INTERNATIONAL DESIGN CONFERENCE - DESIGN 2010
Dubrovnik - Croatia, May 17 - 20, 2010.

USING PRODUCT DESIGN METHODS IN DESIGNING AND VALIDATING ENTREPRISE MODELS

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Keywords: enterprise model, model design, model validation, model function

1. Introduction

In our research, the enterprise is considered as a system evolving in an environment (the market, the concurrences, suppliers, humanity) with given objectives and generating certain values, this system carries out an activity (a set of processes) and sees its internal structure evaluating without loosing its unique identity [Bocquet 2008]. To handle the complexity and the ever-changing state of this particular system, many models are proposed to a point it is confusing to understand and use them. But as enterprises continue their evolution, we will be building new models to fit new enterprise needs that are mainly aimed at enhancing process performances. So enterprises use usually different models for each process without questioning the interoperability of those models and their impact on the coherence of enterprise's systems: The Decision Making System, the Information System, the Knowledge System and the Operations System [Barthelme et al. 1998].

Surprisingly, models design is rarely discussed. Studying models' design and models' validation can give us some criteria to assume that a model is more efficient and though will be better used. We estimate that those criteria can help decision making and give managers some arguments to choose between existing models

In this paper, we, first, draw a state of the art of enterprise models that will justify our focus on some enterprise models. Second, we present a design method to guide the building of selected enterprise models. The proposed design method is made clear by its application to a selected model. Third, we are proposing to validate the model through the functions it is fulfilling for the enterprise. And finally we present the perspective for our research.

2. State of the art of enterprise models

Numerous researches were carried on enterprise modelling proposing several modelling techniques and applying different tools. First, it is important to define accurately some terms like: an enterprise model, a modelling language and a modelling methodology.

Second, we give an idea about previous researches' results on enterprise models. Our state of the art does not enumerate previous papers but classifies them according to two major criteria. The first one is the part of the enterprise emphasised: enterprise functions, enterprise data or information and enterprise resources. The second one determines whether the previous papers refer to an enterprise model, to a modelling language or to a modelling methodology. The proposed classification of the state of the art justifies beginning our study by focusing on certain process models we define later on this paper.

2.1 Sorting through the terminology of enterprise models

Going through the research work on enterprise modelling brought many definitions of a model. Before studying the design and the validation of enterprise models, it is important to give a clear definition of what we consider as an "enterprise model".

A model is basically "every representation of a real system, whether it is a mental representation or a physical representation, that comes into a verbal form, a graphical form or a mathematical form" [Walliser 1977]. Concerning graphical models, each model is based on a modelling language. The language contains the main primitives (used to express real system and real systems components) and the rules to assemble these primitives to form the model. What is important for our research is that a model is a representation of a real system using a specific language. The language is formed by primitives and is assembled according to specific rules.

In the enterprise modelling literature, we distinguish between enterprise models which are designed especially for a certain enterprise system and modelling languages which are used for enterprise system and for other systems as well. We identify also previous research papers that go further than presenting a model for a unique process or viewpoint in the enterprise. Such papers presented, for instance, different models of the enterprise depending on the approach to adopt. We refer to these research results as modelling methodology as they give literally a methodology to link models of different aspects of an enterprise.

2.2 Classifying previous enterprise models

F. Vernadat [Vernadat 1999] identifies three important approaches for an enterprise model: the functional approach, the data/ information approach and the resources approach. From a functional point of view, the enterprise is considered as a set of functional activities or processes that contribute to the execution of planned actions. From a Data/ Information point of view, the enterprise is built on an information system that spans through each department and gathers the important information to run the company efficiently. From a Resources point of view, the focus is on resources (human resources, technical resources, knowledge…) needed to fulfil the enterprise projects. Some results of enterprise modelling are classified in Table1. We follow a chronological order beginning with the oldest ones and ending with the most recent ones.

