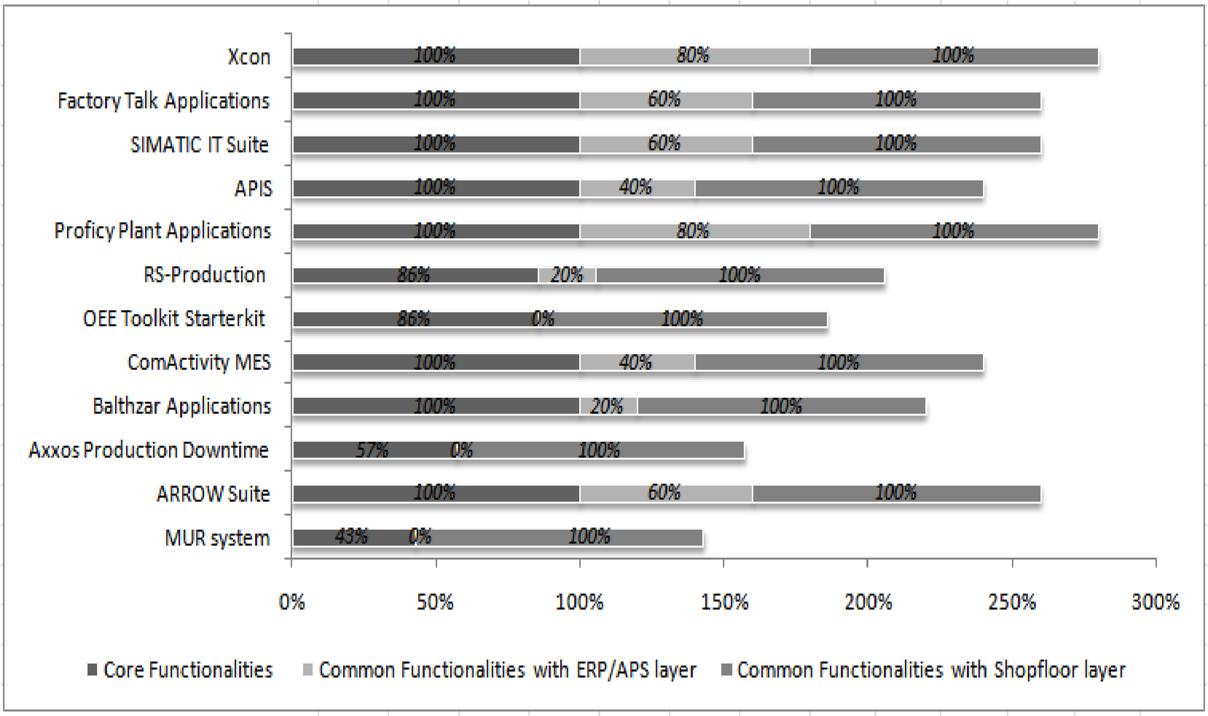

Figure 22 functionalities covered by MES solutions

As shown in the figure 22, most of the software covers more than 85% of core functionalities and 100% common function with shop floor layer including machine control and production data acquisition. “Proficy Plant Applications” and “Xcon” are the only MES solutions on the Swedish market that provide more than 80% of common functionalities with ERP/APS layer.

4.7 SFDAC systems

On t he shop floor as a lower layer of MPCS map, a large amount of data is usually generated daily. According to information that needs to be collected on this level, various methods and techniques can be used. Table 20 shows some methods that are applied by vendors to gather data on the shop floor as well as information collected by these systems. Status requirements are classified in 7 groups; *Job Status, Operation Status, Operator Status, Machine Status, Tool Status, Material Status and Martial Handling System Status.*

As shown in the table, the majority of applied systems can collect all information needed and then send to the upper layers (MES and ERP/APS). Accurate and reliable planning can be provided by MPCS whenever the real-time information is collected on the shop floor.

