Aalto University
School of Business

Assessing Changes for implementing Manufacturing Execution Systems Case: The Switch Model Factory

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Master's thesis

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Department of Information and Service Economy
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AALTO UNIVERSITY SCHOOL OF ECONOMICS ABSTRACT
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ABSTRACT

Objectives of the Study

The goal of the research is to design a method to assess the scope and the extent of change for implementing Manufacturing Execution Systems (MES). On the one hand, the study has elicited a set of business requirements to delineate the scope of implementation. On the other hand, the study has assessed the extent of change within the scope by detecting the inertness that the management should resolve in a social-technical system that comprises the organization, new technology and legacy enterprise information system.

Academic background and methodology

Change takes place in the work system of a company when implementing MES. Before planning any change, the management should assess the change based on the business requirements of a new work system, in which MES come into use. Clearly identified requirements enable the management to plan and direct the change process to ensure a success MES implementation. However, failure rate of implementing new Information System is high in practice. Researchers have ascribed various failures of IS implementation to the vagueness of requirements. Early before planning implementation in detail, the management should first determine what requirements are essential for realizing the business value of a new information technology.

This study assessed the scope of change through requirements elicitation with Critical Success Chain (CSC) method. The study has adapted and operationalized the CSC method in a single case, to demonstrate the method. The case has shown the efficacy and applicability of the method. Further, the study has developed the general CSC method by incorporating a diagnostic guideline to assess the extent of a technochange.

Findings and conclusions

The research has described and framed the problem of assessing changes for implementing MES as requirements elicitation and inertness identifying. Then the study developed a method combining the CSC and Sarker's Guideline. Moreover, the study has found that MES implementation had better go injunction with manufacturing operation improvement. At last, the demonstrational case is able to show that MES implementation focus could have diverge on different products in a company's product portfolio.

Keywords

Manufacturing Execution Systems, Implementation, Requirement elicitation, Critical Success Chain, Change

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Xiaoxuan Wu

in Helsinki, September 27, 2012

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Motivations

This study aims at assessing the scope and the extent of changes to implement Manufacturing Execution Systems (MES), an information technology based solution on shop floor of a factory. MES enhances the visibility to production activities on the shop-floor level and improves production performance (Kletti, 2007).

In this thesis, the word ‘implementing’ takes a broader definition. It is a process of change, through which a complex technology works effectively in an organizational environment to reform current work system. James Fleck (Fleck, 1994) defined the technology implementation as “the process through which technical, organizational and financial resources are configured together to provide an efficiently operating system.” Fleck’s definition distinguishes implementation and installation from each other in their purposes. Limited in a narrow scope, installation based change merely provides the technical feasibility to use a tailored technology, and its target is ensuring the technical part of a solution will function according to expectation of technical specifications. In contrast, Management Information System (MIS) based implementation is a managerial intervention to change current work system for improving the organizational performance. (Bostrom & Heinen, 1977).

The project results are not satisfying when it involves implementation rather than installation. Reported failures of implementing information systems or advanced manufacturing technologies in practices are abundant (Beatty, 1992) (The Standish Group, 1995) (Ramamurthy & King, 1992). A potential IT implementation failure could be that information system does not suffice informational needs of critical business processes (Saarinen, 1993). Markus (Markus, 2004) distinguished common MIS implementation against a common IT project and a pure organizational change program. She referred MIS implementation as a program of technochange, through which management implement a new IT application in conjunction with complementary organizational change to enhance organizational performance.

To implement MES effectively, management needs to assess the scope of the change process before formally planning an implementation project and building up implementing team.

From a perspective of requirements engineering, the scope of changes for implementation is stated and communicated with explicit business requirements. When these requirements are clear, the likelihood of a successful MES implementation increases. Nonetheless, many implementation projects have narrowly confined their scope of changes within a technical solution domain and have neglected links between change and business processes. A firm accomplishes its business requirements through effectively operating business processes, which create or support the creation of business value (Porter, 1985). Rather than merely implement a technology to automate a business processes, management should understand new business requirements and then envision, create and support novel business processes with available technological solutions. In this way, while defining business requirements, management determines the business process they need to build, improve, or re-engineering. Usually, a reason for the innovation implementation failure could be that an implementer who is planning a change often presumes the appropriateness of a well-established set of technical IT project methodologies. The implementer, usually has a proficient technological background has applied these methodologies and project management paradigms on developing and upgrading common technical systems. The developing and upgrading usually involve updating operation system in Personal Computer or maintaining a website. Using the same approach to sail out a technochange (Markus, 2004) might lead an implementation project to a catastrophic failure. The resistances from users and other stakeholders could become overwhelming during implementation. Even though an Information System is eventually installed on site, its usage might be soon or later aborted due to incompatible with work system in the organization.

In this paper, the extent of a change refers to how deep a business process and its peripheral elements are reformed during technology implementation. People who operate a business process interact with each other within a social structure. Implementing a technology requires the management taking account the social aspect of reformation. Since a social group, organization and human beings are much more sophisticated than cybernetic systems or homeostatic systems in the artificial domain of the world (Hofstede, 1979), the more human and social aspects changes involve the greater extent of a change is. Through assessing the extent of a change before implementing MES, the management establishes right expectations to the scale of the implementation project. Should a company assign several technical experts to update technology and automate current processes or should it allocate more resources on fostering the changes of business processes and on the associated human and social aspects?

The extent of change helps to evaluate to what level an implementation program should demand senior management's commitment to engage resources.

Usually, during initiation stage of implementing Manufacturing Executions Systems, business requirements are buried under the ambiguity and the complexity of the situation. Business requirements of an enterprise subject to its supply chain as well as operational strategies, the characteristics of available information technology, and information processing as well as production control systems. Defining objectives for an implement project or rolling out a supportive policy is hard, when there is no clear understanding to requirements. A survey from Standish Group (The Standish Group, 1995) reveals that missing clear requirements was a major cause to the failure of many IT projects. Vagueness in requirements direct leads to partially defined scope of implementation and development projects, mismatching between project expectation and needs, and risk of changing requirements in the latter phase of the project. On the one hand, the vagueness adds complexity to planning. It also impedes effective communication to win executive support and to involve end users.

The study has set its goal as **Designing and developing a method to assess the scope and the extent of changes for implementing MES.**

The study approached this goal through accomplishing following tasks.

- The study first frames the problem of ambiguity in implementing changes as a problem of business requirements elicitation to develop a new work system that deal with the production and operations management.
- Second, to elicit the requirements, the study adapted the Critical Success Chain method (CSC) (Peffers, Gengler, & Tuunanen, 2003). Requirements were presented with several themes of Hierarchical Value Maps.
- Third, for assessing the extent of changes, a theme of a change was analyzed based on the framework of Leavitt (Leavitt, 1965) and guidelines from Sarker (Sarker, 2000).
- Fourth, the study demonstrates the operationalization of the CSC and Sarker's guideline, together with the case company, The Switch Drive Systems Oy, a Permanent Magnetic Generator (PMG) supplier for wind turbines.
- At last, after the demonstration, the study evaluates the efficacy and applicability of the combo method of CSC and Sarker's guidelines.

1.2. Result and contribution

The management needs a systematic way to envision a technochange before implementing MES. The study presented the contextual information to describe the problem that the management confronts in the early stage of implementation. . It scribed down the meaningful context about how a designer perceives the problem as well as wrote about the reasoning for searching a feasible solution. To solve the problem, the study has adapted the CSC method by combine it with Sarker's change assessing guidelines the study operationalized the solution through a demonstrational case. In the end, the study evaluated the efficacy and the applicability of the method.

The contributions of this thesis come from three folds. First, A research contribution is that the study has described and framed the problem of pre-assessing MES implementation requirements as a requirements elicitation problem, through with the management foreseen the scope and extent of changes that bring a new work system into use. Another research contribution on developing the CSC method, the design adapts and operationalizes the CSC method to show its efficacy and applicability in electing the requirements of introduce an IT related reformation to a production operative system. The study has modified the generic procedure of CSC and has applied it on assessing changes during the early envisioning phase of an implementation project. Third, a practical contribution is that the demonstration of the CSC method presents a particular case of implementing MES into a manufacturing environment in which the focal company produce industrial equipment. The case has presented a possible framework how MES is incorporated with many other continuous improvement initiates in a factory.

1.3. Structure of the thesis

The structure of this thesis follows a research paradigm of design science (Peffers, ym., 2007). A designing process solves a practical problem. It comprises a series of sequential phases of problem identification, solution objectives determination, design development, case demonstration, and evaluation.

This design research is aiming at nominating a method to solve a practical problem. The problem identification is the initiate and critical step of the design. Above all, a design is contingent on the understanding of the problem and designer's motivation to solve a practical issue. The design developed from this study attempts to reduce the ambiguity and complexity that managers confront while they are envisioning changes to implement MES into current production system. The designer sets the objective of solution as determining the scope and assessing the extent of inertness in current organization. The solution is essentially a feasible method. Applying this method, an analyst can identify the requirements of improving current production operation with MES and corresponding organizational inertness. The study operationalizes the method to envisioning MES implementation project in one of the factory in The Switch Drive System Oy. The thesis contains a case study that serves as a demonstration to developed method. The designer of the method as well as the solo executor of the method evaluated the method in terms of applicability and efficacy.

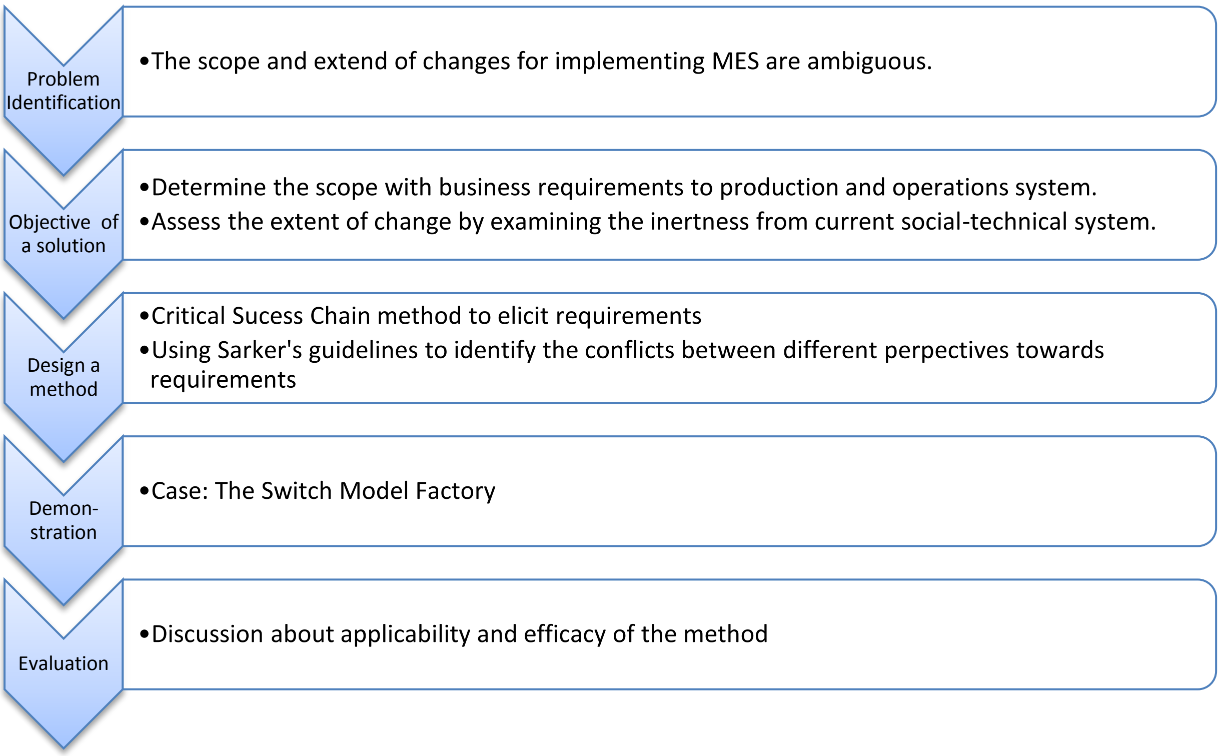

Figure 1: Structure overview

2. PROBLEM IDENTIFICATION: NEEDS TO ASSESS CHANGES TO REDUCE COMPLEXITY AND AMBIGUITY BEFORE IMPLEMENTING MES

2.1 Changes for Information System implementation

This study faces a practical problem, which is helping an enterprise to assess forthcoming changes for implementing MES. The Implementation project would integrate a piece of novel technology to the work system in the organization. It intertwines IS development and organizational reformation. Prior researches on causal structure between IS development and organizational changes diverse in three schools, the technology imperative, the organizational imperatives and the emergent perspectives (Markus & Robey, 1988).

According to the technology imperative, managers in an organization make necessary adaptions to match the implementation of a new technology. The role of changes during technology implementation process is an extension of the IS development cycle to the organization and business process. A typical system development life cycle evolves through sequential phases of definition of need, conceptual design, preliminary design, detail design and development, production/construction, utilization and support and phase-out as well as disposal (Blanchard & Fabrycky, 1998). In the early design phase, systems engineers emphasize on identifying users' needs and interpreting users' needs to system level requirements. In conceptual designing phase, a major task is deploying system performance requirements to sub-system requirements and functionalities. Technology imperative often assumes that a system user is a deterministic element in the to-be system and the user will compliant to a specified behavior model according to system design. Therefore, all users should behave and perform tasks according to pre-determined design. What implementation does is to habituate the people to presumed roles in accordance with system design. Hence, technical resistances from users are a main issue to be deal with, when implementation approach is technology imperative. Neither habituating users nor changing organization to a ridged and oversimplified technical scheme is an easy job. When users deny the role that a system assigns, they will not use the system in the way that they are supposed to behave. Moreover, the user satisfaction is hardly good when resistance is strong. A possible explanation is that, assumed user role model derived from system design, as a simplified reality model, hardly captures the social and cultural life of the user in the organization.

Many administrators of IT system have similar experiences. When they attempt to assign new user accounts to employees, they can hardly find a position in side organizational structure of which the job description and responsibility are exactly matching the role prescribed by the default user accounts.

The organizational imperative emphasizes on strategically planning the information needs to solve a business problem, while the selection of available information technology and supportive organizational structures are unlimited (Markus & Robey, 1988). Business Process Re-engineering (BPR) assumes IS implementation as outcome of re-shaping obsoleted business processes (Hammer, 1990). William J. Kettinger divide re-engineering phase in envision, initiation, diagnose, redesign, reconstruct, evaluation (Kettinger;Teng;& Guha, 1997). The problem of IS implementation is not only about utilizing a new technology, but also about radical reconstructing of the business processes and organizational setting. The implementation usually follows a top-down approach from senior level in the organization. It begins with wining support and commitment from senior management and refining the information processing needs of new business processes. Behavior training, education program and supporting IS are introduced later to support new business processes and organizational setting. In the BPR, changing business processes and their associated information processing requirements forms the core of change. A change implementer should be able to select amongst various available technological options to satisfy their information processing needs (Markus & Robey, 1988).

The emergent perspective assumes a loose causal structure between organizational change and information technology implementation. "Uses and consequence of information technology emerge unpredictably from complex social interactions. (Markus & Robey, 1988) " Theory of Innovation Diffusion reflects an emergent perspective. Innovation diffusionists explain the implementational change as an emergent pattern of a diffusion process in a social system. Heterogeneous adoption processes in individuals' perceptional world emerge to innovation diffusion in a social system (Rogers, 1995). Even though formal implementation intervention can facilitate necessary communication and social interact between individuals, change in terms of diffusion process is largely contingent on characteristics of the innovation and the status quo of the organizational culture that distinguishes innovators from majority and laggards.

To summarize, changes for implementing MES should address the salient problems that trouble the production system. Furthermore, the representation of requirements should be in a way that links the implementation efforts with production improvement objectives of the production and business operations. Addressing the requirements in this way increases the possibility that the advantages of implementing MES are observable and welcomed by production managers.

2.2 Complexity and ambiguity of implementation

On the envisioning stage of an implementation, ambiguity of the implementation objectives and complexity of implementation scope hamper systematic project planning and the adopting of management tools.

Ambiguity is a type of uncertainty that management has to deal with when implementing changes. To conduct successful changes, managers have to weather both the complexity and uncertainty of IS implementation process. According to a survey study to 118 Canadian manufacturers, implementation success, in terms of operational performance enhancement brought by a new technology, is contingent on the management strategy, the degree of assimilation of the technology to the firm, fit between the strategy and the technology, and business environmental uncertainty (Raymond, 2005).

Churchman and Schainblatt (Churchman & Schainblatt, 1965) viewed implementation as "the problem of determining what activities of the scientist and the manager are most appropriate to bring about an effective relationship between the two (technology and organization)". The decision-making to solve MES implementation is never with perfect information. Complexity and uncertainty characterize the implementational situation. Complexity associates with the amount of available information, while uncertainty relates to the availability and the quality of the information (Mathiassen & Stage, 1990).

The degree of complexity increases when available information is abundant. The complexity increases the difficulty to explain the causal relationships between actions and outcomes with fragmented and redundant information on hand (Pich;Loch;& Meyer, 2002). Another outcome from the complexity is the equivocality i.e. multiple conflict interpretation to the interrelationships exists (Fazlollahi & Tanniru, 1991). Massive available information presents feasible actions and possible outcomes to a planner. Nevertheless, interrelated and redundant parameters to the actions and outcomes overload information-processing capability of the planner. In the context of MES implementation, the management first has to synthesize the information about their current manufacturing operative management system, the infrastructure and architecture of legacy ICT system, the alignment between IT strategy and business process. In addition, management needs to validate the benefit of multiple functionalities of MES in terms of enhance the quality, productivity of operation.

Prior researches have tried to quantify the complexity level of a project. According to International Project Management Association (IPMA), the number of the subsystems as well as components, the number of involved different organizational units, the degree of using cross-discipline experts, the extent to which managers applying project management tools and methods, and preceding speed of the project phases are signs of project complexity (Kähkönen;Artto;Karjalainen;Martinsuo;& Poskela, 2008). Burns and Dennis' (Burns & Dennis, 1985) empirical study chose project size, number of users, volume of new information and complexity of new processing as instruments for measuring the complexity of a new IS application. In a company, implementing a complex operative management system could involve senior management, production managers and employees, engineering department, and information system developers. MES users and stakeholders could be some experts from several different disciplines. MES implementation becomes more complicated than developing a software artifact when the implementer has to take into account the companies' strategic environment, production management system and their interfaces with MES. Hence, the researcher argues that complexity of MES implementation project is high.

Within a problem-solving context, uncertainty increases when the key information is either missing or ambiguous. Schrader (Schrader, Riggs, & Smith, 1993) further classified the uncertainty into three types. He framed the problem-solving process as following an algorithm as well as searching for the right value within a set of interrelated variables. A problem-solving situation only with the first order uncertainty is characterized by missing some right values of a given set of relevant variables but knowing the interrelation amongst variables and having clear algorithm. Second order uncertainty, termed as the first level ambiguity by Schrader, refers to a situation that potential set of variables are identified but their interrelationship and the solving algorithm still need to be determined. Third order uncertainty, labeled as second level ambiguity by Schrader, refers to a situation that relevant set of variable as well as their interrelationships and the problem-solving algorithm need to be determine. During the envision stage of MES implementation, the uncertainty is on third order. The management neither knows the concrete benefits from MES nor understands what policies and changes could promote the implementation success.

