An integration between Cognitive Map and Causal Loop Diagram for knowledge structuring in River Basin Management

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Abstract

Making decisions in a real situation takes place in condition in which the most demanding and troubling task is to define the nature of the problem, rather than its solutions. To this aim, cognitive modelling techniques (CMTs) can be really useful as they allows to elicit individual points of views of problem situation. The results of a literature review on CMTs are described in this contribution. Based on the comparison of individual strengths of the CMTs, we propose how CM and CLD can be meaningfully combined to structure stakeholders' knowledge to support participatory decision process in river basin management.

1 Introduction

According to traditional models of decision analysis (e.g. Raiffa, 2002; Failing et al., 2004), a decision process can be divided in several steps: identify the Problem; clarify the Objective; generate creative Alternatives;

evaluate the Consequences; make Tradeoffs. Decision making mainly focuses on the generation and evaluation of alternatives, given a present state and a desirable state. The alternatives are considered as means to reduce the differences between these two states, to transform the current system into the target configuration (Rosenhead and Mingers 2001). Traditional approaches consist of systematically-ordered thinking concerned with means-definition in well-structured problems in which desirable ends can be stated (Rosenhead and Mingers 2001). They assume the decision makers are interested in using the best available information to be used for quantitative and qualitative evaluation and for the comparison of the alternatives (McDaniels and Gregory 2004). The traditional approach assumes that decision-making is largely a rational process in which the individuals order the possible outcomes of a decision situation and choose the strategy according to their preferences (Timmerman and Langaas 2004) and to the available information.

The availability of information influences each of these steps of the decision process. The enhancement of the knowledge can help the decision maker to avoid the restriction of himself to solving only the immediate problem he faces, and to open it to a wider range of possibilities (Raiffa, 2002). Furthermore, the clarifying of objectives and creating new alternatives can benefit from information. Events that have more recently occurred or that have some memorable feature are easy to bring to mind than the others. The cognitive process that causes this phenomenon is referred to the availability. Because the availability the decision-makers tend to anchor their thoughts on the types of alternatives used on recent problem (Keeney, 1992). This causes a tendency to create alternatives similar to those used in recent success, focusing too narrowly on the first one that comes to mind (Raiffa, 2002). The information picked up during the decision process enhance the generating of creative alternatives. The information plays a fundamental role to improve the understanding of the consequences of, and trade-off among, the alternatives (McDaniels and Gregory, 2004). The information reduces the uncertainty and facilitates the definition of alternative scenarios, supporting the decision makers to define the possible outcomes of an alternatives, the likelihoods and the resulting consequences of these outcomes (Raiffa, 2002).

Conversely, in a real situation, making decisions takes place in conditions of complexity, in which the most demanding and troublesome task is to define the nature of the problem, rather than its solutions (Rosenhead and Mingers 2001). Managing means interpreting and reacting to the flux of interacting events and ideas of the real world (Checkland 2001). In this perspective, there is no unique definition of the problem, but each individual has his own perspective in defining and interpreting a problem situation (Lane and Oliva 1998). A distinction is made between hard and soft system thinking, whereas the former adopt an "objectivist" stance that sees problems as independent of individual's views and beliefs. Soft system thinking requires a "subjectivist" stance that recognises the importance of participants' perceptions (Rosenhead and Mingers 2001), and thus of their cognitive models. Cognitive models influence an actor's perception of a problematic situation by influencing both his/her observation of the world and his/her conclusions based on observations (Pahl-Wostl 2007). They can be considered as the window through which people view the world (Timmerman and Langaas 2004). Cognitive models determine what data the actors perceive in the real world and what knowledge the actors derive from it (Kolkman *et al*. 2005).

It will not be possible for any decision-makers to deal with a problem situation adopting a neutral, objective approach. His/her personality traits, experiences, knowledge and interests will affect what is noticed and what is taken to be significant (Checkland 2001). Differences in cognitive models cause communication barriers that prevent mutual learning and understanding (Kolkman *et al*. 2005). Thus, tools able to find the "best" solution, based on mathematical models of factors and relationships in a decision situation are not enough to deal with complexity of real world. It's fundamental to recognize that a the most troubling task in decision making is to decide what a problem is (Rosenhead and Mingers, 2001).