Product	*MUR system*	*ARROW Suite*	*Axxos Production Downtime*	*Balthzar Applications*	*OEE Toolkit Starterkit*	*RS-Production*	*Proficy Plant Applications*	*APIS*
Vendor	Adductor	ARROW Engineering Oy	AXXOS	Balthzar	Full Fact	Good solutions	NovoteK	Prediktor
Industry Focus	Manufacturing	All	Manufacturing	Manufacturing	All	Automated Discrete Production	Manufacturing	All
Industry Size	Small & Midsize	All	Midsize & Large	Small & Midsize	All	All	All	Midsize & Large
Number of Implementation ***Worldwide (W) - Sweden (S)***		W: 400			W: 400	S: 25-30	W: 800 S: 50	
<u>Core Functionalities</u>								
Resource Management		✓		✓			✓	✓
Equipment Management /Maintenance	✓	✓	✓	✓	✓	✓	✓	✓
Manufacturing Execution/Control		✓	✓	✓	✓	✓	✓	✓
Dynamic Routing		✓		✓	✓	✓	✓	✓
Traceability/Genealogy	✓	✓		✓	✓	✓	✓	✓
Production Reporting and Analysis	✓	✓	✓	✓	✓	✓	✓	✓
Master Data Management		✓	✓	✓	✓	✓	✓	✓
<u>Common Functionalities with ERP/APS Layer</u>								
Labor Management		✓						
Gross Planning							✓	
Detailed Scheduling						✓	✓	✓
Quality Management		✓					✓	✓
Production Inventory Management		✓		✓			✓	
<u>Common Functionalities with Shop Floor Layer</u>								
Machine Control	✓	✓	✓	✓	✓	✓	✓	✓
Production Data Acquisition	✓	✓	✓	✓	✓	✓	✓	✓

Table 19 comparison between MES solutions (Part I)

Product	*SIMATIC IT Suite*	*Factory Talk Applications*	*ComActivity MES*	*Xcon*
Vendor	Siemens	Rockwell Automation	ComActvity	SDA
Industry Focus	All	All	Process Manufacturing, Heavy Maintenance and MRO Distribution	Oil, Gas, Food and all types of bulk handling
Industry Size	Midsize & Large	All	Midsize, Large	Midsize & Large
Number of Implementation ***Worldwide, Sweden***			W: 60	S:30
<u>Core Functionalities</u>				
Resource Management	✓	✓	✓	✓
Equipment Management /Maintenance	✓	✓	✓	✓
Manufacturing Execution/Control	✓	✓	✓	✓
Dynamic Routing	✓	✓	✓	✓
Traceability/Genealogy	✓	✓	✓	✓
Production Reporting and Analysis	✓	✓	✓	✓
Master Data Management	✓	✓	✓	✓
<u>Common Functionalities with ERP/APS Layer</u>				
Labor Management				
Gross Planning				✓
Detailed Scheduling	✓	✓	✓	✓
Quality Management	✓	✓		✓
Production Inventory Management	✓	✓	✓	✓
<u>Common Functionalities with Shop Floor Layer</u>				
Machine Control	✓	✓	✓	✓
Production Data Acquisition	✓	✓	✓	✓

Table 19 comparison between MES solutions (Part II)

	Information Collected						
Shop Floor Data Acquisition and Collection (SFDAC) System	Job Status	Operation Status	Operator Status	Machine Status	Tool Status	Material Status	Material Handling System Status
Bar code and labeling Scanning Web services ODBC/JDBC XML- messaging JML - Messaging Java Eclipse Flash/ Flex	✓	✓	✓	✓	✓	✓	✓
Bar code, data matrix, touch screens, PLCs	✓	✓	✓	✓	✓	✓	✓
The client itself is programmed in .net, C, VB. And also taking signals directly from the machine like via OPC-server or a PLC unit called Beck off (BC9000)	✓		✓	✓	✓	✓	✓
Bar code, direct connection to machines and more	✓		✓	✓			✓
RFID, touch screens	✓	✓	✓	✓	✓	✓	✓

Table 20 Information collected by SFDAC systems

5. Conclusion and Discussion

The study was conducted in two parts in order to answer the research questions that were discussed in the problem description. ***First,*** MPCS terms and different layers of MPCS as well as functionalities of each level were described.

1. What is actually meant by the term "MPCS"?
   Manufacturing Planning and Control Systems (MPCS) are developed to manage manufacturing plant performance and to control existing resource including materials, labors, and equipments by providing feasible, time phased plans and monitoring their progress.

