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European Journal of Operational Research 159 (2004) 673–686
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
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Decision Aiding

Analyzing cognitive maps to help structure issues or problems

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Received 20 May 2002; accepted 25 June 2003
Available online 23 September 2003

Abstract

This paper discusses how cognitive maps might be analyzed for the purpose of structuring problems or issues. The paper suggests what the various analysis methods imply for an operational research practitioner when helping a client work on a "messy" issue or problem.

Keywords: Cognitive mapping; Problem structuring; Soft OR

1. Introduction

The term 'cognitive mapping' is here used to describe the task of mapping a person's thinking about a problem or issue. A *cognitive map* is the representation of thinking about a problem that follows from the process of mapping. The maps are a network of nodes and arrows as links (a particular type of 'directed graph' (Harary et al., 1965; Harary, 1972), where the direction of the arrow implies believed causality. Thus, sometimes cognitive maps are known as 'cause maps', particularly when they are constructed by a group, and so cannot claim to be related to an individual's cognition. However, the formalisms for cause maps will be the same as those for cognitive maps. Cognitive maps are usually derived through interviews, and so they are intended to represent the subjective world of the interviewee.

Cognitive maps are not simply 'word and arrow' diagrams, or influence diagrams (as used by system dynamicists (see, for example, Wolstenholme, 1990)), or a 'mind-map'/'brain-map' (Buzan and Buzan, 1993). Mapping processes often lead to the later development of influence diagrams as a lead in to system dynamics simulation modelling (for example, Ackermann et al., 1997; Eden, 1994).

Cognitive mapping is a formal modelling technique with rules for its development. The formal basis for cognitive maps derives from personal construct theory (Kelly, 1955) which proposes an understanding of how humans "make sense of" their world by seeking to manage and control it. This focus on seeking to manage and control is what gives cognitive mapping value in operational research activity. This focus on problem solving and action makes it appropriate for 'problem structuring' and uncovering solution options. Kelly's theory provides the rules for mapping. Without such rules it would not be amenable to the type of analysis expected of a formal model,

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0377-2217/$ - see front matter © 2003 Published by Elsevier B.V.
doi:10.1016/S0377-2217(03)00431-4

and discussed in this paper. Usually cognitive maps of problem situations are reasonably large—over 100 nodes on the map, as compared to 12–20 nodes discussed in some of the research literature.

Group maps are often developed by merging several cognitive maps derived from each member of a problem-solving team. They are inevitably much larger—often over 800 nodes. Thus, the ability to conduct formal analyses, that are meaningful to the client group, becomes of greater importance.

The purpose of this paper is to discuss the use of cognitive maps as the basis for issue structuring—that is, analysis which is designed to "chunk" the map as model so as to reveal emergent properties and surface the "nub of the issue". The paper will not provide a complete introduction to the theoretical and practical basis of cognitive mapping methods, other publications provide this material (Ackermann et al., 1991; Eden, 1988; Eden and Ackermann, 1998). Nevertheless this paper commences with a brief overview of the nature of cognitive maps in order that the analysis methods discussed can be understood.

The paper continues with a presentation of the variety of analysis techniques available. Embedded in each section there are short summary paragraphs which indicate the practical significance of the analysis for the operational research practitioner—these are inset.

2. The nature of cognitive maps

The use of maps to depict and explore the cognitive structures of members of organizations who are facing complex issues has become well established in recent years. The theoretical basis for cognitive mapping, which allows an interpretation of analysis of those maps, is rarely made explicit. Also the link between a theory of cognition and the nature of problems, as it relates to the coding method used to construct a cognitive map is usually difficult to detect.

Cognitive maps are characterized by an hierarchical structure which is most often in the form of a means/ends graph with goal type statements at the top of the hierarchy. However the hierarchical form of a map is often informed by some circularity in which a chain of means and ends loops back on itself. In operational research consulting, circularity is often regarded as a fundamental structural characteristic of a map (Eden, 1994). In effect everything which is a part of a circular structure is of the same hierarchical status and so if collapsed to a single node describing the feedback loop, the general form of the remaining cognitive map can still be said to be hierarchical. These feedback loops, when they exist, usually play an important role in problem solving.

For representational purposes a cognitive map is usually drawn as short pieces of text linked with unidirectional arrows to link them. In the general case, a statement at the tail of an arrow is taken to cause, or influence, the statement at the arrowhead. An important aspect of Kelly's theory argues that we make sense of situations through similarities and differences. Thus, in cognitive mapping we seek to identify each statement (node) as having two contrasting poles (for examples, see Fig. 1). For cognitive maps the causality relates the first phrase of the bi-polar statement to the first phrase of the second statement. When an arrow head is shown with a negative (−ve) sign attached then the first pole of the tail statement implies the second pole of the head statement. Typically a node (or concept) which has no implication (out-arrows) is referred to as a 'head', and a node which has no in-arrows is referred to as a 'tail'. Fig. 1 shows a typical cognitive map. Heads will usually be 'goal' type statements—expressions of desired or not-desired outcomes, and 'tails' will be options. When goals are expressed as not-desired outcomes, sometimes indicating disasters to be avoided at all costs, they are referred to as 'negative-goals'. Usually the map will contain more goal statements than those shown by heads, and more options than those shown by tails.