As a results the role of decision tools in the context of environmental decision-making processes is changing, since it is widely recognised that there should be no single decision maker, rather a process of debate should take place among different actors (Guimãres Pereira et al., 2005). In this perspective, decision tools can play a twofold role. On the one hand, they should support knowledge elicitation from different decision makers, and to make it accessible in order to inform the debate; on the other hand they are the shared platform though which this debate is organised and through which the different sources of knowledge that may emerge during the process, are integrated (Guimãres Pereira et al., 2005).

During the debate, individuals continually negotiate and re-negotiate with others their perceptions and interpretations of the real world outside themselves, leading to a social construction of the problem domain (Pahl-Wostl 2007). During the debate, assumptions about the world are teased out, challenged, tested and discussed (Checkland 2001). The expected outcome is a set of insights that emerge from the comparison of individual perspectives (Lane and Oliva 1998), forming the richest possible picture of the problem situation (Checkland 1981). Therefore, the quality of such decision processes is potentially greater than that of traditional approaches since different knowledge and perspectives are taken into account and integrated. Furthermore, the interaction that takes place during a participative decision process can facilitate the exchange of information and knowledge, leading to a better comprehension of the problem through a social learning process (Maarleveld and Dangbégnon, 1999; Johnson et al., 2001).

In this perspective, Cognitive Modelling can be really useful to disclose individual perceptions of consequences and explanations associated with concepts and it is used by participants to communicate their understanding of the nature of the problem (Hjorsto, 2004).

In this work several methodologies and tools for knowledge elicitation and structuring are discussed, highlighting similarities and differences. Furthermore, a methodology based on the integration between Cognitive Map and Causal Loop Diagram to support Adaptive Management is described.

The results of a literature review are described in section 2. The review is mainly focused on differences and similarities between Cognitive Map and Causal Loop Diagram. Starting from this review, a methodology to integrate these two approaches is described in section 3.

2. Cognitive Modelling approaches to deal with complexity

A cognitive model can be defined as a representation of thought process for how something works in the real world. Most of the techniques for Cognitive Modelling may be viewed as composed by three main phases: identify concepts, refine concepts and identify links. A common characteristic of these approaches is a focus on obtaining the views of people in the problem environment. These views are often obtained using broad questions with the intention that the participants will provide the details they believe are most important.

Two different interpretation seem to emerge concerning what a Cognitive Model represents. On one hand, it can be seen as a model as close as possible to the cognitive representation made by decision makers. Thus the model can be considered as a “mirror” of the causes and effects that are inside the mind of decision makers (Montibeller et al., 2001). On the other hand, the constructivist view of knowledge assumes that knowledge is considered to change dynamically, in order to understand the reality. According to the constructivist approach, the model is a construct that can be useful to generate reflections on the decision maker. The decision makers is involved in the iterative psychological construction of the real world, rather than the perception of an objective world (Eden and Ackermann, 2001).

These two different perspectives originates two general approaches for knowledge elicitation and structuring:

- Cognitive Model as a qualitative model of the decision environment (see for example, Axelrod, 1976; Ozesmi and Ozesmi, 2004): the nodes represent variables and the arcs represent causal assertions. The variables can be physical quantities that can be measured, or complex aggregate and abstract concepts.
- The Cognitive Model as a network of ideas connected by arrows: the arrows indicate the way in which one idea may lead to, or have implication for, another.

In the first case, CM are often defined also as Causal Map or Influence Diagram, and are used to simulate the effects of possible actions taking into account the perceived influences between the elements of the considered system. From now onward, this kind of CM will be called Influence Diagram (ID). Adopting the second approach, CMs are not taken as models of cognition but rather tools for reflective thinking and problem solving. The adopted approach influences the way in which CMs are developed and analyzed.

