

A methodology for Manufacturing Execution Systems (MES) implementation

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Abstract. Manufacturing execution system is information systems (IS) application that bridges the gap between IS at the top level, namely enterprise resource planning (ERP), and IS at the lower levels, namely the automation systems. MES provides a media for optimizing the manufacturing process as a whole in a real time basis. By the use of MES in combination with the implementation of ERP and other automation systems, a manufacturing company is expected to have high competitiveness. In implementing MES, functional integration -- making all the components of the manufacturing system able to work well together, is the most difficult challenge. For this, there has been an industry standard that specifies the sub-systems of a manufacturing execution systems and defines the boundaries between ERP systems, MES, and other automation systems. The standard is known as ISA-95. Although the advantages from the use of MES have been stated in some studies, not much research being done on how to implement MES effectively. The purpose of this study is to develop a methodology describing how MES implementation project should be managed, utilising the support of ISA-95 reference model in the system development process. A proposed methodology was developed based on a general IS development methodology. The developed methodology were then revisited based on the understanding about the specific characteristics of MES implementation project found in an Indonesian steel manufacturing company implementation case. The case study highlighted the importance of applying an effective requirement elicitation method during innitial system assessment process, managing system interfaces and labor division in the design process, and performing a pilot deployment before putting the whole system into operation.

1. Introduction

Manufacturing execution system is information systems (IS) application that bridges the gap between IS at the top level, namely enterprise resource planning (ERP) and IS at the lower levels, namely the automation systems [1]. MES provides a media for optimizing the manufacturing process as a whole in a real time basis. With the support of MES, a company can be provided with updated and complete information that can help the manufacturing department to maintain the quality of its products in a shorter time and with lower cost [2]. Considering the potential benefits provided by MES, MES implementation is one of the strategies that can be utilized by manufacturing companies in their effort to increase competitiveness in facing the globalisation. By the use of MES tin combination with the



implementation of ERP and other automation systems, a manufacturing company is expected to have high competitiveness.

In implementing MES, functional integration -- making all the components of the manufacturing system able to work well together, is the most difficult challenge. Functional boundaries for each system component must be specified before a manufacturing company can integrate its processes. When specifying the system requirement in MES implementation, a company needs to use a reference model as a standard to follow. Without using a reference model, manufacturing companies need to spend more efforts to determine their requirements. Currently, there has been an industry standard that specifies the sub-systems of a manufacturing execution systems and defines the boundaries between ERP systems, MES, and other automation systems. The standard is known as ISA-95. ISA-95 defines the terminology and models that can be used in defining the requirements of a MES application for a specific company and designing the integration of the company's ERP system at a business level with the production automation systems at a lower level [3].

Although the advantages from the use of MES have been stated in some studies, not much research being done on how to implement MES effectively. From a literature study it is found that Hadjimichael [4], Cao [5], and Waldron [6] have studied the design of MES. These studies discuss the development of MES and propose a method in developing MES. The methods proposed are very similar to common IS development methodologies. The studies have not specifically address the unique challenges of MES implementation while discussing MES design process. The studies also do address use of reference models (standards) in MES development methodology. A study by Scholten & Schneider [7] has proposed to use ISA-95 as a guide in defining the requirement of MES. Another study by Govindaraju et al. [8] developed a methodology for MES design utilising ISA-95. This study is focused on how ISA-95 can be utilised for determining MES requirement specification addressing different parts of ISA-95 standards in executing different steps of MES design process. The purpose of the study reported in this paper is to develop a methodology for a MES implementation project, covering the system design and implementation (construction) stage, which an extension of earlier study by Govindaraju et al. [8].

2. Literature Study

2.1. Manufacturing Execution Systems Implementation

According to MESA International, "Manufacturing Execution Systems (MES) is a dynamic information system application that drives execution of manufacturing operations, and by using current and accurate data, MES guides, triggers and reports plant activities as events. The MES set of functions manages production operations from point of order release into manufacturing to point of product delivery into finished goods. MES provides critical information about production activities to other production related systems across the organization and supply chain via bi-directional communication. In a nutshell, MES is defined as the layer that integrates business systems with the plants control systems and is commonly referred as integration from the shop floor to the top floor" [9]. Goals to be achieved by the implementation of MES are among others:

- 1) Optimizing of the entire supply chain through better workflow controls, better and real time documentation of process steps
- 2) Improved data quality for assessing processes and products
- 3) Visibility and transparency throughout the entire production process: only deviations are to be analyzed, a detailed examination of the normal flow of operations is no longer required
- 4) Reduction of storage costs for work in progress (WIP) material due to reduced lead time
- 5) Reduction of administrative work for maintaining manufacturing documents
- 6) Reducing the number of lost batches
- 7) Reduction of operating costs due to a high level of integration and the prevention of isolated solutions

- 8) Better decision making process through easy access to current data and information for all critical business cases

In order to minimize the risks in the implementation process, guidelines for MES design and implementation such as ISA-95 is needed [10], in order to help the manufacturing companies achieved the expected benefits mentioned above.

2.2. Positioning among Production Supply Chain Environment

In the production supply chain, the MES systems contribute to vertical integration. All the individual systems of a company, the ERP system as well as the systems on plant operations level down to the equipment can be integrated into one system. Utilising a standard such as ISA-95, solutions for individual industry can be developed with a reduced development efforts. ISA standard S95 focuses on the aspect of integration into IT environments. The descriptions given in the standard provide a suitable basis for task distribution and interfaces when an enterprise plans to implement an MES system. The proposed system leveling defined in ISA-95 standard is presented in Figure 1.

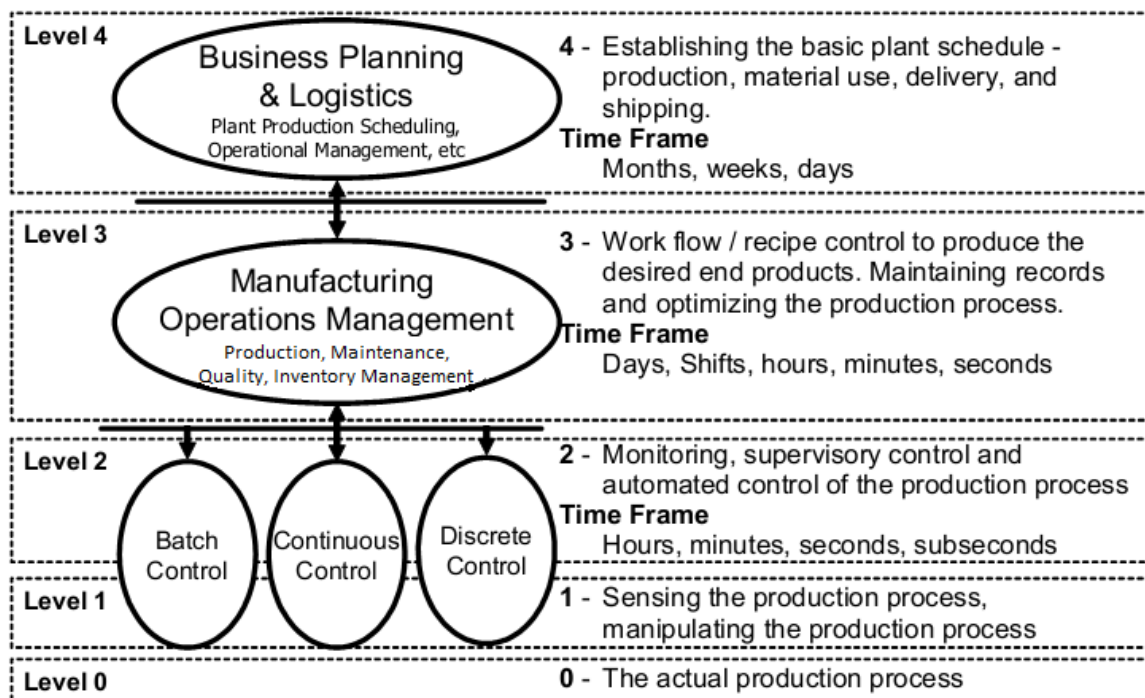


Figure 1. System hierarchy model [10, p. 20]

The distribution of functions to various systems which support the individual task in the best possible way is a common task and can be solved without major problems. However, it is not only necessary to distribute the data but also to define which system is primarily managing the respective data. For material, for example, data should originate in an ERP system and therefore should also be maintained and processed there. An MES may add attributes and data to make sure that different aspects of manufacturing processes can be managed in an effective and efficient way.

3. Model Development

The proposed methodology for MES implementation process developed in this study comprises of five steps: 1) Initial assessment, 2) Design, 3) Configure/Build and test, 4) Deployment and 5) Operation. The developed methodology is presented in Figure 2.