2. What are the functionalities of modern perspective of MPCS?
   Evolution of MPCS consists of 6 primary steps that the first 5 steps including ROP, MRP, MRP II, ERP, and APS belongs to the classical view of MPCS. Since these systems can only provide a holistic view of company-wide business and manufacturing processes, they are not able to supply accurate and real-time information. The last step of evolution including integration of MES and ERP/APS presents the modern perspective of MPCS. At the end of 1990s, this structure was developed to fill the gap between the operation times in reality and in the planning systems. The present structure of MPCS includes 3-level structure (ERP/APS, MES, shop floor) that functionalities with specific time horizons are assigned to each layer. Some functions, called potentially redundant functionalities can be changed between layers based on specific companies' requirements. Therefore each company should develop its own functional reference architecture.
   The 3rd level, called business management, includes the modules relevant to ERP/APS systems such as human resource management, and finance management. In this level, functionalities are in a medium and long term with a commercial orientation. The 2nd level, known as MES level, comprises core functionalities as well as common functionalities with upper and lower levels. The MES functionalities are in real time with a technological orientation. The 1st level (production level) is related to shop floor data acquisition and controls. With respect to the complexity of products and processes, various systems can be used to collect information needed e.g. RFID, bar code technology and PLCs. There is bidirectional information flow between MES level and upper/lower level. Work orders and staff off/on-duty provided by business management level send to the MES level as input data. On the other hand, event messages that may result of shortage of resources are transmitted from MES level to ERP/APS level. In addition, the detailed work orders including daily operation plan for each machine and employee as well as maintenance time-tables are sent from MES level to production level. The shop floor facts e.g. operation status, operator status and machine status are collected and then transferred to the MES level.

3. What are important items for choosing and implementing a right MPCS package?
   the companies that are interested to implement MPCS package in their organization must consider some issues before selecting a planning system, for instance, industry type of a company, the size of the company, which departments of the organization will use the system, functionality needed in each sector, the language requested, total number of software users in the company. Moreover, the following items must be noticed as well, for example, annual revenue, a budget for the project, the capability of a vendor to provide professional help

including hardware and infrastructure, , customization and integration services, implementation, and training.

In the next step, they should evaluate existing software solutions on the market with respect to their needs and it is better to get help from consultants in this step. The MPCS modules requested can be bought from a single vendor or several vendors. In the last step, The MPCS implementation must be applied in several small controllable phases and the validation of implementation can be done by the vendors' tools and the internal quality system. An implementation team which comprises representatives from different sector s of a company and a software solution vendor makes a decision to design these implementation phases.

4. What are advantages of MES implementation in the contemporary perspective of MPCS?
   MES solutions are developed to bridge the gap between operation times in reality and in the planning systems. They provide accurate and real-time information for making decisions and solving problems. Proper Integration of MES software with existing applications from other levels including ERP/APS software (business management level) and bar code systems, RFID and PLCs (automation level) helps the companies to improve utilization of their resources.

   Although some studies regarding the advantages of MES implementation was found, most of them related to American industries and unfortunately there is not any relevant research articles about Swedish companies. These articles illustrate that companies with MES solutions can improve faster than firms not using MES. Since this project is not able to investigate about the influence of MES solutions on the performance of Swedish companies, further research must be done to confirm the capabilities of MES software.

Second, the IT vendors that provide software solutions for each level of MPCS were introduced. In addition, comprehensive information including a number of implementations (*Worldwide, Sweden*), industry focus and size, and the functions of each solution were presented. The following methods were used to collect data about vendors' software solutions; 1- web- questionnaire 2- Companies' website. Since the responses to the web-questionnaire were less than 50%, further information needed was gathered by reviewing the companies' website. Data presented on the vendors' website are usually general and they don't cover detail information. Therefore, the better way would be to apply a trial version of solutions and then to analyze their functionalities by getting help from IT experts. This method leads to have a consistency between the reality and theoretical ideas that have been developed by author.

5. What is IT vendors' viewpoint on MPCS and its functionalities in each layer?
   Since MPCS is a required infrastructure for companies and support the improvement of firms in different areas, to be aware of *business drivers and difficulties* helps the IT vendors to develop solutions according the customer needs and requirements and also to identify appropriate corrective/ preventive actions. Like the studies which has been done by Aberdeen Group in the previous years, the responses to the question about *business drivers* show "Reduce costs" is still the most important item. But a notable point is the priority of "Improve decision-making by planning in real time "as the third one that supports the need of MES layer in MPCS structure.

6. What are the capabilities and functionalities of software solutions introduced to the Swedish market in each level of MPCS?
   Comprehensive information about MPCS solutions on the Swedish market are shown in tables 16, 17, 19 and 20. Most of the software solutions presented in the business management level

are complete suites that cover all functions needed and their performance with regard to the feedback from customers is high or very high. The majority of ERP vendors e.g. SAP, Oracle and Lawson offer APS solutions as well. The main focus of ERP/APS vendors is supporting large and multinational companies.

