The Conceptual Structure of a Unified Framework of Manufacturing and Supply System Management

Track: Operations Strategy

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Abstract

In order to continuously improve their efficiency, many companies have to redesign or restructure their manufacturing and supply (MS) systems, so that a set of coherent strategies can be supported. This paper aims to set systems thinking into the context of manufacturing and supply systems management (MSM), which is defined here as a domain that involves the activities necessary to the design, regulation and optimization of a MS system as it progresses through its life cycle. The conceptual structure of a unified MSM framework is presented. This framework specifies the key functional areas involved, outlines the contents and relationships within them, and then integrates these into a closed-loop logically to provide the basis for the development of a set of consistent parameters and procedures. The framework's industrial applications will also be reported.

Introduction

Due to the fact that it is mainly through their activities that real wealth is created, the economic and social significance of manufacturing industries has long been established. There is little doubt that manufacturing industry will continue to play a vital role, and the experiences of the manufacturing industry in the last decades of the twentieth century have provided strong indication that the companies in the new millennium will face some new challenges. In particular, they highlight the need for a more comprehensive framework to help companies manage their manufacturing system through the life cycles, because the factories of future will need not only manufacturing information systems to plan and control the operation of its existing manufacturing structures, but also methodologies and tools to help restructure their manufacturing and supply (MS) systems themselves. To face this challenge, this paper aims to set systems thinking into the context of manufacturing and supply systems management. A *Manufacturing and supply systems management* (MSM) is described. This provides a MSM process reference architecture that is structured to follow the fundamental systems engineering/problem-solving principals of the previous chapters, as well as a manufacturing system modeling reference architecture which covers the MS systems architectures and sub-architectures. In order to deal with the complexity involved, the systems approach to the design and operation of modern MS system has become more relevant than ever. The structure of the proposed MSM framework closely follows the guidelines provided by the set of prerequisite conditions. The contents of this framework have been derived from an extensive analysis of the relevant methodologies and techniques available in the literature, and from data gathered through industrial practice (Wu, 2000).

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Overview of MSM Framework Structure

So far as the development of the MSM framework is concerned, the following set of conditions necessary for the effective operation and control of manufacturing organizations are especially relevant: coherent organizational and operational strategies, adequate system structure, adequate measurement of the processes and awareness of environmental influences. If one relates these well-proven systems principles to the area of concern, it becomes apparent that a few key elements must be logically incorporated into an overall framework, so as to provide a logical and practical MSM management approach. The MSM framework should consist of three main functional areas: manufacturing and supply strategy analysis (MSA), manufacturing and supply system design (MSD) and manufacturing and supply operations management (MSO), as shown in *Figure 1*. Generally speaking, the nature of MSA approaches can be summarised as a method of helping a company analyse its products, market and operations to identify areas of concern, and then setting objectives for these to be improved. However, the implementation of strategic initiatives will rely on the management of change through MSD projects. The general aim of a MSD project can therefore be defined as the determination of the best structure of a manufacturing and supply system in order to provide the competence needed to support strategic objectives, and this must achieved within the resource and other constraints. A MSD procedure is usually based upon a general model of problem solving cycle as exemplified by the MSD methodology outlined Wu (1994). In addition, the complete MSM cycle should also include the aspects of manufacturing and supply to plan, monitor and control the production processes once the system is implemented and in operation. Therefore, the MSO area reflects to a large extent the planning and control activities normally associated with a MRP/ERP system.

The systems thinking in the management of manufacturing and supply requires the development of a set of coherent strategic objectives and goals. The message bears repetition: a hierarchy of compatible system structures should then support this hierarchy of objectives. Failure to deploy such an approach will tend to produce solutions/systems that may be technically good but not necessarily good for the business as a whole, due to a lack of context and coherence. Therefore, in close relations to the MSA function, a core area involving costing, quality assurance and performance measurement is specified. Its role is to provide a coherent means of establishing goals and objectives, and evaluating the output from various functions in a way that is consistent with the overall strategic aims.

The overlapping between these main areas identifies three additional MSM functions: MSA/MSD interfacing, MS system implementation and MS system status monitoring. One particular feature of this framework is the inclusion of a system status monitoring function. Its function is to regularly monitor the system's performance against the original strategic goals. Modification of the system structure, operational procedures, and even the original strategic contents, can be subsequently necessary. Accordingly, the purpose of this system status monitor is to assess the system's current performance and identify its status along the life cycle, and to trigger appropriate MSA/MSD projects when and where necessary.