As suggested above Section 1, maps used in current organizational studies show a small number of nodes and arrows (6–20 nodes—see Cossette and Audet, 1992; Huff, 1990), whereas maps developed as models for structuring issues in operational research produce large maps (30–120 nodes) from a single 1 hour interview (see Brown, 1992; Eden, 1991; Laukkanen, 1991), and some group maps, created from merging several maps of individuals,

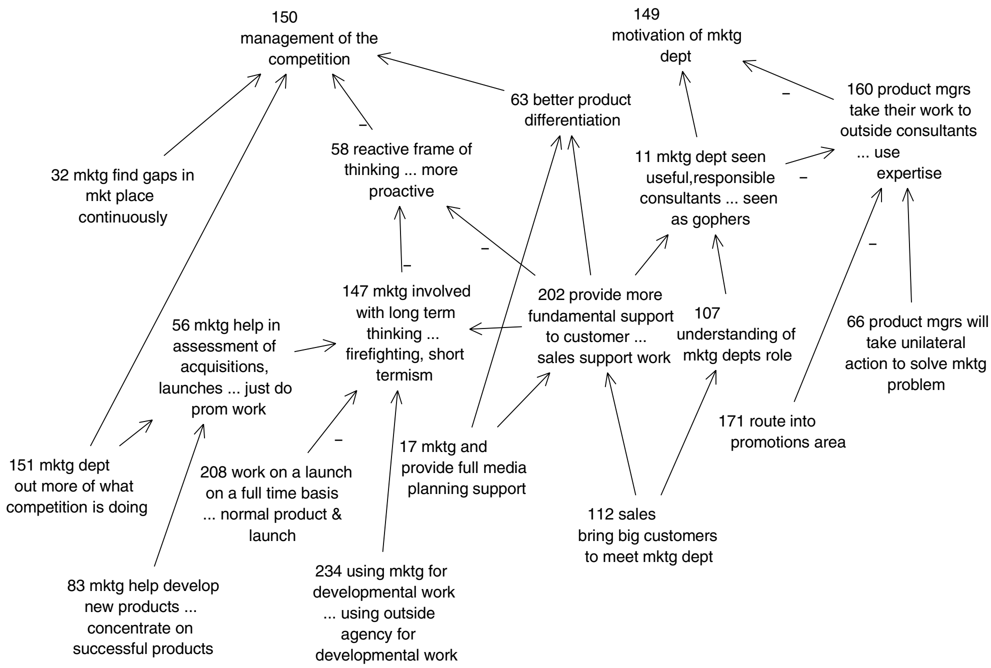

Fig. 1. Part of a cognitive map ("..." within a statement should be read as "rather than", expressing the contrasting pole).

can be very large (800–2000 nodes—see Eden and Ackermann, 1998). It is difficult to identify the "added-value" from issue structuring when the map is small, although they can still provide a starting point for understanding the basic, if not subtle, structure of an issue (Ormerod, 1995; Rosenhead and White, 1996). The emerging characteristics from a small map are sometimes better described through words and certainly demand no extensive analysis to identify them. For example, it may be more efficient and effective to state that "growth has implications for promotion opportunities which cause increases in morale which creates motivation and so reinforces growth" rather than use a directed graph to depict the beliefs. As an operational researcher we are primarily interested in the map as a model that is amenable to analysis. The analysis is expected to inform further work on the issue and identify characteristics of the issue that could not be identified with confidence without the model and its analysis.

Maps are intended, as a representation, to get close to the problem situated world of the interviewee (but see Eden (1992) for commentary on the distance between maps and cognition). However, the quality of the representation depends upon the quality of the interviewer as listener and interpreter. Maps are not just a graphical description of what is said, rather they are interpretations of what is meant by the interviewee.

3. General characteristics of a map

Cognitive maps have some very general properties that can provide an overview of their character. In this section we consider some of these properties. Fig. 2 shows the structure of this section.

3.1. Structural properties through the two-dimensional character of a map

When a map is relatively complex, then the need for easy-to-read graphical representation forces out a pattern or 'shape' as nodes are moved around to make the most easily readable two dimensional display. The pattern helps indicate emerging characteristics simply by the way in

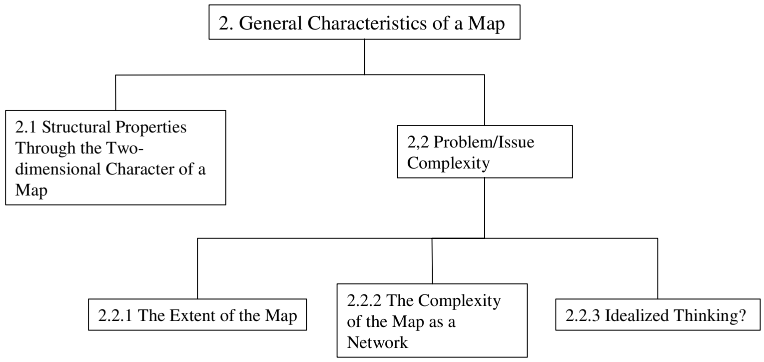

Fig. 2. General characteristics of a map—structure of Section 3.

