Born in Madagascar in 1984, Rianantsoa Ndrianarilala obtained a grant in 2002 thanks to his secondary school results, which permits him to pursue his high studies in France. He entered in Lycée Fénelon, a preparatory class for engineering school integration in Paris. He managed then to get a master in Mechanical Engineering at SUPMECA in 2007. In the same time, he succeeded in obtaining a master in Design and Innovation Management at Ecole Centrale de Paris. In order to develop his knowledge and competencies in innovation management, he began to work on a research project on value-based conceptual design and became officially a Phd Candidate of Ecole Centrale de Paris and EADS in 2008.

**Abstract**

This paper is dealing with the problem of steering the conceptual design by value. Indeed, the preliminary phase of the design process, which generates the innovative concepts that will be developed in detail, already defines broadly the created value of an innovation project. In a contrary to the detailed design phase, the conceptual design is characterized by the fact that, at the beginning, the design objects are not still frozen, known or précised, and have to be defined progressively in a value creation way. Since there are few works on this issue, we tried then to bring new insight on the conceptual design structure and organization in order to enable the maximization of the created value of this phase, and so of an innovative project.

**Key-words:**
Innovation management, value creation, design concepts, knowledge management, question-based design

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Context and issue

The Concept-to-Value research project was launched by the method and tool department of Airbus in EADS group. It’s the coherent continuation of two previous projects:

- The Design-to-Cost (DtC) research project led by a PhD student of Ecole Centrale de Paris (Angéniol, ), which dealt with the support of cost reduction in detailed design phase.
- The Design-to-X (DtX) research project led by the method and tool department of Airbus, which dealt with cost and weight reduction in detailed design phase.

The industrial question was then to know how such value-based approaches (cost and weight reduction) of detailed design phase could be applied in preliminary design phase. The industrial objective was to deliver a method and tool for support of EADS projects in conceptual design for value maximization.

The academic objectives were to provide a descriptive model of the conceptual design dynamics for its capture and support, and a prescriptive model of value maximization.

1. Description of the scientific research contribution

Several research works deal with the issue of design process steering for the achievement of a given type of value. One can then quote some approaches like: Design-to-Cost, Target Costing (Meyssonnier, 2001), Design for Manufacturing, Design for Assembly, Design for Sustainability, Value Engineering (Yannou, 1997). All these approaches share the following characteristics:

- The type of value to create is a preliminary input: cost, weight, time, efficiency, sustainability...
- The design problems and targets are broadly well known
- The main purpose consists in generating the design solutions that realize the best way the value creation, such as the cost, weight or time reduction, or the efficiency increase. Some design problems solving methods are then used for this purpose, such as Triz, Axiomatic Design, Multi-disciplinary Optimization, Functional Analysis System Technique or Genetic Algorithm.

The context, in which the conceptual design phase has to be steered, makes the previous value-based approaches insufficient. Indeed, the preliminary design phase is characterized by the fact that it’s the phase of creativity (Nagai, 2006) and innovation: the CK Theory (Hatchuel, 2002) advises to avoid the psychology inertia and to lose the stable identity of the objects (the products, the processes or the organizations) by the exploration of new concepts and knowledge. Moreover, from marketing domain, the conceptual design is also the phase for the future product positioning among the concurrent ones to ensure a perceived and appreciated differentiation (Porter, 1986). Besides, this phase is also the consideration of the needed knowledge to acquire since it depends on the design problems and has an influence on the latter as well. In other words, the conceptual design is characterized by the fact that the reference objects that are used in more detailed design phase have to be defined: the design problems and targets, the knowledge, the expected value to create, and the solution concepts that realize the value creation. Since the previously described existing methods don’t suite to this phase, the research question consists then in finding a method to support and steer it for value creation in a period of the design process where almost everything has to be defined.

