INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

HOW TO BUILD A DESIGN SYSTEM AND ITS END-PRODUCT SYSTEM? AN ORIGINAL APPROACH CALLED SCOS'

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ABSTRACT
This study presents a Systems Engineering (SE) approach to reach new objectives, especially in term of values creation (such as economic, environmental, societal and scientific values). This paper presents the definition and the modelling issue of an original extension of the SE methodology, called SCOS' (Systemics for Complex Organisational Systems). It focuses on coordination aspects between the Design System and the End-Product System (resulting from the design) and brings a new contribution to the Concurrent Engineering environment.
In a first part we present Systems Science or Systemics as our conceptual reference framework. Thanks to this methodology we consider two systems in interaction: the Design System and the End-Product System.
Our SCOS' general method proposed for both systems is presented. The expected finalities are clarified for each phase (step) of the life cycle and for each customer at the beginning of the general process, so that all the creating values processes are developed to meet these finalities.
In the second part of the paper, the links between the Design System (that is decomposed in subsystems: development, manufacturing, use, support, retirement system) and the End-Product System are developed.
In the last part, two study cases are presented:
- the design of a complex distribution network of hydrogen as an energy carrier for automotive;
- the design of a healthcare research centre.
The same generic approach has been developed to design two different End-Product Systems: a technical infrastructure and a research organisation.

Keywords: complex system, systems engineering, systemic approach, design management, concurrent engineering

1 INTRODUCTION
This study presents how apply Systems Engineering (SE) as a structured approach to coordinate design engineering. SE deployment has been chosen to reach new objectives, especially in term of values creation (economic, environmental, societal, scientific… values). This paper presents the definition and the modelling issue of an original extension of the SE methodology called SCOS' (Systemics for Complex Organisational Systems). It focuses on coordination aspects between the Design System and the End-Product System (resulting from the design) and could bring a new contribution to the Concurrent Engineering environment.
In a first part we present Systems Science or Systemics as our conceptual reference framework. In Structuralist epistemology, the knowledge of a system is developed according to a triptych (Three poles) [1].
- Ontological Pole: what the system is (means…);
- Functional Pole: what the system does (processes…);
- Genetic Pole: what the system becomes (phases…).

These means, processes and phases are designed to make the system fulfil its finalities (teleological aspect).

Thanks to this methodology we consider two systems in interaction: the Design System and the End-Product System.
In a second part of the paper, the links between the Design System (which is decomposed in subsystems: development, manufacturing, use, support, retirement system) and the End-Product System are developed.
In the last part, two study cases are presented: the design of a complex distribution network of hydrogen and the design of a healthcare research centre. We show how the same generic design method can be applied to a technical complex organisational system and to a research complex organisational system.

2 SYSTEMS SCIENCE FOR SYSTEMS DESIGN

The design process, the company organisation, the technical installations, with their human resources, are some examples of complex systems. Systems Engineering is a branch of technology management and engineering dedicated to controlling the design of complex man-made systems [2] [3] [4]. A complex system is a system whose behaviour can not be predicted regarding the behaviour of its components because there exist back loops in the interaction chains and because the response of the system is not the sum of the responses of its subsystems. As noted by P.L. Lewkowicz in 1988 [5] Systems Engineering is adapted for very large and complex systems, and can be used to improve customers satisfaction and profitability. In Structuralist epistemology, the knowledge of a system is developed according to a triptych (Three poles) Von Bertalanffy L. [6], Le Moigne [1]

- Ontological Pole: what the system is (means…),
- Functional Pole: what the system does (processes…),
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These means, processes and phases are designed to make the system fulfil its finalities (teleological aspect).
In this paper we consider simultaneously two systems in interaction: the Design System and the End-Product System.