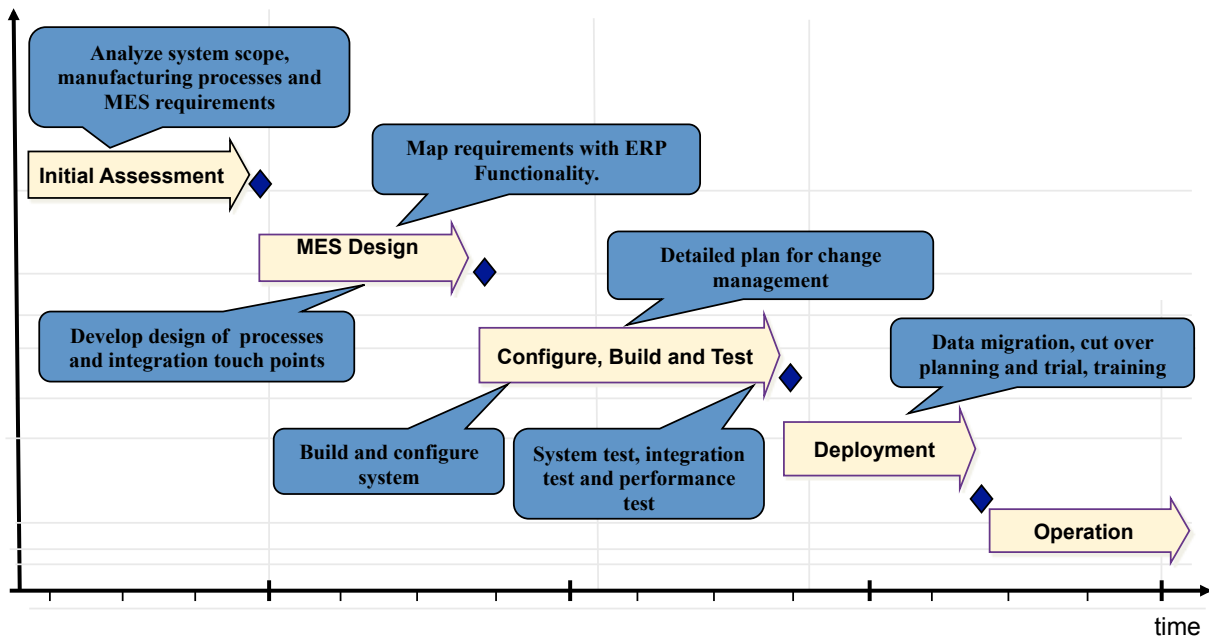


Figure 2. Proposed MES implementation methodology

The stages of MES implementation process proposed in this study are discussed below:

- **Initial assessment.** There are two activities performed at this step:
 - **Determine implementation scope.** System hierarchy model of ISA-95 indicates that there are 5 levels of system in manufacturing process. This model can be used as a guide to determine the boundary of each system level [7]. As can be seen in Figure 1, MES (level 3) interacts with the ERP system and the automation systems. One of the important concern is the distribution of functions to various systems (levels) which support the individual task in the best possible way. This means that the tasks can be solved without major problems. Besides, equipment hierarchical models of in ISA-95 which show the hierarchy of the physical assets of the enterprises engaged in manufacturing activities can be used to determine the physical boundary of the MES system [7]. Figure 2 shows the hierarchical model of equipment.
 - **Analyse MES functional requirements.** Information on the manufacturing operations management (MOM) contained in the document ISA-95 part 3 can be used as a guide to analyze the system functional requirements [7]. MOM Model contains a description of the functional aspects of MES. Diagrams can be used to analyze the functional requirements of the system is use case diagram [12].
- **MES design.** There are two activities performed at this step:
 - **Generic design.** Generic design is divided in two parts: generic function model and generic sequence diagram.
 - **Generic functional model.** ANSI/ISA-95 part 1 (Models and terminology, 2000) and part 3 (Activity models of manufacturing operations management, 2005) help to identify the main manufacturing operations management related activities. They also help to identify the information flowing through the activities of the

company. A boundary is represented to differentiate between activities at level 3 and activities at level 4.

