WORKING PAPER
MANSHOLT GRADUATE SCHOOL

Design of a supply chain network for pea-based novel protein foods

Radhika K. Apaiah and Eligius M.T. Hendrix

DISCUSSION PAPER No. 13
2004

Mansholt Graduate School of Social Sciences

Hollandseweg 1, 6706 KN Wageningen,
The Netherlands
Phone: +31 317 48 41 26
Fax: +31 317 48 47 63
Internet: http://www.mansholt.wur.nl/
e-mail: office.mansholt@wur.nl

Working Papers are interim reports on work of Mansholt Graduate School of Social Sciences (MGS) and have received only limited reviews[1]. Each paper is refereed by one member of the Editorial Board and one member outside the board. Views or opinions expressed in them do not necessarily represent those of the Mansholt Graduate School.

The Mansholt Graduate School's researchers are based in three departments: 'Social Sciences', 'Environmental Sciences' and 'Agrotechnology and Food sciences' and two institutes: 'LEI, Agricultural Economics Research Institute' and 'Alterra, Research Institute for the Green World'. In total Mansholt Graduate School comprises about 250 researchers.

Mansholt Graduate School is specialised in social scientific analyses of the rural areas and the agri- and food chains. The Graduate School is known for its disciplinary and interdisciplinary work on theoretical and empirical issues concerning the transformation of agriculture, rural areas and chains towards multifunctionality and sustainability.

Comments on the Working Papers are welcome and should be addressed directly to the author(s).

Radhika K. Apaiah and Eligius M.T. Hendrix[a]

[a] Operations Research and Logistics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands.

[1] Working papers may have been submitted to other journals and have entered a journal's review process. Should the journal decide to publish the article the paper no longer will have the status of a Mansholt Working Paper and will be withdrawn from the Mansholt Graduate School's website. From then on a link will be made to the journal in question referring to the published work and its proper citation.

Design of a supply chain network for pea-based novel protein foods

Radhika K. Apaiah[*a] and Eligius M.T. Hendrix[b],
[a] Product Design and Quality Management Group, Department of Agrotechnology and Food Science, Wageningen University, P.O. Box 8129, 6700 EV Wageningen, The Netherlands
[b] Operations Research and Logistics Group. Department of Social Sciences, Wageningen University, P.O. Box 9101, 6700HB Wageningen, The Netherlands.

Abstract:
This paper presents an operations research technique that can be used for supply chain design and applies it to create a supply network with a goal to manufacture a pea-based NPF as cheaply as possible.
The current food production and consumption pattern has a strong impact on the environment and resources and is not sustainable. Meat production in particular is not appealing from an environmental point of view, because of the inefficient conversion of protein in the feed into protein in the slaughtered animal. Novel protein foods (NPFs) are non-meat protein ingredients that are designed to replace meat- based ingredients in meals. The non-meat protein products presently available do not meet the expectations of most consumers and cannot be considered as realistic alternatives to meat (www.profetas.nl). They are niche products and are expensive when compared to pork. The prospects for replacing meat-derived ingredients by NPFs are more promising. The partial shift from an animal based diet to a plant, specifically pea-based diet may be feasible only if the price of these products decreases.
A supply chain for NPFs can be divided into three major links: primary production (growing and harvesting), ingredient preparation (milling and concentration of pea protein) and product processing (manufacture of the NPF). The pea-based product is designed for the Dutch market. The peas are sourced from several locations around the world such as Canada, Ukraine, France and the Netherlands and are transported by sea, rail, road or barge. This paper presents a study on the optimisation of the supply network for NPFs in the Netherlands using linear programming. It focuses on finding the lowest cost at which NPFs can be manufactured for a specific market demand; while deciding the location of primary production, ingredient processing and product production areas and modes of transportation by minimising the sum of production and transportation costs.

Keywords: novel protein foods, supply chains, optimisation.

1. Introduction

Consumers today demand high-quality products in various innovative forms through the entire year at competitive prices. Society imposes constraints on producers in order to economise the use of resources, ensure animal friendly and safe production practices and restrict environmental damage. These demands, together with the technological developments and open markets have changed the production, trade and distribution (i.e. the supply chain) of food products beyond recognition (Trienekens and Omta, 2001).

A supply chain (SC) is an integrated process where raw materials are acquired, converted into products and then delivered to the consumer (Beamon, 1998). The chain is characterised by a forward flow of goods and a backward flow of information. Food supply chains are made up of organisations that are involved in the production and distribution of plant and animal-based products (Zuurbier *et al.*, 1996). Such SCs can be divided into two main types (van der Vorst, 2000):

- SCs for fresh agricultural products: the intrinsic characteristics of the product remain unchanged and,
- SCs for processed food products: agricultural products are used as raw materials to make processed products with a higher added value.

The main fact that differentiates food SCs from other chains is that there is a continuous change in quality from the time the raw materials leave the grower to the time the product reaches the consumer (Tijskens *et al.*, 2001). A food SC as defined in this paper consists of six links: primary production, ingredient preparation, product processing, distribution, retail and the consumer (Figure 1).