Table1. A classification of enterprise models

Approach	Identification	Known as :
Functional	Modelling Language	SASS (Structured Analysis and System Specification)
Functional	Modelling Language	SADT Structured Analysis and Design Technique
Functional	Modelling Language	IDEF0 (Integrated Computer- Aided Manufacturing Definition)
Functional	Modelling Language	IDEF3
Functional Data/Information	Modelling Language	IDEFx1
Information	Enterprise model	ARIS (Architecture of Integrated Information Systems)
Information	Modelling Language	MERISE
Functional Data/Information Resources	Modelling Methodology	CIMOSA (Computer Integrated Manufacturing Open Systems Architecture)
Functional Data/Information Resources	Modelling Methodology	GRAI (Graphs with Results and Activities Interrelated)

Approach	Identification	Known as :
Functional Data/ Information Resources	Modelling Methodology	PERA (Purdue Enterprise Reference Architecture and Methodology)
Functional Data/ Information Resources	Modelling Methodology	GIM (GRAI Integrated Methodology)
Functional(Process) Data/Information Resources	Modelling Methodology	GERAM (Generalised Enterprise Reference Architecture and Methodology)
Functional Data/ Information	Modelling Language	UML (Unified Modelling Language)
Functional Data/ Information	Modelling Methodology	UEML (Unified Enterprise Modelling Language)
Functional	Modelling Language	SysML (System Modelling Language)

It is confusing and almost impossible to deal with all enterprise approaches at the same time and all models proposed in each approach. We, therefore, only consider enterprise process models. This approach is explained and justified in the following section of this article.

2.3 Selected Enterprise models

Process thinking has become widely used due to the growing concern for quality. An enterprise process is a sequence of actions transforming an input into an output using certain resources and adding value through the transformation. A process model ideally has to state the enterprise functions needed to be performed to realise the process (an enterprise functional approach), the data flow or information flow generated by the process (a data/ Information approach) and the resources consumed by the process (a resource approach). Hence, we can address the different approaches of an enterprise by studying its process models. Our scope is to focus on the three important business processes in an industrial company or the "key-success factors" [Srivastava et al, 1999]: the supply chain process, the product lifecycle process and the customer relationship process. The methodology we propose is mainly applied to Supply Chain Management (SCM) models, Product Lifecycle Management (PLM) models and Customer Relationship Management (CRM) models.

Our definition of an enterprise model is, though, more specific than the one presented by Walliser (that we already mention in section 2.1 of this paper). Models are mainly used by managers to view the process they are interested in and to enhance the management of this process according to the business plan of the enterprise. Indeed, according to us, a model is a representation of the real process in order to reduce its complexity, understand it and change it for better performances. An enterprise model for our research though doesn't depict only a real system but it allows performing changes on this system in accordance with the modeller's objectives.

3. Designing Enterprise models

Our purpose is to help to design new process models and access the existing models. Like a product, a model is composed of a list of components that are assembled according to a given order. Each enterprise model goes through two different phases within its lifecycle.

3.1 The model Lifecycle

Different lifecycle phases affect the design of any model. The closer we look at these phases the better we will deal with the model in the enterprise. Besides validating the model depends on which phase of its lifecycle we consider. There are two important phases in a model lifecycle: the design phase and the use phase.

3.1.1 The design phase of a model

In this phase, we consider the modelling methodology apart from its application. We focus on the methodology used to go from the real system to a given representation. Only the modeller is involved, the user of the model is not yet involved. Before designing a model of an enterprise process, it is important to clarify the components that are going to be used and the instructions to follow. We are exactly before the application of a modelling methodology, the modeller holds the modelling knowledge, and he is about to pass it to the users of the model or about to apply it himself. We access the clarity of the model's components, their definitions, the information they could contain and the way they must be assembled to form the model.

3.1.2 The use phase of a model

The use phase begins when the model's user understands the meaning of the model's components and the rules leading to build the model. Then, the real system (to be modelled) is accurately defined. Finally the model's user begins translated the components of the real system using the language of the model. Once the translation process is completed, we obtain the model of the real system; this model is in its use phase as it is strongly related to a given real system. In this phase we access the ability of the model to represent a real system, to reduce its complexity and to operate changes on it.

3.2 Proposing a methodology for designing a model

So, first of all, a model is based on a "modelling code". An easy understanding of this modelling code facilitates the use of the model.