which structure of the map forces a 'best' way of laying the map out in two dimensions. For example, the need to locate linked nodes close to one another, and the need to keep the number of crossing arrows to a minimum, hierarchical layout (for example, all arrows pointing up the page), will determine a particular layout for the map. The layout will provide information about the emerging characteristics of the map. Thus, the node that appears in the center of a map is usually significantly central to the construal of the problem or issue being depicted. The basis for the approach to cognitive mapping used by Axelrod and colleagues in the field of political science was that "when a cognitive map is pictured in graph form it is then relatively *easy to see* how each of the concepts and causal relationships relate to each other, and to see the overall structure of the whole set of portrayed assertions" (Axelrod, 1976, 5 my emphasis).

Fig. 3 shows an imperfect 2-dimensional layout of a small map. The figure demonstrates how the layout illustrates the likely centrality of one statement to the structuring of the problem/issue.

The analysis methods discussed below are, in effect, more formal ways of detecting the best ways of representing and displaying the directed graph (or for identifying and displaying abstractions from a directed graph).

3.2. Problem/issue complexity

Determining the complexity of an issue is helpful to both operational researcher and client because it acts as an appropriate preface to

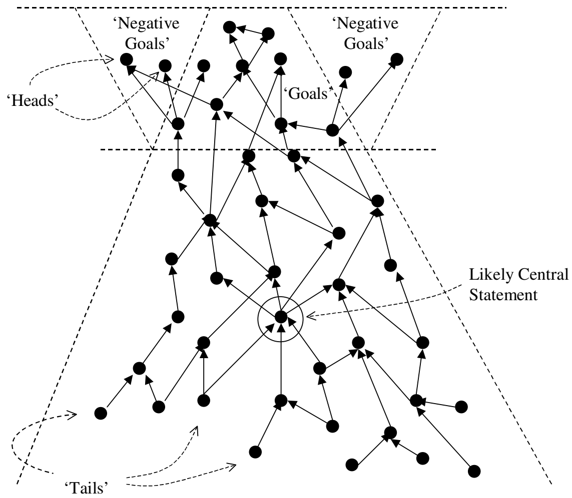

Fig. 3. A problem/issue map: two dimensional character.

"chunking" analyses that are aimed at determining the "nub of the issue" in a manner that is accepted by both analyst and client.

Both cognitive scientists and organizational scientists have been fond of simple analyses of cognitive maps. These analyses are supposed to indicate the central features of a directed graph. The first of these simple analyses explores the total number of nodes and the total number of arrows; and the second is concerned with 'cognitive centrality' of particular nodes.

3.2.1. The extent of the map

Thus the first analysis suggests that the more nodes (or concepts) in a map then the more complex is the map and so the more complex is the issue. Here the method of construct, or concept, elicitation from the client is crucial in determining the validity of such a measure. For structured interviews the number of concepts will be affected significantly by the structuring provided by the interview itself, whether the structure or lack of structure be in the form of poor interviewing skills or the interviewer having a tight agenda of structured questions. Use of multiple choice or closed questions, and an explicit expectation that the interviewee should be consistent, can have a profound effect on the openness of the interviewee. Operational researchers are often sharp critics of clients who show signs of imprecision, inconsistency, or contradiction—and yet these characteristics of a problem/issue, which can be formally revealed in a cognitive map, may be at the core of why the situation is perceived as problematic. Interviews designed around pre-prepared agendas will push the number of concepts elicited towards an interviewer determined level which is primarily a function of the number of questions asked and the time given for each answer. Experience indicates that the number of concepts elicited during an interview is dependent upon the length of the interview and the skills of the interviewer. Poor interviewing skills such as evaluative non-verbal signals and the interviewer taking too much airtime will vitally affect the size and shape of a map. Thus analyses that depend upon the number of nodes should be treated with great care. Nevertheless, the same interviewer (and so map coder) can usually expect to make sensible comparisons between maps based on this simple statistic.

It is not surprising that the degree of openness in an interview is dependent upon the extent to which the interview is itself a rewarding experience for the interviewee. Interviews can be a cathartic experience that encourages the interviewee to be, on the one hand more open, and on the other hand develop their own thinking about the topic. Weick's (1995, p. 12) suggestion that we do not know what we think until we hear what we say is particularly significant in relation to the construction of "cognitive" maps.

These issues of good interviewing in operational research practice persist whether or not mapping is used for modeling, but mapping at least forces the analyst/consultant to question the validity and reliability of their conclusions about the nature of the issue as they understand it. The map, as model, also acts as a device for establishing a mutual understanding of the issue (Eden, 1994; Eden and Sims, 1979).