In addition to specifying the conceptual structure and sequence of the MSM processes, the framework also provides a means of describing the MS system itself. That is, it provides a design process reference architecture, as well as a modelling reference architecture, which covers the MS, systems architectures and sub-architectures. At each stage, a number of systems architectures or sub-systems can be addressed. Three principal MS architectures can be addressed through MSM activities within this framework: the physical, the human and organizational, and information/control (*see Figure 2*).

The overlapping domains of these three architectures provide three further design concepts: the system structure, system decisions and system functions. Hence, the functionality of a MS system is provided through the combination of physical MS facilities to carry out the transformation processes, the organization of the physical facilities and personnel to provide the system structure, and the information structure to define how and what the system should produce. Using these architectures and concepts, a direction for systems design and modeling can be formulated. Progressing from the center, the requirements with respect to the system concepts can be specified in a holistic manner, and then the individual architecture and sub-systems requirements can be defined. The above is further refined by following the structure of a generic MSD methodology, consisting of four stages: project initiation, requirements specification, conceptual modeling and detailed design. The project initiation stage provides the terms of reference for the particular MSD project. The requirements definition stage provides a specification for the MS system. The conceptual modeling stage generates a number of alternative configurations for feasibility assessment. Finally, the detailed design stage provides the opportunity to render an in-depth specification of the chosen conceptual configuration.

Main MSM Functional Areas

The purpose of the first functional area is to help develop and capture a company's future MS strategy. Long-term success requires a company to continually seek new ways of increasing its overall efficiency, and of differentiating itself from competitors so as to enhance its particular competitiveness (Skinner, 1985; Voss et al, 1997). To create such a strategic approach, a company must develop a plan for identifying and building the capabilities that will enable it to do certain things better than its competitors can. So far as MS strategy research is concerned, a general model is usually followed which broadly divides MS strategy into two related domains of MS strategic process and strategic content. *Process* refers to the process of formulating and implementing strategy and *content* refers to the choices, plans, and actions that make up a strategic direction. Several approaches to the formulation of MS strategy have been published in the literature. An analysis of these has indicated that, with respect to strategic content variables, there is a significant degree of agreement amongst the current approaches (Hull and Wu, 1996). This has enabled a generic MS policy model to be developed, which consists of eleven policy areas as shown in *Figure 3*. Each policy area has been defined with respect to its decisions, sub-decisions, options, parameters and influences. It essentially consists of three key stages existing system analysis, MS strategy capture and MS criteria development. The results from these essentially provide an indication of the customer requirements with respect to the MS system in strategic terms. The criteria are grouped into: (1) *System Purpose*. This defines the rationale and aims of the MS system, with respect to its role in the organisation, including the direction in which it is heading and its functionality. Hence, this criterion includes concepts such as the product range, customer demand and volume manufactured and the core processes of the MS system; (2) *System Performance.* This is concerned with the quantitative measures of the system with respect to its competitive performance. Competitive criteria such as product lead-times, customer lead-times, delivery dependability, quality levels and scrap rates, etc.; (3) *System Characteristics.* These are the non-quantifiable criteria of the system and cover a qualitative assessment of the systems operations (such as the degrees of simplification, automation and integration, and the degree of system flexibility); (4) *System Costs.* These relate to the financial aspects of the MS system. They include targets for fixed assets investment costs, materials and inventory costs, and operational costs.

Using MS strategic initiatives as the principal input, this interface aims to assist the association between MS strategy concerns and necessary system design actions (Hull and Wu, 1997). The first stage is concerned with MS requirement specification – the definition of the system with respect to its function, structure and decisions (see *Table 1*). Following this, the MSA/MSD linking process is supported by a series of generic action plans. Each of these plans is associated with a set of MSD tasks derived from the MSD functional area. In fact, the MSD functional area has been specified in such as way so that, to a certain degree, it corresponds to the generic MS policy areas (*see Figure 4*). In addition, the MS criteria defined through the MSA process will relate MS strategy to MS system by defining the system purpose, system performance, system characteristics and system cost structure. Following these, a number of MSA/MSD link-tables can be produced indicating cause-effects relationships. They form a MSA/MSD linking chain through a number of logical steps. For example, the first step (*strategic decisions - MSD tasks)* provides an indication of the possible relationships between each of the sub-decisions, categorised under the strategic decisions of each of the eleven MS policy areas and the approximately 75 MSD tasks of the MSD task Framework. There are currently over 200 separate sub-decisions grouped under 55 decisions within the 11 policy areas.

