Understanding and profiling user requirements to support the conceptual design of an integrated land monitoring system

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Abstract. Acquiring and organizing knowledge and information elements can be essential not only to understand, but also to eliminate, reduce and control complexity and uncertainty. An integration of tools from different disciplines could systematically help in the construction of an agreed framework for problem formulation, above all when the situation is "new". An application was developed in relation to an industrial project, in order to propose profiles of the potential users of an innovative system and of their requirements, and to formally develop models that can orient analysis, decision and action. Some elements and results of this integrated application of "soft" and "hard" decision aid tools are here proposed as steps of an organizational learning cycle, which is a basic element of each innovation process.

Keywords: knowledge acquisition and representation, problem structuring methods, decision support, learning of profiles

1 Introduction

Working with socio-technical systems, in which technological components are related to the complexity that is generated by individual and organizational actions and processes, can create several methodological problems. When an innovation process develops in a socio-technical system, many of the involved factors are not meaningfully quantifiable, since they are connected to technological, but also social, organizational, political and cognitive dimensions. Everything is connected to everything else and "what might seem to be the most marginal of factors can, under the right circumstances, become a dominating force of change" [1].

These innovation processes are characterized by multiple actors and perspectives, competitive or conflicting interests, constraints and uncertainties that (using the distinction proposed in [2]) can be connected to the working environment, the related decision fields and/or the guiding values. All these elements define what Rosenhead and Mingers [3] called "an unstructured problem".

Acquiring and organizing knowledge and information elements can be essential not only to understand, but also to eliminate, reduce or control complexity and uncertainty. "Traditional quantitative methods, mathematical (functional) modeling and simulation will simply not suffice in several cases" [1]. Sociological and psychological literature suggests approaches and methodological tools that can be used to identify and cope with complexity and uncertainty. Logical and structured procedures are also proposed in the Operations Research (OR) literature as "soft OR methods or problem structuring methods (PSM)", to facilitate a shared vision of the situation and to decide how complexities and uncertainties have to be controlled and improvement actions to be elaborated, evaluated, validated and implemented. PSM could be improved through an integrated and interdisciplinary approach, see for instance [4], that systematically helps in identifying or constructing an agreed framework for the problem formulation, above all when the situation is "new".

Actor network analysis and representation could be essential in problems that are characterized by multiple actors, perspectives, experiences and competing interests [5]. Actor analysis methods [6-9] can be used to analyze and understand the decision context, where the individual/organizational actors play a role (or multiple roles), and to reduce organizational complexity, but also to capture and represent differing readings of the situation that induce different problem formulations. Cognitive approaches and mapping techniques are proposed in literature (see, for instance, [10-11]) in order to acquire, synthesize, code and communicate all the elements that emerge from the different points of view of the actors who are, or could, be involved in cognitive processes, but also in decision or in innovation processes. Several types of map can be used to depict, structure and face complex issues [12].

An integration of actor analysis methods and cognitive mapping techniques could produce knowledge elements that are useful to clarify cognitive aspects and complete the vision of the situation. The knowledge elements that originate from the cognitive maps could also be used to improve the actor analysis, in order to propose, for example, new involved roles or actors, and related complex issues, that need to be analyzed, or contradictions between the actors' perceptions of some roles. At the same time, the actor network knowledge can facilitate the analysis of the actors' needs, when less clear or contradictory concepts are proposed and have to be analyzed by means of cognitive maps. The effectiveness of each method can be improved through the integration of a "complementary" method. When the main problems that are related to the situation are formulated, concepts and relationships that are structured and synthesized in actor networks and cognitive maps can be transformed into classical OR models (with actions, criteria and parameters, or objectives, variables, constraints and parameters) and OR methods can be applied, in order to elaborate possible solutions and compare them, or to modify the models and identify new aspects and points of view. An industrial research project and its aims are described together with an integrated application of some decision aid tools in the next sections.

2 The problem context

An industrial research project, SMAT-F1, was activated in January 2009 as the first phase of a global project for a new Advanced System to Monitor the Territory (hence the SMAT acronym) and it was financed by a public institution, the Piedmont Region.

The project involved several enterprises and some research units from the Politecnico di Torino and the University of Turin, under the leadership of Alenia Aeronautica, a company which is active in the military and civil aeronautical field.