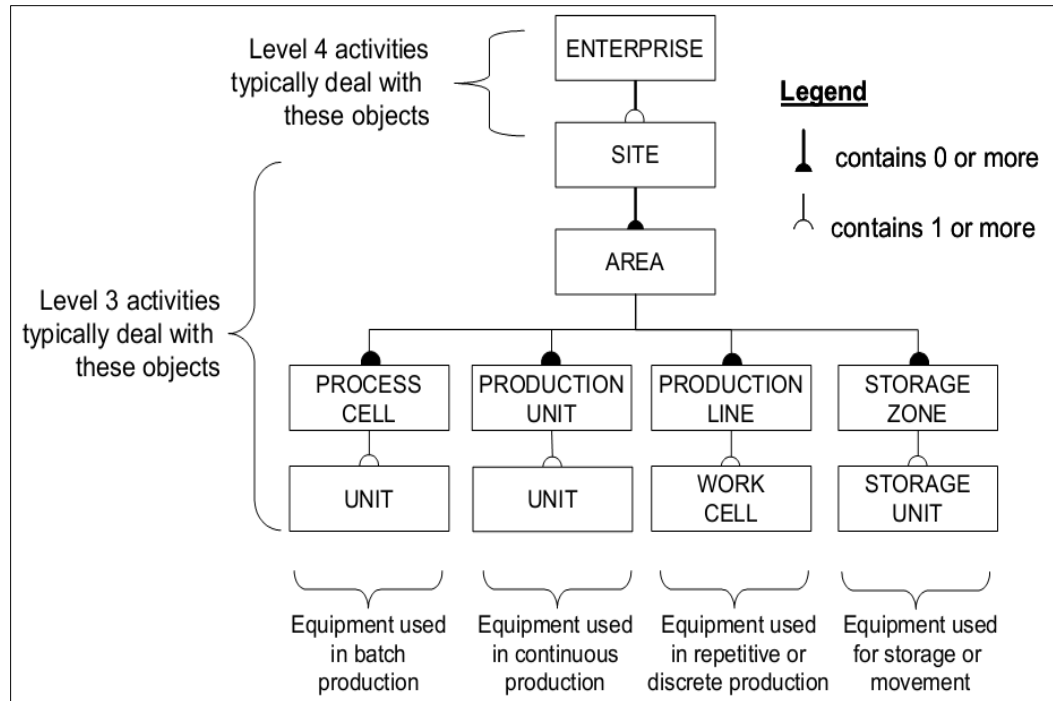


Figure 3. Equipment hierarchy model [11, p. 26]

Only a few activities are carried out at both levels. IDEF0 is chosen to model the functional requirements of the system. The detailed level of the modeling is determined by the development team. A generic IDEF0 functional model is defined, covering all level 3 activities and their communications with some of the level 4 activities. With ISA-95, the functional model is developed in such a way that it separates the business processes from the manufacturing processes. This way, it allows changes in production processes (level 3) to take place without requiring unnecessary changes in ERP (level 4) processes.

- **Generic sequence model.** Information about the order in which different activities are carried out in the manufacturing process provides a behavior perspective about the execution of the activities. In this stage, UML sequence diagrams are used to show which message transfers take place and how communication evolves among the different actors involved to carry out each activity [12]. The generic sequence diagrams defined in this step describe all information exchange between level 3 and 4 of the company, taking into account the activities and objects previously identified in generic IDEF0 diagrams. A detailed model description illustrating standard data flow between the functions for production plants is described in ISA-95 (see Figure 4). The dotted lines define the interface between levels 3 and 4. The arrows show the flow of data between the levels.
- **Specific design.** Specific design is divided into two parts: specific function model and specific sequence diagram.

- **Specific functional model.** Specific functional model is an adaptation of the generic IDEF models, developed using company specific requirements. The first step is to define the (company) specific IDEF0, taking into consideration the generic IDEF0 model of the ANSI/ISA-95 developed earlier. Before making the “To Be” company specific IDEF0, it is proposed to form a multidisciplinary team to firstly develop a current (As-Is) functional model (IDEF0) of the company. Using this model and taking into account the desired final state that is expected to reach with this integration project, the specific IDEF0 (functional) model (To-Be) is defined.
- **Specific sequence diagram.** The second step is to adapt the generic UML sequence diagrams to the specific company’s situation. The integration team defines the current sequence model (As-Is) taking into consideration the As-Is IDEF0 model and the collected information about the flow of current information exchange. Using these sequence diagrams and taking into consideration the specific IDEF0 (To-Be) model as a reference, specific UML sequence diagrams (To-Be) are modeled in order to define clearly the information exchanges that is desired to occur within the enterprise.