The MSM structure provides an effective basis for the clear clarification of its functional domain. The functional area is divided into individual cells, each of which represents a particular module where specific contents regarding functionality, relevant techniques, parameters, values and relationships, etc, can be specified in detail if required. Within such a task frame, which can be considered to represent a self-contained package of work, a collection of design tasks exists that address a specific sub-system at a particular stage in the design cycle. Within the conceptual design stage a number of alternative MSD options can be generated and assessed based upon the requirements, terms of reference and strategy developed previously. The conceptual design stage is based around the three sub-architectures, aiming to identify a number of approaches, which may fulfil the systems requirements. As such it needs to take into account the existing systems structure and functionality as well as any constraints imposed by the existing system, and consists of the MSD tasks as shown in *Table 2*. Within the detailed design stage a number of alternative MSD options are generated and assessed based upon the conceptual design developed previously. The detailed design stage represents a more in-depth investigation of the three sub-architectures and is based upon the development of a series of sub-systems that directly contribute towards the operations of the MS system.

The MS implementation module deals with two closely related areas: system implementation and system change management. In general, a coherent set of detailed plans and instructions should be prepared to effectively manage the necessary change that must take place. An implementation plan should, for instance, include items such as an outline of the requirement of change, a description of method of change, a specification of the tasks and resources required, and a time plan for the implementation project. Eight main components can be identified, which are essential for accelerating change and maximising its chances of success. These components of change management provide the basis for the structure of the MS implementation phase of the MSM framework. The aim is to link the new systems design, developed during the MSD phase, into transition plans and implementation programmes which will lay a foundation for a successful implementation of the new system. Again, the three main aspects that are incorporated in the implementation phase are processes, IT, organisation and human resources. As can be seen, this phase will take the outputs of the MSD phase as inputs, and begins with the stage of *project organisation* to provide a basis for the development of transition plan(s) which include scheduling, budgeting and resource requirements. These plans are the basis to bring the new manufacturing/logistic systems design into the reality. A three-stage procedure has been developed for MS implementation (*see Figure 5*).

In particular, a system performance monitor is needed to complete the MSA-MSD-MSO-MSA cycle. This area is particularly important for the framework's real-life adaptation and operation, because it is responsible for the continuous monitoring and reporting of the current systems performance against the pre-established strategic goals. In addition, external influences should also provide a stimulus to the initiation of the MSA-MSD-MSO cycle. Being an open system, without this the company cannot be certain that its objectives established for future improvement will be adequate to lead to superior competitive performance. This can only be achieved by evaluating and quantify the current state of the company, and highlighting where improvement have been made and which areas need to be improved. By using performance measures that are supportive to a company's strategy, the feedback from the process will provide the company with the right information needed for a process of ongoing improvement. It would allow for monitoring of the critical success areas and correction actions can be taken should a drift occur. Therefore, this MSM performance monitoring module aim to monitor and initiate the right action whenever and wherever necessary on the MS processes.

Various approaches have been suggested for performance measurement, dealing with performance issues at each of the three MS layers (e.g., Benjaafar, 1994; Kasul and Motwani, 1995; Bititci et al, 1997; GAO, 1998). However, within the context of MSM, an extended scheme of evaluation is required so that the key requirements can be addressed, as shown in *Figure 6*. The performance-monitoring module is closely related to the MSA process, with a certain degree of overlapping between the two. The reasons for this are obvious. In order to ensure that a MS system achieves a strategically competitive position and that different parts of the organization are pulling their weight in a combined effort to maintain this position, some form of coherent performance monitoring of both individual units as well as the whole is essential, and the ultimate aim of performance measurement is to motivate behavior leading to continuous system improvement.

