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Food supply chain design using MCDM, a case study on Novel Protein Foods

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Food supply chain design using MCDM, a case study on Novel Protein Foods

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ABSTRACT
Purpose Designing a food supply chain for a completely new product involves many stakeholders and knowledge from various fields in natural and social sciences. This paper describes a methodology to design food supply chains based on the method of Multi Criteria Decision Making (MCDM). A case is elaborated on the design of a supply chain for novel protein foods for Dutch consumers. The project aim is to partially replace meat products in the daily diet, thereby reducing the environmental impact of food production and consumption.
Value of the paper The requirement of the methodology is to enable the selection of the optimal design on a number of given criteria in a balanced and transparent manner. The outcome was that the general model for MCDM helped to coordinate the whole design process. The stepwise procedure made the method transparent for the stakeholders and aided in the evaluation of alternatives.
Methodology Two models, MAVF and AHP, were chosen for the ease with which they can handle a mix of quantitative and qualitative information, quantify the qualitative information and generate an overall value for each alternative.
Findings The preference order for the alternatives generated with the two models was very different, mainly due to the *manner* in which criteria weights are elicited and alternatives scored, as well as the use of scales in MAVF versus the pairwise comparison in AHP. However, the preference order of the top criteria with both methods was the same and the weights were also similar.

KEY WORDS: supply chain design, novel protein foods, Multiple Criteria Decision Making (MCDM), Multi Attribute Value theory (MAVF), Analytic Hierarchy Process (AHP)

INTRODUCTION

Introducing a new product and designing its potential supply chain 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. Given the background of a large study on the introduction of a non-meat protein source to partially replace meat products in the diets of the Dutch consumers (www.profetas.nl), researchers were confronted with the 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, supply chain (SC) management refers to managing a SC to meet end-customer needs through product availability and responsiveness, on-time delivery etc. (Beamon, 1998; van der Vorst et al., 1999; Wang et al., 2004). 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 (Apaiah et al., 2005b). Another characteristic of FSCs is that the attributes of the product important to the consumer (taste, texture, nutritional level), are a result of the SC variables 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 (Apaiah et al., 2005b).

Design of a FSC in a systematic way involves many aspects. Potential chain designs have to be proposed and evaluated to recommend the best design. Selection of attributes, identification of variables, generation of alternatives and finally evaluation require choices to be made. 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 (Belton et al., 2002), the number of alternatives is large and there are multiple stakeholders. Thus a decision making aid like multiple criteria decision making (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 no trade-offs in the traditional sense as each criterion is ranked according to its importance to the DM (Zak et al., 2002). An inherent property about decision making is subjectivity. MCDM does not dispel this but makes the process of making such decisions transparent (Belton et al., 2002). The process of MCDM is divided into three phases-identification of the problem, building the model and finally developing action plans.

Some basic steps are common to all approaches in MCDM (Belton et al., 2002; Triantaphyllou, 2000). The general model of Figure 1 is used to describe the basic steps.

In this paper, the approach is applied to the novel protein food (NPF) supply chain design problem. The terminology used in the rest of this paper is explained below:

- Options/alternatives: choices of the DM, e.g. which car to choose, where to buy a house.
- Criteria: goals or attributes or objectives that the DM wants to achieve. They are the means by which the DM can evaluate the alternatives, e.g. cost of car, mileage. These can be directly measurable e.g. cost of a house, or indirectly measurable e.g. location of the property. In the latter case, a performance indicator is required to measure the criterion, while in the former case, the criterion is the performance indicator.
- Criteria weights: represent the relative importance of each criterion.
- Scores/value/performance: 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 as described in sections that follow.
- Ranking: after weights and scores are obtained, the alternatives are graded with respect to all criteria simultaneously. This specific method depends on the model.

THE NOVEL PROTEIN FOOD CASE

The steps of the MCDM approach (Figure 1) are followed for the case. The first three steps- the generation of ideas, the structuring of these ideas and the generation of alternatives- are descriptive and do not depend on the type of model being used. We report on findings.

Steps 1, 2 and 3 of the MCDM Approach

Step 1: Generation of ideas

The material presented was collected in the framework of PROFETAS (www.profetas.nl). This project, involving many researchers, 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 can not yet be considered realistic substitutes to meat; hence, the prospects for replacing meat-derived ingredients by non-meat ingredients- Novel Protein Foods (NPF) was investigated in more detail.

The DMs involved in this project were food technologists, environmental scientists and economists. The issues that arose during brainstorming sessions were:

- Current food production and consumption patterns have a strong impact on the environment and natural resources
- Meat production is not appealing from an environmental point of view, because of inefficient conversion of protein in feed into protein in slaughtered animal, 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 feasibility study on partial diet conversion (pork products to NPF) could be done
- A possible vegetable source to partially replace pork is dry green peas. Peas are popular in the Netherlands, they are grown locally and expertise is easily 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.
- A product is successful if consumers want it; consumer studies are important to discover what product attributes make a NPF desirable to consumers
- New products should have low environmental impact, to start with, lower than meat
- The entire supply chain, from primary processing to the consumer impacts the product
- The feasibility study should aim at partially replacing processed pork products.

Step 2: Structuring of ideas

Main ideas that came up from Step 1 are summarized below.

- The feasibility study will look at a partial conversion of the diet; 20% of processed pork products by the year 2020 (Apaiah et al., 2005a; www.profetas.nl)
- Developing a product with good texture has priority
- A new product must be more environmentally friendly than pork meat
- Consumer studies and market research are necessary to make a successful product
- The entire supply chain has to be investigated

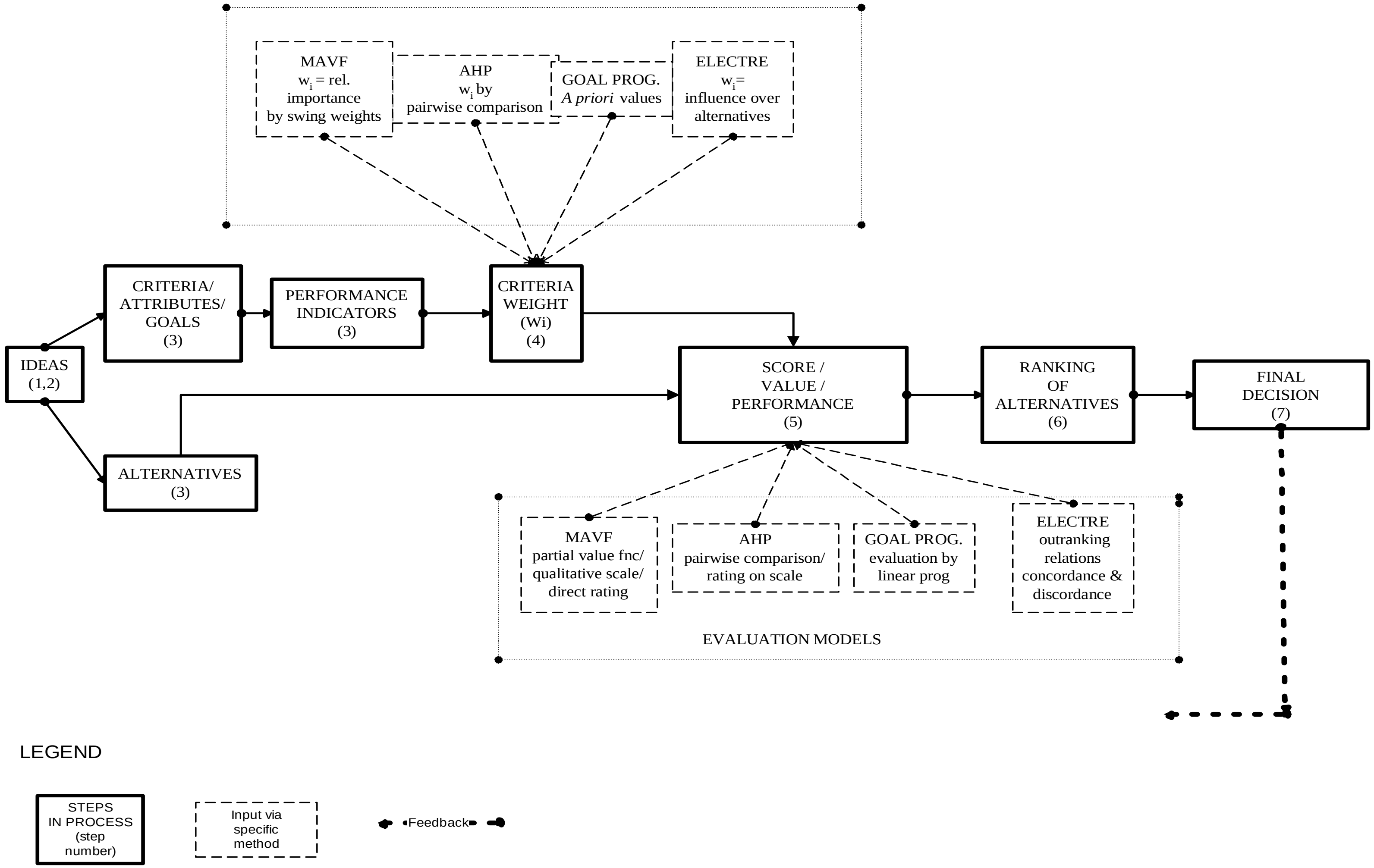

Figure 1: Steps in a Multi Criteria Decision Making approach (Apaiah, 2006).

