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APPLICATION OF MATHEMATICAL PRINCIPLES TO THE FORMALISATION OF A SYSTEM-BASED MODELLING FRAMEWORK : APPLICATION TO ENTERPRISE SYSTEMS

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Abstract: The aim of this paper is to propose a system-based modelling framework to understand and model an enterprise (e.g. an SME) in order to design and implement integrated business solutions (e.g. Enterprise Resource Planning ERP) while keeping the legacy of the SME's original human-centred organisation. We have used mathematical principles to formalise the system characteristics and mechanisms and to propose a formal system-based modelling framework. *Copyright©2001 IFAC*

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1. INTRODUCTION

The need of business integration and new business organisation are now so widely accepted by companies that it is impossible to give it a miss in any enterprise development project. Being under an obligation to face up to globalisation, competition, etc most of the companies decide to improve their competitiveness by developing new ways of acting such as the re-organisation of their processes. Commonly companies consider re-organisation as an action to improve the company's capabilities, competencies, reducing costs of production, physical location etc., namely, in terms of abilities to respond to economical needs and to satisfy customers.

Difficulties arise where the established organisational structures of a company – which are often based on *local* goals of enterprise units, departments, teams, employees – cut across these new *global* goals. These goals are themselves subjected to a complex and

uncertain environment (political, social, economical change) in which the enterprise operates.

To overcome these difficulties, information technologies (IT) offer support to achieve the company's main goals. They allow new solutions to design and implement the new organisation of units, departments, resources, employees in order to achieve both the global and local company aims. For this aim, Enterprise Resource Planning (ERP) offers integrated business solutions for *large companies*. They can be used to structure and support the "optimised" organisation, to dispatch and monitor company activities and operations, tasks, flows, resources etc.. Through automated and computerised synergy, ERP allows to integrate company functions through shared business information.

SMEs have the same global goals to achieve competitiveness as large enterprises. Therefore they try to use also this kind of integrated business solutions (e.g. ERP). But there is a difference: large companies and SMEs differ fundamentally from each

other. It is well-known that *people* have a major role to play in an SMEs' organisation through their ability to function intuitively, their particular competencies, jobs and social purposes, etc.. Specific products and activities are the main characteristics of SMEs. Most of these activities require a strong involvement of human resources, etc.. Therefore Weston (Weston, 1999) and our team (Laroche, 1999; Mayer et al, 2000) have shown that SMEs do not conform to any existing "big picture" of enterprise needs or solutions.

Thus it seems difficult for SMEs to benefit from integrated business solutions like ERP. In fact, the implementation of these computer applications are costly solutions (but SMEs make often an effort). We have noted through our research that the needed re-organisation induced by these solutions has also additional "social" costs. In fact, the implementation of ERP is frequently accompanied by too radical a recasting of the enterprise organisation, and by the lack of information and training concerning both the real needs of people and their use of ERP (even if an effort has been made to develop improved human-machine interfaces). ERP induces an increase of sensitive social issues. Obviously a major social impact is generated by introducing ERP. We have noticed that this impact is highlighted in SMEs because these are the socio-technical systems where *people* play a major role.

However, ERP can be the means of modernising SMEs in order to improve their competitiveness. Regarding our own research (Laroche, 1999), the implementation of an ERP system in one particular SME, has shown the specific difficulty: how to manage such ERP implementation while both :

- preserving human know-how and skills, and
- avoiding the pitfalls of a too strongly computerised and rigid organisation as imposed by the ERP ?

As proposed by Morel (1998), the development of the SME organisation itself (figure 1) means:

- to give the major importance to human skills and to the existing organisational structures,
- to use ERP as an additional organisational facility.