This research issue leads to make investigation on two sides. At first, a descriptive model has to be built for the description of the intermediate objects that have to be generated in conceptual design phase, their evolution and their inter-relations. At second, a prescriptive model is to be defined on the way the intermediate objects are to be produced and on the way their contribution to the value creation is measured and maximized.

2. Research methodology

First of all, an investigation was planned on Airbus practices and tools for value creation in a design project. It mainly focused on the As Is and To Be DtX practices and the DtX tool that support the cost and weight targets achievement in a design project. The deployed DtX approaches were studied since they represent the best practices of Airbus in term of design project management by value. The DtX practices and the DtX Tool functionalities were analyzed in order to define the expected added value of the CtV approach and the CtV Tool that have to be specified in this research project.

In a second time, in order to analyze in deeper way the industrial needs, a cluster was built between operational and research engineers from Airbus and Eurocopter working on aircraft systems design. The goal of this cluster is to experiment the use of DtX tool for the support of some systems design cases. Some types of intermediate objects, which appear in the design cases and which are formulated by the engineers, have already been identified and modeled using UML tool. The limits of DtX Tool for the support of conceptual design are to be described, and the new functionalities of the future CtV Tool are to be specified. This cluster contributes then in the definition of the descriptive and prescriptive models of CtV and in their validation.

In parallel to these industrial investigations, a scientific state of the art was made on the intermediate objects generated by the design process, on their representation...
and on their evolutions. At first, this leads to the study of research works on the first type of intermediate objects, which are the design solutions: works on concepts modeling, cognitive process of concepts development, concepts links were analyzed. At second, a study on design issues was undertaken: works on question-based design (Aurisicchio, 2009) and design problems modeling were analyzed. At third, a state of the art has also been made on knowledge management and acquisition process. These academic studies contribute in the definition of the CtV descriptive model of intermediate objects.

Finally, a state of the art was achieved on the innovation and design process, the design dynamics and value-based design management approaches. This last study permits to build the prescriptive model which shows the way to ensure value creation through the intermediate objects production.

3. Research results

The first research result is a descriptive model of the intermediate objects (Boujut, 2003) to be manipulated in conceptual design. It mainly consists of three types of intermediate objects: the issue, the knowledge and the solution:

- There are two types of issues: the design issues and the knowledge issues. The design issues represent the design problems that need to be solved. They correspond then to product requirements, functions or expected behavior (Gero, 1990). The knowledge issues describe some information requests and lead to knowledge acquisition tasks like technological benchmark, competencies hiring, simulation and market analysis. The knowledge issues are triggered off by the design issues.

- The knowledge or information acquired from the knowledge issues permits to build, refine or solve the design issues. The knowledge represents for instance the project team competencies, the project domain knowledge and the experiments results.

- The design solutions to the design issues consist of the design concepts, the scenarios and the ideas of concepts development. The design concepts represent the structural architectures and the behaviors of the solutions. The design scenarios are combinations of design concepts and answered higher level design issues. Finally, the ideas of concepts development describe the modifications or refinement of concepts that can appear for design problems resolution.

Besides, the decisions are also presented in the descriptive model and represent the choices to continue or not on working on the concepts, scenarios and the development ideas. Finally, the model describes also the contributions of the intermediate objects to the value creation. These contributions that have to be maximized will also be named as the values of the IO (intermediate objects):

- The design issues contributions can be assessed by the definition of the expected values to create that they specify, such as for instance the amount of cost and effort reduction, or the level of performances improvement that has to be achieved.

- The knowledge issues contributions can be evaluated through the importance or utility of the knowledge requests for value creation. The evaluation dimensions of this type of contributions will be described in more details below.

- The design concepts and scenarios contributions are assessed through the degree of realization of the expected value (the evaluation dimensions and the possible methods are explained below).

- The contributions of the ideas of concepts development can be assessed as well through the degree of achievement of the expected value that they trigger off. For example, their contributions are evaluated through the values of costs or weight decrease that they lead to.

