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Fuzzy Cognitive Maps to Implement Corporate Social Responsibility in Product Planning: A Novel Approach

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*Abstract--***Product development can support proactive CSR strategies by changing product features, materials, and processes in order to reduce or even eliminate negative environmental and social impacts. However, the CSR literature provides little practical guidance for new product development, but promotes general principles for responding to environmental and social issues. One of these guiding principles is the concept of stakeholder engagement, but to date, few practical approaches for integrating stakeholder views and needs into product development exist.**

To address this gap, the paper discusses the use of Fuzzy Cognitive Map Modeling. The method, which has been applied in participatory stakeholder studies and in product development before, but never in conjunction, helps product planners to understand and assess stakeholder needs and to select product concepts that respond to them. It thus allows organizations to remain true to their CSR strategies.

I. INTRODUCTION

Though there still is considerable debate about the ethical foundations and business impact of Corporate Social Responsibility (CSR) [see e.g.1, 2], even companies that do not fully embrace the concept cannot ignore the issue: globally connected stakeholder groups are pressuring corporations to take responsibilities for the societal and environmental impact of their actions [3-9]. Senior managers are recognizing the strategic importance of CSR [10-16] to respond to stakeholder pressure, to secure and improve market positions, to minimize business risk, and as a matter of business ethics [17]. As a result, some corporations are choosing to go beyond compliance policies [10, 17] and philanthropy [15], and define CSR objectives that are proactive in that they anticipate responsibility and attempt to lead the industry through innovation [4]. And, even corporations who simply want to remain in compliance with government regulations need to become increasingly proactive as ever changing product stewardship policies force them to consider future impacts of their products throughout their entire lifecycles [18].

One business process of particular importance for CSR is new product development. It can reduce or even eliminate negative environmental and social impacts by changing product features, materials, and processes associated with production, distribution, and disposal. This is achieved through incremental improvements of existing products (e.g. internal combustion engines with higher fuel efficiency), and through entirely new products (e.g. electric vehicle) and substitutable materials, which can lead to so-called strong sustainability [19, 20]. New product development is thus essential to companies who follow a proactive CSR strategy

[21, 22], but the CSR literature provides little specific guidance for new product development.

Instead, CSR publications promote general principles and strategies for responding to social and environmental issues [e.g.23, 24]: to engage in CSR, companies identify issues, including environmental concerns and social problems, that are important to their stakeholders and respond to them. Stakeholder engagement is not only important for reasons of procedural justice and ethics, but because empathetic understanding or stakeholder interests allows managers to recognize problems, avoid involuntary negative impacts, and make better decisions. Some authors therefore even claim that no separate CSR approaches are required, if stakeholders are defined widely and their concerns are integrated into business processes [25].

The systematic integration of stakeholder concerns in product planning, however, is currently in its infancy and product planners receive no guidance on how to capture stakeholder concerns, how to balance conflicting stakeholder interests, and how to assess alternative new product ideas with regard to CSR objectives. As a result, product development projects easily fall short of the proactive CSR strategy envisioned by the company or may even be perceived to be in conflict with it. This paper presents a method that can potentially address this gap: Fuzzy Cognitive Maps (FCM) make qualitative cognitive maps, which are commonly used in strategic management and stakeholder analysis, computable. They can be used to capture, integrate and analyze stakeholders' mental models and to forecast how stakeholders will perceive alternative product concepts. This paper provides an introduction into FCM methodology and its application. It thus presents the theoretical and practical foundations of a novel approach for stakeholder engagement in new product development, that is currently under development.

II. A BRIEF REVIEW OF STAKEHOLDER THEORY

Stakeholders are organizations and individuals that have a stake in the activities of a corporation: primary stakeholders, such as customers and employees, exchange resources with the corporation and are thus essential for its business activities, whereas secondary stakeholders, such as consumer organizations, government agencies, and environmental groups influence or affect the corporation or are influenced or affected by it, but they are not directly involved the business transaction [4]. All business activities, including those relevant for CSR strategies, impact and are impacted by various primary and secondary stakeholders: environmental

pollution, for example, can lower brand image and employee morale, thus affecting primary stakeholders, and can lead to government intervention and reactions by environmental groups, which are examples of secondary stakeholders. By systematically identifying stakeholders with environmental and social issues, communicating with them, developing sensitivity for their concerns, and acting in a way that respects their interests and carefully balances it against those of other stakeholders, including shareholders who expect profits, companies engage in CSR [26]. Broad stakeholder engagement, also labeled "inclusivity" is consequently the foundation of several CSR standards, such as AccountAbility [27] and ISO 26000 [23].

