A MANUFACTURING INFORMATION SYSTEMS ARCHITECTURE FOR THE 21ST CENTURY

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Abstract: The 21st century marketplace poses many challenges for modern manufacturing organizations thus requiring them to display increased levels of agility supported by an effective information systems infrastructure. The objective of this paper is to propose an Information Systems Architecture that meets the challenges of modern manufacturing organizations. For the manufacturing information systems architecture (MISA) to successfully meet these challenges it must satisfy five objectives: 1. Support the Value Chain Activities; 2. Support the interactions among the five Interacting Organizational Variables (i.e. Task, Communication, Technology, People, Structure); 3. Effectively deal with Industry Factors and Forces; 4. Integrate the organization internally and with its environment; and 5. Address other Enterprise Engineering issues. We present a MISA that satisfies these five objectives.

1 INTRODUCTION

Modern manufacturing organizations must contend with social, political, economic and technical changes (Scott-Morton, 1991) that include globalization (Rockart and Short, 1991), accelerated product life cycles, demanding customers, and rapidly changing technology. These changes require modern manufacturing companies to display increased levels of agility supported by an effective information systems infrastructure (i.e. architecture) that enables them to exchange information in an inexpensive, efficient, and maintainable manner (Nagel and Dove, 1993; Madnick, 1991). Developing a MISA is difficult and challenging because it must be balanced with the organization structure, culture, processes, business strategy, technology strategy, and the human resources (Madnick, 1991). Currently there are few methodologies for the systematic planning and development of MISA (Grant, 1999). This has fostered ad-hoc development practices that are associated with a number of manufacturing problems (Grant, 1999)

In developing this paper, we researched the literature to identify organizational characteristics deemed necessary for the success of modern manufacturing companies. The first characteristic is that companies must effectively coordinate the value-added activities of the business (Porter, 1985; Snow et. al., 1992). Second, companies are viewed as highly interactive social systems where technology, tasks, people, communication, and structure are intertwined (Leavitt, 1965; Grant and Mergen, 1996; Scott-Morton, 1991). Changing one part of the social system inevitably affects changes to other parts and the lack of anticipation of such changes has crippled companies in the past. Third, companies operate in a business environment with external forces (Porter, 1985). Fourth, companies should be seamlessly integrated both internally and externally (Grant 2002; Scheer, 2000; Truman 2000). Fifth, effective control-mechanisms for product/process design and manufacturing are extremely important for the long-term success of companies (Grant, 2002; Hammer and Champy, 1993; Davenport, 1995). These and other control-mechanisms are addressed in the enterprise-engineering framework of Sarkis et al. (1997, 1995).

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If these control-mechanisms are poorly implemented, quality control, process control, and change management initiatives are compromised. The objective of this paper is to propose a MISA that meets the challenges of modern manufacturing companies by addressing the five organizational characteristics.

2 THE ORGANIZATIONAL CONTEXT OF MANUFACTURING

This section describes five theoretical models that were chosen from the management information systems (MIS) and engineering literature to support the five characteristics and objectives listed earlier.

2.1 Value Chain

Every company has a set of value added activities that are necessary for the production of goods and services. The Value Chain Model (Cash et al., 1992) defines this critical set of value-added activities as Inbound Logistics, Operations, Outbound Logistics, Sales and Marketing, and Customer Service.

2.2 Five Interacting Internal Organizational variables

The second characteristic is that companies are a collection of highly interactive mechanisms of Task, Technology, People, Communication, and Structure (Leavitt, 1965; Grant et al., 1996). This set of organizational variables play an important role in factory automation (Leavitt, 1965) and in information systems (IS) (Grant, 1999).

2.3 Five Industry Forces

The third characteristic deals with external forces from the business environment in which the company operates. Porter's Industry and Competitive Analysis model, well known in academia and practice, identifies these forces as: power of buyers, new competitors, new product substitutes, power of suppliers, and industry rivalry.