One of the purposes of SMAT-F1was to identify all the specific innovations that have to be introduced in order to guarantee the civil use of some Unmanned Aerial Vehicles (UAVs) working as an integrated monitoring system. SMAT-F1 was completed at the end of 2011 and the second phase, which is foreseen for the autumn of 2012, will implement innovations in the control station functions, and in some sensors, for specific data acquisition, and communication systems, as well as for data transmission, even in critical situations.

In the first phase of the project, the aim of our research unit was to identify the organisations that could become the clients of a new monitoring service and to analyse their monitoring needs, for the future phases of the SMAT project, in which the innovations have to be designed and implemented.

In aeronautics, where many years are required not only to create a new aircraft, but also to innovate some elements of a legacy system, a clear understanding of the points of view of the potential users of a new system is essential to identify and structure the requirements that orient the design. In this case, the key actors of the current land monitoring processes are some of the potential users of the SMAT technology, and recording and tracking their points of view could be important to understand the situation and also to involve some of them, in the future, in a decisional structure that could facilitate the design of both the innovative system and the new monitoring service. Several decisions in a design process are difficult or almost impossible without focusing attention on alternative ways of managing technical, political or structural uncertainty [2]. The nature of the prevailing uncertainty has to be identified and specific responses have to be developed to deal with it. Responses of a relatively technical nature can involve surveys, research investigations, or costing estimations, when there is a limited knowledge of the problem. Another kind of uncertainty calls for a more political response that might become an exercise in clarifying objectives and political or organizational constraints. There is often uncertainty about the structural relationships between the current decision and others that could be connected. A broader design perspective could be required and new time horizons and new actors should be considered. The points of view of the key actors in the current land monitoring processes should be acquired, and understanding and control of the main uncertainties that are present, in relation to the new technology, are essential. Conflicting objectives, interests, matters of concern or priorities of the key actors, i.e. their value systems, should be clarified and the nature of the operational relationships between the organizations that are involved in land monitoring processes should be investigated. Open interviews, starting from a framework of key questions, can be more useful than a questionnaire to underline and analyse these uncertainty elements and to obtain an idea of what the knowledge elements that have to be acquired and analysed are. The validity of the acquired knowledge (e.g. in terms of reliability, consistency, completeness) also has to be investigated.

At the start of the project, our research unit was requested to dedicate a period of four weeks to collecting as much information as possible about the present land monitor-

ing needs. Due to limited time available, a local agency, the Turin Provincial Authority, was chosen as an organization-laboratory in which all the potential users of a new monitoring system were identified and interviewed. After these four weeks, and after the analysis and presentation of the first results, the time that was dedicated to this task was extended, and the inquiry was thus continued at a regional level, a territorial scale more consistent with the aims of the SMAT project.
Forty-nine potential users were identified and interviewed, in order to collect knowledge elements concerning any possible gaps between their present monitoring activities as well as the actual needs and their points of view in relation to the new system. Starting from the knowledge elements that the survey had proposed, an integrated procedure was activated with the characteristics of a PSM.

Cognitive mapping methods were used to deal with unstructured knowledge elements, in order to enrich the whole picture, to reduce the number of uncertain elements pertaining to the possible role of the innovation and to understand the nature of the new uncertainties the interviewees expressed. An integrated application of actor analysis and cognitive mapping methods allowed us to validate the collected information and to verify the reliability of the sources and their skills. Eventually, the main users and their requirements were identified and modelled, in relation to technological and organization factors that will need to be analyzed in the future design phases of the SMAT project.

3 Integrated application of decision aid tools

An integrated application of "soft" and "hard" decision aid tools was developed, to deal with the structured, partially structured and unstructured knowledge elements that were acquired during the interviews. Problem situations, that are above all connected to the uncertainties the interviewees expressed were identified, formulated and structured. Model frameworks and parameters were defined in order to facilitate communication, organizational learning and decision making.

The first analysis phase is related to the structured knowledge elements that emerged from the interviews. Their texts were analysed and all the structured knowledge elements (above all the characteristics of the current land monitoring activities, such as costs and required quality, and factors that should characterize the new monitoring activities) were acquired and organized in tables. A clustering approach was then applied to these elements and used to define land monitoring categories (or *macro activities*) and to assign all the expressed needs to these categories. At the same time, a data base, Monitoring activities, was elaborated from the literature and point of view of some experts. It was used to test the completeness of the set of macro activities and the consistency of the clustering approach, in which the proximity of the needs that were expressed during the interviews, in relation to the identified categories, was maximized and the number of the *basic activities* that synthesize similar needs was minimized. The last activity pertaining to the structured knowledge elements consisted of the definition of the main parameters that allow the basic activities to be described.