3.2.2. The complexity of the map as a network

In order to take some account of these concerns about the absolute number of concepts, an alternative analysis of issue complexity is to determine the ratio of arrows to concepts. Thus a higher ratio indicates a densely connected map and supposedly a higher level of complexity. The robustness of the analysis is dependent upon the coding skills of the mapper. Inexperienced mappers tend to generate a map with a smaller number of concepts than those identified by an experienced mapper and in addition they generate more arrows. More arrows result from coding A causes B, B causes C, C causes D (4 nodes, 3 arrows) with elaborated arrows adding A causes C, B causes D, and A causes D (4 nodes and 6 arrows). Each of the last arrows are true as summaries of more detailed paths but do not represent a different causality to the indirect linkage, however, the ratio of arrows to nodes has increased from 0.75 to 1.25. The author would expect ratios of 1.15 to 1.20 for maps elicited from interviews following the form of mapping based on personal construct theory presented here. This expected ratio does not seem to vary to an extent that could significantly identify differences in cognitive complexity—there are likely to many other more plausible reasons for this relatively constant ratio such as the nature of verbal argument in interview conditions.

3.2.3. Idealized thinking?

Other simple analyses of complexity derive from consideration of the ratio of number of 'heads' and number of 'tails' to total number of nodes. So-called "idealized" thinking about a topic tends to generate maps with a small number of 'heads' (ideally a single end/goal/outcome/objective/value—a "pyramid" map). The map supposedly depicts someone able to think about situations within the context of a simple hierarchical value system where each value implies another that ultimately implies a single super-ordinate value.

- A person might be judged to be cognitively simple and well organized in relation to the topic when a map takes the form of an "idealized" pyramid structure. In this case, the operational researcher will probably be dealing with a relatively tractable issue where the client requires technical or computational assistance. Conversely, a map with a relatively large number of 'heads' indicates recognition of, and a concern for, meeting multiple and possibly conflicting objectives; such a person could be seen as cognitively complex. In this case, the operational researcher will probably be concerned with helping the client, or client group, work on a "messy" issue, where issue/problem structuring will play the most significant role.

The content of the nodes that are heads is also of some significance in this type of analysis, particularly when the same content appears as a tail for one person and a head for another. For example, our work with public policy makers has shown some of them viewing "mandates" as legitimizing goals (heads) whereas others in the same organization see them as constraints (tails).

Interpreting the analysis of the ratio of number of 'tails' to total number of nodes is more problematic and necessarily contingent. The number of tails gives some indication of the range of possible options for acting to alleviate the issue. In general the ratio of tails to total nodes provides an initial indication of the relative 'flatness' (see also below for an analysis of "shape") of the cognitive structure—a cognitive structure is relatively flat where causal arguments are not well elaborated and use short chains of argument.

4. Exploring the emergent properties of a map

If issues are complex then there is a need to discover appropriate methods of analyzing for emerging structural properties and then using those emerging properties as a basis for finding the "nub of the issue". Such analyses also act as a point of comparison between individual maps in order to ascertain the form of convergence and potential for consensus emerging among a client group. Reductionism in the initial construction of maps is necessary if emergent properties are to be analytically rather than intuitively discovered. As Herbert Simon has argued

> ...given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole... in the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist (Simon, 1981).

A cognitive map has several structural properties: the property of hierarchy and the more general property of linkage. Each of these provides opportunities for analysis of structure. These analyses, discussed below, are difficult to conduct without the help of a computer and associated software. [1]

This section presents seven types of analyses, which when taken together provide a compendium of emergent properties, each of which give an insight into ways of managing the issue or problem. The analyses are:

- 'Islands' of themes: clusters—without accounting for hierarchy.
- Networks of problems: clusters—accounting for hierarchy.
- Finding 'Potent' options.
- Virtuous and vicious circles.
- Central concepts as the "nub of the issue".
- Simplifying the issue through emergent properties.
- Shape.

[1] A software package "Decision Explorer" has been developed for the purposes of problem structuring using cause maps. The software permits visual interactive modelling where concepts can be entered, edited, and moved around a computer screen. It also allows all of the analyses discussed in this paper to be undertaken with client. The software has been used across the globe by OR/MS consultants, strategy consultants, group decision support facilitators, and others for about 10 years. Information about suppliers can be obtained from Banxia Software Ltd in the UK at www.banxia.com.

4.1. 'Islands' of themes: Clusters—without accounting for hierarchy

At one extreme a map can comprise several clusters of nodes and arrows that are each disconnected from one another: 'islands' of material. In this circumstance the detection of each 'island' as a separate map allows an exploration of the content of each island to identify themes that describe each cluster. At the extreme, the map may contain no arrows between nodes—each node forms an island in a fragmented model of cognition. Towards the other extreme, a map may be highly interconnected (most likely when the ratio of arrows to nodes is high). In this case it is difficult to "break apart" the map into relatively separable but connected clusters: the map is one 'island'. However more typically a map is not in the form of islands or a single "unbreakable" cluster but rather connected clusters of nodes. In this case the identification of clusters that break the map into a system of interrelated themes becomes worthwhile. Simon's (1981) arguments about the property of near de-composability have relevance here. In many complex, hierarchic systems, intra-component linkages are stronger than inter-component linkages and discovery of where the weakest linkages lie within the system is one basis for the analysis of complexity. The identification of themes depends upon seeking out tight interconnection between nodes, and usually pays no attention the nature of the arrow.