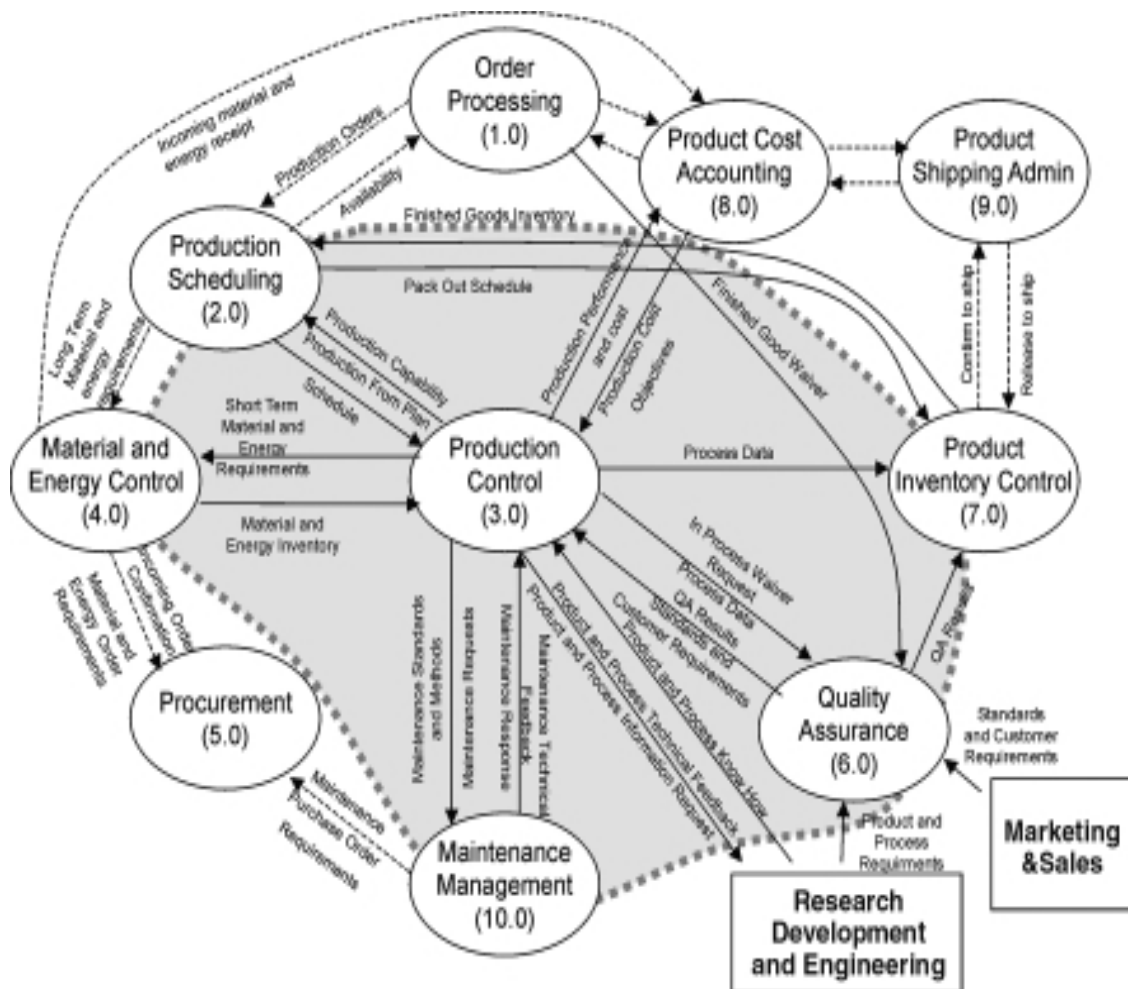


Figure 4. Enterprise control integration [10, p. 26]

- **Configure, Build and Test.** The goal to be achieved at this step is to configure, build and test the module components according to the approved design specifications (which were developed based on MES requirements). In general, MES application is developed, data migration is performed, and system test is executed in this step. System testing comprises of unit test, integration test and performance test.
- **Deployment.** In this step, final preparation for system transition is executed. Trainings are delivered, cut-over planning is developed, and troubleshooting activities are performed, before the new system is put into operation.
- **Operation.** The new system is put into operation, and the post-project support is provided to help users work with the new system. Besides, a final system quality audit is needed to be done at this step.