MES software solutions based on their specifications shown in the table 19 can cover various functions including core functions and redundant functions. In order to choose a proper MES solution, the companies should consider the following criteria; 1- software that is used on business management level as well as SFDAC systems applied on the shop floor 2- company-specific requirements. The study about the performance of MES software in non- functional requirements (table 18) shows most of the vendors have developed their MES solutions based on these requirements. In addition, it indicates that IT vendors are aware of the importance easy MES software integration can have with other applications.

6. Suggestions for further research

In further studies, the MES reference model can be applied by Swedish companies and the factors influencing this model can be investigated. The following questions can be studied about the firms that have successfully implemented MES solutions:

- What were the main reasons that a firm decided to implement an MES solution and did the organization get the results expected?
- What kind of approach and method has been used by the firm with respect to system functionality, difficulties and risks during implementation, validating a solution, implementation costs, change management and etc?
- What were the bottlenecks during the implementation process and how did the company overcome these obstacles?
- The company thinks which part of the implementation would be better to be done in another way and why?

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Appendix 1

IT vendors contact information

Company	Website	Email & Tel of Contact Person
Adductor	www.adductor.se	information@adductor.se 0470-48230
ARROW Engineering Oy	www.arroweng.fi	dirk.bogdahn@arroweng.fi +49 2054 8755 602
Axxos	www.axxos.com	henrik.renstrom @ axxos.com 036 - 33 20 604
Balthzar	www.balthzar.se	per.falkman@delacroy.se 0371-83830
ComActivity	www.comactivity.se	magnus.gronvik@comactivity.net 08 - 500 001 00
Full Fact	www.fullfactoee.com	sales@fullfact.com +31 (0)499 872 507
Good Solutions	www.goodsolutions.se	mikael@goodsolutions.se 031- 711 60 63
IBS	www.ibs.net	Jeanette.lind@ibs.net 08- 627 23 00
IFS	www.ifsworld.com	lena.ottosson@ifsworld.com 031- 726 30 00
JDA	www.jda.com	mats.carlberg@jda.com 08 – 506 363 84
Lawson	www.lawson.com	charlotte.darth@se.lawson.com 031- 792 81 00
Novotek	www.novotek.se	info@novotek.se 040 - 31 69 55
Oracle Svenska AB	www.oracle.com	direkt_se@oracle.com 031-733 55 00
Prediktor	www.prediktor.no	aksell@prediktor.no 0708 117 150
Rockwell Automation	www.rockwellautomation.se	pkransdal@ra.rockwell.com 0771- 219 219
SAP	www.sap.com	anders.schyllert @sap.com 020 79 40 29
SDA	www.sda.se	info@sda.se 040 - 41 75 70
Siemens IT Solutions AB	www.siemens.com	Fredrik.hallenborg@simens.com 08 - 730 65 00
Supplychain Consultants	www.supplychain.com	sales@supplychain.com +32 3 232 2391
Syncron International AB	www.syncron.com	andreas.brase@syncron.com 08 - 410 802 00
SYSteam	www.systeam.se	bo.oskarsson @systeam.se 036 - 14 91 00
SystemAndersson	www.systemandersson.se	emma.candemar@systemandersson.se 036-14 20 60

Appendix 2

What problems are addressed by Manufacturing Execution System (MES) based on updated information? (Deuel, 1994)

For instance:

Equipment and labor management

- What was the equipment utilization rate on a specific shift?
- Is any extra worker needed for a specific shift?
- What is the equipment utilization rate in general?
- When is the correct time for the equipment maintenance?
- How the equipment setup and changeover can be reduced?

Material Management

- How much waste is produced in general/ for a specific shift?
- What is the yield rate of each product?
- What batch sizes are being processed?
- Do the finished products in warehouse meet the customer's needs?
- In order to produce different products, what raw materials and equipment is required?

Planning and scheduling management

- What product must be produced for the next shift/day?
- Which machine is available for making product X?
- The production plan is met?
- How the bottlenecks in production can be eliminated?

Quality management

- How the product quality specifications can be connected to the process control parameters?
- How the production processes can be improved?
- What production factors are important with respect to costs?

Operations management

- Do operators work according to the standard procedures?
- Will the next shift recognize what operations have been done?

Regulatory compliance management

- The status of emissions and energy consumption?

Appendix 3

Detailed MES functions that are developed by (Schmidt, et al., 2009) based on different MES standards such as MESA, NAMUR and ISA are described below.