Thus one important analysis of emerging features relates to the detection of clusters, where a cluster may be more or less separable from other parts of the map. One form of analysis follows the principles of simple linkage clustering (Gower and Ross, 1969; Jardine and Sibson, 1971) by looking at each node and its immediate context of nodes to determine a similarity rating (known as the Jaccard coefficient). Clusters are formed gradually by putting relatively similar nodes into the same cluster until a defined level of dissimilarity has been reached (see also Smit (1991) for the analysis of similarity). The intention is to attempt the formation of clusters where the nodes in each cluster are tightly linked to one another (similar) and the number of arrows (or bridges) with other clusters is minimized. In some senses this analysis identifies the "robust" parts of the cognitive map—those parts of the map that are relatively insensitive to small changes in the structure of the map (see Smit, 1991) for a formal definition of the notion of robustness as applied to individual nodes).

Each cluster, so formed, and the interrelationship between clusters form summary characteristics of the overall map. Clearly this type of analysis provides a further insight into complexity, where the proposition suggests that a map which can be broken apart into relatively unconnected smaller maps represents lower complexity than one which is difficult to break apart. In other words, cluster analysis can suggest whether or not (or to what extent) the world has been simplified by a form of categorization.

- The purpose of analyzing for clusters, in operational research, is to identify the "system of problems" that make up the "issue" being addressed. Thus each cluster, when summarized through a descriptor, represents a relatively separable part of the issue which *may* be addressed relatively independently of addressing other parts.

4.2. Networks of problems: Clusters—accounting for hierarchy

Alternatively, clusters may be formed by consideration of the hierarchical structure of the map. "Complexity frequently takes the form of hierarchy and that hierarchic systems have some common properties that are independent of the specific content... hierarchy... is one of the central structural schemes that the architect of complexity uses" (Simon, 1981). Each node is supported by a "tree" of other nodes that have implications for the node of interest. Thus, in general, each node can be inspected for its own hierarchical cluster. However, in order to detect emerging features of the cognitive map, it is more helpful to consider a subset of nodes and their hierarchical relationship to one another and to other nodes not members of the subset. In this way, selected hierarchical clusters may be formed and the thematic content explored in relation to other hierarchically linked, hierarchical clusters. Each hierarchical cluster is similar in form to another: it will have a super-ordinate 'head' which represents the 'sub-goal' for the particular cluster, and 'tails' that represent the most detailed options for addressing that goal. In contrast to the first type of cluster analysis a hierarchical clustering permits any node to appear in more than one cluster—and this is a very useful addition to the analysis.

- 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 (Fig. 4 shows this conceptualization). In issue resolution the task of OR/MS is to gradually provide the support which enables the network of "problems" to be translated into portfolios of options, some of which may be converted to agreed-upon actions.

A helpful, exploratory, form of this analysis is conducted using "core, or central, concepts" (as they are defined below) and "heads" as the seed nodes. This means that analysis is focused on those concepts that are central in linkage terms and those nodes that are, by definition, at the top of a hierarchy, thus ensuring that all nodes in the map are considered within the analysis, and considered

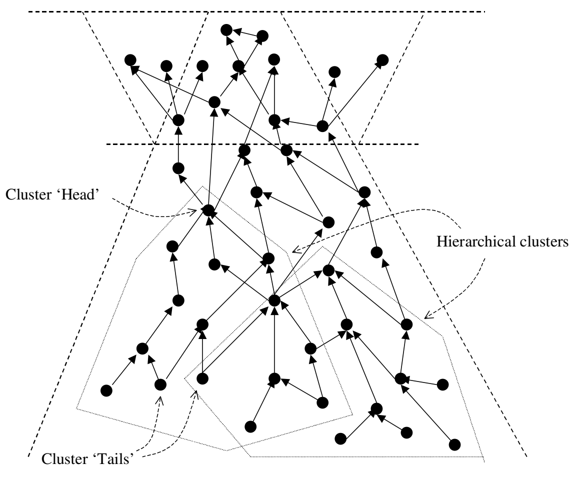

Fig. 4. Hierarchical clusters.

with respect to goals and to central/core concepts. The analysis then traces down the tree from each member of the subset and continually pulls nodes into a cluster until another member of the subset is met or the trace reaches a "tail". In this way the hierarchical relationship between each hierarchical cluster is noted.

The meaning of an analysis for hierarchical clusters is dependent upon the selection of the subset. By using "central concepts" as the basis for analysis, clusters are formed in relation to structural properties only. With care in the choice of content-based core concepts, interpreting the analysis is likely to be easier when the starting subset can be formed with reference to the content of nodes.

- Hierarchical clusters are another view of "chunks" of the issue. Here each chunk is not mutually exclusive of other chunks, but it is representative of that part of the issue that relates to any particular goal within the goal system or to 'central' nodes that are descriptive of different content aspects of the problem or issue. Thus once again the analysis suggests that the issue or problem is made up of a system of interrelated sub-problems.

4.3. Finding 'Potent' options

The appearance of nodes in a number of hierarchical clusters creates a further emergent characteristic of the issue. A node that appears in several clusters is "potent" for it has ramifications for a large number of themes. It may therefore be referred to as a core concept.

