모호인식도를 이용한 생산전략의 수립*

The Use of Fuzzy Cognitive Maps for Manufacturing Strategy Formulation

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Abstract

This paper examines the use of fuzzy cognitive maps to help understand manufacturing strategy processes. This technique is illustrated through a case study of a manufacturing strategy formulation. Advantages of fuzzy cognitive maps are highlighted by comparing the level of understanding before and after the technique was used. The merit from the use of fuzzy cognitive maps for manufacturing strategy formulation is also discussed.

(Manufacturing Strategy Formulation, Fuzzy Cognitive Map, Strategy Process Model, Feedback)

1. Introduction

Manufacturing strategy can be a powerful force in a business if it is properly developed and implemented. Recently, industry has exhibited a great deal of interest in the strategic planning of manufacturing function. This has been caused by the increase of competition, particularly from overseas, the decline of productivity growth and the need to revitalize manufacturing.

Many companies, however, do not have well developed manufacturing strategies and there appears much demand to build effective manufacturing strategies to help firms gain competitive advantage.

The effective use of manufacturing strategy comes to be greatly required. But manufacturing strategy formulation is not so easy for manufacturing strategy contains simultaneous associations among a large number of variables.

What management wants is a framework to design a manufacturing strategy which can meet their individual requirements and thereafter to use this framework as a long term guide. Strategic planning is only a first step toward the strategic management of manufacturing on an ongoing basis to gain a real competitive advantage.

This research explores the use of fuzzy cognitive map (FCM) model of manufacturing strategy for overcoming the multiple performance goal problems, while capturing the complex patterns of the strategic, operating, and environmental variables that influence goal achievement.

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However, there are few references which describe a planning process to be used for strategic planning in manufacturing.

The processes of determining manufacturing strategy and its contents have both been addressed in the manufacturing strategy literature, although rather more emphasis has been given to the content of strategy than to the process by which it has been made.

We are suggesting that the use of the fuzzy cognitive mapping technique might be useful in a number of cases, particularly those involving ill-structured decision environments, an in-depth understanding of the activities and accompanying decision processes within an organization.

It has now been widely recognized that many problems faced by decision-maker exist within complex, ill-defined, and interconnected messes, located in turbulent environments. Accordingly, much attention is now directed toward the problems of strategic decision-making and decision-making in conflict and crisis. It is recognized that purely analytical approaches are inadequate to deal with such problems, and the need for the development of a more general "science" of decision-making has been identified (Klein and Cooper, 1982).

A fuzzy cognitive map provides a means of representing the way a decision-maker models his decision-making environment in terms of the concepts he himself uses. The technique has been used to examine the causal belief systems of decision-makers in a variety of contexts (Klein and Cooper, 1982).

Despite the simplicity of this approach, cognitive mapping can provide a useful analogy, enabling predictive inferences to be drawn about the outcomes of decision-making processes.

Complex social systems are difficult to represent. Relationships between social forces demand feedback. For example, the casual connection between manufacturing strategy variables is a feedback system. A dynamic system is needed to model shifts in equilibrium caused by changes in the casual environment.

In practice, FCM allows a firm to see potential outcomes of various decisions quickly and easily. It helps identify irrelevant data. It can be used to evaluate the factors that affect a given class of decisions. It enhances the overall understanding of decision maker's environment, particularly when it is ill-structured (Montazemi and Conrath, 1986).

The objective of this study is to examine how to develop a production/ operations decision support system that would assist decision makers in facing an ill-structured environment. In addition, we want to construct manufacturing strategy planning system that would be used by managers facing similar decision environments and to evaluate the utility of a manufacturing decision support model for improving inter functional decision-making.

This paper is organized as follows. The next section provides a brief review of the FCM. Then, we describe the manufacturing strategy formulation processes which use FCM. The paper concludes with a brief discussion of positive and negative aspects of using such a model, and evaluates the utility of a FCM model for improving inter functional decision making.

2. Development of FCM

(1) A brief review of FCM

A cognitive map is a representation of relationships that are perceived to exist among the attributes and/or concepts of a given environment (Zhang et. al., 1989).

