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Food chain design using multi criteria decision making, an approach to complex design issues

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ABSTRACT

Designing: a food supply chain for a completely new product involves many stakeholders and knowledge from disciplines in natural and social sciences. This paper describes how Multi Criteria Decision Making (MCDM) facilitated designing a food supply chain in a case of Novel Protein Foods. It made the procedure transparent and aided the evaluation of alternatives. Two models, namely the Multi Attribute Value Theory (MAVT) and the Analytic Hierarchy Process (AHP), were used, due to the ease with which they handle a mix of quantitative and qualitative information, quantify the qualitative information and generate an overall value for each alternative. The resulting preference order differed mainly due to the manner in which criteria weights were elicited, alternatives scored and the use of scales in MAVT versus the pairwise comparison in AHP. However, the preference order of the top criteria with both methods was the same and weights were similar.

1. Introduction

Introducing a new product and designing its potential supply chain (SC) involve information from various fields and several stakeholders and experts. Most literature on food supply chain design aims at improving existing supply chains and not at the complete design of a new supply network. The background of our research is a large study on the introduction of a non-meat protein source to partially replace meat products in the diets of the Dutch consumers [1]. The study was confronted with a gap in literature on designing a completely new food supply chain. This paper introduces and investigates a methodology to approach this issue. The methodology is first embedded in the literature on supply chain design in general and Multi Criteria Decision Making (MCDM) in particular. This is followed by elaborating the approach for the new non-meat protein food.

Traditionally, SC management refers to managing a SC to meet end-customer needs through product availability and responsiveness, on-time delivery etc. [2–6]. The SC starts at the supplier and ends at the retailer or the consumer and costs are minimised over links of the chain. However, when a food supply chain (FSC) is considered, the chain starts a few links earlier, *i.e.* at the primary production of the raw ingredients and goes all the way through to the consumer [7,8]. Another characteristic of a FSC is that the attributes of the product important to the consumer (*e.g.*, taste, texture, nutritional level), are a result of the SC decisions in each link. These attributes influence the success of the product. FSC design should focus on product attributes by looking at the FSC backwards, from consumer through to primary production [7,9].

Systematic design of a FSC involves many aspects including potential chain design and evaluation, selection of attributes and identification of variables. The problem has qualitative and quantitative elements; the decision space is discrete and conflicting criteria have to be considered simultaneously. The criteria are hybrid in nature [10–12], the number of alternatives is large and there are multiple stakeholders. Thus a decision making aid like MCDM is ideal for a problem of this genre. MCDM models handle qualitative data well. These models do not try to compute an optimal solution. Instead, many alternatives are proposed or generated and the decision maker (DM) ranks them with respect to the criteria (attributes). There is no objective statement and therefore there are no trade-offs in the traditional sense as each criterion is ranked according to its importance to the DM [11]. An inherent property about decision making is subjectivity. MCDM does not dispel this but makes the process of making such decisions transparent [10].

The question is how MCDM can be an aid in a large multidisciplinary research project that includes researchers from various disciplines and stakeholders from industry. To respond to this question, we go over the various steps that have been taken and report

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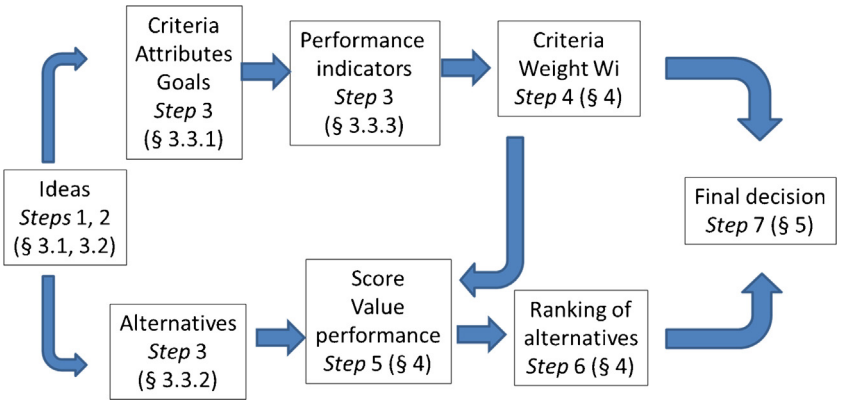

