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(Article begins on next page)

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Francesca Montagna, Maria Franca Norese
DISPEA, Politecnico di Torino, Torino, Italy.

***Abstract*— Several people who are interested in the challenging possibility of producing an innovative light aircraft that utilizes hydrogen as a fuel, have decided to join their efforts in a collective project that involves researchers from different Departments of the Politecnico di Torino and a start-up company from the internal incubator.**

The main technical decisions were made during the first phase of the decision process, and the others are quite easy to make but the information on the consequences of making or buying decisions, in terms of time, cost and risk, are not shared and are often not present in the context in which the project develops.

The authors were invited to participate in order to support project management, i.e. to facilitate communication, coordination and decision-making. The paper proposes our methodological approach to face uncertainties and complexities of these multi-actor decision processes and presents the description of how the tools we chose for this application were integrated and used to elaborate and represent alternative solutions, to collectively evaluate and choose and to create a communication space for the project.

***Index Terms*— Decision Analysis with MCDA (1.1), NPD management and Communication (1.2)**

I. Introduction to the Problem Situation

The "Sky-Spark" project has recently been activated by several research groups at the Politecnico di Torino. The objective of the project was to demonstrate the feasibility of a piloted flight, with complete electric propulsion and energy derived from hydrogen fuel cells, and to create an innovative and "greener" light aircraft.

This project falls into a very particular temporal context. In 2007, the International Aeronautic Federation assigned the World Air Games (WAG) to the city of Turin. The games are like the Olympic Games, but for the sporting aviation activities and they are scheduled for June 2009. The WAG will certainly be a great source of attraction and will surely attract the media from all over world. The focal target of the project is the speed record for the light aircraft class and this event constitutes the occasion to attract the media and to provide exceptional visibility for the sponsors.

The technological and research context is also very particular. The evolution of systems for electric energy storage, due to the wide use of cordless electronic devices, has provided batteries with a high capacity per weigh unit. Moreover, the exploration of ecological solutions for the chemical production of energy has stimulated scientific research in the fuel cell field. Hydrogen represents the ideal element for energetic capability and environmental compatibility as it allows energy savings as lower polluting emissions and less noise to be obtained. Electric engines have already surpassed endothermic ones as far as efficiency and compaction are conceived. Brushless technology, which has been adopted in this project, also determines increased motor reliability, maintainability and duration. The electronic control systems allow speed and torque to be regulated with a precision that cannot be reached by other traditional propulsion systems. These considerations have constituted the ideal condition for applied research projects on electric propulsion combined with hydrogen fuel cells.

The presence of other concurring research projects demonstrates that this research context is focal. Another project, the "Enfica-Fc" (ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells), is coordinated by the Politecnico di Torino and it will last for three years. Many European institutions, which have been certified and selected by the European Committee for Aeronautic and Space Planning, have collaborated in Enfica-Fc.

The Sky-Spark project team is smaller than the Enfica-Fc one. The Sky-Spark team includes different departments, but all belong to the Politecnico di Torino and all the partners (technological or financial sponsors) are located in and around Turin, as well as the main component suppliers. These conditions define agility in coordination and in project management and they could determine a competitive advantage for the Sky-Spark project.

Another project, the Boeing project, using the high-performance two-seat motor-glider Super Dimona, is also involved and it concerns the development of a JAR/VLA aircraft with hydrogen propulsion. This project could have problems concerning certification release, given the aircraft category, and the schedules could consequently be compromised. The presence of this competitor is a source of pride for the Sky-spark team and it stimulates people to individual objectives accomplishment.

The Sky-Spark project could therefore produce the first hydrogen-supplied aircraft in the world to fly with a pilot. A

Manuscript received February 1, 2008.

F. Montagna is with the Politecnico di Torino, Production and Management Engineering Department (DISPEA), Corso duca degli Abruzzi 24, Torino, Italy (corresponding author, phone: +39-011-5647213; fax: +39-011-5647299; e-mail: Francesca.montagna@polito.it).

M. F. Norese is with the Politecnico di Torino, Production and Management Engineering Department (DISPEA), Corso duca degli Abruzzi 24, Torino, Italy (e-mail: mariafranca.norese@polito.it).

dream, which arose from the passion and competence of a team of practitioners, could lead to new perspectives in the aeronautic field, conjugating three competitive factors: innovative technology, ecological aspects and commercial attraction. On the other hand, some technological, managerial and organizational criticalities also exist.

From a technological point of view, the most critical uncertainties concerning the Sky-spark design were: how to assure flight autonomy in safety and which components had to be selected to have a light enough weigh to allow the take off. Higher autonomy is required, more hydrogen is needed, with procurement problems, costs and risks for hydrogen storage. The weigh limits, as a consequence, mean that back up of some components cannot be present. Therefore the original components have to guarantee very high reliability.