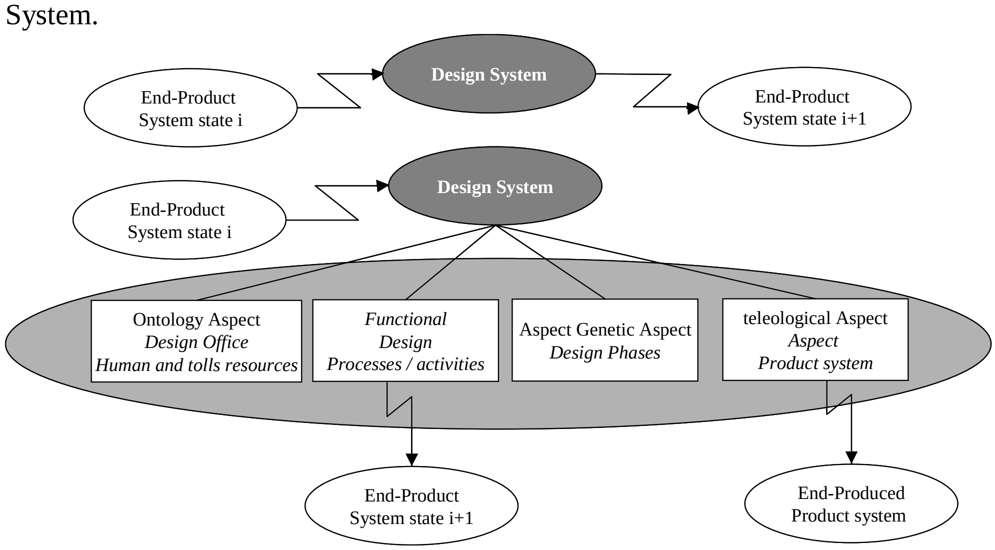

Figure 1. The Design System and the End-Product System

Le Moigne [1] defines a system as "an entity that, in an environment, equipped with finalities, carries on a design activity and sees its interne structure evolving through time, without losing its unique identity." From this general definition, we propose the definition of the Design System and of the End-Product System.

▪ The Design System is defined as "the entity (with its human and design tools resources) that, in the environment of the company (competitors, suppliers, market, etc), with the finality of formalisation of the End-Product System, meeting their needs, carries on the design activities and sees its internal structure (its organisation, its processes, its resources) evolving throughout its life cycle (according to the phases, such as feasibility, definition, detail studies etc), without however losing its own identity of design system".

▪ The End Product System (the system which results of the design) is considered as “the entity (materials, architecture, components, information, energies, users …) that in the environment of the product (competitors, suppliers, market…) has several finalities (specifications and values customers, sold quantity, financial margins, level of quality…), carries on their functionalities (to move, transport, protect...) and sees its internal structure (its structure, its functions, its entities) to evolve throughout its life cycle (according to the phases: design, production, use, maintenance, recycling...), without however losing its own identity of product system”. During its design, the states of each End-Product-System’s components change.

These two systems (Design System and End-Product System) are considered as an “Industrial system” as any other systems of the company. In fact, each system of a company contributes to the same global finalities (i.e. company strategy), their components (processes, resources, phases etc) can be considered at the same type. So we obtain a generic model of an industrial system (cf. figure 2), particularly for the Design System and the End-Product System (if the End-Product System is a system of a company).