4. Methodology

In order to check the appropriateness of the methodology developed in this study, an empirical investigation was done at a steel manufacturing company. The investigation was done through in depth interviews with MES project manager, and a series of discussions with a number of key MES project members. From the investigation, a number of findings were collected, explaining how the execution of the steps and sequence in the proposed methodology considered to be appropriate and recommended, for a smooth MES implementation process. Besides, findings related to important risks or problems to be anticipated in each step of the methodology were also collected. Based on the findings, recommendations for improvements in the developed MES implementation methodology were generated.

5. Empirical Investigation at a Steel Manufacturing Implementation Case

Empirical investigations were done at a steel manufacturing company in Indonesia (SteelCo). The company is currently in the process of finishing its MES implementation project, which was started in the year 2012. The scope of MES implementation project covers Production Operations Management, Quality Management, and Inventory Management. As mentioned in the project documentation, by implementing MES the company aims to support the improvement of supply chain performance, through the use of a more integrated solution with real time information, to enable realistic business decisions. At the moment investigation was done, the implementation process has entered the deployment phase.

Two important issues in the initial assessment stage are scoping and defining the user requirements. The case company experience shows that it is very important that management is able to define properly the scope and extent of changes that is brought by MES implementation, before formally plan the implementation project. The case also shows that in defining system requirements, requirement elicitation is an important challenge. Requirement elicitation is the activity of discovering and gathering relevant information from user, customer, and other stakeholders who have direct or indirect influence on the performance of the system [13]. An effective method is needed to support the company in finding the right information from the right stakeholders (actors) involved. In the case study, a series of workshops were executed for requirement elicitation purpose. Different topics were discussed within big groups. The discussion topics were divided based on modules to be developed. For each module, workshops were executed to firstly discuss the old systems and the problems, followed by the basic concept of best practices provided by software vendor. The workshops were executed for all the modules. The workshops were successfully executed, but the results seems to be not that satisfying. The key users from the case company were not able to see clearly what are the gap to be filled with MES implementation and what functionalities the systems should provide in order to get a comprehensive solution for the company's problems.

MES design stage is divided into two stages: basic design and detailed design. Activities performed at the basic design stage is the documentation of the system design using descriptions and flow chart diagrams. The activities carried out in the detailed design stage is drafting detailed MES systems and interfaces requirements using UML diagrams. Design is generally done by using the ISA-95 standard. Stages of design activities on this project has a slightly different grouping of activities with the phases of the proposed methodology. However, in general, the activities carried out in the design phase commonly inline with the activities in the MES design methodology developed. One important thing that needs to be underlined related to the design of the system is the importance of clearly defining the mapping between the system features (functionalities) and user groups (actors). Developing use case diagrams in this case becomes an important part of the system design, in addition to the manufacturing process activity mapping using IDEF and the sequence of events mapping using sequence diagrams. The development of the use case diagram is necessary to determine a division of tasks and actors which is needed to ensure that no conflict happen from different users (subsystems) performing the same functions, and also to assure that all the functions assigned to certain user groups.

From interviews and discussions during the investigation, it was found that to smoothen the implementation process, it is important to add one more step after MES application is build and test, before the implementation process moves to final deployment step. The additional step is needed to create a pilot case (pilot deployment) and do a comprehensive review on the pilot deployment, before entering the full system deployment. A proper pilot system covering end to end processes needs to be developed, in order to ensure success of the overall MES deployment. Pilot deployment determines how well current requirements fit into an MES and validates the integration strategy (to level 4 system as well as level 2 system), before overall deployment takes place. In order to make sure that pilot deployment takes place in a proper way, different actors need to be involved. They area: project leader, ERP experts (because of the integration with ERP), automation experts, QA/QC, integration experts (XI experts, etc.) and shop floor automation/SFA experts (because of the integration with SFA systems). For SAP implementing companies such as SteelCo, ERP experts to be involved are the experts for MM/PP/PI, QM and APO modules.

With the addition of pilot deployment step, change management needs to be executed at the later step (deployment step), considering that change management should consider the results of the comprehensive review of pilot deployment. Final data migration needs to be finalised at the (final) deployment step, after all the important logic of system integration being tested, through the pilot deployment. Thus, the (final) deployment step will include cut-over preparation and test, final data migration, final change management, and trainings.