These technical requirements lead to a long development time, which could be critical for the time constraints created by the WAG date. Cost constraints are also present and connected to the nature of the project. A small project, internal to the Politecnico, where only regional partners are involved, guarantees agility in coordination and in project management, but also cost constraints.

For these reasons, all the components have to be provided on time and have to have low costs. This means that each supplier has to be carefully identified and all the commercial channels have to be activated and controlled.

The organizational complexity elements are due to the systemic and multidisciplinary nature of the project which involves five departments of the Politecnico di Torino and DigiSky, a start-up company from the internal incubator. Therefore the decision context should be considered as a multi-project where each unit has autonomy in some technical and organizational decisions, but also has to be connected to the others when a local decision can have an impact on the decision space and the activities of some other units.

The most central department is the Aeronautic and Space Engineering Department (DIASP), which institutionally represents the core competence of the project and which is the organizer of all the systemic aspects.

The Production and Management Engineering Department (DISPEA) have to guarantee the activity planning and the project management and it has to support DIASP and DigiSky in the project coordination. The DISPEA experience in decision aiding was used to propose the observation that, in multi-actor contexts, operational tools can be useful but they also have to be integrated with other tools that are more oriented towards supporting a shared vision of the problems and a structured and evolving problem formulation.

The other internal institutions study specific technical aspects (for instance the power-line, the propulsive engine and the electronic devices). Their decisions can only be autonomous in some cases, while, in others, they have to be made with the coordination group. Some external partners exist and the multiple interactions (determinant for objective achievement of the times and costs) with the suppliers and the technological and financial sponsors also have to be considered by the coordination group. Environment Park, which is the regional institution for research on advanced solutions and innovative technologies in the fields of energy and the environment, is one of the external partners, and it covers a focal role in the relationships with local public institutions and also provides technical support for the experimentation.

When a product implies a multidisciplinary design process, the design problems are often the result of the organizational philosophy that can be found in many design groups, where specialists are usually separated according to discipline and they speak different “technological languages” [1]. At the beginning of a multidisciplinary project, such as the design of a new aircraft, the project-leader usually decomposes the global problem and distributes the relevant parts among the existing organizational groups. This *modus operandi* induces problems such as disciplinary sequencing, where one technical group must wait for data to be computed by another group or for activities (for example component testing) to be made by some specific groups to start the component integration. A more difficult multidisciplinary interaction could also be due to a lack of communication. In this project, coordination and communication problems exist in particular. All the main technical decisions have been made, but the consequences of “making or buying” decisions, in relation to some components and in terms of required time and associated costs and risks, have not been analysed and shared in the project context.

In these design processes, where multiple communities are involved with highly specialized technologies and different knowledge domains, defining a common language among the actors is vital to create an exchange of knowledge concerning common problems [2]. All the aspects that are relevant in the design should be managed to become coherent in relationship to each other; such technical, managerial and organizational aspects may be individually modelled and related to each other through a common integrated framework [3, 4].

A methodology that is able to lead to effective integrated design contexts, capitalizing on the systemic perspective and the multidimensional (organizational, technical and financial) characteristics of the project, and orienting towards specific decision contexts and problems, to support a shared vision and communication [5], could be very useful.

In the next section, the paper presents the MACRAME methodology and its use to identify uncertainties that make the decision difficult and to control them, acquiring a systemic perspective of reading the main characteristics of the project, and orienting communication and action. The approach we adopted in the intervention is described in the third section, with a synthetic description of how the tools we used for this application were integrated in a communication space to underline problems, structure decision models, elaborate alternative solutions and propose them for collective evaluations and decisions.

II. THE METHODOLOGY

MACRAME, as a proposal of methodological and operational support [6, 7], is oriented towards multiple functions and two main uses: assisting the analyst in the structuring of complex and uncertain decision problems and then in the communication and documentation process. The main functions are:

a) formulation of the problem at hand, i.e. explanation of the client's initial demand and then identification, detailing and structuring of all the relevant elements, b) the acquisition, analysis and selection of information elements that are useful in the modelling phase (i.e. data storage, processing and validation activities, lack of information recognition, etc.), c) structuring of the model, which is the formal representation of the decision problem and the possible actions, d) model validation and model documentation (in terms of sources and structure of a dedicated information base, structure and parameters of the model, results of the validation tests, tools that have to be or are used and results of each tool application), e) model management, to change its structure or modify parameters and information elements, to integrate tools that support the different functions and the results of each tool application in the global vision of the problem.

These functions are suitable for all tasks concerning global management of problems and models [8]. Functions a, b and c, which are oriented towards problem and model formulation and representation, from an individual point of view, are developed mainly in the initial phases of the work when the unstructured problem and the acquired information elements are analysed and structured. Functions d and e are oriented towards formulation and representation, from a system point of view, and/or to collective model analysis and implementation.

