A contribution of System Theory to Sustainable Enterprise Interoperability Science Base

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Abstract

Even if the research domain related to interoperability has been developed for more than ten years and particularly for the last eight years, the different kinds of interoperability and the different problems to solve need to be consolidated in order to define a real science. Moreover, because of the continuous evolution of enterprises in supply chains, interoperability problems must continuously be considered and solved in order to reach a sustainable interoperability.

The objective of this prospective research paper is to discuss how System Theory (ST),applied to System of Systems, is able to support the development of Sustainable Enterprise Interoperability Science Base. After an introduction which reminds the definition of Enterprise Interoperability and the development of this domain in Europe, the system theory conceptsare introduced. Then,the requirements are described to support the determination of the necessary concepts to develop a Science Base for Sustainable Enterprise Interoperability. This part also describes how the concepts of System Theory meet the defined requirements. The fourth part presents a specific approach based on system theory in order to manage the evolution of interoperability in enterprises and to reach sustainable interoperability. Then last part illustrates this workwith a concrete example showing how ST concepts are used in GRAI methodology for instance to represent business process and decision interoperability problems.

Key words

System theory, organisational interoperability, enterprise modelling, evolution management

1. Introduction

Interoperability is defined as « the ability for a system or a product/service to work with other systems or products/services without special effort of the user » [1].

Enterprise Interoperability (EI) is defined as « the ability of an Enterprise to interact with other Enterprises, not only on an Information Technology point of view, but also on organisational and semantic points of view. This interaction must be flexible and developed at the lowest cost" [2].

This last definition was step by step elaborated through a serial of works and projects developed in the frame of the European Commission since 2000's.

Enterprise Interoperability in fact appears long time ago when the economic world starts to exist: the enterprises have to interact in order to develop business.

The use of IT applications has supported the development of EI with a strong acceleration in the last twenty years.

But the economic environment has obliged Enterprise to develop EI solutions at a low cost and in a flexible way. It was recognised that 40% of the IT budget of enterpriseswas the consequence of the non interoperability of IT applications. This situation was the driver of an initiative launchin 2000's by the European Commission to create a working group in order to develop several research works to meet the new economic constraints (cost, flexibility, security...).

Based on the suggestions of this expert group composed of the main stakeholders, the thematic network "IDEAS" (Interoperability Development of Enterprise Applications and Software) was launched within FP5 (July 2002 - June 2003). The objective of this network was to elaborate a roadmap to develop a research program in EI. Two main initiatives were launched within FP6: ATHENA Integrated Project (IP) (Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Applications)[3] and INTEROP Network of Excellence (NoE) (Interoperability Research for Networked Enterprise Applications and Software) [4].

In the FP7, several projects were launched, among them the COIN FP7 Integrated Project (Collaboration and Interoperability for networked enterprises) which developed an advanced integrated solution, made of a secure Generic Service Platform providing the European Industry (and mostly SMEs) with EI and EC (Enterprise Interoperability and Collaboration) services, under innovative business models inspired by the SaaS-U paradigm (Software as a Service-Utility).

Through all these results developed since 2000's, the concepts of Enterprise Interoperability have been established, the domain has been defined, the problematic identified and some solutions proposed. A new scientific domain is born which must be promoted in order to allow the recognition of this new discipline, its understanding and its use by the stakeholders of the domain.

Moreover, in order to take into account the rapid evolution of enterprises inside supply chains, EI domain must be extended towards sustainable EI. This last concept aims to manage continuously the evolution of interoperability between partners through the continuous modelling, the continuous performance measurement and the continuous implementation of interoperable solutions.

This situation might be compared to the emergence of Enterprise Modelling (EM) at the beginning of 80's, when it was necessary to create a Science Base for EM. System Theory was a good support to elaborate the theoretical concepts of EM.This research paper proposes to use a similar approach in order to contribute to the development of a Science Base in the domain of EI and sustainable EI.The European FP7 ENSEMBLE project which aims at developing a Science Base for Enterprise Interoperability has identified a list of relevant established sciences that potentially can contribute to Enterprise Interoperability development [5]. System science / General system theory is considered as one of the most relevant ones. In this paper, we start to investigate the basic concepts and principles of General System Theory and its use in Enterprise interoperability domain. Other system related approaches such as Complex Systems, System Dynamics or Systems Engineering could be studied in the next stage of the research.

So, in the following part, the requirements to support the development of an EI science base will be detailed. Then, the concepts of system theory will be presented and their contribution to the EI science base will be discussed. In the fourth part of this paper, the evolution management approach based on system theory will be presented to reach a sustainable EI. Finally, a case study will be detailed to demonstrate the interest of system theory.

2 The System Theory

The system theory is the result of the research works done by many authors among whose one can cite L. Von Bertalanfy [6], H. Simon [7], K.E. Boulding [8], Von Neuman [9], Jean Louis Le Moigne [10], Mesarovic[11] and many others. These research works applied originally the same concepts (System theory concepts) in various disciplines: biology, physics, economy, organisation, computer sciences, cybernetics.

From all these works, several definitions are proposed below fora system and its related concepts.

A system is composed of a limited set of elements having attributes and relations between these elements. So, a system has a particular structure. It answers to the question WHAT?

The elements composing a system have the particularity to contribute to reach one or several common objectives. These are the objectives of the system. These objectives answer to the question WHY?

In order to reach these objectives, a system has several functions which are related to its structure. This answers to the question HOW?

Moreover, a system has a boundary. Sometime it is easier to determine the elements inside the system by determining the elements outside the system. The elements outside the system composed the environment of the system and enable to also the borders of the system. This environment answers to the question IN WHAT? But this environment has the ability to modify the system properties and to influence its evolution. This capacity of evolution is the last property of a system.

A modification of the borders and of the objectives of a system might lead to the modification of the different status of a system.

So, a system can be represented by the figure 1 below:

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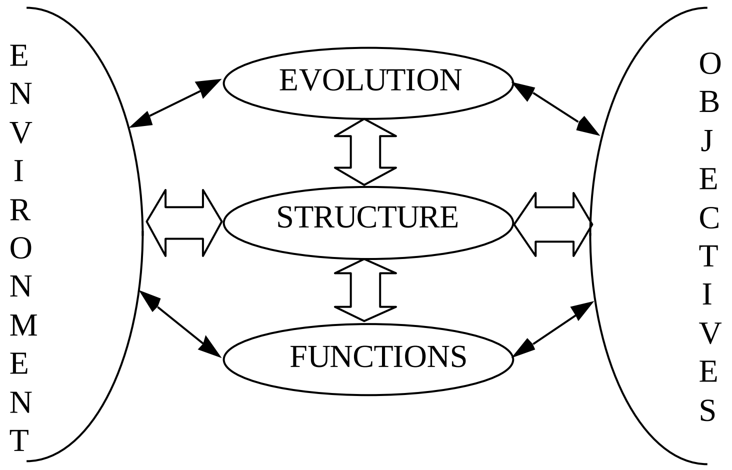

Figure 1: The concepts of the system

But in the frame of new complex systems, the notion of system of systems is emphasised.

Indeed, few systems are running independently to their environment and this environment plays a more and more importantrole. Moreover, few companies are able to manufacture a product or a service in a whole (for economic reason they are focused on their core business) and they are obliged to look for partners in the frame of a network of companies. This network is in fact a network of systems which has the same properties than a single system, i.e. a structure, functionalities, objectives, an environment, and its own evolution. This leads to the concept of system of systems.