6. Discussions

MES implementation is a critical project in a company, that may bring lots of changes, especially in the production environment. The importance to properly define the scope and extent of changes driven by MES implementation is in line with Markus [14] which stated that information systems implementation is a technochange program, through which management implement a new IT application in conjunction with complementary organizational change to enhance organizational performance. In the assessment stage, managers wanted to identify the most salient problem in their manufacturing operations system. Very often a manager who is responsible for a partial function perceives a subset of a manufacturing system problem. Therefore it is necessary to find a way to be able to aggregate the needs from individual managers to a collection of requirements that deliver a comprehensive understanding, during MES requirement elicitation process. Requirement elicitation method used in a MES project should be effective enough to discover management's and stakeholders' requirements to the new work system. Requirement elicitation process should be able to address the critical success indicators the company needs to address with MES implementation, the critical processes to be supported by the new systems and what performance indicators are related to those processes. The processes here are meant to address the manufacturing processes and the interface processes between MES and ERP/SFA (shop floor automation).

Furthermore, the case study also highlighted that system integration which involves many interfaces is a very important challenge. When managing the integration between MES and ERP systems, understandings regarding the important focus of each system is very important for a smooth integration. MES software manages production orders on the shop floor, collecting information on materials being used, process parameters, quality test results, errors, etc. In short, MES compiles a detailed record of how product was made. An ERP system manages information regarding a product, orders related to a product, and the materials used to manufacture the product, from a more accounting point of view. To achieve a smooth implementation, during the system design phase, it is important to pay enough attention on the interfaces. It is necessary to focus the information exchange between MES and ERP to what is needed, considering the relevance and importance of the information for each systems. This is very much in line with suggestions provided in Meyer et al. [15].

During the investigation in the case study, a number of important risk factors for MES implementation project were identified. First one is the risk factor related to interface developed between MES and related systems. It is very important to follow the reference model in defining the interfaces. The ISA-95 Standard Enterprise — Control System Integration provides a framework within which a system in an integrated solution should perform certain functionalities, together with the key data exchange that should occur between interfaces.

Data exchange in a real-time manner helps to eliminate manual data collection that is often less precise and time consuming. Besides, with real time data collection, human errors in the data collection are minimized [16]. Still related to system interface, it is necessary to limit information exchange to what is needed for collaboration, when integrating MES systems and both ERP and SFA systems. There could be a lot of data to be exchanged, but overloading the network with data with little value or relevance will have an impact of system operation.

Second, risk factor related to usage conflict in the operation process. When setting up a workflow in the MES and related systems, it is necessary to determine a correct division of labor to ensure that no conflict was resulted from different users (subsystems) performing the same functions. Use case diagrams which defines the map between user (groups) and different system functionalities should be validated and agreed by all the system users before the system is put into operation.

7. Conclusion and future directions

In this study, a methodology was developed for the design and implementation (construction) of manufacturing execution systems, comprising of five steps: Initial assessment, Design, Configure/Build and test, Deployment and Operation. This study highlighted the importance of defining properly the project scope, extent of changes driven by MES implementation, and applying an effective requirement elicitation method, during initial system assessment stage. In the design stage, the identification of MES system functionalities and the interfaces among MES, ERP and SFA were effectively executed by the support of the reference models. Beside following the standard defined in reference model, designing system interface should consider that information exchange, especially between MES and ERP, takes place only when the information is relevant and important, considering the focus and concern of each involved system.

After initial assessment and design phase, MES modules can be constructed and test. The construction and test of the modules were done in the same stage. Before putting the whole system into operation, it is necessary to perform a pilot deployment. A pilot system covering end to end processes is needed to ensure success of the overall system deployment. With the inclusion of a pilot deployment, it is suggested to perform change management in a later stage, after a comprehensive pilot results available to be used in the change management process.

Future studies can be done to elaborate the requirement engineering process in MES implementation, especially the requirement elicitation process. Another direction of future studies is to elaborate the pilot deployment stage considering that the design and execution of the pilot system will have a great impact on the success of final system deployment. One of the the important questions to be answered is how the effectively identify the best arrangement of end-to-end business case to be

used in the pilot deployment. Another important issue regarding the pilot deployment is how to perform an effective test in the pilot deployment stage, especially integration and performance test, to be able to prevent failure in final system deployment.

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