Fuzzy Cognitive Maps analysis of
Green Supply Chain Management: a case study approach

Bevilacqua M.* Ciarapica F.E.*
Marcucci G.* Mazzuto G.*

*Department of Industrial Engineering and Mathematical Science
Università Politecnica Delle Marche, Ancona, AN 60131 Italy
(Tel: (+39) 071.2204771)
(e-mail: m.bevilacqua@univpm.it f.ciarapica@univpm.it
g.marcucci @staff.univpm.it g.mazzuto@staff.univpm.it).

Abstract: The Green Supply Chain has proposed to innovate industrial production by implementing a radical perspective change: reconcile economy and ecology. This study aims to contribute to the realisation of a new idea of eco-sustainable industrialisation. Anyone making decisions within any dynamic system faces serious difficulties. For this reason, the proposed study analyses this system using Fuzzy Cognitive Maps arriving at the formation of a real map of the causal relationships between the concepts identified, then divided by areas of membership. In doing so, the most relevant factors affecting the Green Supply Chain decision-making process have been identified and analysed.

Keywords: Sustainability, Modelling Social and Environmental Change, Human-centered systems engineering

1. INTRODUCTION

Currently, the world is characterised by a series of pollution-related problems, and the industrial sector is one of the main causes of this negative situation. On the one hand, this sector is a threat to society, but on the other hand, it indeed is the first supporter of today's livelihood. Taking this into account, together with the increasingly pressing needs in terms of business efficiency and effectiveness, Supply Chains (SCs) are right now evolving into a new paradigm (Bevilacqua et al., 2018a).

Recently, a strategic choice made by many companies is the pursue of Green Supply Chain Management (GSCM). The goal is to improve the company's performance while fostering sustainable development (Zhang et al., 2019), as GSCM is to be considered as a business value driver and not as a cost centre (Wilkerson, 2005). Nevertheless, GSMC is also driven from regulatory requirements and consumer pressure: therefore, the scope of GSCM ranges from reactive monitoring of the general environment management programme,s to more proactive practices implemented through various Rs: Reduce, Re-use, Rework, Refurbish, Reclaim, Recycle, Remanufacture, Reverse logistics, etc. (Srivastava, 2007). Morevoer, it's important to point out that throughout this development is necessary to take into account all three pillars of sustainability: society, economy and environment (Bhinge et al., 2015). However, the overall impact of such models on these three perspectives is unclear, as the implementation of non-proprietary models involves several factors of uncertainty (Gnoni et al., 2017).

Therefore, it is essential to construct models that can comprehensively evaluate the GSCM as a whole: to reach this goal, this paper make us of Fuzzy Cognitive Maps (FCM), a peculiar tool with many comparative advantages, including the possibility of simplifying a complex decision-making environment by integrating the different perspectives and ideas of the actors involved. To explain the research approach, this paper is organized as follows: Section 2 reviews the extant literature about FCM and GSCM. Section 3 shows the research approach while Section 4 exemplifies the application of the proposed method in an operating context. Finally, Section 5 shows the research conclusion and further research.

2. LITERATURE REVIEW

Axelrod (1976) introduced cognitive maps in the context of human systems, to exemplify the parts of a system and associate them to a decision-making structure. Later, Kosko and Bart (1986) introduced the concept of fuzziness, which plays a crucial role when we have to link multidimensional and multidisciplinary concepts, especially within the so-called soft knowledge domains, such as organisational theory and political science. Since then this area of research has progressed significantly, and applications have spread to various fields of study: medicine (Bevilacqua et al., 2018c), neurocomputing (Papageorgiou and Poczęta, 2017), risk management (Jamshidi et al, 2016) social sciences (Pluchinotta et al., 2019) and financial science (Ganesan et al., 2019; Groumpos, 2019b; Groumpos, 2019) are only some of the fields of studies in which FCMs have been used as study tools (Groumpos, 2018a).