The concept of system of systems could be represented in the figure 2 below:

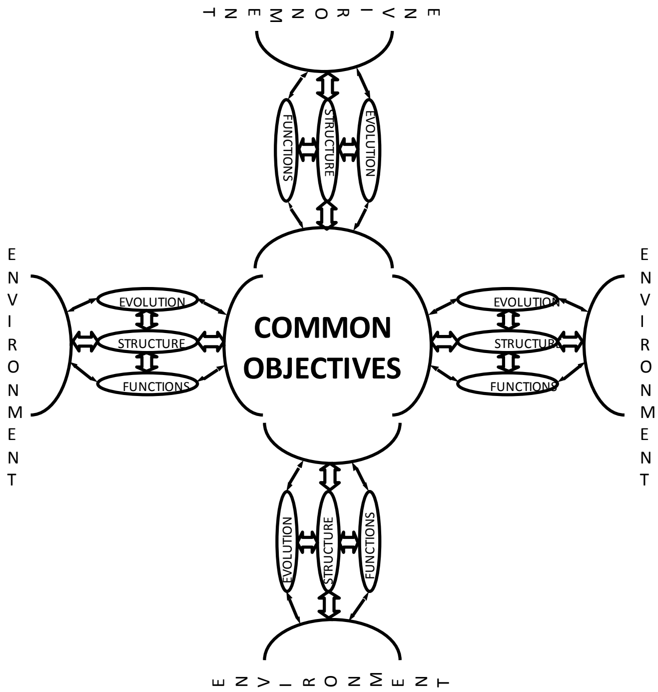

Figure 2: System composed of four systems with common objectives

Based on these definitions, the system theory aims to represent (to model) the realities of a system, concrete or abstract, highlighting at the same time the global and the detailed representations of this system. For instance, GRAImethodology (Graph with Results and Activities Interrelated) is based on the system theory, allowing to represent the controlled system (often called the Operative System, including the added value activities of the enterprise) and the control system at the global (GRAI Grid, GRAI Nets and functional view) level and at a detailed level (GRAI Nets and business process views) and taking into account system objectives and environment. The explicit description of the control system enables to represent the elements which aim to reach the objectives [12] [13] [14].

This definition shows the importance to represent and to study the system at the global level (the level of the system of systems) and the detailed level, i.e. the level of each system. The first one allows to understand the whole system and to consider its whole objectives and structure and the second to understand each system separately in terms of practices and of control of these practices.

One of the main problems, in the running of system of systems, is then the interoperability problem. This interoperability problem can be then defined at different levels, contributing to the E.I. science base definition:

- At the level of each system,
- At the level of the system of systems, it means between the various systems of the network.

3. Contribution of System Theory to the development of EI Science Base

There are mainly two main scientific approaches in the history of sciences: natural sciences and sciences of artificial.

In the domain of natural sciences, the main objective of scientific investigations is to observe the real world phenomena, to explain it based on some hypotheses, and to verify those hypotheses are correct.

In the domain of sciences of artificial, the objective is different. This domain is also called engineering sciences which aims at elaborating solutions to achieve a pre-defined engineering goal (control, design,…).

Concerning the Enterprise Interoperability domain, how can science contribute to its development?

As a science of explanation, the natural sciences can provide concepts and methods for observing the phenomena of non-interoperability and for explaining why systems are not interoperable. A better understanding of non-interoperability problems might lead to development of adequate solutions to solve these problems.

On the other side, concerning the role of engineering sciences (i.e. science of artificial), it can contribute to elaborate scientific solutions to solve interoperability problems. The criteria to judge a scientific solution, is the repeatability and verifiability. In the future, based on the improved understanding of enterprise interoperability problems, repeatable and verifiable solutions can be built.

Philosopher Karl Popper (1902-1994) considered that a statement is only scientific if this is open to the logicalpossibility of being found false [15]. This means that interoperability problems and solutions must be therefore tested in real systems and situations.

To explain the phenomena of non-interoperability that can be observed in various situations, the following hypotheses can be made:

(1) Enterprise systems are not interoperable because there are barriers to interoperability that obstruct exchange of information and services.

(2) Barriers are different kinds of incompatibilities and can be found at different levels and sub-domains in an enterprise.

(3) Heterogeneity is the source of Incompatibilities. Whenever there is heterogeneity in two collaborating systems, there is a risk of non-interoperability

(4) Barriers can be specifically linked to a particular application in a specific domain; however there are generic barriers which are common to all situations of non-interoperability.

One of the requirements to develop a science base is to define an 'instrument' to use for observing the phenomena of non-interoperability. However this is difficult because non interoperability problems are not always directly observable. They may be only observed through their consequences, such as for example, the impossibility to communicate, the impossibility to use or to understand the transmitted information etc.

On the other hand, system theory can also provide concepts to represent interoperability problems through modelling approaches. One of the coming research subject identified is to develop formalisms (modeling constructs) in the frame of the enterprise modeling domain to model interoperation / interface problems and requirements for interoperability.

Another requirement is to definean 'instrument' for measuring the different degrees of interoperability [16] [17]. As it is obvious that interoperability is not a binary state (all or nothing), metrics for measuring interoperability levelare needed to base any research in this area withan objective to keep a rigor basis.

In the Framework for Interoperability defined in the frame of Interop NoE, the phenomena of non-interoperability is approached and three categories of barriers (dimension of interoperability barriers) have been defined [18], namely conceptual, technological and organizational barriers. These barriers can appear in the four interoperability aspects (dimension of interoperability concerns): data, service, process, business. These two first dimensions composed the problem space of enterprise interoperability (see figure 4). The intersection of an interoperability barrier and an interoperability concern is the set of interoperability problems having the same barrier and concern. A solution is considered as relevant to interoperability if it enable to remove at least one barrier for at least one interoperability concern. In such ways, the scientific interoperability research is problem driven.

Some examples of interoperability barriers and problems are illustrated in the figure 3 below. For example, at the cross of conceptual barrier and process concern, one interoperability problem is the impossibility of exchanging process model information between IDEF3 and BPMN models because of the syntax incompatibility between these two models.

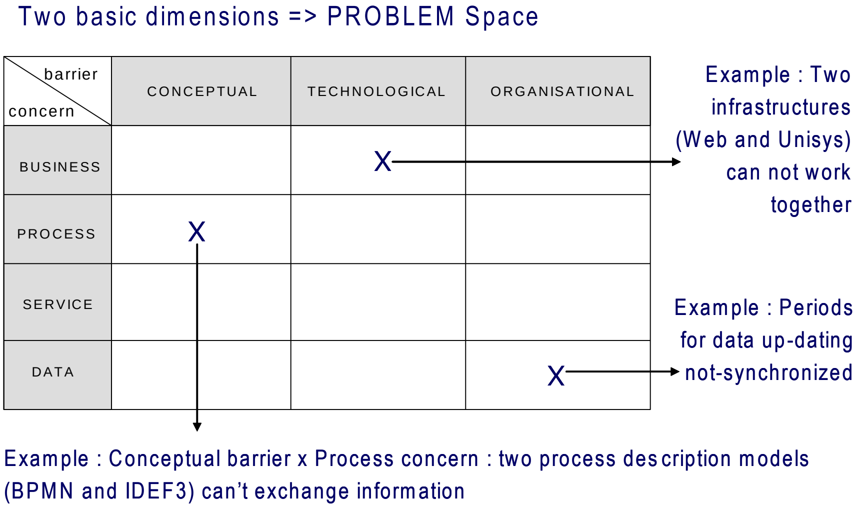

Figure 3: The problem space of enterprise interoperability

The third dimension that must be added is named interoperability approach (integrated, unified and federate) (figure 4). The three dimensions together (also see figure4) composed the solution space of enterprise interoperability. The cross of an interoperability barrier, an interoperability concern and an interoperability approach includes the set of solutions to breakdown a same interoperability barrier for a same concern and using a same approach.