Three kinds of cognitive maps are simplest form, weighted map, and fuzzy map. Recent extension to the weighted maps come from the notion that causality is fuzzy. Fuzzification admits descriptive terms (e.g., little, somewhat, much, or very much) of the relations. Fuzzy cognitive maps would be useful for approximate reasoning when casual relationships are specified by individual beliefs without evidence (Lee et al., 1992).

The FCM is a signed directed graph with feedback. Its nodes are problem domain concepts. Edge weights are the degrees to which concepts interact. FCM graph search places no restriction on graph complexity. At the core of the FCM is an unrestricted network. Consequently, the cycles required for knowledge expression fit naturally into the FCM's feedback framework.

The FCM is able to represent complex causal relationships. It provides a framework that insulates the domain expert from the formation of a rule-base (Taber, 1991).

In FCM, the hypothesized causal relations among variables are highlighted, while analysis of the feedback loops can provide insights into the dynamic behavior of the system. Therefore, FCM may be a particularly valuable tool for both consultant and theorist in conflict-laden situations.

In modern control theory, because certain social and natural worlds to be modeled are quite fuzzy, we meet difficulty in setting up state equations precisely. Furthermore, if a CM in consideration is large, the state equations will be complicated, and it will be very difficult, if not impossible, to obtain a numerical solution.

Cognitive maps have been used for many purposes. For example, it is used to analyse political decisions, to bring order and to provide self-insight to problem solving, and to analyse military scenarios. The cognitive maps which were the focus for this research are developed as tools for use in manufacturing strategy research, where part of that research includes determining manager's beliefs about strategic domains.

Axelrod (1976) has observed that although a policy maker do not have a clear map of his policy terrain, he has no difficulty in accepting the causal links making up a more comprehensive map.

System modeling can be invaluable in a crisis by reducing the equivocality surrounding the problem and aiding the construction of a rich map of the policy terrain with which to search for a safe passage (Hall and Menzies, 1983).

FCM is a useful model. The model, therefore, is presented here, not as an optimizing or accurately predicting device, but as a tool for manufacturing strategy formulation, implementation, and analysis in a time of conflict.

(2) Building FCM

The principal reason for developing a cognitive map is to obtain insight into the structure of the decision environment that might be difficult to obtain otherwise. The cognitive mapping technique is akin to the use of simulation techniques. It permits the building of a complex, interactive system based on simple, understandable components.

Perhaps the greatest case for the FCM approach is its ease

Table 1. A Definition of FCM and Related Terms

Method	Definition	Related Terms
Fuzzy Cognitive Map	A signed directed graph with feedback. Its nodes are problem domain concepts. Edge weights are the degrees to which concepts interact.	Cognitive Map
Cognitive Map	A positive(+) and negative(-) representation of relationships that are perceived to exist among the attributes and/or concepts of a given environment.	Influence diagram
Knowledge-based System	A program in which the domain knowledge is explicit and separate from the program's other knowledge.	Expert System
System Dynamics	The influence relationship which is expressed as mathematically quantifiable functions and time dimension of the influence.	
Econometric Methods	An extension of regression analysis and include a system of simultaneous regression equations.	Simultaneous equation model
Influence Diagram	A relevance diagram constructed to visualize the probabilistic dependencies in a decision analysis and to specify the states of information for which independencies can be assumed to exist.	Knowledge Map

of use. The domain expert draws diagrams instead of listing rules. The knowledge engineer has a well-defined procedure for processing the captured knowledge. All maps share a common structure. Methods that work for one map work for all (Taber, 1991).

Specifying the frameworks (optimal, exhaustive, meaning-ful, well-defined categories), specifying elements, specifying relationships among elements, specifying strengths of relation-ships between elements, mapping influence diagram, the interpreting influence diagrams are the stages of FCM methodology (Ramaprasad and Poon, 1985).

In FCM, the directed edge E_{ij} from casual concept C_i to concept C_j measures how much C_i causes C_j. FCM models the world as a collection of classes and causal relations between classes.