A model is like a language; it is composed of structural words: the structural components that form the model. The syntax of the language dictates the rules of assembling these words in order to be understood by the modeller who forms meaningful sentences for the reader (who is in fact the user of the language). The language modeller and the language user could be different persons or the same person. For an enterprise model, the modeller could design the model for his own use or design a model for other users. Each model has its own syntactic rules that depict the way the model components are to be used in order to understand the whole structure. But sorting the words according to correct syntactic rules sometimes leads to meaningless sentences. So a model has to be checked both by the modeler and the user in order to assert that it corresponds to a real case or to a possible real case. Already we can say that these steps are rather important when designing a model:

- Determining the basic components of a model.
- Stating the syntactic rules of a model.
- Avoiding meaningless association by checking the consistency of the whole model according to the objectives of the modeler.

Being able to distinguish the structural components of a model and proving that it has coherent syntactic rules is already an indication that the model is well-structured. A coherent, easy to understand structure guarantees that the model will be better applied and though will meet the modeller needs

If we include these three recommendations, the steps to design a process model could be:

1. To understand the basic components of a model and the rules to assemble these components
2. To delimit the real system, we want to model its components, its functioning and the objectives of this real system
3. To state the objectives of the modelling process that is to say what we are expecting the model to perform on the real system
4. Translate the real system into a model using the model's components
5. To ensure that all the model's rules are respected
6. To verify whether the obtained model is coherent with the reality or not
7. To check whether the objectives of the modelling process are realised

In our research, we check the process models we are studying using these simple steps. From a syntactic view, we check that the syntax of the model can be easy to understand and apply. From a

semantic view, we check that the application of the model on a real case can lead to a meaningful result.
As an example, we are trying to access the design of a supply chain model: The Value Stream Mapping model [Womack and Jones 2003].

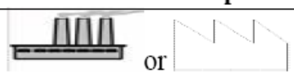
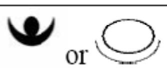
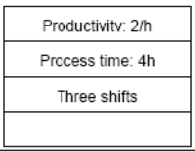
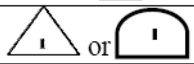
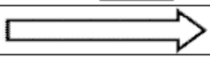
4. Applying the design methodology to an enterprise process model

In this example we are trying to apply the design steps introduced in the former section on the case of the supply chain process of a manufacturing company.

4.1 To understand the basic components of the model and the rules to assemble these components: The Value Stream Mapping (VSM) model

The VSM model is part of the "lean manufacturing" toolkit [Womack and Jones 2003]. The model is meant to represent the current state of a broad production supply chain (starting from the raw material suppliers and ending by the final customer). The main objectives of the model are to separate value – adding actions from non-value-adding actions, to determine the reasons of wastes in processes and eliminates its roots [Shingo 1989]. A VSM model could present many components, but the most used ones are introduced in Table 2.

Table2. The structural components of a Value Stream Mapping model

VSM structural component	Meaning of the component
	A supplier or a customer in the supply chain
	The presence of an operator executing an activity
	A production process in the production line
	A box holding the important data about a production process
	The application of a planned instruction
	A warehouse or a stocking supermarket (containing many items or goods)
	An intermediary stock point indicating the stocks level (of a particular item)
	Material flows (semi finished products) between different production process
	Information transmitted on paper or orally from an operator to the other
	Information transmitted automatically without the intervention of an operator
	Transport between the company, its suppliers and its customers (raw materials from the suppliers to the first process of the production process and final finished products to the customer)

The figures presented in Table2 are extracted from different VSM models in the literature. The meanings of each component are well known and do not change between the models. For example, a truck means that transportation is needed; a simple arrow means that information is being transmitted and a triangle indicates a stock point.

4.2 To delimit the real system, we want to model: its components, its functioning and the objectives of this real system

The Supply Chain is the set of procedures and software using for managing optimally the information flows, material flows and the interfaces between the different actors: suppliers, producers and customers that are related to the manufacturing of a product or the delivery of a service. All the data (from the customer requirement until the distribution scheme, through the conception and production) are gathered and used to build the supply chain [Eymery 2003]. In order to apply the model we took here the simple case of a manufacturing company, with two suppliers, two customers and a four-step-production process.