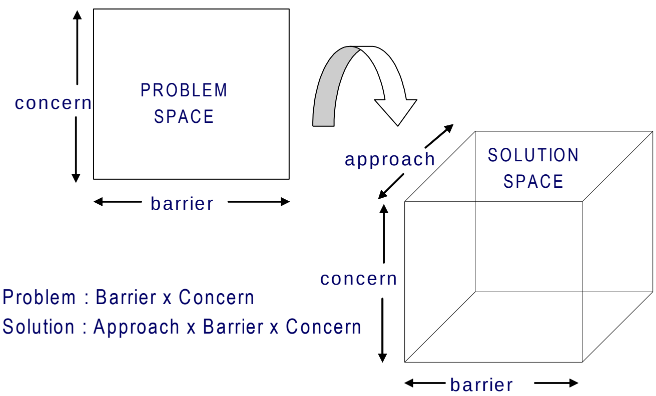

Figure 4. Problem space vs. solution space of enterprise interoperability domain

Indeed based on the hypotheses made, the research in Enterprise Interoperability domain consists in elaborating solutions to remove barriers (i.e. incompatibilities between systems or components of systems that are concerned by interoperations). Therefore another requirement to develop a science base is to identify in all relevant existing sciences, the concepts, principles and methods that allow removing incompatibilities. This is defined as one of the grand challenges in the roadmap for enterprise interoperability published by the European Commission [19]. Among these sciences, system theory (or System of Systems) is considered as one of the most important ones.

Among the three categories of barriers (conceptual, technological and organisational), the organisational barriers can be best dealt with system theory.

The organisational barriers are concerned with the incompatibilities of organisation structure, decision-making procedure and management techniques implemented in two enterprises. Indeed if two companies have different organisation structures (ex. hierarchical vs. networked) and management techniques, some necessary mappings may need to be done before the two systems become interoperable at the operational level. More precisely the three followingorganisational requirements (barriers) to meet are:

- Responsibility needs to be defined to allow the two parties knowing who is responsible for what (process, data, software, computer,…). If responsibility in an enterprise is not clearly and explicitly defined, interoperation between two systems is obstructed.
- Authority which defines who is authorised to do what. For example, it is necessary to define who is authorised to create, modify, maintain data, processes, services, etc. and who is authorised to take decisions in case of problems, etc.
- Organisation structure refers to the style by which responsibility, authority and decision making are organised. For example one can consider centralised vs. decentralised organisations, or hierarchical vs. matrix or networked organisation structures.

These organisational barriers (or problems) can concern four interoperability aspects, namely: data, service, process and business. Among these four aspects, the system theory can contribute in particular to solve problems of process interoperability and business interoperability thanks in particular to the global and local structure modelling and to the common (system of systems) and specific (system) functions and objectives identification:

- The interoperability of processes aims to make various processes work together. In the case of the networked enterprise, it is necessary to study how to connect internal processes of two companies to create a common process (collaborative process for example). In this sense, the modelling of the network processes and the definition of the systems objectives contributes to the process interoperability definition and solving.
- The interoperability of business refers to the ability to work together at the levels of organization and company in spite of the different modes of decision-making, methods of work, legislations, culture of the company and commercial approaches etc. In this sense, the definition of system functions and objectives and of system environment and evolution contributes to a first step in the business interoperability problems solving.

The system theory can also contribute to propose solutions for the three main approaches in order to relate systems together to establish interoperability, namely:

- *Integrated Approach:* itmeans that there is a common format for all models. Diverse models are built and interpreted using/against the common template. This format must be as detailed as the models themselves. The system structures are aligned in this case and common objectives are defined.

- *Unified Approach:* It means there is a common format but it only exists at meta-level. This format is not an executable entity as it is the case in the integrated approach. Instead it provides a mean for semantic equivalence to allow mapping between models and applications. In this case, the system functions are coherent and common objectives are defined.
- *Federated approach*, there is no common format at all. To set up interoperability, parties must accommodate and adjust 'on the fly'. The use of the federated approach implies that no partner imposes their models, languages and methods of work. In this case, only common objectives are defined but each system keeps its own structure and its own functions. The environment of the systems must be accurately defined in order to adapt continuously the interoperability requirements 'on the fly'. This is also crucial to identify the potential of evolution of each system.

It has been considered that a scientific approach for Enterprise Interoperability research should be problem-driven. Considering interoperability as a problem is remarkable. Interoperability is a requirement inside a system, whosematurity depends on the interactions or composition among itscomponents. This is the same for the system itself, when it needs to besufficiently flexible to interact with another system, or when itneeds to be open to new components. As soon as this ability is notachieved when systems or system's elements need to operatetogether, interoperability becomes a problem that must be solved[20]. The basic concepts of the Framework for Enterprise Interoperability is modelled in relation to a system approach and integrated in OoI (Ontology of Interoperability) initially developed under INTEROP NoE and progressively enhanced in [21] (see figure 5).

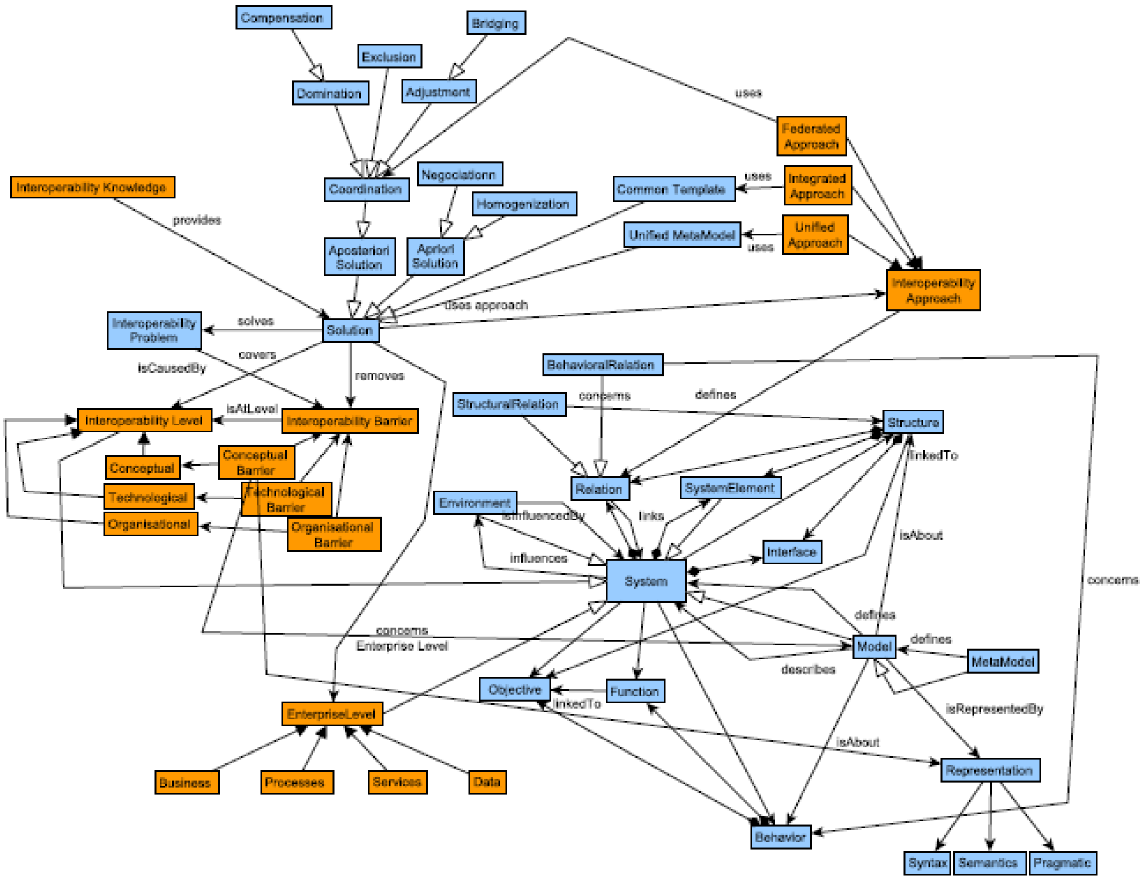

Figure 5. System theory based Ontology for Enterprise Interoperability

In figure 5, basic concepts of the enterprise interoperability (framework) are represented in ‘orange colour’ around the three concepts: enterprise level, interoperability barrier and interoperability approach. System theory concepts are represented in blue colour and consist in two parts: system concepts (right part in figure 5 around system concept) and upper part (left) representing system theory solutions around the ‘solution’ concept. Enterprise level (data, service, process and business) is referred to system concepts represented at the right side. Interoperability approach concept (integrated, unified and federated) is related to ‘relation’ concept of the system theory. Interoperability barriers are removed by solutions provided from system theory perspective. For example (see figure 5), to solve interoperability problems (by removing the three kinds of interoperability barriers) using a federated approach, there are two types of solutions: a priori and a posteriori. A priori solution consists in negotiation and homogenization actions before the beginning of an interoperation. A posteriori solution takes place after collaboration starts. It consists in a domination, an adjustment or an exclusion.