The FCM allows experts to represent factual and evaluative concepts in an interactive framework. Experts can quickly draw FCM pictures or respond to questionnaires. Knowledge engineers can transcribe interviews or printed documents. Experts can consent or dissent to the local causal structure and perhaps the global equilibration. The FCM knowledge representation and inferencing structure reduce to simple vector-matrix operations, favor integrated-circuit implementa-tion, and allow extension to neural, statistical, or dynamical systems techniques.

(3) Building a simulator

Building a software simulator for a FCM is not so difficult, certainly much easier than building an expert-system shell. We make use of the FCM feedback algebra and Caudil's (1990) pseudocode for a simulator program. The program is coded by using C language.

We reason with FCMs as we recall with TAMs (Temporal Associative Memories). We pass state vectors I repeatedly through the FCM connection matrix E, thresholding or nonlinearly transforming the result after each pass. Indepen-dent of the FCM's size, it quickly settles down to a TAM limit cycle or "hidden pattern". The limit cycle inference summarizes the joint effects of all the interacting fuzzy knowledge. A FCM as a dynamical system takes its equilibrium behavior as a forward-evolved inference (Kosko, 1986, 1992).

FCM feedback algebra is as follows;

$$I_{K+1} = \Gamma\ (I_k\ E)$$

$$\Gamma(I_k\ E_j) = 1 \text{ if } I_k\ E_j > 1 \text{ or if j is the element of promoters}$$
$$\Gamma(I_k\ E_j) = -1 \text{ if } I_k\ E_j < -1 \text{ or if j is the element of demoters}$$
$$\Gamma(I_k\ E_j) = I_k\ E_j \text{ otherwise}$$

where $\Gamma(.)$ is threshold function

I_k is k $_{th}$ order inference

E is FCM connection matrix

E_j is the column vector of E

FCM dynamical systems behave as "associate memories". They are decoded by allowing the FCM to equilibrate. The matrix is excited by a vector of inputs. Excitation is vector-matrix multiplication. Continued excitation by repeated vector multiplication leads to equilibration. If the input is an ordered list of antecedents ("what-if" questions or symptoms), the vector matrix product is an ordered list of consequences (answers of diagnoses).

Iteration terminates when it fails to yield new data or simply when a predetermined iteration count has been reached.

A limit cycle of length zero is an attractor. That is; only one vector is produced by iteration. A limit cycle of length one is bistable; two vectors alternate.

The FCM is a hybrid of a rule-based system and an expert network: it handles high level concepts in its nodes and links as a rule-based system does, yet it's built and operates much more like a neural network. A FCM is particularly good when many experts of varying believability and skills are available, and it avoids most of the knowledge-extraction problems of rule-based system development (Caudil, 1990).

3. Manufacturing Strategy Formulation Using FCM

(1) Manufacturing strategy process

In many manufacturing companies, the production/ operations function plays a central role. A low-cost producer that makes its products available off-the-shelf must depend on its production/operations function, and its manufacturing strategy must be coordinated to achieve its goal. A differentiated firm is one that has a flexible producing system. If its image is one of providing the highest quality, the operations system must have that unique capability. A firm that attempts to succeed through market segmentation should have a coordinated manufacturing strategy that meshes carefully with the corporate strategy or business unit strategy.

The reasons for manufacturing strategic planning are

(1) To help the business compete by guiding the day to day tactical decision-making which goes on in manufacturing and by setting priorities among daily activities which establishes long-range objectives and strategies.

(2) To identify the external environment and adapt themselves to it in a strategic sense.

(3) To improve communication with other functions.

(4) To give manufacturing a proactive role.

The development of a manufacturing strategy is an interactive process involving planning and execution at various levels and in a variety of areas.