Figure 1. Steps in a Multi Criteria Decision Making approach; the numbers between brackets indicate the sections that describe how the steps were executed.

on the lessons learned. Numerous models are proposed for valuating alternatives in MCDM. Of them we investigated the Multi Attribute Value Theory (MAVT) and the so-called Analytic Hierarchy Process (AHP). These methods mainly differ in the way criteria are treated and in the use of partial value functions in the former and pairwise comparisons in the latter. Other methods are, for instance, goal programming and ELECTRE [10]. Goal programming relies on quantitative data only and was therefore not applicable in this case. ELECTRE requires more interaction with stakeholders and DMs than was possible in this case.

Below we first sketch what the theory of MCDM teaches us to do, after which it is reported how this was elaborated for the specific case of designing a FCS. Next the results of the two models used, namely AHP and MAVT, are compared followed by the evaluation of the robustness of the conclusions with respect to varying circumstances in a sensitivity analysis. Finally, lessons learnt from this experiment on applying MCDM in a large supply chain design case are presented.

2. The MCDM approach

Some basic steps are common to all MCDM approaches [10,12] and can be divided into three phases, namely (a) identification of the problem, (b) building the model and (c) developing action plans (Figure 1).

The general terminology in MCDM includes the following concepts:

- Options/alternatives: choices to be made, *e.g.* where to buy a house.
- Criteria: goals, attributes or objectives that the DM wants to achieve. They are what the DM uses to evaluate the alternatives. These can be directly measurable *e.g.* cost of the house, or indirectly measurable, *e.g.* the location of the property. In the latter case, a criterion needs to be formulated to measure performance.
- Criteria weights: represent the relative importance of each criterion.
- Scores/value: alternatives are evaluated with respect to each criterion and scores are assigned to each alternative. Usually the scores have no units; the evaluation method depends on the MCDM model being used.
- Ranking: after weights and scores are obtained, the alternatives are graded with respect to all criteria simultaneously.

This paper assesses the application of the MAVT and the AHP approach to evaluate alternatives.

3. The novel protein food case

This section describes how the MCDM approach (Figure 1) was elaborated for the novel protein food case. The case material was collected in the framework of PROFETAS [1]. This project concerned the conversion towards non-meat protein sources in the daily meal in The Netherlands and ran during the years 1999-2006. One of the tenets of the PROFETAS project was that non-meat protein products currently on the market do not meet expectations of most consumers and cannot yet be considered realistic substitutes to meat. Hence, the prospects for replacing meat-derived ingredients by non-meat ingredients, so-called Novel Protein Foods (NPF), was investigated.

3.1. Identification of the problem

The DMs in this project were food technologists, environmental scientists and economists; in total about 50 researchers. When we use the term stakeholders, this also includes representatives from industry who showed their interest in the outcomes of the study. Issues that arose during brainstorming sessions with the participants were:

- Current food production and consumption patterns have a huge impact on the environment and natural resources
- Meat production is not appealing from an environmental point of view because of, *e.g.*, the inefficient conversion of protein in feed into protein in slaughtered animals, manure generation and amount of water use
- A shift to a completely vegetarian diet is not a sensible suggestion
- Pork meat is popular in the Netherlands
- A possible vegetable source to partially replace pork is dry green peas; peas are popular in the Netherlands, grown locally and expertise is readily available
- Non-meat protein products presently on the market do not meet expectations of most consumers and thus cannot be considered realistic substitutes to meat; there are problems with texture and taste of products and they are expensive compared to pork

3.2. Idea generation

The main outcomes of the idea generation process were:

- A feasibility study should be conducted and target a replacement of 20% of processed pork products by the year 2020 [1,13]
- Developing a new product with good texture has priority