Step 3: Model building- determining relevant criteria and alternatives

The model values: from consumer studies and discussions with stakeholders, the overall goal appeared to make a 'good' meat substitute. Important product attributes arising from discussions were good taste and texture, competitive pricing and environmental consciousness. The chain study concentrated on product attributes rather than on delivery of the product. This implies that goals/criteria of good quality, environmental and economic sustainability (Apaiah et al., 2005b) should be taken into account while designing the chain. According to the requirements in Belton et al. (2002), the criteria were found to be relevant, understandable and independent of each other. They were however not directly measurable. Goals were further defined and performance indicators chosen as follow:

- Economic sustainability: cost to manufacture the product (Apaiah et al., 2005b)
- Environmental sustainability: exergy input required was chosen as measure of environmental sustainability (Apaiah et al., 2006)
- Quality: texture, absence of undesirable flavours, nutritional level

The alternatives: Generation, evaluation and screening of alternatives are important aspects in MCDM. The generation of alternatives requires a complete understanding of the problem on hand and it's surrounding situation as well as a great deal of creativity and imagination (Walker, 1988). Alternatives represent different choices available to the DMs. In our case, alternatives are potential chain designs *i.e.* a combination of links and transport modes.

Generation of alternatives: In cases like location selection, alternatives are explicit and well defined. In this study however, generating alternatives is an integral part of the methodology. Two factors have to be taken into account when designing food supply chains:

- Start from the consumer and go back to the very beginning, *i.e.*, in case of a food product, to the production of raw ingredients that are in the product.
- The boundaries of the system have to be demarcated, i.e. what constitutes the primary chain and what inputs will be considered, have to be specified. Raw materials are not the only inputs into the product. Fertilizers, electricity, labour, machinery are few of the 'other' inputs. However, the chains for these products are not included in the design as this is not practical and probably impossible considering the manpower and time required.

Figure 2 gives an overview of variables and links in a generic food supply chain for NPFs. These variables are the result of brainstorming sessions. Potential alternatives for the supply chain design are a combination of choices for the control variables i.e. transport modes, locations for production, preparation and processing plants, processing methods, storage time and temperature and aspects of consumer processing.

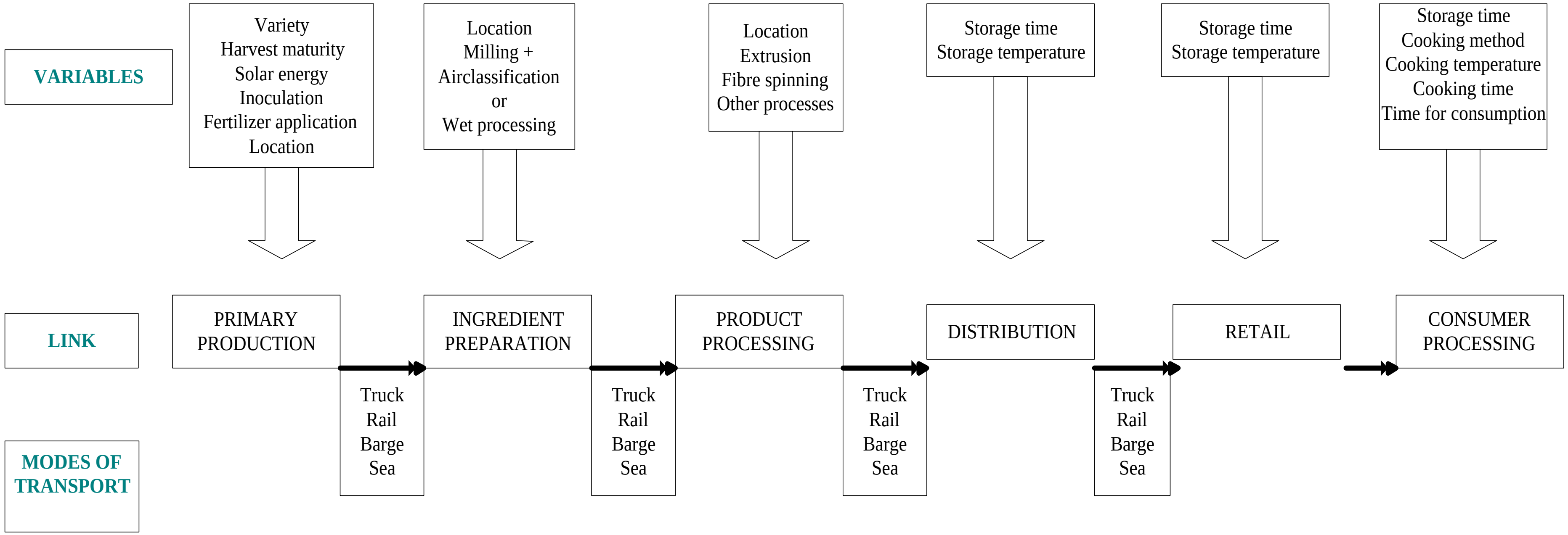

Figure 2: Generic supply chain for NPFs (Apaiah et al., 2005b)

Screening variables for alternatives: Further sessions were conducted to screen variables. Results are presented in Table 1. Strategies used to discard variables were:

1. If a variable does not affect one of the three criteria, it will be discarded
2. Commonly used farming and industrial practices are considered, *e.g.* peas are almost always harvested at 11% moisture
3. If a variable cannot differentiate between alternatives, it is discarded

Table 1: Results of screening strategies: effect of variables on criteria.

			Effect on		
	Link	Variable	Cost	Quality	Env. load
5	Primary production	Location	x		x
		Variety			
		Maturity			
		Fertilizers			
		Inoculation			
		Solar energy			
4	Ingredient preparation	Location	x		x
		Processing method	x	x	x
3	Product processing	Location	x		x
		Processing method	x	x	x
2	Distribution	Storage time	x	x	x
2	Retail	Storage temperature	x	x	x
	Mode of transport	Rail, barge, Truck, sea	x	x	x

x indicates that a criterion is affected by the variable under consideration

Table 1 shows the only variable in link 5 to affect cost and environmental load is location. Pea varieties and inoculation do not change cost of the end product. Maturity of the pea is not a variable in this case as it was decided to use peas harvested at 11 % moisture (see screening strategy 2). Solar energy and application of fertilizers depend on location, so are not included. Quality, as specified earlier, refers only to texture, absence of components that cause undesirable flavours and nutritional composition of the end product. Work done by O'Kane (2004) shows that gelation of pure pea protein solutions is affected by the ratio of proteins, legumin and vicilin present in pea. The texture of gels obtained and rate of formation would therefore also be affected. However, the effect of the ratio of proteins on texture and gelation of real food systems is not known yet. Therefore, influence of varieties and breeding was not considered.

Aiming at the Dutch market, location alternatives for distribution and retail were not considered. After the NPF is made, all products that enter the distribution channel are handled in a similar manner. The quantity of product under consideration is about 30,000 MT per annum. This is not sufficient market share to have a separate distribution network. The product will be incorporated into existing networks of retail companies. So, variables in link 2 affect the criteria, but all products are influenced to the same extent.

<u>Final selection</u>:

- Locations for primary production were determined with the following rules:
  - NL (The Netherlands) - was chosen as the product is meant for the Dutch market
  - FR (France) - is the largest pea growing nation in the EU
  - UKA (Ukraine) – is a large grower of peas outside the EU, with relatively low labour and utility costs (www.researchandmarkets.com & www.cerc.gouv.fr)
  - CAN (Canada) – is the largest pea growing nation in the world.
- Choices for processing locations are the same as for primary production
- Ingredient preparation. Main step is the concentration of pea flour. The industry uses two methods, air classification and wet extraction, to make pea concentrates and pea isolates. Both methods have been considered.
- Product processing: Three methods were evaluated- air classification + extrusion, specialised processing A and specialised processing B (details are in the appendix).