A new technology Implementer may apply various requirements determination methods to reduce the uncertainty and complexity. Burns & Dennis dichotomized the requirements determination methods into rational approach and experimental approach. Rational approach means solving a problem through abstraction, decomposition and presents the solution in some specifications (Burns & Dennis, 1985). Rational approach emphasizes on planning and control (Saarinen & Vepsäläinen, 1993). An ideal and usually abstract model is projected into the real world through an implementation process. In contrast, the experimental approach seeks using prototypes to accumulate experience with trials. Rational approach and experimental approach have different impacts on reducing uncertainty and complexity. Rational approach is more effective in reducing the complexity, while experimental approach is effective in reducing uncertainty. When implementation process is complex and uncertain, managers can apply a mix of above approaches. Moreover, according to the "principle of limited reduction", removing either complexity could add in more uncertainty or vice versa (Burns & Dennis, 1985). Combining above two points, throughout the implementation process, implementers should iteratively use mix of above two approaches.

If a group of requirements analysts is in charge of the pre-implementation study, when they start to examine the situation for implementing MES, they usually find out that they have limited and fragmented initial amount of information. By abstracting and analyzing available information, the analysts can build a prototype. The prototype can even be a preliminary conceptual model for communication and discussion with the management. Through empirical learning with prototyping, the analysts become aware of some new and relevant information. Nonetheless, added information into the analysis scope increases the complexity again, thus it require a new round of abstracting and modeling to digest information.

2.3 Contextual factors of implementing Manufacturing Execution Systems (MES)

This part of the paper will show how MES implementation is understood in a context where the supply chain strategy, the information system architecture and operative management infrastructure interweave. The motivation to adopt MES is to align the technology with the operative management as well as an agile supply chain strategy of a company. The implementation also has to take account the architecture of IT system in an enterprise. The second section of this part presents relationships between MES and other legacy information system in a typical manufacturing enterprise. The third section presents the typical functionalities of a MES, which are configurable to the need of production operation environment.

2.3.1. Supply chain Strategy

Global based customers and fluctuation in demand requires the supply chain of wind turbine industry to be agile, i.e. the supply chain can weather through external fluctuation and promptly response to short-term change in demand as well as supply and (Lee, 2004). Wind farms are constructed in multiple locations. When a wind farm settles, it purchase and installs wind turbines on its location to match its expansion and replace obsoleted turbines.

The product, which a generator manufacturer is selling, is a customized solution with high complexity. It has to meet the technical requirements of the turbine design, wind farm and power grid. The technology in wind power industry advances vary fast, the lacking of or being immature of technical standards (Liu, 2011) demands a leading generator suppliers work closely with customer to continuous develop and re-engineering their product as well as manufacturing process. For some key components of a generator, there is low commonality between different product models.

Generator suppliers face the pressure to meet the growing demand from dispersed wind farms. For them, applying a speculation strategy (Pagh & Cooper, 1998) to meet demand is risky. Predicting the place and the pace of the construction of wind farms is hard, because the expansion is under influences of business, politics, and technology.

A leading generator manufacturer can gain agility by configuring its supply chain in an innovative manner. In a few factories proximate to its design and engineering resource, it maintains a flexible capacity for prototype and small batches of less matured products. In these factories' production system, the manufacturer trials and develops the product and manufacturing technology. When a product becomes relative mature and its volume grow larger, the manufacturer immediately scales up the production into factories that locate next to the market and with competitive labor force. The factories in which a manufacturer hatches their new product and trial its production is termed Model Factory (Kurttila, Shaw, & Helo, 2010). The owners of the other factories could even be some supply chain partners of the generator manufacturing. The duplication of production system and scaling-up for volume production are termed as capacity ramp-up.

Nowadays, allying with supply chain partners and ramping up assembly capacity proximate to customers is a viable strategy, because there is overcapacity in the wind turbine and generator manufacture sector (Williamson, 2012). Moreover, doing capacity ramp-up enables a firm to reconfigure the geographical settings of its supply chain network and response to social and economic disturbances. For example, when the importing cost of a vital raw material soars up, shifting the production capacity to the exporting country becomes a more attractive option. Furthermore, ramping-up capacity with a supply chain partner's manufacturing facility reduces the risk and dependence of heavy investment in fixed assets, thus let the firm concentrate on its core capabilities in advancing the engineering technology.

Implementing Model Factory concept and managing a supply chain based on that concept faces following challenges. The first challenge is about the visibility to the actual throughput rate of production lines. When franchising the assembly line to a supply chain partner, the company needs to keep a transparent view to throughput rate of each line. With that, the company plays its role as a coordinator from the control tower of its global supply chain (Bhosle;Kumar;Griffin-Cryan;Van Doesburg;Sparks;& Paton, 2011). The accurate information is vital for it to allocate demand to available capacity in its supply network. The second challenge is about the quality of product from lines. Model Factory strategy differentiates from traditional production outsourcing strategy. It learns from and offers engineering supports to the production at the partner's site. Instead of maintaining a transactional relationship, between the partnering companies there is an alliance type relationship. Within the alliance, the generator supplier assures that the control and standardization extends to in-detail operational task specifications in partners' manufacturing, when its strategic partners lack of the engineering capability to improving manufacturing quality under the pressure of cost reduction (Coates, 2012). The Model Factory aims at facilitating the entire alliance to developing and improving the manufacturing and assembly standards. The third challenge regards the communication of design changes during products life cycle. When product is under frequent engineering and design changes, documentation and revision of work instruction in detail is not effective via paper based archive system. Replacing the circulation of paper copies with transmission of digital files decreases errors in the distribution and save work force. It also opens the opportunity to support assembly line and communicate the work instruction updates remotely through a Virtual Private Network (VPN).

2.3.2. Configurable and compatible to legacy information system

Information Systems for operations management

An implementer needs to find out a suitable configuration that enables MES to work with legacy MIS system in an enterprise. Since entering the information era, companies have been adopting varies of IT. In the beginning, these IT based applications aim at supporting the activities in single functions. Later they become more and more integrated packages and evolve to holistic networked Management Information Systems (MIS). The functional expansion of IT enabled production planning and control systems exemplified this expansion (Rondeau & Litteral, 2001). In 1970s, to manage the inventory of components and raw materials for production, manufacturers in the mainstream adopted the Material Requirement Planning (MRP) systems. Later the systems developed to Manufacturing Resource Planning (MRPII), which includes Master Scheduling, Rough-Cut Capacity Planning, Capacity Requirements Planning, and other modules. In late 1980s, Enterprise Resource Planning (ERP) emerged and offered a promising feasibility to integrate all business processes in a corporation.

MES complements legacy ERP systems in supporting the management in production execution and control. Though widely implemented, the ERP is far more less ambitions in supporting the manufacturing activities on the production level. ERP systems are to a large degree confined in the accounting and administrative functions of an enterprises (Paul, 2009). A particular explanation is that the needs to information are heterogeneous in different layers of the management. Professionals in manufacturing field has been complained about reports and information received from current information systems, saying either that the information is irrelevant to steering the manufacturing activities or that the information for control and monitor hardly keep up with the daily manufacturing execution (McClellan, 2001). Louis and Alpar (Louis & Alpar, 2007) stated that the missing part of today's ERP-systems for supporting of shop-floor processes are availability of some key functionalities, robustness, flexibility, real-time ability, information detail level and traceability.

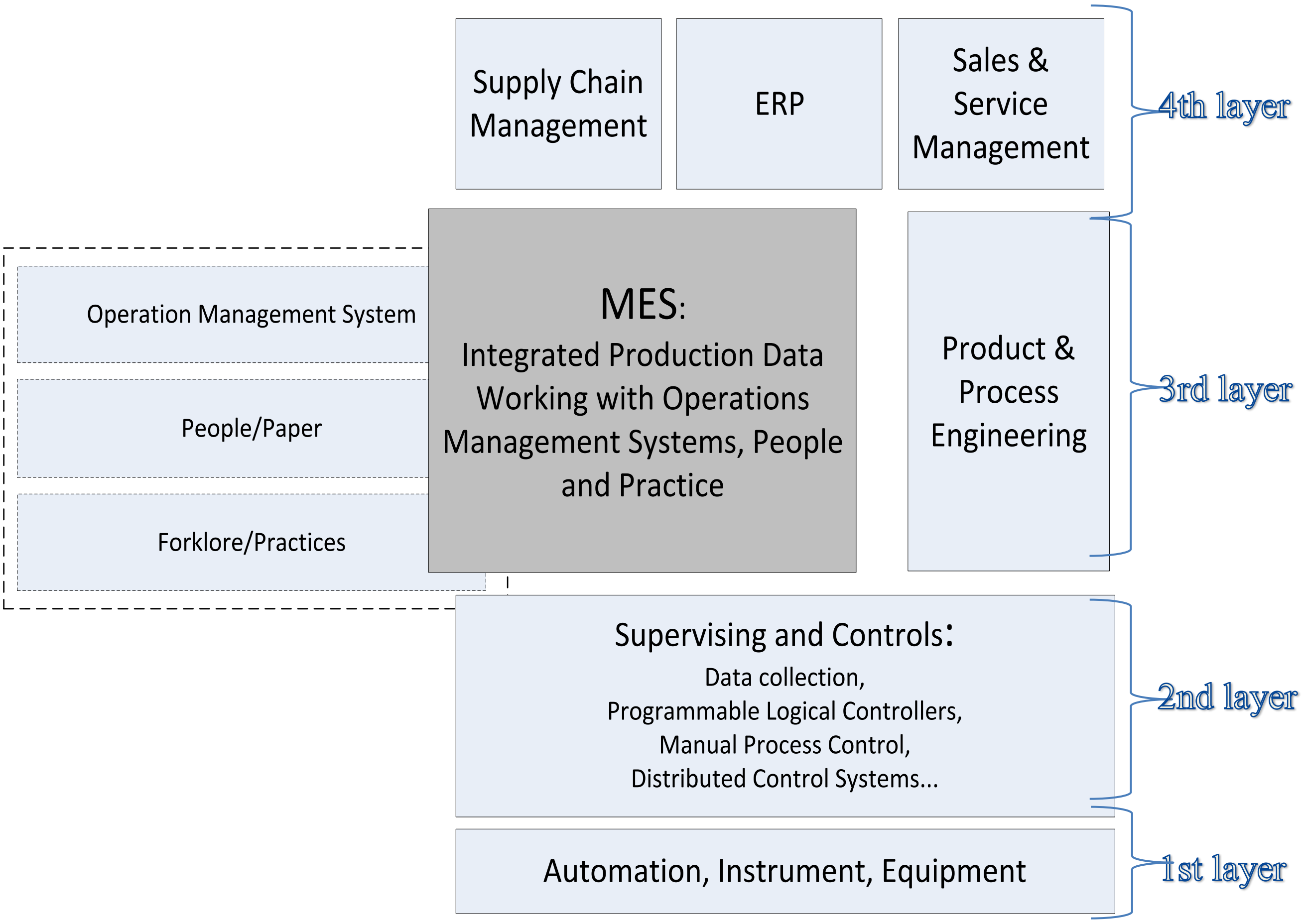

Figure 2: Plant information layer model (Manufacturing Execution Systems Association, 1997)

MESA (Manufacturing Execution Systems Association, 1997) has published a layer model to describe MIS in a manufacturer (Figure 2: Plant information layer model .

On the top layer, which is the fourth layer, information systems serve the needs of upper management. The blocks of information system represent the business processes on a manufacturer's value chain. A sales and service management system supports Customer Relationship Management. Through ERP, the manufacturer plans and allocates the resource to support business operations. Supplier relationship is managed with the support from a Supply Chain Management system. The time frame of the management information is on monthly or weekly basis (ISA 95.00.03, 2005).

On the third layer, management scope zooms into the operations for one product or a product family. Engineers design covers the entire life cycle of product definition, production process definition and after sales maintenance. An information system filling this block is the Product Life-cycle Management (PLM) (Meyer, Fuchs, & Thiel, 2009). MES are framed into the third layer of such IS architecture where management scope is manufacturing operations on a factory's shop floor. On the shop floor, MES replaces obsoleted operative management system, through which communication media are people and papers and dissemination of information totally relies on folklore and practices. For operative management on shop-floor level, the time frame of information is days, shifts, hours, minutes or even seconds.

Below the third layers, the information system directly control and supervises the automation of equipment and workstations. The scope of the informational control could be to automation logic of workstations or machinery. For example, Programmable Logic Controllers are industrial computers that control the logics of automated machinery. The needs of information exchange and control are in the scope of automation equipment vendors.

MES – Configurable Application

MES is a configurable application. Its functionalities can be tailored to fit a particular production system. A MESA prescribed 11 generic functionalities of a MES (See Table 1: Generic Functionalities of MES adapted from MESA's prescription (Schmidt, 2011)). An implementer has to decide which functionalities are valuable to the business. The value of functionalities depends on business processes of operative management in a factory. The exact configuration varies across different industries, companies and plants. Business processes in a factory may include production scheduling, production control, material and energy control, procurement, quality assurance, product inventory control, product cost accounting, product shipping administration and maintenance management (ISA 95.00.01, 2000). The importance of this process varies across industries. For example, maintenance management related process and functionality are important for power plants. For production heavily relied on manual work and general-purpose hand tools, maintenance management is less important than it is in a power plant.

Configuring modules in MES also have to deal with the interfacing between MES and IS systems in other layers. The issue concerns with assigning functionalities to information systems in different layers in the architecture. To define the interface with EPR and other higher-level system, management needs to determine the boundary of responsibilities of production managements. Industry type, regulatory control, and physical properties of production are determinants of the responsibility decisions. ISA enumerated some conditions under which an implementer should assign direct responsibility to manufacturing management. Manufacturing management should be responsible for an activity, if the activity is critical to plant safety, plant reliability, plant efficiency, product quality or maintaining regulatory compliance (ISA 95.00.03, 2005).

MESA suggested drawing a technical integration line as the boundary of layers in architecture of enterprise information system (ISA 95.00.03, 2005). On the one hand, technical integration lines determine which functionalities are essential to be included into MES layer and which ones can be excluded and should be allocated into other layers. On the other hand, the decision rules of selection technical options might be different from dividing managerial responsibilities. The rules should take account of the availability of installed systems, cost of new systems and integration of existing systems (ISA 95.00.03, 2005).

Table 1: Generic Functionalities of MES adapted from MESA's prescription (Schmidt, 2011)

Function	Description
Resource Allocation and Status	Manages resources including machines, tools labour skills, materials, other equipment, and other entities such as documents that must be available in order for work to start at the operation. It provides detailed history of resources and insures that equipment is properly set up for processing and provides status real time.
Operations/ Detail Scheduling	Provides sequencing based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation such as shape of colour sequencing or other characteristics which, when scheduled in sequence properly, minimize setup.
Dispatching Production Units	Manages flow of production units in the form of jobs, orders, batches, lots, and work orders. Dispatch information is presented in sequence in which the work needs to be done and changes in real time as events occur on the factory floor.
Document Control	Controls records/forms that must be maintained with the production unit. It sends instructions down to the operations. It would also include the control and integrity of environmental, health and safety regulations, and ISO information. Storage of historical data.
Data Collection, Acquisition	This function provides an interface link to obtain the intra-operational production and parametric data which populate the forms and records which were attached to the production unit. The data may be collected from the factory floor either manually or automatically from equipment in an up-to-the-minute time frame.
Labour Management	Provides status of personnel in and up-to-the-minute time frame. Includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities such as material preparation or tool room work as a basis for activity based costing.
Quality Management	Provides real time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, including correlating the symptom, actions and results to determine the cause.
Process Management	Monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities.
Maintenance Management	Tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems.
Product Tracking and Genealogy	Provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. The on-line tracking function creates a historical record, as well.
Performance Analysis	Provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison to past history and expected business result.

2.3.3. Information processing needs of Manufacturing Operations Management

In general, managerial activities in a plant cover four areas, production operations management, quality management, maintenance management and inventory management. ISA categorized the information for operative management into four groups, schedule/request information, performance/response information, definition information, and capability information (ISA 95.00.03, 2005). Four groups of information build a closed-loop control to production system. Schedule/request information trigger a particular operation at a specific time. Performance/response information feeds back the output of the operation. Definition information records the rules and knowledge about what the operation is and how it is done. Capability information describes the state of availability of resources such as equipment, personnel to an operation.

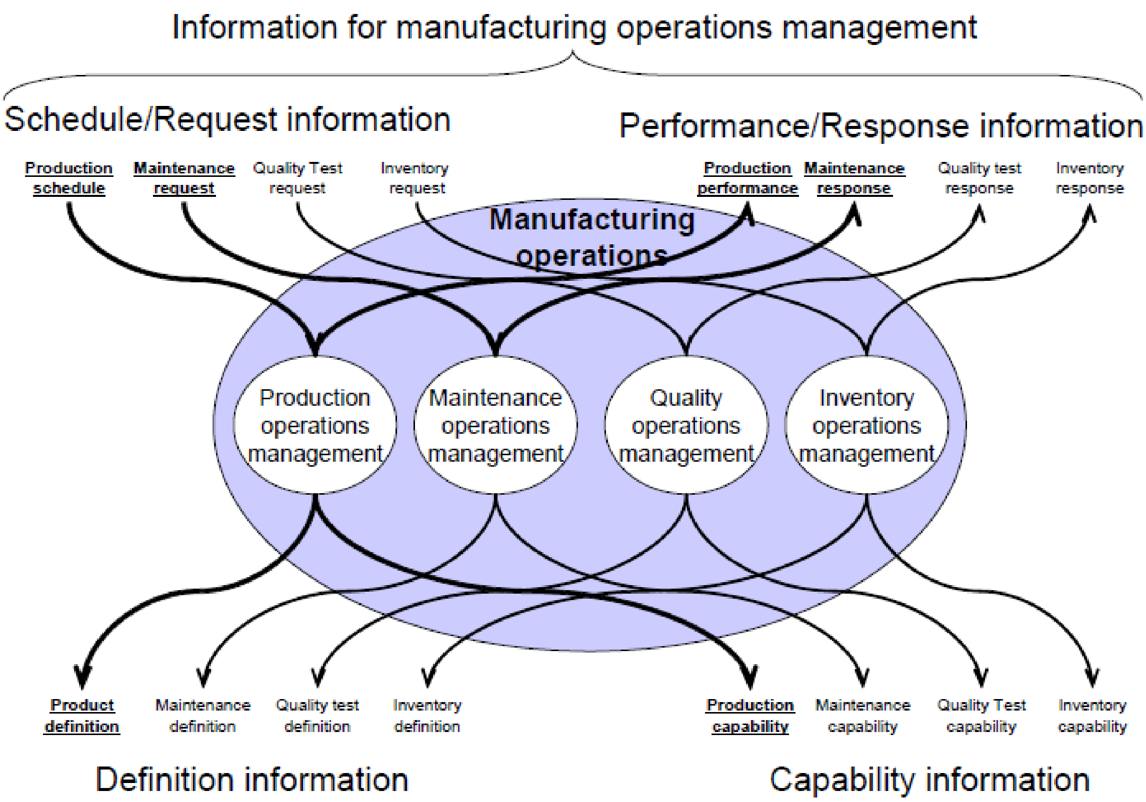

Figure 3: Information in Manufacturing Environment (ISA 95.00.03, 2005)

A hypothetical assembly line further explains above concepts. The line converges and joints components and parts together as an assembled product. Definition information of a product and its production may include, bill of material, assembly chart and bill of resources. Bill of

Material (BOM) lists the parts and structure of a final product. A typically BOM has a tree type of structure to indicate how different components and parts interrelate with each other. Assembly diagrams reveal the detail about the geometric features of parts and describe how parts and components match and joint to each other. Production rules, more specifically assembly design, delineate how parts and components match and joint together and which types of tools and equipment should be used during assembly. By identifying specific tools, equipment and personnel to the task, managers define a bill of resource for production.