When maps are coded as means/ends relationships "heads" represent the most super-ordinate end (the "objective function" or "goal system") and potent nodes become potent means or options because they reach many goals. When heads are used as the only members of the starting subset the number of potent options provides an indication of the complexity of possible action within the context of multiple criteria.

Fig. 5 shows how an analysis of two possible hierarchical clusters reveals three potent options—tails that are within both clusters.

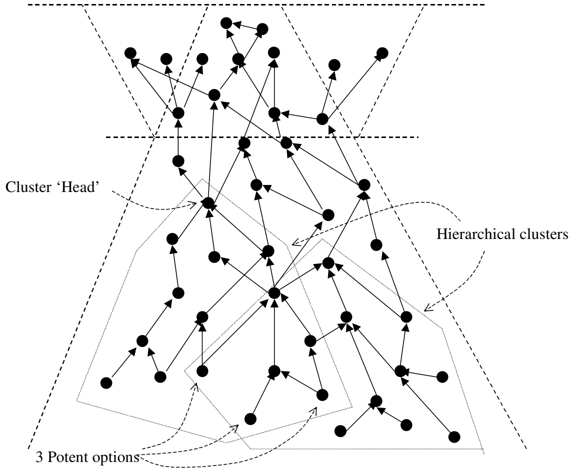

Fig. 5. 'Potent options' based on two hierarchical clusters.

- For problem solving, an important "chunk" of the issue, resulting from this analysis of hierarchical clusters, is that of determining "potent options" for achieving the "goal system".

Significantly the analysis can also reveal the extent of dilemmas which are a common consequence of recognition of multiple ramifications or goals. Each potent node may have both positive and negative consequences indicating the recognition of a problematic situation. The ability of an individual to manage cognitively both high numbers of potent options that are also dilemmas provides a powerful perspective on cognitive complexity. Analysis of cognitive maps in these terms and ways can, at the same time, provide a powerful method of helping the individual *manage* the complexity. Alternatively, it acknowledges an ability to be unaware of, or be confused by, a high level of complexity.

4.4. Virtuous and vicious circles

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. Without such formality any analysis is meaningless—this is particularly the case for an analysis to discover loops, because a feedback loop is absolutely dependent upon the directionality of the arrows.

The possibility of circularity was discussed earlier. For many operational researchers the detection of causal loops is the most important, and sometimes only, aspect of their investigation (for example, Bougon and Komocar (1990), Forrester (1961), Richardson (1991) and Senge (1992) are all excellent, but different, examples showing how central the notion of feedback may be). Their purpose is to discover those aspects of the issue which are amenable to building system dynamics simulation models. The detection of feedback loops is one, but not the only, crucial outcome of the analysis of maps. Within any context of the analysis of directed graphs the existence, or not, of feedback loops will be of interest for two reasons. First, the existence of a loop may be a coding accident that needs correcting. Second, and of great interest to the operational researcher, loops imply the possible existence of dynamic considerations within the issue—that is the cognition has acknowledged either implicitly or explicitly growth, decline or feedback control.

Unintended incorrect coding with respect to loops tend to be common with cognitive maps because of the problematic nature of determining the interviewee's view about what is cause and what is effect. Fig. 6 demonstrates how two different and plausible beliefs about the relationship between "expanding the range of courses" and "business experience" result in either a feedback loop or a hierarchy.

The existence of mistaken or unintended loops will have a significant impact on the results of all of the above analyses by leading to completely erroneous results. In most of the analyses above, every concept on the loop will be accorded the same analytical status. This means that analysis for the existence of loops should usually be undertaken before conducting any other analysis. In this way the coding can be checked and corrected if necessary before any other analysis is conducted.

When analysis results in the existence of 'true' loops then there will be a concern to establish the nature of feedback. When the loop contains an odd number of −ve arrows then the loop is depicting self-control. That is, any perturbation in the state of the variables will result in stabilizing

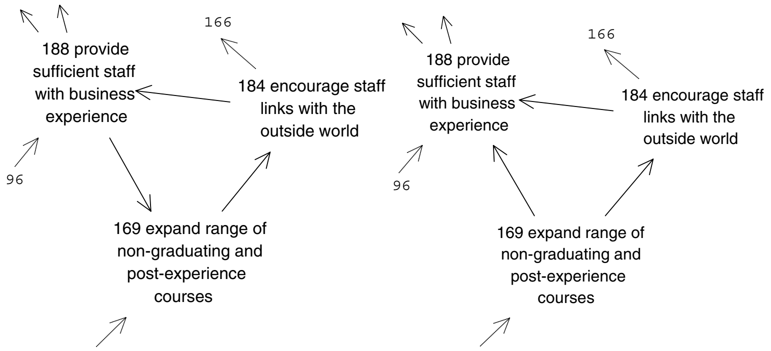

Fig. 6. A feedback loop re-coded as a hierarchy (depending upon the interpretation of the link between 169 and 188).

dynamics to bring activity into control. Alternatively an even number of negative arrows or all positive arrows suggest regenerative or degenerative dynamics where a perturbation results in exponential growth or decline. In many studies loops relate to a small number of nodes and it is possible that the implications of the loop are well known to the individual whose issue is depicted. In other cases where a loop is detected that relates to a large number of nodes then it is possible that the map has facilitated detecting counter-intuitive dynamics (Forrester, 1971). As such, the loops are a measure of complexity of the issue. Often analysis of 'word and arrow' diagrams of this nature derives from "qualitative System Dynamics" work (Wolstenholme, 1985).