Strategic planning problems are complex and ill-structured. They includes numerous important elements and their relationships, such as important "feedback". A FCM is a map of these elements and relationships. It offers a graphic map

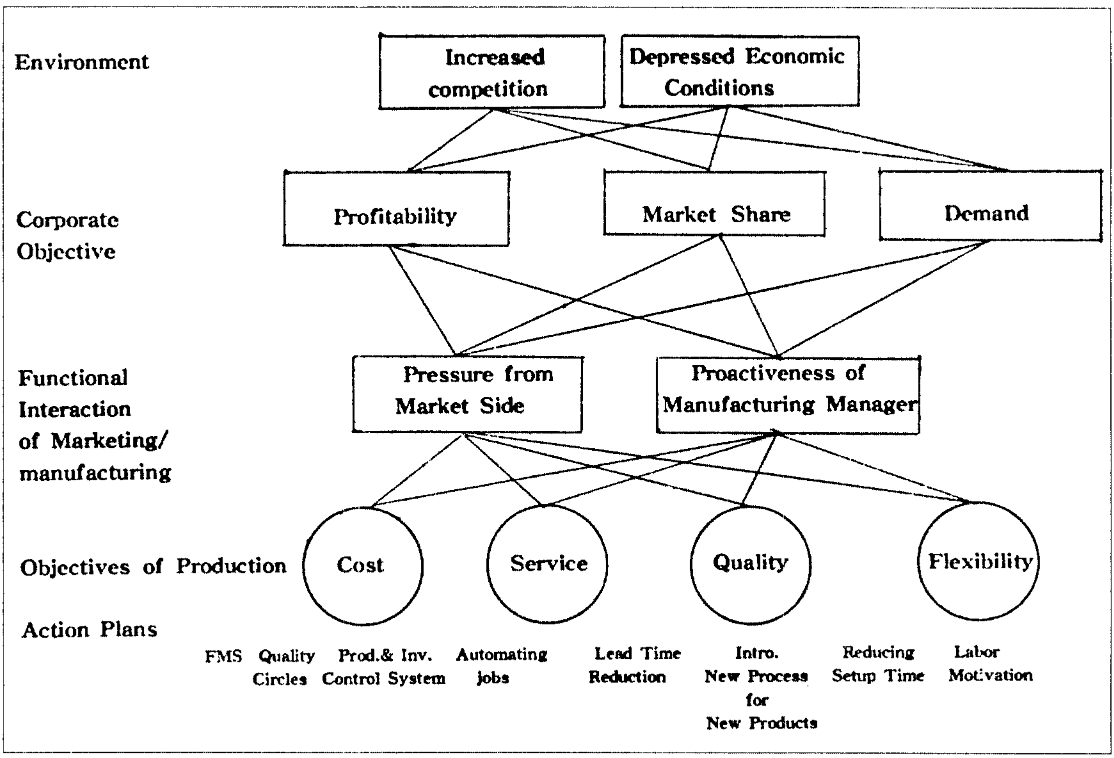

Fig.1 A Structure of Manufacturing Strategy Formulation in Consideration of Marketing/Manufacturing Interfaces