All corporations face the same generic stakeholder groups, such as customers, suppliers, and regulators, but the specific stakeholders vary from company to company and business process to business process. Furthermore, over time, stakeholders can lose or gain interest in issues, and shift their power and influence (e.g. through coalitions). As a result, stakeholder management needs to be an ongoing activity, customized to the reality of each organization, linked to particular issues, and dynamic in nature. The stakeholder management literature provides a diverse set of methods for stakeholder identification, stakeholder analysis, and the formulation of stakeholder strategies: Stakeholder identification often starts by surveying managers about a generic list of stakeholders [25, 28] or by asking them to list "groups, organizations, and individuals that have the power to influence the delivery of - and/or had a significant interest in - the organization's strategy" [9]. Stakeholder analysis aims at narrowing down the resulting, oftentimes extensive, list of stakeholders to those that are (or will be) important to the corporation, to understand their interests, world views, and objectives, and to anticipate their actions [29]. Various approaches exist: Mitchell et al., for example, propose a stakeholder classification that is based on presence or absence of 1) "legitimacy" of the stakeholder's claim; 2) the degree of "power", which determines a stakeholder ability to influence the corporation; and 3) "urgency" which determines the attention required to the claim [8]. Frooman differentiates stakeholders according to the way in which they exert influence on a corporation's resources through four basic strategies: 1) direct withholding, 2) indirect withholding, 3) direct usage, and 4) indirect usage [30]. Ackermann and Eden categorize stakeholders in a four by four matrix that shows stakeholder power (high vs. low) and influence (high vs low) [9]. Based on the analysis, the organization determines whose stakeholder concerns will be considered and how they will be managed. The literature remains somewhat fuzzy on how these decisions are made: The strategic management literature emphasizes the need to "manage" critical stakeholders to shore up their support, reduce their opposition, dampen their impact on other stakeholders, or minimize risks that stem from their actions (e.g. Ackerman & Eden), but provides little guidance which specific management action to take. The CSR literature puts emphasis on "engagement", rather than management of stakeholders and sets standards for how organizations should interact with them [27]. However, it does not explain how stakeholder inputs result in specific company actions and how conflicting interests should be balanced. The literature assumes that managers' awareness of stakeholder issues increases their empathy and leads to improved managerial decisions [29]. While this assumption is debated, it is in line with the concept of learning organizations, as described by Senge [31].

If knowledge of stakeholders and their interests leads to better, more socially and environmentally responsible products, it is important that product planners are provided with opportunities to understand stakeholder interest and to test their designs against stakeholder needs throughout the development process. However, specific approaches to stakeholder management in new product development are rare and focused on few primary stakeholders, namely customers and some internal functions, such as manufacturing. During the early stage of the new product development the needs of these stakeholders are translated into product requirements and subsequently into technical specifications. The emphasis lays on customer needs and compliance with standards, such as health and safety regulations. Furthermore, the needs of downstream functions, such as manufacturing and service, are systematically analyzed and taken into account through Design-for-X approaches [32]. Positive environmental and societal outcomes are not guaranteed - since decisions are solely based on economic objectives, it is possible that products only meet minimum environmental standards, even though higher standards are technically feasible or that service concepts increase waste and lifetime repair costs for the benefit of the service provider.

Alternative approaches are needed if product planners want to understand and improve the broader societal and environmental impacts of their decisions. Building on our prior work in product planning and scenario management [33-35], we are exploring the potential of one particular methodology that is closely linked to the idea of stakeholder modeling and system learning: Fuzzy Cognitive Maps.

III. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps were invented by Bart Kosko in 1986 [36] who proposed them as a means to make qualitative cognitive maps, which had originated in social science [see e.g. 37, 38, 39] computable and understand the dynamic behavior of the system they represent. The starting point of any FCM is a causal map like the map depicted in Figure 1: Concepts (= "nodes" or "ovals") are linked through arrows that represent causality. Concepts are described verbally and can represent hard-to-quantify phenomena such as "customer satisfaction", "environmentalism", and "free trade".
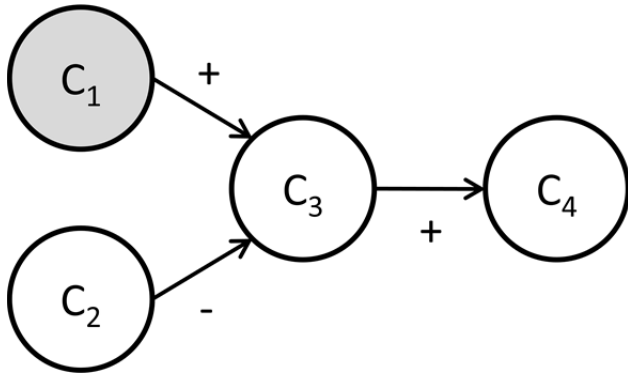
Figure 1: A causal cognitive map