As mentioned before, the current trends in the industrial systems, such as energy depletion and pollution problems, have also naturally channelled FCMs to a more detailed study of the field of sustainability. Han et al. (2019) conducted a sustainability assessment study specifically in the chemical industry, developing a novel hybrid multiple criteria decision-

making framework under bipolar linguistic fuzzy environment based on VIKOR and FCM. Through this methodology they have been able to model the various intrinsic characteristics of the system in question, considering both the importance and the interrelationships between the various decision-making criteria and obtaining a better understanding of the assessment of the sustainable chemical industry.

Martin (2017), in his research, analyzes the impact of the implementation of Green Manufacturing on aspects of environmental promotion, the nature of the product and customer behaviour. The objective of this study is to identify the key implications of these factors, through the use of FCM, to accelerate and facilitate the implementation of the principles of Green Manufacturing.

Gnoni et al. (2017) assess, through the examination of a case study (i.e. washing machines SC), the different impacts on ownership-based sustainability to a product-as-a-service based model in direct and reverse SC. This study is also conducted through an FCM model, to directly quantify the indirect effects on the social, economic and environmental dimensions due to the transition from one business model to another.

Buruzs et al. (2019) have instead developed a horizontal methodology for all industrial sectors, to provide the necessary knowledge to policy and decision makers for the planning, design and operation of a system within the framework of the circular economy. FCMs were used to model this system, as it involved the analysis and interconnection of a wide variety of interdisciplinary services.

Martin et al. (2018) point out the pressing need for humankind to shield the environment from getting degraded. In their study, they shine the light into the promotion of green economics and eco-related activities for sustainable development by developing supportive measures for industries to switch to green economy. In this research work, they carry out an FCM analysis with hexagonal weights, in order to prevail over the uncertainty situations in decision making.

The work by Wang et al. (2019) is focused instead on the client-end of a green SC, by studying the interaction between the essential functional value of green products and their social and epistemic value in green purchasing behaviour. In this research, a FCM methodology is used to analyse the gap between green intention and actual purchasing client behaviour.

3. THE RESEARCH APPROACH

3.1 The Procedure

As shown in Fig.1, the procedure is composed of six steps:

1. **Problem Identification** – This phase concerns the identification of the parameters influencing the Green Supply Chain as well the top event, that is the single event that is influenced by all other events.

2. **Experts' panel establishment** – Each member must be selected according to the following criteria area and competence criteria. The call for a group of experts,

although better than individual evaluations, try to avoid the possible problem of evaluations subjective.

3. **Concept Identification** - The relevant factors, related to the questioned problem and named concepts, are identified through data from literature and expert opinion.

4. **Relationships Identification** – Experts identify all the possible relationships among the concepts, also referring to the literature review.

5. **FCM design and refinement** – Concepts and relationships are used to model collective FCM. Then, interviews with staff not included in the committee of experts allows modifying the FCM by adding details that in the previous steps can be omitted or escaped. This step is analysed in-depth in Section 3.2.

6. **FCM Analysis** – In this step, according to the FCM methodology, the FCM is analysed in terms of structure and concepts concatenations and results are discussed.
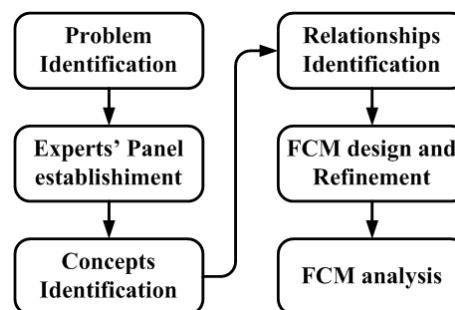

Figure 1: the research approach scheme.

3.2 The FCM methodology

A cognitive map (CM) can be thought as a concept map describing a mental process, gathering information and defining cognitive abstractions, through an individual filter, concerning physical phenomena and experiences. Cognitive maps are visual representations of an individual's "mental model" constructs, analogous to concept maps for representing human reasoning and knowledge or beliefs (Miller, 1979).