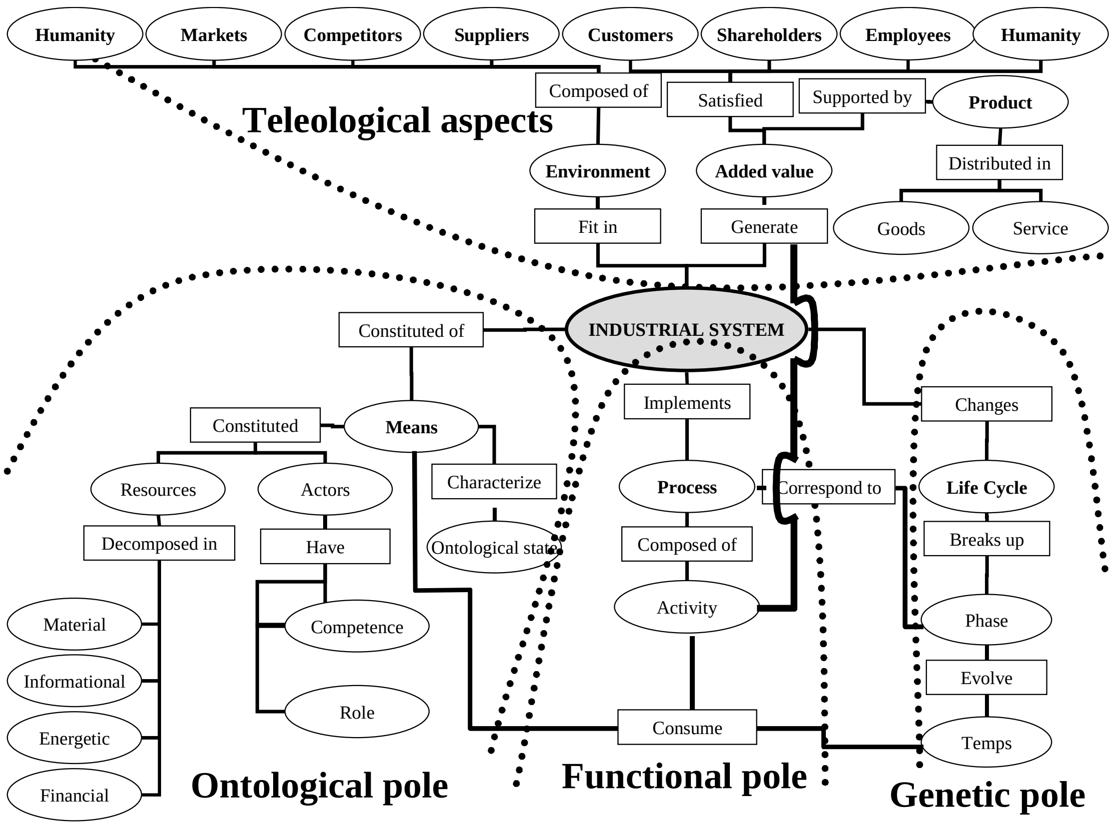

Figure 2. The generic model of an industrial system

Moti F. [8] and Lewkowics P. [4] precise that Systems Engineering considers all customers with the goal of providing a quality product that meets the user needs. Such works do not focus on the methodology to apply these systemic concepts in organisations. So we have developed an original general method called SCOS’ (Systemics for Complex Organisational Systems) that supports the Systems Engineering concepts. This general method proposed for each system is represented below (cf. figure 3). The finalities are clarified for each phase (step) of the life cycle and for each customer at the beginning of the general process, so that all the values creation processes are developed to answer at this finalities. It becomes “easy” to establish a feedback to control the efficiency of the processes. The processes are under control.

The quality of the design process and consequently the quality of the result (the end product system) depend of the quality of the finality expression. To express the finality, it is necessary to consider for each customer of each phase its ambitions, its expected values, its interests and finally, to synthesise these requirements.

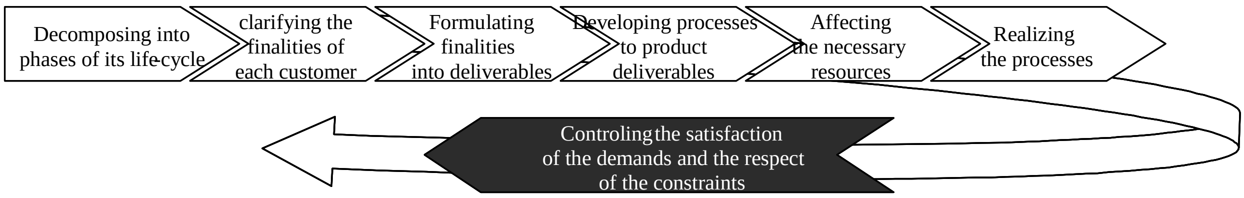

Figure3. The general method SCOS'

We propose to fill out for each Stakeholder of each phase the following table 1. At each finality we define a deliverable (or specifications of deliverable), finally this elementary deliverables are regrouped in some homogenous deliverables (homogenous deliverables that have a sense compared to the processes that will be necessary to their realisation).