The arrows are denoted with "+" or "-", depending on what type of causality exists. Positive arrows between two concepts (e.g. C_1 and C_3) imply that an increase in one concept causes an increase in the other concept. Negative arrows (e.g. between C_2 and C_3) reflect a decrease of the second concept, when the first concept increases.

Causal cognitive maps are frequently used in social sciences to capture the mental models of decision makers and stakeholders [39-41]. They were first invented by Axelrod, who used them to analyze and predict the decisions of political elites [37]. They are furthermore used in strategy workshops to elicit how managers think about their business environment, to identify and discuss areas or agreement and disagreement in the management team, and to foster manager's understanding of the dynamic complexity of the problems they are facing [41-43]. Because they are popular as a research, communication, and planning tool, a vast body of literature and specialized software for cognitive mapping exists [44].

Causal cognitive map, however have several drawbacks: in complex maps, it is difficult to assess how the network under investigation will behave dynamically and which concepts will increase or decrease as a result of environmental changes or actions taken by the decision makers - cognitive limitations make it impossible to keep track of cumulated direct and indirect effects [45]. Also, if a concept has the same number of in-going positive and negative arrows, it is undetermined if it increases, decreases, or remains the same [37].

Bart Kosko addressed these issues and applied principles of fuzzy set theory and neural networks to traditional cognitive maps [36, 46, 47]: Structurally, the resulting FCM are not different from traditional cognitive maps in Figure 1: they are directed graphs with positive or negative "arrows". To model the strength of causal links, weights in the range of [-1;1] can be assigned. In many cases, this is done through Likert-type scales, so that experts can use every day language to describe the strength of the relationship. It is also possible to determine edge weights by combining the causal maps of multiple experts and calculating the average weight for every edge [47, 48].

While the structure of causal cognitive maps and FCMs are identical, Kosko changed the way in which the graphs are analyzed: FCMs are regarded as a simple form of recursive neural networks, with concepts being the equivalent to neurons. Other than neurons in a neural networks, concepts in FCMs, however, are not either "on" (= 1) or "off"(= 0), but can take states in-between. They are therefore "fuzzy". Fuzzy concepts are non-linear functions that transform the path-weighted activations directed towards them (their "causes") into a value in [0, 1]. When a neuron "fires", i.e., when a concept changes its state, it affects all concepts that are causally dependent upon it. Depending on the direction and size of this effect and on the threshold levels of the dependent concepts, the affected concepts subsequently may change their state as well, thus activating further concepts within the network. Since FCMs allow feedback loops, it is possible that the newly activated concepts influence concepts that have already been activated before. Thus, the activation spreads in a non-linear fashion through the FCM net until the system reaches a new stable state.

FCM calculation models spreading activation through the network by multiplying a state vector of causal activation with the square connection matrix derived from the FCM graph and by thresholding the result in accordance with the concepts' squashing functions, as the following example will illustrate:

If concept C_1 (highlighted in grey) in Figure 1 is activated, while all other concepts are turned off, the initial state vector is:

$$S = [1\ 0\ 0\ 0]$$

It is multiplied with the square connection matrix that is equivalent to the signed digraph in figure 1.