In accordance with Mayer *et al.* (Mayer *et al.*,1996) and Morel (Morel, 1998), we have observed that the existing SME organisational structures and the new ERP system require modelling approaches which can deal with complexity. Thus, it is necessary to combine the *global* orientation of the SME with its *local* "reactivity". It means to combine on the one hand, the competencies and the ways of working of employees and on the other hand, the facilities offered by ERP to organise and structure interactions

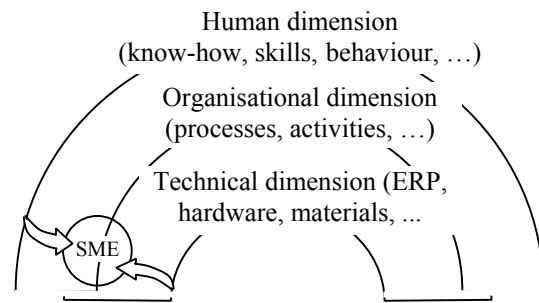


Figure 1: Proposed SME organisation according to Morel (Morel, 1998)

between people and between human and technical resources. To reach this aim, two types of approaches can be considered (Mayer *et al.*, 2000) : the *ERP approach* in order to integrate and organise *business processes*, and the *Model Warehouse approach* which supports the *global* modelling of the enterprise in order to design a "global" IT solution integrating different computer applications.

Part 2 of this paper presents a short overview of these two modelling approaches. Part 3 presents issues of implementation of integrated business solutions in SMEs taking into account the increased complexity of the SME organisation. Paragraph 4 presents the need of a system-based modelling approach which is able to deal with both the "artificial" complexity due to the implementation of a too strongly computerised organisation, and the "natural" complexity inherent to the human-based organisation of SMEs. This approach is based on System Theory (Lemoigne, 1977) and on certain mathematical principles to organise the modelling process.

2. HOW COULD THE ENTERPRISE GO ABOUT REORGANISATION ?

The design of an integrated business solution means first of all, to model what the enterprise should do to achieve its different goals; how it needs to be organised to do it etc.. The design and implementation of any business solution are based on these models (Mayer, *et al.*, 1996).

2.1 The ERP approach

ERP needs a reference model of the enterprise's business organisation. This reference model is used to model the new enterprise organisation. It is afterwards configured to design and to implement the ERP. Thus ERP supports the enterprise-wide computerised integration through business data processing functions (integrated modules). This integrated business solution may be seen as a means to lead to the "ideal" computerised organisation as the enterprise tries to achieve its

goals. To do that, the approach proposes to map the existing enterprise organisation on the ERP computerised organisation in order to automate enterprise processes. The result is an "IT-pushed" organisation.

2.2 The Model Warehouse approach

The Model Warehouse approach acts as a particular modelling strategy applied to the enterprise organisation as a whole. This approach does not use an enterprise reference model but what we call a "meta-model" which describes the components of the enterprise system. Thus the Model Warehouse approach can provide an operational overview of the enterprise.

The Model Warehouse approach is used for design and implementation of a data warehouse which carries out integration across the enterprise. The application of this approach is a way for enterprises to get to a more optimised organisation in order to achieve their particular goals. Thus information technologies lead enterprises to reducing inherent complexity and to improve operations within uncertain and complex environments. But we have shown in Laroche (Laroche, 1999) that a successful implementation of ERP and Model Warehouse approaches can introduce *more* complexity into an SME. This is the subject of the next paragraph.

3. DESIGNING AND IMPLEMENTING INTEGRATED BUSINESS SOLUTIONS IN AN SME

To face up to increased needs for competitiveness, a certain SME decided to implement a new integrated business solution in order to support and optimise its business activities. This process became one of our research projects.

3.1 The ERP implementation project

Persuasive vendors managed to convince the SME discussed here, to buy their ERP system in order to re-configure its information system according to the new business challenges and in order to develop new modern business attitudes. For this project, various employees needed to work in a coordinated way with the project management consultants and the ERP system integrators and builders. In theory, this partnership was the opportunity to develop a better design and implementation of the ERP; in practice, it introduced new differences of points of view, know-how, enterprise culture and goals. Thus the project management process became complex!

The project started with the application of the ERP approach. The modelling of the new SME business

organisation, the specification of the different data processing strategies and the configuration of the ERP reference model were the first steps of the project. The operational implementation of the ERP was the final phase of the project.