Table 1. Steps to build the finalities

Phase :				
Stakeholder	Ambition(s)	Expected value(s)	Own interest(s)	Finality
Customer	…	…	…	….
…				

3 LINKS BETWEEN THE DESIGN SYSTEM AND THE END PRODUCT SYSTEM

So we develop the links between the design system (which could be decomposed in subsystems: development, manufacturing, use, support, retirement systems) and the End-Product System.

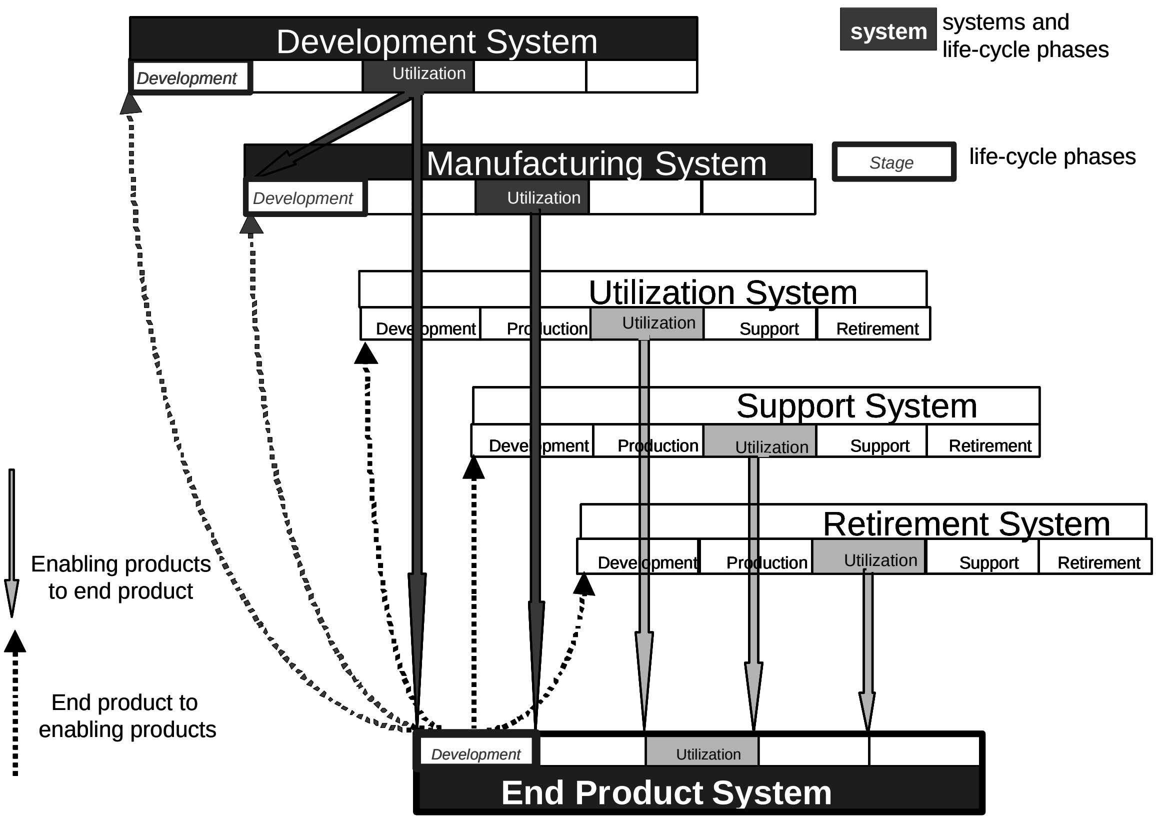

Figure 4. Links between the design system and the end product system adapted from [9]

We can indeed consider the global Design System which is composed of subsystems: development, manufacturing, use, support, retirement systems. In fact each subsystem contributes at the End-Product System through their links. So the management of their links constitutes an integral part of the design process. By example the phase of use of the Development System generates on the one hand the development phase of the manufacturing system specifications (decisional process) and on the other hand the implementation note of the End-Product System (informational process).