2.4 Integration Issues

The importance of integration and its impact on company performance is well known (Somers and Nelson, 2003; Madnick, 1991). Grant (Grant, 1995; Grant et al.; 2002) identified six types of integration, three of which are relevant to this discussion. **Islands of Technology** integration ties together various islands of manufacturing in order to support the exchange of information. **Socio-organizational** integration is concerned with how well the MISA supports company goals, objectives, and mission including internal vertical, internal horizontal, strategic, and internal temporal integration. **Global** integration is concerned with how well companies effectively operate in the global economy, and includes how well horizontal and temporal information are exchanged at the international level.

2.5 Enterprise Engineering Framework

Modern manufacturing organizations often have to re-engineer both products and processes in order to successfully meet the challenges of the marketplace. It is fairly well known that the re-engineering of a given process often affects other processes and so business process reengineering (BPR) should have an enterprise engineering focus. Therefore, to address the fifth characteristic, which deals with engineering mechanisms for process and product control, we draw on Sarkis et al. (1995). His enterprise-engineering model consists of four activities (i.e. Develop Vision and Strategy, Change Culture, Integrate & Improve Enterprise, Develop Technology Solutions) that must be addressed in BPR.

3 THE MANUFACTURING INFORMATION SYSTEMS ARCHITECTURE (MISA)

The proposed MISA (**figure 1**) is made up of eleven conceptual models, many of which are well known and have been used in the past with success.

1) Internet Model (IO): This model provides a blueprint of how the company should be connected and integrated with its external environment via B2B and B2C. Relevant issues include supply chain management, customer relationship management, employee mobile computing, and business alliances.

2) Intranet Model (IN): This model facilitates the dissemination of information between individuals, groups, functions, and departments. It focuses discussion on the primary information arteries that exist between islands of technology, business functions, and groups.

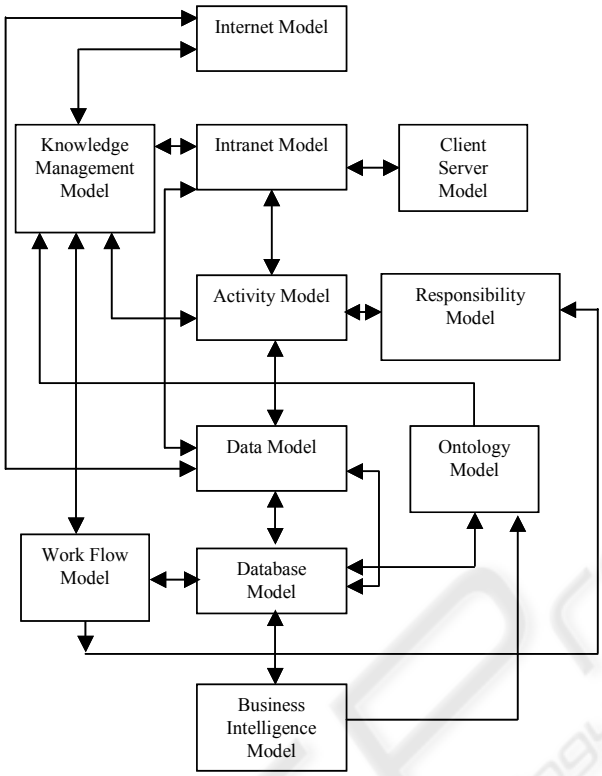

Figure 1: Manufacturing Information System Architecture

3) Activity Model (AT): This model represents the business activities performed by employees of the company and the information that flow between them. It is a model of how the business operates and it serves to document the operations and the activities of the company. Information from the activity model aids the development of the data model, responsibility model, and the knowledge management model.

4) Responsibility Model (RS): This model describes the roles that employees perform and the information requirements to support them. A connection exists between the activities of employees and their roles, hence the connection between the activity model and the responsibility model.

5) Enterprise Data Model (ED): This model describes the data objects used or generated by the business activities, and the relationships between them. The model is the foundation and the source for satisfying the daily information and business intelligence requirements of the business.

6) Database Model (DB): This model describes the collection of databases that are required to hold the data that were defined in the enterprise data model. It should also identify the locations of the databases, and the rules for maintaining currency and security of data.

7) Client Server Network Model (CSM): This model describes the types of computer networks required to link the various parts of the company or islands of technology. It makes explicit the systems, middleware, computing platforms, and operating systems that need to communicate and how the communication is handled.