An important differences between these two approaches regards the nature of the links. In ID, there are two different kind of links, i.e. positive and negative. A positive arc from variable a to b means that an increase of a will cause an increase of b. A negative arc from variable “a” to “b” means that an increase of “a” will cause a decrease of “b” (Marchant, 1999). In the second approach, a link between two concepts indicates the existence of a logical implication between concepts. In this kind of CM, the meaning of a concept is derived from its implication and explanation through an action orientation; not by any dictionary definition (Eden and Ackermann, 2001).

The different nature of relations and elements leads to different methods to develop the CM and to different analysis of the results.

The CMs are developed using formal modelling technique with rules (Eden, 2004). CMs are characterized by a hierarchical structure which is most often in the form of a means/ends graph with goal type statements at the top of the hierarchy. When the map has been coded properly the top part of the map (“heads”) will depict the “goal system”, and the bottom part the detailed potential action points or options.

There are two different approaches to develop the CM. The first is to explore the goal system further and then work down the map towards increasingly detailed options for achieving goals. Alternatively, one can start from the detailed options and then work up the map towards goal (Eden and Ackermann, 2002). Working in the first mode implies focusing on the concepts at the top of the map and asking to the participants to identify possible high level strategies to reach the goals. Once this stage has been reached, the participants are asked to define possible detailed actions. Independently from the adopted approach, the CM has to be oriented to action rather than problem description (Eden and Ackermann, 2001).

The concepts and links forming a CM are not exactly the replication of linguistic argumentations. They are modified to reflect the need for an action orientation, or problem solving orientation. The argumentation is such that an option always lead to a desired outcome, with the most important outcome hierarchically superior to others. Deciding which concept is the outcome and which is the action in a linked pair of concepts is important in developing CM (Eden and Ackermann, 2001).

As stated before, CM is not a model of the system behaviour, but it's a map of person's thinking about a problem or an issue. Important phrases are selected to capture the essential aspects of the arguments. CM is based on the subjectivism, according to which an individual is considered as problem finder/problem solver, using concepts to guide the actions (Eden and Ackermann, 2001). The understanding of the real world can be, then, structured in a "system of concepts". In a cognitive mapping exercise, participants are involved in the psychological construction of the world, rather than the perception of an objective world (Eden and Ackermann, 2001). Cognitive mapping focuses on the interpretation of an event rather than on its perception.

According to Eden's definition of CMs (Eden, 2004), the nodes do not represent variables taking their values in ordered sets and the arcs are not causal assertions. The existence of a link between a and b means that "if a is true then b is true". It doesn't implies cause-impacts relations. Thus, causal inference to assess impacts of policy options is not possible using CMs as defined by Eden. Moreover, the instabilities in system dynamics are not taken into account. That is, if an arc is considered as an implication, the cycle "a implies b, and b implies a" means only that if a is true then b is true, if a is false then b is false. Time is not relevant in this framework, nor stability nor instability over time (Marchant, 1999). Therefore CM cannot support decision making by modelling the impacts of possible action in different scenarios. The analysis of CM can support reflective thinking in problem solving by providing information about the characteristics of the issues to be addressed, which are often difficult to be identified.

Influence Diagram (ID) can be defined as a directed graph that represents the cause-effects relations embedded in participants' thinking (Nadkarni and Shenoy, 2004). ID expresses the judgement that certain events or actions will lead to particular outcomes. There are three main components in an ID: causal concepts, causal connections and causal values. Each concept represents an entity, a state, a variable, or a characteristics of the system (Xirogiannis et al., 2004). A causal connection depicts an antecedent-consequent relation between two concepts. A causal value represents the strength of causal connection (Nadkarni and Shenoy, 2004).

Different methods have been used to express the causal value. Traditionally, links are characterized by a positive or negative links. The causal inference is performed along paths, that is a sequence of distinct concepts connected by arrows. A path starts from the first concept (cause) until the last concept (ultimate effect). To assess the effects of each cause on the ultimate effect, it's fundamental to calculate two indexes (Axelrod, 1976), i.e. the partial effect and the total effect. The partial effect is obtained through multiplying the signs along each path. The total effect between the cause and the ultimate effect is positive if all partial effects between these two concepts are positive; it is negative if all paths have a negative partial effect; and it is undetermined otherwise (Montibeller et al., 2001).

