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Formula Optimization and LCF: Lessons from the Meat Industry

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What is a Formula?

- Expression that describes
  1. Resources (raw materials and ingredients) necessary to manufacture a desired product
  2. Levels in which these are combined, or allocated
  3. Rules, or constraints, that place restrictions on how resources are allocated, in response to *variable inputs,* such as
     - Raw material cost and availability
     - Raw material and/or ingredient chemical and physical attributes
     - Manufacturing asset availability
- Not a *recipe*
- Can be aided by *Linear Programming*, or *Optimization (*a.k.a., *Least Cost Formulation, Least Cost Optimization*)

Least Cost Linear Programming (LCLP) Defined

- What is it?
  - A mathematical method to allocate limited resources (decision variables) in a way that *optimizes* a linear objective function (e.g., cost) while meeting a given a set of linear equality and inequality constraints
- What is it used for?
  - To arrive at the formula, or combination of formulas, that represents the most economical (i.e., least cost) allocation of raw materials and ingredients and results in a consistent-quality product
- Who uses it?
  - Meat, cheese, ice cream, animal feed industries, among others

Advantages of Least Cost Formulation

- Results in most economical allocation possible of RMs
  - Can result in savings of 1–3% of cost of raw materials
- Yields predictable and consistent finished product quality
- Helps optimize RM utilization and inventory levels
- Saves time over more traditional formulation methods

Basic Elements of a LCF LP Model

- Parameters (Inputs)
  - Fixed, uncontrollable values (i.e., constants) inherent to each variable, e.g., RM/ingredient composition, prices, volumes, etc.
  - Change in parameters changes model assumptions and requires it to be re-run
  - Precision of model is directly related to completeness and accuracy of parameter data

Basic Elements of a LCF LP Model, cont.

- Constraints
  - Mathematical expressions that place restrictions on the values that decision variables (and, hence, the solution) may take
  - Expressed as equalities (=, ≤, ≥) or inequalities (≠)
  - Define the "space" or "boundaries" of the model
  - Provide flexibility for the LP model to reach its optimal solution
  - Must be loose enough to allow for feasible solutions and not so tight that acceptable solutions are ruled out
  - Critical to ensure product quality is consistent regardless of raw materials used
  - Quality of constraints determine accuracy and usefulness of LP model
  - Development of good constraints requires good understanding of RM/ingredient functional properties and desired product composition

Basic Elements of a LCF LP Model, cont.

- Objective function
  - Value to be optimized (maximized or minimized)
  - There can be only <u>one</u> per model
  - In LCF, objective is to minimize *formula cost*

Basic Elements of a LCF LP Model, cont.

- Decision (or *problem*) variables
  - Values determined by LP model
  - Values define:
    - Amounts or usage levels (i.e., allocation) of resources (raw materials (RMs)/ingredients)

      → The "Formula"
    - Product chemical and nutritional composition
    - Product physical attributes (color, texture)

Basic Elements of a LCF LP Model, cont.

- Solution (Output)
  - *Feasible solution*
    - Set of values for decision variables that satisfies all constraints
    - There may be multiple feasible solutions
  - *Optimal solution*
    - Feasible solution where the objective function is optimized
    - In most cases there can be only one

Mathematical Description of an LP Model

Calculation	Mathematical Notation
Linear function	$f(x_1,x_2,\ldots,x_n) = a_1 x_1 + a_2 x_2 + \ldots + a_n x_n = \sum_{i=1}^{n} a_i x_i$
Objective function	$f(x_1,x_2,\ldots,x_n) = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n = \sum_{i=1}^{n} c_i x_i$
Linear constraints	$\left\{ \begin{matrix} a_{11} x_1 + a_{12} x_2 + \ldots + a_{1j} x_n \leq b_1 \\ a_{21} x_1 + a_{22} x_2 + \ldots + a_{2j} x_n \leq b_2 \\ a_{31} x_1 + a_{32} x_2 + \ldots + a_{1j} x_n \leq b_3 \end{matrix} \right\} \sum_{i=1}^{n} a_{ji} x_i \leq b_j \quad j = 1,2,\ldots,m$

x: problem variable (e.g., RM/ingredient use level)

a: parameter (e.g., RM/ingredient composition)

c: objective (e.g., RM/ingredient price)

b: constraint value

Assumptions of LP Models

- Linearity of functions
  - Proportionality
    - Contribution of any decision variable to objective function is proportional to its value
  - Additivity
    - Contribution of any decision value to objective function is independent of other decision variables
- Certainty
  - All constants, objective function and constraint coefficients are known with absolute certainty and will not change