4.3 To state the objectives of the modelling process: what we are expecting the model to perform on the real system

The VSM model is expected to depict the supply chain, including the raw materials providers, the manufacturers, the distributors and the final product customer. It is supposed to make visible the different flows exchanged and to allow its evaluation. The main objective of the VSM model is to reduce waste and eliminated waste roots. In our case, the first objective of the model is to evaluate production and delivery times (the upper line below the production boxes in figure1) and to reduce them. The second objective is to evaluate the quantities of raw materials (the bold line below the production boxes in figure1) used and try to reduce it also.

4.4 To translate the real system into a model using the model's components

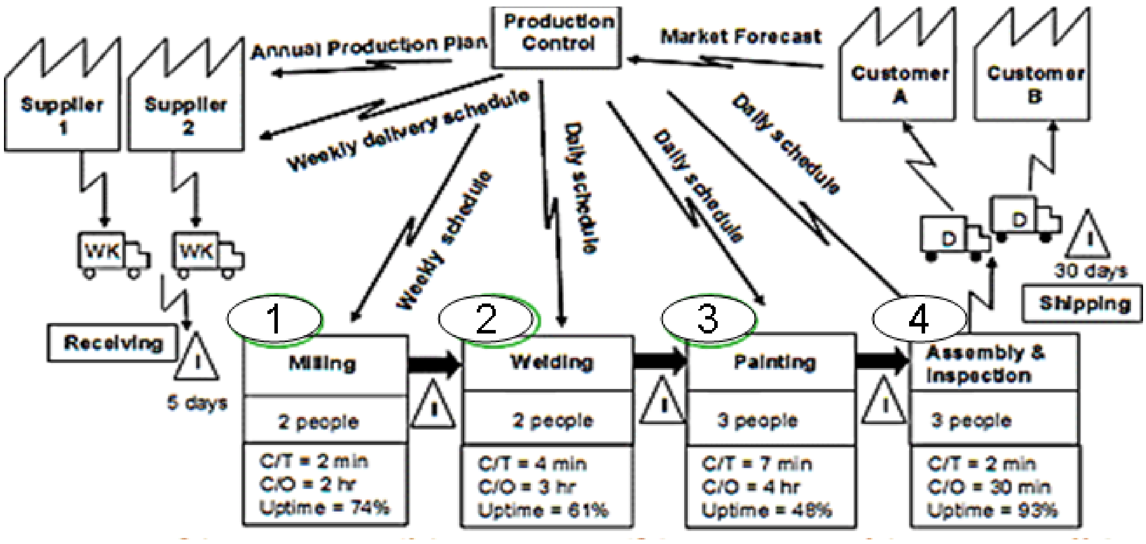


Figure1. An example of a Value Stream Mapping model

The example depicted here is of a company producing simple (two parts) steel tubes that has to be painted before the final assembly.

4.5 To ensure that all the model's rules are respected

In Figure1, the VSM model's rules are respected. The whole supply chain is depicted, performance measures are put on the right places and waste roots are visible. First, the supply chain begins by the suppliers and ends by the customers, the manufacturing steps are detailed in between.

Second, all the different flows are depicted: information and material flows. The manufacturing times are estimated according to the corresponding time line (the upper line below the production boxes in figure1). Information flows are mainly exchanged with the production control (market forecast, production plans…) And finally, performance measures are pointed out: manufacturing times, stock quantities, number of employees needed, time of shipment and quantities of material flows consumed at each step.

4.6 To verify whether the obtained model is coherent with the reality or not

Even if our model is that of a virtual company, we could see that there are no improbable associations. The model is acceptable and could be perfectly fit the case of a real company. But in a real case this step will mainly concentrate on establishing the acuity of the performance measures of the model and whether they are prone to depict the real performance measures on the supply chain.

4.7 To check whether the objectives of the modelling process are realised

The objectives of a VSM model are to depict the supply chain which is naturally met: the principal actors are at their due places, material flows are described and information flows are specified.
Then the determination of performance measures allows the managers to evaluate the efficiency of their supply chain and perform enhancements to improve these measures. The main concern in this model is to reduce stock times and reduce the quantities of materials used.