Industrial Application

Through an approach known as business process development (BPD), as used in the case of the design of a major European car manufacturer's new engine factory, this case illustrates how a MSM framework can be applied in practice to deal with a range of issues related to the analysis, design and implementation of a new manufacturing system and how, as an integral part of the MSM framework, this enables the system to be continually re-engineeringed in accordance with environmental changes (Wu et al, 2000). In the case of the company's new European engine factory, a number of strategic drivers, derived from the group's acquisition of another organization in 1994, existed. To achieve the business objectives of this acquisition, the product strategy of both organizations had to be aligned. For instance, it was decided to pursue a common engine strategy, where families of 'new generation' engines would be designed for the complete range of vehicles. For this factory to fit into the group's production network, many of its engineering, logistical and business processes had to interface to processes within the network. Hence, they were required to share functional commonality with those within other engine factories. The framework provides a mechanism to categorize the interdependent components of a MS process. Within the three MS system layers, in this particular case the hierarchy of processes contains 11 high level processes, which can be broken down into 70 distinguishable MS processes. These processes can be broken down further into about 300 sub-processes. The process design itself starts with the formation of a process design team for each high-level MS process of the model plant. The team is lead by a process owner and contains members of process customer functions and inputting/executing functions of the process. This team is responsible for the delivery and ongoing management of an improved MS process for the life of this process. The relevance and practical value of the framework is clearly illustrated by this greenfield MSD project: it helps the company to design and implement all MS processes required for the new factory, in time for its operation and in line with the strategic targets of the organization.

Conclusion

A logical MSM framework helps to set systems thinking into the context of manufacturing systems management, which is defined as a domain that involves the necessary activities needed to regulate and optimise a manufacturing system as it progresses through its life cycle. This paper has outlined its main functional areas, specified the generic processes and contents of these areas, and then logically integrated them into a closed-loop to provide the basis for the development of a set of coherent processes and tools, and a means of bridging the existing MSA/MSD/MSO gap. Within the systems design area in particular, the framework also provides a design process reference architecture, structured to support systems engineering principles. From the perspective of systems life-cycle, the MSM reference structure provides a more complete framework to link manufacturing strategy and systems specifications, specifying the conceptual structure and sequence of the design process, together with a means of describing the system itself. The cases of its industrial application have clearly demonstrated its practical value.

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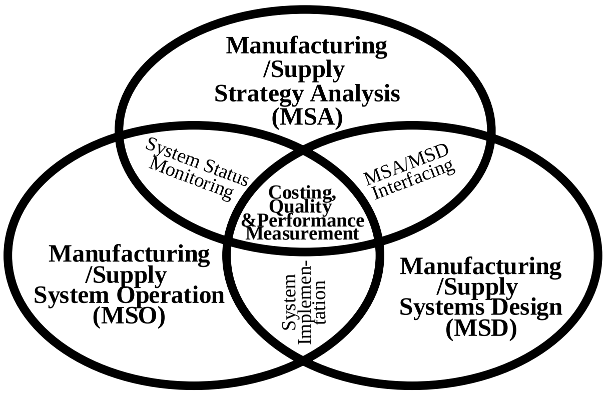

Figure 1 Overall functional structure of a unified MSM framework (source: Wu 2000)