This generic approach SOCS' constitutes a real generic method of design. SOCS' could be applied indeed to design two different End-Product Systems:

- a technical infrastructure;
- a research organisation.

In the last part of this paper, two study cases are presented briefly, these two cases are more largely developed by Patay E [10] and Schindler A. [11] within the framework of this ICED' 07 conference:

- the design of a complex distribution network of hydrogen as an energy carrier for automotive. The objective is to design the best deployment of all required infrastructure for the French gas supplier Air Liquide to enter this new market;
- the design of a healthcare research centre. Organisational strategic objectives and stakeholders' points of view are taken into account thanks to this integrative method which allows designing agile organisations. This approach has to be iterated and is composed of many back loops and forth between integrated vision and detailed vision.

4 TWO DESIGN STUDY CASES WITH SCOS' METHOD

The first concerns the design of a future complex distributions network, with new technologies and a lot of uncertainties. We applied SCOS' method to realise an aided design tool, to build a technical economic model with SCOS'M as SCOS'Modelling. The second study case is the design of a future complex R&D organisation, we applied SOCS' method to design the organisation (that is for example decisional flows, informational flows and processes) and to produce maximal values (such as economics, scientific, environmental, societal values) with SCOS'D as SCOS'Design.

4.1 The design of a complex distribution network of hydrogen as an energy carrier for automotive

In the future, hydrogen could be used as a fuel for cars to satisfy objectives of reduction of carbon emissions. To make this fuel (hydrogen energy) usable, a vast distribution infrastructure needs to be developed. The Distribution Network of Hydrogen Energy (DNHE) does not exist today, it is necessary to design it. DNHE is a complex system; our SCOS' method is particularly adapted.

The challenge for potential energy market actors, like AIR LIQUIDE which wants to develop this business, is to measure the investments that have to be done in order to develop a distribution infrastructure satisfying cost objectives, environmental constraints and customers' satisfaction. We are in the feasibility design phase typically. The goal is to make a model and to use it in a simulation and/or an optimisation tool to select the best design options. Those tools are then used to choose between the possible technologies and to dimension the system.

We propose to use the SCOS' method as a modelling method supported by the own objectives of the system (objectives in term of technical performance, economical performance and also in term of environmental performance for each type of customer).

The characteristics of the DNHE (the system does not exist, a lot of uncertainties apply on the system, the limits of the system are not well defined and the actors of the system are numerous) drive us to apply the SCOS' method. Firstly, the DNHE system is decomposed into subsystems. Then, for each subsystem, keeping in mind all the links between them, the methodology SCOS' exposed with figure 4 is followed. This systemic approach requires initially isolating the system, regarding its relations with its surrounding. It obliges to specify the limits of the design field and the system to be conceived. The expression of the phases of the life cycle of the design system results "mechanically" in the consideration of its customers and surrounding specific needs (with a robust expression of needs).

To follow the steps of the approach, we will consider the whole system and decompose it into subsystems regarding the interactions between the pairs of identified subsystems.