A second analysis phase, which is described in section 3.1, integrates cognitive mapping and actor analysis techniques. It was developed in relation to partially structured elements (e.g. actors who have been mentioned and indications about their role in the current processes) or unstructured knowledge elements (above all opinions about specific themes) with the aim of structuring all these elements, in order to highlight and visualize the complexity of the monitoring organization and to analyse the nature and structure of the proposed knowledge elements.

Actor networks, cognitive maps and model frameworks were created and used in this first phase of the project in order to reduce, or control, the uncertainty elements. The analysis of an actor network can reduce some of the uncertainties that are evident in a cognitive map. A map, that is, a model of action-orientated thinking, can be used to clarify the relationship between actors or an actor's role, through the understanding of current constraints on the acquisition and the use of data. Constraints, opportunities and preference systems can be used to generate model frameworks. The elaborated knowledge structures were created to activate a learning cycle, and to develop it in the subsequent phase of the SMAT project, where the possible problems can be analysed from different points of view and their (formal) representation could be changed, improved or shared in a decision context where the individual/organizational actors play a consistent role with the (visualized) decision space.

3.1 The procedure

The organisations that develop monitoring activities (data acquisition, treatment, transfer or use) were considered potential users of SMAT in the industrial project.
A synthetic actor network was defined, as a first analysis step, on the basis of a first interview conduced with one of the directors of the Turin Provincial Authority. Each new interview allowed the actors who are involved in land monitoring processes with different roles to be added to the list of organizations that should be contacted. It was sometimes difficult to identify and understand the working relationships between these actors because the interviews were often not sufficiently clear. The actor network was frequently upgraded and analysed in order to understand how to complete the investigation, but also in order to have a better understanding of the actors' points of view. Many of the actors involved in the monitoring processes, both technicians with specific and various competencies and managers at different levels, were interviewed. They were required to describe the monitoring needs that a new technology could satisfy. They were also asked to describe their current monitoring activities in relation to different topics (agriculture, pollution, transport, waste, cartography, data updating, emergency situations, such as landslides and floods) and the main constraints that today limit some monitoring activities. But they also described the aspects that could positively or negatively affect the adoption of new procedures (expected benefits and perceived risks or criticalities) and doubts and uncertainties about any organizational change and some proposals to reduce these difficulties. Their points of view were sometimes contradictory and often unclear. The knowledge elements that emerged from the interviews sometimes presented interpretative uncertainties and lead to methodological questions.

As a second analysis step, a cognitive mapping approach can reduce these uncertainties. A specific cognitive mapping technique, Representation network, has been proposed in [6] and [13] and used in some different application contexts. The unstructured knowledge elements that emerge from the validated interviews are organized in statements, and then coded, synthesized in concepts, clustered and connected in representation networks or cognitive maps in which the logical relationships between the concepts can be analysed. A statement basically corresponds to a grammatical unit, or a sentence, of the interview and two elements are indicated for each statement: the source and a label in relation to the nature of the sentence (criticisms, proposals, wishes, but also aims, constraints and possible criteria, or specific information elements such as, in this case, actors that are or should be involved, their responsibility and specific relationships with other actors, as well as the nature and structure of the relationships) and/or to the related theme or subject (in this case, the control system, economic dimension, organization of a service), if it is clear enough. With this coding system, the statement that is taken out of a response is transformed into an information cell. All the information cells of the same nature, or which are related to a specific theme, are included in a list, with the original information (name of the proponent source, nature and theme). They are analysed together, in order to synthesize information into concepts (c*oncept identification*), *create clusters* of concepts pertaining to a theme and identify relationships between the concepts (*arcs* of the *representation network* with *concepts as nodes*). These networks are analysed in order to reduce interpretative uncertainties and improve knowledge reading and interpretation, to produce a whole vision of the problem components, to improve or complete an actor network or to extract the main elements of a model framework.