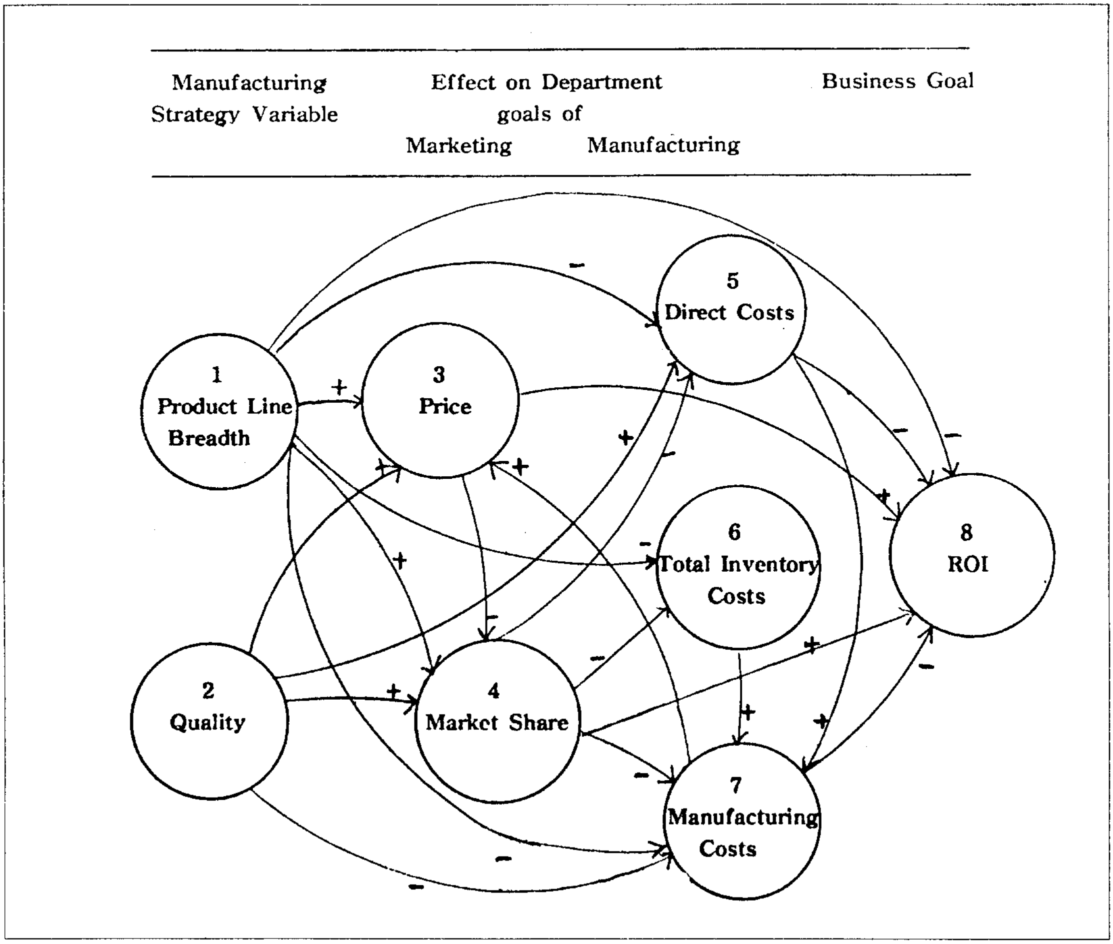

Fig.2 Direct and Indirect Effects of Manufacturing Strategy Variables on Performance in Marketing/Manufacturing Interface

of the web of relationships bearing on an issue. Its purpose is to make the dynamics of the interrelationships more visible, more explicit, and more comprehensible. A FCM should ideally make the complex problem cognitively manageable to the strategist, so that s(he) may analyze the problem and synthesize a strategy (Ramaprasad and Poon, 1985).

Skinner's work (1978 and 1985) suggests a hierarchical model of manufacturing strategy formulation. The model suggests a bottom-up approach to effective strategy making. Skinner's model of manufacturing strategy process is essentially a top down view of manufacturing strategy. Other writers have added support to this view, including Miller (1981) and Wheelwright (1978) (Swamidass and Newell, 1987).

Key elements of the top-down manufacturing process are (1) the establishment of manufacturing task -- a statement of goals and means, (2) the alignment of the policies and actions of the manufacturing infrastructure with the task established earlier, and (3) the involvement of manufacturing managers/executives in the strategic decision process.

While the top-down view of manufacturing strategy is very prevalent, in certain firms, Hayes and Wheelwright (1984) see a need for an interactive development of manufacturing strategy.

There are four important steps in of developing SBU

(Strategic Business Unit) plans for the production/operations function:

1) Analyzing the situation

2) Developing strategic alternatives

3) Selecting a manufacturing strategy in harmony with the business strategy

4) Formulating detailed plans and budgets to implement the manufacturing strategy

These steps are not independent of each other; rather they involve cycling back to previous steps as new information is developed in subsequent ones. Therefore, the development of a manufacturing strategy is an interactive process involving planning and execution at various levels and in a variety of areas.