Before scheduling assembly work, a production manager has to check the availability of equipment, personnel and other resource. Capability information contains the up-to-date information about the status of the equipment, personnel and other resources. In an assembly production layout, equipment and personnel are usually arranged into work cells or lines. Status of a unit could be busy, idle or down for maintenance.

Detailed production scheduling is a "collection of activities that take the production schedule and determine the optimal use of local resources to meet the production schedule requirements. This may include ordering the requests for minimal equipment setup or cleaning, merging requests for optimal use of equipment, and splitting requests when required because of batch sizes or limited production rates. Detailed production scheduling takes into account local situations and resource availability. (ISA 95.00.03, 2005)" When a schedule is determined, it is transmitted into a series assembly request to cells or other production units.

Performance information of a production unit is a collection of responses as feedbacks to production requests. For instance, the performance could be measured with cycle time of the operations. Performance information could also contain the outcome as the inspection result of operation output. Performance metrics might mark the outcome as pass, rework or scrap. Regarding with an assembly line, statistics such as throughput rate, takt time (Rother & Shook, 1999), first time test past rate, can be selected as critical measurements to the performance of entire production system.

3. OBJECTIVES OF A SOLUTION: ELICITING REQUIREMENTS AND ASSESSING CORRESPONDING CHANGES

The objectives of the solutions are two folds. One is eliciting requirements to determine the scope of changes to implement MES. The other is assessing the extent of corresponding changes. A work system offers a view to an artificial environment where work is done (Alter, 2002). Through requirements elicitation, a requirement analyst determines requirements to a particular work system in a production management with MES implemented. After narrowing down the scope of changes to a particular work system, management can assess the fitness of the as-is work system to suffice requirements. Gaps may exist in business processes within the work system, employees' profiles, the technology, and structure of the organization. Scanning these aspects allows the management to assess the extent of changes on multiple aspects of the work system.

3.1. Determine scope of change with business requirements

3.1.1. Taxonomy of Requirements

What is a requirement? A definition drawn from IEEE-STD-1220-1998 says that a requirement is "a statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability (by consumers or internal quality assurance guidelines). (Hull, Dick, & Jackson, 2011)" according to the definition, it is possible to divides requirements into two categories, functional and non-functional requirements. Functional requirements define what a system is doing. Non-functional requirements are the other characterizes that the system must have or constraints to which the system subjects to. In the context of MES implementation process, the output from this process is a reformed production operation and management system integrated with MES. Therefore, instead of selecting a MES application, an implementer should consider the work system of production management as the focused system. Requirements should reveal what a production management system in factory is doing and must do, if MES has been used successfully.

Broadening the system definition provides the management with a new perspective to look at the problem of implementation. Implementing MES is rather managerial than technical. Hull et al (Hull, Dick, & Jackson, 2011) emphasized distinguishing the requirements in a problem domain and the requirements in a solution domain. A particular IS artifact is a part of a solution to a real-world problem. The highest-level requirements describe what a solution should be doing rather than what it does. Especially in the early phase of development, initial statements about the requirements of a solution should avoid using descriptions that closely associate with a particular solution (Christel & Kang, 1992). In other words, the description should use statements about the problem and stakeholder's value. The principle seems to be paradoxical but it makes sense. Introducing concepts and conceptualizing of a solution too early impose constraints to understanding of the problem and determining requirements. Therefore, identifying requirements start with increasing the understanding to the problem domain. If the implementation directly begins from the requirements that derive from a presumed operation model of an IS artifact, neither the implementation will suffice the actual business needs nor the IS will function at hundred-percent level.

MES implementation introduces a series of changes to a business operation system in factory level. Above all, requirement elicitations method should be able to gather stakeholder's understandings to manufacturing execution. Moreover, the description to these requirements should only contain stakeholders' words about the problem domain without any exact functionalities of a presumed technical solution.

3.1.2. Requirements Engineering (RE) Process model

Kotonya & Sommerville (Kotonya & Sommerville, 1998) have defined a coarse-grain activity model of the process. They have categorized RE activities into requirement elicitation, requirement analysis and negotiation, requirement specification and documentation, and requirement validation. Though the exact boundaries between these activities are blurring, the model roughly sequence the activities along a time line. The critical success chain method focuses on elicitation.

- 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 (Sommerville & Sawyer, 1997) (Kauppinen, 2005). Through requirements elicitation, an analyst unveils customers' needs and wants. Needs and wants are the substantial requirements that state the value of a solution to shareholders. Directly asking stakeholders what their requirements are would unlikely collect those substantial requirements. A viable approach is collecting information about viewpoints based on their cognitive understandings to a desirable state of the system (Tuunanen & Rossi, 2004). In the coarse-grain activity model, the existence of various sources of requirement implies that the choice of elicitation method should appropriately match the characteristics of available sources.

- Requirement Analysis and Negotiation generate acceptable requirements. Analysis focuses on an initial set of information and seeks for conflicts, overlaps, omissions, and inconsistencies. Negotiation is the way to resolve conflicts among people to decide which requirements are acceptable (Kauppinen, 2005).

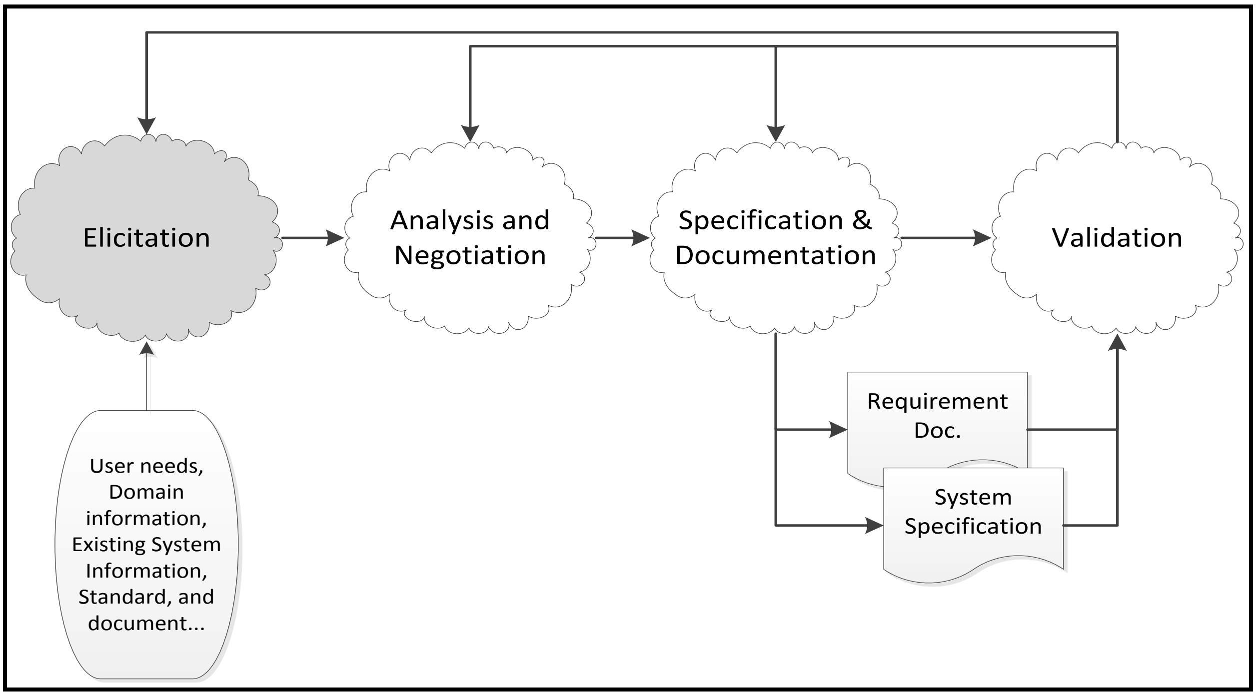

Figure 4: Requirement Engineering Process model (Kotonya & Sommerville, 1998)**.**

- Requirement Specification and Documentation are the activities of presenting and recording the requirements in a way that is assessable by stakeholders. The representation is either in some forms of diagrammatical notation or natural language (Pohl, 1994). Requirement document and system specification developed in this phase records the non-functional requirements and functional requirements respectively.
- Requirement Validation checks consistency, accuracy and completeness of documented requirements (Kotonya & Sommerville, 1998). The checking creates a feedback mechanism to previous three activities.

3.1.3. The context of requirements elicitation

The activities of conducting elicitation depend on situational circumstance. Rzepka (Rzepka, 1989) summarized the activities in elicitation as identifying source of requirements; collecting, documenting as well as refining the "wish list" for each relevant party; synthesizing various wish lists into themes of viewpoint and determining nonfunctional requirements. Coulin (Coulin, 2007) decompose the elicitation into activities as identifying the source, understanding the domains, selecting method, eliciting requirements and organizing information. Situational circumstance provides a context of elicitation scope. Elicitation could roll out during the initiate, planning and analysis phase of software, or it can happen during a business change project (Coulin, 2007). Sometimes, elicitation is used to evaluate several projects to see whether they are managed on the right course to meet changing shareholders requirements.

Hickey & Davis (Hickey & Davis, 2004) argues that elicitation activities, especially the selection of elicitation approach is contingent on the situation and known requirements at a particular moment. In their model of elicitation activities, stakeholder's unsolved problems trigger the elicitation.

The scope of elicitation is more or less limited by analysts' understanding towards problem and solution domain. On the one hand, problem domain means a subset of the real world, which presents a problem and establishes boundary conditions. The problem shows conflicts amongst unfulfilled goals, needs and wants. On the other hand, solution domain is only about an artifact that does the job. For example, the problem domain of MES depicts the manufacturing operations and associate information processing and exchange. None of features in a MES application exists in a problem domain. The solution domain of MES states the functionality of MES. Understanding the solution domain answers how a solution functions but does not answer what a problem-solver expects his/her solution to do.

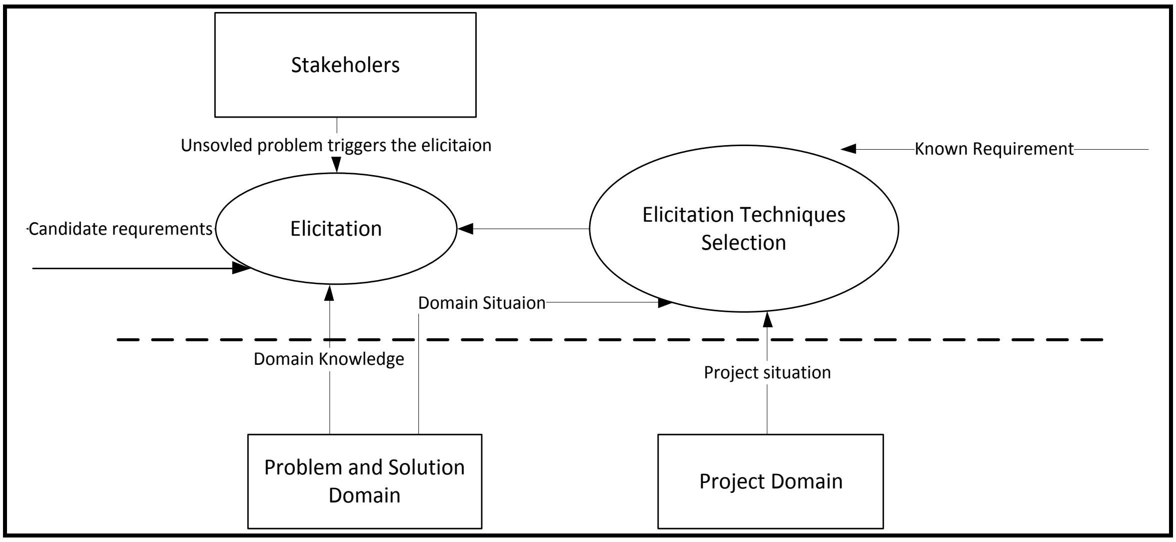

Figure 5: Context of elicitation (Hickey & Davis, 2004)

The situation of these two domains affects the selection of elicitation techniques. The characteristics of these domains may change as time goes by. Characteristics of the problem domain are relative static throughout a project's life cycle. Yet, characteristic of the solution domain varies whenever a new solution is proposed. For example, if a problem is that worker' manual operation introduces too much variations to the assembly. A solution could be breaking down an operation into atomic simple tasks and training workers to perform specific tasks in a standard way. Alternative solution could be automating the operation and replacing manual work elements. The first solution offers a training and instruction system for executing assembly operations. Corresponding elicitation may employ techniques such as ergonomic work design methods to study manual work. Elicitation approach for automation system substantially differs from the approach for standardizing manual work. Programming and prototyping robotic motion in a working environment could be the choice.

Hickey & Davis (Hickey & Davis, 2004) introduced the concept about the project domain. The situation of a project domain is characterized by the capability of the analyst and the available resources with which a company initiates and organizes the elicitation project. Some elicitation technique consumes more time and requires supports from a specific technology. For example, elicitation through prototypes requires resource and time to develop and build prototypes. Analyst should be aware of the constraints that impose on the selection of the elicitation approaches.

Known requirements are another factor that influences the selection of elicitation method. Through prior iterations of elicitation, known requirements are accumulated. Analyst can use them as input to a new round of elicitation. Some analytic oriented elicitation techniques demands input of high-level requirements. For example, Quality Function Deployment (QFD) (Hauser & Clausing, 1988) can deploy the needs and performance requirements from stakeholders to some functional specifications of a product. However, building the requirement-specification matrix in the quality house relies on initial set of performance requirements as input. Further, QFD needs a reference of existing systems to determine the competitive level and priority of the performance requirements. When Toyota used QFD to elicit and analysis requirement of their cars, they used the competitors' car offering for comparison (Hauser & Clausing, 1988). Nonetheless, when many enterprises start to implementing MES, stakeholder requirements are vague and information from existing system is insufficient.

To summarize, the elicitation method should aim to discover management's requirements to the new work system. The domain knowledge to desired work system resides within managers and key stakeholder's mind. Hence, elicitation should aim at discover and gather requirement for production managers and key operators.

3.2. Assess the extent of changes

After determining the scope of changes, the study will give a preliminary diagnosis to current work system. The diagnosis attempts to discover the gaps of which the changes should fill to meet the requirements. These gaps also give management an expectation to what extent a work system should change.

Many change diagnosis tools have their origin more or less affiliated with Lewin's Force Field Model (Lewin, 1951). A Force Field Model checks a transient state when change driving force and restrain force are influencing an organization at a particular moment. If the driving force is stronger than the restrain force, an organization will shift towards a disequilibrium state. Equilibrium reestablishes when goal of the change has been reached, because the driving forces are weakened and has less influence than restrain force does. When change is goal oriented, the extent of change is affected by the difference between the strength of driving and restrain force. Instead of building a process model, Leavitt (Leavitt, 1965) postulated a dynamic framework that investigates the harmony amongst task, structure, technology and actor. When work system is in equilibrium, the four elements in the framework fit well with each other. These elements interrelate with each other in a dynamic way. Any change in one of the elements would affect the other three elements.

Business requirements of implementing MES set goals for re-engineering business processes. Implementing MES offers a technological solution to support the operation of a business process. The extent of change involves training actors of the business process with new skills and adjusting the organizational structure that administrates the operation. The solution should help management foresee the possible change by identifying conflicting setting among these elements.

4. DESIGN: CRITICAL SUCCESS CHAIN AND LEAVITT'S DIAMOND MODEL OF SOCIO-TECHNICAL INFORMATION SYSTEM CHANGE

4.1. Requirements elicitation with Critical Success Chain (CSC) Method

This research adopts the Critical Success Chain (CSC) method as the requirements elicitation approach to discover shareholders' requirements to implementing MES. Factors influenced the selection of the elicitation approach are from three fold. First, the implementation process is at early envisioning phase. Managers wanted to identify the most salient problem in manufacturing operations system. Elicitation should help the implementation planner to find requirements that link with the needs of production management. Second, a manager who is responsible for a partial function of operative management merely perceives a subset of a manufacturing operations problem. The approach should be able to aggregate the needs from individual managers to a collection of requirements that deliver a comprehensive understanding. Third, the company has capabilities to further configure and develop the software. Solution to the problem might be a hybrid of a new MES functionality and some new management policies. The elicitation should provide MES developers and the operative management team sufficient freedom in creating new solutions.

The objectives of the elicitation approach are

- Collecting wish lists from managers from different functions of operative management,
- Merging wish lists to a collective view toward stakeholder requirements so as to solve salient operation problems,
- Present the view in a way that does not demand special knowledge to understand the meaning.

To achieve the objectives, CSC method is able to identify and present the critical success factors for business goal in operations management by using personal constructs (Kelly, 1955) of managers.

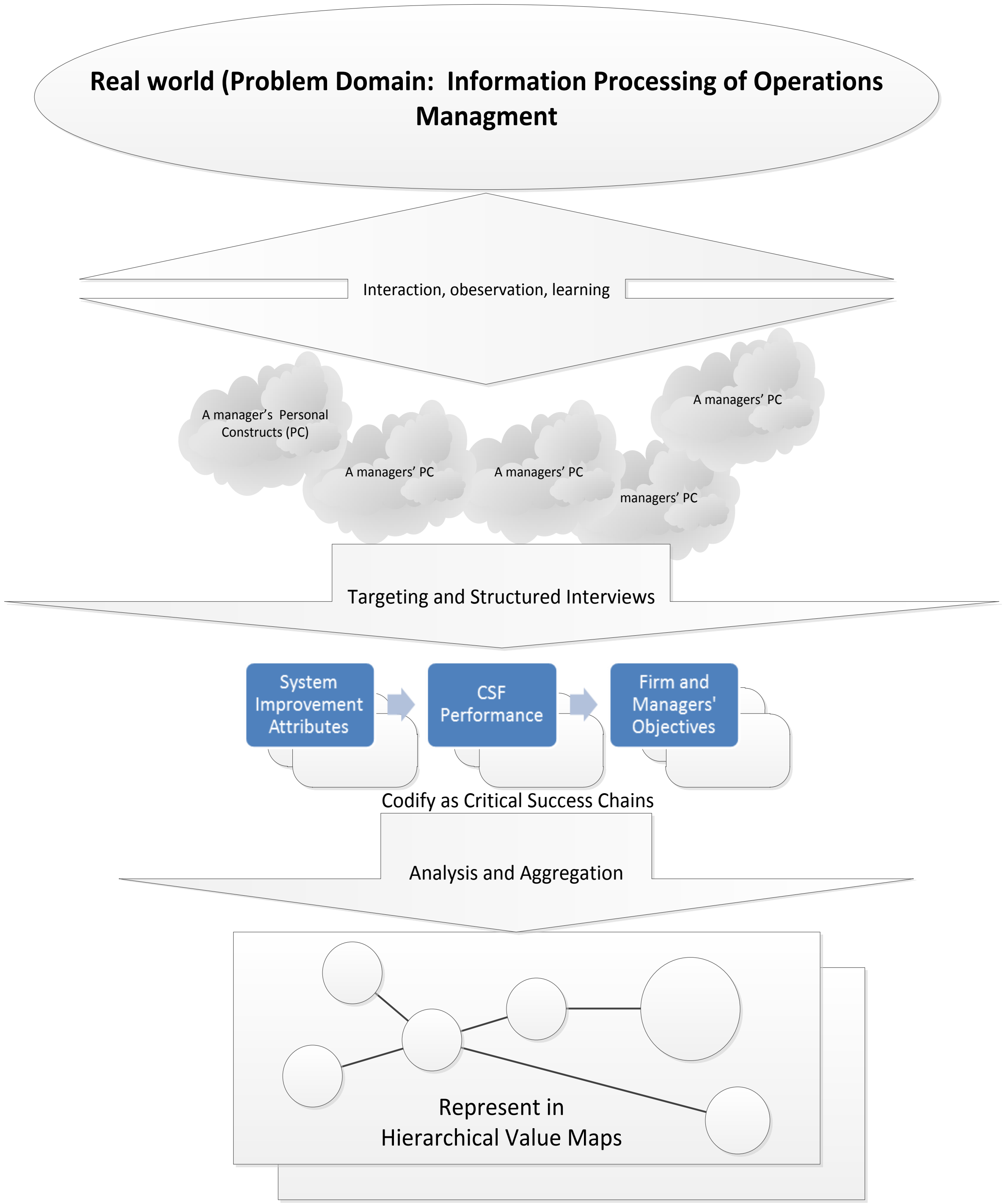

Figure 6: An overview to Critical Success Chain Method

Ken Peffers et al (Peffers, Gengler, & Tuunanen, 2003) extended the critical success factors (CSF) method by incorporating the personal construct theory (PCT) (Kelly, 1955). The extended CSF method is termed as Critical Success Chains (CSC) method. People try to interpret and rationalize relationships between some states of the universe, the consequences of these states and the impact of these consequences on their value. Through observation, interaction, learning, education and interpretation of series of events, individuals will develop their own multi-dimensional models in their mental worlds. These multi-dimensional models contain personal constructs and their interrelationships. A person ascribes a perceived state of world as consequences of some attributes and behavioral setting. Further, People judge the consequences basing on their effects on people's value (Peffers, Gengler, & Tuunanen, 2003).