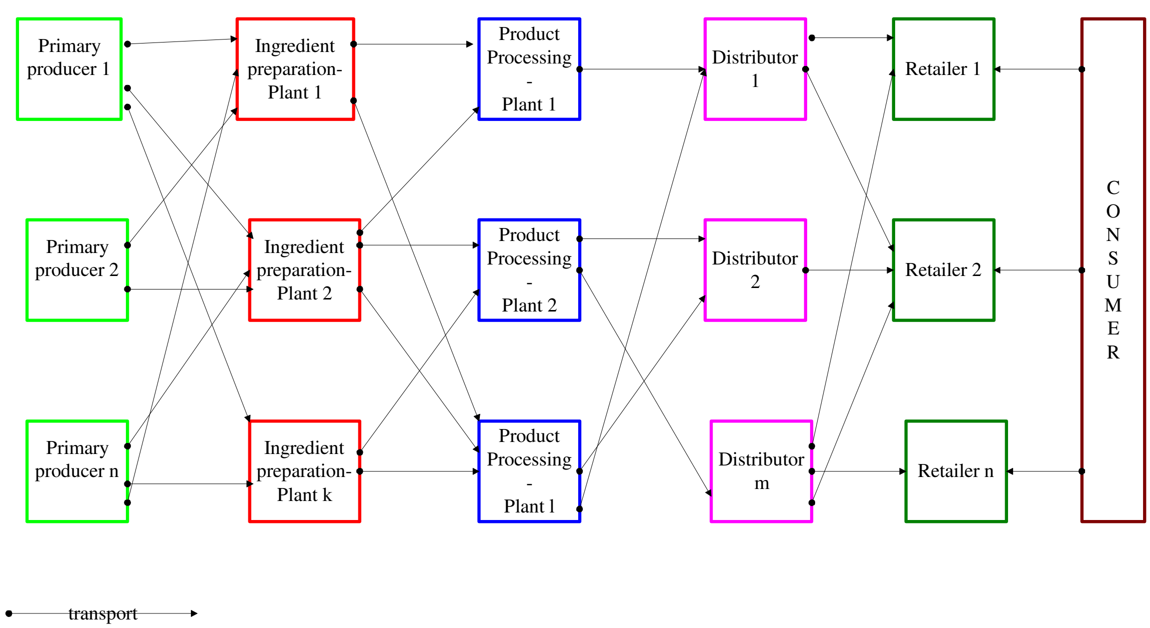

Figure 1: Food supply chain

Performance measures or goals are used to design SCs or supply networks by determining the values of the decision variables that yield the desired goals or performance levels (Beamon, 1998, Apaiah, *et al.*, 2003). The design of the chain or network changes with the goal for which the chain is being designed and optimised. As consumer demand has to be met, it is important to ask the consumer what attributes he/she desires in the product as these attributes are used to select the goals to design the chain, e.g. if the goal is quality at any cost, then technologically advanced and consequently expensive equipment can be used to produce the product and it can be transported to the consumer by air. However, if the goal is a low priced product, care has to be taken to minimise production and transportation costs.

PROFETAS is a research programme dedicated to making food production and consumption more sustainable (www.profetas.nl). The current food production and consumption pattern has a strong impact on the environment and resources and is not sustainable. Meat production in particular is not appealing from an environmental point of view, because of the inefficient conversion of protein in the feed into protein in the slaughtered animal. Novel protein foods (NPFs) are non-meat protein ingredients that are designed to replace meat- based ingredients in meals. The NPFs presently available do not meet the expectations of most consumers and thus cannot be considered realistic alternatives to meat. They are niche products and are expensive when compared to pork. The prospects for replacing meat-derived ingredients by NPFs are more promising. The partial shift from an animal based diet to a plant, specifically pea-based diet may be feasible only if the price of these products decreases. This paper considers an OR approach that can be applied to explore possible chain designs. The interesting question here is whether an NPF based on pea protein is feasible as a price-competitive product, when all essential cost sources are identified.

2. Case

NPFs based on pea proteins do not currently exist. The proposed product is designed to resemble the vegetarian mincemeat currently available. As mentioned earlier a supply chain consists of two basic processes: 1. Production planning; 2. Distribution and logistics planning (Beamon, 1998). In this study, this is modified as: 1. Production- this includes all the links from primary production to product processing and 2. Distribution- the remaining links. This paper focuses on the first process. The second process of distribution and logistics planning, similar to that of chilled meat products, has been much researched (Chopra, 2003; Jayaraman and Ross, 2003). Designing this part of the chain will not lead to a distinction between the costs of NPF and of the chilled meat Production planning for pea-based NPFs , is a new and unknown area. The aim is to generate scenarios that lead to low costs by designing supply chains with the aid of OR techniques.
The supply chain for the first process is divided into three major links: primary production (growing and harvesting), ingredient preparation (milling and concentration of pea protein) and product processing (manufacture of the NPF). The product is designed for the Dutch market. Figure 2 shows the production scheme for 1000 kg of the pea-based NPF. The peas are sourced from several locations around the world such as Canada, Ukraine, France and the Netherlands and can be transported by sea, rail, road or barge.