The third step is activated by analyzing the results from the actor network analysis and the cognitive mapping approach together. The representation networks in Figs.1a, 1b and 1c are cognitive maps that were developed during the project in relation to the "natural risk assessment, forecast, prevention and management" monitoring context. Each map proposes the different points of view of the interviewees in relation to a specific topic. All the nodes are concepts that were expressed during the interviews by a source who is indicated in brackets. The sources, who represent organizations that are connected to this specific context, are included in the network in Fig. 2. The links between the nodes are the result of a logical analysis of the concepts and their possible relationships and they define the knowledge structure that the involved sources propose. The relationships can be different (cause and effect, specification, exemplification, contradiction and so on). Some links are of an operational nature. They can make the need of new investigation activities explicit or connect a map with another representation network or suggest connections between concepts and possible elements of formal models, such as constraints, judgements, objectives, possible criteria, trade-off or the relative importance of the proposed aspects.

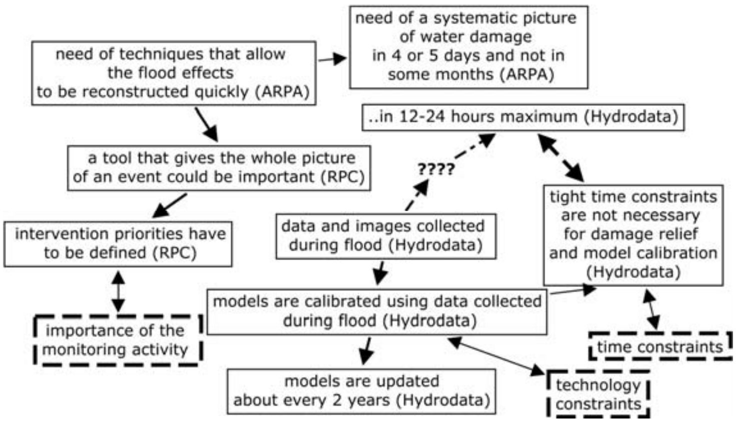

Fig. 1a. Representation network: ***Compatibly with the event timing***

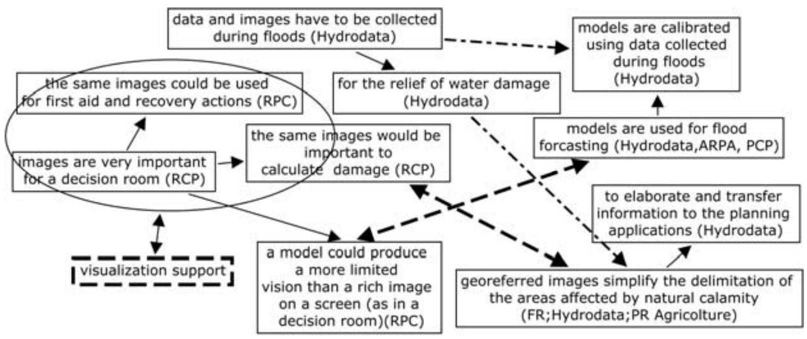

Fig. 1b. Representation network: ***Data or Images?***

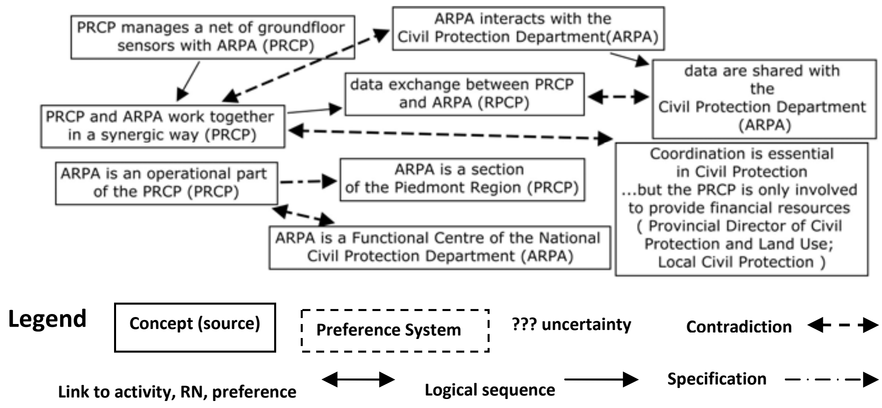

Fig. 1c. Representation network: ***Role and Relationships of ARPA and PRCP***

The other relationships facilitate the cognitive analysis and are examined to clarify concepts that are considered too generic or to verify and better explain others that are too confused or to underline uncertainties and apparent contradictions that have to be analyzed in detail and reduced or understood. The map in Fig. 1a is related to the problem Compatibility with the event timing. It includes not only some time constraints, but also an uncertainty element and a possible contradiction between some expressions of these constraints. A contradiction between monitoring flood needs is present, and it is more evident in the representation network in Fig. 1b where the distinction "Data or images?" is not always clear and a possible misunderstanding emerges about the terminology or the actual nature of the need. The integration of this knowledge structuring with the reliability analysis of the sources, whose roles and relationships are described by means of an actor network, could clarify these contradictions and reduce the uncertainty that has an impact on each attempt to size the demand of a new monitoring system. If also the actor network presents uncertainties, these have to be reduced by improving the analysis with new information.