The second research result is a prescriptive model that describes the process of the IO production for value creation and maximization in the preliminary design phase. The CtV process is an iterative process decomposed into seven elementary steps:

- First step: the initial design issue formulation. It corresponds to the first input of the project, to the project statement.

- Second step: knowledge acquisition. It consists in the implementation of different types of knowledge acquisition tasks or methods

- Third step: design issue reformulation. This step consists in the refinement or generalization of the initial design issue, or the establishment of a new design issue.

- Fourth step: generation of solutions. It consists in the implementation of different types of solutions generation tasks or methods.

- Fifth step: new design issues formulation. The new design issues are triggered off by the specification of the design solutions.

- Sixth step: evaluation of the values or contributions of the IO produced. This evaluation step has to be implemented after the generation of any type of IO.

- Seventh step: ordering, selection and decisions for values increase.
Concept-to-Value: method and tool for value creation in conceptual design
Ndrianarilala RIANANTSOA

Figure 1: Descriptive model of the conceptual design intermediate objects

Figure 2: Prescriptive model for values maximization in conceptual design
The last step of the CtV process has to be implemented after the evaluation of any type of produced IO. The values of IO permit then to order alternatives of IO (solutions, design issues or knowledge issues), to select the alternatives with the highest values, to make decisions either to continue or not on some alternatives, or to generate new ones for their values maximization. This process is iterative since it has to be repeated until it produces design concepts that create enough values. The prescriptive model is based mainly on the permanent evaluation of the IO contributions. A model of value of the IO has then to be built precisely. Such a value model describes as following the dimensions through which the contributions of the IO are assessed:

- Values dimensions of the design issues: the degree of covering of new satisfying usage surface, of covering of new satisfying subjective values, of implementation of new trends, of life cycle costs and efforts reduction and of performances improvement.
- Values dimensions of the knowledge issues: the degree of knowledge accuracy, the knowledge acquisition cost, the acquisition of knowledge on new technologies, on customers usages and preferences, on processes, methods and tools, and on market products.
- Values dimensions of the design solutions: the degree of design issues satisfaction (from design issues criteria and objectives), of maturity, of originality, of feasibility and of availability of proof of concept.

The previously described value model will be further developed and the possible methods of evaluation of the value dimensions will be presented and analysed.

4. Validation of the results and left research works

The descriptive and prescriptive models are being validated through their use on different aircraft systems design cases. The test cases deal with the design of innovative aircraft systems concepts that create value.

The validation process is performed within the previously described cluster of EADS aircraft systems engineers. This process is simply run in two steps for each test case:

- 1st step: capture of the design case. This step corresponds to the audit of the test design case and all the information that is given by the engineers on the case is captured by using the descriptive model of CtV. The IO generated by the engineers in the design case are then identified and captured, as well as their evolutions, relations and values. This step has to permit then to check the robustness of the CtV descriptive model for conceptual design capture. Thus, one has to verify that all the information given on the design case is defined by the descriptive model.
- 2nd step: implementation of the CtV process on the design case. The design case is then replayed through the use of the prescriptive model. This step permits to check the efficiency of the prescriptive mode for value creation and maximization. Therefore, the values of the IO generated with and without the CtV process are compared and one has to check that the implementation of the CtV process leads to the delivery of more valuable or interesting IO. This comparison has to be made for each type of IO, i.e. the knowledge, the issues and the solutions.