Sometimes a loop will show a dynamic of a "vicious or virtuous circle". This will be detected when the number of −ve signs in the loop is even. Whether this "positive feedback" loop is virtuous or vicious will depend upon whether the current dynamic behaviour is desirable or not. Sometimes a loop will show a dynamic of "control". This will be detected when the number of −ve signs in the loop is odd.

Interventions which may be considered are:

Positive feedback loop

- *virtuous circle*. Reinforce one or more of the nodes by exploring influences on each node in turn.
- *vicious circle*. "Rub out" one of the arrows by a change in policy or by changing the nature of one of the beliefs (make the loop into a controlling loop [−ve] by changing the direction of causation, or destroy the causation): find a number of influences on nodes that can shift the direction of behaviour so that a vicious circle becomes a virtuous circle.

Negative feedback loop. If the degree of control is undesirable, if possible, break the loop by a change in policy; change the direction of causation so that the loop behaves as a virtuous circle.

Major strategic change. Occurs when the structure of the situation is changed: e.g., new loops become dominant, the 'central' core of the cognitive map/influence diagram shifts by the deletion of some beliefs (that become insignificant) and others move to prominence when the desired outcomes (goals—those variables with no arrows out of them) change.

4.5. Central concepts as the "nub of the issue"

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. For the purposes of detecting the structural characteristics of issues these analyses can be a "first draft" of the "nub of the issue". However this analysis should be used alongside others discussed below.

Attending only to the immediate domain of a node the analysis completely ignores the wider context of the node. It is possible to extend the analysis of the structural significance or centrality of single concepts within the map by exploring the impact of adding successive layers of domain to the domain count. Intuitively, it seems sensible to give each successive layer of concepts a diminishing weight—a distance decay function. For example, each node directly linked to a central node may be given a weight of 1. Nodes in the next layer out are given a weight of 1/2. The next layer is given a weight of 1/3, and so on. Where a node with a high domain score is linked directly to another with high domain, then the two will bolster one another's the extended domain score. Thus, for example, if three nodes with equal local domain scores form a row then usefully the middle node will score most highly given this form of analysis, indicating greater centrality. This is an important distinction between the output from a simple domain analysis and a weighted extended domain analysis.

- A domain analysis that considers more than the immediate context will reveal "bridging nodes", which if the cross linkage did not exist then the centrality of other local nodes would drop significantly. Thus, within the context of the issue structure, they are worthy of further exploration with the client group.

4.6. Simplifying the issue through emergent properties

Simplification, or complexity reduction rather than the management of complexity, is always a dangerous process. Simplification will often lose the subtlety that characterizes the personal ownership of an issue by the client. Thus as the operational researcher progresses towards more formal quantitative modeling there is a danger that ownership will be lost and solutions become too distant from the reality of the issue as it is seen by the client. Nevertheless, a highly complex cognitive map is debilitating (Eden et al., 1981) and the appropriate management of complexity is an important aspect of the added value from modeling detail and subtlety and yet providing summaries that can encompass simplification without losing that which is significant. The detection of systemic, emergent, properties is an effective way of ensuring that richness is retained and less necessary detail lost, and thus the "nub of the issue" is identified.

When no prior analysis has been conducted, and each node has the same status as all others, the map can be simplified by excluding those causal paths that are simple elaboration. If nodes have one causal link in and one causal link out then the path can be collapsed from two arrows into a single link by, in effect, merging the node with its tail or head node. Thus, an argument that has been mapped as A > B > C can be reduced to A > C with loss of detail only. Similarly nodes with a single link to other parts of the map can be deleted to strip the map of detail. The process must not be incremental (where each stage assumes no prior stages) as this is likely to lead to the deletion of the whole map; the starting state of the map must be retained and each deletion determined in the light of this initial state. When computer software is used this process can be undertaken with greater assurance that the subtlety of detail contained in argument strings is not lost. The software allows nodes to be merged easily and with attention to content and yet automatically retaining structure. Without this careful merging process, which is difficult to undertake manually, it is likely that the "bridging nodes" discussed above are lost.

The effect of this process of stripping out detail is to "collapse" the map to include only those nodes with a domain score of three or more—which retains those nodes that sit at branch points and deletes those nodes that are simply a part of extended elaboration. Often interviewers will code their first maps to exclude this detail, on the grounds that it is unnecessary elaboration. Indeed good interviewers are sometimes regarded as those who can "sort the wheat from the chaff" in this manner. However, experience suggests that this "on-the-hoof" analysis process can be dangerous for it inevitably means anticipating the role of concepts used by the interviewee too early and risks missing systemic properties of the map that only emerge after more reflective coding and more formal analysis.

