

CIM requires a new manufacturing engineering

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CIM requires a new manufacturing engineering

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1. Introduction

In the past decade industry has invested significantly in computer integrated manufacturing (CIM) systems. Organizations did and do so for various reasons. Given the breadth of the impact CIM can have it is quite unlikely that even an individual organization is driven by only one, narrow objective. Still, within the range of motives a number of reasons can be distinguished that were important for all but a few organizations. *Need for flexibility* is one of them (Czajkiewicz and Wielicki 1994; Mejabi 1994; Shahabuddin 1994).

In itself this is not very surprising. The current environment of most organizations requires them to be inherently adaptable. Nowadays being competitive implies being able to adjust rapidly to changes in customer demands while maintaining adequate price and quality levels. CIM systems can provide important leverage to confront that challenge. However, even in **computer** integrated manufacturing systems the greater part of their flexibility can still be accounted to people. To regard a completely automated manufacturing system which could operate without human intervention as the ideal CIM system is unrealistic. The awareness of the disadvantages of this type of the factory of the future is growing and the attention for the role of man in a CIM system is rising correspondingly. For instance, the importance of an adequate human resources management for reaping the benefits of CIM has been recognized (Pesch et al. 1993). Unfortunately this attention is almost completely restricted to man's role in the system after implementation. The role of the CIM operator in the design itself is relatively ignored. In this paper it will be explained why a more elaborate theory on this issue needs to be developed. The shortcomings of the dominating perspectives on this matter will be explained and an alternative will be presented.

The structure of the paper is as follows. In the next section a classification of approaches to system development will be presented. Of the four approaches which are distinguished the three best known will be discussed in section 2. Section 3 will be devoted to a discussion of the fourth approach. Based on the expected changes in the characteristics of the operational core in manufacturing organizations it will be explained why this approach should become a more prominent one. In section 4, 5 and 6 the alternative will be discussed in more detail. Section 7 will be devoted to the conclusion.

2. Four approaches to CIM system development

CIM system development can be based on a wide variety of assumptions. Hirschheim and Klein have proposed a classification of such assumptions for system development in general. First we will discuss their original model. Then we will present a variation more specifically aimed at CIM system development. Hirschheim and Klein use two dimensions to distinguish four paradigms of system development. The first dimension is associated with the acquisition of knowledge needed to design a system. It has objectivism and subjectivism as its extremes.

In a design approach with an objectivist orientation it is assumed there is only one "reality". Differences in opinion about this reality originate purely in a lack of understanding. When two individuals have different opinions about the system requirements, at least one of them is **wrong**, e.g. because he is insufficiently trained in system design. Misunderstandings can be prevented or resolved rationally through the application of objective models and methods similar to those used in the natural sciences. Over time our knowledge of these methods will increase until eventually misunderstandings will disappear.

To the contrary, in a design process with a subjectivistic nature the attitude towards methods from the natural sciences is a very critical one. It is stressed that design is essentially a human affair. For us as human beings the study of human behaviour is fundamentally different from the study of other natural entities. Consequently methods similar to those used in the natural sciences are only of limited value in system development. Instead of considering human beings as uniform entities with requirements the subjective experience of individuals should be taken as a basis. Essentially nobody is wrong. Effort should be put in making it possible for every user to express his requirements and motivate them. Group sessions are used to try to come to a system specification which is satisfactory to every participant.

The second dimension is associated with the designer's view of the environment of the system. Here the extremes are integrationism and conflict. Integrationism assumes a world of order and stability. One of the characteristics of an integrationistic position is the pretension to be able to describe the target process in terms of long lasting regularities. A design process with an integrationistic accent attempts therefore to produce an optimal design. In the conflict position however it is stressed that turbulence rules in our world. In order to survive in a dynamic environment organizations have to be fundamentally organic and change continuously in varying degrees. What seems optimal today is archaic tomorrow. Hirschheim and Klein's taxonomy is illustrated in table 1.

	integrationism	conflict
objectivism	functionalism	radical structuralism
subjectivism	social relativism	neohumanism

Table 1. Four paradigms of information systems development according to Hirschheim and Klein

The taxonomy in itself may still look quite philosophical and detached from "real life", but it provides a starting point for a typology more closely related to CIM system development. The four paradigms of Hirschheim and Klein can be connected to four development approaches. This is illustrated in table 2.

	no explicit coordination	explicit coordination
objective	traditional	architecture based
subjective	participative	learning