5. Validating Enterprise models

Most of the work related to model validation deals with quantitative models that are based on mathematical equations and formulas. Qualitative models are scarcely addressed. We consider a model like many other product for which certain criteria are to be validated, so our work is inspired from the Functional analysis methodology and the Quality Function Deployment methodology. According to our analyses of a model lifecycle, the validation of the model in the design phase is different from the validation in the use phase. During the design phase we evaluate more the model's language: the primitives and the rules to assemble them. Whereas during the use phase of the model we evaluate more the whole model as we have an example of its application in a real case.

5.1 The design phase of a model

In this phase we consider mainly the construction of the model apart from a real system it is meant to depict. In the literature, some papers define the important functions of a model and focus on the importance of these functions to validate the model and validate thought the choice of the model [Walliser 1977, AFIS]. Besides we consider enterprise models as products so we propose to adapt Functional analysis tools to process models.

5.1.1 The required functions to prove the model validity

Walliser [Walliser 1977] proves that all models are meant to fulfill a given set of functions. The four important functions are "the descriptive function", "the cognitive function", "the decisional function" and the "normative function".
The descriptive function states that the model makes a clear distinction between the "internal variables of the system" (its internal structure) and the external variables which are to be split into the "in variables" that enter the system and the "out variables" the system produces. A model with its internal components made clear and designed on strict syntactic rules is more validated if it provides different components to designate the different types of variables (internal, in and out variables) and states in its rules that these components can not be interchanged when designing a model of a real system.
The cognitive function assumes that the model has to be understood by a large number of people as it represents the internal relationship of the studied system (its internal structure). This function is made possible by the descriptive function that presents the "actor" providing the internal relationships within the system.
The decisional function states that the model helps predict and picture the evolution of the variables to exit the system in accordance with the changes of the variables that entered the system. These predictions can orientate the decision in order to meet or to avoid a predicted evolution of the system. Ideally, Walliser states that the decisional function is stronger if the model runs a procedure to check that a proposition is "true" or "false".
AFIS, the French Association of System Engineering [AFIS] consolidated some of Walliser's ideas by proposing a classification of the models according to the functions it delivers, particularly cognitive models and normative models. But, we are not discussing the "normative function". Walliser

[Walliser, 1977] defines it as the faculty of the model to create norms and references. In our research, we do not reach the point of questioning the ability of the model to become a norm or a reference model.

5.1.2 The Functional analysis to determine required functions of a model:

In product development field, the functional analysis defines the customers' needs. The aim of this methodology is to draw a complete list of functions that the product has to fulfil in order to answer corresponding customers' requirements. Then a value analysis is carried out to translate customer requirements into the appropriate technical solutions for each stage of product development and production. Once we have the required functions of a product and the technical solutions, we, finally, can check whether each technical solution fulfils or not the list of the product functions. The choice is directed towards the solutions that fulfil, in the best way, the product functions. The advantages of this methodology are that we consider the customer requirements from the design of the product and that we obtain validated criteria to choose between all the possible technical solutions.

For these particular reasons we chose to run a similar methodology on our system (an enterprise model). In this paper we begin by running a functional analysis that helps to identify the required functions to prove the model's syntactic validity. We followed "the external environments method" that considers the studied system at the centre of other systems, parts of its environment. The studied system has a certain number of relations with those surrounding elements expressed in terms of functions. The models environment, in its building phase, is composed of three important elements:

- The modeler
- The real system to be modeled
- The result of the modeling (the representation we get of the perceived system using the components of the model and its rules)

Figure2 depicts the model in its environment. In figure2 CF, bold black arrows stands for Contact Function, it links the model to only one of the elements of its environment. The function detailed then is a service, an action or a modification done by the model to this particular element. TF, black normal arrows stands for Transfer Function; it links two elements of the environment of the model. The function detailed here is essentially aimed at determining the nature of the links between two elements of the model. The model "transfers" the action of an element A to the element B.