8) Business Intelligence (BI) Model: The Business Intelligence model addresses non-trivial business questions that cannot be answered from an operational database. It includes understanding the value chains of major customers, primary suppliers, and major competitors, while improving the firm's ability to perform at an optimal level. Part of the Data Model is represented here.

9) Knowledge Management Model (KM): The knowledge management model identifies, captures, stores, manages, and disseminates relevant organizational knowledge. Knowledge from this model will find its way in the Activity, Workflow, and the Ontology models.

10) Ontology Model (ONT): An ontology is a formal, machine-readable, explicit specification of the conceptualization that consists of a representational vocabulary with precise definitions plus a set of formal axioms that constrain interpretation and well formed use of these terms (Bernaras et. al., 1996; Campbell and Shapiro, 1995). It can be used to communicate between

systems, people, and organizations, support the design and development of knowledge-based and general software systems, as well as support knowledge management, knowledge sharing, knowledge acquisition, and knowledge reuse, and the specification of vision & strategy.

11) Work Flow Model (WF): The purpose of the Work Flow Model is to capture, store, and disseminate information concerning the routing (i.e., movement) of widgets and information about them. It should also capture and disseminate information about manufacturing machines and robots that are responsible for manufacturing the parts. The capability of a robot will affect the path (routing) a product takes through the manufacturing plant. This information becomes critical especially in a non-flexible production environment with demanding schedules.

4 RELATIONSHIP OF OBJECTIVES AND CONSTITUENT MISA MODELS

Given our position that a good MISA must possess the five characteristics identified in section 1, each characteristic must be addressed by one or more of the constituent models of the MISA. **Tables 1, 2 and 3** describe the relationships between the MISA models and the characteristics.

5 THE MODELING PROCESS

The MISA is comprised of eleven interconnected enterprise-wide conceptual models. Developing such comprehensive models requires the use of a methodology that is appropriate for large scale enterprise-wide IS architecture development. While there may be several appropriate methodologies, we choose the 7-phase information engineering (IE) approach by McDonald (1986). **Table 4** shows the connection between the models, the IE phases and some of the issues that ought to be considered in the development of the architecture. In this paper we only show a subset of the possible combinations, focusing on those IE phases that differ from traditional systems development methods.

6 CONCLUSION/DISCUSSION

In this paper, we presented an MISA that satisfies five critical objectives of modern manufacturing organizations. We recommended the use of IE as an appropriate modeling process, and established the connection between the IE modeling process and the models of the MISA.

While there is considerable overlap between the MISA and a generic ISA, there is some significance difference between them. The overlap stems from the fact that modern organizations, regardless of the type of business, require a minimum set of models as described in the MISA. However, two models of the MISA (i.e. Workflow, Ontology) stand out in a manner unique to manufacturing. Although these two models may be useful in some non-manufacturing organizations, they are likely to be critical to the success of modern manufacturing organizations. The nature of work in manufacturing places a premium on the movement of parts through the shop floor. Workflow should be a highly coordinated and efficient process that pays specific attention to the route a part takes through the shop floor, how fast it moves, it design specifications, the design processes, machine capabilities, and so on. The ontology model is critical to manufacturing because many minute and specific details need to be specified. This level of specification is required by machines and people and are often in the form of mechanical drawings and manufacturing processes that must be translated in a from intelligible to human and machines. Consequently, there is a need for formal representational schemas and axioms that constrain multiple interpretations of data and process. These two models in conjunction with the Knowledge Management Model, account for the bulk of the production issues that are prevalent in manufacturing. It is these production issues and the emphasis placed on them that separate manufacturing from the non-manufacturing companies