For information: *The DNHE is composed of several stages from production to final consumption. Indeed, hydrogen (H2) is a gas which must be produced from different raw materials (natural gas, biomass…), transformed (compressed or liquefied), stored, transported and distributed to customers. Hydrogen can be produced from several primary energy sources. Subsequently, due to its very low volume density, hydrogen needs transformations to be stored and transported. Hydrogen can be compressed from a low pressure, out of production unit, to efficient storage pressures (we talk about Compressed Gaseous Hydrogen – CGH2). Hydrogen can also be liquefied (Liquid Hydrogen – LH2) making it possible to store ten times larger quantities in the same volumes than compressed hydrogen, but it needs a liquefaction step and the use of cryogenic storage and trucks. Another way of transporting hydrogen is as medium pressure gas (Gaseous Hydrogen – GH2) in pipelines. Hydrogen should be distributed to customers. Refuelling stations should permit to fill a tank in a reasonable time at a high pressure or as a liquid. Hydrogen could be delivered to the station in different conditioning, in bulk, as a liquid or a gas, or directly in full tanks.*

The preliminary degree of decomposition of the system into functional subsystems, verifying the material flows is proposed in Figure 5.

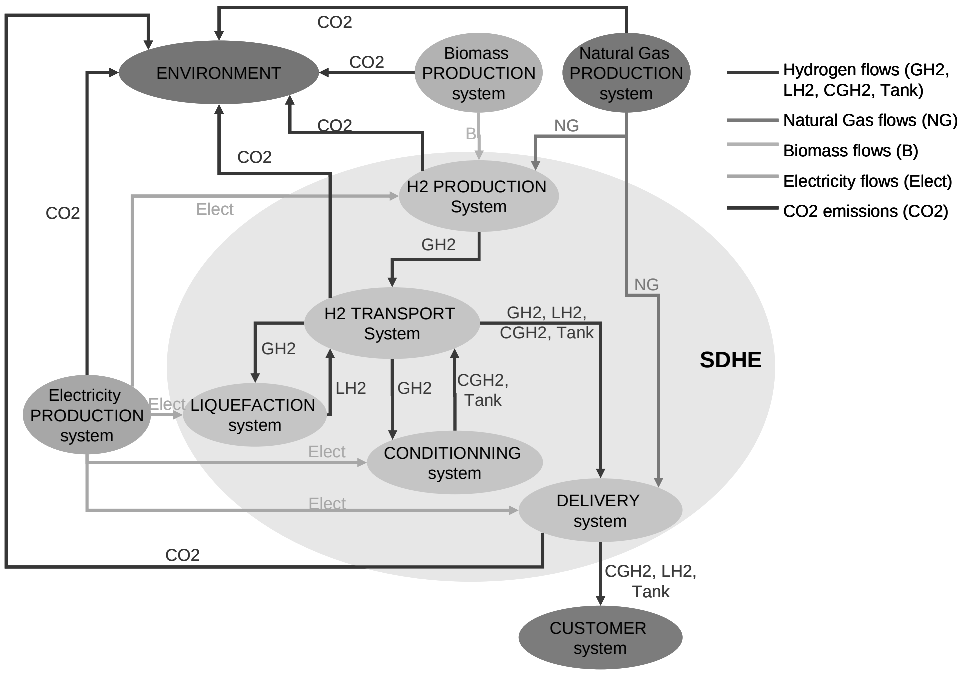

Figure 5. Presentation of the system of distribution of hydrogen energy (extracted from [10])

The system description method presented with Figure 5 was applied to define the teleological (finalities, objectives), ontological and genetic aspects of the DNHE. We present only, in Table 2, the teleological aspects.

Table 2. Description of the teleological aspects of DNHE from [10]

Teleological aspects	The DNHE fits in an **environment** composed of:	
	Markets	- energy in transport - heating for residential - …
	Competitors	- current fuel suppliers - current hydrogen suppliers - …
	...	
	The DNHE generates **added value** supported by:	

	Goods	- hydrogen - at fixed pressure dependant of the application - …	
	Services	- supply fuel to motorists - supply energy to stationary clients - …	
	The DNHE generates **added value** satisfying:		
	Customers	- stationary applications: - availability - cost - flow	- motorists : - good repartition on area - availability - cost - velocity for filling
	Stockholders	- profit	