Variables were screened according to the rules mentioned above. Figure 3 shows the SC after screening. The grey highlighted areas are links and variables that were used to construct alternatives. Table 2 shows details of 11 alternatives that resulted from generation and screening procedures described above.

Table 2: List of alternatives that resulted after screening

Alt	PP location	Transport mode	ING location	Processing Method [Prot Concentration (%)]	Transport mode	NPF preparation Method in NL	Transport mode
1	UKA	Truck	UKA	AC [50-60] D	Truck Rail	Extrusion	Truck
2	NL, FR CA, UKA	Truck Sea Rail	UKA CAN	AC [50-60] D	Truck Rail	Extrusion	Truck
3	NL	Truck	NL	AC [50-60] D	Truck Rail	Extrusion	Truck
4	NL	Truck	NL	WP [25] W, **A**	Truck	**A**	Truck
5	FR	Truck	NL	AC [50-60] D	Truck	Extrusion	Truck
6	FR	Rail	FR	AC [50-60] D	Truck	Extrusion	Truck
7	UKA	Truck	NL	WP [80-90] D, **B**	Truck	**B**	Truck
8	FR NL	Truck Rail	NL	WP [25] W, **A**	Truck	**A**	Truck
9	CAN	Rail	CAN	AC [50-60] D	Sea	Extrusion	Truck
10	CAN	Rail	CAN	WP [80-90] D, **B**	Sea	**B**	Truck
11	FR	Rail	FR	WP [80-90] D, **B**	Truck	**B**	Truck

D= Dry; W= slurry; AC= air classification; WP= wet processing, **A, B =** processes A or B

PP = Primary production; ING = ingredient preparation; NPF = product processing; NL = The Netherlands; FR = France; CAN = Canada; UKA = Ukraine

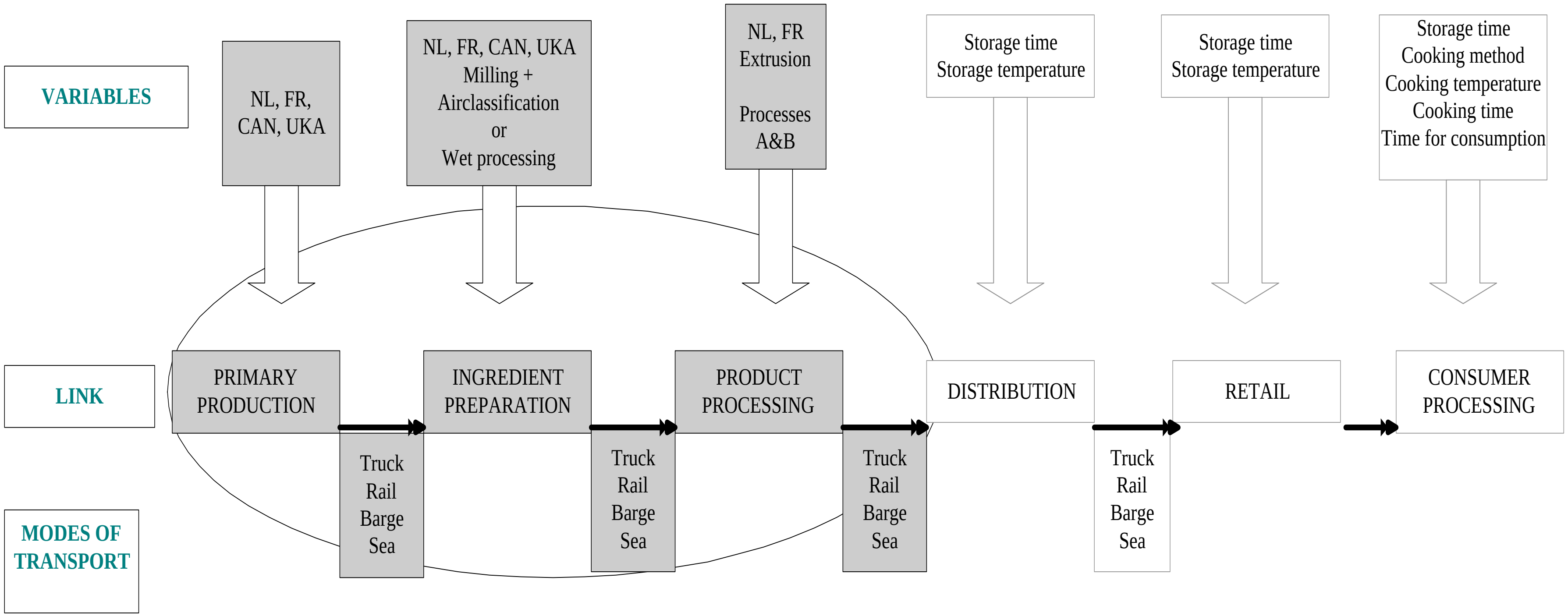

Figure 3: Potential alternatives for production of NPFs after screening

Steps 4, 5 and 6 depend on the type of MCDM model. The Multi Attribute Value theory (MAVF) and Analytic Hierarchy Process (AHP) models were applied to this case. 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. Below, the ways of performing these steps are described for MAVF and AHP. 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. Using this input, Figure 1 was modified to give a case specific model (Figure 4).

I. Steps 4, 5 and 6 with Multi Attribute Value Theory (MAVF) Method

Step 4: Determining relative importance of criteria

As in most multi-criteria decision problems, the considered criteria are not of equal importance to DMs- *i.e.* they do not have the same weight. Therefore it is important to assess the relative importance of criteria. Three top-level criteria of cost, quality and environmental load were weighted according to the swing method (Belton et al., 2000) by a panel consisting of food technologists, social scientists, engineers and environmentalists. These criteria were defined as follows:

- Cost- this refers to cost of manufacture of NPF. This cost was calculated (Appendix) and ranged from €215 - €610 per MT over 11 alternatives.
- Environmental load was measured by the exergy input required for each alternative. Exergy input was calculated (Appendix) and ranges from approximately 14,000 MJ/MT (mega joule per metric ton) to 34,000 MJ/MT over 11 alternatives.

Raw data of cost and exergy input of each alternative were converted to partial value scales where a score of 100 represents the cheapest cost alternative and lowest exergy requiring alternative and a score of zero the other extreme.

- Quality of the end product was defined by consumer research and brainstorming sessions to be nutritional value, texture and absence of undesirable flavours (sub attributes/criteria). Nutritional value was further sub divided into the following: amino acid availability, anti-nutritional factor (ANF) level and natural fibre content.
  - Texture: good texture implies a structure resembling that of meat. A score of 100 implies good structure formation and zero implies no fibre formation.
  - Absence of off-flavour: refers to absence of components causing undesirable flavours. A score of 100 implies no beany off flavours after processing; zero implies a perceptible beany flavour.
  - Nutritive value: refers to amino acid availability (score of 100 is no destruction of amino acids; zero implies most of amino acids are destroyed), ANF content (lectins and trypsin inhibitors: a score of 100 implies no ANFs present and a score of 0 indicates presence of a large amount of ANFs) and presence of natural food fibres in the NPF after processing (score of 100 indicates that there is an appreciable amount of fibre and a score of zero indicates no natural fibre remains in the product).

Panellists were asked to consider how the swing from 0 to 100 on one preference scale compared to the 0 to 100 swing on another scale and filled in tables like Table 3.