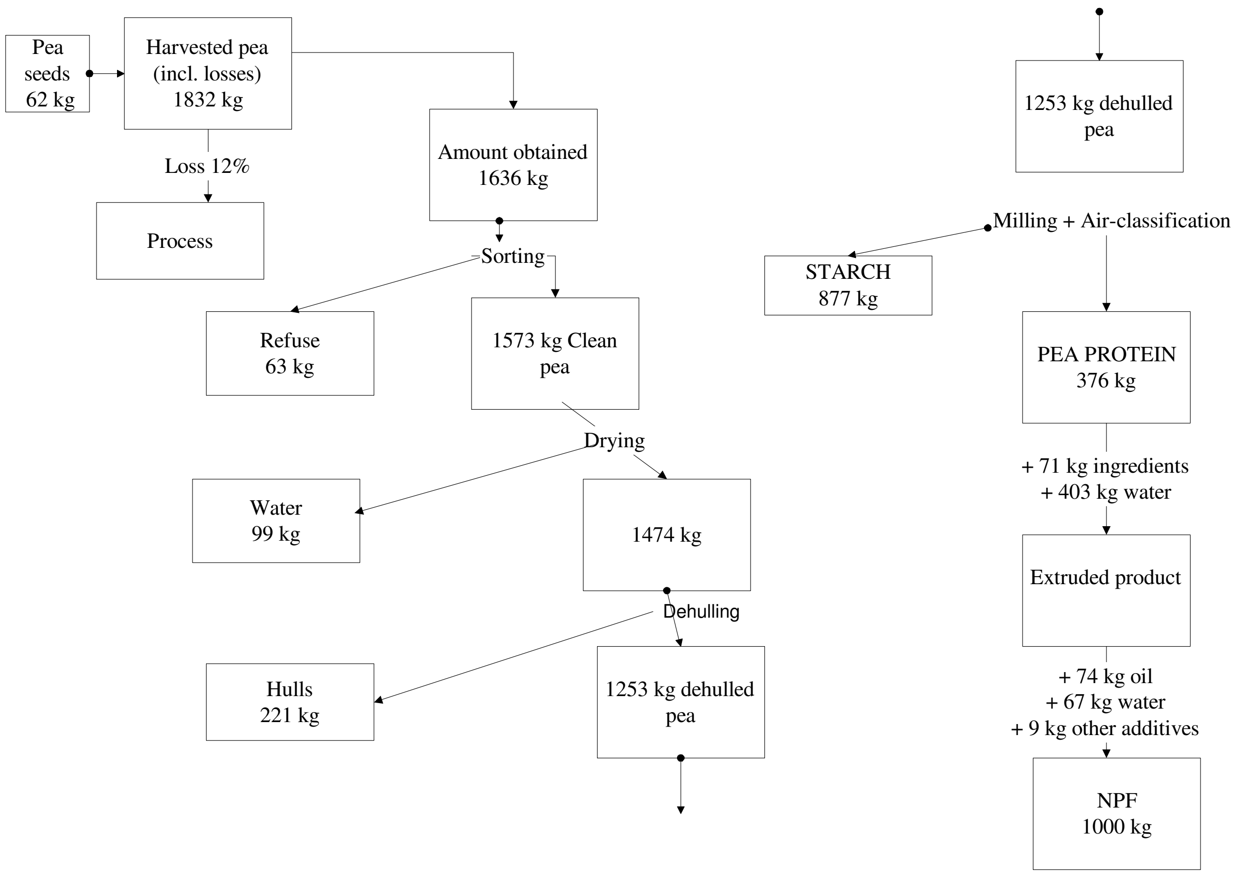

Figure 2: Production scheme for NPFs (1000kg basis)

Figure 3 illustrates the steps in each link of production. In primary production (PP) plant refuse is the main by-product. In ingredient preparation (ING), the hulls and starch are by-products. Starch comprises about 70% of the dehulled peas and therefore the selling price of the starch (starch is used as a raw material in many applications) is important in the overall cost of manufacture.

3. Model development

The following approach was developed in Apaiah *et al.* (2003). For a given product, goals and production possibilities are identified and the relationships between the performance indicators of the goals and the control variables are determined. The important relationships are identified. A quantitative model is then developed and optimisation approaches and sensitivity analysis are used to design the chain quantitatively.

The paper deals with a long-term exploratory question of the feasibility of pea-based NPFs and therefore considers possible flows and quantities of products, by-products, refuse and production schemes. This deviates from the usual set-up and locations decisions in similar logistics modelling that is used to support decisions for particular companies (Jayaraman and Ross, 2003; Wouda, *et al.* 2002). These typically lead to MILP type of models, whereas this paper considers a network flow, a linear programming approach from a long-term perspective.