From this complete description of the DNHE, we use the functional analysis to determine the functions accomplished by the system (corresponding to step 2 of the method figure 3). Then, we identify the performance criteria (step 3): constraints or objectives, corresponding to each function the system should fulfil. This description reveals about thirty functions. Next step is, from those criteria, to make out the parameters and variables of the system (step 4).
The same approach was made for all subsystems, and reveals a list of variables and parameters. The application of step 4 of the systemic approach reveals a hundred variables and parameters necessary to model the system. Step 5 could correspond to the optimisation of the model we build with the identified variables. Step 6 and 7 correspond to its validation.
This example is detailed in the paper of Patay E. [10].

4.2 The design of a healthcare research centre

The second example deals with a systemic approach for the multi-criteria design of a research centre, called MIR*Cen* (Molecular Imaging Research Centre). This example is detailed by Schindler A. [11]. Here we show the principle of SCOS' application to the design of an organisation. MIR*Cen* is a research centre of the CEA (Commissariat à l'Energie Atomique) on preclinical imaging for gene and cell therapy. Its main objective is to facilitate and accelerate new drug creation and development thanks to the gathering on a single geographical site of technological skills, medical skills and industrial network.
The general objective of this research is to design, anticipate and improve the management of such a pole of competence, especially in terms of costs and creation of values (such as scientific, environmental, social or ethical values).
Our systemic approach SCOS'D (Systemics for Complex Organisational Systems' Design) is used to design this new organisational system to meet in the best possible way the expectations of all stakeholders.
For information: *MIRCen represents about 6.000 m² and 80 permanent persons on the site and approximately 150 persons which are linked to the project, like physicians, mathematicians, chemists, neurobiologists, pharmacologists, clinicians or medical practitioners. The research topics are pharmacological tests, cardiovascular diseases, central nervous system diseases, hepatic diseases and AIDS. MIRCen has three goals: to develop fundamental researches, to develop innovative therapeutics and to develop and validate new tools of imaging. But it is not only a pole of development. It is a technological valorisation pole too and it has different formation missions.*
Performance, innovation and values creation are thus for this centre a priority. For this study case, the costumers are: the leader of the internal industrial partnerships, the scientific project manager of the future research centre MIRCen, the director of the Institut, the director of the general medical centre and the second-director of the Direction des Sciences du Vivant. This collaboration enables to regroup technical operational vision, organisational operational vision and strategic vision.
The most significant characteristics of this study case are the multiplicity of the stakeholders, the multiplicity of the values, the type of the system (an organisational system) and the phases (feasibility, design and production) to consider. The SCOS'D Design System and the End-Product System are presented in Table 3 in conformity with the SCOS' general approach proposed in the part 1 of this paper.

Table 3. SCOS'D general method and application to the Design System and the End-Product System (extracted from [11])

SCOS'D general method	Design System	End-Product System
Decomposing into phases of its life cycle	Feasibility study, preliminary study, study, launching…	Feasibility, definition, development, production, use, end of life…
For each phase, clarifying the finalities of each customer and the constraints of each environment	Working out a structure of research, an organisational structure to advance scientific research, to equip the country with means of research …	Producing high level scientific results, providing results of experiments, supporting new drugs development…
Formulating these finalities into deliverables	Argued report about the governance modes which have to be set up for the new R&D centre, a balanced scorecard of the creation of values…	A profit and loss account of the creation of values…
Developing the processes which are going to produce the deliverables	Design processes of the governance modes, of the balanced scorecard…	
Affecting the necessary resources to the activation of the processes	…	
Producing the processes	…	
Controlling the satisfaction of the demands and the respect of the constraints	…	

The aim of this study is to design and install the specific and appropriated processes for this system and its strategic objectives. From its principal issues and objectives, we can structure the necessary organisation. For instance, we can consider the first strategic driver "generate and produce original and innovative scientific results". In order to answer this objective, we need processes and flows which generate, produce and create the values. To realize the processes and flow we need human resources and means. Moreover, measure tools to define and evaluate the original and innovative aspects can be developed. Considering now the only two principal phases of the project (setting up and exploitation), we can associate each element (like process, flow or human resources) to an action to set up. We can then regroup these actions into systems and the links between them appear. We thus obtain a first structural organisation of the research centre (cf. Figure 6).