Uncertainties emerged about two important actors involved in this context, ARPA Piedmont and the Piedmont Region Civil Protection (PRCP), from an analysis of the interviews, and clear contradictions between the concepts that synthesize the descriptions of the different roles and functions can be seen in the map in Fig. 1c (the concepts in the left part of the network are in contradiction with the others in the right part). Therefore, an analysis of the roles and relationships of these actors, and the others who are involved in the "natural risk assessment, forecast, prevention and management" context became crucial and an integration of the actor analysis and cognitive mapping approaches reduced uncertainty and explained some contradictions. The actor network in Fig. 2 includes all the knowledge sources (the interviewees) of this context and the other actors who were mentioned during the interviews as involved in these monitoring processes. All the technologies that were mentioned and described during the interviews (information systems, inventories, models, public registers, communication technologies and so on) are included in the network as *non human actors*, a terminology that was proposed in the Actor Network Theory [11] to define and analyse this kind of actor. Their role is important to understand which monitoring processes are currently activated and which organizations are operationally involved, in order to identify a market for SMAT and its characteristics. The arcs connect technology resources to the actors who are involved as users, developers or responsible organisations, or describe information exchange, the transfer of monetary resources, responsibility or specific actions, such as delegation. Some arcs in Fig. 2 show question marks that propose uncertainties in relation to the contradictions in Fig.1a. In order to limit these uncertainties and have a better understanding of the whole situation, a deeper analysis (with experts and using the Italian Civil Protection web site [14]) was conducted and this led to a new actor structure that clarified the situation.

The different Civil Protection organization levels (national, regional, provincial or local) and the roles of the actors in all the processes were analysed, not only in emergency conditions, but also in the prevision and prevention contexts. ARPA Piedmont (one of the main sources of the cognitive map shown in Fig. 1c and a crucial actor in Fig. 2) is described in the Italian Civil Protection web site as one of the few decentralized functional centres of the national Department of Civil Protection and as a Competence Centre. As far as the official Civil Protection processes are concerned, ARPA

Piedmont is not an “operational part of the Regional Civil Protection” in Piedmont but it works closely with the national Department of Civil Protection. With this information, it was possible to understand some other apparent contradictions in the maps.

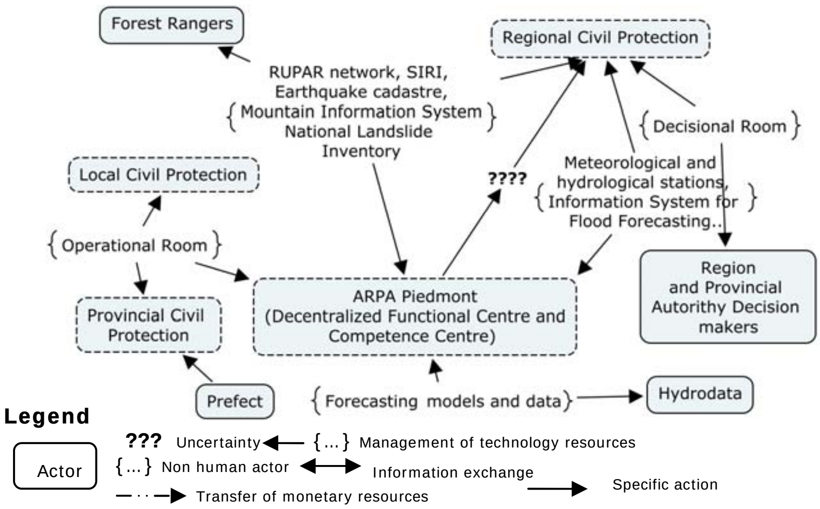

Fig. 2. Actors in the context of prevention, prevision and management of natural risks

4 Conclusive remarks

“Cycling between modeling approaches gave benefits that could not have been attained by either hard or soft modeling in isolation” [15].