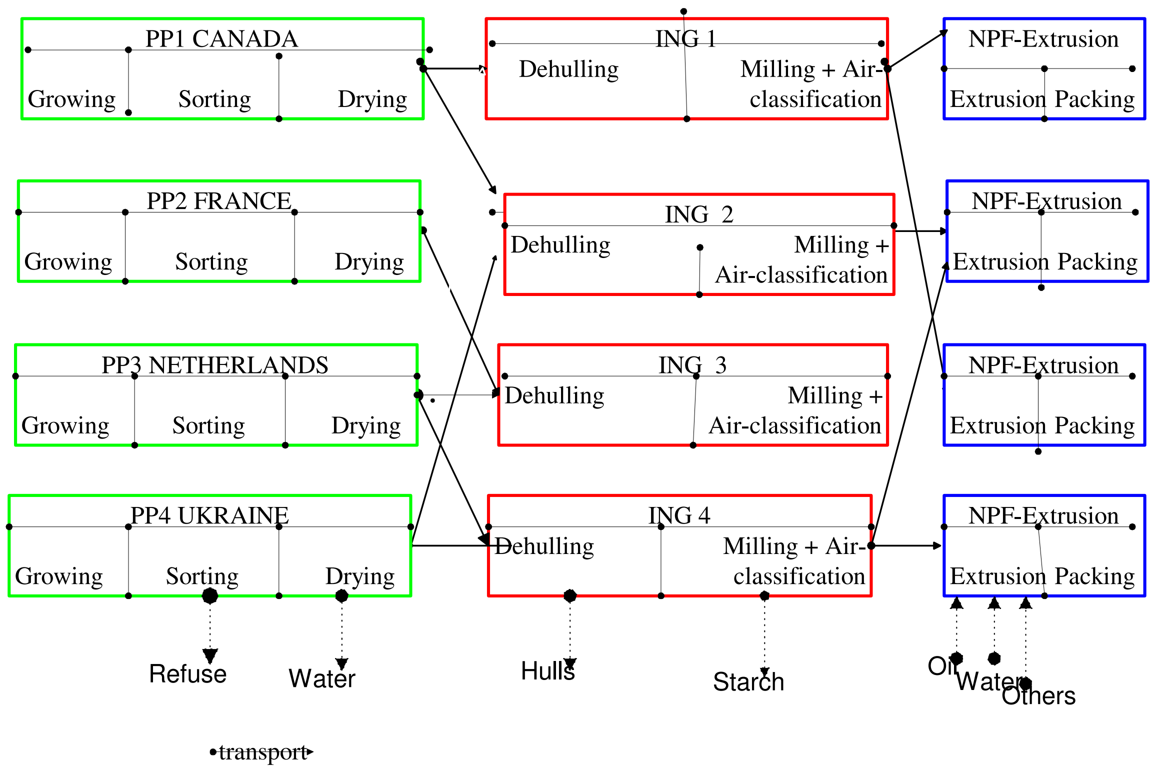

Figure 3: NPF production chain

3.1 The qualitative model.

According to the methodology presented in Apaiah *et al*. (2003), the relevant aspects to model the underlying supply chain are identified.

Product: A pea-based NPF resembling vegetarian mincemeat

Attribute (as specified by the consumer): An inexpensive product. This product is designed to replace pork meat. The retail price of pork is about €6/kg. The cost of manufacturing is about 38-40% of retail cost (www.ers.usda.com).

Goal: Minimise cost of manufacturing

Chain: An important boundary condition for these chains is that consumer demands should be met. The chains are therefore traced backwards, i.e. described from what the consumer wants back through to primary production. The links are: Consumer processing, Distribution/retailing, Product processing- Extrusion, Ingredient processing- milling and air classification, Primary production.

Performance indicator: Value added at each link

Control variables: In this supply chain design problem the following decision variables are considered.

Figure 4 shows the supply network with the associated variables.
PP_i = amount of pea produced at primary production location i
TPI_{ijn} = amount of dry pea transported from location i to facility j via transport mode n
ING_j = amount of ingredient, pea protein concentrate produced at facility j
TIP_{jkn} = amount of protein concentrate transported from facility j to facility k via transport mode n
NPF_k = amount of NPF produced at facility k
SA_j = amount of starch produced at facility j

Data to evaluate a specific supply chain design includes the following technical and cost coefficients:
wpc_i = Whole dried pea cost at location i, €/ton
$tcdp_{ijn}$ = Transportation cost of dried pea from PP location i to ING facility j via transport mode n, €/ton
ipc_j= Pea protein cost at facility j, €/ton
$tcpp_{jkn}$ = Transportation cost of protein concentrate from ING facility j to NPF production facility k, via transport mode n, €/ton
ppc_k= cost of producing the NPF at location k, €/ton
ss_j = Selling price of starch from facility j, €/ton
stpt = starch per ton of dehulled pea= 0.7, ton/ton
npfp = pea protein per ton NPF = 0.376, ton/ton
ppdp = pea protein per ton of dry transported pea = 0.255, ton/ton
pwp = percentage of dry pea from total pea produced = 0.805, ton/ton
demand = total amount of NPF put into the market = 30744, ton ;

Where:
i = index for PP location (i = 1,2,3……I)
j = index for ING production facility (j= 1,2,3…….J)
k = index for NPF production facility (k= 1,2,3…….K)
n = modes of transportation (n= sea, rail, road, barge)

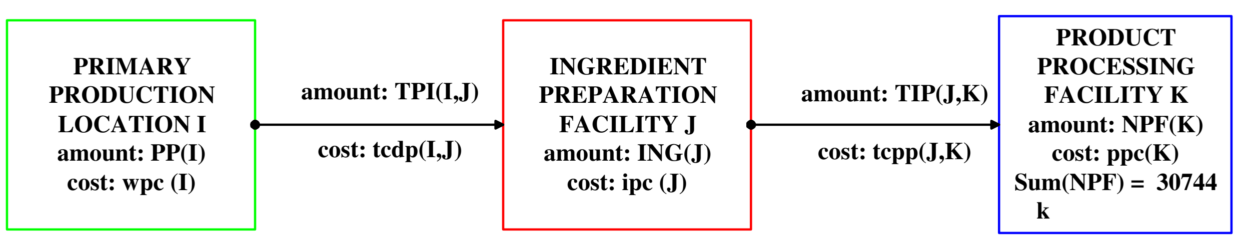

Figure 4: Supply network with associated variables and cost coefficients

The optimisation of the supply network for NPFs in the Netherlands is done using linear programming, similar to work done by Wouda *et al.* (2002). It focuses on finding the lowest cost at which NPFs can be manufactured for a specific market demand; while deciding the location of primary production, ingredient processing and product production areas and modes of transportation by minimising the sum of production and transportation costs (Appendix).
The market demand: as mentioned earlier, pea-based NPFs are not currently available. The cost of manufacturing a product depends largely on the quantity in question; the larger this amount, the more

will be the effect of economies of scale. The research program PROFETAS aims to replace 20% of processed pork consumption by the year 2020. An amount equal to 20% of the processed pork consumed in 2000 is used as the market demand for this exercise (30744 MT).

3.2 The quantitative model:

A quantitative linear programming model was formulated and implemented using the GAMS software (www.gams.com) to generate various scenarios. As mentioned earlier, the objective is to minimise the sum of the production and transportation costs. This is:

Minimise: $\sum_i wpc_i * PP_i + \sum_i \sum_j \sum_n tcdp_{ijn} * TPI_{ijn} + \sum_j ipc_j * ING_j + \sum_j \sum_k \sum_n tcpp_{jkn} * TIP_{jkn} +$

$$\sum_k ppc_k * NPF_k - \sum_j ss_j * SA_j$$

Constraints: The model has some constraints or restrictions for the supply of raw materials and ingredients and the demand of the final product.