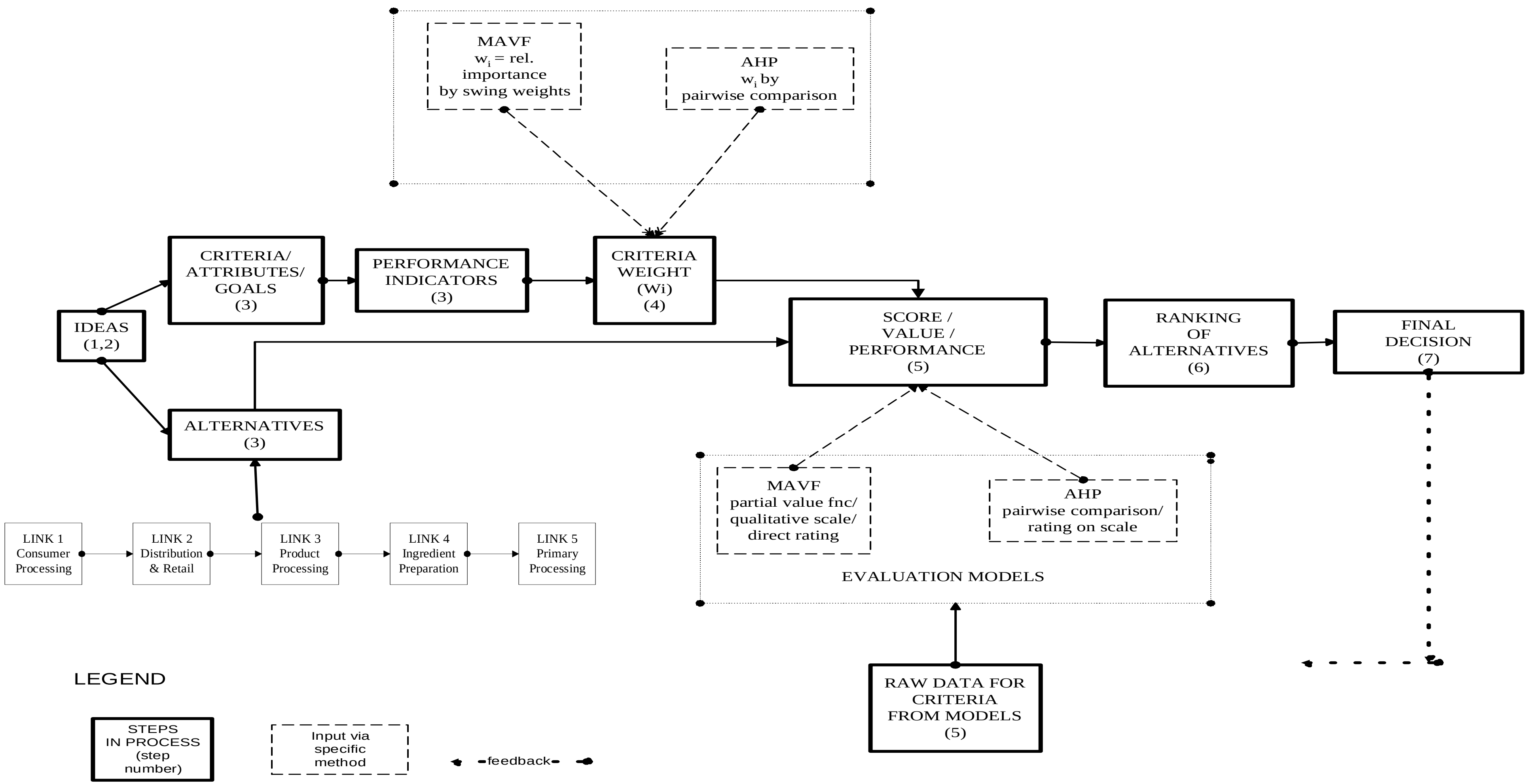

Figure 4: The case specific MCDM approach

Table 3: Elicitation of weights in the swing method

Criteria	Order	Weight	Normalised weights
Cost			
Quality			
Environmental load			

Results presented in Table 4 are from four panellists. Panellists first ordered criteria and then assigned weights. Data on weights and orders were used to calculate the normalised weights and the average. Table 4 shows that panellists 1, 2 and 3 have similar preferences with regard to the order of the criteria, but differ greatly on the relative importance of criteria. Panellist 4 ranked environmental load as the most important criterion, but the relative difference between criteria is small in his case. This highlights that opinions and bias of DMs can exist and possibly influence the final ranking of alternatives.

Table 4: Top criteria weights for NPF via swing method

Panellist		Cost	Quality	Environmental load
1 (Food engineer)	Order	2	1	3
	Weight	80	100	20
	Normalised weight	0.4	0.5	0.1
2 (Food engineer)	Order	2	1	3
	Weight	50	100	25
	Normalised weight	0.29	0.57	0.14
3 (Consumer scientist)	Order	2	1	3
	Weight	50	100	5
	Normalised weight	0.32	0.65	0.03
4 (Environmental scientist)	Order	2	3	1
	Weight	90	70	100
	Normalised weight	0.35	0.27	0.38
Average weights		**0.34**	**0.5**	**0.16**

The swing method was also used to elicit weights for quality sub criteria. Table 5 gives normalised weights calculated from responses elicited from experts (similar to Table 4). Three of four experts ranked texture as the most significant sub criterion. The fourth expert ranked texture and absence of off flavours at the same level.

Table 5: Quality sub criteria weights for NPF elicited via the swing method

Experts	Texture	Absence of off flavours	Absence of ANFs	Amino acid availability	Presence of natural fibres
A (Consumer scientist)	0.42	0.25	0.08	0.13	0.12
B (Food scientist)	0.31	0.31	0.28	0.03	0.06
C (Food scientist)	0.43	0.34	0.13	0.06	0.04
D (Food chemist)	0.36	0.33	0.15	0.13	0.04
Average	0.38	0.31	0.16	0.09	0.07

Step 5: Determining the impact of alternatives on criteria (scoring)

The 11 generated alternatives will have a different score on each criterion.

Table 6: Processing methods and alternatives

Processing method*	Number of alternative
AC+ Extrusion	1,2,3,5,6,9
From process A	4,8
From process B	7,10,11

*details on processing methods available in appendix, AC: air classification

i. Scoring alternatives for quality

The quality of the end product from each alternative is the result of the processing method used to make it (Table 6). Three processing methods can be used; NPFs of three different qualities were defined. A qualitative scale was used. Each sub-attribute was scored as: Good (10 points), Acceptable (5 points), and Bad (zero points), with respect to alternatives by experts from various areas of food science (the same as those used in Table 5). Table 6 classifies alternatives on the basis of processing methods. Results of the scoring are given in Table 7. The weighted score was calculated by multiplying the numerical score elicited from panellists with criteria weights (Table 5). The weighted score thus takes into account the relative importance of quality sub attributes.

Table 7: Weighted scores of alternatives for quality with the MAVF method

Attributes\Processes → ↓	AC+ Extrusion	From process A	From process B	Weights
Texture	0	10	5	0.38
Absence of off-flavours	0	5	10	0.31
Absence of ANFs	10	5	10	0.16
Amino acid availability	0	10	5	0.09
Presence of natural fibres	10	0	0	0.07
Weighted scores (numerical score*weight)	**23**	**71**	**70**	

ii. Scoring alternatives for cost

To ensure economies of scale, 30,744 MT per annum was used as the demand for the product in the Netherlands. Cost of manufacture (ex-factory) of NPFs was calculated for each alternative (Appendix) and the derived cost per ton is given in Table 8. The bisection method (Belton and Stewart, 2002) was used to scale this cost data onto a partial value scale with using a partial value function. The value of the cost is non-linearly related to the hard data as can be seen from the derived partial value function (Figure 5). This function decreases monotonically and is non-linear. Two scales were used to present two different viewpoints- how different scales (global and local) would affect the final ranking of alternatives.

In the first case, a global scale (the end points represent the worst and best possibilities ever) was used. The NPF should ultimately replace pork meat; therefore the worst cost option is a cost of manufacture more than that of pork mincemeat. '0' represents this worst cost option, *i.e.* €1200 per MT. The '100' on the scale represents the 'best' price that was achieved in this exercise. The partial value function in Figure 5, case 1 was derived with the bisection method. A score of 50 represents a cost of €950, 75 represents €650 and 25 represents €1100. Partial value function $y = -.00009x^2 + 0.0373x + 95.24$ was obtained from this data and was used to calculate scores for other alternatives.

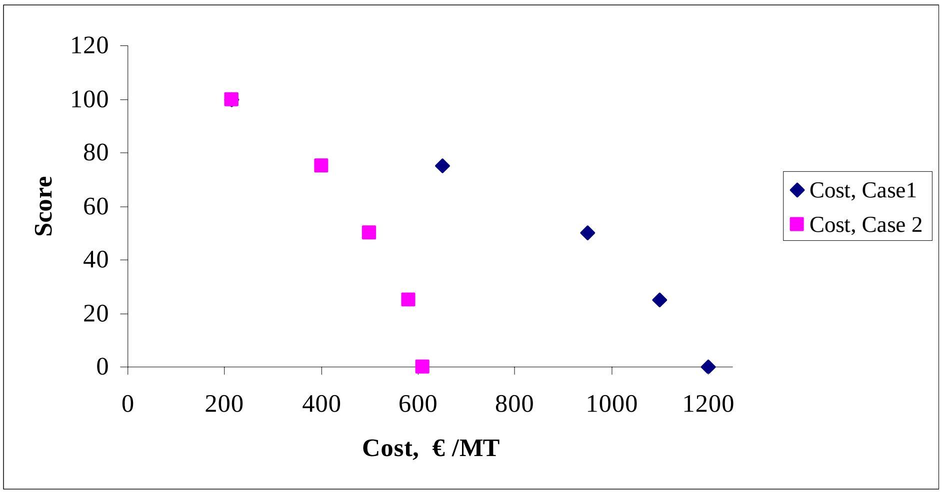

Figure 5: Partial value function for both cost cases

In the second case, a local scale was used; the end points represent the worst and best alternatives in this case. The '0' represents the worst cost option- *i.e.* the cost of manufacture of the most expensive alternative, €609 per MT. The '100' on the scale represents the 'best' price that is achievable *i.e.* the cheapest alternative. The partial value function in Figure 5, case 2 was also derived via bisection. A score of 50 represents a cost of €500, 75 represents €400 and 25 represents €580. Partial value function $y = -0.0006x^2 + 0.2297x + 76.26$ was obtained and used to calculate scores for other alternatives. Table 8 gives the scores for both cases.