Managers will develop their own personal constructs through committing to practice in the problem domain. Using personal construct is subconscious to them but common. Many decision-makings with a manager's intuition can be explained with personal construct theory. In a social context, the collective knowledge in a social group is established through communication and aggregation of personal constructs into norms in the group culture (Peffers, Gengler, & Tuunanen, 2003). The CSC method probes individual managers' personal constructs with a structured in-depth interviewing technique, laddering (Reynolds & Gutman, 1988). An interviewer collects and codifies interviewees' statements into personal constructs. These constructs can be arranges into several attributes, consequences and values of chain structures. The method attempts to represent the aggregation of individuals' personal constructs on some two-dimensional maps. The maps are termed as the Hierarchical Value Maps (HVM).

It is worthy of mention that a critical success chain is not an objective causal relationship but a perceived expectancy to value. One should not confuse these two types of relationships. The idea is using the chains to uncover hidden expectancy to key consequences and value. The substantial requirements rather than the causal relationships are the focal interest of CSC.

The general procedure of the CSC method (Peffers, Gengler, & Tuunanen, 2003) goes through four stages, pre-study, laddering in-depth interview, analysis and the workshop.

Table 2: General procedure of CSC (Peffers; Gengler; & Tuunanen, 2003)

CSC Procedure	Description	Output
Pre-study	Determine the scope of the study. Select and contact the participants for the study. Introduce the purpose of the research to participant and collect initiate ideas as stimuli for laddering interviews. Schedule and arrange the interviewing time.	• A list of participants, • Scheduled interviews • Stimuli
Laddering interviews	Ask participant to rank-order stimuli or import ants. Ask them "Why would this be important…" to probe the consequences and values. Ask them "What is it about the thing that makes you think it would work/do that…" to detect attributes. Record answers as linked ladders. Do the one-on-one interviews with each participant.	• Several ladders from each interviewee
Analysis	Codify the statements in the ladders into consistent labels across participant. Codification converts ladders of statements into chains of concepts. Cluster the chains and map clusters into network model (HVM).	• HVM
Ideation Workshops	Invite experts to the workshop. Evaluate the CSC network model (HVM). Elicit feasible strategic options to satisfy the relationships implicit in the map. Create brief descriptions and network business value model for each idea.	• Back-of-envelop description to project initiates

4.2. Assessing framework to the extent of change

The solution adopted Leavitt's diamond (Leavitt, 1965) as an assessing framework. The model is a paramount diagnostic tool to examine the fitness between people, task, technology and structure.

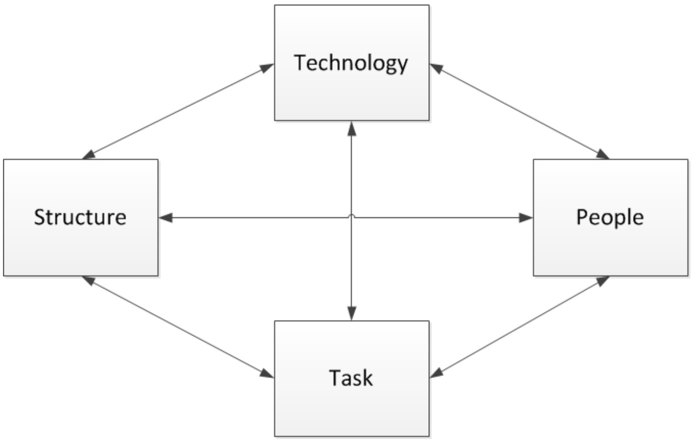

Figure 7: Leavitt's diamond model

People or actors are the employee and managers in the company. Besides looking actors from their position, the element also taking account the skills level, capability of the actors (Thakur, 2011). People tend to respond to changes from the other elements in following three aspects. When task changes or a new type of task is assigned, people adapt to the new way of working through education and training. In an organization or a micro social group, people have to adjust the role they used to play and accept the new responsibility. While actor is adopting a new technology effectively, training and coaching are necessary to strengthen their relevant skill to the technology.

The element of task emphasizes on the objective and executive procedures to accomplish a business task. If the degree of institutionalization is high, a task might be formally defined as a business process of which the procedure and goals are specified explicit in the organizational routine. In another way, a task could be accomplished on an ad hoc basis. In that case, its objective is implicit and its procedure is unstructured. The task should be assign to people with adequate knowledge and skills. If actor changes, the task needs to be redesigned to fit the capability of the people. The structural change in organization requires corresponding adjustments in task definition. The adoption of a technology may raise the objective of a task to a new level. A new technology, for example, using the augment reality to aid assemblers in locating a part that they have to mount to an assembly, can significant lowers the error rate of manual work, and new standards could be set for the task.

Structure not only refers to the hierarchical layout of an organization but also implies the relationships, communication patterns and coordination between different management level, departments, and amongst co-workers (Thakur, 2011). The concept comprises the division of responsibilities between parties, the asymmetric information accessibility of different parts, the reward and incentive mechanism and protocol of conducting communication as well as coordination. If an actor is highly skilled specialist in her/his job, the management may empower them through a more flat supervising structure. The objective of a task has impacts on the structure. For example, if the objective of a business process is highly customers-centric, the structure should shadow an order fulfillment process to key customers. Technological change may leads obsolete the structure of an organization. A good example is that nowadays the large department that manually handles paper invoices shrinks in size when electronic invoicing technology becomes widely adopted.

Technology facilitates actors and organization to perform the tasks. The technology could be in any form and in any domain. It could be using of computer, automated machinery or a systematic way of using Kanban cards to control production. Computer based technology requires adequate IT skill from employees. Automated machinery requires programming, error diagnosis and maintenance skill of the workers. The structure of the organization, the task affects the appropriateness of a technology and the diffusion rate of the technology.

Sarker (Sarker, 2000) incorporated notions of objective and subjective realities from the arena of sociology of knowledge into Leavitt's model. He argued that people from different social group perceive objective reality differently. Therefore, implementers should "firmly uphold the assumption that the stakeholders like most other human beings, act rationally according to their own utilities (Sarker, 2000)." Sarker proposed (See Figure 8: Adapted Sarker's implementation guidelines a guideline for implementation manager to scan the elements in Leavitt's model from different stances.

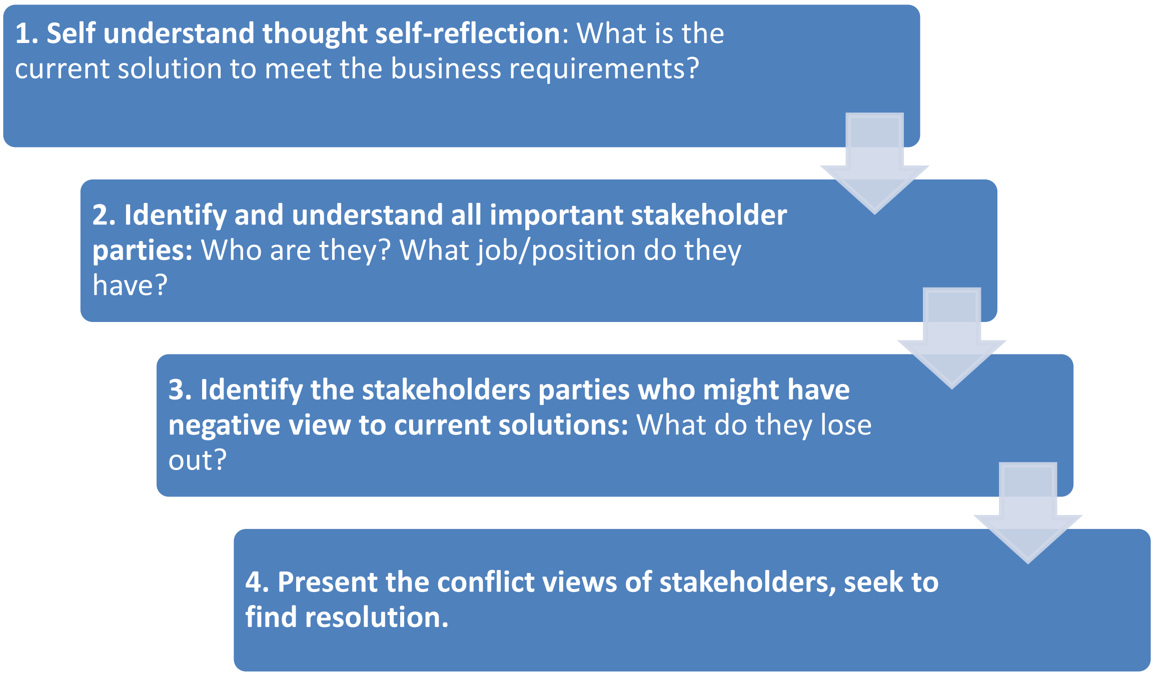

Figure 8: Adapted Sarker's implementation guidelines (Sarker, 2000)

This study adapted this general guideline in workshop and openly discussed with managers an informative view to perspectives of different parties. The view of different parties are drawing base on the assumption that human beings, act rationally according to their own utilities instead of maximizing the organizational benefit.

4.3. Change assessing procedure

The assessing procedure resembles the general procedure of CSC method but it differs in pre-study phase and workshop phase. The CSC method aims at carrying out study with board-audience participation (Tuunanen & Rossi, 2004), because the method has been adopted for planning a mobile financial service to a broad customer base. For implementing MES to a business unit of an enterprise, the objective is to capture and utilized the knowledge of several key persons who have deeper understanding to salient problems in production system. In a pre-study phase, adapted design in this study uses an order fulfillment flow chart to targeting managers whose job is closely relevant to MES implementation. In fact, it increases the efficiency of collecting relevant information in an organization. In the workshop phase, the generic CSC method aims to help the management to evaluate project proposals by roughly estimating relevant costs, risks and committing resources. In the workshops of new designed method, the objective is help management foreseeing the extent of change by depicting gaps in multiple aspects of current work system. Hence, instead of using a back-of-envelop description to project proposals, this method aims to identify the resistances in current work system.

3.4.1. Pre-study

In this phase, the analyst determines the scope of the elicitation. Basing on the scope and available resources, the analyst selects participants for laddering interview. Through brief meeting with participants, analyst establishes contact with participants and introduces the purpose of the study. Regarding the minimum and maximum number of participant, there are no theoretical limit (Peffers;Gengler;& Tuunanen, 2003). People within a social group may develop consensus on their personal constructs. Interviewing people from a common social group, analyst may collect redundant statements that she or he merges into the same chain of constructs. Including a large number of interviewee increases the time for interview, but marginal participants' contribute decreases. An argument is that the result is sensitive to the choice of interviewee rather than number of the interviewee. Analyst had better select a few managers and representatives who have deep knowledge to the problem domain to increase the efficiency of elicitation.

To pinpoint precisely the managers who have deep knowledge on manufacturing operations, analysis can explore the organization with a coarse-grain flow chart (See Figure 17, Appendix A) of order fulfillment process. The flow chart emphasizes on the information exchange in the manufacturing system and divides the order fulfillment process into five layers of activities. On the lowest layers, production units execute physical operations. The execution is trigger by data request from second layer. Current archive system records the progress and output of physical operations and feeds records back as response to the data request. On the third layer, a production controller does the execution scheduling. Above the planning layer, there is knowledge as the rules and definition information for the scheduling. Production definition information and capability information are in this layer. Above fourth layer are design processes through which engineers increase, and modify the knowledge on the fourth layer.

Through discussing the flow chart with managers in the factory, the analyst and managers establish a common understand to information processing in the manufacturing operations management system. The analyst and managers work together to identify the ownership for information exchanges and processing. For example, analyst may ask questions like, “Who makes production master schedule, who define the detail assembly routines…” Answering to the question nominates candidate whose job are closely relevant to implementing MES.

After drafting a preliminary list of candidate, the analyst can appoint brief meetings with these candidates. These meetings are for pre-interviews. There are three objectives in a pre-interview. The first one is establishing contact and arranging time as well as places for the forthcoming laddering interviews with candidates. The second objective is collecting some preliminary idea about how to improve the production as stimuli. The third objective is validating the candidate selection. Interviewees may suggest including new candidates, whose jobs are relevant to MES, into the candidate list. This snowballing method expands the list of candidates.

An important output from pre-study that serves as a critical input to the next phase are those collected stimuli from pre-interviews (Appendix F). Because the purpose of implement MES is to improve production, stimuli are ideas to improve current production.

3.4.2. Laddering interviews

Laddering refers to a structured one-on-one interviewing technique that probes the Mean-End (Gutman, 1982) structure of interviews’ personal construct. Ladders are a series of statements about the attributes that an entity possesses (means), and the associated consequences that the attributes provide and values that the consequences support (Reynolds & Gutman, 1988).

To probe the requirements during laddering, the analyst first presents interviewees with a set of implementation and production improvement ideas as stimuli. Interviewer asks an interviewee to rank his preference to the ideas. The task for interviewees is picking out three the most favorable ideas. Then the analyst as the interviewer chooses one of three ideas and asks interviewees a question like, “Why would this be important to improve production?” Normally, the response from interviews will either indicate some important attributes that the idea has or reveals an expected consequence from the idea. Depending on the response to first “why” question, interview have two strategies to continue the probing. If the answer indicates some attributes of the idea, interviewer can keep on with the established moment of conversation and ask, “What else about the thing that makes you think it is important”. The question will elicit more attributes from an idea. The interviewer can further ask again, why an attributes are important to probe the consequences and value. Through repeat asking “why” question, the ladder will reach to statements about values either to the individual or to the organization. If the interviewee respond the first “why” question with expected consequence, interviewer just need to repeat the “why question” to keep the moment of conversation toward “end” direction of a ladder. When a ladder is complete, interviewers can to go back to the first statement and ask a question like “What is it about the thing that makes you think it would work/do that…”

In the practices, repeatedly asking tedious “why” question may not able to receive an answer. Reason could be that the topic is sensitive or the interviewee just does not know the answer. Strategy to solve this problem includes recording the stop point and come back later, using silence to give a respondent more time to think, providing contextual information to create a scenario or using negative laddering (Reynolds & Gutman, 1988). Negative laddering means asking a respondent what matters if some attributes or consequences are missing.

Regarding the method of recording the ladders during interviews, this study uses both audio recording and hand notes. Hand notes records the statements of ladders from respondents during interviews. Sharing hand notes the respondents facilitates the conversation. Listening to audio records helps the analyst to review and codify statements into constructs.

An interview should be arranged in a place that is comfortable to interviewees. This place could be an office or a meeting room. The purpose is to ensure the interviewees are at ease during the laddering. Besides asking questions, interviewer could give some confirmative comments to interviewee’s answer to encourage them to speak more and deeper about a topic.

This method assigns 90 minutes for each interview. An analyst can do two to three interviews per day. Listening to audio records and reviewing the hand notes will cost about 90 minutes per interview. Basing on these figures, an analyst or a group of analysts can proper schedule their work. Previous researches that operationalize CSC method usually collect four to seven ladders per interviewee in average (Peffers, Gengler, & Tuunanen, 2003).

3.4.3. Analysis

A crucial output from laddering is a series of statements of personal constructs. These constructs are attributes, consequences and values. Analysis to the series of statements from interviews goes through three major steps, content analysis, clustering and graphical presentation.

The data process starts with content analysis. Through content analysis, analyst codifies the ladders of statements into constructs on critical success chains. For examples, the analyst may codify following two statements into one single common construct.

> "It (assembly work standard) allows experienced worker and inexperience worker produce do the assembly in the same way…"

> "A new worker learns the assembly work from skilled work and performs same assembly method."

These two statements represent a common construct, which says, "Little variation of assembly work between workers." In content analysis, an analyst can further abstract the concept by labeling a code, for example "C1", to denote the construct. The abstraction is essentially a process of abstract critical information from interviews. It spins off lots of contextual information from a concrete statement. Hence, it reduces the complexity of the information collected from interviewees. Prior research on laddering addressed a coding reliability problem in which the codification depends on the subjective judgment of individual analysts and then proposed parallel coding through independent coders to reduce the subjective bias (Reynolds & Gutman, 1988) (Peffers, Gengler, & Tuunanen, 2003). After coding contents from interviewees, the analyst has a list of codes as well as their corresponding constructs. This study represents the chains collected from interviews in a tabular format (See Appendix B).

The next step is clustering chains. Clustering means that the analyst sorts chains with high similarity into same groups. These groups are termed clusters. The idea is that one can conclude meaningful understanding from an aggregated set of interweaved ideas with high similarity among them. The analysis in the end presents the understanding with hierarchical value maps. It makes sense that each map will present an aggregation from one cluster. On final state, analyst may synthesize understanding from several maps.

To perform cluster analysis, the analyst denotes critical success chains in a data matrix (Appendix C). A row vector of the matrix denotes a chain. The elements of the row vector can be either zero or one. An element of a row vector taking value one means a corresponding construct is presenting in that chain. From the column vectors of the matrix, we know which construct presents in which chains. For instance, from the first row of data matrix, we have column A1, A2, C1, C2, V1 and V2 have value 1. That means the first chain includes construct A1, A2, C1, C2, V1 and V2.

An analyst needs an algorithm that puts the similar vectors into same clusters. The mathematical problem here is clustering row vectors. Ward's method (Ward, Jr., 1963) provides a solution to the problem. Above all, mathematician needs to define what is similar and how to measure similarity between two vectors. In fact, rather than measures the similarity between two vectors, the algorithm measures the dissimilarity between each two vectors. Measuring by squared Euclidean distance, the analyst develops a distance matrix. From distance matrix, he/she knows the dissimilarity between any two vectors. The generic step of agglomerative hierarchical clustering methods (Schmidhammer, 2011)is:

1. Start with two vectors with minimum squared Euclidean distance and merge them into a cluster. The new cluster is represented with a vector of its center.
2. Remove merged vector from distance matrix and replace with new cluster center vector. At the same time, we update the value in the distance matrix.
3. Start a new run of iteration by re-do step one.

Most statistical software packages embed algorithms to perform a hierarchical clustering. The method finally merges all clusters into one agglomeration if there is no criterion to abort the iterations. Thus, the analyst has to determine a tolerable level of dissimilarity for choosing a proper clustering solution. Any two of cluster cannot merge if their dissimilarity is higher than the tolerable level. The tolerable level is essential a cut-off line in a clustering Dendrogram (Spotfire, TIBCO, 2012) to stop the agglomeration procedure (See Figure 18: Cluster Dendrogram , in Appendix D).