- ***Labor Management***: controls staff working time logging; manages and controls staff data; makes personnel scheduling and capacity planning; assigns staff on schedule provided; carries out time and attendance reports.
- ***Gross Planning*** : makes rough cut capacity planning; assigns production needs to potential production plants; generates bill of materials; determine lot sizes and lead times; controls feasibility
- ***Detailed Scheduling***: analyzes production constraints with regard to resource availability and conditions; calculates plant time and equipment loading; updates and optimizes production plans according to delays; interruptions and shift patterns; carries out short time resource allocation; creates sequence scheduling; defines production orders based on production needs; generates concrete production plan.
- ***Quality Management***: provides quality and inspection planning; makes registration of quality test samples taken by production control; carries out quality inspection and document quality tests; manages and controls testing equipment; provides relevant quality data for production documentation; generates action plan in order to correct errors and failures; manages and controls rework; carries out quality audit process; creates and evaluates analysis reports.
- ***Production Inventory Management***: collects and manages information about workflow of production units; provides input material needs by getting from outside source or in-house production; monitors incoming and outdoing deliveries; manages and controls the amount of work in process (buffer management); supervises scheduled/unscheduled material flow.
- ***Resource Management (or Martial Management)***: makes sure resource availability and tracks resource status; records detailed resource information; manages and controls WIP buffers, provides reservation and dispatching of resources; makes sure equipment is appropriately set up.
- ***Equipment Management /Maintenance***: manages and controls equipment maintenance activities; carries out status management of equipment; makes sure equipment and tools availability for manufacturing processes; makes sure scheduling for periodic and preventive maintenance; documents information about past events and problems.
- ***Manufacturing Execution/Control***: manages and supervises production according to orders received; monitors and adjusts order sequence; maintains current order feedback; compares actual production schedules against planned schedules; provides production plans in real time; monitors and controls stations electronically; sends orders for in-process controls to Quality Management (QM); collect historical data of waste; monitor material movements by controlling inventory; provides relevant production data for production documentation.
- ***Traceability/Genealogy***: provides status information; makes available online tracing of date related to parts assembled into parent; traces work in process material; manages historical data related products/production.
- ***Dynamic Routing***: manages deviations and exceptional issues; provides inventory planning and re-sequencing; and carries out real-time load balancing. This function usually is considered as a part of "*Manufacturing Execution/Control*".

- ***Production Reporting and Analysis***: provides long term production analysis and evaluation report; compares production goals to actual situation; monitors the consistency of processes and triggers alarm when there is any deviation (Statistical Process Control).
- ***Machine Control***: supervises and controls the status of machines; gathers plan and machine data (Machine Data Acquisition); enables electronic control station functionality.
- ***Production Data Acquisition***: manages and processes input data; enables plausibility controls and dashboard functionality (present production information); gathers shop floor data in an up-to-the- minute time frame.
- ***Master Data Management***: captures master data from higher level (ERP/APS); makes available electronic documentation for manufacturing processes; generates, keeps and updates information related to products, equipments and tools; records versions of specifications.

Appendix 4

Planning System Questionnaire

Researcher: Ashkan Mohajeri Naraghi
Supervisor & Examiner: Prof. Peter Almström
Master Dissertation of the Graduate School of Materials and Manufacturing Technology
Chalmers University of Technology, Gothenburg, Sweden

Note to the respondent:
Please assist me to collect and establish detailed research data about the IT solutions that are presented to the Swedish market in each layer of planning system (APS/ERP, MES, and Automation) and also help me to determine the critical success factors for developing a good IT solution in each layer. This research will provide a guideline for IT vendors which are looking to bridge the gap between operation times in reality and in the planning system.
Although I would like you to help me, you do not have to participate in this survey.
All answers in this questionnaire will be used in my master thesis work.

How to fill in the web questionnaire:

- The first two questions are general questions about MPCS.
- Question 3, 4, 5 and 6 are about your ERP or APS system (if applicable).
- Question 7, 8, 9 and 10 are necessary to answer when you have more than one type of APS/ERP software.
- Question 11, 12, 13 and 14 are necessary to answer when you have more than two types of APS/ERP software.
- Question 15 is general question about MES system.
- Question 16, 17 and 18 are about your MES software (if applicable).
- Question 19, 20 and 21 are necessary to answer when you have more than one MES solution.
- Question 22 and 23 is about your shop floor data acquisition and collection system (if applicable).
- Question 24 and 25 are necessary to answer when you have more than one SFDAC system.
- Question 26 and 27 are necessary to answer when you have more than two SFDAC systems.