Other authors suggest to use fuzzy weights to express the strength of causal relations between concepts (e.g. Xirogiannis et al., 2004). The sign of the weights indicates whether the relations is positive or negative, while the value indicates how strongly one concept influences the other. The weights can also be expressed using linguistic terms and fuzzy linguistic variables. Mostly the weights are defined asking to the participants to describe the interconnection influence of concepts. Given the partial effects of means variables, the total effect on the end variable is calculated using fuzzy aggregation operators (Montibeller, et al., 2001). The policy alternatives can be evaluated considering their performances in terms of total impacts (Montibeller et al., 2007).

The approaches described above are based on the means-ends perspectives, where decisions are based on a perceived gap between desired goal and the actual situation of the system. The linear causal thinking assumes that certain causes are acting together linearly to result in an event. The outcome of an event is assumed not to affect input (Hjorth and Bagheri, 2006).

Complexity in a system arises not merely because of the number of parts, but it's mainly a consequence of the nondeterministic and nonlinear characteristics of the components and from the structure of the interconnections between them. In these highly interconnected system, components are required to observe and respond to each other's behaviour in order to improve their behaviour. Thus, feedback is the first core properties of a complex systems. Such feedback loops facilitates learning processes in complex systems (Fowler, 2003).

Many authors (e.g. Diehl and Sterman, 1995) shown decision makers have great difficulty managing dynamically complex systems, generating significant, systematic and costly errors. They argued that the observed dysfunctions arises from the systematic misperception of feedback (Diehl and Sterman, 1995). To deal with complexity of real world, decision process needs not to be linear, open-ended sequence but may manifest as a closed loop feedback system in which the decision outcome may have impacts, after some times, on the original problem, or creates a new problem (Fowler, 2003). Moreover, it becomes important to take into account the time, appreciating delays between actions and responses (Diehl and Sterman, 1995). Decision making has to be considered as a dynamic process in which decision makers and the system are entwined in feedback loops whereby decisions alter the environment, giving rise to new information and leading to new decisions.

System dynamics is a thinking model and a simulation methodology that was specifically developed to support the study of dynamic behaviour in complex system (Hjorth and Bagheri, 2006). System dynamics modelling is about discovering and representing feedback processes. The understanding of these processes is then used to draw causal loop diagram (Hjorth and Bagheri, 2006).

Causal Loop Diagram (CLD) is a modelling device which has been developed to better represent the complexity and dynamicity of systems behaviours. It responds to the requirement of system dynamics approach to move away from looking at isolated events and their causes, and start to look at some organization as a system made up of interacting parts. CLD presents relationships that are difficult to verbally describe because normal language presents interrelations in linear cause-and-effect chains, while, in a system dynamic approach, leaving aside the circular chains of cause-and-effects can lead to erroneous conclusions.

From a practical point of view, CLD is made by variables connected by cause-effects links. Thus, while CMs are composed by concepts, ideas which are directly elicited from what participants to decision making say, CLDs are characterized by variables. In CLD it's fundamental to use nouns or noun phrases to represent the elements, rather than verbs. That is, the actions in a causal loop diagram are represented by the links (arrows), and not by the elements. For example, use "cost" and not "increasing cost" as an element. CLD are intended as qualitative models describing how a given system operates. These models can be built up incorporating lags, delays and nonlinearities characterizing the complex systems.

To better represent the system complexity, the links can be represented as a causal loop. Formally, a causal loop is a closed sequence of causes and effects, that is a closed path of action and information. In CLD links are considered as causal relations. That is, if two variables A and B are connected by a positive link, then a change of A implies a change of B in the same direction; if the link is negative, a change in A produce a change in B in the opposite direction. CLD provides a greater appreciation and awareness of the interactions of variables. CLD can be used to map out system variables and the interactions between them, particularly the chain of interactions that form feedback loops that represent either balancing or reinforcing effects. The CLD links seek to develop an holistic view of how relationships between variables influence system dynamics.