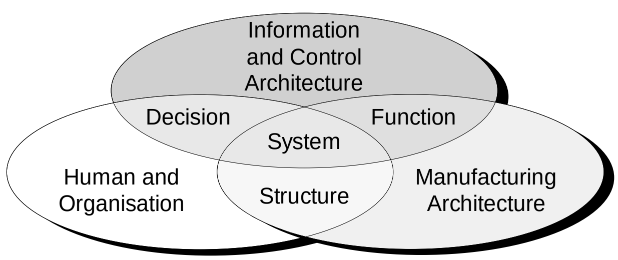

Figure 2 A conceptual MS systems architecture

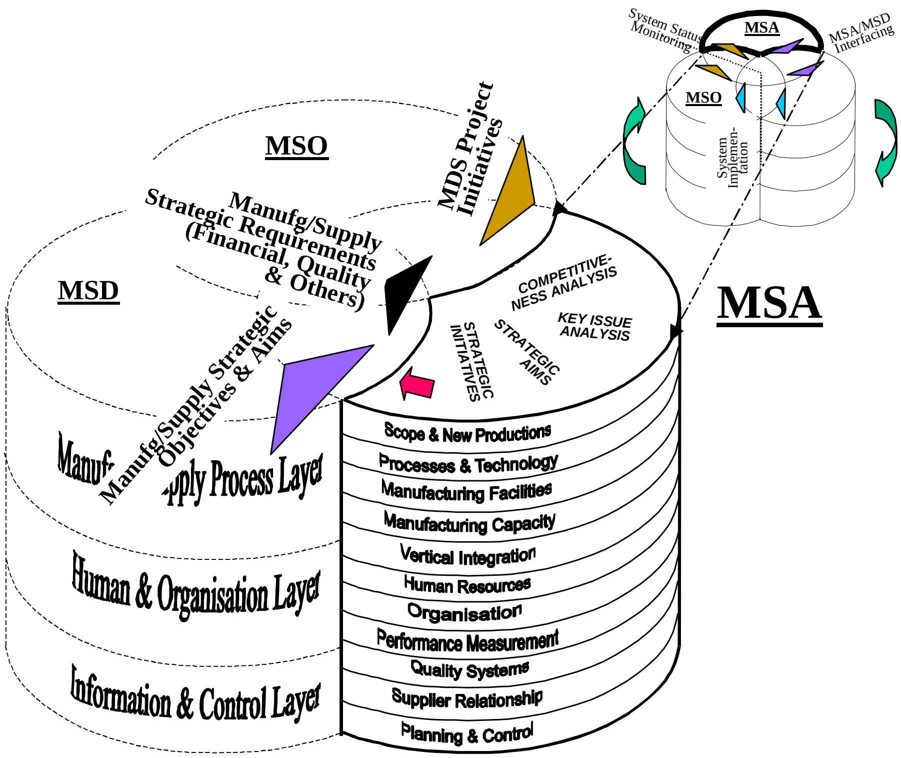

Figure 3 Processes and contents of the MSA area within MSM (Wu 2000)