(2) An interactive model of manufacturing planning

Many managers, when asked about the relationship between the marketing and manufacturing functions in their companies, such as capacity, lead time, inventory, quality, breadth of product line, cost control, new product introduction, and after service, tend to describe it as troubled and strained.

Most business processes are complex sequences of activities containing both positive and negative feedback loops. Almost all business processes are nonlinear because of such feedback loops. Moreover, most of these loops act with time delays, making the overall sequence not only nonlinear but dynamic. In a nonlinear dynamic system the global optimum is not the sum of local sub optima. No specialized activity manager, doing his utmost for productivity within his area, can know whether his action is helpful or harmful to the entire system.

The marketing/manufacturing interface is the focal point of much more frequent and heated disagreement than occurs between other pairs of functions (Hayes and Wheelwright, 1984).

This is hardly surprising, given the often conflicting goals of the two functions (Shapiro, 1977). Broadly speaking, marketing's goal structure focuses upon demand simulation, while, manufacturing's goal structure centers around supply regulation.

A structure of manufacturing strategy formulation in consideration of marketing/manufacturing interfaces will be as Fig. 1.

Kekre and Srinivasan (1990) show an example of strategic decision for product line breadth which evokes differential responses from the manufacturing and the marketing areas. They systematically investigate the markets' benefits and cost disadvantages of broader product lines which use weighted two stages least squares procedure for simultaneous equations. The relationship among endogenous variables (market share, relative price, direct cost, total inventory, manufacturing costs, and ROI), and product line breadth was presented.

Modified graph of this model that includes quality variable (Fig. 2) will be suggested as an example of manufacturing strategy formulation using fuzzy cognitive map, because we would like to use the result of that research for determining the weight of FCM and showing the advantage and disadvantage of FCM and those of the other approaches.

(3) FCM for manufacturing strategy formulation

A FCM development procedure for manufacturing strategy formulation is shown in Table 2.

Each weight of FCM is obtained from the results of Kekre and Srinivasan's (1990) study. Values of the weight are given in proportion to the coefficient of their simultaneous equations.

We tested the effect of line breadth ($I_1=(1,0,0,0,0,0,0,0)$) in this FCM (E). Hidden pattern of this FCM by the inference I_1(Table 2) is that if we broad the product line, we can attain high relative price, high market share, and high ROI, still attaining low direct costs, low total inventory costs, and low manufacturing costs.

This result is the same as the result of the Kekre and Srinivasan's (1990) study which uses simultaneous equations. They said that the lack of any strong negative impact of a broader product line on direct costs and manufacturing costs was an unexpected outcome of their analysis, and concluded that the future research should identify firm characteristics that might help facilitate broadening of a product line.

We tested a sensitivity analysis of this FCM by changing some weights of FCM (E_{15} → .05, E_{16} → .01, E_{17} → .01, E_{27} → .04) which conforms to the traditional beliefs of manufacturing managers — the product line breadth and the quality increases costs. However, we could obtain even the same result in these weights' structure (E').

Immediate revealing which factor or paths of these variables make this possible can be an advantage of the FCM analysis. This result is due to the cost structure of above FCM of E'. This is due to the large effects of the product line breadth to the market share (E_{14}=.9), and the negative effect of the market share to the direct cost (E_{45}=-.06) and to the inventory cost (E_{46}=-.03). If the product line breadth to the market share (E_{14}) and the market share to the direct cost (E_{45}) and to the inventory cost (E_{46}) is less than the effects of the product line breadth to the direct cost (E_{15}=.05) and to the inventory cost (E_{16}=.01), we can not obtain the same result.

Additionally, we test simultaneous effects of product line breadth and quality on the FCM E. We could obtain the same result as above (Attractor=(1, 1, 1, 1,-1,-1,-1, 1)). Simultaneous effects of product line breadth and quality on the FCM E' is (1, 1, 1, 1, 1,-1, 1, 1).