	E_1	E_2	E_3	E_4
E_1	0	0	+1	0
E_2	0	0	−1	0
E_3	0	0	0	+1
E_4	0	0	0	0

Matrix multiplication and the application of a threshold function lead to a new state vector:

$$S^1 = [1\ 0\ 0\ 0]$$

(In this particular example a binary threshold function that converts inputs of ≤ 0 to 0 and inputs of > 0 to 1 is used). The resulting new state vector is again multiplied with the connection matrix. The process is repeated until stability is reached (in this case after S4), or a stop criterion is met:

$$S^2 = [0\ 0\ 1\ 0]$$
$$S^3 = [0\ 0\ 0\ 1]$$
$$S^4 = [0\ 0\ 0\ 0]$$
$$S^5 = [0\ 0\ 0\ 0]$$

The calculation is slightly different, if activation of concept C_1 is not a one-time impulse (e.g. an election, a natural disasters), but a change that lasts over extended periods of time (e.g. new tax laws). In this case, the concept

is "clamped" and always set back to its initial activation level, as the following example, which already reaches a stable state after three cycles, will show:

$$S'^1 = [1\ 0\ 0\ 0]$$
$$S'^2 = [1\ 0\ 1\ 0]$$
$$S'^3 = [1\ 0\ 1\ 1]$$
$$S'^4 = [1\ 0\ 1\ 1]$$
$$S'^5 = [1\ 0\ 1\ 1]$$

All FCMs have "meta-rules": several input vectors – so-called input regions – lead to the same final system state. The meta-rules of a FCM can be identified experimentally through simulation [49] and, if strict restrictions are met, analytically [50]. The system's behavior depends on the structure of the causal map, the input vector, and the choice of squashing functions that determine the state of each activated concepts: FCMs with bi- or trivalent concept states (so-called "finite state machines") have meta-rules that stabilize the system in a fixed point or a limit cycle after a few iteration. This means that reentering the output vector into the system does not lead to a different output vector or, alternatively, activates a cycle of vectors that finally results in the same final state. In "continuous state machines" – FCMs

with concept values in the intervals [0; 1] or [-1; 1] – chaotic system behavior is possible, though it rarely occurs in real-world applications that are characterized by relatively small models with few interdependencies [35].

Once a stable state is reached, it becomes clear which concepts have changed as a result of the initial changes to the system and which ones have remained the same. Figure 2, which was adapted from our earlier work [34], illustrates this: It shows an excerpt of an FCM that looks at the environmental forces that impact customer requirements for a wind turbine. Concept 3 (high electricity prices) was activated, which means that prices further increase. After four cycles, the FCM settles down and reaches a new stable state that is different from the final state that the FCM reaches without the price increase (see "internal dynamics"): without the price increases there was less media coverage of opposition to wind energy (C_1), less opposition by electricity companies (C_2), and more support for a federal law that guarantees prices for wind energy that is supplied into the grid (C_4). As a result, the product requirement that wind generated electricity should be easily transmitted into the public grid (C_5) has slightly less impact on the customer's overall objective of profitability (C_7).
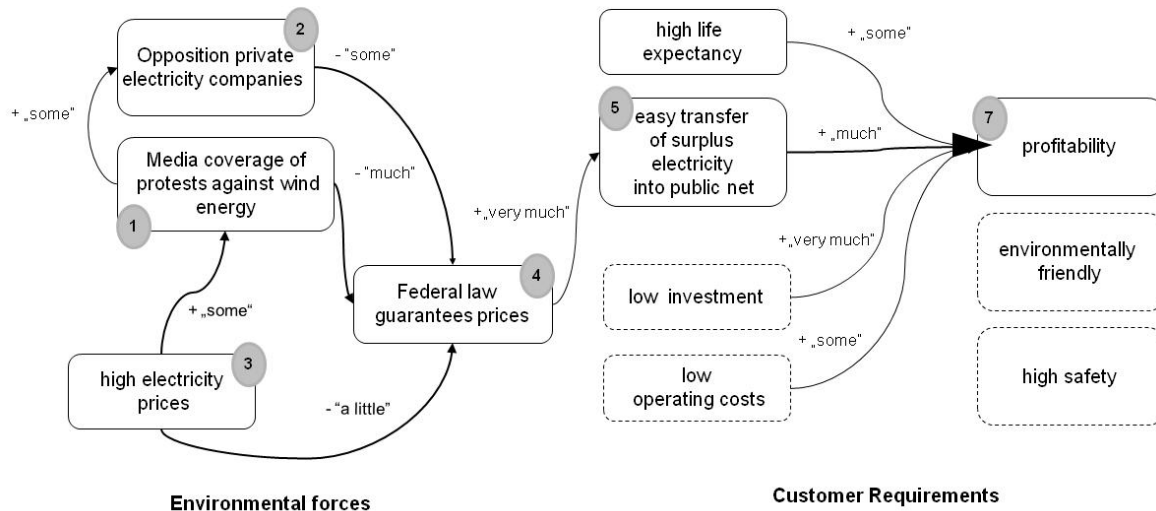
Results	C1	C2	C3	C4	C5	C6	C7
Start	0,000	0,000	1,000	0,000	0,000	0,000	0,000
t=1	0,622	0,570	1,000	0,278	0,575	0,500	0,664
t=2	0,622	0,577	1,000	0,269	0,569	0,500	0,664
t=3	0,622	0,577	1,000	0,268	0,567	0,500	0,663
t=4	0,622	0,577	1,000	0,268	0,567	0,500	0,663