The final step of the analysis is presenting the chains in clusters on separated maps. A map contains many bubbles and arcs. Those linked bubbles forms critical success chains. The size of a bubble represents the frequency that a cluster includes a particular construct. There are few strict guidelines about how a map should be drawn. To increase the readability of the map, Peffer et al. (Peffers, Gengler, & Tuunanen, 2003) suggest one should avoid crossing of arcs.

3.4.4. Workshops

There are two objectives of workshops. The first is to validate the HVM by feeding them back to participants. In this study, the analyst presents the HVM with short stories that address the theme of the map and summarize critical success factors on different HVMs. The second objective is to assess the current work system to foresee to what extent changes are. Workshop should recruit managers who are familiar with detail production operations and have authority to allocate necessary resources to meet requirements implicated from VHM.

Prior researches report cases in which an ideation workshop lasted up to five hours (Peffers, Gengler, & Tuunanen, 2003). Analyst may consider dividing a workshop into several separate sessions. For example, HVM confirmation and assessing the extent of change could be split into different sessions.

5. DEMONSTRATION CASE: THE SWITCH DRIVE SYSTEMS OY

This chapter demonstrates the operationalization of the adapted CSC method in one of The Switch's Model Factory in Lappeenranta. The case first introduces the case company and the supply chain of wind power industry. The second section presents an in-house developed web-based Manufacturing Execution Systems, NetMES. The actual data collection and carrying out the designed method are described in the third section. The fourth chapter shows a part of HVMs and major result.

5.1. The Switch Drive System Oy (The Switch)

The Switch Drive System Oy designs and produces Permanent Magnetic Generators for wind turbines. The company established in 2006 from the merge of Rotatek Finland, Verteco and Youtility. From 2006 to 2010, the company had experienced dramatic growth. In 2010, the company's net sales reached EUR 134.6 million, which was almost seven times as many as the net sales in 2007. In 2010, the company had about 280 employees (The Switch, 2010). The Switch expanded internationally. It has chartered manufacturing facility in Finland, China, and the US. In early 2012, it had sales contacts in more than seven countries.

The Switch situates on the upper stream of the supply chain providing key electrical system to wind turbine manufacturers. Changing demand in terms of product evolution has a fast clock-speed. To keep the position as a leading supplier for PMG, since 2010 the company has been developing its product in multi Mega Walt segment. The company now has mastered technology to design and manufacturing PMG of three to seven mega Walts (MW). A generator has relative high technical complexity and its customers require high reliability for such industrial solution. The Switch customized products for different customers to meet the requirements of developing standard and diverse need (Patton, 2012). An industrial wind turbine generator is usually large in dimension and heavy. A direct drive generator can weigh up to 80 tons and have its diameter longer than 6 meters. Transporting an integrated product over a long distance is a logistic challenge. Shortening the lead-time to deliver generators on wind turbines to meet the expansion of wind farms and meanwhile reducing the costs per MW are crucial pressures imposed on the generator suppliers (Kurttila, Shaw, & Helo, 2010).

In wind power industry, rapid market expansion in the wind power industry results fragment competition structure among the wind turbine manufactures. In 2012, none of the wind turbine manufacturer occupied more than 13% of the market (Ben Backwell, 2012). The competition among wind turbine vendors is intensive. The critical success factors to serve customers are on time delivery and shorten the lead-time for order fulfillment. As a result, the company is pursuing an agile supply chain strategy (Lee, 2004) for its PMG. A core concept The Switch employed for its agile supply chain strategy is ramping-up production capacity by replicating and scale up the production system developed in model factory (Kurttila, Shaw, & Helo, 2010). The company has been ramping-up production capacity in China, the largest market for wind power product since 2010.

Ramping-up capacity has three folds of meaning. The first fold is transferring and duplicating the technical part, such as product definition, production definition of manufacturing processes. The product definition and production definition describe what the output from the production is and by which means the output is achieved. The second, The Switch has to establish or localized production planning and control process through which they operate and administrate the execution. The third fold is reconfiguring the supply chain architecture to support the production.

5.2. Manual assembly in Model Factory

This research focuses on the MES implementation in one of The Switch's Model Factories, in Lappeenranta, Finland. A typical life cycle of a PMG goes through four phases, product creation, prototype production, Zero-series production and volume production (Figure 9: Product development. Model Factory mainly produces prototypes and zero-series. Zero-series refers to first several small batches production of a product. Developing and validating the quality of product design and the production design are key issues in early product life cycle. The Model Factory hatches new product prototypes and zero-series until the product and its production technology are mature enough. Volume productions are ramped-up in supply chain partners' or new manufacturing facilities.

The Switch outsourced the components fabrication to third party manufacturers. The final assembly of a generator was carried out on the factory shop floor. The assembly can be roughly divided into phases of pressing stator into generator frame, assembling terminal box, assembly rotor, pressing rotor into stator, bearing assembly, final assembly and cleaning. The manual assembly of mechanical parts of the generator includes four types of operations, cleaning the surface of metal or mechanical parts, jointing parts, adjusting the position as well as balance of mechanical components and inspecting the parts in intermediate steps.

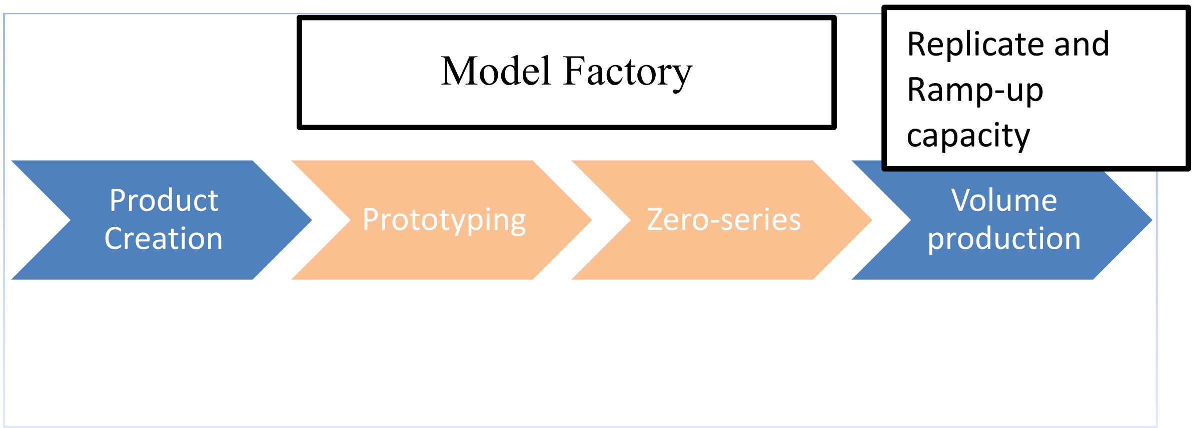

Figure 9: Product development

The Switch's products are highly customized for different customers' technical requirements. It means the production should be flexible enough to manufacture a great variety of unstandardized products. The flexibility of assembly operation relies on human workers' versatile skills and expertise. Workers doing the manual assembly job perform multiple tasks of assembly and switch between tasks frequently. Some tasks require the cooperation between two or more workers. The assembly job of a worker is semi-routinized. Workers' experience and capability of cognitive reasoning and discretional decision-making are important to their operational performance. For example, balancing a rotor requires workers to measure static position, weight distribution, and rotation vibration. The worker analysis the metrics and decide the best adjustment to reduce the vibration within tolerance.

5.3. NetMES application

NetMES is a web-browser-based manufacturing execution system for dispersed manufacturing. User can assess to the NetMES via web browser on a personal computer. Now, the development team of NetMES has released functionalities of work queue management, process data collection, work instruction and interfacing with Andon (ELSE, Inc., 2012) system.

Work queue management (Figure 10: A snapshot to the dashboard of work queue management) provides a visual interface to visualized Work in Process (WIP). The progress of a product's finishing is marked with defined assembly phases. For any product that belongs to a released order, managers can view its completeness by counting how many phases it has gone through and how many phases are left. When the workers in a cell report the completion of a phase by clicking a button on the client end of the NetMES, they update the work queue. The updating can also be done by regularly following up the production in assembly cells trough manual checking.

Figure 10: A snapshot to the dashboard of work queue management

Process data collection offers features that enable the quality manager to trace key components during production. When a key component is mounted onto assembly, workers inspect its condition and scan the bar code on it. The collected data will be saved into a tracing log to the product. When repair and quality claims occur in the late life cycle of the product, the product log functions as reference for maintenance and repairing.

Work Instruction (WI) function (Figure 11) distributes and displays manual assembly work procedure in detail. Displaying digital work instructions replaces circulating papers and assembly charts on the shop floor. It reduces the management effort to distribute and archive paper document. The Switch expects that standardizing work between individual assemblers would help transferring the production technology to partners. The content of WI includes visualization of the current state as well as the goal state of assembly steps, visualization of a part's geometric feature that is to be jointed, and guideline of cleaning, jointing, adjusting and inspecting.

The Andon system signals and reports the occurrence of quality problems in manufacturing execution. In the Switch, when a quality problem occurs and interrupts the production, a worker or his/her supervisor triggers an Andon alarm. NetMES sends production managers SMS. Production manager or a supervisor does the immediate diagnosis and responses to the problem. The original purpose of Andon alarm was to signify and visualize the internal quality failure in production system to reduce downtime. In Model Factory, managers use

Andon as a "field note taking" system to accelerate the learning through product prototyping. Workers on the shop floor can report and suggest product or production improvement ideas by type them in electronic dialog box in a client interface. By doing these, a case of production problem is created for production development team's periodic review. Production development team discusses Andon cases with product designer to improve the design for manufacturing and assembly (DFMA).

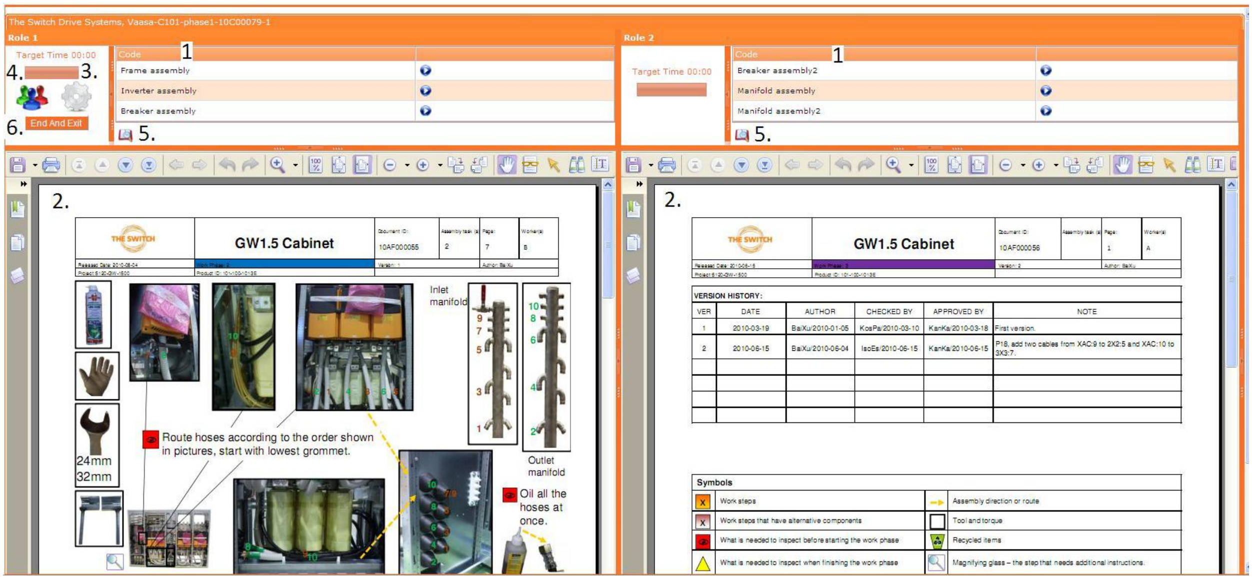

Figure 11: A snapshot to the interface that displays work instructions

5.4. CSC Data collection and analysis

The study selected the interview candidates by using of an information processing flow chart (Appendix A) in manufacturing system. Together with the managers in manufacturing department, process owners were identified. The analyst then scheduled pre-interviews with process owners. During pre-interviews researcher confirmed selection of candidate and invited the candidate to in-depth interview.

In laddering interviews, analyst eventually invited six managers whose jobs were most relevant to MES implementation. Four of managers were from production development and planning department, the rest were from engineering department.

The analyst scheduled six one-on-one structured interviews. Each of the interview reserved 90 minutes. The meetings were hosted either in an interviewee's office or in a discussion room. Audio recorder was used to record the conversations. Besides asking question, analyst wrote down brief notes about interviewees' statement and clarified the ladders with them immediate after an interview. Finally, the laddering collected 32 ladders from interviews in total.

By listening to audio record and reviewing interview note, statements were codified into 51 constructs. These construct made 32 chains. In average, there were 4.6 constructs per chain. To perform the clustering, data was transformed into a 32 by 51 matrix with elements that were either one or zero. The matrix were stored first in electronic spreadsheet and then converted to a file of comma-separated values. The agglomerative hierarchical clustering was performed in R environment (See appendix E). The application read data and utilized its embedded algorithm to do the clustering. From the dendrogram (See Figure 18, in Appendix D), the researcher determines the meaningful result. By setting a dissimilarity tolerance level at approximately four, solution provided result of seven clusters. One of the clusters was less understandable and was decomposed and merged into other meaningful clusters. In the dengrogram, final six clustering solution was marked with blocks in different colors.

5.5. Result: Hierarchical Value Maps and assessing the extent of forthcoming changes

The demonstration presents some of the hierarchical value maps and shows that how the scope of change is determined. The result shows three HVMs of which the implementation requirements have close interrelation and implicate a direction of change. The requirements provide a vision to a new business process that can boost the production performance. Shifting to this new process demands adaptations both in the organization and in the work system. The extent of changes is assessed by using an analysis to show the potential inertness in organization.

5.5.1. HVM I: Support manual assembly

The HVM I (Figure 12: HVM I Instruct Manual Assembly) illustrates a mean-end structure perceived by management. The Switch was keen on assuring high product quality. The Switch keeps the final assembly and testing operations in-house and outsources part fabrication from its 3rd-party manufacturers. The quality of the generator depends on how well the assembly is planned and operated. The differences between manual works of individual operators introduce variation to a production process. One of the critical success factors to quality is that operators are able to perform manual assembly in the same way and within same amount of time. A requirement that implied from this HVM is that NetMES implementation should improve the quality by improving human performance.

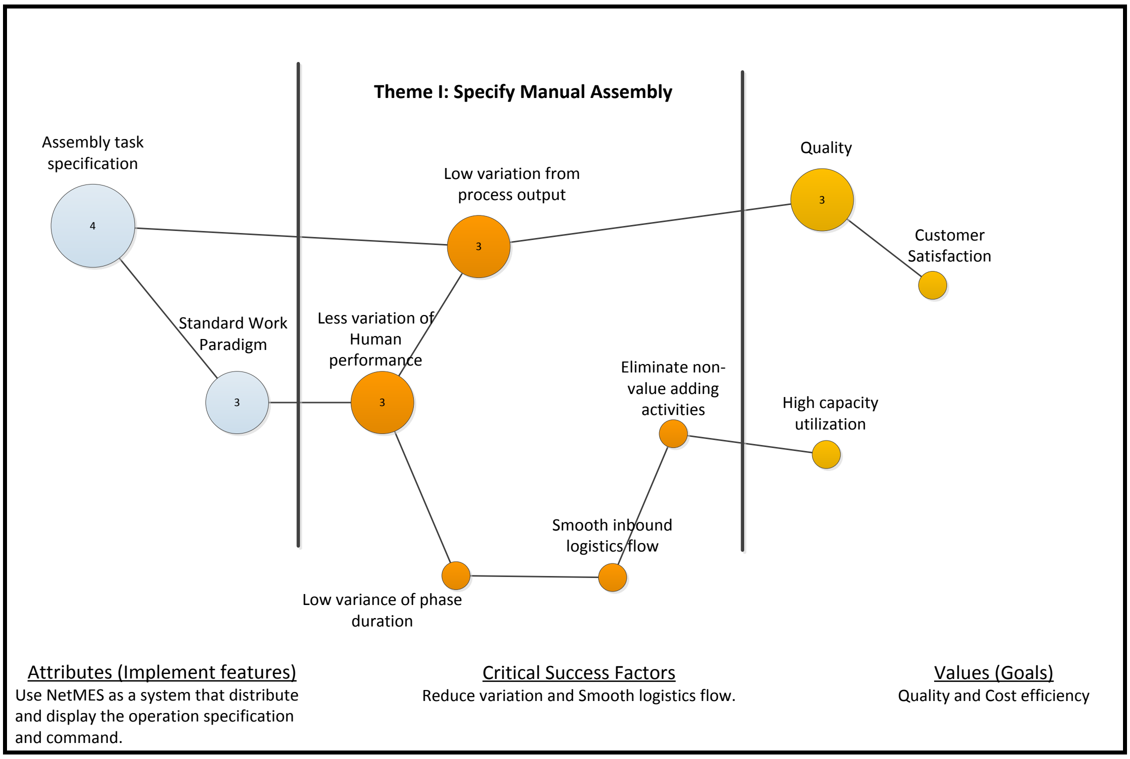

Figure 12: HVM I Instruct Manual Assembly

The production development team adopted two strategies to improve manual assembly performance. The first strategy was workplace design and planning following 5S (MLG Management Consultants, 2012) principle in lean manufacturing philosophy. Management had assigned a dedicated team to arrange assembly cells to a standard physical placement. In a designed assembly cell, parts and tools were sorted and placed to specific area. By doing so, designed workplaces optimized the parts handling and worker's movement in assembly cells. Workplace redesign and standardization also prepared the production systems and technology ramping-up to new production facility. The objective of the standardization of workplaces is that different workers can reach same level of performance in a standardized assembly cell or line.

Another strategy to reduce the variation of manual assembly was through specifying detailed work instruction and displaying them in a work environment. Work instructions decomposed a complex assembly job into manageable atomic tasks. Disciplined workers will follow a planned sequence of tasks as what work instructions defined. If all workers followed work according to a standard assembly procedure, their works would have little variation. Consequently, outputs and the execution time of a process would have small variance. Standard output means that the variation between works fall within a range. Little variance in processing time facilitates the realization of a smooth material flow. It eliminates queuing and waiting in production system.

5.5.2. HVM II: Archive assembly designs and their associated performance

The requirements drawn from the HVM II is that an assembly plan and corresponding performance of an assembly design should be well archived. First, it is important to distinguish a blueprint of assembly design against a work instruction. A work instruction contains a series of imperatives about performing a job to aid task switching (Stork & Schubö, 2010). The communication object of a work instruction is the worker. Content of work instruction should be concise notes and hints as cognitive aids for performing and switching tasks. In contrast, an assembly blueprint serves as a model of production definition and the corresponding performance evaluation. The blueprint delineates workplace design as well as layout, posture concerns, feasible assembly sequences, assembly method as well as special tools and possibly a time measurement system with Predetermined Time Standard.

Model Factory strategy values the continuous learning and improvement to the assembly design and plan for products. NetMES's supports to continuous learning are twofold. On the one hand, real-time performance data collected by NetMES validates the expected performance of an assembly design. Performance of the assembly system execution reflects the performance of an established assembly design to a product. Performance tracking and design archive provide a chronological benchmarking system to the assembly design improvement. On the other hand, effectively using MES demands the production-developing engineers formally delineate the assembly design into a codified format. The information system in fact codifies the assembly designing and planning knowledge in an easily retrievable format. Production developers can reuse the knowledge of assembly design and planning for developing assembly for new products. Because the PMG manufacturing is Engineering-to-order, reusing the knowledge about production development and planning reduces the development costs and accelerates the new product and production development projects.