As other analyses discussed earlier are completed, some nodes take on a different status to others—for example, as core concepts, potent options, etc.

- An operational researcher can help the client manage complexity and sharpen the focus on important aspects of the issue or problem by providing a useful overview of the map. The ability to "collapse" a map by focusing only on those emerging characteristics of the map is in its own right a powerful analysis. Thus, the sum of core concepts, heads, loop nodes, and potent options provides an important overview, or summary, of the cognitive map by showing the linkage between "important" elements of the map. However the cluster analyses reveal the structural properties of interconnections between the themes detected from an analysis of the content of each cluster. Notably the cluster analysis that does not root itself in a starting subset, and produces clusters with no overlapping nodes, provides the most "naturalistic" overview of the structure of the map, since it involves the least intervention by the analyst.

4.7. Shape

A cognitive map, because it is an hierarchy, reveals itself through the shape of the map. Here shape means considering the number of nodes at each level of the map in relation to more subordinate and super-ordinate levels. Thus the most super-ordinate level is the number of heads in the map, the second most super-ordinate level is the number of nodes that relate directly to the heads, and so on. The significance of this form of analysis in relation to an understanding of cognitive complexity is problematic. In principle when a shape is flat (lots of short paths between tails and heads) it may indicate little depth of thinking but contrarily it also suggests consideration of a high range of choice and alternative views. A thin tall shape (a small number of long paths between tails and heads) may indicate detailed argument without a consideration for alternative definitions of the situation.

The shape of a map will be different if it is determined from tails to heads rather than the heads to tails method outlined above. Which of these two methods of analysis is more appropriate depends upon the coding method used. Most of the maps used by consultants tend to lay emphasis on the role of heads because they represent desired outcomes, goals, or objectives. In these cases an exploration of top-down shape is most appropriate because tails represent an elaboration in further detail of the means or options.

- The interpretation of a shape analysis is problematic and can significantly depend upon the stage at which the analysis is undertaken. When conducted on the summary model it will reveal the structure of relative complexity between the categories of nodes (options, central concepts, and goals), whereas for the detailed and un-categorized model the shape will be more indicative of depth of detail (depth vs. width) as against multiplicity of aspects to the issue (width vs. depth). Other possibilities include—triangular shapes where a pyramid may imply tidiness of goals where each goal supports a summary goal, whereas an upside down pyramid may imply a lack of options coupled with multiplicity of different types of goals.

5. Conclusions

This paper has introduced a variety of methods for exploring cognitive maps. They were all developed within the context of using cognitive maps to help individuals (Eden et al., 1979) and teamwork on complex issues or strategy development (Eden, 1989, 1990; Eden and Ackermann, 1998). Their use for issue structuring within the context of a Group Decision Support System is well established (Eden and Ackermann, 2001). The GDSS use of mapping and analysis conducted with the client group increases the probability of group ownership and so the likelihood of implementation of agreed solutions (Eden, 1992). For OR/MS practitioners the group setting provides the possibility of creating a clear mandate for further modeling to support particular aspects of the issue revealed as significant through the analyses conducted with the group. Thus, typically, statistical modeling, simulation modeling (both discrete event, and system dynamics) (Eden, 1994; Ackermann et al., 1997), and MCDA (Belton et al., 1997) are likely project work for the OR/MS group.

Cognitive maps have not been taken as models of cognition but rather tools for reflective thinking and problem solving. Within this context of issue construction and problem solving the analyses have a very particular meaning, and a meaning that is transparent to the decision makers whose cognition is explored. Thus, for example, the discovery of loops usually arises from the aggregation of beliefs from a number of participants in the process and thus represents synergy from the synthesis of individual wisdom. As such loops can become a significant focus of group effort, where the group is encouraged to identify other concepts that impinge on the loop and which may become intervention points for changing loops from vicious circles into virtuous circles and so move to a strategy for changing a problematic situation (Eden et al., 1983).

This paper has been written so that a range of possible analyses can be applied in many different consultant/client contexts. Consequently it is difficult to be forthright about the role these analyses may play. The analyses provide *indications* of features of the map (not of cognition) and enable emerging features to be detected. As the introduction suggested, it is absolutely crucial to see analysis within the context of a clear theoretical framework, and so map coding procedure, as well as analytical purpose, without which the interpretation of the analysis will be problematic.

Most of the above analyses provide the basis for analytically simplifying a cognitive map. The approach contrasts with an operational researcher simplifying "on the hoof" during an interview by seeking to uncover "core concepts" through structured questions, tight interview agenda, or through acute observation of non-verbal cues. When an interviewer uses cognitive mapping as the basis for recording the interview and for the purposes of designing the interview as it unfolds, then the operational researcher armed with the above analysis methods can apply them informally to the map as it develops on paper. The approach is less reliable than analyses conducted with a finished map that is reconstructed after the interview and amenable to computer assisted analysis. Nevertheless, mapping and analysis conducted during the interview will provide a more reliable approach to surfacing the issue as it seen by the client than directed interviews that cannot respond effectively to the material presented in real time.

Acknowledgements

I would like to thank two very helpful unknown referees for their help in improving the original version of this paper.

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