Paths from the policy variable to goal in FCM E are shown

Table 2. A FCM Development Procedure for Manufacturing Strategy Formulation

<table>
<tr><td>1. The Purpose of The Model</td><td>Manufacturing Strategy Formulation and Simulation</td></tr>
<tr><td>2. The Relevant Variables</td><td>Product line breadth (C_1)
Quality (C_2)
Price (C_3)
Market share (C_4)
Direct costs (C_5)
Total inventory costs (C_6)
Manufacturing costs (C_7)
ROI (C_8)</td></tr>
<tr><td>3. Map Acquisition</td><td>Figure 2</td></tr>
<tr><td>4. Conversion to Matrix Form</td><td>E =
<table>
<tr><th></th><th>C_1</th><th>C_2</th><th>C_3</th><th>C_4</th><th>C_5</th><th>C_6</th><th>C_7</th><th>C_8</th></tr>
<tr><td>C_1</td><td></td><td></td><td>.77</td><td>.9</td><td>-.15</td><td>-.01</td><td>-.01*</td><td>-.4</td></tr>
<tr><td>C_2</td><td></td><td></td><td>.09</td><td>.06</td><td>.03</td><td></td><td>-.04</td><td></td></tr>
<tr><td>C_3</td><td></td><td></td><td></td><td>-.16</td><td></td><td></td><td></td><td>.95</td></tr>
<tr><td>C_4</td><td></td><td></td><td></td><td></td><td>-.06</td><td>-.03</td><td>-.00</td><td>.06</td></tr>
<tr><td>C_5</td><td></td><td></td><td></td><td></td><td></td><td></td><td>.27</td><td>-.8</td></tr>
<tr><td>C_6</td><td></td><td></td><td></td><td></td><td></td><td></td><td>.4</td><td></td></tr>
<tr><td>C_7</td><td></td><td></td><td>.08</td><td></td><td></td><td></td><td></td><td>-.09</td></tr>
<tr><td>C_8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>5. Inference
(promoters or demoters)</td><td>The effect of line breadth
I_1=(1,0,0,0,0,0,0,0)</td></tr>
<tr><td>6. Paths from the Policy Variables to Goal</td><td>Table 3</td></tr>
<tr><td>7. Hidden Pattern</td><td>I_1E= (0.0, 0.0, .77, .9, -.15, -.01, -.01, -.4)
→** (1.0, 0.0, .77, .9, -.15, -.01, -.01, -.4)=I_2</td></tr>
<tr><td></td><td>Attractor= (1.0, 0.0, 1.0, 1.0, -1.0, -1.0, -1.0, 1.0)</td></tr>
</table>

* shadow means that weights will be changed in FCM E'

** → means threshold operation

Table 3. Paths from the Policy Variable to Goal in FCM E

Change Product Line Breadth — Broadening product line leads to

	Path	Links	Polarity	Arguments
1	(1,3,4,5,7,8)	6	−	more price, direct costs, and manufacturing costs, less market share and ROI
2	(1,3,4,5,8)	5	−	more price, and direct costs, less market share and ROI
3	(1,3,4,6,7,8,)	6	−	more price, total inventory, and manufacturing t costs, less market share and ROI
4	(1,3,4,7,8)	5	−	more price, and manufacturing cost, less market share, and ROI, less
5	(1,3,8)	3	+	more price and ROI
6	(1,4,5,8)	4	+	more market share and ROI, less direct cost and manufacturing cost
7	(1,4,6,7,3,8)	6	−	more market share, less total inventory costs, manufacturing costs, and price, and ROI
8	(1,4,6,7,8)	5	+	more market share, and ROI, less total inventory costs, and manufacturing costs,
9	(1,5,7,3,8)	5	−	less direct costs, manufacturing costs, price, and ROI
10	(1,5,7,8)	4	+	more ROI, less direct costs and manufacturing costs
11	(1,5,8)	3	+	more ROI, less direct costs
12	(1,6,7,3,8)	5	−	less total inventory costs, manufacturing costs price and ROI
13	(1,6,7,8)	4	+	more ROI, less total inventory costs and manufacturing costs
14	(1,7,3,8)	4	−	less manufacturing costs, price, and ROI
15	(1,7,8)	3	+	more ROI, less manufacturing costs
16	(1,8)	2	−	less ROI