The sign of a loop is the algebraic product of the sign of its links. A positive (reinforcing) loop reinforces changes with even more change. This can lead to rapid growth at an ever increasing rate, according to an exponential growth pattern. In this case, the influence is usually destabilising, leading to explosive behaviour (Fowler, 2003). Therefore, in the beginning of the growth process something that is going to be a major problem can seem minor because it is growing slowly. If this exponential growth is not considered, it could be too late to solve whatever problem this growth is creating.

The negative loop tends to balance the value of a variable towards a goal. The value of the variable is pushed up if the current level is below the goal. If the level is above the goal, the negative loop pushes the value down. In positive loop, an output is fed back to activate a balancing or controlling mechanism, guiding the system to some defined equilibrium condition (Fowler, 2003).

Dynamic system are also characterized by delays or inertia. The concept of inertia implies the property of elements within the system to naturally maintain their current state over time. Hence, state can only be changed incrementally over a period of time, as a result of a net imbalance between the forces, or energy streams, acting on particular elements within the system. The affect of a pure delay is to produce a change in output, which reflects exactly, the change in input but displaced in time by some finite interval (Fowler, 2003).

The combination of feedbacks, inertia and delays ensures that considerably complex dynamic behaviour can be taken into account in system modelling.

The development of CLD need to follow some basic rules. Firstly, it's important to highlight that the elements of a CLD have to be thought as variables. The action in a CLD are represented by links and not by the elements. The links between variables have to be conceived according not to a time sequence (first A then B), but to a causal sequence (when A increases then B increases). The possible side effects of actions should be represented in the CLD. Short term and long term consequences should be distinguished.

An extension of the causal loop diagram is the stock and flow diagram, which represents, respectively, accumulation of certain entities or state variables that are of primary interest, and the flows that create or deplete them (Fowler, 2003). Thus, this kind of representation distinguishes between two different types of variables, i.e. stock and flows. A stock represents the accumulation of something, and a flow is the movement of something from one stock to another. The stock variables constitute a memory of past events that condition new decisions (Diehl and Sterman, 1995). The stock and flow diagram contains also information links. The existence of information links between two variables means that the information about the value of one variable influences the value of the other. Furthermore, the absence of the information link means that information about the value of one variable doesn't influence the value of the other.

3. An Integration between CM and CLD to support river basin management

As described previously, several approaches can be adopted for knowledge modelling. In this section, the potentialities of an integration between Cognitive Mapping and Causal Loop Diagram are described. To this aim, it's fundamental to highlight the different usability to support decision process. On one hand, CM are not used to assess the impacts of different decision alternatives, but to provide useful assistance to those processes of dialogue and debate between decision makers which prepare the way for decisions. On the other hand, CLD aims to model the whole structure of elements and relationships characterizing the system to be managed, adopting an holistic perspective. Thus, these two modelling devices are not mutually exclusive. They are rather complementary in structuring different part of the system knowledge.

To investigate to interaction between CM and CLD, it's fundamental to make a distinction between convergent and divergent thinking in decision making (Montibeller et al., 2001). The goal of divergent thinking is to generate many different ideas and proposals about a topic. Following divergent thinking, the ideas and information will be organized using convergent thinking; i.e., putting the various ideas back together in some organized, structured way. Thus, convergent thinking can be defined as the movement towards a single solution to a problem that involves generating a large number of ideas.

From decision analysis point of view, during the divergent thinking stage, the issue is disclosed, different views are encouraged and proposed, alternatives are generated, objectives are defined and the boundaries of the problem definition are discussed during the debate among decision makers. During the convergent phase, criteria are defined to measure the performances of alternatives on the

objectives, data about these performances are gathered, compensations between criteria are stated, alternatives are ranked, and the 'best' alternative is selected and implemented.

Thus, CM can be useful during the divergent phase. In fact, CM supports the creative definition of the problem's characteristics and identification of alternatives. It can be used to make clear the interests involved in the discussion and to facilitate the debate. Moreover, CM is able to structure the natural language used by participants to make their argumentation. CM takes into account the cognitive limitations in providing quantitative information. Decision makers usually prefer to express using qualitative information instead of qualitative. CM describes the knowledge concerning salient factors and conditions that influence decision-making more descriptively than CLD, facilitating knowledge elicitation by decision makers. A significant strength of CMs is that the modelling is closed to natural language, which reflects the ways decision makers are used to talk and think about decisions. The adoption of a descriptive approach enhance the comprehensibility of the CM. Moreover, CM is more comprehensive, less time-consuming and causes lesser inconvenience to experts during knowledge elicitation than other techniques (Nadkarni and Shenoy, 2004).