Table 8: Score for cost and environmental load with the MAVF method

Alternatives	Cost, € /MT	Cost score, Case 1	Cost score, Case 2	Exergy input, MJ/MT	Exergy score
1	215.90	99	99	27415	35
2	266.11	99	9	22007	63
3	282.89	99	95	15109	99
4	570.00	87	17	14761	100
5	315.80	98	91	18468	81
6	304.42	98	92	16213	93
7	609.42	85	0	33891	0
8	584.70	86	10	15551	96
9	315.47	98	91	21679	64
10	487.89	92	49	23605	54
11	484.01	92	50	16892	89

iii. Scoring of alternatives with respect to environmental load (exergy input)
Environmental load of alternatives is measured as exergy input required for each alternative. The exergy input required to make 30,744 MT of NPF was calculated for each alternative (Appendix). The requirement per ton is shown in Table 8. This data was converted to a partial value scale using a partial value function. This linear function decreases monotonically. Linear partial value function $y = -0.0052x + 177.17$ is used to convert required exergy data to partial value scores (Table 8).

Step 6: Processing values to arrive at a ranking for alternatives

The additive model is used to calculate the total score value V(A) of alternative A.

$$V(A) = \sum_{i=1}^{m} w_i v_i(A) \qquad (1)$$

where w_i is the weight of criterion i and $v_i(A)$ is the partial value of alternative A for criterion i. The criteria weights used were the averages obtained (Table 4). As described earlier, cost was scored using two different scales. The aim is to see how different scales (global and local) affect the final ranking of alternatives (case 1 and 2). Table 9 shows scores, criteria weights and value V(A) of each alternative.

Table 9: Value of alternatives via the MAVF model

		Alternatives										
Criteria	w_i	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven
Quality	*0.50*	23	23	23	71	23	23	70	71	23	70	70
Environmental load	*0.16*	35	63	99	100	81	93	0	96	64	54	89
Cost: Case 1	*0.34*	99	99	99	87	98	98	85	86	98	92	92
V(A) 1		**51**	**55**	**61**	**81**	**58**	**60**	**63**	**80**	**55**	**75**	**81**
Cost: Case 2	*0.34*	99	96	95	17	91	92	0	10	91	49	50
V(A) 2		**51**	**54**	**60**	**57**	**56**	**58**	**35**	**54**	**53**	**60**	**66**

Figure 6 compares alternatives on the basis of their ranks, where the alternative with the highest value getting rank '1'. The preference order in the two cases is not the same because of different scales that were used. Alternative 4 is expensive (€570/MT) compared to other alternatives but is cheap compared to cost of pork mincemeat (€1200/MT). Therefore, with the global scale, this alternative scores 87 for cost giving it an overall value of 81, whereas on the local scale, it scores only 17 for cost, resulting in an overall value of 57. Alternative 4 therefore goes from rank 1 in the first case to rank 5 in the second case. Alternative 8 similarly falls from the third to the seventh place. This large difference in ranking emphasises the importance of the selection of the scale and fixing end points. The facilitator or analyst must impress this on the DMs so that generated results represent their viewpoints and opinions adequately. Alternative 11 is ranked at the first place in both cases.

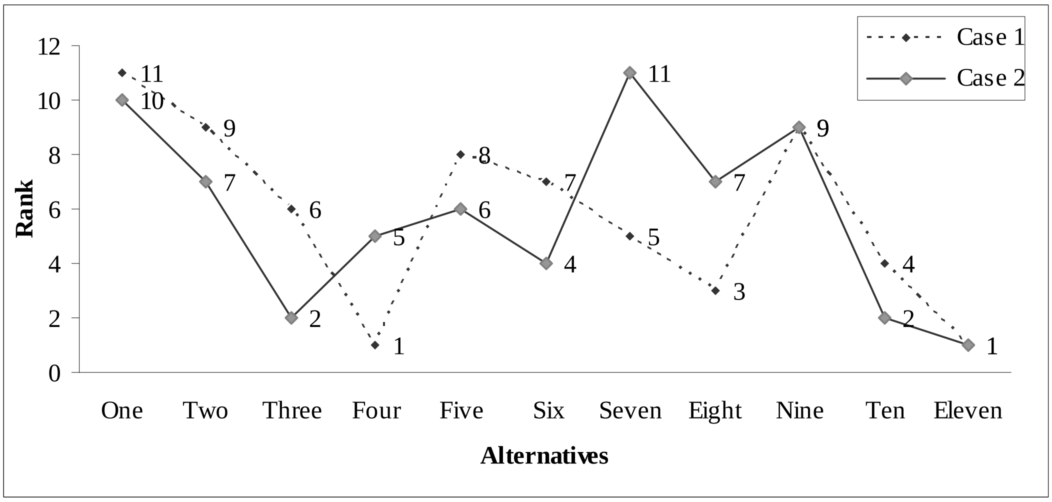

Figure 6: Comparison of two cases in the MAVF model

II. Steps 4, 5 and 6 with the AHP Method

Step 4: Determining relative importance of criteria

The three top-level criteria were weighted according to the pair-wise comparison method by the same panel used for the swing method. Normalised weights of pair-wise comparison are shown below (Table 10, details in appendix 6).

Table 10: Normalised top criteria weights for NPF via the AHP method

Panellist	Cost	Quality	Env. load
1 (Food engineer)	0.28	0.64	0.07
2 (Food engineer)	0.19	0.74	0.08
3 (Consumer scientist)	0.29	0.65	0.06
4 (Environmental scientist)	0.30	0.07	0.63
Average weights	0.27	0.52	0.21

This method of elicitation was also used to weigh quality sub criteria. The five bottom level criteria were compared to each other pairwise. The panel was the same as used to elicit these weights with the swing method. The comparisons of panellists 4 and 5 appeared inconsistent and were not included in the calculation of average weights (Table 11, details in appendix). Inconsistency can occur even when experts in the field give there preferences, as people are not always able to convert opinions into numbers easily. Figure 7 shows the hierarchy of criteria and weights.

Table 11: Normalised quality sub criteria weights via the AHP method

Panellist	Texture	Absence of off flavours	Absence of ANF	Amino acid availability	Natural fibres
1	0.58	0.20	0.04	0.09	0.09
2	0.40	0.40	0.13	0.04	0.04
3	0.56	0.19	0.05	0.05	0.15
Average	0.51	0.26	0.07	0.06	0.09

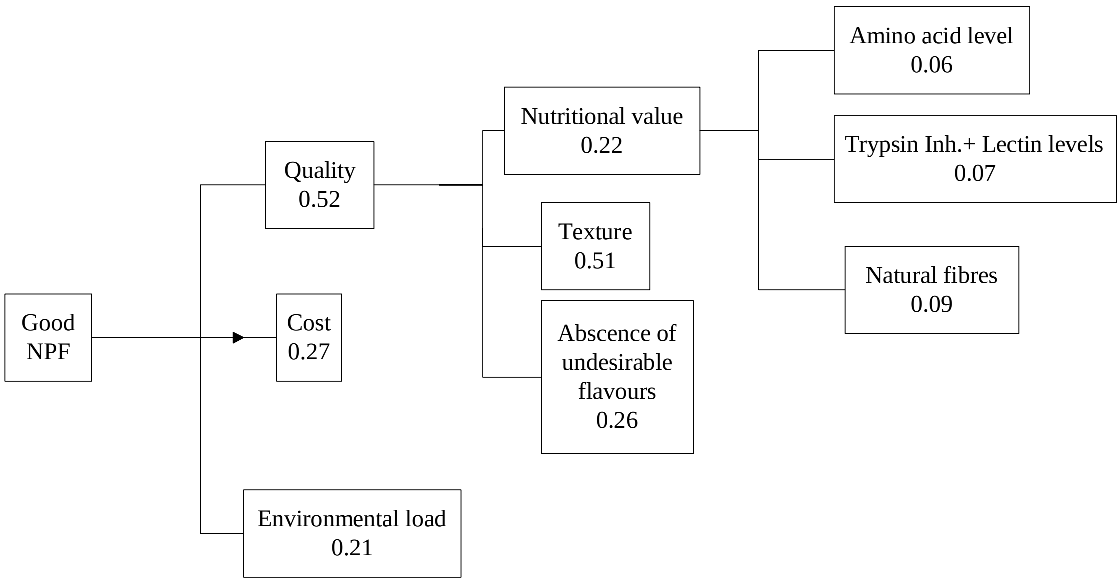

Figure 7: The AHP hierarchy

Step 5: Determining impact of alternatives on criteria (scoring)

i. Scoring of alternatives with respect to quality

The overall score for quality of alternatives via the AHP method is the weight of quality attributes multiplied by the score (obtained by pair-wise comparison) of each alternative on the corresponding attribute. The quality of NPF from each alternative is the result of the processing method that was used to make it. As three processing methods were used, NPFs of three different qualities were defined.