According to the Ontology of Enterprise Interoperability presented in figure 5 [22] [23], Enterprise interoperability problems are caused by the interoperability barriers (of three types) which exist at four different enterprise levels where system entities operate to fulfil their missions. A system has objective, function, structure, behaviour and operates in an environment. There are two types of relations that impact interoperability: structural relation and behaviour relation. A system can be represented by various models in which the mismatches of incompatible syntax and semantics are main problems of non-interoperability.
So, based on these assumptions, the table 1 below summarizes and explain possible contributions of identified system theory concepts and principles to enterprise interoperability development. The 1st column lists system concepts /principles presented in the ontology. In the 2nd and 3rd columns, the ‘x’ indicates if the concept or principle contributes to EI problem space and solution space. Necessary explanations are given as remarks in the 4th column.

Table 1. Contribution of system theory concepts and principles to EI development

System theory concepts / principles	EI problem space	EI solution space	Remark
Objective, function, behaviour, structure, environment	X		Their differences (heterogeneity) in two systems are sources of EI problems
Relation	X		Interoperability problem may occur when one puts two entities in relation
Model, representation,	X	X	Model and representation can be considered as both problem (semantic, syntax,…mismatch) and solution (explicit description)
Interface	X	X	Interface is a solution to relate and map two entities. But inadequate (or ill designed) interface is also source of EI problem
Metamodel		X	Metamodel is used for mapping (example: unified metamodel considered as a solution)
Coordination (domination, adjustment, exclusion)		X	They are a posteriori solution principles
Negotiation, Homogenisation		X	They are mainly a priori solution principles to harmonise differences (heterogeneity)
Common template		X	This is a solution principle to support integrated approach or unified approach (used at metalevel)

The table 2 below gives non-exclusive examples of barriers to enterprise interoperability [24] and relationships to system concepts and solutions.
An ID is given to each barrier allowing categorizing the barriers according to the framework. This ID is constructed according to the following syntax: <type of barrier>’/’<type of concern>’-‘< number within this category>, where the types are identified by the first letter in their respective names. For instance, O/P-2 is the second organizational barrier at the process level. The description of barrier is expressed as the heterogeneity (or difference of things) considered as the source of incompatibilities (barriers).
In this table, the last column gives the relevant concept(s) from system theory and solution elements that is/are used to remove the barrier according to system theory concepts described in figure 5.

Table 2. List of the barriers with ID, name and a brief description

Id	Name	Description	System concept
C/D-1	Data content	Coverage, i.e. content, of the respective data representation	Representation, Model, Information System structure
C/D-2	Data syntax	Heterogeneous data format and structure	Representation, syntax, Information System structure (homogenisation or mapping)
C/D-3	Data semantics	Data meaning disagreements	Representation, semantics, Information System structure (Semantic annotation, mapping)
C/S-1	Service content	Differences in the coverage, i.e. content, of the services offered	Function concept, Representation, model
C/S-2	Service syntax	Language/formalism syntax used to describe the services	Representation, syntax (homogenisation, mapping)
C/S-3	Service semantics	The meaning of services descriptions	Representation, semantics (Semantic annotation)
C/P-1	Process content	Coverage, i.e. content, of the processes	Behaviour (Coordination)
C/P-2	Process syntax	Process description language grammar and graphical representation	Representation, syntax (homogenisation, mapping)
C/P-3	Process semantics	The meaning of the processes description	Representation, semantics (Semantic annotation)
C/B-1	Visions, strategies & Culture	Differences in the respective companies goals, views, etc.	Objective, environment. (Domination, adjustment, negotiation)
C/B-2	Business syntax	Format, template or model used for describing enterprise business	Representation, syntax (homogenisation, common template, mapping)
C/B-3	Business semantics	Meaning of terms used to express business issues	Representation, semantics (Semantic annotation, mapping)
T/D-1	Exchange format	Protocol or format available to exchange information	Interface, representation, (Metamodel, common template)
T/S-1	Service granularity	Definitions of what constitutes the services, i.e. interface problems	Interface, structure
T/P-1	Process behaviour	Order of operations in the computerized processes	Behaviour, function, objective (Model)
T/B-1	Degree of computerization	How much of data, services and processes that are automated in IT	Objective, function
T/B-2	IT requirement fulfilment	The ability of IT to support the requirements of the business	Objective, function
O/D-1	Information ownership	The structures for assigning rights to data (different rights for different partners)	(Organisation) structure
O/D-2	Classified information	Differences in which an information is to be regarded as classified with respect to the collaboration partner	Organisation (Homogenisation)
O/S-1	Service management	Incompatible service management rules and practices	Organisation (structure)
O/P-1	Business process behaviour	Order of operations in business processes	Behaviour, model (negotiation, homogenisation)
O/B-1	Legislation	The legislative requirements that influence different actors.	Environment (homogenisation, mapping)
O/B-2	Organization structure	How enterprises are organized on a high level	Relation, (organisation) structure, model
O/B-3	Methods of work	High level differences regarding how work is performed in the organizations	(Organisation) structure (homogenisation, adjustment)

However,the barriers listed in the table 2 are not exhaustive and need to be further identified and completed. For each barrier, the solution needs to be identified in the solution space. For example, PSL (Process Specification Language) [25] contributes to remove *conceptual* barrier (both syntax and semantics) concerning *process* through an*unified* approach. Figure6 shows the position of PSL solution in the framework.

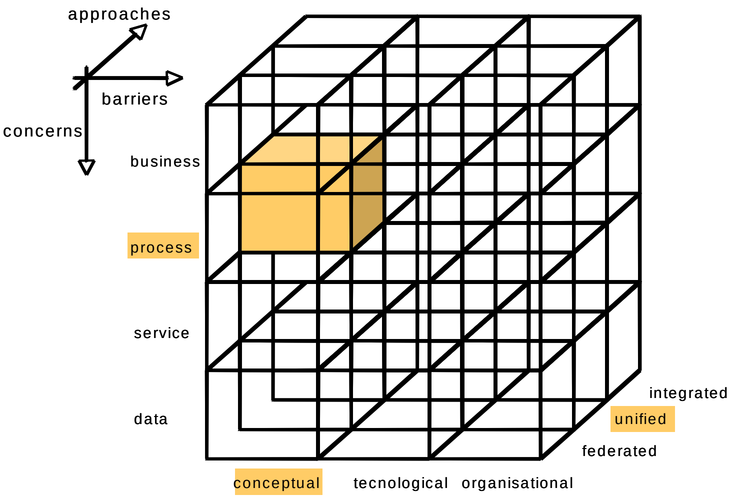

Figure 6. Position of PSL in the framework.

Finally, the last problem to solve is the continuous management of enterprise interoperability to go towards sustainable interoperability.

In this sense, system theory must enable to identify interoperability problems, to evaluate performance of interoperability and to facilitate the identification of decisions to make in order to implement new interoperable solutions.

Moreover, the contribution of system theory to interoperability, and in particular organisational interoperability problem solving and then science base, depends on the system life cycle phase which is considered.

There are two types of solutions depending on the life cycle phase [22]: *a priori*i.e interoperability solutions during the system design and *a posteriori*i.e. during the execution of the system.