For each MACRAME application, a modular and multilevel schema and a map are activated in relation to a "problem" object. The 'Multilevel Schema' disaggregates the problem into levels of growing specification and lower analysis complexity and into modules. The basic elements of MACRAME are proposed in each module and in a modular way, at each level, from the General Level, i.e. the global view of the problem situation, to the following ones. The elements are the *problem formulation*, which may be expressed by one or more of its possible structures (*statement of problem description*, *actor structure network* and *representation networks*), the *dimensions of the problem* and the *dimensions of model structuring (or model dimensions)*. The dimensions of the problem are the main elements of the sub-problem that is analysed at a specific level (and then the topic of the level). The problem dimensions have to be treated separately and then integrated in a global view. The model dimensions are the transition structure from a problem dimension to an activity of problem treatment that is explicitly required, from one part of the schema to another and from one level to another, which is activated when a new level of representation structuring becomes possible or necessary.

The 'Map' is a scheme that consists of 'elements' and 'connections'; the 'elements' are either intermediate or final states of knowledge (which are synthesized in the MACRAME modules or in the results of the tool applications that the modules activate); the 'connections' are refinement processes (called steps), which lead one from one state to the next. The Map allows a dynamic view of the analyst's intervention to be obtained, in relation to the knowledge states that the Multilevel Schema produces and organizes in modules, which propose the knowledge elements on the problem that are essential at different levels of problem structuring and modeling.

Local formalized results can be obtained at almost all the different levels, but only at the last one can the global model be formulated in relation to a sufficiently structured and therefore reduced complexity. All the elements of the model are shown, in explicit mutual relationships and related to sources and proponent sectors or actors.

MACRAME is used in the "structuring phase" and then in the collective "critical reading phase". The Multilevel Schema and the Map offer both a global view of the problem structure and the possibility of navigating through the Schema modules, in order to analyse, discuss and change some basic elements of the problem and model structure and/or some relationships between these elements and between each element and all the related databases. Modifications of the Schema can be frequent in the "structuring phase"; any change is stored in the "Steps" file that is attached to any specific application, in order to be used in this modelling phase or in future model-management actions. Substantial changes require control activities to assure global coherence and can induce a new "structuring phase".

III. THE INTERVENTION

The Map in figure 1 synthesizes the activities and results of the first intervention phase. At the General Level, the main problem dimensions are the uncertainties concerning the costs and the required time for each activity, the need to control some technical requirements and the organization of the project team. Two model dimensions are activated, the first (D1) declares an assumption and stimulates some activities. Assumption (Λ_1) is "the specific elements of the project have to be analysed from the different points of view of the involved groups" and the activation of a set of interviews is the immediate consequence of Λ_1. The interviews, but also the syntheses of all the themes that are discussed in the meetings, have to be inserted into a structured Document base.

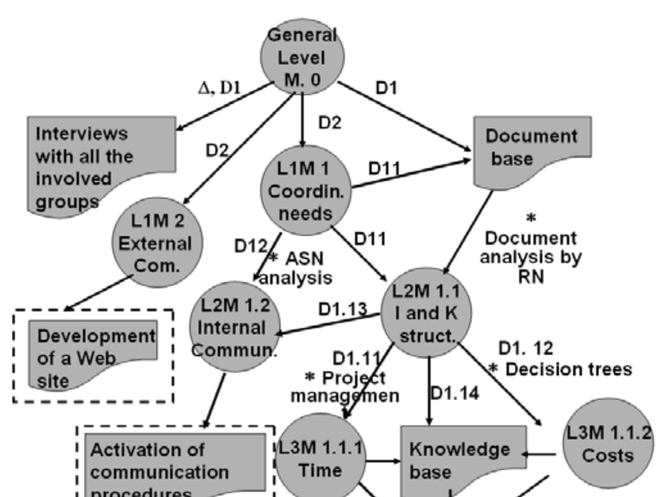

Fig. 1. The map of the intervention

The second dimension, (D2), activates the second level of the Multilevel Scheme, where the needs for coordination that the promoters express, in relation to the nature of the project, have to be analysed in one specific module (Level 1 Module 1, labelled L1M1). The needs for communication towards external agents and new possible sponsors have to be analysed at the same level but in another module (L1M2), to define the different modalities of communication, such as a periodical meeting with all the involved technological and financial sponsors, and to at least produce a Web site.