LP Example Calculations

- Constraints

  Shear Stress = 38.0 – 50.0; Shear Strain ≥ 2.30; Whiteness ≥ 75.0

- Objective Function: minimize blend cost

- Parameters

Raw material	Price/lb	Shear Stress	Shear Strain	Whiteness
Surimi A	$0.95	64.5	2.65	75.5
Surimi B	$0.80	28.2	0.93	81.0
Surimi C	$1.05	52.5	2.75	78.0

- Linear Functions

  Cost/lb = $0.95 (% Surimi A) + $0.80 (% Surimi B) + $1.05 (% Surimi C)

  Shear Stress = 64.5 (% Surimi A) + 28.2 (% Surimi B) + 52.5 (% Surimi C)

  Shear Strain = 2.65 (% Surimi A) + 0.93 (% Surimi B) + 2.75 (% Surimi C)

  Whiteness = 75.5 (% Surimi A) + 81.0 (% Surimi B) + 78.0 (% Surimi C)

Surimi LP Example Model

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	
Surimi A	
Surimi B	
Surimi C	
Surimi D	
Surimi E	
Surimi F	
Surimi G	
Surimi H	
Surimi I	
Surimi J	
Blend Total	

Surimi LP Example Model

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	Price ($/lb)	Protein (%)	Moisture (%)	Fat (%)	Shear Stress (kPa)	Shear Strain	Whiteness (L*-3b*)	Purity
Surimi A	0.95	15.0	76.0	0.9	64.5	2.65	75.5	8
Surimi B	0.80	15.0	76.0	0.9	28.2	0.93	81.0	9
Surimi C	1.05	15.0	76.0	0.9	52.5	2.75	78.0	7
Surimi D	0.75	15.0	76.0	0.9	23.5	0.85	67.0	8
Surimi E	1.15	15.0	76.0	0.9	39.0	2.85	75.0	8
Surimi F	1.10	15.0	76.0	0.9	43.0	2.75	82.0	8
Surimi G	0.75	15.0	76.0	0.9	24.0	1.80	65.0	0
Surimi H	0.58	15.0	76.0	0.9	25.0	0.90	53.0	8
Surimi I	1.50	15.0	76.0	0.9	50.0	2.60	57.0	8
Surimi J	1.05	15.0	76.0	0.9	50.0	2.55	62.0	9
Blend Total								

Parameters

Surimi LP Example Model

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	Price ($/lb)	Min (%)	Max (%)	Protein (%)	Moisture (%)	Fat (%)	Shear Stress (kPa)	Shear Strain	Whiteness (L*-3b*)	Purity
Surimi A	0.95	0.0	100.0	15.0	76.0	0.9	64.5	2.65	75.5	8
Surimi B	0.80	0.0	100.0	15.0	76.0	0.9	28.2	0.93	81.0	9
Surimi C	1.05	0.0	100.0	15.0	76.0	0.9	52.5	2.75	78.0	7
Surimi D	0.75	0.0	100.0	15.0	76.0	0.9	23.5	0.85	67.0	8
Surimi E	1.15	0.0	100.0	15.0	76.0	0.9	39.0	2.85	75.0	8
Surimi F	1.10	0.0	100.0	15.0	76.0	0.9	43.0	2.75	82.0	8
Surimi G	0.75	0.0	100.0	15.0	76.0	0.9	24.0	1.80	65.0	0
Surimi H	0.58	0.0	100.0	15.0	76.0	0.9	25.0	0.90	53.0	8
Surimi I	1.50	0.0	100.0	15.0	76.0	0.9	50.0	2.60	57.0	8
Surimi J	1.05	0.0	100.0	15.0	76.0	0.9	50.0	2.55	62.0	9
Blend Total										