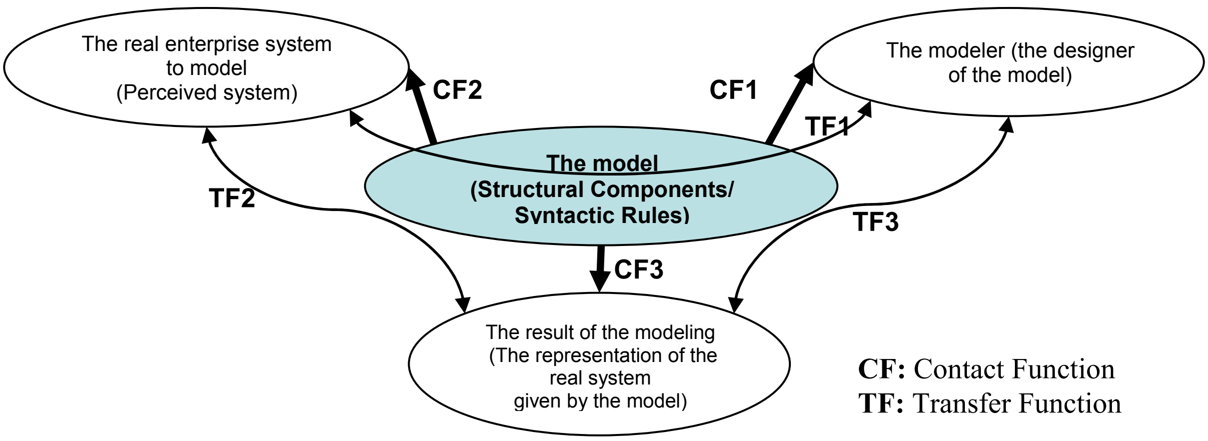


Figure 2. The model and functions between environments

The Connection functions are:

- CF1: The model must be easy to use for **the modeler.**
- CF2: The model must cover more than a case **of real enterprise systems** (not exclusively designed for a specific enterprise case). In the design phase of the model, we do not have, yet, an application on a real system, so the model has to cover different potential real enterprise systems.

- CF3: The model must provide a **modeling result** using its structural components and following its syntactic rules.

The Transfer Functions are:

- TF1: The model must help **the modeler** to understand, control or monitor **the real system**.
- TF2: The model must make it possible and easy to design **a modeling result** of **the real system** under study (the perceived system) (the modelling result expresses the modeller's vision of the real system using the model language).
- TF3: The model must present the necessary internal characteristics to help **the modeler** access and work on a **modeling result** (like simulating different scenarios, or predicting the system's evolution).

Studying more closely the Transfer functions of a model, we could find the same functions pointed out by Walliser. TF1 is about understanding the system by the modeler: it is mainly the "cognitive function". TF2 is about giving the possibility to represent a real system: it is mainly the "descriptive function". TF3 is about working a modeling of a real system. The decisional function will require also working on the modeling method to make choices concerning the real system so those two functions are similar.

To summarize our functional analyses (Table3 summarizes the set of functions obtained), we find out that the list of functions obtained, when filled in, guarantees a validation of the model. The connection functions guarantee the ease of use of the model, its possible adaptation to different real systems and the fact that we are sure to get a result. The Transfer functions are consolidated by Walliser analyses and guarantee the "cognitive function", the "representational function" and the decisional function" proved.

Table 3. The result of our functional analysis of a model

Contact Function 1	The model must be easy to use for the modeler
Contact Function 2	The model must cover more than one case of real enterprise systems (not exclusively designed for a specific enterprise case)
Contact Function 3	The model must provide a modeling result using its structural components and following its syntactic rules
Transfer Function 1 or "the cognitive function"	The model must help the modeler to understand, control or monitor the real system
Transfer Function 2 or "the descriptive function"	The model must make it possible and easy to design a modeling result of the real system under study (the perceived system) (the modelling result expresses the modeller's vision of the real system using the model langage).
Transfer Function 3 or "the decisional function"	The model must present the necessary internal characteristics to help the modeler access and work on a modeling result (like simulating different scenarios, or predicting the system's evolution).

Table2 and Table3 are meant to be a list of criteria to help choose the most efficient model to use on a certain process. The validation of the model is still to be completed during the use of the model.

5.2 The use phase of a model

As we said before, this phase begins when the model is applied to a real case. We have, thought, in hand a model of an enterprise process: a supply chain process, a lifecycle management process or a customer relationship process. We strongly believe that the model is validated when it meets the objectives it is designed for. A process model is validated in practice if process enhancements are proved. In fact a manager chooses the model for a given purpose and it is validated for him if this purpose is attained. The work of [Abdulmalek et al, 2007] with a VSM model confirms this idea.