3.2 Issues of the project

Obviously ERP supported and structured the organisation in a way that only high-value business processes and production control functions were automated and, thus, preserved. Many other specific activities as well as administration and production processes of the company were cut out of the enterprise in order to be subcontracted. From an *industrial* point of view, the expected results were reached: better productivity and strong business management of the SME, which means better competitiveness.

However, some weaknesses have become visible concerning this new "IT-pushed" organisation:

- some specific original activities of this SME were cut out due to the ERP implementation,
- ERP led to a drastic standardisation of human skills and their functioning,
- SME employees considered the resulting enterprise as too strongly computerised,
- the process of change was not sufficiently documented to justify different organisational choices.

Thus from a *human* point of view, the following issues have become apparent: the disagreement of employees with the ERP project; the lack of training to the new ERP ways of working; the gap between the ERP organisation and the former human-based organisation of the SME, the need of re-qualification of employees ...: it means an increase of social problems inside the company. This development means *increased* complexity. To overcome these problems, it was necessary for the SME to find solutions to manage :

- the impact of the ERP deployment on the "current" organisation,
- the integration of the ERP system into the SME legacy organisation,
- the use of the ERP by the enterprise employees.

However, in order to keep the benefits of ERP solutions, the SME attempted:

- to adapt ERP functions to SME functions including further significant extensions of SME functions (e.g. implementing new program units),
- to expand some computer applications to make them more acceptable to employees thus

- ensuring that employees work harmoniously with regard to both the ERP functions, and the SME's original goals,
- to start intensive training in the use of the ERP system.

But the organisational procedures proposed by the ERP are designed to be well suited to the dimensions of bigger corporations. Hence it was difficult for the SME to adapt them to the size and the characteristics of its organisation without additional costs. Therefore a different strategy of the implementation process are suggested in the following paragraph.

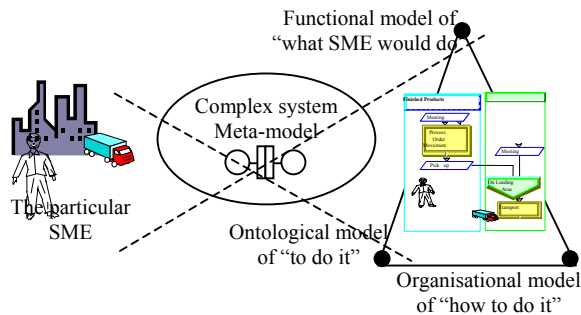


Figure 2: System oriented modelling process

4. STEPS TOWARD A SYSTEM ORIENTED MODELLING OF ENTERPRISE SYSTEMS

Obviously the implementation of ERP in this SME had increased complexity in managing the company, instead of reducing it. It had generated further problems, especially concerning costs, time and human resource issues. This was to be expected as the design and the implementation of the ERP system within the existing organisational structure was never undertaken with a *systemic* picture of the enterprise in mind. Therefore the specific characteristics of this SME could not be taken into account in this ERP project.

4.1 The "global" modelling approach

This illustration of the weaknesses of the ERP approach (and also the Model Warehouse approach). shows the needs for a different approach :

- which models the enterprise as a *system*, it means as a finalized operational *whole* where the use of *human and technical* resources is systemised to carry out what the enterprise should do, and how it could do it, ... (Weston, 1999)
- which models the enterprise as a set of predefined business "objects" with desirable qualities and models its organisation as the integration of these objects with the hope of generating a near-ideal whole.

So, in our research, we have proposed to apply a "global" approach dealing with enterprise systems based on System Theory. The research of Meinadier (Meinadier 1998), Weston (Weston, 1999) and Leger (Leger, 2001) have shown the need of this kind of particular approach for industrial application. This System Theory approach provides a prescriptive conceptual framework to model a system as a whole and to model characteristics of its complexity (human-based organisation as well as business goals, new merged industrial paradigms, new technologies etc.).