Abbreviations

- MPCS: Manufacturing Planning and Control Systems
- APS: Advanced Planning System
- ERP: Enterprise Resource Planning
- MES: Manufacturing Execution System
- SFDAC: Shop Floor Data Acquisition and Collection

Thank you for taking your time to complete the questionnaire and your consideration in advance.

Ashkan Mohajeri Naraghi

1. In order to meet sustainable future business growth, MPCS is a required infrastructure for companies. In addition, it is a potential source of cost savings and operational improvements. While growth of income, profits and also remaining competitive are the main goals of companies, how do you rate the following business drivers that impact a customer's decision to select MPCS? (No.1 counts for the most important and No.7 counts for the least important one.)

   Note: Don't repeat any number in your answers.

Business Drivers	**No.**
Reduce costs	
Improve overall customer experience	
Manage growth	
Improve customer response time	
Increase interoperability across multiple operating locations	
Innovate to deliver more value	
Improve decision- making by planning in real time	

2. Every software implementation faces difficulties that lead to delayed implementation. How do you rate the following problems? (No.1counts for the most common problem and No.8 counts for the least common problem one.)

   Note: Don't repeat any number in your answers

Problems	**No.**
Users resistance to change	
Employees Training (no time for training)	
Employees Training (learning ability)	
Employees Training (hard to learn software)	
Difficulties in data transformation from previous applications	
Difficulties in adjusting applications to the MPCS environment	
Difficulties in integrating existing systems with the MPCS	
Lack of management commitment	

3. Which types of MPCS have your company released to the market?

The Name of Software			
ERP or APS	☐ ERP	☐ APS	
Industry Focus			
For Which Industry Size	☐ Small	☐ Midsize	☐ Large
Number of Implementation	Worldwide --------------	Sweden --------------	

4. If the software is ERP, please indicate the modules and functions included.

1. Financials	
☐ *Accounts Receivable & payable*	☐ *Cost-Element & Cost-Center Accounting*
☐ *Asset Accounting*	☐ *Profit-Center Accounting*
☐ *Cash Management & Forecasting*	☐ *Standard & Period-Related Costing*
☐ *General Ledger*	☐ *Financial Consolidation*
☐ *Product – Cost Accounting*	☐ *Executive Information System*
☐ *Profitability Analysis*	
2. Sales & Marketing	
☐ *Order Management*	☐ *Pricing*
☐ *Sales Management*	☐ *After-Sales Service*

☐ *Sales Planning*	
3. Operations & Logistics	
☐ *Inventory Management* ☐ *Material Requirements Planning (MRP)* ☐ *Materials Management* ☐ *Production Planning* ☐ *Plant Maintenance* ☐ *Project Management*	☐ *Quality Management* ☐ *Purchasing* ☐ *Routing Management* ☐ *Shipping* ☐ *Vendor/Supplier Evaluation*
4. Human Resources	
☐ *Payroll* ☐ *Personnel Planning* ☐ *Travel Expenses*	☐ *HR Time Accounting* ☐ *Training*

5. If the software is APS, please specify the following items.

Ability of Optimization	☐ In-house developed	☐ Commercial	☐ N/A
Integration Method	☐ Standard	☐ Vendor specific	☐ SOA
Integration Mode	☐ Online	☐ Batch	
<u>Planning Processes Covered</u>			
☐ Strategic Network Planning (SNP) ☐ Demand Planning (DP) ☐ Demand Fulfillment and ATP (DF&ATP) ☐ Master Planning (MP) ☐ Production Planning and Scheduling (PP&S) ☐ Transport Planning and Distribution Planning (TP&DP) ☐ Purchasing and Material Requirements Planning (P&MRP)			

6. How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers? *(Very High, High, Medium)*

Criteria	**Very High**	**High**	**Medium**
Ease of customizing	☐	☐	☐
Simulation capabilities	☐	☐	☐
Ease of creating/modifying report	☐	☐	☐
Speed of(re)planning	☐	☐	☐
Ease of integration with other applications	☐	☐	☐
Ability of optimization (for APS system)	☐	☐	☐
Ease of maintenance	☐	☐	☐
Ease of operation	☐	☐	☐