Table 12: Normalised weighted scores for quality sub attributes via the AHP method

Attributes\Processes	AC+ Extrusion	From process A	From process B	Weights
Texture	0.07	0.66	0.27	0.51
Absence off-flavour	0.10	0.46	0.45	0.26
Absence of ANFs	0.47	0.09	0.45	0.07
Amino acid availability	0.13	0.55	0.32	0.06
Fibre	0.74	0.13	0.13	0.09
Weighted score	**0.17**	**0.51**	**0.32**	

Table 12 gives the normalised score for quality of NPF as a result of processing methods. Alternatives 1, 2, 3, 5, 6 and 9 have a score of 17, alternatives 4 and 8 have a score of 51 and alternatives 7, 10 and 11 have a score of 32.

ii. Scoring of alternatives with respect to cost

Cost of manufacture was divided into ranges *i.e.* 200-300, 300-400, ….>600, where 200-300 implies manufacturing cost from € 200 to € 300. Preferences (weights) for the ranges were calculated by comparing them pair-wise as shown in Table 13.

Table 13: Preferences for cost ranges

	200-300	300-400	400-500	500-600	>600	Weights
200-300	1	3	5	7	9	0.5
300-400	1/3	1	3	5	7	0.26
400-500	1/5	1/3	1	3	5	0.13
500-600	1/7	1/5	1/3	1	3	0.07
>600	1/9	1/7	1/5	1/3	1	0.03

Alternatives were then scored according to these weights or preferences, see. Table 14.

Table 14: AHP cost and environmental load scores

Alternatives	Cost, € /MT	Cost range	**Cost score**	**Environmental load score**
1	215.90	200-300	**0.5**	**0.35**
2	266.11	200-300	**0.5**	**0.63**
3	282.89	200-300	**0.5**	**0.99**
4	570.00	500-600	**0.07**	**1.0**
5	315.80	300-400	**0.26**	**0.81**
6	304.42	300-400	**0.5**	**0.93**
7	609.42	>600	**0.03**	**0**
8	584.70	500-600	**0.07**	**0.96**
9	315.47	300-400	**0.5**	**0.64**
10	487.89	400-500	**0.13**	**0.54**
11	484.01	400-500	**0.13**	**0.89**

iii. Scoring of alternatives with respect to environmental load (in terms of exergy)

Environmental load of alternatives was measured as required exergy input. The exergy input required to make 30,744 MT of NPF was calculated for each alternative. The requirement per ton is shown in Table 8. AHP normally uses a pairwise comparison to directly compare alternatives or divides them into ranges and then elicits preferences. Environmental load is however scored on a linear scale in this case.

Step 6: Processing values to arrive at a ranking for alternatives

Also here the additive model (Equation 1) is used to calculate value V(A) of alternative A. The criteria weights w_i are obtained from Table 10. Table 15 shows the scores, criteria weights and the value, V(A) of each alternative. Alternatives 4 and 8 are ranked the highest, because they give an end product with a very good quality and quality has a high weight. The weight and score of quality are high enough to compensate for a low score for cost (0.07). Alternative 1 has a high score for cost and a medium score for environmental load, but the poor quality pulls it down in the ranking. The importance of criteria weights can easily be seen here.

Table 15: Value of alternatives via the AHP method

		Alternatives										
Criteria	w_i^*	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven
Quality	*0.52*	0.17	0.17	0.17	0.51	0.17	0.17	0.32	0.51	0.17	0.32	0.32
Env. load	*0.21*	0.35	0.63	0.99	1.00	0.81	0.93	0.00	0.96	0.64	0.54	0.89
Cost	*0.27*	0.5	0.5	0.5	0.07	0.26	0.5	0.03	0.07	0.5	0.13	0.13
V(A)		30	36	43	50	33	42	17	49	36	31	39
Rank		10	7	3	1	8	4	11	2	6	9	5

$^*w_i$ are criteria weights

Comparison of MAVF and AHP Methods

The final ranking of alternatives with the two methods are not the same (Figure 8). Even within the MAVF method, the ranking of alternatives in case 1 and case 2 is different. These dissimilarities are due to different scaling and scoring methods that result in different criteria weights and scores. This can be seen clearly in the scores for quality. The MAVF method uses a qualitative scale; processes A and B had almost similar scores of 71 and 70. The pairwise comparison method of the AHP however differentiated more between end product quality from process A and B (scores of 51 and 32 respectively).

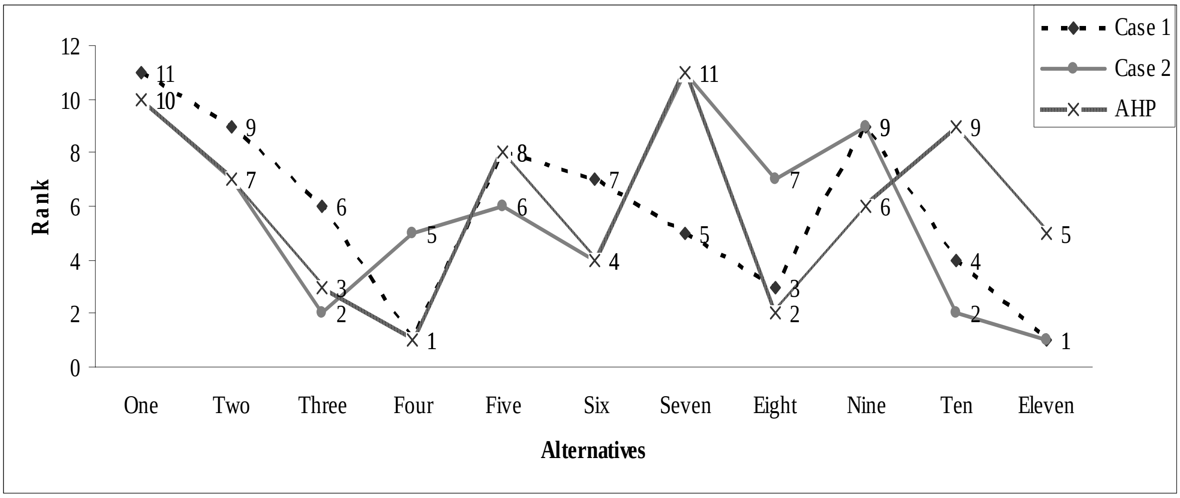

Figure 8: Overall ranking of alternatives

Sensitivity Analysis

The data from MAVF case 2 was analysed to examine sensitivity of the overall preference order to criteria weights and preferences of panellists. Criteria weights were varied from 0 to 1 to observe changes. This analysis was carried out on Microsoft Excel and web hipre (www.hipre.hut.fi/). Results are reported in Apaiah (2006). Here we focus on sensitivity to panellist preferences. Ranking of alternatives in case 1 and 2 was done with average criteria weights (Table 5). However, weights or preferences of individual panellists vary. If individual weights are used instead of the average, preference orders change. Figure 10 shows alternatives from best to worst using average values and compares preference orders from each panellist to this.