But often such a system approach is defined from a *philosophical* point of view: it is not sufficiently *formalised* for enterprise system modelling applications. According to ICIMS-TC3¹ on "Systems Engineering", our research deals with the *formalisation* of the concepts, theories, models, methods, methodologies, languages and tools to support such a system-oriented modelling process for enterprises as systems. This approach consists of designing the model of the SME by making reference to a "meta-model" of complex systems (figure 2). This meta-model is mainly composed by the system *components* and system *mechanisms*.

4.2 The system oriented meta-model

The system-oriented meta-model contains the system *components* (which manage, act and observe the process of physical, informational, ... flows) They are organised within basic system *activities* or *mechanisms* (to transform the flow through time, space, shape and nature activities). Furthermore they carry out *global* processes to manage the whole system in order to produce and maintain its finality (output and results) and its goals.

Certain elements of this meta-model are derived from System Theory. They have been formalised by the application of mathematical principles. To do that, we have used the NIAM-method (Habrias, 1988) which supports this formalisation process through the application of Set Theory principles. Furthermore Informal Discourses of System Theory have been used. The complete formalisation process consisted of two steps: firstly, the isomorphic transformation of the Informal Discourse components into a binary relationship model of these components; and secondly, the homomorphic feedback of the binary natural language of the meta-model onto the initial System Theory Discourse to improve its semantic and syntactic completeness (figure 3).

¹ ESPRIT V 23447 ICIMS-NOE on Intelligent Control and Integrated Manufacturing Systems Network of Excellence - Technical Committee on "Systems Engineering"

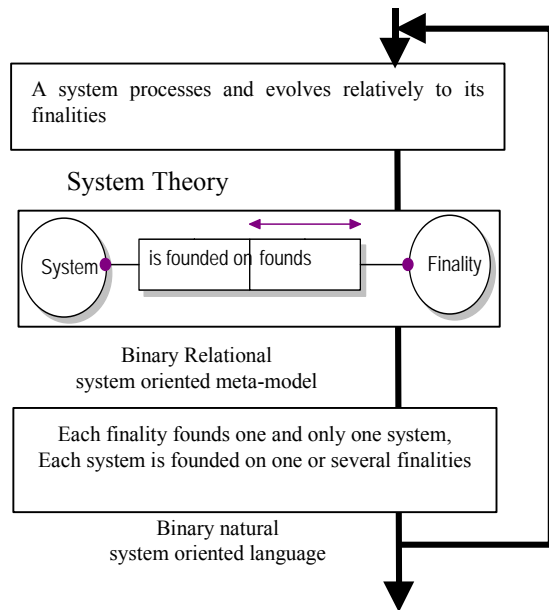


Figure 3: NIAM modelling process of the system oriented meta-model

Furthermore, we need to understand the complexity of the different flows interacting in the system (physical, human, informational, ...), particularly in SMEs. Therefore we highlight their roles by applying some linguistic principles to identify the different flow processes:

- “having to do” flows (finality/output and goals of the system and its different components),
- “knowing how to do” flows (knowledge to achieve finality and goals),
- “being able to do” flows (resources to do),
- “wanting to do” flows (events to do).

The resulting system-oriented meta-model describes the different components of the system to prepare the specific system model of the SME.

4.3 The system based modelling mechanism

Subsequently it is necessary to take into account that the properties of a system as a whole are not identical with the sum of its parts. New properties *emerge* from the integration of its parts. Thus the mechanism of *emergence* can be applied. In practice, it means, firstly, to look *outwards* in order to globally understand the interactions between system components and their resulting output, and secondly, to look *inwards* to understand their finalised behaviour. This approach replaces the ERP procedures to decompose a system into islands for which fragments of behavioural models can be generated, and subsequently to re-integrate them with the hope of modelling in this way, the system as a whole.

Primarily, we have formalised this important mechanism of modelling a complex system by applying the principle of “substantivation” (to use a verb as a noun) formalised by the NIAM method (figure 4).