Moreover, the CMs can support divergent thinking facilitating the debate among decision makers. The analysis of CM, in fact, provides useful information concerning the different perspectives of the problem at stake. CM allows to identify central concepts (Eden, 2004). The simplest analysis available for seeking out the "nub of the issue" is generally known as a domain analysis because it calculates the total number of in-arrows and out-arrows from each node, that is its immediate domain. Those nodes whose immediate domain are most complex are taken to be those most central. The analysis indicates the richness of meaning of each particular concept.

The identification of key concepts is fundamental to understand the stakeholders' interests. The assumption here is that the higher is the central degree of a concept, the more important is the concept in the stakeholders perception of the problem. The results of this analysis can be used to inform the debate about the most important elements of the problem at stake.

The results of this debate can be used to identify the variables of the CLD, as described later in the text.

Moreover, the analysis of CM allows to compare the different interests emerging during the decision process and to identify the potential conflicts (Giordano et al., 2007). The conflict assessment results can be used both to provide the participants with a map of the underlying conflicts that will need to be addressed during the negotiation process (Susskind and Thomas-Larmer, 1999), and to evaluate the policy options according to their degree of consensus (Giordano et al., 2007). The assumption here is that the implementation of the alternatives with a high degree of consensus could be more efficacious since no, or at worst, weak conflict may emerge.

The analysis of CMs can also support the evaluation of the alternatives. The key concepts may work as axes of evaluation, aggregating the information of all subordinated attributes. They may act as guides to indicate where the researcher should look for further attributes (Bana e Costa et al., 1999; Montibeller et al., 2001). The CMs can be used to identify the Fundamental Point of View (FPV), that is the most critical success or fail factors of an action.

Nevertheless, CM cannot be used to assess changes in the system under investigation due to the impacts of management actions. Concepts have an unstable meaning, far from being variables. While it's easy to detect negative or positive links in a CM, the definition of numerical weights seems difficult to obtain and with an unclear operational meaning.

On the other side, the capability of CLD to model the impacts of management actions, considering the complexity of the real world, may be used to help the convergent phase. CLD allows to evaluate management actions according to the expected impacts on system variables, supporting the decision process. Thus, CLD can facilitate the convergent thinking phase, which aims to evaluate the different proposed alternatives according to their impacts towards objectives achievement, in order to select the most suitable ones.

Thus, we proposed a methodology moving from a less formalized cognitive model at the beginning, facilitating divergent thinking, towards a more structured model at the end, stressing convergent thinking and having some power of inference to support the assessment of strategies' effects. In this way, CM can be used to inform causal loop diagram in terms of a more explicit social and political theory and a more clear understanding of the importance of the interaction of mental models in the understanding of the system structure.

The proposed methodology comprises two main steps:

- Development of CM;
- Modification of CM to construct CLD.

The two steps need be considered from an integrated perspective, since some important issues have to be addressed to construct a CLD starting from a CM.

The development of CM is based on SODA methodology as described by Eden and Ackerman (2001). Therefore, the process starts exploring the goals system, and then gradually work down the map towards increasingly detailed options for achieving goals. In order to use the CM to construct CLD, some issues have to be addressed.

The procedure for deriving CM does not provide for a distinction between “direct” and “indirect” relationships between concepts. A clear distinction between direct and indirect cause–effect relations is important in CLD development, because it helps us understand the nature of relations between variables. It tells us whether the effect of a variable on another is completely modelled by the effect of the first on a third mediating variable (Nadkarni and Shenoy, 2004). Therefore, it’s fundamental have clear in mind this distinction when developing CM.