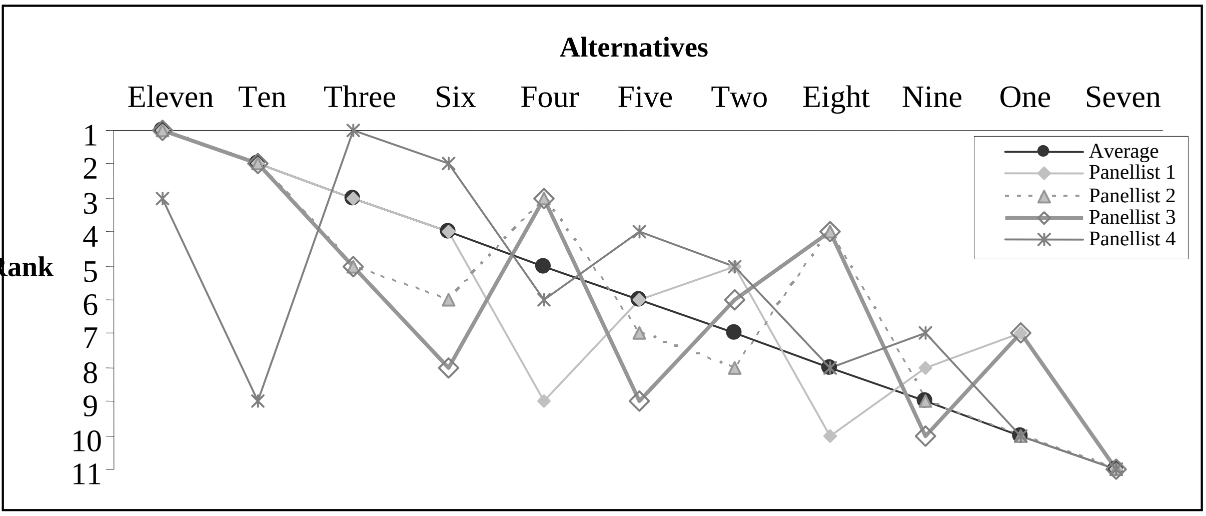

Figure 9: Sensitivity of ranking to panellist preferences

Results from this graph correspond to those of the sensitivity analysis performed earlier. Panellist 4 weighted quality at 0.27. According to earlier sensitivity analysis of preference order to quality weight, any weight more than 0.4 results in alternative 11 being the best. Below this value, alternative 3 gets rank 1, see Figure 9.

CONCLUSIONS AND DISCUSSION

Aim of this paper is to investigate possibilities of MCDM in designing FSCs. Generation of ideas helped to make goals concrete. In this case, the overall goal was to make an NPF that consumers want to buy. Structuring of ideas gave a concrete list of attributes for the product by which the goal could be reached. To be able to give the consumer a product that he/she wants, the whole chain of the product, from primary production of ingredients that went into the product, to distribution and retailing of the product, had to be studied in detail (Apaiah et al., 2005b). The SC consists of five links. As shown in Figure 2, there exist variables in each of these links that influence the attribute values of the end product. Potential SCs (alternatives) to achieve a desired end product are a combination of values for these variables. An infinite number of possibilities existed at this stage. Screening strategies were developed to narrow possibilities. The important strategy states that if a variable or link does not differentiate between alternatives, it should be discarded. The last two links in the chain, distribution and retail, are the same for all possible alternatives as the product is for the Dutch market only. Thus these links were not considered constructing alternatives.

The general model for MCDM helped to coordinate the whole design process. The stepwise procedure made the method transparent for the DMs and the analysts, and aided in evaluation of screened alternatives. Two out of the four models, MAVF and AHP, mentioned in Figure 1 were chosen and a case specific model was formed (Figure 4). The most important factor in the choice of these models is the ease with which they can handle a mix of quantitative and qualitative information, quantify the qualitative information and generate an overall value for each alternative.

The preference order generated with the two models is very different. The main reason for this difference is the *manner* in which criteria weights are elicited and alternatives scored, as well as the use of scales in MAVF versus the pairwise comparison in the AHP model. It is interesting to note though, that the preference order of the top criteria with both methods is the same and the weights are also similar (Tables 4 and 10).

MCDM gives recommendations to the DMs (Table 16). It is then up to them to look at the preference orders and make their final choice. In case 1 of the MAVF method, alternatives 4 and 11 have the same overall value.

However, each alternative scores differently on the three criteria. The quality of alternative 4 is better than of alternative 11, but alternative 4 is more expensive and exergy intensive compared to alternative 11. The picture is clear and therefore the DMs can choose which supply chain (alternative 4 or 11) they would like to implement or they can opt to study the two alternatives in greater detail.

Table 16: The top ranking alternatives*

Alternative	PP location	Transport mode	ING location	Processing Method [Prot Concentration (%)]	Transport mode	NPF preparation method	Transport mode
4	NL	Truck	NL	WP [25] W, A	Truck	A	Truck
11	FR	Rail	FRA	WP [80-90] D, B	Truck	B	Truck
8	FR NL	Truck Rail	NL	WP [25] W, A	Truck	A	Truck

*refer to Table 2 for the abbreviations used in this table

In case 2 of the MAVF method, the use of a local scale differentiated the alternatives to a greater extent and therefore the overall value of each alternative changed. As alternative 4 was more expensive compared to alternative 11, it was scored lower and alternative 11 was ranked the highest. The AHP model ranked alternative 4 as the highest followed by alternative 8.

The methodology was successful in focussing DM attention on the issues at hand. The ideas generated were made concrete and the path to final choices is clear. The stepwise process made the decision making process transparent and easy to review and audit.

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APPENDIX: SAMPLE CALCULATIONS USED TO CALCULATE THE EXERGY LOAD AND COST FOR AN ALTERNATIVE

Table A1: Alternative11

	PP location	Transport mode	ING location	Processing Method [Protein Concentration (%)]	Transport mode	NPF (NL) preparation method	Transport mode
11	FR	Rail	FR	WP [80-90] D, B	Truck	New process from B	Truck

D= Dry; W= slurry; AC= air classification; WP= wet processing, A, B = processes A or B
PP = Primary production; ING = ingredient preparation; NPF = product processing; NL = The Netherlands; FR = France; CAN = Canada; UKA = Ukraine

Four countries were chosen as potential candidates for study. The table below shows possible growing areas and processing sites for ingredients and the final product.

Table A2: Countries for primary production and processing

Country	Growing area	Processing site
Netherlands	Brabant	Europoort
France	Provence/Cote d'Azur	Marseille
Canada	Saskatchewan	Churchill, Hudson Bay
Ukraine	Entire country	Kiev

Table A3: Distances in km between the four areas considered

	To			
From/By	NL	FR	UKA	CAN
NL/sea		(100)+3900		(100)+7300
NL/barge	100	1142	2100	
NL/rail	100	1142	2100	
NL/truck	100	1142	2100	
FR/sea	3900			8800
FR/barge	1362	185	2475	
FR/rail	1362	185	2475	
FR/truck	1362	185	2475	
UKA/sea				
UKA/barge	2325	2856	288	
UKA/rail	2325	2856	288	
UKA/truck	2325	2856	288	
CAN/sea	(950)+7400	(950)+8800		
CAN/barge				950
CAN/rail				950
CAN/truck				950

Total cost per MT of NPF = Dry pea cost * quantity + transportation cost from PP location to ING location * quantity + ING preparation cost (labour + energy+ equipment cost) * quantity + transportation cost from ING location to NPF location * quantity + NPF preparation cost (labour + energy+ equipment cost) * quantity

Total exergy required per MT of NPF = Exergy for [PP + transportation from PP location to ING location + ING preparation + transportation from ING location to NPF location + NPF preparation]

Table A4: Fuel efficiency* of the four modes of transport considered.

Transport mode	Miles per gallon for 1 ton
Sea	607
Barge	514
Rail	202
Truck	59.2

*http://mts.tamug.tamu.edu/Modal_Shift/modal.html#top
*http://www.geo.msu.edu/glra/workshop/01wresworkshp/AMtalks.htm

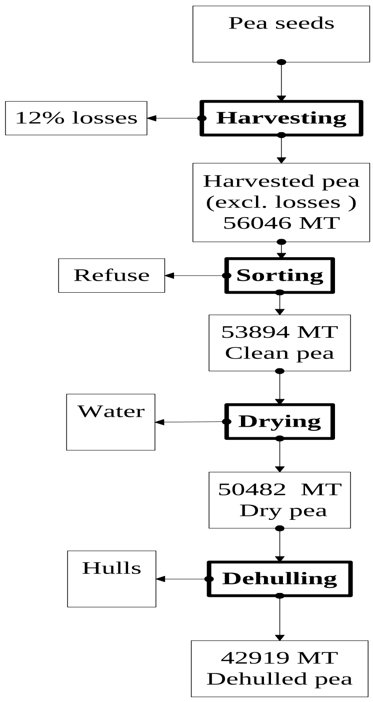

Figure A1a: First part scheme to make the NPF via processes A and B (Vereijken J.M. and Goot A.J. van der, personal communication)

Alternative 11 considers process B to make the NPF. The details on composition and the process are given below in the tables and schemes.