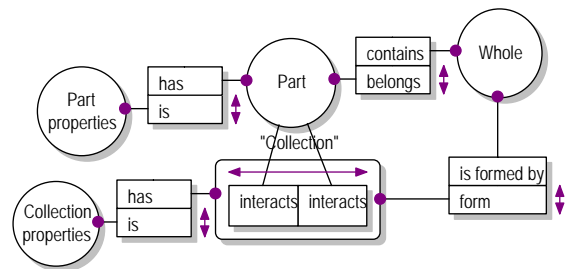


Figure 4: Emergence as a modelling mechanism

In theory, namely from a conceptual point of view, this formalisation of the emergence mechanism has come up to our modelling expectations. In practice, however, namely when applying this mechanism to modelling a particular system, the emergence of new properties of the whole system and the integration of components have not taken place as expected. It has been due to the mathematical principles used by NIAM, in particular the Cartesian product.

In fact, the *substantivation* of two components leads to the emergence of a new entity (figure 4) which is characterised by the *concatenation* of the properties of the two original components, not by new properties characteristic of the *integrated* entity. This is the translation of the Cartesian product. Hence it is necessary to extend the concept towards a “hand-made” emergence.

There exist certain principles of the Categories Theory which seem to achieve a real *emergence* as needed here. For that aim, it is necessary to define the system as a *category* consisting of two fundamental sets (Ducrocq, 1996): the set of the system *components*, called the *material* or *objects* of the system, and the set of the *relations* or *morphisms* between the system components, called the *semantical* of the system.

By using this definition, our research (Lavigne, 2000) has shown that it is possible to consider a system in general (e.g. an SME) as a *category* : a set of *objects*, namely the components of the system, and a set of *morphisms*, namely the relations which link the system components.

We have applied this principle in order to formalise the emergence mechanism. For that task, we consider a pattern (P) which describes the different interacting objects (O) of the system category. These objects can have actions (formalised by morphisms) towards an object (O) out of the pattern (P). The principle of

Induction defines on an upper level, a new object L in the following way:

- morphisms (actions) between P and L are identified,
- morphisms between P and O are identified as one unique morphism between L and O.

In conclusion, this new object L is partly in accordance with the emergence mechanism. It follows: the different identified morphisms represent on the one hand, the interactions between initial objects and their emerging object, and on the other hand, the properties of this new object as the result of the emergence mechanisms.

Our current work consists of completing this first formalisation of the emergence mechanism in order to propose it as a strategy of a system-based modelling process. Our goal is to support this “mathematical” emergence by a more acceptable method than the NIAM method.

5. CONCLUSION

In order to reconcile *computerised* integrated business solutions with *human-based* systems as SMEs, we have proposed to define a modelling framework based on System Theory in order to take into account the complexity of these particular enterprises considered as systems. The aim is to model the SME as a system where *human and technical* resources have to be harmoniously organised in order to carry out the SME processes towards its goals. The result of applying this modelling process in the SME can be represented by the following organisational model (figure 5).

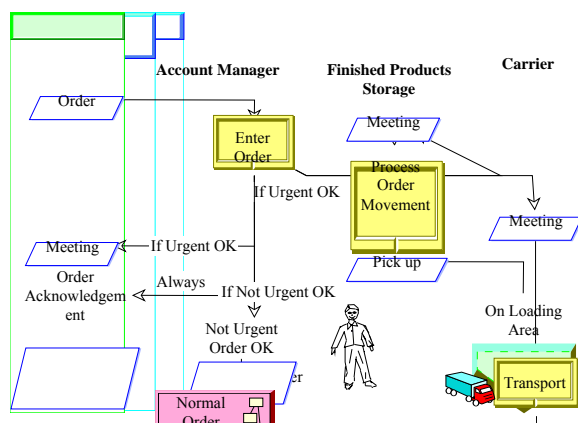


Figure 5: Part of the SME organisational model

According to the ICIMS-TC3 approach on “systems engineering”, our research is meant to be a contribution to the definition of a system-oriented modelling process according to the discussions of the IFAC Committee on Social Impact of Automation: a way to perform harmoniously the joint design of technology and human-based organisation.

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