For *a priori* solutions, system has a structure and behaviours, and most often, the structure determines the behaviour. Stating that some systems have higher interoperability potential than others, one can deduce that these interoperable systems might have some common structure characteristics can be defined. It means that some structure patterns supporting interoperability. System Theory allows toidentifysystem properties or attributes that must be amplified to improve interoperability potentials, such as openness, adaptability, flexibility, re-configurability, modularity etc. These properties must be designed in the system as *a priori* solution.

For*a posteriori* solutions, three systemic solutions for interoperability can be considered: (1) Exclusion (rejection of a problematic subsystem), (2) Domination (modification of the system's structure while keeping its original objective), and (3) Adjustment (limitation of the action field of a sub-system) [23].

System theory might also support the three main phases of interoperability problem solving during both phases of system life cycle:

- Identification of problem, through the consideration of the system structure and then of the structure of system of systems,

- Evaluation of interoperability level in the system of systems through the consideration of system finality and objectives to reach in the frame of this finality,
- Interoperability improvement through the modification of the system structure in the system of systems. This last point is linked to the management of system evolution in order to reach a sustainable interoperability all along the collaboration between systems of system as presented in the next part of the paper.

So, contribution of system theory concerns organisational interoperability characterisation, evaluation and evolution management. Indeed, as explained previously, organisational interoperability is mainly related to the coherence of decisions and practices inside each system and between systemsof system.

Indeed, system theory will allow torepresent the decisional structure insisting on the hierarchicallinks between decisions,enabling to define also responsibilities and authorities at the global and the detailed levels of decision.

Moreover, system theory allows to consider and represent business processes and practices at different levels of granularities, from the global activity of the system of systems, to the detailed activities of each system, and allowing continuously to link all these practises.

System theory, allowing to identify system objectives and structure also allows to characterise organisational interoperability authorities and responsibilities. The system theory is also very useful to represent and understand decision coordination and synchronisation and then improve the control of the system of systems and its evolution.

Other contributions of system theory to sustainable enterprise interoperability have been studied in [23]. Several characteristics of systems can be observed to determine their potential forinteroperability. Based on [26],the main characteristics are considered as follows[20]:

- The *openness* of a system refers to relations between the system and its environment. A closed system, which does not or cannot interact with outside is itself not interoperable, as it cannot be connected to other systems. Exotropic systems, that can only send information to their environment, can be connected but have a poorinteroperability since they force other systems to be adaptable. Endotropic systems (that only support inputs from the environment), or mixed systems have a better interoperability since they are able to react to inputs coming to their environment.

- The *stability* of a system should be considered for interoperability. An unstable system will be prone to create interoperability problems due to its changing nature.

- The *adaptability* of a system is obviously an important factor for interoperability. A system that can self-react to changes and adapt its structure or behaviour accordingly while keeping its original objectives, has a greater interoperability potential with other systems.

- The *reversibility* is one of the properties that interoperable systems should have: Even if the implementation of the interoperability between two systems leads to their adaptation or modification, these systems have to be able to come back to their initial state (both from the point of view of structure and behaviour), when interoperation is over.

The interoperability of systems that have predictable behaviours, can be better quantified since their inputs and outputs can be matched more easily with other systems to interoperate with. This is true for causal and deterministic systems. However this is much more difficult for stochastic or undetermined systems for whose interoperability is hardly predictable.

However, in order to reach sustainable interoperability, systems must solve continuously interoperability problems and implement continuously new small projects to reach and to maintain interoperability. So, the following part proposes a specific method of evolution management to reach sustainable interoperability based on system theory concepts and in particular modelling and performance evaluation.

4 Towards sustainable interoperability management using evolution management method based on system theory

The aim of this part is to show how the concepts of ST are important to consider for the definition of a management evolution method to ensure sustainable EI.
Moreover, this part also aims to show how ST concepts can be considered when modelling a set of companies in order to ensure the interoperability of practices and decision making.

The aim of the following method (figure 7) is to manage continuously interoperability performance in order to reach a sustainable interoperability. This method is based on system theory and on the GRAI Evolution Method (GEM) [27]developed at the origin to allow isolated enterprises to move towards the organisational interoperability and the collaboration inside a network. The principle of this method is to manage system evolution like a continuous process. In practice, the evolution process is composed of a sequence of steps representing the evolution of the system states. In figure 7, GEM was modified to take into account interoperability problems. Then, two different enterprises are considered, the Enterprise 1 (E1) and Enterprise 2 (E2). One considers that before the beginning of the evolution they do not collaborate because of a lack of organisational interoperability.
The AS IS represents the model of existing systems, insisting on the part dedicated to collaboration. The components of the system are here described and formalisedin a coherent way thanks to the GRAI Conceptual model which includes system theory concepts: it is possible to better understand how the system is running and also to detect the points to improve. The system theory, using to identify systems objectives, structure and evolution, as presented previously,is useful for this part of the evolution method.

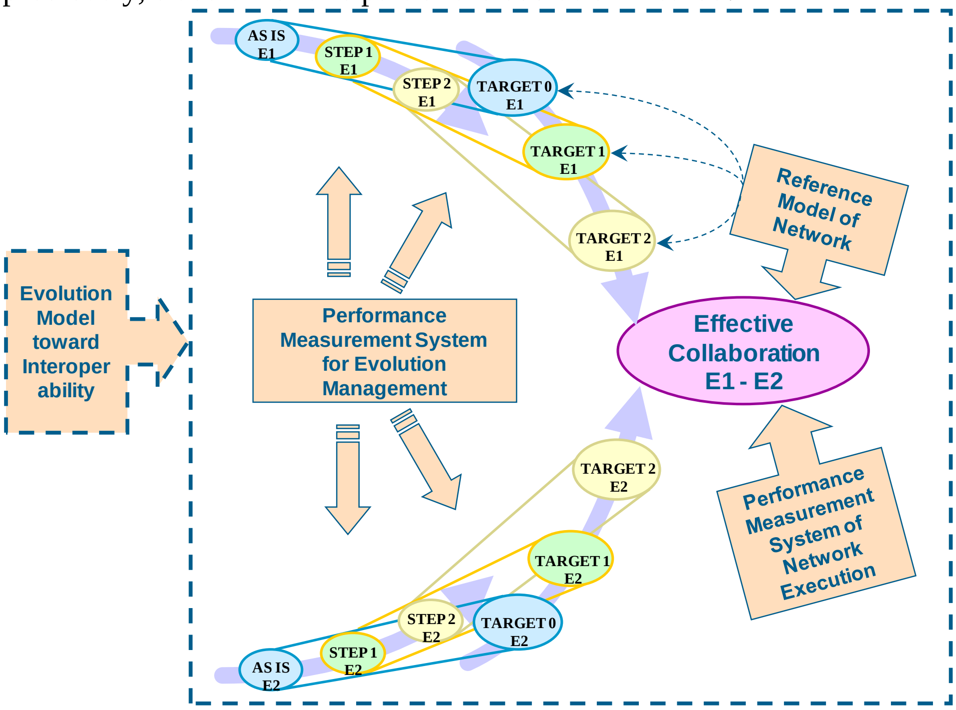

Figure 7: Method to manage interoperability convergence

The TARGET corresponds to the strategic objectives of the network. The TARGET implementation corresponds to the "Effective Collaboration" between E1 and E2. The STEP is an intermediate stage between the AS IS and the TARGET. It corresponds to the future system which will be implemented.
To validate each step, a performance indicator system is established. In fact, in this method, there are two different measurement systems:

- Performance Measurement System to manage the Evolution (PMSE),
- Performance Measurement System to manage the NetworkExecution (PMSNE).

PMSE is readapted at the end of each step and is transformed in PMSNE when the collaboration becomes effective. The final goal is an effective collaboration between the two (or more) concerned enterprises: E1 and E2. The main objectives for the future Network are described at the beginning of the evolution project. They result from a Network Reference Model and are validated by the PMSNE.