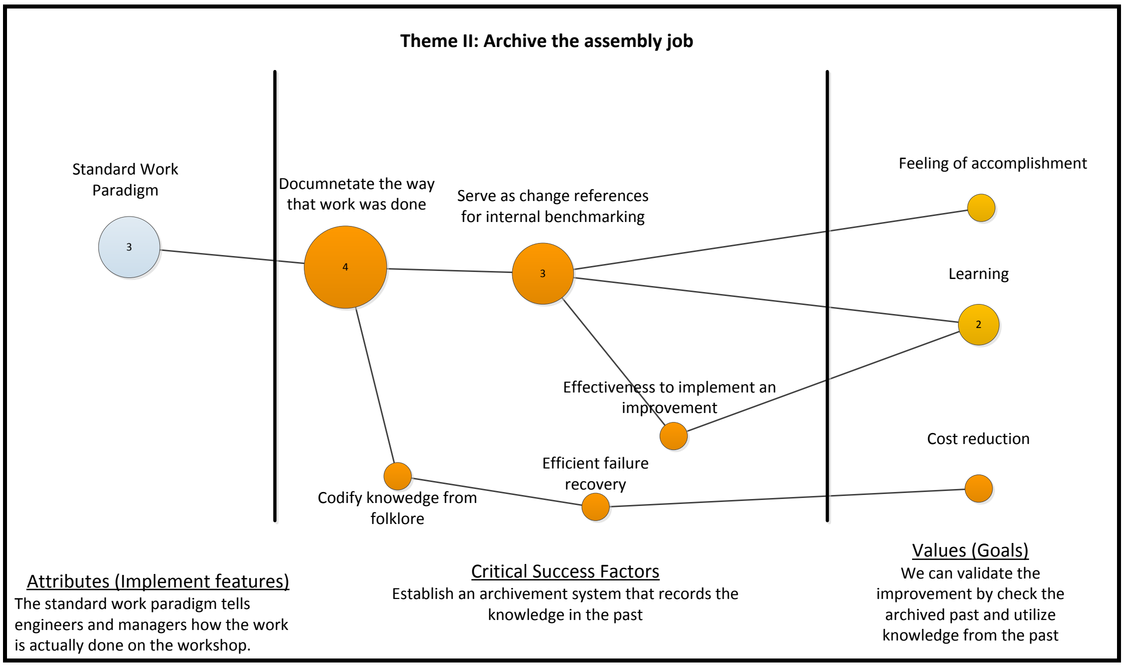

Figure 13: HVM II – Archive assembly design and performance

5.5.3. HVM V: Communication between production & engineering

Optimizing design of a product improve the easiness of performing assembly and manufacturing tasks. The notion is termed as design for manufacturing and assembly (DFMA) under concurrent engineering conceptual framework (Fine, 1998). According to this view, manufacturing is an internal customer to engineering and design department. Production department sends DFMA requests to engineering department. When a product becomes mature, its production volume increases to mass production, and manufacturing department's interest in improving product's design of manufacturability becomes more salient. A risk to incur enormous manufacturing costs could be repetitively executing an inefficient production process for thousands of times.

Production manager can use the performance tracking data from NetMES to justify the product DFMA improvement idea. After designers improved the DFMA, NetMES assists the implementation of design changes onto shop floor. Through work instructions and cognitive guidance systems, it notifies workers a new way of doing the assembly job based on improved design. Through production performance tracking, it also validates the efficacy of design changes on improving execution. The system bridges the communication between product designer, production developer and production operators.

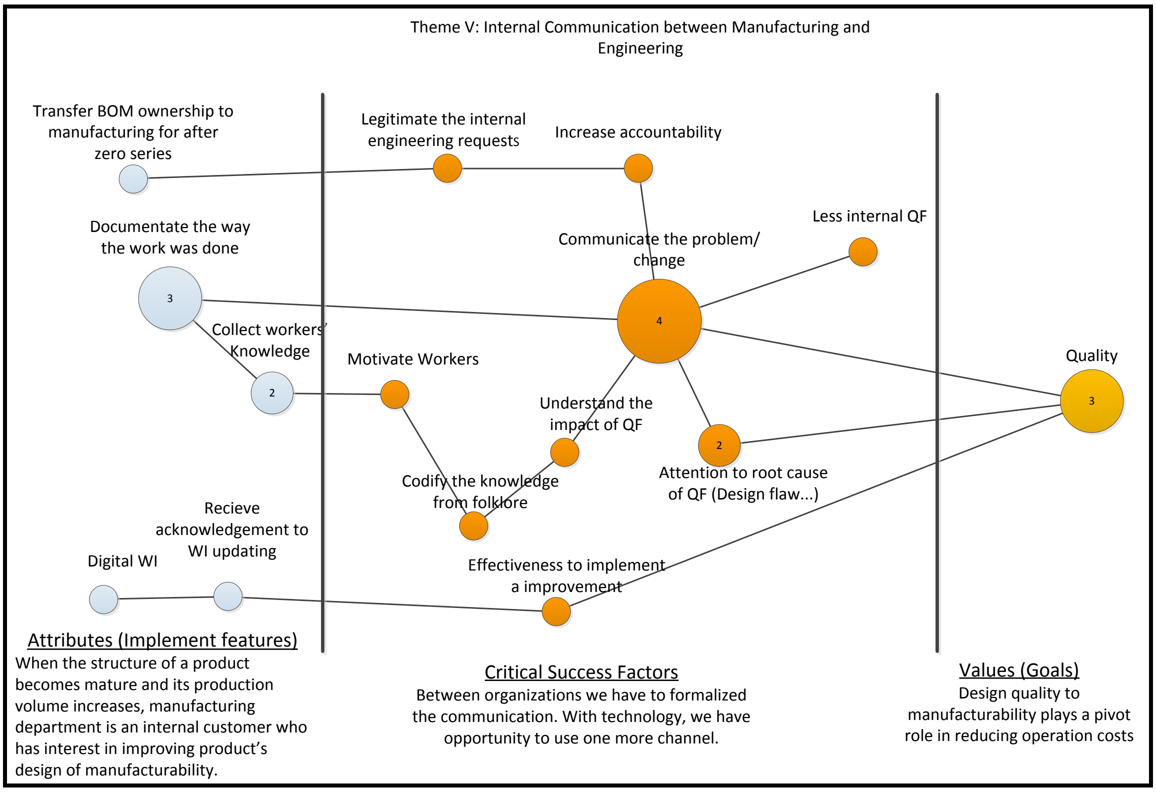

Figure 14: HVM V – Communication within organization

5.5.4. Envisioning the integration of MES to business

Critical success factors of implementing NetMES are

- Improving human performance in manual assembly,
- Archiving assembly design to support continuous learning, and
- Communicating DFMA requests.

However, merely installing a NetMES does not realize them. Reforming the business processes to accomplish these objectives demands integrating NetMES with business. Figure 15 illustrates this could be done. The core elements of this integration are formally store the definition information about assembly design and establish standard procedure for planning. Assembly design and plan is the backbone of the execution system. The quality of assembly design and plan direct affect the performance of assembly execution. Execution of a poorly designed assembly plan is error-prone and cost-inefficient. A good assembly design example is feeding assembly cells with sorted parts and components hold in material kits. The material kits ease the searching for right parts when an operator is reaching part for assembly. The kits save searching time and decrease the likelihood of picking wrong parts. MES collects data from the manufacturing execution environment to validate the quality of assembly plan. The data associates the execution performance with an instantaneous of the evolution of the assembly design. It provides chronological benchmarks of the maturity of the assembly technology to a product.

Instructional guidance and cognitive assistive system (Stork & Schubö, 2010) are able to aid front-line operators to execute designed assembly plans more efficiently. The system consists of an instructional handbook for assembler training, presentation of assembly diagrams to the workers, and cognitive assistive labels, sign, marks and devices that embed into the workplace, material kits and tool kits. System can reduce the complexity of performing assembly tasks and considers the worker's physical as well as mental workload. It brings benefits both to entire organization and to front-line workers. Organizational-wide, reducing the complexity of performing manual assembly tasks in fact lowers the criticality of person-bounded assembly skill level to the quality; therefore, it is viable approach to fundamentally rule out human factor's influence onto quality variation. The instructional guidance and cognitive assistive systems enhance individual workers' productivity and reduce the error rate of human operations. This enables the order fulfilling process to serve customers with cost efficient production and high quality products. Building an effective instructional guidance and cognitive assistive system requires the system designer understand the ergonomics and cognitive process of manual assembly tasks. Moreover, the effectiveness and economic benefits of the system has to be continuous validated and experimented with performance metrics captured by MES.

Assembly definition supports the product design by providing a transparent view to cost effect of the design features of a product. Linking assembly design with its performance information on manufacturability is valuable to communicate DFMA requests. Periodically reviewing and evaluating assembly design and planning with performance data create an institutionalized channel for the communication between product designer, production planner and front-line operators. Through this channel, requests for improving DFMA of product design become associated with their returns by improving manufacturing execution performance. The return on DFMA investment and improvement benchmarks legitimate resource allocation to DFMA activities and project inside the enterprise.

NetMES increases the visibility of the cost structure of a product to a Technical Account Manager (TAM) who is the product owner in The Switch. They keep their eyes on the cost and performance of a product. When offering a product to customers, they provide a comprehensive picture to the overall cost structure of a product. The overall cost includes not only the engineering and sourcing costs of a product's components but also the production cost incurred by operating an assembly system. High visibility to the overall cost allows sales offerings to become more competitive.

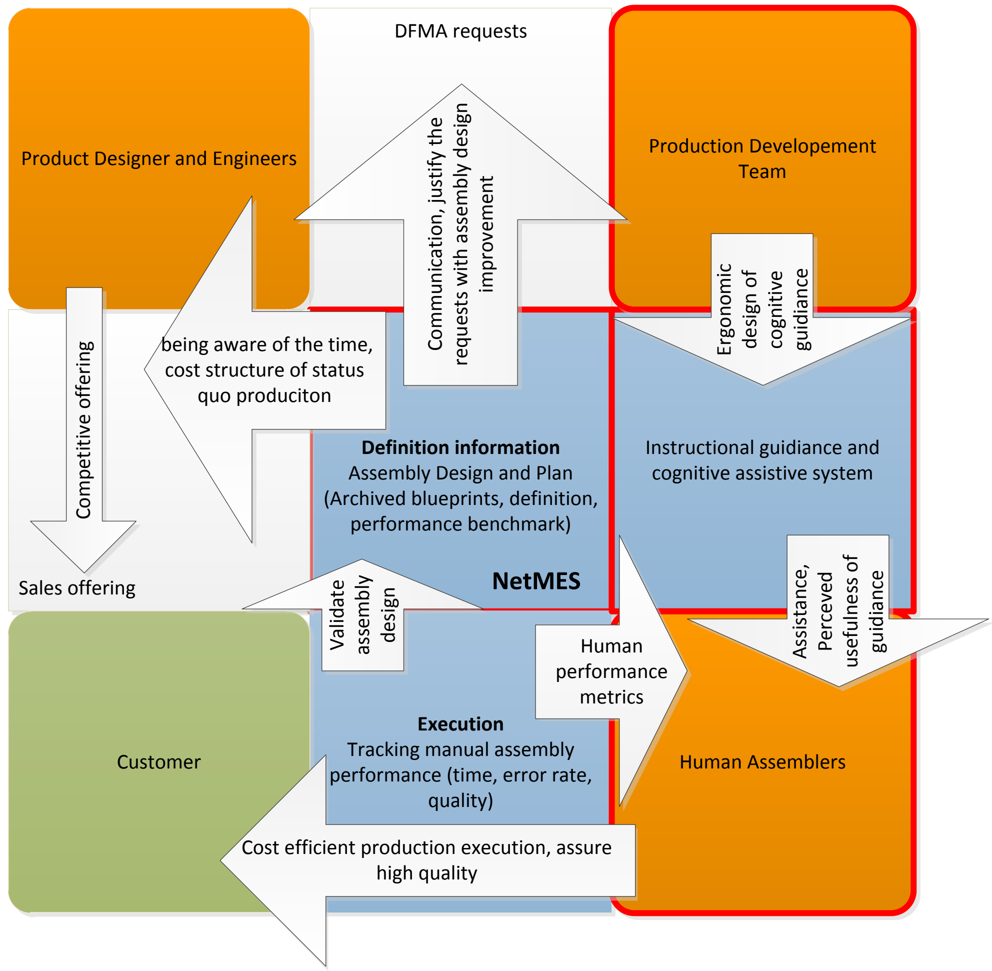

Figure 15: NetMES Integrated with business processes

5.5.5. Foresee the extent of change

Assembly design and planning determines assembly sequence and method. Apply Sarker's perspective comparison guideline (Sarker, 2000), the analyst foresee a risk that centralized assembly design and planning strategy could intensify the conflicts between workers and instruction composers (Table 3: Assessing inertness to planning standard manual assembly with MES (1/2)). The core conflict between production development team and front-line workers is that instruction composers as assembly planner are taking away the autonomy of scheduling detailed execution from veteran.

Current structure of semi-routinized manual assembly work assumes the autonomy of a worker or a work team. In a typical assembly cell, two workers form an autonomous team and carrying out assembly. They determine the internal assignment of tasks and schedule detail work sequence according to actual work environment and workload. Although workers informally carried out detail assembly planning by discussing and exchanging views to a product assembly diagram, it is more efficient than a top-down planning approach, which poorly takes feasibility assessment of actual execution circumstance into account (Zaeh, Wiesbeck, Stork , & Schubö, 2009). Here the top-down planning approach refers to the detail assembly execution planning and instruction compiling carried out by engineers or administrative clerks. Using NetMES, through compile and publishing a standard work instruction, the detail planning activity is centralized and taken away from workers who are actual doers of a task. Furthermore, the strategy is contradictory to a flexible assembly system of which the detail execution planning and control is delegate to autonomous teams.

Table 3: Assessing inertness to planning standard manual assembly with MES (1/2)

Objective reality (Current NetMES solution)	**Subjective Reality (Workers perceptions)** Assumption: A worker optimizes his own utility	**Subjective Reality (Engineers' perceptions)** Assumption: Engineers optimizes his own utility
Structure: • Engineer optimizes assembly work and publishes standard work instructions. • Workers follow the work instructions to perform standard work.	Structure: • The power of planning assembly work is taken away by engineers. • Workers are under stress because they feel they are supervised for every step of work according to guidelines. • WI devalues veteran workers in social group who used to help plan the detail assembly and give verbal/oral instruction to new workers.	Structure: • Engineers' design and specification create valuable solution. • Assemblers are doing the job to realize the solution. • Engineers know the best way to optimize detail works thus improve productivity and quality.
Task: • Instruction guide workers' operation. • Engineering plan the assembly for workers by specify the output and methods for every step of assembly work.	Task: • Manual assembly work is complex and unpredictable. They work as autonomous team to plan detail execution and sort out disruption from parts defects and operation errors. • Instruction composers assume the assembly execution in a purely deterministic way. They do not comprehend the actual assembly environment.	Task: • A worker mechanically follows job steps that what engineers instruct. • A production engineer improves the productivity and quality of the production system by removing any deviation from design/plan.

Table 4: Assessing inertness to planning standard manual assembly with MES (2/2)

Objective reality (Current NetMES solution)	**Subjective Reality (Workers perceptions)** Assumption: A worker optimizes his own utility	**Subjective Reality (Engineers' perceptions)** Assumption: Engineers optimizes his own utility
People: • Workers have proficient skills to execute specified work steps. • Engineers use analytic skill to optimized detail assembly plan for workers and specify the work steps in detail.	People: • Workers' skill and experience are crucial to quality and productivity of the complex assembly. • Engineers do not perform assembly by themselves and have to learn the detail from workers.	People: • Workers do not understand the technical detail of product. Their improper assembly method breaks product. • Engineers are experts of design and should specify the method to achieve the design.
Technology: • NetMES displays systematic instruction of planned assembly work.	Technology: • NetMES is a tool that enables production engineers to manipulate workers.	Technology: • NetMES is a tool to specify intermediate assembly output. • Personal computers are not suitable for displaying instruction in a tough work environment.

Table 3 and Table 4 list some conflicting views towards NetMES between worker and instruction composers. The underlying perceptional discrepancy between worker who execute the assembly operations and instruction composers is perceived predictability in work environment of manual assembly. Workers are doers. They perceive manual assembly less predictable than assembly designers do. The autonomous team has to adapt the detail execution plan in actual environment. For example, a task requires the cooperation of two workers in a team. The readiness to switch on to the task chiefly depends on whether both workers have been free from their preceding tasks. The worker free from his/her task first can either switch to some other feasible individual tasks or wait for his/her co-worker finishing the individual tasks. The adaptation is especially necessary when individual tasks are complex thus have high variances in their completion time. In contrast, instruction composers do not expose to detail variation during execution. They consider the execution more deterministic in its nature. The execution is more or less imitating a work paradigm prescribed in the work instruction in which specific steps and their sequences are “optimal”.

The management issue of implementing NetMES to support manual assembly is finding an appropriate instructional guidance strategy that match the current maturity level of planning processes for assembly system design. Figure 16 describes the architecture of a manual assembly planning and supportive system. It decouples the assembly design level planning and executional schedule into different production developer and autonomous execution unit. The architecture took the ideas from a hierarchical framework of planning processes for assembly system design and implementation which Sanderson et al (Sanderson, Homem de Mello, & Zhang, 1990) have proposed. The human performance guidance mainly focusing on attentional guidance during assembly task execution and schedule supporter that help worker better prepare for the assembly task switching (Stork & Schubö, 2010).

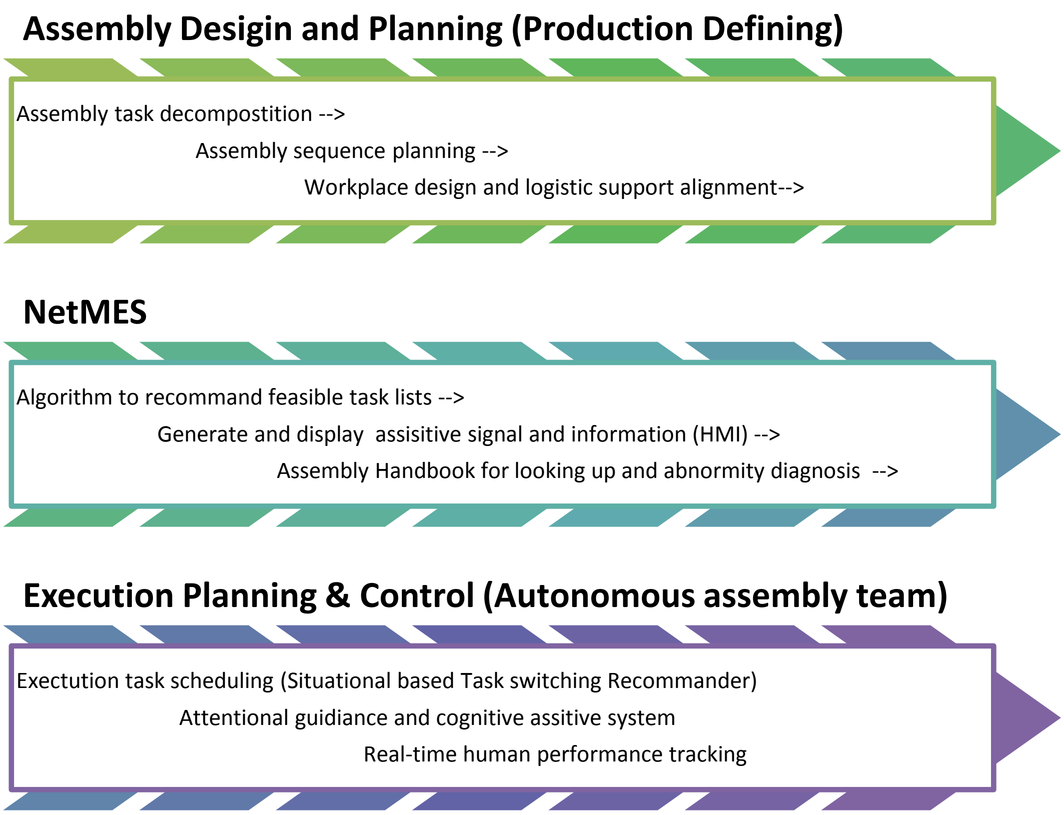

Figure 16: Architecture of implementing Assembly Planning processes

6. EVALUATION:

The evaluation to the adapted CSC method is basing on its efficacy and applicability of assessing changes for implementation. Efficacy problem concerns whether the change assessing method elicits the scope of change and estimates the extent of changes in the work system. The applicability concerns more about generalizing the method to a generic MES implementation context. The evaluation discusses the efficacy and applicability separately.