Moreover, the difference between deductive and abductive reasoning has to be taken into account. Deductive reasoning provides us arguments the premises of which entail or ensure the truth of the conclusion. abductive reasoning takes startling fact and infers the best available explanation of it (Cavana and Mares, 2004). A reasoning process is called abductive when we reason from effects to causes, i.e., in the direction opposite to causation (Nadkarni and Shenoy, 2004). The difference between deductive and abductive reasoning has an impact on representation of causal linkages in CM. Causal statements involving abductive reasoning are misinterpreted in CM by an arc from effect to cause. Particular attention has to be paid to the direction of causation expressed by causal statements in constructing CM and CLD. The existence of a link in CLD means that a variable has a causal impact on another. Therefore, it’s important to develop CM adopting a deductive reasoning.

According to SODA approach for CM development, the argumentation (direction of the arrows in CM) is such that an option always leads to a desirable outcome. CMs have a strong actions, or problem solving, orientation. Therefore, using CM to inform CLD enhances the usability of CLD as a tool to support decision making, rather than simple system description.

One of the primary steps to convert CM into CLD is the “operationalization” of the concepts to create variables: i.e., convert the concepts into variables, remove redundant concepts, and introduce additional variables where necessary. In our approach, CLD are used to describe system behaviour due to the implementation of management alternatives. Therefore, the variables associated to each concept shall measure the performance of each alternative according to the aspect that was considered in the concept. The identification of the key elements in CMs, as described above, can support the debate to define the important variables to describe the system behaviour.

Once defined the variables associated to each concepts to measure the performance of a given alternative, it is necessary to define how the performances shall be propagated in the model. To this aim, a relation shall be defined for each pair of variables associated to two linked concepts. This relation measures the directions (polarity) and the strength of perceived influence of one variable over another. During this phase, delays can be introduced in the map to take into account also long term impacts.

One of the most important step in the process to convert CM into CLD is the identification of reinforcing or balancing loops. A CM is characterized by a hierarchical structure which is most often in the form of means-ends graph, with the goal statements at the top of the hierarchy. The formality of coding demands that options lead to outcomes, means lead to ends, the head of an arrow shows the more desired outcome or goal. This formality is fundamental for the analysis to discover loops, because a feedback loop is absolutely dependent upon the directionality of the arrows (Eden, 2004). The analysis of CM can support the identification of loops and of all concepts included in these loops. The detection of loop in CM allows to verify whether the existence of loop is due to a coding accident or not. Unintended incorrect coding with respect to loops tend to be common in CMs because of the problematic nature of determining the interviews' view about what is cause and what is effects. The existence of mistaken or unintended loops can lead to erroneous conclusions in modelling actions impacts. Thus, a debate on the detected loops can be supported by CM analysis.

The debate can also lead to include new linkages and variables in the diagram to convert the hierarchical – linear approach of CM to the more "closed loop" thinking characterized by the system thinking approach.

4. Conclusions

The importance of Cognitive Modelling to support decision process in complex domains is widely acknowledged. In this contribution, starting from a deep literature review about the different methodologies and tools in Cognitive Modelling, the potentialities of an integration between Cognitive mapping (CM) and Causal Loop Diagram (CLD) are discussed. Particularly, the usability of CM to inform the development of CLD is the focus of our approach.

In this perspective, we assume as premise the distinction of a decision process in two stages, i.e. divergent thinking and convergent thinking. We demonstrate how CM development can support the generation of creative ideas and the elicitation of several point of views, as requested during the divergent phase. A significant strength of CMs in this phase is that the modelling is closed to natural language, which reflects the ways decision makers are used to talk and think about decisions. CM is more comprehensive, less time-consuming and causes lesser inconvenience to experts during knowledge elicitation than other techniques. In our approach, CM are not considered as models of cognition but rather tools for reflective thinking.

Moreover, the results CM analysis – i.e. identification of key concepts and of loops – supports the debate among decision makers leading to the definition of the most important aspects of the problem to be considered. This information can be used to define the variables of the CLD. During this debate, participants can be encouraged to identify concepts which may become intervention points for changing loops from vicious circles into virtuous circles and so move to a strategy for changing a problematic situations.

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