1. The flow in the whole chain is demand driven. The amount of NPFs produced in all the locations should be equal to the demand.
   $\sum_k NPF_k = demand$

2. The amount of pea protein transported from all facilities j to facility k by all modes of transportation is equal to the amount of pea protein concentrate in the final NPF.
   $\sum_j \sum_n TIP_{jkn} = npfp * NPF_k$ for all k

3. The amount of pea protein transported from each facility j to all locations k cannot exceed the amount of concentrate produced in location j.
   $\sum_k \sum_n TIP_{jkn} \leq ING_j$ for all j

4. The amount of pea protein produced at facility j cannot exceed the amount of protein contained in the dry peas transported from all locations to facility j by all modes of transport.
   $ppdp * \sum_i \sum_n TPI_{ijn} \geq ING_j$ for all j

5. The amount of dry pea transported from all locations i to facility j cannot exceed the amount of peas grown in location i minus the harvest losses and refuse (expressed as a percentage of peas grown)
   $\sum_j \sum_n TPI_{ijn} \leq pwp * PP_i$ for all i

6. The amount of starch produced as a by-product at each facility j is equal to the percentage of starch in the dry peas transported from all locations to location j by all modes of transportation.
   $SA_j = stpt * \sum_i \sum_n TPI_{ijn}$ for all j

4. Data acquisition:

The model provides a systematic tool to identify the relevant information required to answer the question: how cheaply can this product be manufactured. This information, called the cost coefficients (defined in section 3.1) are:
wpc_i, $tcdp_{ijn}$, ipc_j, $tcpp_{jkn}$, ppc_k and ss_j.
The data was acquired after an extensive search that involved personal and telephonic interviews with experts and companies in the respective areas, internet searches and estimations based on the above.
In the model it is possible to specify as many areas/ countries as required to source/manufacture the products. For the purpose of this exercise, four countries were selected to give a diverse range of characteristics. They were: Netherlands (area of interest), France (a major grower of peas in western Europe), Ukraine (major grower in eastern Europe) and Canada (large grower in the Americas). Table 1 shows the primary production data for these countries. The coefficient wpc_i can be calculated from here.

As can be seen from Table 1, the yield and the areas under cultivation differ greatly between countries. However the average protein content of the peas is about 22 % and the quality of the peas is similar. It may appear from table 1 that the best option is to choose the country where the cheapest peas are available. However as costs integrate over the entire supply chain, this may not be the optimal strategy. There could be strategic reasons to obtain peas from various sources and to put a limit on the amount of peas from each country.

Table 1: Data for primary production information

	Total production, metric tonnes#	Total area, hectares#	Yield, MT/hectare	Export price, €/tonne*	Import price, €/tonne*
Netherlands	4000	800	5.0	473	147
France	1,700,000	334,119	5.088	154	231
Ukraine	746,800	540,007	1.383	129	337
Canada	1,492,600	719,071	2.076	160	401

* http://apps.fao.org; # www.statpub.com

The next information of interest is the transportation costs ($tcdp_{ijn}$) from the primary production locations to the protein production location. The details are summarised in table 2 (Personal communication 1). It was not possible to obtain costs for rail transport and in some cases for internal transport in certain countries. As a result these costs were not considered in the model. However they could be included later and lead to a reduction in total transportation costs.

The next coefficient is the cost to make the pea protein (ipc_j) at the different locations. The cost per ton of pea protein are summarised in figure 5 (web addresses 1)

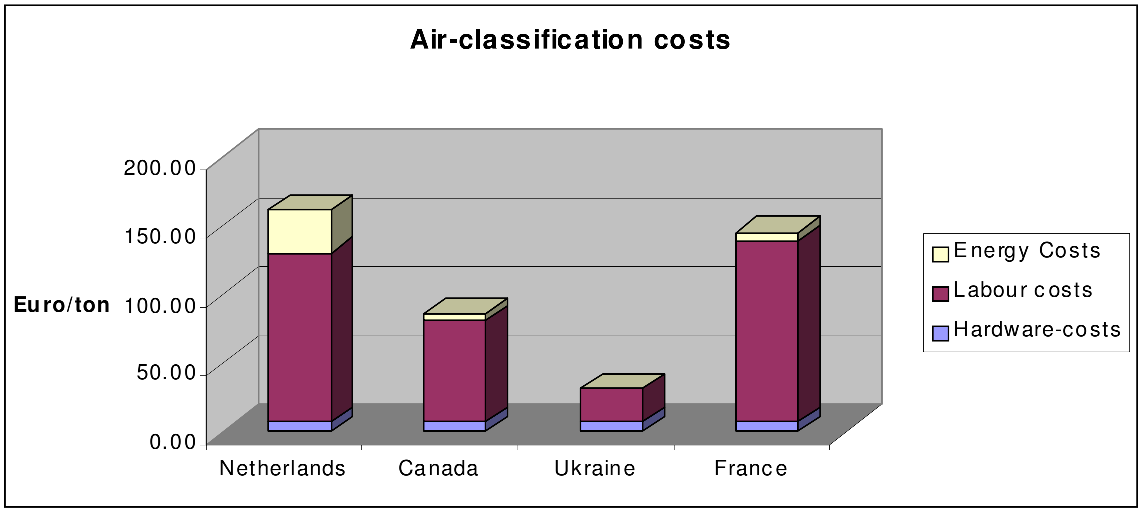

Figure 5: Production costs

The process of manufacturing pea protein involves dehulling, followed by milling and air-classification. Pea hulls and starch are by-products that are important because they have a high resale value: the cost of cereal starch is € 70/tonne and the price of pea hulls is € 108/tonne (raw fibre).