Results without exogenous change of C3 (internal dynamics only)

internal dynamics	0,562	0,570	0,500	0,303	0,575	0,500	0,664

Figure 2: Sample FCM & Calculation (Activation of Concept C_3 leads to new steady state).

IV. DISCUSSION: FCM FOR STAKEHOLDER ENGAGEMENT IN NEW PRODUCT DEVELOPMENT

FCMs have properties that make them particularly attractive for both, new product development and stakeholder engagement [33-35, 46, 51]:

- Knowledge acquisition is relatively easy: causal cognitive maps are intuitive and a variety of methods exist to uncover knowledge from written documents, through interviews, through mapping exercises, and through group sessions. New knowledge, such as the views of additional stakeholders can be easily integrated into the model. As a consequence, large knowledge bases that reflect the world views of many respondents (stakeholders) can be created .

- FCMs can deal with qualitative and fuzzy inputs, which dominate in the early stage of product planning. They can answer what-if questions for product planners who can assess how changes impact stakeholder views or product attractiveness. They can use this information to change product concepts so that they better reflect known or anticipated concerns. They can also attempt to dampen the consequences of uncertainty by designing products that are attractive in different possible scenarios.

- FCMs can provide a simulation environment for product planners that allows them to experience the dynamic complexity of their stakeholder environment through experimentation. It can prevent decisions that have unintended consequences because indirect effects, feedback cycles or fringe stakeholders needs do not become sufficiently obvious.

Despite these potentials, FCMs have never been applied for implementing CSR strategy in business processes, such as new product development. However, the methodology has been used in related fields with promising results

Jetter & Schweinfort [33] have used FCMs to identify the scenario drivers for photovoltaic solar panel technologies by integrating the views and concerns of various stakeholders, such as customers, energy consultants, and technology specialists. Their FCM model integrated the partial and sometimes conflicting views of their respondents and resulted in usable, in parts surprising, and insightful raw scenarios for future scenario studies. Van Vliet, Kok, and Veldekamp [52] used FCMs in a participatory stakeholder workshop on Europe's freshwater futures and concluded that the method leads to a good representation of stakeholder inputs and can bridge the gap between narrative storylines and quantitative analysis in scenario planning. Özesmi & Özesmi [53] used FCMs to capture experts' and local people's mental models of a large dam project and to compare different policy options. They conclude that FCMs are useful in facilitating the development of participatory environmental management plans.

In the context of new product development, we have developed an FCM based product planning method that captures managers' knowledge about market and technology trends, customer requirements, and technology attributes through linked FCM models [34, 35]. The models are used to assess relevance and impact of newly available planning information and assess and select alternative product concepts. In one implementation of our approach [35], the FCM models were built without stakeholder input and only reflected what managers already knew. Nevertheless, the FCM models lead to surprising insights: among others, managers became aware that their assumptions about customer needs where highly questionable, that their technology focus was too narrow, and that feedback loops will change the importance of some product attributes over time. Supported by FCM simulations, managers engaged in system learning and increased their understanding of a complex planning task.

Current FCM research thus demonstrates that FCMs foster stakeholder participation, improve the knowledge base of decision makers by integrating the individual and only partially overlapping cognitive maps of stakeholders, enable the formal analysis of alternative scenarios and policies, and potentially improve decision-makers' understanding of complex and dynamic systems. FCMs are therefore a highly relevant methodology for implementing proactive CSR strategies.

In our future research we are planning to use FCM to systematically capture and model stakeholder views and integrate those perspectives into our existing product planning model. Product planners can then evaluate the impact of alternative product concepts on all relevant stakeholders, thus ensuring that their decisions are socially and environmentally acceptable. Furthermore, the impact of anticipated or already occurring changes in the stakeholder environment, such as newly arising issues or changing stakeholder views, can be systematically investigated to make sure that product concepts that were once environmentally and socially acceptable do not fall short of changing needs.

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