It is possible to further detail the management evolution process described inthe figure 8. Here, there are not only the AS IS, the STEP and the TARGET, but also a set of complementary steps which allow the definition of the three first.
This reduces the field of the evolution, being focused on the interoperability problems. When the model of existing system (AS IS) is defined, *points of interoperability* can be identified thanks to previous method. The *Users Specifications*are derived from the comparison between the AS IS and the TARGET. This comparison must be done for the business process and decision models and also at the global and local levels of running as proposed by ST. The Users Specifications concern flows, resources and activities modified and added to the system. These must indicate the technical and organisation solutions to integrate into the existing system. In most of cases, *technical solutions* refer to existing tools on the market. These tools have the advantage of being compliant to standard and of offering periodic updates. However, the greatest interest is an easy and controllableimplementation in term of time and cost. An intermediate *step* is characterized by the implementation of a project of change or an action allowing to establish an interoperable solution.

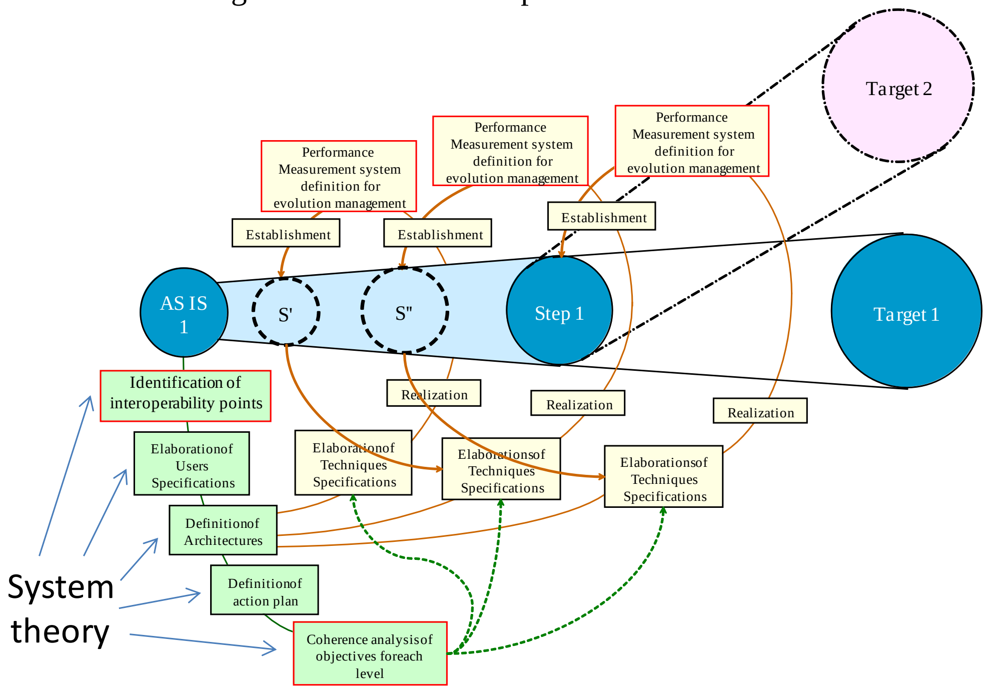

Figure 8: Method for sustainable interoperability management based on system theory

It is possible to identify various kinds of actions according to the priority of their implementation: strong, average and weak priority. The definition of the priorities associated with the intermediate states is done through the definition of an *Action plan*. When defining the action plan, it is necessary to valid the *coherence of objectives*of actions in comparison to the objectives of the network, in order to ensure that the implementation of actions will contribute to the Network objective's achievement. *Performance measurement system* must be defined, just before the action plan definition, in order to measureits effects after the implementation.
Thus, all this evolution management approach is required to reach a sustainable interoperability. Moreover, this approach is obviously in line with ST in the sense that the modelling of the various concepts of a system is performed, the environment is taken into account, the functions and the objectives of each system are identified in the decision modelling and of course the evolution of each system is considered.

5 Example of application

The objective of this chapter is to illustrate the previous requirements and concepts through a real case study, showing how enterprise modelling technique based on system theory allows in particular the characterisation of organisational interoperability. The companies belong to the furniture sector.

The furniture sector is a very complex industry regarding data sharing, process methodologies and business processes between organisations across the supply chain.

The EU furniture industry accounts for about half the world furniture production. The furniture industry is one of the largest manufacturing industries in the EU. The furniture industry in the EU accounts for 8,800 enterprises with over 20 employees, employing 600,000 people, and more than 80,000 enterprises with under 20 employees (employing almost 300,000 people). The SMEs which are mostly owned by families as a labour-intensive industry provide employment for around one million people including sub-contracting. Those companies are using a wide range of information systems, many of them developed by small software companies, usually in a very strong competition in the market. Design, production and available services are the major aspects that SMEs have to deal with in order to achieve the success.

The current usage of EI within the furniture industry is reduced to the use of internet for some email exchanges without a specific format.Everything is donemanually and in some cases the exchange of Information is done via postal mail or via fax.

In this project, the objective of the furniture e-Procurement use case wasto developinteroperable solutionsin two domains:the selling which is oriented towards the Customer (Retailer), and the procurement which is oriented towards the Provider.

The diagraminfigure 9describes the e-Procurement scenario, as well as the flow of documents between the different actors involved in the scenario: Retailer, Manufacturer and Provider. These documents are marked as follows:

R1, R2, R3, R4: these interactions are part of the Retailer's side of the scenario. In this part, the Retailer asks for information onfurniture's and receives the Manufacturer answers.

M1, M2, M3, M4: on the other hand, these documents are part of the Manufacturer procurement side. In this part, the Manufacturer asks for raw material and the provider serves it.

The figure 9shows the usual process between the different actors involved in the scenario including the Interior Decoration Project. The Interior Decoration Project is a draft performed by the Retailer according to the Consumer's requirements. In a Deco Project, the pieces of furniture are placed in a room which takes into account the special configuration of the future room (dimensions, shape, walls, and painting …).