Table 2: Transport cost in € per ton

	sea	rail	barge	truck
CANADA.CAN *				
CANADA.FRA	55.02			
CANADA.UKA	55.02			
CANADA.NLD	55.02			
FRANCE.CAN	55.02			
FRANCE.FRA				
FRANCE.UKA	50.9		21	20
FRANCE.NLD			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			13.5	16
NETHERLANDS.UKA	50.9		21	20
NETHERLANDS.NLD			5	10

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

The fourth coefficient of interest is the transportation cost from the ingredient processing facilities to the NPF production locations ($tcpp_{jkn}$). The costs are the same as those in Table 2. However, in reality, there may be some differences if the locations lie further apart than assumed in the previous case. Moreover, in the model NPF production facilities were limited to the Netherlands and France because of the time it would take to transport the product from Canada or the Ukraine to the Netherlands. The cost of refrigerated transport was found to be so high that those options were not explored further.

The cost of manufacturing the NPF (ppc_k) in France and the Netherlands are estimated as being € 19.82 and € 17.84 per ton respectively (web addresses 1). The differences arise because of the higher energy costs in the Netherlands. The selling price of starch (ss_j) was calculated as a world average of € 70 per ton.

5. Scenarios

The model can be used to develop scenarios. The scenarios that arise depend on the constraints that are part of the model. The exploration was limited to two cases. In the first case, no additional capacity constraints were added and the optimisation reduces to a simple shortest path problem that identifies the cheapest supply chain in the network. In the second case, giving an upper limit for the primary production sources simulated the strategic consideration of obtaining peas from several sources.

Scenario 1: there are no constraints on the amount of pea that can be sourced in each primary production area. This therefore results in a single flow/chain with the model choosing the cheapest route through all the links. Figure 6 illustrates this chain. The optimal path is then to source the peas in the Ukraine, make the pea protein there and then transport it by truck to the Netherlands.

Figure 6: Scenario 1: Uncapacitated network

Scenario 2: Simple upper limit capacity constraints were used. The model specifies the amount of pea that can be sourced from each location. This is done to ensure a supply from all sources so as not to be dependent on only one country. The flow changes from a single chain to a network (Figure 7).

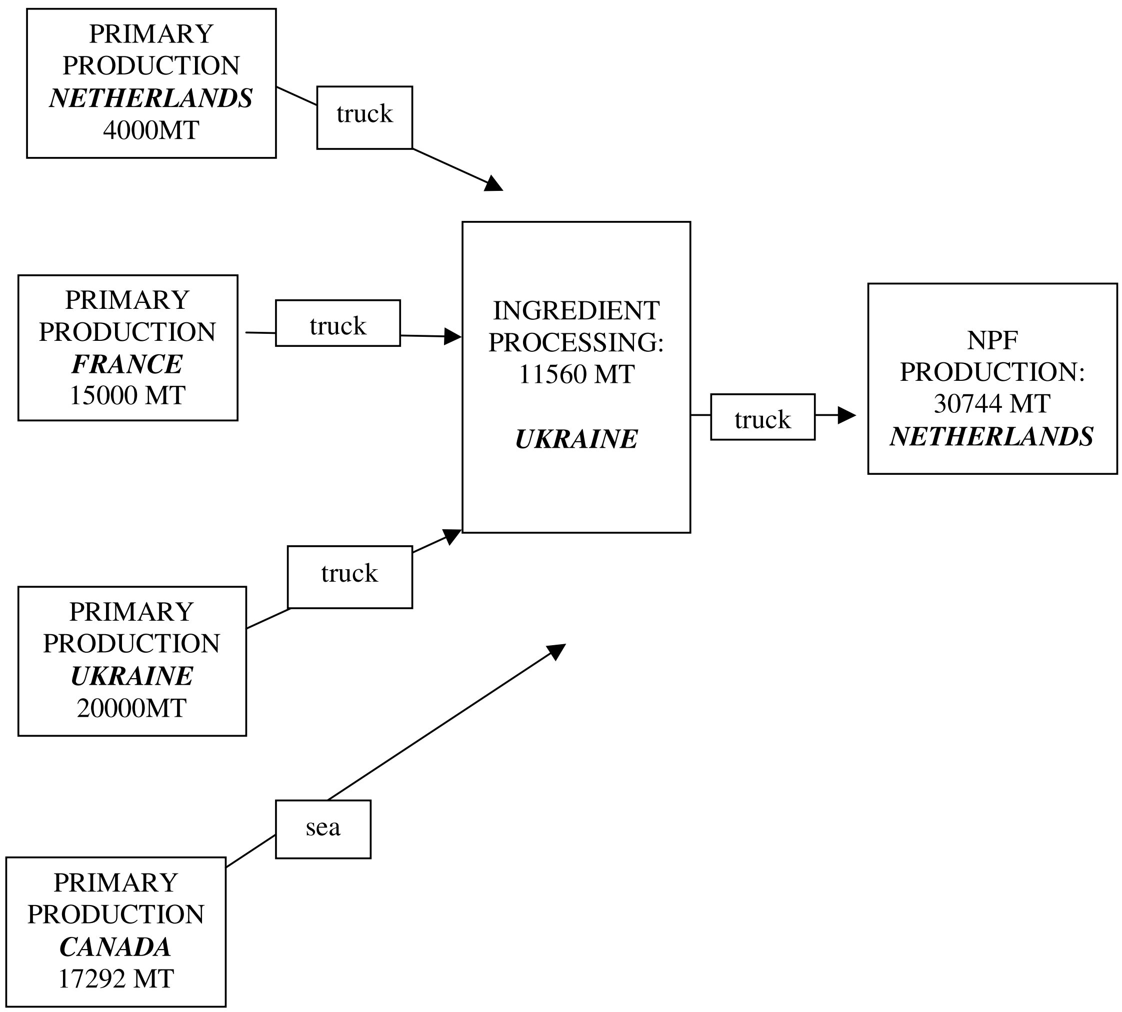

Figure 7: Scenario 2: Capacitated network

The final product is made in the Netherlands and the pea protein is made in the Ukraine. The model calculated that the optimal path is to source the peas in all the countries, transport them by various means to the Ukraine to be converted to pea protein and then transport the protein concentrate by truck to the Netherlands. The estimated costs apparently show that this is cheaper than setting up an additional processing facility in the Netherlands to process the pea sourced in the Netherlands.