Table 2. Four development approaches characterized along the dimensions of Hirschheim and Klein

Note that the extremes *integrationism* and *conflict* are replaced by the extremes *no explicit coordination - coordination* respectively. This has been done to give more concrete form to the underlying notions. From an integrationistic perspective explicit coordination can be limited because separate initiatives will converge towards the stable optimal. In the conflict situation coordination is necessary to ensure that subsequent initiatives, with altered objectives, are compatible. Although closer to regular system development idiom, the four approaches in this taxonomy still are ideal types. All but a few of the actual development projects will reflect characteristics of more than one approach, although most of them will gravitate towards one quadrant. We will briefly characterize the traditional, participative and architecture approach subsequently.

traditional approach

After the client has specified what he wants he can rely on the expertise of the designer to get it. Requirements determination can be a cyclical process, where the analyst tries to develop an understanding for the client's problem. But once the requirements are fixed the client remains outside the project until acceptance testing.

participative approach

In this approach the end user is intensively involved in system development. Requirements are established in group sessions. Usually the knowledge of a participant is restricted to a subsection of the problem domain which is going to be covered by the system. In addition most participants need to develop their understanding of the possibilities and limitations of information systems. As a consequence development is often evolutionary.

architecture based approach

In this approach system integration is a leading motive. It is approached in an objective, "expert" way. It starts with an assessment of the information requirements in the organization. Then it analyses the requirements to see if overlap or significant similarity exist between the requirements from different organizational units. This similarity is an important criterion for the clustering of requirements. Each cluster of requirements demarcates the functionality of a future system. Often the analysis and clustering activities are supported by automated tools. The whole exercise results in a model of the functionality of the future systems and their interdependence. This is the *architecture*. From the architecture a project plan is derived for the subsequent development of the systems.

With all these three approaches the experience in practice is extensive. This is not the case for the fourth one, the learning approach. In the next section it will be explained why this approach in particular provides the most suitable basis for CIM system development in the future.

3. The learning approach to CIM system development: motivation and characteristics

It is a central point of this contribution that the learning approach should be the basis for CIM system development in the future. To support that it will first be explained that the characteristics of the organizations where the system will be implemented influence what design approach should be used. To characterize organizations we rely on the typology by Mintzberg (1983).

	no explicit coordination	explicit coordination
objective	simple structure	machine bureaucracy
subjective	adhocracy	professional bureaucracy

Table 3. Organization type implies design approach

Table 3 should be read inside-out, since it expresses which approach is enforced upon a design team in a particular organization type. In a simple structure, with a simple administration and a charismatic leader, the design approach will gravitate towards the characteristics of functionalism. In an adhocracy, formalization is low as well, but given the sophistication of the members the design approach should be more participative than the one in a simple structure. A machine bureaucracy can be typified by a high level of vertical and horizontal specialization and formalization. Given its usual size this type of bureaucracy will put more emphasis on the coordination of design efforts and rely heavily on formalization to achieve it. Thus design tends to be architecture based there. We will start reflecting on the conclusions we can draw from table 3 regarding CIM system design before the discussion of the fourth quadrant.

At first sight the typical organizational environment of CIM systems will be characterized as a machine bureaucracy. Yet when we take into account the importance of flexibility, mentioned already in the introduction, we can conclude that in fact the machine bureaucracy is not an ideal home for CIM systems. Because machine bureaucracies do not provide a good breeding ground for flexibility serious criticism on this type of organization has been ventilated in an impressive amount of recent publications, especially those on business reengineering (Hammer 1990; Davenport and Short 1990). One of the points that are mentioned frequently is the required changes in the characteristics of the operational core of the organization. To realize the flexibility deemed necessary to survive, a kind of operator is required who differs significantly from the standard machine bureaucracy operator. It is stressed that the operator should become a *professional*. But the consequences of such a transformation in terms of organizational characteristics and corresponding types of control are not worked out.