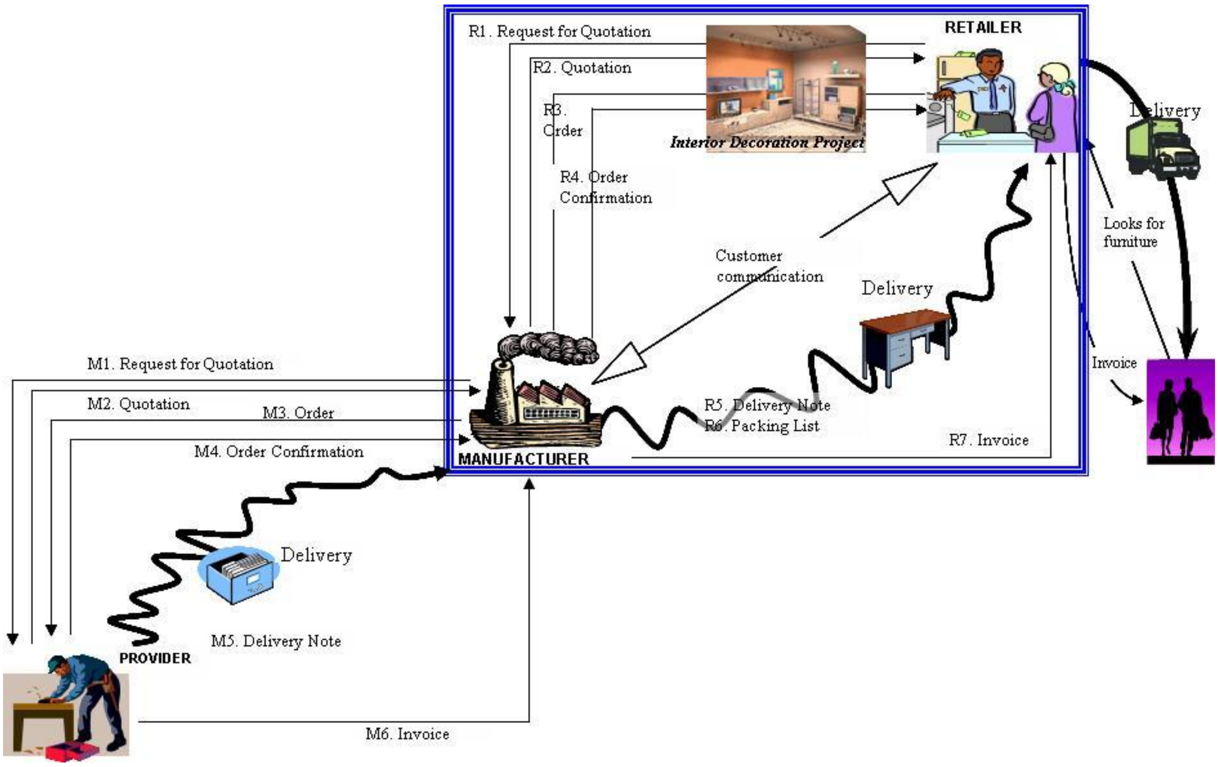

Figure 9: Document flow including the Decoration Project

Analysing the information already presented, it is possible to observe different interoperability issues at all three levels of the interoperability framework namely: Knowledge, Business and ICT levels. These are described below:

Knowledge level interoperability issues

- Confusion resulting from poor product descriptions (The clients often order the wrong products)

- Missing information, both from supplier and buyer (the furniture company has 3 people employed on the client side and one person employed on the supplier side to ensure the integrity of received orders and RFQs)

Business level interoperability issues

- Lead time from product order to the delivery could be reduced (a shorter lead time from ordering to receiving raw materials from the supplier has a direct effect on the delivery date of the finished product)

- Lead time spent to score suppliers (the furniture company performs tri-monthly reviews of their suppliers to ensure that standards are kept)

ICT level interoperability issues

- Repetitive manual process for regular bulk orders. Most of the manufactured products are generic and this involves repeated periodic processing of similar or identical orders.

Then, GRAI enterprise modelling method [12] [13], which is directly derived from System

Theory, was used in order to represent the running of the scenario in detail in order to understand interoperability problems from a business and decisional points of view.

It was necessary to model first the relationships between the three actors: Retailer, Manufacturer and Provider: This is "the system of systems". This action is directly linked to the concept of "global model". The result is given in the next figures:

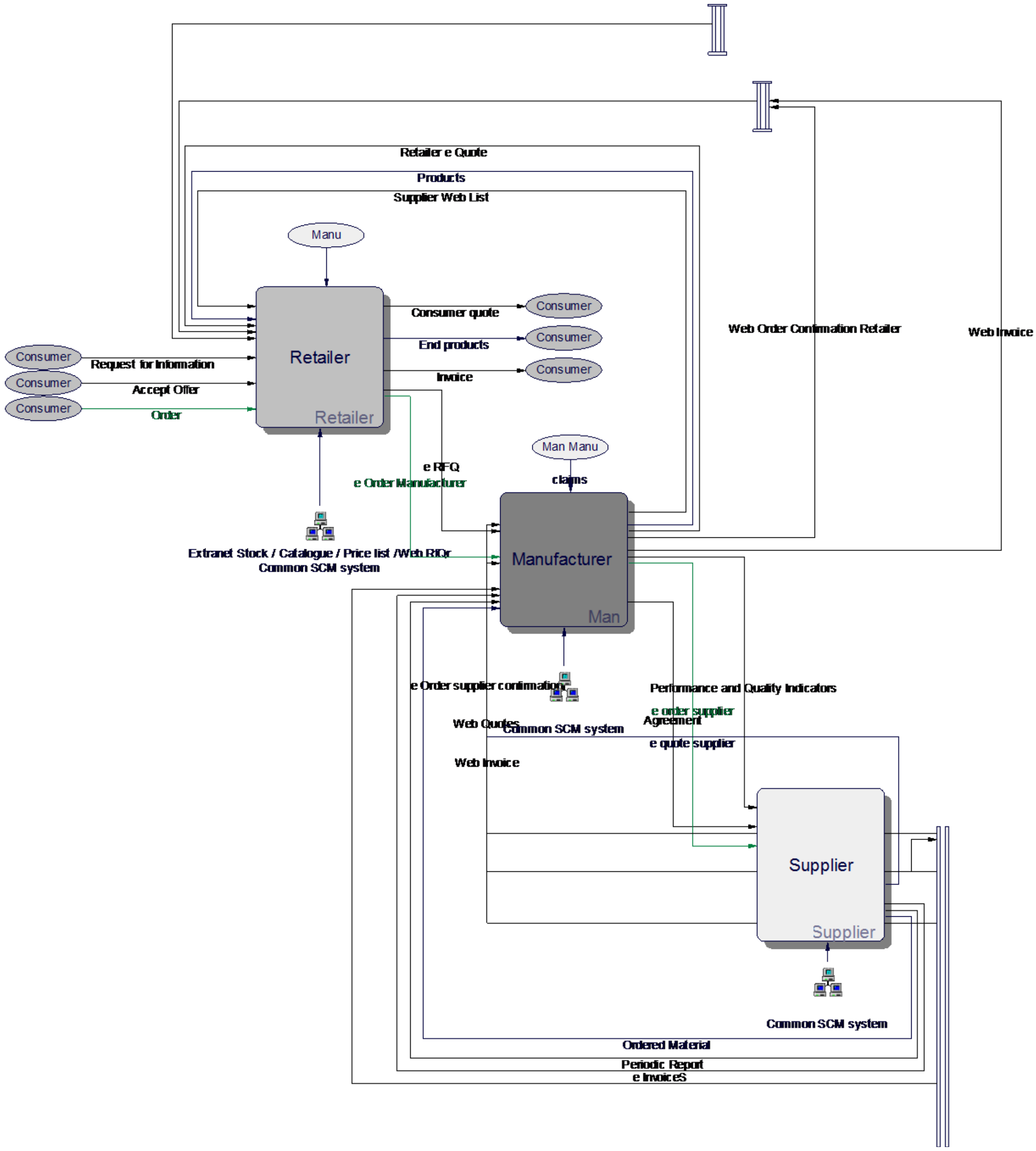

Figure 10: Interactions between retailer, manufacturer and supplier

The business process model above (figure 10) represents accurately the relationships between the retailer, the manufacturer and the supplier, as presented globally in figure 9.

Figure 10 shows that there are a lot of interactions between the three kinds of systems and then a lot of potential interoperability problems to solve in terms of software tools but also in terms of practices.This is the global modelling of the system proposed in the system theory in order to understand the global exchanges and the global interoperability problems between systems. The models highlight the importance to consider each system concept (structure, functions, and environment) in order to identify EIproblems.