Cost comparisons: Figure 8 illustrates the difference in total costs for the two scenarios. Scenario 1 has lower total costs (for the first part of the supply chain) and therefore a lower product cost. This is because there are no constraints on capacities and the model chooses the cheapest path of manufacture. Initial estimates show:

- Scenario 1: cost per ton of product = € 216/ton
- Scenario 2: cost per ton of product = € 273/ton

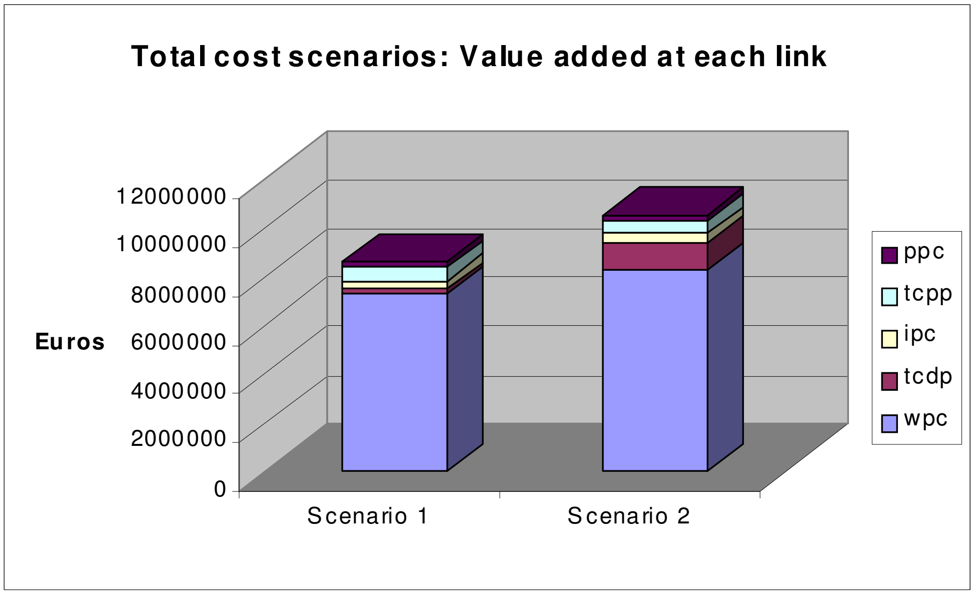

Figure 8: Cost comparison

The cost estimations are limited to that for the main ingredient, the pea and the concentrate made from the former. The procurement costs for the other ingredients like oil, functional ingredients, flavours are not considered here. However it is known from preliminary calculations, that the inclusion of these costs would still limit the production cost per ton of the product to below € 1000 euro. Further value is added with the inclusion of the costs of the second part of the supply chain – packaging, distribution and retail.

As mentioned earlier, NPFs are targeted to replace pork meat in the consumer's diet. The retail cost of pork meat is about € 6/kg and the cost to make pork meat is about 38-40 % of this value (www.ers.usda.com). It can be seen from above that the cost of manufacture of NPFs is much below this figure. This answers the question posed at the beginning of section 4- how cheaply can this product be manufactured.

6. Conclusions

This paper presents a systematic method to develop/design a supply network for a particular product with a specific design goal. The OR liner programming model is a tool that can be used to generate and evaluate different scenarios that are based on differing constraints. The model also provides a methodical way to collect relevant information

Acknowledgements

The authors would like to thank Joris Sprakel and Bas Toonen for all their help in data acquisition. They would also like to thank Dr. A.R. Linnemann and Dr. M.A.J.S van Boekel for their comments and suggestions.

References

1. Apaiah, R.K., Hendrix, E.M.T., Meerdink, G. and Linnemann, A. R. 2003. *A methodology for efficient food chain design I- Qualitative investigation of the goals of quality, cost and environmental load independently of each other.* Submitted to Trends in Food Science and Technology.
2. Beamon, B.M., *Supply chain design and analysis: Models and methods.* International journal of production economics, 1998. 55: p. 281-294.
3. Chopra, S., *Designing the distribution network in a supply chain.* Transportation Research Part E, 2003. 39: p. 123–140.
4. Jayaraman, V.A. and Ross, A. *A simulated annealing methodology to distribution network design and management.* European Journal of Operational Research, 2003. 144: p. 629–645.
5. Tijskens, L.M.M., Koster, A.C., Jonker, J.M.E. *Concepts of chain management and chain optimization*. Food Process Modeling, ed. L.M.M. Tijskens, Hertog, M.L.A.T.M., Nicolai, B.M. 2001: Woodhead.
6. Trienekens, J.H. and Omta, S.W.F. *Paradoxes in food chains and networks.* in *Proceedings of the Fifth International Conference on Chain and Network Management in Agribusiness and the Food Industry*. 2001. Noordwijk, The Netherlands.
7. Vorst, J.G.A.J., van der, *Effective food supply chains. Generating, modeling and evaluating supply chain scenarios.*. 2000, Wageningen University: Wageningen.
8. Wouda, F.H.E., Beek, P., van Vorst, J.G.A.J., van der, Heiko, T. *An application of mixed-integer linear programming models on the redesign of the supply network of Nutricia Dairy & drinks Group in Hungary.* OR Spectrum, 2002. 24: p. 449-465.
9. Zuurbier, P.J.P., Trienekens, J.H., Ziggers, G.W. *Verticale Samenwerking*. 1996, Deventer: Kluwer Bedrijfswetenschappen.