6.1. Efficacy

Though the CSC method has been applied on requirements elicitation for developing a technical solution of an information system (Peffers, Gengler, & Tuunanen, 2003), it has not been adapted to determine the requirements of establishing a work system that incorporates the both the technical and social elements. In this implementation study of MES, CSC method is adapted to elicit the scope of change to a new work system. The primary objective of CSC method is requirements elicitation for an improved work system that supports the execution of manufacturing.

Christel & Kang (Christel & Kang, 1992) categorized the common issues with requirements elicitation techniques into scope problem, understanding problem and volatility problem

- Scope problem means whether a requirements elicitation technique can gather and synthesis sufficient broad scope of information of boundary conditions to envision a subset of targeted system and at same time to avoid introducing detailed design concept.
- Understanding problem refers to finding a common language to interpret as well as aggregate information from diverse stakeholder communities and express the requirements back to communities with structured the representation.
- Volatility problem concerns accumulating knowledge about problem domain, when newly discovered requirements are included into original elicited requirements set and when there are dynamics of the situation in problem domain.

This research developed a design that fairly copes with these issues. The design solves the scope issue through aggregating and synthesizing clusters of critical success chains into a meaningful vision of change for implementation. Furthermore, the laddering interviews avoiding discussing and introducing any design details about MES functionality and their realization to stakeholder. The CSC concentrated on probing the value and higher-level objective of the work system. Deriving requirements from stakeholders' value allows more freedom for implementers to choose design options of new work system. The degree of freedom also provides some flexibility for requirement negotiation amongst conflicting stakeholders. Regarding the understanding issues, the CSC method avoids discussing the requirements with technical jargons. The presentation, information gathering and structure of expressing collective information are in a way that a common person with adequate business background can understand. The last concern about the volatility problem is resolved by a systematically exploration to personal constructs of first-tier management members of product development, production planning and operative management. The personal constructs are relative stable views to the world based on managers' value system. Through sorting and ranking stimuli, the laddering approaches towards the most salient issues in a situational context. Hence, Researcher argues that the CSC method properly copes with the dynamics of problem domain.

Besides discovering the scope of changes, the CSC method also provides adequate analysis to the conflicts between different stakeholders. Unsolved conflicts present inertness to changes and facilitate management to foresee the extent of forthcoming change. For envisioned scope of changes, the analysis presents a potential conflict based on the assumption that actors would maximized their own utility stead of the organization's utility.

Through assessing the extent of changes, the analysis is able to identify the parties that might lose out in determining, directing and accessing manufacturing execution related information. In addition, the analysis uses a role-play method to present the subjective perception to preliminary implementation policies. The analysis contributes to proposing a solution in which the intensity of the conflicts is alleviated.

To summarize above arguments, the efficacy of the method is adequate for assessing the scope and extent of change.

6.2. Applicability

This research evaluates the applicability of the method to generic MES implementation from three facets and concludes that the method has good applicability.

The applicability first depends on whether the method has a replicable procedure. On this matter, the design is a combination of CSC method and Sarker's guidelines assessing for change perspective. CSC method and Sarker's guidelines are well-structured method that generates predictable output. The CSC method generates HVMs that will be synthesis to determine the scope of changes for implementation. Through Sarker's guideline, involved stakeholder's perspectives are compared based on a given framework.

Second, the operationalization of the method does not employ any special software applications and experts of MES design and development. Therefore, the researcher argues that the method is robust to the availability of special tools and specialized analysts. The tools used to carry out the study are paper notebooks, common audio recorder, electronic spreadsheet, word processor and a general statistical software application. The method adopted a clustering technique to quantitative process the data. Many freeware on the internet offers embed algorithm to perform the clustering. The researcher chose R statistical software for statistically processing the quantified data, largely due to that the R is free. The analyst who carried out the study had some experience in statistically mining data. To synthesize the clustering result to meaningful theme, the analyst utilized his knowledge in manufacturing and operative management. In a general case, this dependence on analyst' knowledge and skills can be resolved by hiring relevant experts into the analyst group.

Third, the method is robust to the scaling-up issue and decomposability issue. The research invited six most relevant candidates for the in-depth interviews. They composite the management team that develops production system as well as controls the production operation. In a general case, one can scale up the method to collect more information about the issue that involves a broader community of stakeholder. On the matter about the decomposability, the operation of the method can be divided into sub-tasks and assign to multiple analysts. For example, the laddering interview is structured probing process following a routinized scheme. To speed-up and scale up the operation, the method can employee multiple analysts to conduct interviews and merge the information in the latter analyzing phase.

7. CONCLUSION:

The research designed and operationalized a method to envision the MES implementation about the scope and extent of changes. This chapter first summarizes the findings from the research and then concludes the validity and reliability of this design science research (Peffers, et al., 2007). In the end, the chapter discusses some interesting directions for future study.

7.1. Findings of the thesis

The findings of the thesis work come into two aspects, academic and practical. The academic ones are

- Describing and structuring changes assessment of MES implementation as requirements elicitation problem, and
- Adapted CSC method for eliciting requirements of MES implementation.

On theoretical contribution, the study has framed a requirements elicitation problem of pre-assessing changes in implementing MES. The research has found that mangers can start planning MES implementation with eliciting the requirements, when there is high ambiguous about value of MES and the way MES aligning with operative management as well as the way MES fitting together within the enterprise information architecture. The study reviewed prior researched on implementation, and proposes that the ambiguity and complexity of the implementation can be reduced by eliciting and by analyzing the requirements of a reformed work system in which MES would have been implemented. In other words, the management can solve the problem of assessing changes to implement MES through requirements elicitation.

The research developed and demonstrated a method to elicit the requirements of implementing MES, after the problem has been framed as requirements elicitation problem. The research adapted the CSC and Sarker's guideline to develop a requirements elicitation method. Next, the research operationalized the method in the case company. Through a demonstration case, the research has validated that the CSC method has fair good applicability in eliciting requirements on the early stage of the MES implementation. In such a highly ambiguous situation before planning the implementation process, the analyst was able to rely on a structured method with a clear procedure to gather information from a broad base of participants. The elicitation technique is able to encourage participants share their perspective to the potential contribution from the MES. Several HVMs illustrate a vision about how MES can fit into the mean-end perceptions of key stakeholder. Though taking an insightful look at the HVMs requires the analyst having a certain level of operative management knowledge and some understanding to business, in general, the themes reflected by the HVMs are straightforward. Including an expert from the management community of manufacturing to the analyst team may be an effective way to acquire the necessary knowledge.

Practical finding from the study carried out in the case company is that

- MES implementation had better incorporated with an ongoing continuous improvement project of manufacturing system.
- A company should match the capability of MES with the partners of different product in the product portfolio.

MES implementation usually is and should be piggybacked on an improvement project to manufacturing operation. The case demonstration in the study has shown that the very attractive feature of the NetMES is piggybacked on project that formalizing assembly planning process. Planning the assembly and improving the design for assembly of new developed products is two focal issues for the production development team in case company. Since the case company has committed to improve assembly planning which has a direct and fundamental contribution to the quality of PMG and quality of manufacturing process, an immediate expectation is that NetMES displays planned assembly scheme to operators and feeds back the actual execution of the scheme. The work instruction and Andon alarm of the developed NetMES application manifested the expectation from the company. Piggybacking MES with a manufacturing improvement initiative allows the implementation being associated a clear business improvement goal, thus give MES implementation a traceable target to win commitment from the organization.

At the last, for a firm in the sector of industrial equipment, a finding is that the strategic contribution of MES may be different for products in different stages of their lifecycles. For a volume-produced product, its manufacturing plan is developed. Work instruction and guidance system has more importance to volume-produced product, because it provides an effective way to communicate a standardized operation plan to front-line operators. For a product prototype, work instruction and guidance system has limited contribution, since manufacturing plan that standardized the operation is still under development. What MES should offer is an archive system that promotes the knowledge spanning between front-line doers and product engineering. On this matter, the manufacturing performance tracking and continuous improvement supporting features in MES are vital.

7.2. Validity, reliability and limitation

Regarding the validity of study, the research has identified the MES implementation problems as reducing the ambiguity and complexity issues about assimilating a new technology by integrating it with a novel work system. The problem does not merely bother a particular case company, but troubles many enterprise during the early stage of implementing MES. Solving the problem with the CSC method has been demonstrated with a single case study. The case has validated the efficacy and applicability of the method and has generated demonstrational analysis. Though the case lacks of longitude observations about how the valuable information provided by the CSC affects the goodness of upcoming implementation, the case is capable of showing how elicited requirements helps to determine the direction of change and narrows down the management focus into a sub-set of work system improving issue. The analysis on the extent of change also support proposing improvement proposal that eases tension between diverged stakeholders' perspectives.

On the matter of reliability, the efficacy and applicability of the design is evaluated through a single case in which the researcher carried out the execution of the method from beginning to the end. Raw data and information generated from intermediate steps of analyzing procedure are included in the paper. Moreover, the algorithm to statistically abstract and process the data was described in detail. Besides writing down the data collecting procedure, the research also recorded the interview process that conducted date gathering for verification. Future researchers are able to verify the reliability of study by replicating the data analysis process.

The study has limited the scope to pre-implementation assessment of changes, of which the goals are determine the scope and the extent of changes. Identifying requirements and the magnitude of risk in corresponding changes does not guarantee a successful MES implementation. It reduces the ambiguity and complexity of implementation, hence diminished the likelihood of failure. The research is able to demonstrate applicability of the ambiguity with CSC method but it has excluded the investigation to causal relationship between applying CSC method and implementation success. Furthermore, due to the time and resource constraints of the thesis work, the study has neither compared the CSC with other elicitation method nor counted the critical requirements that are missing from the first round of elicitation. Consequently, the efficient of the design is not proper evaluated against alternative methods.

7.3. Future studies

The future study can investigate the answers to following questions. First, what is a holistic way to identify the relevant stakeholders for information gathering in CSC? The targeting and selection of key stakeholder was through discussion of an order fulfillment flow chart on ad hoc basis. A holistic approach of candidate selection for the interview facilitates an external analyst, who comes outside from production management community, to find key candidates. Second, what is the efficient framework to visualize the inertness of changing organization desired scope. The framework adopted in this design was Leavitt’s diamond (Leavitt, 1965), because of its simplicity. Besides building a more efficient framework, future research can develop a more comprehensive design to assess current organization’s readiness to change. The last, how does the change assessing activity itself affect implementation project? Future empirical and ethnological studies can verify the longitude effects from change assessment on MES implementation success.

Assessing changes of implementing MES before carrying out the project has a vital importance to success of implementation program. A quotation from The Art of War will put a full stop to this paper. “Those who have considered more details during planning and assessment in the temple will win while those who have considered fewer details will lose. The more details considered, the higher the chances of winning and vice versa. How much more certain is defeat, if no planning is done at all? (Sun, 515 BC.)”

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APPENDICES

APPENDIX A - A COARSE-GRAIN FLOW CHART

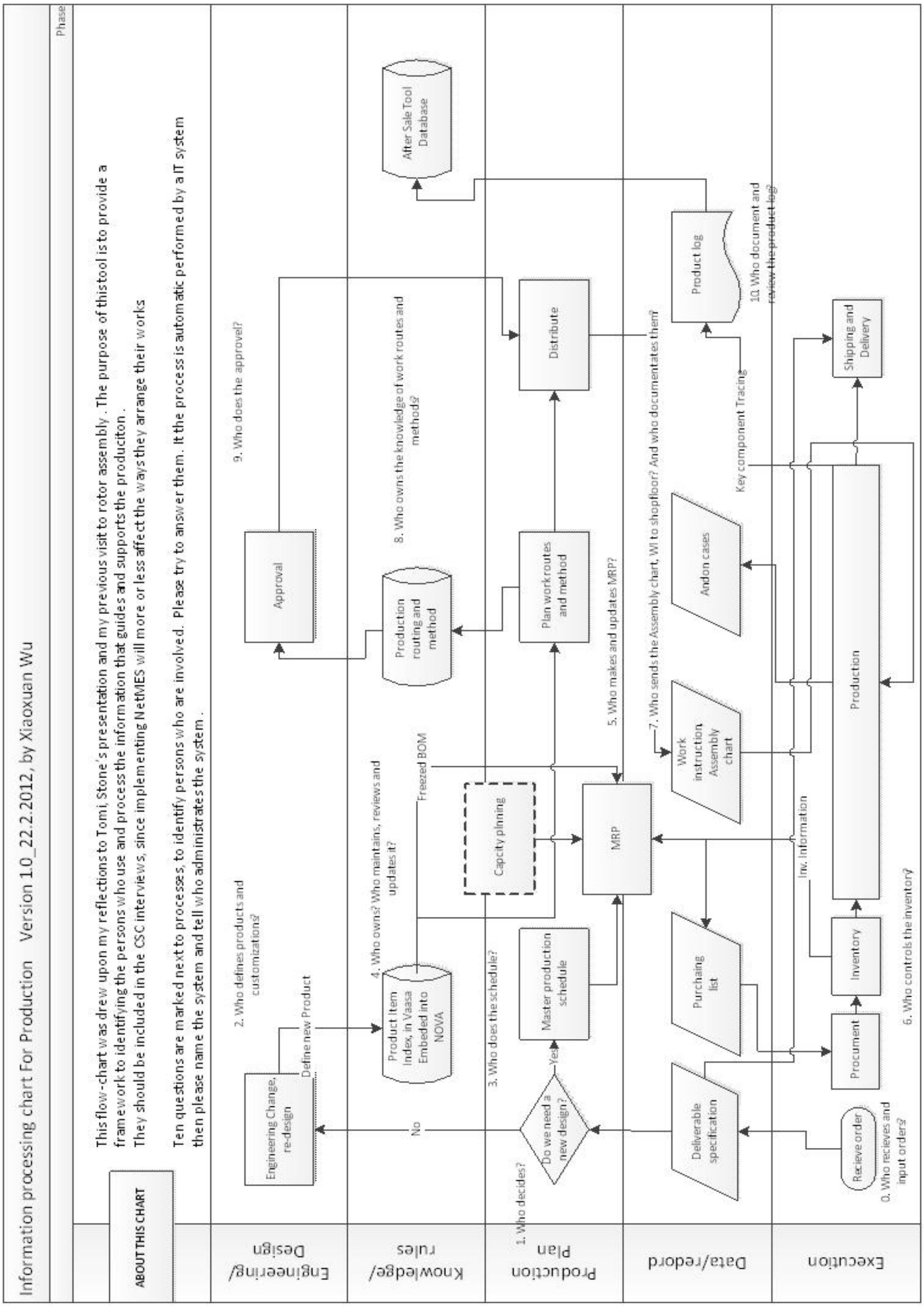

Figure 17: A coarse-grain flow chart of order fulfillment

APPENDIX B – CRITICAL SUCCESS CHAINS (CODIFICATION)

A1	Operational task specification
A2	Standard work paradigm
A3	Designed workplace
A4	Synchronized BOM
A5	Shared plan
A6	Build tangible Gateway between Phase
A7	Smooth logistics flow
A8	Monitor state of production progress
A9	Signify internal failure
A10	Measured downtime
A11	Participator understanding
A12	Assign Ownership
A13	Document the way that work was done
A14	Precisely measure phase duration
A15	WI version control
A16	Collect worker's knowledge
A17	Digital WI
A18	Tracking acknowledgement to WI updating
A19	System Interfacing with ERP
A20	Validate data through their consistency
A21	Transfer BOM ownership to manufacturing for after zero series
A22	Legitimate internal engineering requests
C1	Little variation between human performance
C2	Low variation of process output
C3	Low variation of Process cycle time
C4	Eliminate non-value adding activity
C5	High Capacity Utilization
C6	Coordination
C7	Less delayed project
C8	Less inventory
C9	Understand the impact of QF
C10	Communicate the problem/change
C11	Less internal quality failure
C12	Sustained MES implementation
C13	Reference of Change for internal benchmark
C14	Codify the knowledge from folklore
C15	Efficient Failure recovery
C16	Motivate worker
C17	Attention to the root cause of QF
C18	Effectiveness to implement an improvement
C19	Tight Control on plan execution
C20	Better Planning
C21	Reliable information

C22 Accountability
V1 Quality
V2 Customer Satisfaction
V3 Productivity
V4 Feeling of Accomplishment
V5 Feeling Control and certainty
V6 Cost reduction
V7 Learning

Chain 1	A1	A2	C1	C2	V1	V2	0	0	0
Chain 2	A3	C4	C5	V3	0	0	0	0	0
Chain 3	A4	A5	C6	C7	V5	V4	0	0	0
Chain 4	A6	A7	C8	V6	V3	0	0	0	0
Chain 5	A9	A10	C9	C10	C11	C4	C5	V6	V3
Chain 6	A11	A12	C12	V4	0	0	0	0	0
Chain 7	A4	A5	C11	V1	0	0	0	0	0
Chain 8	A4	A5	C11	V5	V4	0	0	0	0
Chain 9	A2	A13	C13	V4	0	0	0	0	0
Chain 10	A2	A13	C13	V7	0	0	0	0	0
Chain 11	A4	A5	C6	C11	C4	C7	0	0	0
Chain12	A5	C6	C11	0	0	0	0	0	0
Chain 13	A13	C14	C15	V6	0	0	0	0	0
Chain 14	A15	C1	C11	C4	V6	0	0	0	0
Chain 15	A3	C4	C5	V3	0	0	0	0	0
Chain 16	A1	A2	C1	C2	V1	0	0	0	0
Chain 17	A1	A2	C1	C3	A7	C4	C5	0	0
Chai18	A13	A16	C14	C9	C10	0	0	0	0
Chain 19	A13	A16	C16	C10	C17	C11	0	0	0
Chain 20	A17	A18	C18	V1	0	0	0	0	0
Chain21	A14	A8	C19	C7	V2	0	0	0	0
Chain 22	A2	A13	C13	C18	V7	0	0	0	0
Chain 23	A13	A14	C20	C5	V3	0	0	0	0
Chain 24	A1	C2	V1	0	0	0	0	0	0
Chain 25	A13	C10	V1	0	0	0	0	0	0
Chain 26	A14	C20	V6	0	0	0	0	0	0
Chain 27	A19	A20	C21	A8	0	0	0	0	0
Chain 28	A19	C14	V7	0	0	0	0	0	0
Chain 29	A8	C10	C6	0	0	0	0	0	0
Chain 30	A21	A22	C22	C10	C17	V1	0	0	0
Chain 31	A4	C6	C11	V1	0	0	0	0	0
Chain 32	A4	C6	V5	V4	0	0	0	0	0