7. Answer to question 7, 8, 9 and 10 if you have more than one MPCS.

The Name of Software			
ERP or APS	☐ ERP	☐ APS	
Industry Focus			
For Which Industry Size	☐ Small	☐ Midsize	☐ Large
Number of Implementation	Worldwide --------------	Sweden --------------	

8. If the software is ERP, please indicate the modules and functions included.

1. Financials	
☐ *Accounts Receivable & payable* ☐ *Asset Accounting* ☐ *Cash Management & Forecasting* ☐ *General Ledger* ☐ *Product – Cost Accounting* ☐ *Profitability Analysis*	☐ *Cost-Element & Cost-Center Accounting* ☐ *Profit-Center Accounting* ☐ *Standard & Period-Related Costing* ☐ *Financial Consolidation* ☐ *Executive Information System*
2. Sales & Marketing	
☐ *Order Management* ☐ *Sales Management* ☐ *Sales Planning*	☐ *Pricing* ☐ *After-Sales Service*
3. Operations & Logistics	
☐ *Inventory Management* ☐ *Material Requirements Planning (MRP)* ☐ *Materials Management* ☐ *Production Planning* ☐ *Plant Maintenance* ☐ *Project Management*	☐ *Quality Management* ☐ *Purchasing* ☐ *Routing Management* ☐ *Shipping* ☐ *Vendor/Supplier Evaluation*
4. Human Resources	
☐ *Payroll* ☐ *Personnel Planning* ☐ *Travel Expenses*	☐ *HR Time Accounting* ☐ *Training*

9. If the software is APS, please specify the flowing items.

Ability of Optimization	☐ In-house developed	☐ Commercial	☐ N/A
Integration Method	☐ Standard	☐ Vendor specific	☐ SOA
Integration Mode	☐ Online	☐ Batch	
Planning Processes Covered			
☐ Strategic Network Planning (SNP) ☐ Demand Planning (DP) ☐ Demand Fulfillment and ATP (DF&ATP) ☐ Master Planning (MP) ☐ Production Planning and Scheduling (PP&S) ☐ Transport Planning and Distribution Planning (TP&DP) ☐ Purchasing and Material Requirements Planning (P&MRP)			

10. How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers? *(Very High, High, Medium)*

Criteria	Very High	High	Medium
Ease of customizing	☐	☐	☐
Simulation capabilities	☐	☐	☐
Ease of creating/modifying report	☐	☐	☐
Speed of(re)planning	☐	☐	☐
Ease of integration with other applications	☐	☐	☐
Ability of optimization (for APS system)	☐	☐	☐
Ease of maintenance	☐	☐	☐
Ease of operation	☐	☐	☐

11. Answer to question 11, 12, 13 and 14 if you have more than two MPCS.

The Name of Software			
ERP or APS	☐ ERP	☐ APS	
Industry Focus			
For Which Industry Size	☐ Small	☐ Midsize	☐ Large
Number of Implementation	Worldwide --------------	Sweden --------------	

12. If the software is ERP, please indicate the modules and functions included.

1. Financials	
☐ *Accounts Receivable & payable*	☐ *Cost-Element & Cost-Center Accounting*
☐ *Asset Accounting*	☐ *Profit-Center Accounting*
☐ *Cash Management & Forecasting*	☐ *Standard & Period-Related Costing*
☐ *General Ledger*	☐ *Financial Consolidation*
☐ *Product – Cost Accounting*	☐ *Executive Information System*
☐ *Profitability Analysis*	
2. Sales & Marketing	
☐ *Order Management*	☐ *Pricing*
☐ *Sales Management*	☐ *After-Sales Service*
☐ *Sales Planning*	
3. Operations & Logistics	
☐ *Inventory Management*	☐ *Quality Management*
☐ *Material Requirements Planning (MRP)*	☐ *Purchasing*
☐ *Materials Management*	☐ *Routing Management*
☐ *Production Planning*	☐ *Shipping*
☐ *Plant Maintenance*	☐ *Vendor/Supplier Evaluation*
☐ *Project Management*	
4. Human Resources	
☐ *Payroll*	☐ *HR Time Accounting*
☐ *Personnel Planning*	☐ *Training*
☐ *Travel Expenses*	

13. If the software is APS, please specify the following items.

Ability of Optimization	☐ In-house developed	☐ Commercial	☐ N/A
Integration Method	☐ Standard	☐ Vendor specific	☐ SOA
Integration Mode	☐ Online	☐ Batch	
Planning Processes Covered			
☐ Strategic Network Planning (SNP)			
☐ Demand Planning (DP)			
☐ Demand Fulfillment and ATP (DF&ATP)			
☐ Master Planning (MP)			
☐ Production Planning and Scheduling (PP&S)			
☐ Transport Planning and Distribution Planning (TP&DP)			
☐ Purchasing and Material Requirements Planning (P&MRP)			