A sufficiently clear idea of some of the central problems in the SMAT project has been obtained through an integrated analysis of concepts and actor networks which identified the main constraints that currently limit several monitoring activities, the aspects that could positively or negatively affect the adoption of new procedures, the benefits that are expected and the main risks that are present in some situations, as well as the spaces of action of some potential users who should be involved as actors in the next phases of the project. Another integration of decision aid tools can be activated to transform concepts and relationships that are structured and synthesized by actor networks and cognitive maps into formal models (with actions and criteria, or objectives, variables and constraints) and to test the applicability of classical OR methods (in particular mathematical programming and multiple criteria decision analysis, as used in [16]), in order to elaborate possible solutions and compare them, also in relation to the end users’ points of view.

The concepts of a representation network built in a cognitive mapping process can often be considered as elements of a “multi-actor” preference system that the interviewees have expressed. In a new decision space, with all the key actors of the concept design phase, an integrated analysis of the concepts and structures of the actors could be used to better define the uncertainties, constraints and expectations. These elements are essential to elaborate the components of formal decision aid models (such as structural dimensions and criteria, the importance of an aspect in relation to another one, goals and constraints, risks that cannot be accepted, and so on) and to evaluate and compare design alternatives that can be elaborated through the application of a mathematical programming method or proposed by the actors in the future design process phase. A sequence of "simulated" applications of the OR methods could be implemented, not as a problem solving approach, but to activate a new learning cycle, both at a technical and at an organization level, which could facilitate the conceptual design of an innovation.

References

1. Ritchey, T.: Problem Structuring using computer-aided morphological analysis. J.Oper.Res.Soc. 57, 792–801 (2006)
2. Friend, J.: The strategic choice approach. In: Rosenhead, J. (ed.) Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict, pp. 71-100. Wiley, Chichester (1989)
3. Rosenhead, J., Mingers, J.: Rational Analysis for a Problematic World revisited. Wiley, Chichester (2001)
4. Eden, C., Ackermann, F.: Where next for problem structuring methods? J.Oper.Res.Soc. 57, 766-768 (2006)
5. Norese, M.F.: MACRAME: a problem formulation and model structuring assistant in multiactorial contexts. Eur.J.Oper.Res. 84, 25-34 (1995)
6. Ostanello, A., Tsoukias, A.: An explicative model of public interorganizational interactions. Eur.J.Oper.Res. 70, 67-82 (1993)
7. Bowen, K.: An experiment in Problem Formulation. J.Oper.Res.Soc. 34, 685-694 (1983)
8. Law, J.: Actor network theory and material semiotics. Ind.Law J. 35, 113-139 (2007)
9. Freeman, L.C.: Centrality in social networks: Conceptual clarification. Soc.Networks. 1, 215-239 (1979)
10. Eden, C.: On the nature of cognitive maps. J.Manage.Stu. 29, 261- 266 (1992)
11. Tegarden, D., Sheetz, S.: Group cognitive mapping: a methodology and system for capturing and evaluating managerial and organizational cognition. Omega. 31, 113–125 (2003)
12. Novello, C.: An integrated use of tools to acquire and structure knowledge elements and to support decision in innovation processes. Ph.D Thesis in Production System and Industrial Design. Politecnico di Torino, Turin (2011)
13. Buffa, F., Marzano, G., Norese, M.F.: MACRAME: a modeling methodology in multiactor contexts. Decis. Support Syst. 17, 331-343 (1996)
14. Italian Civil Protection, http://ec.europa.eu/echo/civil_protection/vademecum/it/2-it-1.html
15. Ackermann, F., Eden, C., Williams, T.M.: A persuasive approach to delay and disruption using 'mixed methods'. Interfaces. 27, 48-65 (1997)
16. Norese, M.F., Liguigli, E., Novello, C.: Integrated use of linear programming and multiple criteria methods in an engineering design process, In: Carrea, E., Greco, A., Penco, C. (eds) Placing humans at the center of knowledge, production and interaction networks, Proceedings of the fourth workshop on Human Centered Processes, Genoa, pp.10-16 (2011)