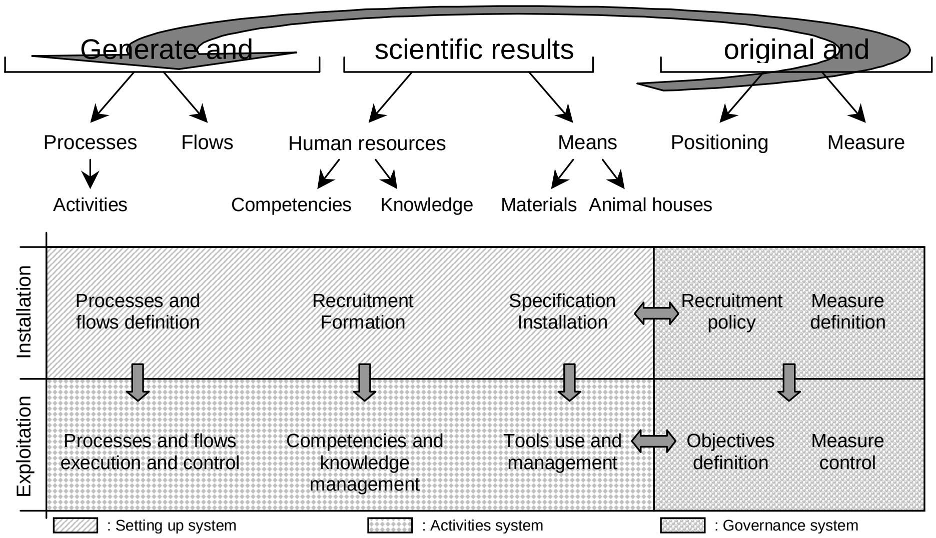

Figure 6. System decomposition method from [11]

This approach can be reiterated for each action. We consider then the action as an objective and we decompose it into needs (such as processes, flows, human resources or means), then into actions.
By applying this approach to the integrated research centre MIR*Cen*, a first modelling of this organisation is obtained (cf. Figure 6) as detailed in Schindler A. [11].

5 CONCLUSION

In this paper we present an original research on a method of research organisational structures and technical organisational structures design, called SCOS'. Based on a systemic approach inspired from the works of Jean-Louis Le Moigne, this method allows integrating all the company's stakeholders' points of view and expectations in order to design an End-Product System. This End-Product System can be a research system as much as a technical systems. The engineering design is considered as a system, just like the End-Product System resulting. The quality of the designed processes and of the results depends on the quality of the finalities expression. Indeed the SCOS' method clarifies the use of an approach SE, indeed for each phase of the life cycle and for each customer at the beginning of the general process, so that all the creating values processes are developed to answer at the defined finalities. It becomes "easy" to establish a feedback to control the efficiency of the processes. The processes are under control.
Finally, two different study cases have been presented:
- the design of a complex distribution network of hydrogen as an energy carrier for automotive. The objective was to design the best deployment of all required infrastructure for the French gas supplier Air Liquide to enter this new market. The technical/economic model (thus generated by SCOC'M) to choose the technologies of our complex system is considered relevant and powerful by Air Liquide;
- the design of a healthcare research centre, especially its decision system. Organisational strategic objectives and stakeholders' points of view have been taken into account thanks to this integrative method which allows designing agile organisations. This approach has permitted to consider all the creations of values expected by all the customers.
The same generic approach SCOS' has been applied to design two different End-Product Systems: a technical organisational system and a research organisational system. In both cases the application of this method allows to speed up the design process of complex systems.

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