Thus, considering a generic problem, an experts' panel is established for an in-depth analysis, since different individuals may face the same question differently, according to their area of expertise through fuzzy logic, to model a collective Fuzzy Cognitive Map (FCM) identifying concepts and relationships about the considered problem. In particular, concepts, in number of N, are the FCM key elements that stand for the main characteristics of the abstract mental model for whichever complex system (Mazzuto et al., 2018c). Once concepts are identified, experts are asked to assign a numerical w_{ij} (the weight of the relation between concept i-th and j-th) for the W matrix, representing the influence between concepts C_i and C_j. According to (1) It ranges in $[-1, 1]$. Specifically, $w_{ij}=0$ indicates no causality relation between concepts; $w_{ij}>0$ means that if C_j increases then, also C_i increases (or C_j decreases and C_i decreases), and $w_{ij}<0$ describes negative causality so if C_j decreases then C_i increases (and *vice-versa*).

$$FCM = \begin{bmatrix} w_{1,1} & \cdots & w_{1,N} \\ \vdots & \ddots & \vdots \\ w_{N,1} & \cdots & w_{N,N} \end{bmatrix} \quad (1)$$

Although several studies exist with respect to the dynamical representation of an FCM, generally, with concern to the aggregation of the experts' opinions for the collective matrix designing, the provided fuzzy experts' estimate are gathered using the SUM method (Fang, 2006) and, then, a final linguistic weight is calculated referring to the centre of gravity (COG) defuzzification rule (Tsoukalas and Uhrig, 1996). Some examples are presented by (Bevilacqua et al., 2018d, 2014, 2012; Stylios et al., 1998) where a unique credibility value is assigned to each expert, and a threshold function is used in the aggregation. On the other hand, a modification of the above-mentioned approach has been provided by (Stylios and Groumpos, 2004, 2000) introducing a corrective factor for an experts' credibility value if, and only if, his/her judgement is too much dissonant with the others. This, however, does not consider that in a sophisticated multidisciplinary problem experts can have in-depth knowledge of some parts of the problem.

Once designed the total weights matrix, W, it is possible to identify the system behaviour through the analysis of all the possible concatenations starting from one concept and ending into the top event. Consequently, identified all of the possible concepts concatenations, it is possible to join to each of them a relevance factor, also said: "Indirect Effect" (Bevilacqua et al., 2019, 2018b). The "Indirect Effect" is defined as shown in (2).

$$I_k(C_i, C_j) = \min\{w(C_p, C_{p+1}\} \tag{2}$$

Specifically, if a path exists between the concepts C_i and C_j, and (p,p+1) are the contiguous left-to-right path indices, then, the "Indirect Effect", for the considered path, is equal to the minimum of the weights of the connection composing the path.

Moreover, when there is more than a concatenation among the cause node and the effect node, it is useful to define the concept of total effect $T(x,y)$. According to Axelrod (2015), causal variable C_i's total effect on effect variable C_j is the aggregate sum of all the paths' indirect effects from each causal variable associated with each effect variable, as shown in (3).

$$TE(C_i, C_j) = \max\{I_k(C_i, C_j\} \tag{3}$$

In particular, a positive total effect implies that each indirect effect is also positive; a negative total effect implies that each indirect effect is also negative; an indeterminate effect, on the other hand, means that some indirect effects manifest positive effects while others manifest negative effects (Kosko, 1988). By sorting TE, it is possible to highlight the most relevant concepts within a specific problem domain.

4. CASE STUDY

In order to illustrate the application of the proposed method, a case study of a fashion SC is put into analysis. First, a detailed analysis of the literature is performed, in order to carry out the Problem Identification Step. In this respect, it surfaced that in the past few years there has been recognize an increase in the environmental awareness of consumers and therefore that environmental issues are becoming a source of competitiveness among companies. In the literature there are several studies that agree on the existence of such strong link between the adoption of green practices and corporate competitiveness (Famiyeh et al., 2018; Zhan et al., 2018). To this regards, "Sustainable Value Added" is chosen as Top Event, which measures whether a company creates extra value while ensuring that every environmental and social impact (Figge and Hahn, 2004).