Table A5: Composition of the NPF via processes A & B*

Composition	Kg
PP isolate	254
Polysaccharides	83
Water	555
Fat	108
	1000

* Boekel, M.A.J.S. van, Vereijken J.M. and Goot A.J. van der, personal communication

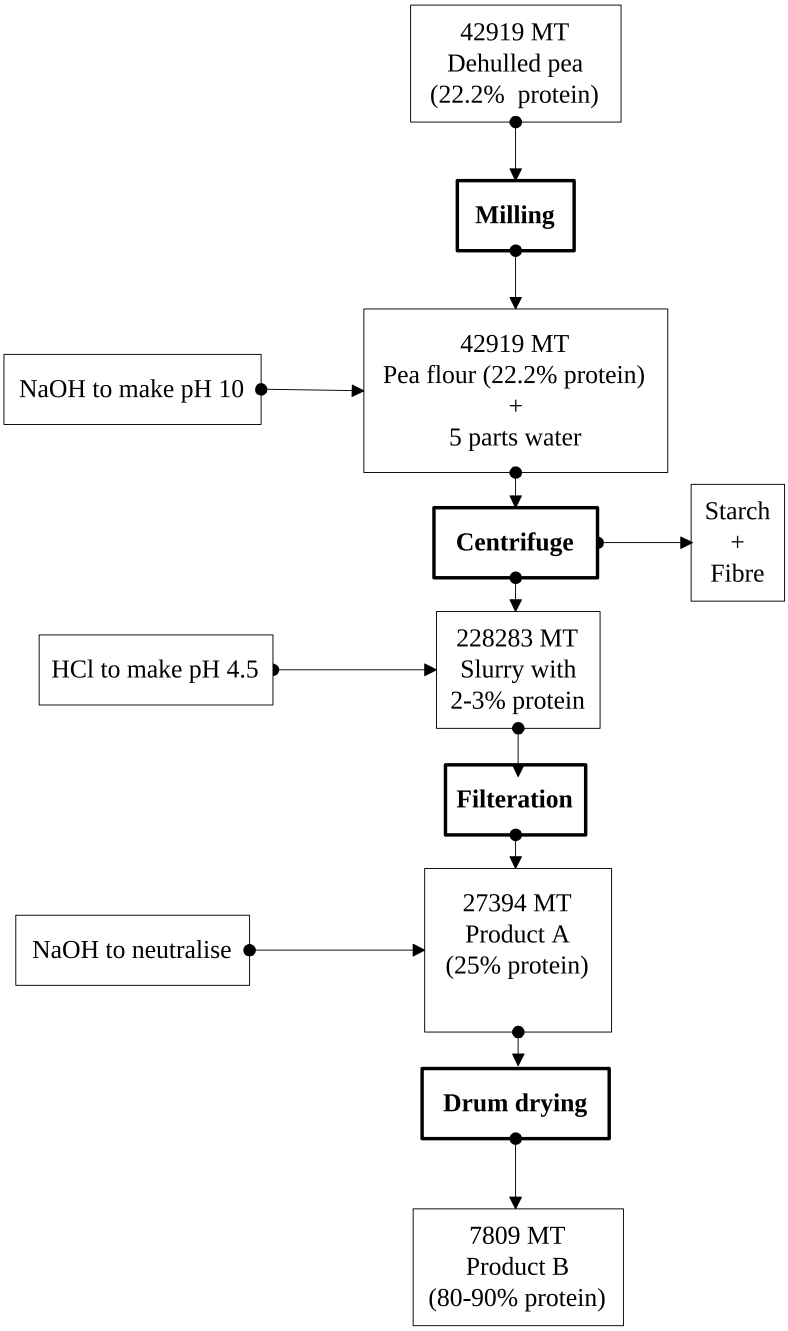

Figure A1b: Second part scheme to make the NPF via processes A and B (Vereijken J.M. and Goot A.J. van der, personal communication)

Table A6: Composition of pea protein isolate

PP isolate composition	%	In 254 Kg
Protein	87.7	222.76
Starch	0	0.00
Water	3.3	8.38
Fibre	0.2	0.51
Ash	5.8	14.73
Fat	3.0	7.62

[*] Sosulski et al., 1988

The wet isolation process yields 18.2% of pea protein isolate (87.7% protein) (Sosulski, Sosulski, & McCurdy, 1988). The Figure below presents a scheme to make the isolate from dry peas. The quantities considered in Figure A2 are those required to make 30744 MT of the product (Apaiah et al., 2005a).

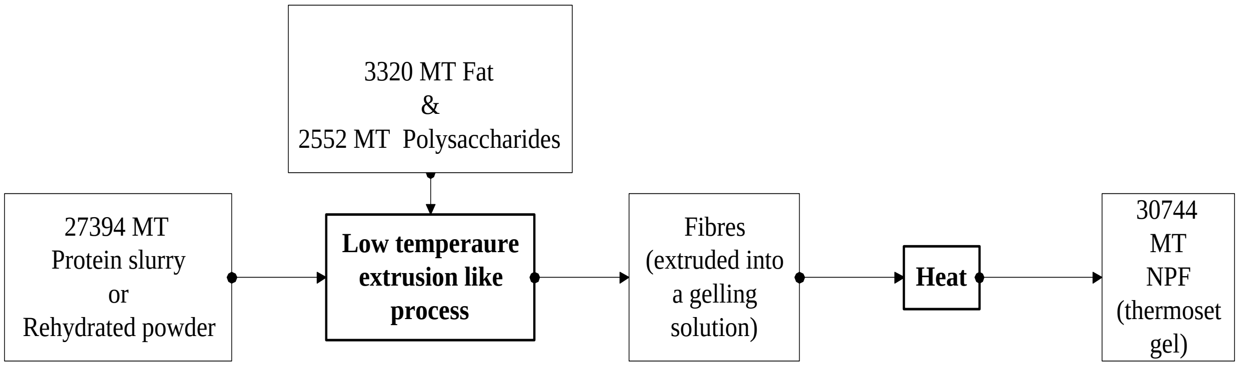

Figure A2: Scheme to make the NPF via processes A and B (Vereijken J.M. and Goot A.J. van der, personal communication)

Energy (electricity) requirements for various processes involved in manufacturing NPF are shown in the table below.

Table A7: Electricity requirements[#] for processes in NPF manufacture

Process	Energy, MJ/MT
Drying	2250
Dehulling	108
Milling	158
Mixing/ Centrifuging	7.2
Drum drying	2257
Cutting	158.00
Shaping [*]	57.14
Packaging, electricity[*]	685.68
Extrusion like process[+]	230.19
Heating["]	242.31

[#] Goot A.J. van der, personal communication, Perry, 1997, [*]van der Steen, 2002
[+]calculated using specific heat capacity of the mixture

Table A8: Transportation cost in € per ton (using fuel costs 2003-2004)

	sea	rail	barge	truck
CANADA.CAN *		16.62		
CANADA.FRA	55.02			
CANADA.UKA	55.02			
CANADA.NLD	55.02			
FRANCE.CAN	55.02			
FRANCE.FRA		10.88		
FRANCE.UKA	50.9	167.9	21	20
FRANCE.NLD		75.4	13.5	16
UKRAINE.CAN	55.02			
UKRAINE.FRA	50.9		21	20
UKRAINE.UKA				
UKRAINE.NLD	50.9		21	20
NETHERLANDS.CAN	55.02			
NETHERLANDS.FRA		50.96	13.5	16
NETHERLANDS.UKA	50.9	91.4	21	20
NETHERLANDS.NLD		3.92	5	10

* CANADA, FRANCE, UKRAINE, NETHERLANDS are the primary production locations;
CAN, FRA, UKA, NLD are the ingredient preparation locations
www.railcan.ca

Table A9: Cost data

		NL	Canada	UKA	FRA
Cost of dry peas	€/MT	147	160	129	154
Energy	€ /MJ	0.0361	0.0069	0.0006	0.0083
Labour	€ /year/person	40462.4	24024	7884.8	42926.4
	€/year for 30 people	1,213,872	720,720	236,544	1,287,792
Equipment cost*	€	239,258	239,258	239,258	239,258

* equipment cost = 10% (total cost * fanning factor of 2)

Table A10: Primary production figures

		NL	Canada	UKA	FRA
Yield for dry peas	Kg/ha	4500	1672	1102	4406
Dry peas for 1 MT NPF	Kg (process B)	2041	2041	2041	2041
Land for 1MT NPF	ha	0.454	1.221	1.852	0.463
Exergy required for PP*	MJ/MT	3819.76	10280.46	15597.94	3901.25

Exergy = fuel for sowing, harvesting and other related activities and exergy of fertilizers and pesticides