Table 1: Relationship between MISA models and first three MISA Objectives

Models	**Interacting Organizational Variables**	**Value Chain**	**Five Forces**
Knowledge Management Model	Task	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	Power of Buyers; Power of Suppliers; New Substitutes; Industry Rivalry; New Competitors
Internet Model	Communication, Technology	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	Power of Buyers; Power of Suppliers; New Substitutes, Industry Rivalry; New Competitors
Intranet Model	Task, Communication, Technology		
Enterprise Data Model	Task	Sales & Marketing, Customer service	Power of Buyers, Power of Suppliers
Database Model	Task, Technology	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	Power of Buyers; Power of Suppliers
Activity Model	Task	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	Power of Buyers; Power of Suppliers
Responsibility Model	People, Task	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	
Client/Server Model	Structure, Technology, Communication	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	
Business Intelligence Model	People, Task	Sales & Marketing, Customer service	Power of Buyers; Power of Suppliers; New Substitutes, Industry Rivalry; New Competitors
Work Flow Model	Task, Technology	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	
Ontology Model	People, Task, Communication	Inbound Logistics, Outbound Logistics, Sales & Marketing, Customer service	

Table 2 Integration Levels and MIS Models

Integration Level	**MISA Models**
Islands of technology	*Process, Ontology, Intranet, Client Server*
Socio-organizational	Ontology, Knowledge Management, Responsibility, *Intranet*
Global	Ontology, Knowledge Management, *Intranet*, *Internet, Client Server*

Table 3: Enterprise Engineering Framework Sub-Activities & MISA Models

Sub-Activity	**MISA Models**
1.1. Develop Vision	*Intranet, Ontology, Knowledge Management, Business Intelligence*
1.2 Develop Enterprise Engineering Strategy	*Intranet, Ontology, Knowledge Management, Business Intelligence*
1.3 Develop Business Strategy	*Intranet, Ontology, Knowledge Management, Business Intelligence y*
1.4. Organize for Improvement	*Intranet, Ontology, Knowledge Management, Business Intelligence, Responsibility*
2.1 Evaluate & assess existing culture	*Intranet, Responsibility*
2.2 Facilitate & commit to improved communication	Ontology, *Intranet, Responsibility*
2.3 Share & sell vision	*Ontology, Intranet, Responsibility*
2.4 Build Trust	*Intranet, Responsibility*
2.5 Empower people	*Responsibility, Internet, Intranet*
3.1 Understand the Customer	*Business Intelligence*, *Knowledge Management*, *Data, Database, Internet*
3.2 Understand the Product	Knowledge Management, Business Intelligence, Ontology, Workflow, Data, *Database*
3.3 Understand & Improve the Process	*Ontology, Knowledge Management, Activity, Responsibility, Workflow*
3.4 Design & Implement Effective Controls	*Activity, Responsibility, Intranet, Ontology, Knowledge Management*
4.1 Understand the Needs	*Activity, Responsibility, Workflow, Intranet, Ontology, Knowledge Management*
4.2 Design the System/Solution	*Activity, Responsibility, Workflow, Intranet, Ontology, Knowledge Management*
4.3 Construct System/Solution Model	*Activity, Responsibility, Workflow, Intranet, Ontology, Knowledge Management*
4.4 Implement the System/Solution	*Activity, Responsibility, Workflow, Intranet, Ontology, Knowledge Management*

Table 4: relationship between models, IE phases, and consideration issues

MISA MODEL	**IE PHASES**	**ISSUES TO CONSIDER**
Knowledge management	Information strategy planning, Business area analysis	Organization wide best practices; Problems to avoid; Business unit best practices
Intranet/Internet	Business area analysis, Technical design, Business design	Information content; Which intranets should be connected; How should they be connected; What information should be shared
Business intelligence	Information strategy planning, Technical design	Information content; Sources of information; Schema representation
Enterprise Data	Information strategy planning, Technical design	What has to be represented; What entities are required; Centralized vs. decentralized DB
Database	Information strategy planning, Technical design	What has to be stored; What questions require answers; Type of DBMS
Ontology	Information strategy planning, Business area analysis	Organizational terms to be defined; Terms specific to business units
Client server	Business design, Technical design	Type of data to be supported; Data Traffic patterns; What type of network; Network Performance requirements
Responsibility	Information strategy planning, Business design	Access to information; Data security; Roles and responsibilities

MISA MODEL	IE PHASES	ISSUES TO CONSIDER
Work Flow	Information strategy planning, Business design, Technical design	Information to support work processes; Process flow; Efficiency
Activity	Information strategy planning, Business area analysis, Technical design	What information supports a particular activity; What are the activities of the business unit; How best to implement the activity

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