We can however turn to Mintzberg's description of the *professional bureaucracy* to increase the insight in the consequences of a professionalised operational core. On the one hand professionals want to be left alone by the administrators so they can do their job. On the other hand they want to have a say in the development of the systems that have to support them in their tasks. This has important consequences for the approach to system development. Commitment of the operator may be more crucial than it ever was. At the same time he will no longer take the objectives of a design for granted. The operator will actively seek to influence the decisions. It would be unrealistic to assume that the objectives of various stakeholders in the design and implementation will match naturally. It is clear that the social costs and benefits of new organizational forms, to which CIM systems provide significant leverage, are not automatically evenly distributed over the subclasses of society (Victor and Stephens 1994). According to Hirschheim and Klein failure to focus on the legitimation of the ends (as opposed to the efficiency oriented discussion about the means of an investment in IT) has led to an inappropriate conception about why users resist change. Much more attention should be given to their motivations and objectives than is usually done. To start a reengineering project, e.g. a CIM implementation initiative by saying, as Hammer claims he does: "Folks we are going on a journey. On this journey we will carry the wounded and shoot the dissenters" is not only grossly underestimating the effects of a century of labour emancipation but also ignoring an important source of manufacturing expertise.

Experience with the participative approach, suitable for an adhocracy, makes clear that it does not suffice to deal with this problem. Methods to support it have been available for over two decades. Socio-technical approaches have been worked out especially for information system development, e.g. the ETHICS method (Davis and Olson 1987, Mumford 1990). The explicit attention which is given to resistance management in these methodologies is favourable. However, in some respects these methods rely too heavily on the power of intersubjectivity and thus have serious drawbacks as

well. The development group is assigned the same 'divine' providence as the expert-designer in functionalism. From this idea the methods tend to approach development as greenfield operations. This is becoming increasingly unrealistic. Already the vast majority of implementations are in fact reengineering projects. Especially where significant design and development responsibility is assigned to end users, several reasons exist for the fact that requirements change within the life time of a complete system:

- * end user have great difficulty anticipating their reactions to future systems ("floating requirements");
- * end users move and are replaced; it is very likely new users have different requirements than the initial ones;
- * the environment changes within the expected life time of a CIM system.

End users bear another drawback when acting as system designers: they lack an infrastructural orientation. It is very difficult for them to look beyond their own application, to see how their requirements relate to others and to recognize the *generic* element in it. It will be clear that this is a crucial ability in order to establish computer **integrated** manufacturing systems. Appreciation of the uniqueness of a specification is necessary to produce useful systems. But to positively influence maintainability and thus the life time of a system requires that during requirements specification an understanding of its similarity to others exists as well. Especially unexperienced specifiers tend to emphasize uniqueness. They need assistance in relating their problem to (a custom-made mix of) standard solutions. With its underappreciation of the importance of system integration the participative approach is insufficient for a professional bureaucracy.

To conclude this section we can say that to utilize the professionalization of the CIM operator a system development approach should be employed which not only stresses participative development, nor only emphasizes system integration, but one which combines the prominent motives of both. In the next three sections an approach will be presented with those objectives.

4. Towards a "facilitating change" orientation of CIM systems development

At this point it should have become clear that notwithstanding the necessary stimulation of CIM operators taking initiatives and employing their expertise in manufacturing engineering, it should at the same time be accepted that their professionalization is not in IT. Although the CIM operator's proficiency in systems design will increase, he does not devote his full attention to IT-application and thus some knowledge and attitudes essential to system design and development will remain fundamentally untransparent to him. That implies that his manufacturing expertise should to a large extent be utilized indirectly in the design and development of manufacturing systems. Consequently the design of integrated, adaptable systems should in a sense be split up in two major processes.

The first one should result in a set of generic, interchangeable system components. The characteristics of this set of components should be such that the infrastructural issues mentioned in the previous section are hidden for its users. It should be possible to custom-fit the components with the use of parameters. This enables the CIM operator to exploit his manufacturing expertise in the second design process, by designing enhancements to "his" system with the use of the standard components and the help of specific experts. These experts will be discussed in section 6. Naturally, one design process of the first type can support many of the second type.

This approach implies that with the increasing IT-proficiency of the end user the IS management function will change, but not disappear. It will become much more facilitating and concentrated on a (quite notable!) subclass of the issues it has to cover now (van den Berg et al. 1994). The roots of this alternative can be traced to the theoretical framework of generic product types (Hegge 1995), but also to trends distinguished by researchers in the management information systems field. Dixon and John (1989) for instance describe how as a direct consequence of the end user's increasing responsibility for development of his systems the involvement of the central IS authorities in that area is changing. They remain responsible for planning and "selling" technology and systems within which local decisions can be made freely. Their primary interest consists of providing the base provisions. Others have discussed this concentration of information management effort and supported it by empirical results, e.g. Boyton and Zmud (1987), Niederman et al. (1990), Clarck (1992) and Goodhue et al. (1992).