6. An example of a process model validation:

To carry on our VSM model study, after building the model, we propose to validate it using the table3 that we obtained in section 5.1 of this paper.

Table 4. The functions of a VSM model

Contact Function 1	The VSM model must be easy to use for the modeler	A VSM model is composed of a set of pictograms that are easy to understand and use and rules that are simple and easy to understand for Supply Chain specialists but also for operational workers (who could have little knowledge about the global Supply Chain)
Contact Function 2	The model must cover more than one case of a supply chain	There are many cases of supply chains and the variety of symbols a VSM model displays should allow the representation of a handful of these cases
Contact Function 3	The model must provide a modeling result using its structural components and following its syntactic rules	The VSM maps and the improvement plan are modeling results. VSM symbols are used to establish the current state map and the future state map and VSM rules are used to constitute the improvements actions.
Transfer Function 1 or "the cognitive function"	The model must help the modeller to understand, control or monitor the real system	A VSM model gives a representation of the Supply chain for the supply chain managers and operators to understand how it works and monitor performance indicators like stock levels and production times.
Transfer Function 2 or "the descriptive function"	The model must make it possible and easy to design a modelling result of the real system under study (the perceived system) (the modelling result expresses the modeller's vision of the real system using the model language).	The maps of the Supply Chain are drawn using the VSM modeling techniques applied on the studied supply chain, the result expresses the modeller vision of its supply chain and allows the calculation of performance indicators.
Transfer Function 3 or "the decisional function"	The model must present the necessary internal characteristics to help the modeller access and work on a modelling result (like simulating different scenarios, or predicting the system's evolution).	The improvement plan that draws a future state map is the result of decisions to change the actual state map of the supply chain. Drawing a VSM model applies taking some decisions to perform some changes in order to obtain better performance criteria (like lower stock levels or shorter production times.

And finally the use phase validation of the model is strongly related to the company it is applied on, such us reducing manufacturing times, reducing raw material consumed quantities or changing the number of employees at each step.

7. Discussions and research perspectives

In this paper we focus on the design and the validation of enterprise models. It will take more than a PhD-study to consider all enterprise models under all viewpoints. We decide though to limit our focus to the important process models under the process viewpoint of the enterprise.

The design steps that we estimate a model must have are a way of building new process models like PLM models [Fathallah et al 2008] which are required to manage product lifecycle processes in an enterprise. The validation technique we propose is inspired from product design techniques, we perform a functional analysis centred on the enterprise model. This step provides us with a list of generic functions of an enterprise model.

The Value analysis of enterprise models will be conducted in collaboration with an industrial company. About twenty interviews are planned with employees working in different departments of the company (mainly departments managing the supply chain, the product design and the customers' relationship). The result is to draw possible solutions to answer the company's needs for models. The solutions will be completed by models we found in our state of the art. At this point we have the list of functions that a generic enterprise process model must fulfil and the solutions proposed in the industry. The final step is to check how each enterprise model fulfils the functions.

Other research perspective is to keep the coherence of the enterprise Information system and the enterprise Knowledge system. We believe that Information assets and knowledge assets are valuable resources in the enterprise [Boughzala and Ermine 2007]. The model interacts with both the enterprise Information System and the enterprise knowledge system. The challenge is to keep a coherent Information Systems and Knowledge system even if the enterprise is using different process models: supply chain models, product lifecycle models and customer relationship models.

8. Conclusion

A process-based approach can be considered as a good way to address the complexity of the enterprise. If we focus on the key- enterprise processes, there is a serious competitive advantage to be expected from this methodology. However the variety of modeling techniques is confusing. It is difficult to make a choice of the suitable model and method to be used. In this paper, we tried to set up a simple way to understand the design of models by determining the design steps necessary to build up a model. We define a set of functions to guarantee that a model will meet its objectives. Proving the model validity can help managers select the models suited to the needs of their enterprises without asking them to go through all of available models, test them and choose the ones giving the best results.

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