Subsequently, in the second step, an expert's panel is established to achieve a better knowledge of the case study in question (Mazzuto et al., 2018a, 2018b). In this work, the group includes four academicians in the field of management, economy, energy and waste disposal, and three managers along the case study SC, with roles in logistics management, energy management and waste disposal management. The panel met several times over a total period of three months given the complexity of the subject in question, and each expert has given the own contribution of knowledge and information of the process.

The first job of the experts' work is aimed at identifying of the concepts (step 3, Concept Identification) characterising the case study SC and after some meeting, as many as 194 concepts (n=194) are found.

During the step 4, as outlined before, the panel identifies the relationship among concepts, to design the adjacency matrix: at the end of this phase, the panel defined as much as 2999 relationships.

During the 5th step, the Fuzzy Weight Matrix is produced: the experts' panel is asked to explain in-depth the relationships meaning and weights between every pair of linked concepts. This approach consists in studying the potential conflicts between the various concepts and relationships previously identified, analysing the differences between the different mental models. To this end, it is estimated the relative importance of semantic distance that the experts attributed to an unusual feature of the issue. The opinion expressed by the experts may differ from case to case: even more likely is the emergence of conflicts concerning the information associated with that concept. Finally, the decision to refine the FCM, eliminating or grouping some concepts (Cole and Persichitte, 2000) should be carried out after considering each of them regarding the relevance of its removal on the map. To this end, since the high quantity of concepts found, these 194 concepts are grouped by reference area. Eight distinct area were identified, as Fig.2 exemplifies.

The sixth and last step, "FCM Analysis", allows researchers to identify all hidden concepts concatenations inside the generated FCM: "hidden" concatenations because of the involvement of different experts with different experiences to the problem addressed by the research work (Kandasamy and Smarandache, 2003). Finally, analysing the obtained FCM,
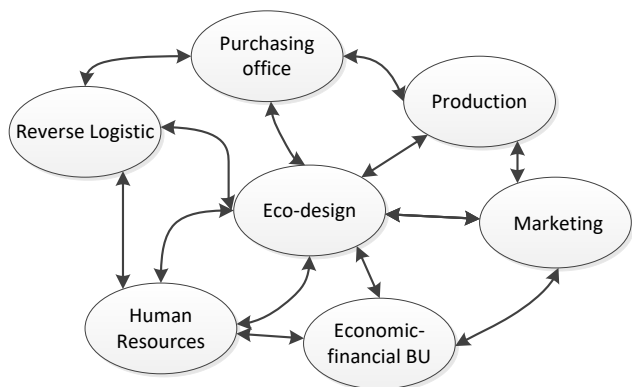
Figure 2: SC Concept Clusters identified

experts know the strength of all the considered concepts. The Indirect and Total Effects quantify this strength.

#	Concepts					TE
1	C4	C15				0,98
2	C3	C15				0,97
3	C1	C15				0,95
4	C10	C1	C15			0,95
5	C12	C1	C15			0,95
6	C9	C1	C15			0,87
7	C8	C15				0,86
8	C13	C15				0,86
9	C2	C14	C9	C15		0,83
10	C5	C14	C9	C15		0,83
11	C6	C6	C14	C9	C15	0,83
12	C11	C2	C14	C9	C15	0,83
13	C14	C9	C15			0,83
14	C7	C15				0,58

Table 1: Eco-Design cluster list of concepts

#	Concept
C1	Use of the Life Cycle Assessment (LCA) methodology
C2	Use of environmentally friendly materials
C3	Modular Production
C4	Understanding of the Porter's Value Chain at an SC level
C5	Packaging Optimization
C6	Use of simulation software
C7	Using CAD tools
C8	Establishment of patents aimed at the protection of the environment
C9	Measures to anticipate consumer and regulatory needs in relation to green awareness
C10	ISO 14000 implementation level
C11	Eco-design in packaging
C12	PDCA Cycle Implementation
C13	Vertical integration of processes along the SC
C14	Brand equity
C15	Eco-Added Value