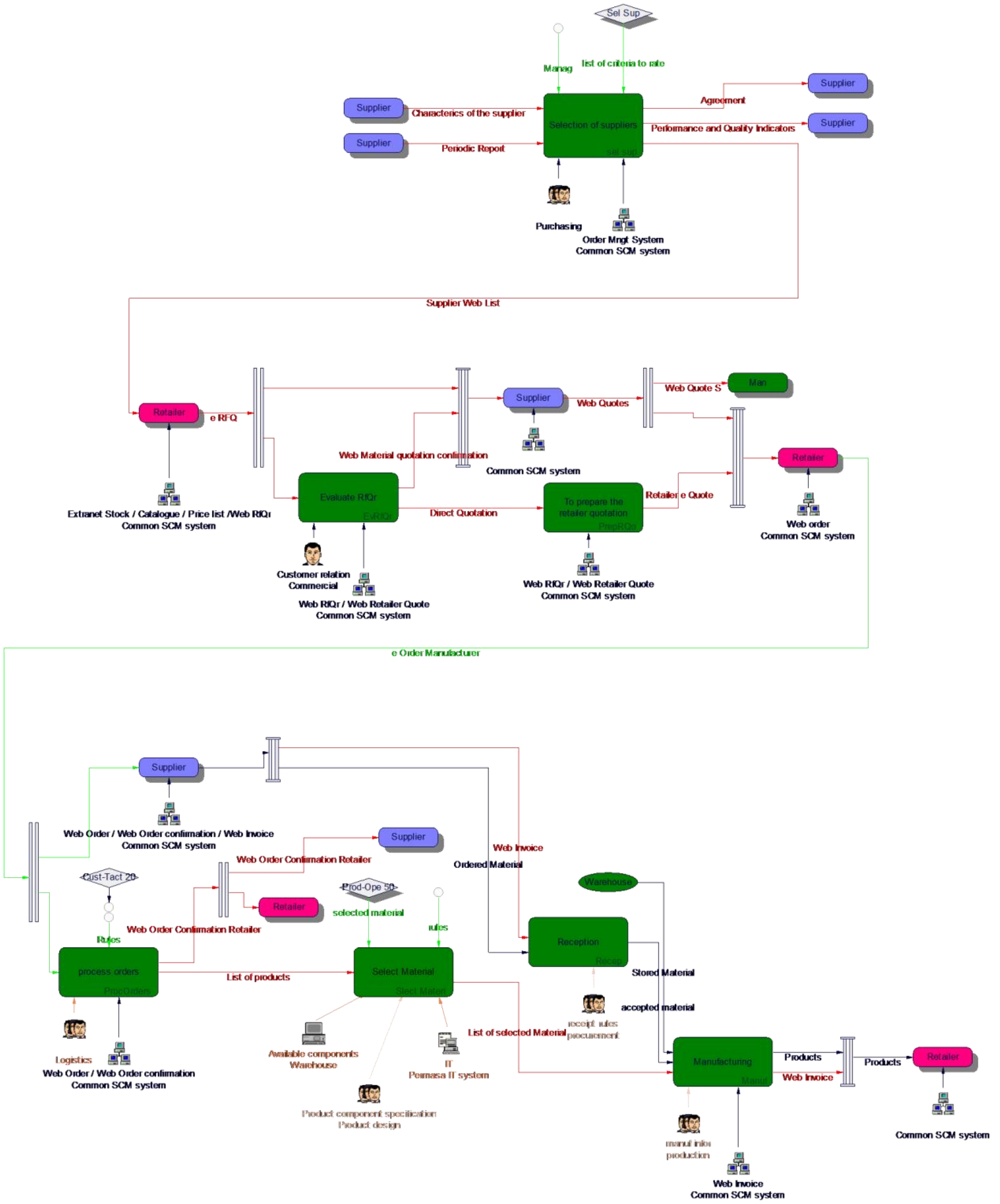

Figure 11: The business process of manufacturing

Figure 11shows the detailed manufacturing business process using the same concepts than the global one. This is an inclusive modelling as proposed by the system theory. This modelling allows to represent at which step of the process the various systems are in contact and then have to exchange information or products.This local/detailed representation, complementary to the previous one,is the second phase proposed by the system theory in order to identify and understand local problems. Indeed, the interoperability of tools and practice has a sense only in a certain context of use and this context is represented in this model.

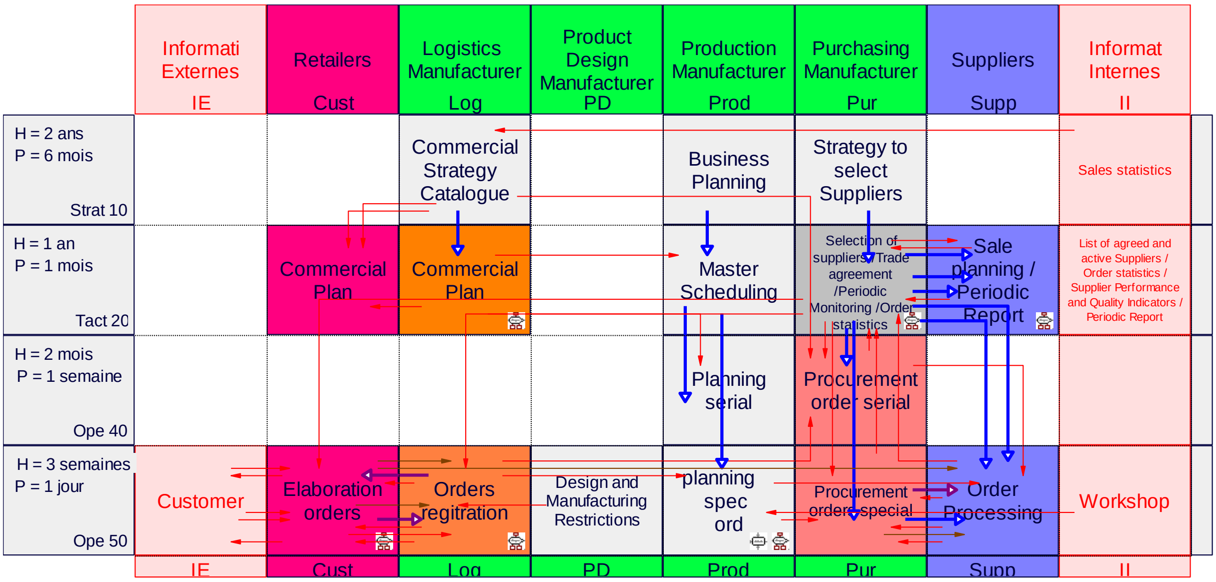

Figure 12: GRAI Grid representing the control of business processes at the global level

In the decision model presented in figure 12, the columns correspond to the functions of the various systems/actors. The retailer decisions in the column on the left, the manufacturer decisions in the four columns at the centre and the supplier/provider decisions in the column on the right.

Then this GRAI Grid represents the decisional interoperability problems between the various actors of the system of systems.For instance, the various decision frames (blue arrow) from the purchasing manufacturer function to the supplier, at the tactical level (level 20) shows potential problems in the collaborative decision making between partners. Indeed, the supplier may receive opposite objectives through these various decision frames.The decision frames include system objectives and decision variables as proposed in the ST.

Again, this representation at the global level aimsto consider the interoperability problems related to global objectives which must be coherent between systems, decisional structures which must be compatible between systems andenvironment.

Additionally to these interoperability issues, the following challenges have been identified:

- Media break: from paper and phone to Internet-based technology
- Integration of orders/quotations directly into ERP software's implemented in each system.

As the furniture is a traditional industry with small companies, in terms of technology use, most of the commercial transactions are performed in paper and by phone/fax. Therefore, there is a lack of integration among the different companies involved in the scenario. Solving these two issues would imply a clear change in their way of doing business, shifting from paper to e-documents and from phone/fax to Internet-based communication. Additionally, the solution would help in the integration of the commercial documents into their ERP systems, as the information would be easily treated.

7 Conclusion

In conclusion, organisational interoperability is one of the main interoperability requirements which are not very investigated in recent research works on interoperability.

System concepts and more particularly system theory which aims to represent these concepts in the real systems and system of systems, must strongly contribute to the organisation problem solving through: identification of decisions, responsibilities, authorities and organisational structure or decision system, identification of business process practices, all these systems being represented at the global and the detailed levels, with identifying links between the different levels.
The sustainable interoperability can be reached through the management of system evolution using modelling, objectives identification and performance evaluation all along the life of collaboration between systems.
One perspective of this research work is also to consider interoperability problems between different kinds of systems: ecological, economic, research… included inside the same global system or ecosystem. The science of global system is emerging and is undertaken at European commission instigation. So, it is then necessary to reconsider the system of systems concepts, to valid their existence in the global systems and to define the new emerging concepts. Then, it will be necessary to undertake research on EI to represent these concepts. However, EC has identified that business process and decision modelling are key points to represent and control such kinds of global systems as this is coherent with the work presented in this paper.

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