Personal communication 1

Product-agency Pulses, cereals and seeds, Netherlands
MSC Shipping Rotterdam, Netherlands
Shortsea, Netherlands
Vd Bosch, Erp, Netherlands
Vd Linde Rotterdam, Netherlands
Zijdehand Moerkappelle BV, Netherlands

Web addresses 1

www.fao.org
http://www.alberta-canada.com
http://www.euireland.ie
www.cbs.nl
www.nuon.nl
www.edf.fr

APPENDIX : GAMS Model formulation
Model 1: Uncapacitated
Sets
I primary production locations / CANADA, FRANCE, UKRAINE, NETHERLANDS /
J Ingredient preparation facilities / CAN, FRA, UKA, NLD /
K NPF production facilities / fran, neth /
N Modes of transportation / sea, rail, barge, truck / ;
PARAMETER
wpc (I) cost of production of dry pea at location I in euro per ton
/ CANADA 160, FRANCE 154, UKRAINE 129, NETHERLANDS 147 /
ipc (J) cost of making the pea protein ingredient at location J in euro per ton
/ CAN 86.7 , FRA 145.7, UKA 31.69, NLD 161.9 /
ss(J) selling price of starch in euro per ton
/ CAN 70 , FRA 70, UKA 70, NLD 70 /
ppc (K) cost of producing the NPF at location K in euro per ton
/ fran 19.82, neth 17.84 / ;

Table tcdp(I,J,N) transport cost in euro per ton

	sea	rail	barge	truck
CANADA.CAN				
CANADA.FRA	55.02			
CANADA.UKA	55.02			
CANADA.NLD	55.02			
FRANCE.CAN	55.02			
FRANCE.FRA				
FRANCE.UKA	50.9		21	20
FRANCE.NLD			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			13.5	16
NETHERLANDS.UKA	50.9		21	37.5
NETHERLANDS.NLD			5	10

Table tcpp (J,K,N) transport cost in euro per ton

	sea	rail	barge	truck
CAN.fran	55.02			
CAN.neth	55.02			
FRA. fran				
FRA. neth			13.5	16.0
UKA.fran	50.9		21	20
UKA.neth	50.9		21	20
NLD. fran			13.5	16
NLD. neth			5.0	10.0

Scalar
stpt starch per ton /0.7/
npfp pea protein per ton npf /0.376/
ppdp pea protein per ton of dry transported pea /0.255
pwp percentage of dry pea from total pea produced /0.805/
demand total amount of NPF put into the market /30744/;

```
 Variables
         PP(I)  amount of pea produced at primary production location i
        TPI(I,J,N)  amount of dehulled pea transported from location i to facility j
        ING(J)  amount of ingredient pea protein concentrate produced at facility j
        TIP(J,K,N) amount of pea protein concentrate transported from facility j to facility k
        NPF(K)  amount of NPF produced at facility k
        SA (J)  amount  of starch produced at J
        Z       total costs     ;
  Positive Variable PP, TPI, ING, TIP, NPF ;

Equations
      cost       define objective function
      supply(K)   observe supply limit at j
      demand   satisfy demand at market j
      sup(J)  supply from location j
      supl(I) supply from location I
      sta (J) starch limit
      deli(J) delivery to ingredient production                           ;

  cost ..  z  =E= sum(I,wpc (I)* PP(I)) + sum((I,J,N), tcdp(I,J,N)* TPI(I,J,N))+ sum(J,ipc (J)* ING(J))
+ sum((J,K,N),tcpp(J,K,N)* TIP(J,K,N))+ sum(K, ppc(K)* NPF(K)) - sum(J,ss(J)* SA(J))   ;

  supply(K) ..   sum((J,N)$(tcpp(J,K,N) gt 0), TIP(J,K,N))  =e= npfp* NPF(K) ;
  demand ..   sum(K, NPF(K))  =e= demand ;
  sup(J) ..    sum((K,N)$(tcpp(J,K,N) gt 0), TIP(J,K,N))=l= ING(J) ;
  deli(J)..           ppdp*sum((I,N)$(tcdp(I,J,N) gt 0), TPI(I,J,N))=g= ING(J) ;
  supl (I) ..  sum ((J,N)$(tcdp(I,J,N) gt 0), TPI(I,J,N))=l= pwp* PP(I);
  sta(J) ..   SA(J)=e= stpt* sum ((I,N)$(tcdp(I,J,N) gt 0), TPI(I,J,N));

  Model model1 /all/ ;
  Solve model1 using lp minimizing z ;
  Display  PP.l,  pp.m,TPI.L,  TPI.M,  ING.L,  ING.M,  TIP.L,  TIP.L,  NPF.L,  NPF.M  ;Capacitated
model:
```

Model 2: Capacitated

The capacitated model is similar to the uncapacitated model. The capacity constraints added are for the primary production of peas.

The extra parameter is:

```
 PARAMETER
 ppu (I) upper limit for primary production in tons
/ CANADA       20000, FRANCE       15000, UKRAINE      20000, NETHERLANDS    4000   /  ;
```

The upperbound for the production is also declared as a positive variable.

```
  Positive Variable PP, TPI, ING, TIP, NPF ;
                        PP.UP(I) = ppu(I) ;
```