Table 2: Total Effects

The first three of Table 1 are characterized by concepts directly linked to the top event "C15: Eco-Added Value". Among

them, the most relevant path is "C4: Understanding Porter's Value Chain at an SC Level – C15: Eco-Added Value", with an IE of 0.98. This result is worth noting, as the development of sustainable Value Chain Analysis tools must identify business opportunities that are consistent with Porter's value chain philosophy, as already highlighted by Fearne et al. (2012). The paths "C3: Modular Production (7R) – C15: Eco-Added Value" and "C1: Use of LCA methodology – C15: Eco-Added Value" can be found after, respectively with a TE of 0,97 and 0,95. These results are consistent with the actual trend from both an industrial and an academic point of view since the LCA methodology is a well-established tool to measure and then improve the life cycle of a product. Ma and Kremer (2016), performed a detailed literature review about the correlation of these two topics, stating the positive impact of Modular Production Design on sustainability performance, both from a financial and social point of view. Subsequently, the next three paths that can be found are "C10: ISO 14000 implementation level – C1: Use of LCA methodology – C15: Eco-Added Value", "C12 - PDCA Cycle Implementation level - C1: Use of LCA methodology – C15: Eco-Added Value" and "C9 – Measures to anticipate consumer needs and regulatory requirements - C1: Use of LCA methodology – C15: Eco-Added Value", respectively with a TE of 0,95, 0,95 and 0,87. In these three paths, the LCA methodology is a crucial concept since it can be found in each one of them, right before the top event. Of course, since the LCA methodology is part of the ISO 14000, the compliance with this standard requires the application of this tool. Moreover, in path #6, it can be seen how LCA methodology is also considered a way to anticipate consumer and regulatory needs. An impressive result can be found in the five paths from #9 to #13, all of which end with the subsequent concatenation of concepts: "C14: Brand Equity - C9: Establishment of patents aimed at the protection of the environment - C15: Eco-Added Value", all with a TE of 0.83. This result can be interpreted as one company who reaches well-established brand equity would, therefore, maintain this status and so fostering the continuous establishment of patents with this aim.

5. CONCLUSIONS

This work has carried out a static analysis of the Green Supply Chain system and, through the extrapolated data, it has been possible to provide a general picture of the subject in question and it has been tried to understand which were the main characteristics and how they could influence each other. subject of future developments, could be to extend the static analysis to a dynamic simulation by studying how the system evolves over time to analyze whether the initial conditions remain unchanged or whether they have some changes. The research approach exemplified by this work can be repeated in a systematic way, within different actors of a SC and even in different business unit of a single company: the FCM model can aid managers to understand in more detail the behaviour of a system, by considering the mind models of different playes of the SCFor further study, it could be interesting to try to extend the FCM according to Kosko with Carvalho's observations (2002) in order to implement real fuzzy inferencing rules.

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Appendix A. FIRST APPENDIX

Table 3: Fuzzy Weight Matrix of the Eco-Design Cluster

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0	0,68	0	0	0	0	0	0,77	0,89	0	0	0	0	0,89	0,95
C2	0	0	0	0	0	0	0	0,35	0,75	0	0	0	0	0,9	0,8
C3	0	0	0	0	0,85	0	0	0,4	0	0	0	0	0	0	0,97
C4	0	0,45	0	0	0	0	0	0	0,5	0	0	0	0	0	0,98
C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0,98	0,71
C6	0	0	0,67	0	0,92	0	0	0	0	0	0	0	0	0	0,54
C7	0	0	0,52	0	0	0	0	0	0	0	0	0	0	0	0,58
C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0,25	0,86
C9	0,87	0,82	0	0	0	0	0	0,87	0	0	0	0	0	0,3	0,64
C10	0,98	0,87	0	0	0	0	0	0,76	0,56	0	0	0	0	0	0,32
C11	0	0,84	0	0	0,34	0	0	0	0,72	0	0	0	0	0	0,47
C12	0,97	0	0	0	0	0	0	0	0,67	0	0	0	0	0	0,85
C13	0	0,83	0,23	0,25	0	0	0	0	0	0	0	0	0	0,87	0,86
C14	0,68	0	0	0	0	0	0	0,83	0	0	0	0	0,73	0	0,76
C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0