A first test is being made on the design of the radio communication and navigation system of a Eurocopter helicopter. The first results show that the descriptive model captures well the design case and is therefore robust, and that the CtV process leads to the generation of more valuable knowledge and design issues. The corresponding design solutions will also be analyzed. The validation process started on this design case was performed as following:

- 1st step: capture of the system design case. The initial design issue consists in designing a new system of radio communication and navigation (RCN) in the framework of a new civil helicopter design project. The project engineers already refine this initial issue by specifying two traditional functions to be satisfied by the RCN system: the ACAS function and the TDR function. The ACAS function consists in making two given close helicopters to communicate to each other and to avoid the collision. The TDR function consists in setting the radio communication between the helicopter crew and the control towers on the ground, and in giving the permanent position of the helicopter in the space thanks to the ground-based radars. The expected value to create of this refined design issue was a given amount of cost and weight reduction in comparison with existing RCN systems that perform exactly the same functions. For this design issue, two design concepts were captured: a baseline concept, which corresponds to the most existing RCN systems, is composed of two equipments satisfying separately the two functions; an innovative concept with only one equipment satisfying simultaneously the two functions. The value of the innovative concept is higher that the baseline one since it’s lighter and cheaper. Besides, some modification ideas were captured with their values for the cost and weight reduction of the two concepts. Finally, from the two concepts, two sets of design issues (for example the type of equipment connectors to be used) were generated for the design of their harness installations. Two harness concepts corresponding to the two RCN concepts were generated, as well as some ideas of modification for their cost and weight decrease (for example, the change of the steel wire into...
aluminum wire). Two global design scenarios were then identified for this design case: a baseline scenario defined by a RCN system concept with two equipments and its corresponding harness concept, and an innovative and more valuable scenario represented by a RCN system concept with one equipment and its corresponding harness concept.

- **2nd step:** implementation of the CtV process on the RCN system design case. The initial design issue (the RCN system to design) leads to valuable knowledge requests: knowledge on the customers needs, on the needs covered by the existing civil helicopters and on the new developed technologies are captured. The knowledge acquisition permits to refine the initial issue in a more innovative way and for more value creation. Besides the ACAS and TDR functions, the refined design issue covers new additional functions: the obstacle avoidance function that permits to avoid all types of obstacle (tour, tree, crane...). The ground visualization function to visualize the ground at any weather condition and the global navigation function to travel above desert areas. The expected value to create of the new refined issue corresponds to the possibility to travel everywhere and whenever. It consists then in covering a new usage surface and not simply in cost and weight reduction. The design solution concepts of this innovative design issue can be based on new proven technologies like the OASys (Obstacle Avoidance System), the GNSS (Global Navigation Satellite System) and the LiDAR (Light Detection and Ranging). The values of the concepts will be evaluated in deeper way through the CtV value model.

The main next step is to complete the value model of IO by defining a way to assess the global created value of a conceptual design. Indeed, the previous value model of CtV describes only the contributions of the IO separately and not in a global way. Therefore, this model should be completed by the definition of the relation between the global created value of a conceptual design process and the IO values. The validation process will then check the improvement of the global created value through the use of the CtV process.

Finally, a tool, named CtV Tool, will be specified for the support of the CtV process. It will permit to capture the IO generated during a conceptual design with their evolutions, relations and values, but also the made decisions. The CtV Tool will facilitate the implementation of the CtV process based on the descriptive and prescriptive models.

5. **Conclusion: limits and future research perspectives**

The CtV process is mainly based on intermediate objects capture and on their values assessment throughout all the conceptual phase. It aims at maximizing at any time the generated IO values. This method is novel and interesting since it considers that the IO contributions to the global value creation of a project should be measured and maximized. The limit of this method is the fact that it’s not based on a common value model of innovative projects. Such a model will permit to define and compare objectively the global created values of different innovative projects. The latter can then be added to the CtV process in its future development.

This paper presents a method to conduct the conceptual design for value creation and maximization. The CtV process aims to give the insurance to designers at any time of the conceptual phase that the generated design objects will contribute finally to the value creation and maximization. Such a method will permit the engineers to be confident in every step of the conceptual phase and to avoid the iterative design loops due to non-value creation, that consume development costs and time.

6. **Referees**

- Aurisicchio M. and Bracewell R. (2009), *Engineering design by integrated diagrams*, ICED, Stanford University