The L1M1 module identifies the main dimensions of the problem "Needs for project coordination", that is, the distribution of global knowledge among several people with different competencies, the fact that a local decision can have an impact on other decisions, at a local or global level, and the idea that some local decisions could have been made but, not communicated to the others. The first model dimension of the L1M1 module (D11) defines the content and the aims of the interviews, which at this point, can be conducted and inserted into the Document base. The same dimension, D11, activates the third level of the Multilevel Scheme where the L2M1.1 module has to analyze the structured elements of the Document base and to translate them into information and knowledge structures. Each interview (from the Document base) has to be analyzed separately and then all the identified knowledge elements have to be integrated by the modality Representation networks (RN in figure 1) and inserted into the Problem formulation of L2M1.1. Here, the Representation networks are analyzed, with the aim of sub problem identification and specific action planning and activation, to limit uncertainty and treat the sub problems. D12, the second model dimension of L1M1, underlines the need for a validation of all the knowledge elements and then transferring them, at least to the project coordination team, but in some cases to other components of the project team, by communication protocols that have to be defined at the third level by the L2M1.2 module. The Analysis of the Actor Structure Network (ASN in figure 1) facilitates the definition of all the actors' roles and functions in the communication network.

The first problem dimension of the L2M1.1 module is the uncertainty concerning the time that each activity for each project unit requires and the global time necessary to build the prototype for its final test. The second dimension is the uncertainty concerning the costs of the different activities.

In relation to the first uncertainty, the D1.11 model dimension activates a data acquisition and structuring procedure in a Gantt scheme, to stimulate a project management action. The use of the Microsoft SW Project packet was considered sufficiently adequate for the nature of the project.

The second uncertainty implies (D1.12) another data acquisition and structuring procedure and the use of decision trees to define the alternatives of the first decision problem. When two options (making a prototype component or buying the same component) in a project unit are recognized possible, they have to at least be analysed in terms of cost, time and risk.

These options, which are analysed at a local level, have to be combined with all the other similar 'make or buy' options in the other project units, in order to have a global vision of how many and what the different decision alternatives are. The decision trees were used to describe the possible different local or global decisions.

The two model dimensions activate two new modules that allow the results of all the different activities to be analysed and synthesized, in order to produce new knowledge elements and to make decisions.

The knowledge base includes all the elements that were elaborated in the L2M1.1 module and the new ones from the L3M1.1.1 and L3M1.1.2 modules. These elements were used to define some multicriteria models, where the costs that are associated to each (made or bought) component are analysed in detail and the other aspects that distinguish the alternative decisions are considered. Multicriteria models (and methods to apply to the models) are included in the model base.

At the end of this first intervention phase, a Document base is structured and can include all the documents from the involved units. This can be considered a first result. Three other results are considered only partial and temporary because they have to be developed over the subsequent months and be only completed in the next phase of the detailed design.

Modifications of the Multilevel Schema could result from the next coordination actions and will surely be present in the detailed design phase. Any change will be memorized to allow control activities to be developed in order to assure global coherence.

Substantial changes could be necessary when (and if) the nature of the project results to be different from the initial vision. These changes could induce a new "structuring phase" starting from this one and critically using all the produced and documented elements.

IV. CONCLUSION

Several people who are interested in the challenging possibility of producing an innovative light aircraft that utilizes hydrogen as a fuel, have decided to join their efforts in a collective project that involves researchers from different Departments of the Politecnico di Torino and a spin-off from the internal incubator.

New perspectives in the aeronautic field, that conjugate an innovative technology, ecological aspects and commercial attraction, could be created but some technological, managerial and organizational criticalities exist

The decisional context should be considered as a multi-unit project where the local decisions of each unit have to be connected to the other decisions and can have an impact on the decision space and the activities of some other units and, in some cases, the effectiveness of the global project. Different “technological languages” are present and the information on the consequences of “make or buy” decisions, in terms of time, costs and risks, is not shared and often not present in the context in which the project is developing.

Two important constraints are present. Time is a critical variable (the aircraft should be the first of this kind in the world, but other organizations, at research or commercial levels, want to obtain the same result) and the monetary resources have to be acquired and used quickly.

The MACRAME methodology is used to identify uncertainties that make the decision difficult and to control them, thus acquiring a systemic reading perspective the main characteristics of the project, and orienting communication and action. The Multilevel Schema and the Map offer both a global view of the problem structure and the possibility of navigating through the Schema modules, in order to analyse, discuss and change some basic elements of the problem and of the model structure and/or some relationships between these elements and between each element and all the related databases. The Map also offers a synthetic description of how the tools used for the application were integrated in a communication space to underline problems, structure decision models, and elaborate alternative solutions and propose them for collective evaluations and decisions.

At present, at the end of a first phase of conceptual design, the presence of a unit that could be critical from different points of view has become evident. The next phase should be oriented towards focusing on this problem using all the possible tools to reduce criticality and to plan alternative actions, in relation to different possible development scenarios.

Some tools, which were perceived in the first phase as the most ‘visual’ and which are able to structure the problem situation, have to be oriented to create a communication space that facilitates a shared vision of the new problem and reduces the risk of converging towards a blind alley.

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