=

		Protein	Moisture	Fat	Shear Stress	Shear Strain	Whiteness	Purity
		>=	>=	>=	>=	>=	>=	>=
Minimum	Target	0.0	0.0	0.0	38.0	2.30	75.0	7.5
		<=	<=	<=	<=	<=	<=	<=
Maximum	Target	100.0	100.0	100.0	50.0	100.0	100.0	10.0

Constraints

Surimi LP Example Model

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	Price ($/lb)	Optimal Blend	Min (%)	Max (%)	Protein (%)	Moisture (%)	Fat (%)	Shear Stress (kPa)	Shear Strain	Whiteness (L*-3b*)	Purity
Surimi A	0.95		0.0	100.0	15.0	76.0	0.9	64.5	2.65	75.5	8
Surimi B	0.80		0.0	100.0	15.0	76.0	0.9	28.2	0.93	81.0	9
Surimi C	1.05		0.0	100.0	15.0	76.0	0.9	52.5	2.75	78.0	7
Surimi D	0.75		0.0	100.0	15.0	76.0	0.9	23.5	0.85	67.0	8
Surimi E	1.15		0.0	100.0	15.0	76.0	0.9	39.0	2.85	75.0	8
Surimi F	1.10		0.0	100.0	15.0	76.0	0.9	43.0	2.75	82.0	8
Surimi G	0.75		0.0	100.0	15.0	76.0	0.9	24.0	1.80	65.0	0
Surimi H	0.58		0.0	100.0	15.0	76.0	0.9	25.0	0.90	53.0	8
Surimi I	1.50		0.0	100.0	15.0	76.0	0.9	50.0	2.60	57.0	8
Surimi J	1.05		0.0	100.0	15.0	76.0	0.9	50.0	2.55	62.0	9
Blend Total											
		=									

		Protein	Moisture	Fat	Shear Stress	Shear Strain	Whiteness	Purity
		>=	>=	>=	>=	>=	>=	>=
Minimum	Target	0.0	0.0	0.0	38.0	2.30	75.0	7.5
		<=	<=	<=	<=	<=	<=	<=
Maximum	Target	100.0	100.0	100.0	50.0	100.0	100.0	10.0

Objective Function

Surimi LP Example Model

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	Price ($/lb)	Optimal Blend	Dual Value	Min (%)	Max (%)	Protein (%)	Moisture (%)	Fat (%)	Shear Stress (kPa)	Shear Strain	Whiteness (L*-3b*)	Purity
Surimi A	0.95		0.00	0.0	100.0	15.0	76.0	0.9	64.5	2.65	75.5	8
Surimi B	0.80		0.00	0.0	100.0	15.0	76.0	0.9	28.2	0.93	81.0	9
Surimi C	1.05		0.03	0.0	100.0	15.0	76.0	0.9	52.5	2.75	78.0	7
Surimi D	0.75		0.07	0.0	100.0	15.0	76.0	0.9	23.5	0.85	67.0	8
Surimi E	1.15		0.07	0.0	100.0	15.0	76.0	0.9	39.0	2.85	75.0	8
Surimi F	1.10		0.00	0.0	100.0	15.0	76.0	0.9	43.0	2.75	82.0	8
Surimi G	0.75		0.00	0.0	100.0	15.0	76.0	0.9	24.0	1.80	65.0	0
Surimi H	0.58		0.00	0.0	100.0	15.0	76.0	0.9	25.0	0.90	53.0	8
Surimi I	1.50		0.65	0.0	100.0	15.0	76.0	0.9	50.0	2.60	57.0	8
Surimi J	1.05		0.16	0.0	100.0	15.0	76.0	0.9	50.0	2.55	62.0	9
Blend Total		**100.00%**	-	-	-							
		=										

		Protein	Moisture	Fat	Shear Stress	Shear Strain	Whiteness	Purity
		>=	>=	>=	>=	>=	>=	>=
Minimum	Target	0.0	0.0	0.0	38.0	2.30	75.0	7.5
	Dual Value	$0.00	$0.00	$0.00	$0.00	($0.20)	($0.01)	($0.01)
		<=	<=	<=	<=	<=	<=	<=
Maximum	Target	100.0	100.0	100.0	50.0	100.0	100.0	10.0
	Dual Value	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Decision Variables