5. CIM system development in the future

CIM system design based on standard system components implies reuse. We can rely on the results on this issue to describe the proposed design approach in more detail. Future development of CIM systems should rely on configuration from a limited set of system modules. Naturally, the development of the interchangeable system modules should not be the responsibility of the end user. In addition **indirect** end user configuration of the modules should be enabled through linking to business process models, thus facilitating *generative reuse*. Table 4 illustrates how this type of reuse relates to ad-hoc and compositional reuse. Since generative reuse relies on the specification of the end product to drive the reuse process it is the most difficult to achieve, but also has the highest potential pay-off.

type of reuse	characteristics
ad-hoc reuse	decision about what to reuse is completely arbitrary
compositional reuse	standard components are available; how and when to configure them is left to discretion of the developer
generative reuse	standard components are available; specification drives automatic generation of system

Table 4. Three levels of reuse

Automatic generation requires **formal** business process models. In the past decade significant progress has been made in the usability of formal specification techniques. Petrinets for instance form a successful class of such techniques with promise for enterprise modelling (Wortmann 1993). With the progress in research and the increased experience with practical application of formal languages it becomes more likely that the language primitives can be combined into domain specific "building blocks" that can be custom-made through parameters. This allows for rapid modelling, relatively detached from the mathematical peculiarities of the language. Van der Aalst for instance developed a number of standard building blocks for the modelling of logistical chains based on Hierarchical Timed Coloured Petrinets (van der Aalst 1992). With the assistance of experts the CIM operator can specify his suggestions for improvements in such specification languages. Based on this model the system generator would then create the system from the modules. Ideally it would be able to only change the parts of the system that are affected by the mutations in the business model and does not produce a completely new system (van den Berg 1994).

6. Roles in development

In a design and development process as outlined in the preceding section four different types of stakeholders can be distinguished:

- * the software module provider
- * the business process expert
- * the change agent
- * the end user

Their precise roles will be discussed subsequently.

Software module provider

This should be a software engineering expert in the somewhat visionary sense, working in a way generally associated with a software factory (Van Genuchten 1990, Cusumano 1992).

This is certainly not current practice yet. Van Genuchten discussed a number of reuse dilemmas, e.g. regarding the right size of modules. The larger their size the higher the pay-off of reuse, but the smaller their size the higher the likelihood of reuse. The system module provider should concentrate his effort on facilitating *compositional reuse*: module selection and retrieval, module understanding, module adaptation and module integration.

Business expert

This type of facilitator should be highly qualified in domain analysis: "identifying objects and operations of a class of similar systems in a particular problem domain" (Neighbor 1980). He uses his experience with manufacturing systems to rapidly specify a particular situation in terms of formal business model components. Until a system can be generated automatically from the business model, the business process expert also has to act as a *meta-generator* and deduce the consequences of a specific model regarding the configuration of system modules.

Change agent

Not each configuration that can be realized with a certain set of standard system components will be equally socially acceptable. The change agent has to assist in finding a workable configuration and is responsible for the transformation from the old to the new situation. His expertise lies in human resources and change management. Although the change agent is most likely an external project consultant, it is also possible that this role is fulfilled by an internal *champion*.

End user

More and more the end users will become the most likely party to take the initiative for changes in the system. They are most familiar with the peculiarities of the manufacturing process and consequently should and will play an active role in system (re)design. Yet, in spite of their increasing IT proficiency they will not be able to develop a CIM system independently. The afore mentioned experts will guide them in the specification and dependable implementation of their suggestions.

7. Conclusion

Although the term may suggest otherwise, the flexibility attributed to **computer** integrated manufacturing systems has to be realized to a large extent by people. Consequently the increasingly professionalized CIM operator should be assigned an active role in design and development of CIM systems. Unfortunately methods for that purpose, dominantly functionalistic in nature, bear serious shortcomings in this respect. Other methods, stimulating participative design, rely too much on the power of intersubjectivity. Their appreciation of the inherent limitations of end users as designers is insufficient.

The objective of the alternative presented here is to provide the CIM operator with an infrastructure of experts and systems. It enables generative reuse of CIM system components through formal business process models. This allows the CIM operator to utilize his expertise in manufacturing during design and development of CIM systems, without being directly confronted with design issues that are fundamentally untransparent to him. In the scenario presented here the system module provider, the business process expert, the change agent each play an indispensable role in enabling the operator to realize improvements in 'his' system in a liable way.

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