APPENDIX C – DATA MATRIX [A B C]

A

Name	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22
Chain1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain3	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain4	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain5	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Chain6	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Chain7	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain8	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain9	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain10	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain11	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain12	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Chain15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain16	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain17	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain18	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Chain19	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Chain20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Chain21	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chain22	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Chain24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain25	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain26	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain27	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Chain28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Chain29	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Chain31	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain32	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

B

Name	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22
Chain1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain3	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain5	0	0	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Chain6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Chain7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain8	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain10	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Chain11	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain12	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Chain14	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain15	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain16	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain17	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain18	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
Chain19	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0
Chain20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Chain21	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Chain22	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Chain23	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Chain24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chain25	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Chain26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Chain27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Chain28	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chain29	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Chain30	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1
Chain31	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chain32	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

C

Name	V1	V2	V3	V4	V5	V6	V7
Chain1	1	1	0	0	0	0	0
Chain2	0	0	1	0	0	0	0
Chain3	0	0	0	1	1	0	0
Chain4	0	0	1	0	0	1	0
Chain5	0	0	1	0	0	1	0
Chain6	0	0	0	1	0	0	0
Chain7	1	0	0	0	0	0	0
Chain8	0	0	0	1	1	0	0
Chain9	0	0	0	1	0	0	0
Chain10	0	0	0	0	0	0	1
Chain11	0	0	0	0	0	0	1
Chain12	0	0	0	0	0	0	0
Chain13	0	0	0	0	0	1	0
Chain14	0	0	0	0	0	1	0
Chain15	0	0	1	0	0	0	0
Chain16	1	0	0	0	0	0	0
Chain17	0	0	0	0	0	0	0
Chain18	0	0	0	0	0	0	0
Chain19	0	0	0	0	0	0	0
Chain20	1	0	0	0	0	0	0
Chain21	0	1	0	0	0	0	0
Chain22	0	0	0	0	0	0	1
Chain23	0	0	1	0	0	0	0
Chain24	1	0	0	0	0	0	0
Chain25	1	0	0	0	0	0	0
Chain26	0	0	0	0	0	1	0
Chain27	0	0	0	0	0	0	0
Chain28	0	0	0	0	0	0	1
Chain29	0	0	0	0	0	0	0
Chain30	1	0	0	0	0	0	0
Chain31	1	0	0	0	0	0	0
Chain32	0	0	0	1	1	0	0

APPENDIX D – CLUSTER DENDROGRAM

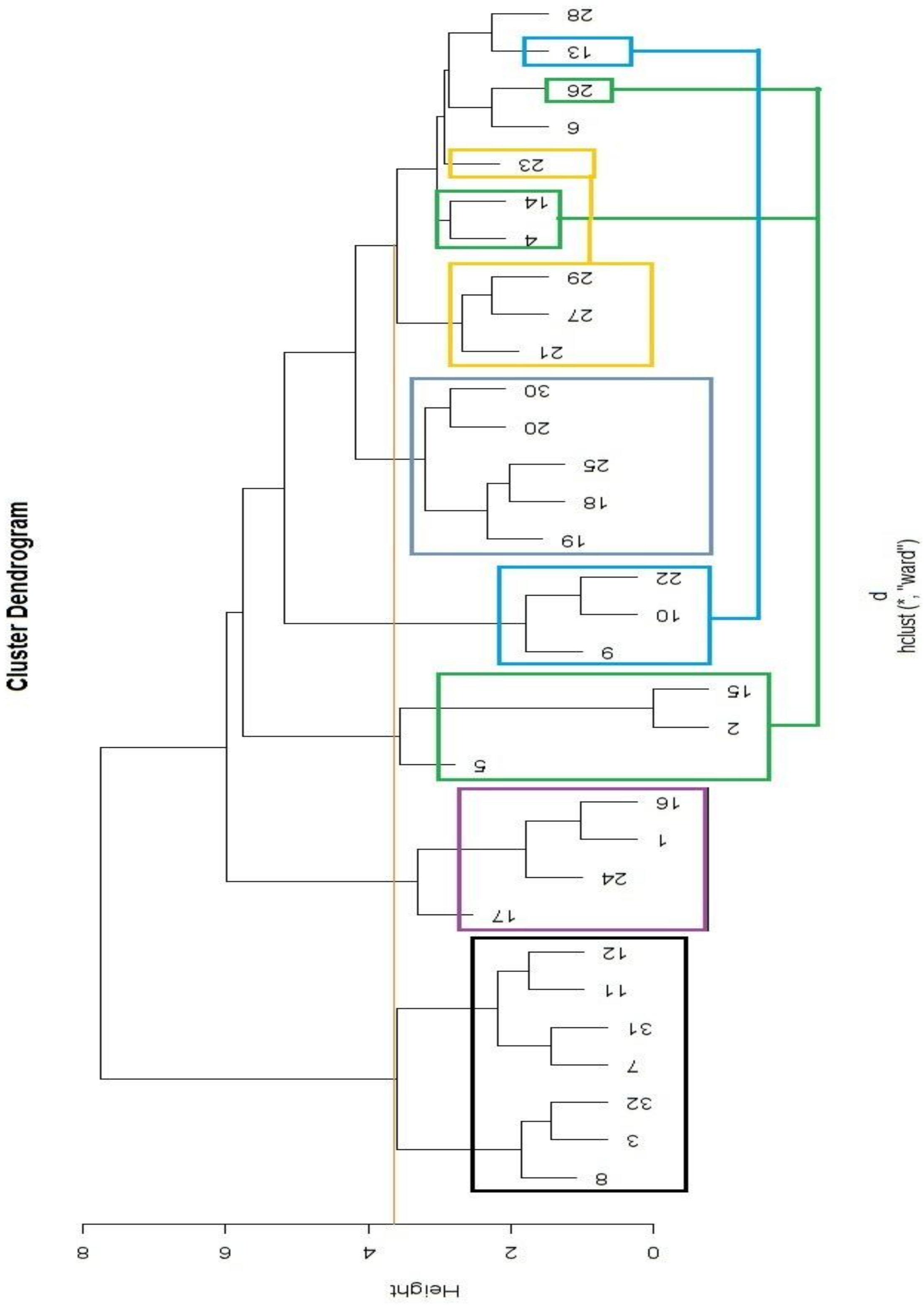

Figure 18: Cluster Dendrogram

APPENDIX E – CLUSTERING COMMON IN R ENVIROMENT

> CSC <- read.csv (file="csc.csv", header=TRUE, sep=";")	// csc.csv is the name of file where data matrix is stored.
	// “header = TRUE’’ means the data matrix contains a header.
	// sep=”;” means value are separated with seminomas in data file.

> d <- dist(as.matrix(CSC))	// Compute dissimilarity matrix d, and by default //dissimilarity is measured with squared Euclidean distance.
> hc <- hclust(d, method="ward")	// using ward’s method perform clustering on the basis of matrix d.
> plot(hc)	// Draw a dendrogram of clustering result.

APPENDIX F – STIMULI FOR LADDERING INTERVIEW

There are three tasks during the interview.

1. Rank following ideas according to their importance to NetMES implementation:

Rank	Ideas	Description
	Operation standardization	Standardize work and workplace arrangement. Workers have to comply and follow specified work sequences and method.
	Promotional training	Promote the benefits and features of NetMES through educational training. Help users to make sense of using a new system in terms of helping their job.
	Flow-based layout	Adopt a flow-based layout (Lines) for production phases.
	Synchronized BOM	Engineering, purchasing and inventory controller use a synchronized BOM.
	Version control to Work Instructions (WI)	Assign right version WI to guide right operation, and enable updating and obsoleting of WI.
	Smooth interfacing with other systems	NetMES is integrated with the systems that report production performance, send purchasing and engineering requests. It has digital data exchange from ERP and After sales tools.
	Timing the production progress	Using time stamps on key components to mark and measure the completeness of production tasks.
	Transfer the ownership of BOM	Establish a formal transferal of the ownership to BOM from engineering to production. Thus the product development focus shift from functionality of the product to manufacturability of the product.

2. Try to answer, “why would this be important…?”
3. Try to answer, “what is it about this idea that makes you think it would do that…?”

Additional note:

- Interviewer will use audio recorder to assist data collection.
- Questions in task 2 and 3 may be repetitively asked during the interview.

There is no right or wrong answer, the purpose of the interview is to gather the viewpoints from different people.

APPENDIX G – HVM (1/3)

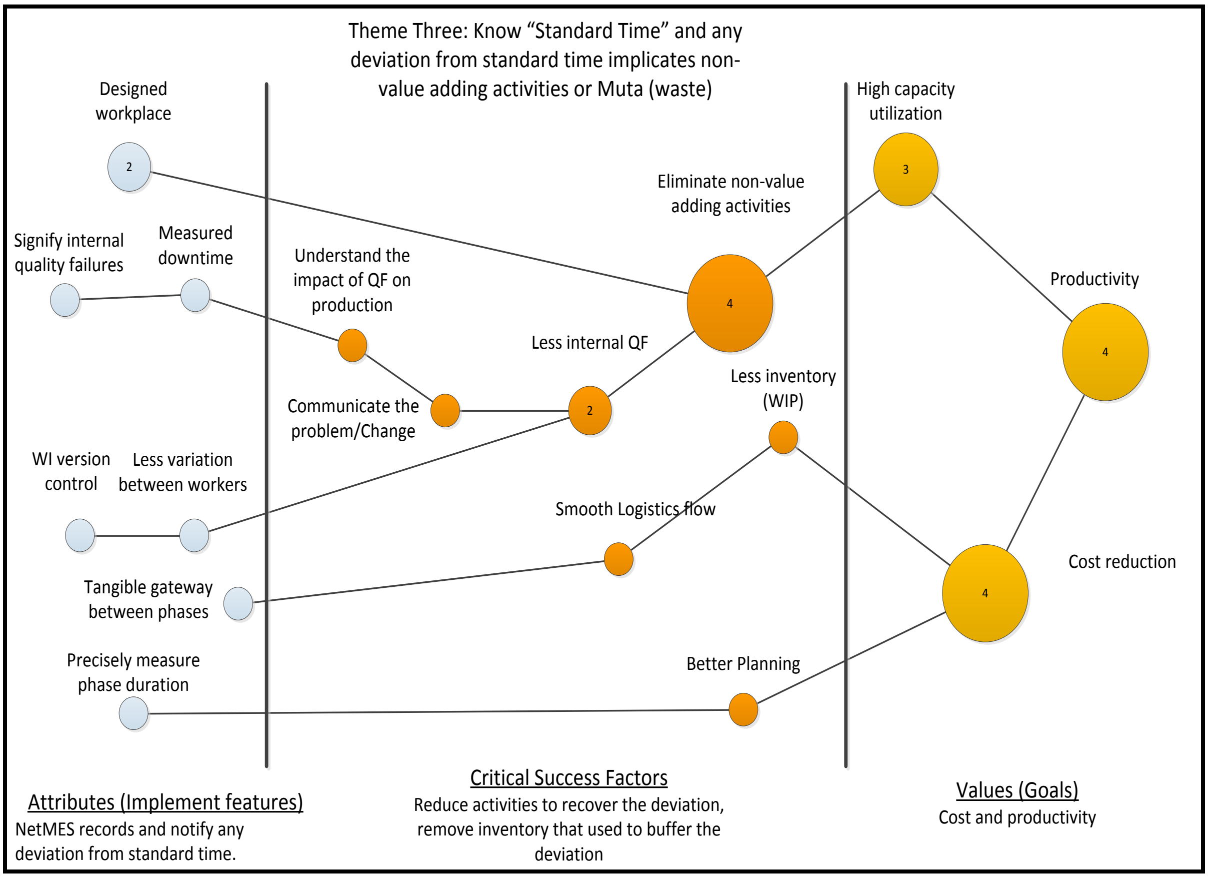

Figure 19: Study Standard Time

NetMES offers promising features to track activities and time-stamp evens. To effective use these features managers have to study and set the standard time for operations. The standard time is the expectation and target that the production system should meet if all the process operate normally. Inventory stock out, internal quality failure (QF) such as rework, scrap, backlogs will deviate actual performing time from standard time. Waiting and redundant inventory for recovery the deviation hamper the manufacturing to become lean. NetMES could be used as a tool to study the standard time by tracking historical activities and collect relevant statistics about the standard time for each assembly job.

APPENDIX G – HVM (2/3)

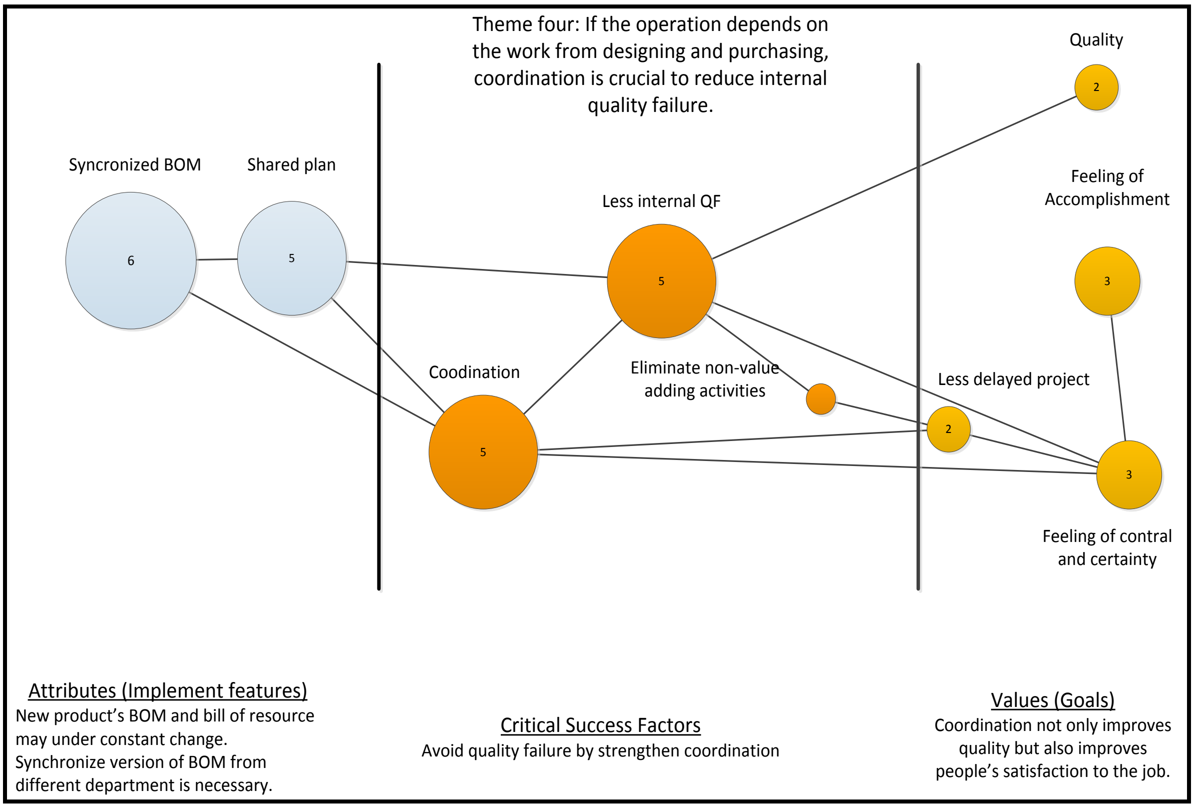

Figure 20: Coordination matters

The database in MES might provide a coordination mechanism to synchronize BOM distributed to different departments. Coordination is crucial to information quality. It assures product definition in MES being up to date. Having correct product structure definition in NetMES depends on the coordination between product design team and production department. Moreover, in-detail assembly route design and assembly job specification are deducted from a given product structure. There is no sense of specifying the assembly task of a component if the component has been replaced. Coordination also has psychological effect on individuals. When an individual's job performance relies on the collective performance of a coordinated team, he or she feels more control and certainty. Frequent delayed project due to incoordination work, individual would be more or less frustrated.

APPENDIX G – HVM (3/3)

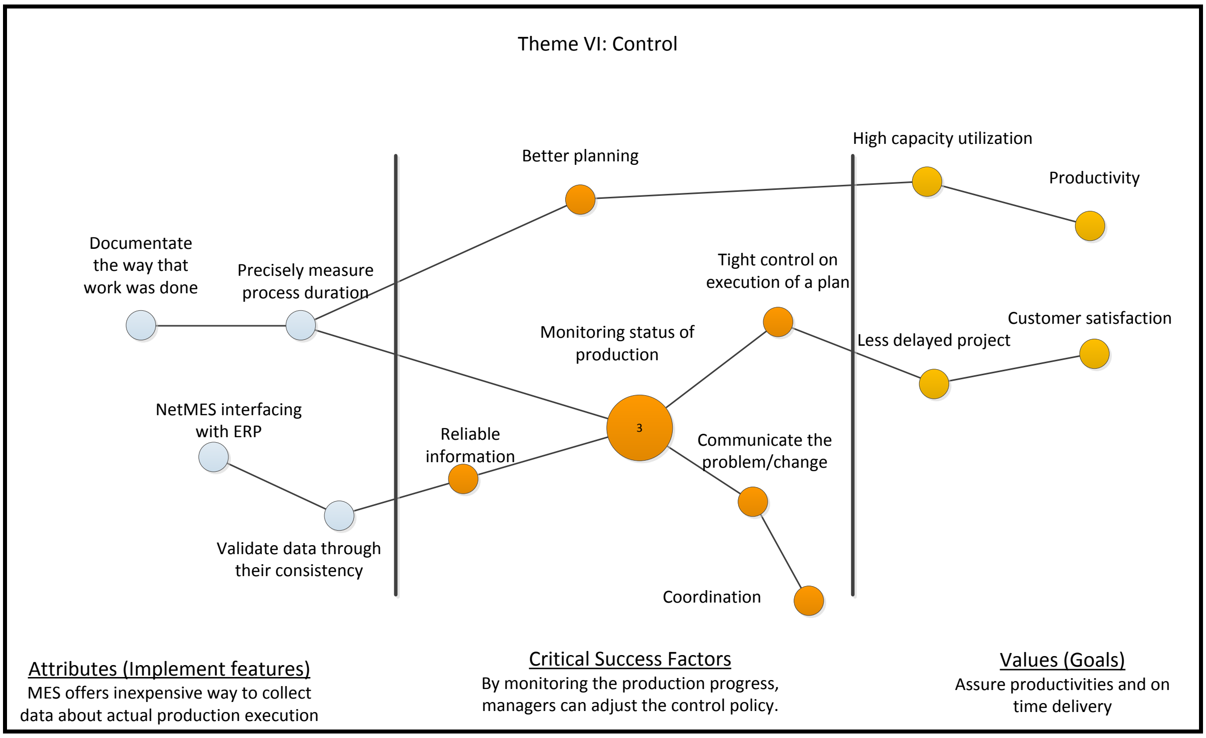

Figure 21: Clarify control strategy to production

MES offers an inexpensive way to track the production progress. In manufacturing environment, managers would like have production goes as scheduled planned. To control, they check the production process regularly and intervene to correct small deviations. Monitoring frequency characterize a control policy. Tight control policy is adopted when a process is not stationary or is critical to plan execution. MES should support different types of control policy in tracking production status. For example, NetMES offers tracing function to key components. Work inspects and reports status of a key component during assembly. The tightest control policy might check every component of a product and time-stamp the progress of production. Through those time points, managers follow production closely. If the progress deviates from standard time, manger could schedule extra shifts as intervention.