Surimi LP Example Model - Solved

OTHER WHITE MEAT Surimi Company

Surimi Blending Sheet

Surimis ↓	Price ($/lb)	Optimal Blend	Dual Value	Min (%)	Max (%)	Protein (%)	Moisture (%)	Fat (%)	Shear Stress (kPa)	Shear Strain	Whiteness (L*-3b*)	Purity
Surimi A	0.95	**52.54%**	0.00	0.0	100.0	15.0	76.0	0.9	64.5	2.65	75.5	8
Surimi B	0.80	**10.16%**	0.00	0.0	100.0	15.0	76.0	0.9	28.2	0.93	81.0	9
Surimi C	1.05		0.03	0.0	100.0	15.0	76.0	0.9	52.5	2.75	78.0	7
Surimi D	0.75		0.07	0.0	100.0	15.0	76.0	0.9	23.5	0.85	67.0	8
Surimi E	1.15		0.07	0.0	100.0	15.0	76.0	0.9	39.0	2.85	75.0	8
Surimi F	1.10	**22.18%**	0.00	0.0	100.0	15.0	76.0	0.9	43.0	2.75	82.0	8
Surimi G	0.75	**7.52%**	0.00	0.0	100.0	15.0	76.0	0.9	24.0	1.80	65.0	0
Surimi H	0.58	**7.60%**	0.00	0.0	100.0	15.0	76.0	0.9	25.0	0.90	53.0	8
Surimi I	1.50		0.65	0.0	100.0	15.0	76.0	0.9	50.0	2.60	57.0	8
Surimi J	1.05		0.16	0.0	100.0	15.0	76.0	0.9	50.0	2.55	62.0	9
Blend Total	0.925	**100.00%**	-	-	-	15.0	76.0	0.9	50.00	2.30	75.0	7.5
		=										

		Protein	Moisture	Fat	Shear Stress	Shear Strain	Whiteness	Purity
		>=	>=	>=	>=	=>=	=>=	=>=
Minimum	Target	0.0	0.0	0.0	38.0	2.30	75.0	7.5
	Dual Value	$0.00	$0.00	$0.00	$0.00	($0.20)	($0.01)	($0.01)
		<=	<=	<=	=<=	<=	<=	<=
Maximum	Target	100.0	100.0	100.0	50.0	100.0	100.0	10.0
	Dual Value	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Parameters | Constraints | Decision Variables | Objective Function

Key Elements of a Formulation LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Standard formula(s) • Raw material inventory • Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, shear stress, shear strain) • Raw material prices • Yield factors	• Batch sizes • Raw material/ingredient constraints – Surimi (e.g., species, nonfish protein, fresh vs. frozen) – Restricted ingredients • Product constraints – Chemical composition: moisture, fat, protein, sodium, salt, etc. – Physical attribute values (e.g., color, shear stress, shear strain) • Regulatory/standard of identity constraints	• Optimal Formula(s) – Batch sheets or batch recipes • Formula (least) cost • Finished product attributes – Chemical composition – Physical attribute values (e.g., color, bind) – Nutritional information

When to use LCF in the Business Cycle

- Production Planning
  - To optimize purchasing decisions based on formula and production requirements, and raw material pricing and availability
  - Most impactful stage at which to use LCF, since it is the point at which raw material costs are truly controlled
- Production Scheduling
  - To optimize allocation of existing inventories and guarantee formula targets are met for consistent quality
  - Limited usefulness in terms of cost control, but still valuable
- Batch Adjustments
  - To correct deviations from formula targets caused by compositional variations in raw materials in-hand
  - Little to no value in terms of controlling costs

Commercial LCF Software Suppliers*

- Sunsphere Software (Optimal)
- Least Cost Formulations, Ltd. (Least Cost Formulator)
- Owl Software (TechWizard)
- Arrow Scientific (ROI Formulation System)

* Not an exhaustive list

Thank You