14. How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers? *(Very High, High, Medium)*

Criteria	Very High	High	Medium
Ease of customizing	☐	☐	☐
Simulation capabilities	☐	☐	☐
Ease of creating/modifying report	☐	☐	☐
Speed of(re)planning	☐	☐	☐
Ease of integration with other applications	☐	☐	☐
Ability of optimization (for APS system)	☐	☐	☐
Ease of maintenance	☐	☐	☐
Ease of operation	☐	☐	☐

15. How do you rate the importance of the following criteria for evaluation of MES solutions? (No.1 counts for the most important and No.6 counts for the least important one.)

Note: Don't repeat any number in your answers.

Criteria	No.
Adaptability and Extensibility	
Operating Reliability and Robustness	
Usability and Simplicity	
Integrability and Connectivity	
Value (function/cost)	
Central Deployment	

16. What is the feature of your MES software that has been released to the market?

The Name of Software			
Industry Focus			
For Which Industry Size	☐ Small	☐ Midsize	☐ Large
Number of Implementation	Worldwide -------------	Sweden -------------	

17. Which following modules are included in your MES software?

Core Functionalities	
☐ *Resource Management*	☐ *Traceability/Genealogy*
☐ *Equipment Management /Maintenance*	☐ *Production Reporting and Analysis*
☐ *Manufacturing Execution/Control*	☐ *Master Data Management*
☐ *Dynamic Routing*	
Redundant Functionalities	
☐ *Labor Management*	☐ *Production Inventory Management*
☐ *Gross Planning*	☐ *Machine Control*
☐ *Detailed Scheduling*	☐ *Production Data Acquisition*
☐ *Quality Management*	

18. How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers? *(Very High, High, Medium)*

Criteria	Very High	High	Medium
Adaptability and Extensibility	☐	☐	☐
Operating Reliability and Robustness	☐	☐	☐
Usability and Simplicity	☐	☐	☐
Integrability and Connectivity	☐	☐	☐
Value (function/cost)	☐	☐	☐
Central Deployment	☐	☐	☐

19. Answer to question 18 and 19 if you have more than one MES solution.

The Name of Software			
Industry Focus			
For Which Industry Size	☐ Small	☐ Midsize	☐ Large
Number of Implementation	Worldwide --------------	Sweden --------------	

20. Which following modules are included in your MES software?

Core Functionalities	
☐ *Resource Management*	☐ *Traceability/Genealogy*
☐ *Equipment Management /Maintenance*	☐ *Production Reporting and Analysis*
☐ *Manufacturing Execution/Control*	☐ *Master Data Management*
☐ *Dynamic Routing*	
Redundant Functionalities	
☐ *Labor Management*	☐ *Production Inventory Management*
☐ *Gross Planning*	☐ *Machine Control*
☐ *Detailed Scheduling*	☐ *Production Data Acquisition*
☐ *Quality Management*	

21. How do you estimate the performance of your software in the following criteria with regards to the feedback from your customers? *(Very High, High, Medium)*

Criteria	Very High	High	Medium
Adaptability and Extensibility	☐	☐	☐
Operating Reliability and Robustness	☐	☐	☐
Usability and Simplicity	☐	☐	☐
Integrability and Connectivity	☐	☐	☐
Value (function/cost)	☐	☐	☐
Central Deployment	☐	☐	☐

22. What technology has been used to form your SFDAC system? (For example bar code technology)

23. What status information is collected by your SFDAC system?

☐ Job Status	☐ Tool Status
☐ Operation Status	☐ Material Status
☐ Operator Status	☐ Material Handling System Status
☐ Machine Status	

24. Answer to question 24 and 25 if you have more than one SFDAC system.

25. What status information is collected by your SFDAC system?

☐ Job Status	☐ Tool Status
☐ Operation Status	☐ Material Status
☐ Operator Status	☐ Material Handling System Status
☐ Machine Status	

26. Answer to question 26 and 27 if you have more than two SFDAC systems.

27. What status information is collected by your SFDAC system?

☐ Job Status	☐ Tool Status
☐ Operation Status	☐ Material Status
☐ Operator Status	☐ Material Handling System Status
☐ Machine Status	