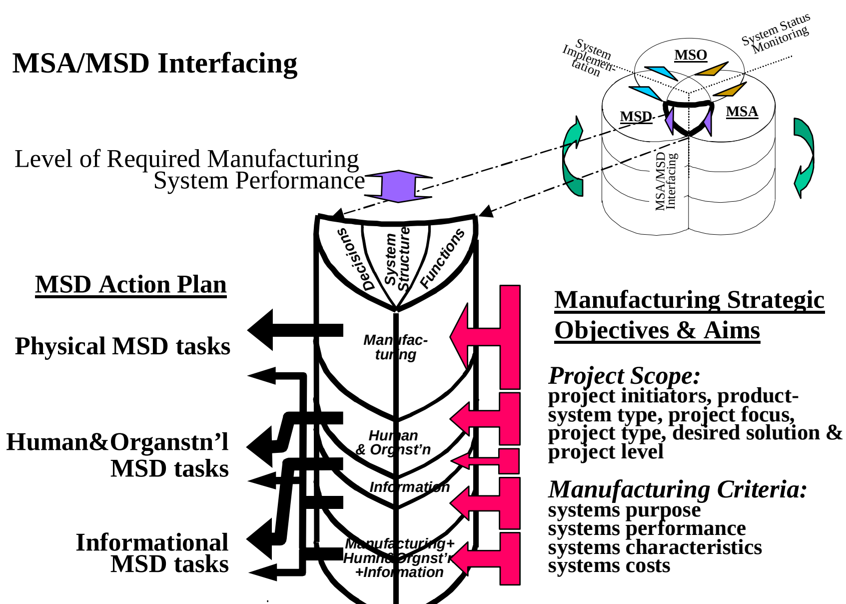

Figure 4 MS Requirement specification

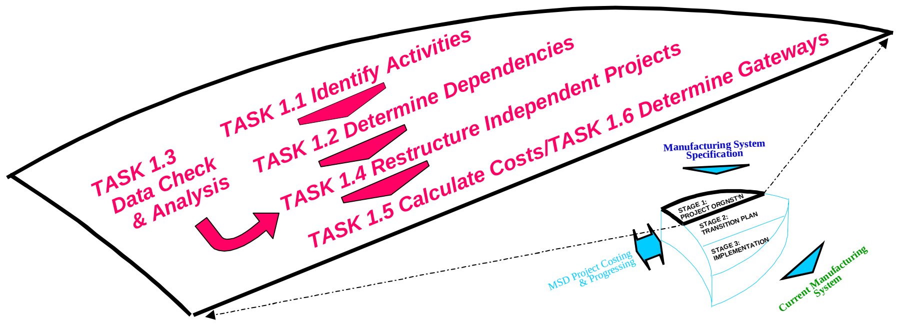

Figure 5 Project organisation stage

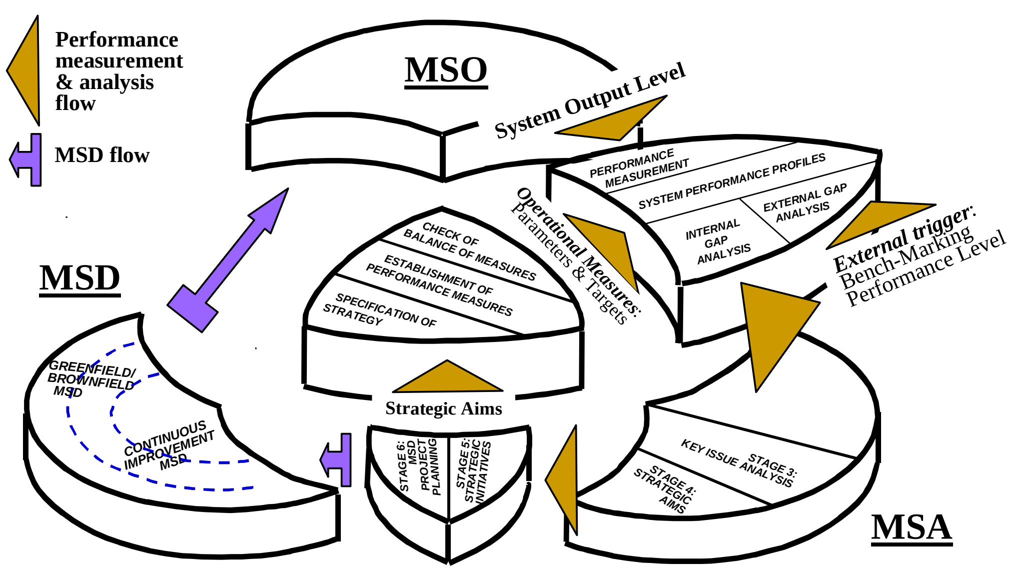

Figure 6 Overall structure of system status monitoring

Table 1 Requirement specification

	MSD Task	Description
System Function	Product Analysis	specification of requirements of new and existing products
	Part Analysis	specification of requirements of new and existing parts
	Process Analysis	specification of processes and process technologies required
	Make versus Buy	analysis of processes for in-house or sub-contract
System Structure	Functional Grouping	specification of functional groups (process or product)
	Capacity-Demand	specification of capacity required for each group
	Structural Layout	specification of MS organisation and structure
	Integration-Modularization	specification of degree of modularization and integration and identification of individual modules
System Decisions	Information Functions	specification of information functions
	Decision Variables	specification of level of decision making, level of control, decision making hierarchy

Table 2 Manufacturing MSD task documents

	MSD Task	Description
Manufacturing and Supply Processes	Process Planning	verification and specification of process plans for part manufacture
	Part Grouping	specification of part groups according to a variety of criteria
	Make versus Buy	part level make versus buy analysis
	Cell Formation	specification of cells according to a variety of criteria
	Conceptual Layout	conceptual modelling of factory layout
	Conceptual Capacity	specification of required capacity of individual cells
	Space Determination	specification of space required in individual cells
	Material Handling	specification of material handling requirements
	Factory Storage	specification of factory storage requirements
	Support Services	specification of support services required
	Factory Facilities	specification of factory facilities required
	Supply Chain Structure	suppliers and customers
	Supply Chain Modelling	visualisation of logistics network
	Facility Location Planning	location of manufacturing & distributing facilities
Human and Organisation	Organisation Structure	specification of type of structure of the MS organisation and
	Organisation Culture	specification of culture required for the MS organisation
	Organisation State	specification of operating conditions for the MS organisation
	Labour Policy	specification of labour policies to be adopted within the factory
	Quality Policy	specification of quality policies to be adopted within the factory
Information and Control	Integration	specification of degree and extent of integration of identified
	Autonomy	specification of degree and extent of autonomy of identified entities
	Automation	specification of degree and extent of automation of identified
	Planning and Control	specification of planning and control functions
	System Architectures	specification and modelling of information and decisional
	Data Flows	identification and modelling of major information flows