Recursive Path

a. (3,4,5,7,3)	5	+	more price leads to less market share, more direct costs and manufacturing costs which makes yet more price
b. (3,4,6,7,3)	5	+	more price leads to less market share, more total inventory costs and manufacturing costs which makes yet more price
c. (3,4,7,3)	4	+	more price leads to less market share, more manufacturing costs which makes yet more price

in Table 3. The cost structure of the FCM can be revealed more explicitly by the analysis of the paths of FCM. Each path is an argument from cause to effect and represents a policy, such as increase the product line breadth to increase the amount of ROI (path #16). Some are simple (e.g., path #16 has only two links), and some are tenuous (e.g., path #1, #3, #7 has six links). If there is indeterminacy, the shorter path (e.g. #16, #5, #11, #15) will be easiest to argue in decision-making, and hence most likely to be chosen (Hall, 1984). Alternatively, path representing arguments congruent with the production/operations department's current beliefs also may be likely choices (e.g., path #10, #11, #15 in FCM E'). In this decision environment, decision maker cannot accept product line broadening and quality improving as a manufacturing strategy. However the truth is not on the shorter path or current belief, but on the cost structure of the firm.

Note that paths #a, #b, #c represent feedback loops of positive polarity. Since these loops have positive polarity, unless the effect of the product line breadth to cost paths through the market share has strong effect (path #6, #8), the ROI will fall.

By the above analysis, we can suggest that a process model of manufacturing strategy formulation is invaluable in making a search of a suitable manufacturing strategy.

4. Discussion

The FCM approach to manufacturing strategy formulation provides distinct advantages over the alternatives. The FCM represents complex casual relationships. By analysing structure of FCM connection matrix, We can find same robust results of FCM analysis which use different connection matrix E and E' and can reveal the manufacturing strategy processes throughly.

We can suggest several advantages of using FCM for manufacturing strategy formulation;

(1) to understand better the value of one factor as it relates to the values of other factors.

(2) the cognitive map might be used as a basis for determining independently the strategic importance of any given factor based on the extent to which it directly or indirectly influences other factors.

(3) because the technique is simple to use, it enables one to individualize the manufacturing decision support system (Montazemi and Conrath, 1986).

FCM may be a particularly valuable tool for both consultant and theorist in conflict-laden situations. The hypothesized casual relations among variables are highlighted, while analysis of the feedback loops can provide insights into the dynamic behavior of the system. The methodology in this study helps generate an overall view of the manufacturing/marketing interface problems.

However, main problem of FCM is that the value of a cognitive map depends upon how the data are analyzed. Worse, different experts differ in how they assign causal strengths to edges and in which concepts they deem causally relevant. The FCM seems merely to encode its designer's biases, and may not even encode them accurately. FCMs combination and simultaneous equation solution can provide a partial solution to this problem.

The absence of any reliable procedure for formally constructing the organization's map of causality and checking the verity and the absence of guiding principles for decision making in complex interactive systems where the natural policy making process becomes less reliable, is also part of problems of FCM (Hall, 1984).

Further study is required to find the correct weight assigning method of the FCM of the manufacturing strategy. In this paper, we can not obtain normalized regression coefficient β from Kekre and Srinivasan(1990)'s paper, so our weights are somewhat arbitrary. But our results seem fairly robust.

In our paper, we can not suggest the heuristic path search algorithm, which is a kind of depth first search and is necessary for the path analysis.

However, in this paper, we suggest a refined procedure of FCM for manufacturing strategy formulation in a conflict laiden manufacturing/marketing interface situation and show a in-depth analysis of the manufacturing strategy process.

Therefore a new role of management science in production/operations management is suggested that might involve systematic procedures and algorithms for equipping manufacturing firms with effective and adaptive production/ operations decisions and accurate and updatable cause maps of the manufacturing strategy domains.

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