January 29, 2013

Formulation and Reformulation of Processed Meat Products

Rodrigo Tarté, Ph.D., *Iowa State University*

Formulation and Reformulation of Processed Meat Products

Rodrigo Tarté, Ph.D.

Director, Research & Development

John Morrell Food Group

Lisle, Illinois, USA

Meat and Poultry Processing: A Global Perspective

Atlanta, GA | 29 January 2013

Disclaimers

The contents of this document, and the opinions expressed therein, represent the professional opinions of the author, and not necessarily those of the John Morrell Food Group, its employees or subsidiaries.

The contents of this document are provided for informational purposes only. The author assumes no liability in connection with results that may arise from reliance on this information.

Outline

I. *Formulation* Defined

II. Formula Optimization

III. Formulation in Product Development

IV. Formulation in Manufacturing

V. Reformulation

I. *Formulation* Defined

What is a Formula?

- Expression that describes
  1. The ***resources (raw materials and ingredients)*** necessary to manufacture a desired product
  2. The ***proportions*** in which these are combined, or allocated
  3. The ***rules*** that place restrictions on how resources are allocated, in response to *variable inputs* (e.g., raw material cost and availability, manufacturing asset availability)
- Although sometimes incorrectly referred to as a *recipe*, it differs in that a recipe specifies exact usage quantities which never change (ever wonder why the cookies don't bake the same every time?).

What is *Formulation*?

- *Formula development*

  The series of tasks involved in the creation of a formula ("standard" formula) as part of the product development process.

- *Production*

  The process by which a standard formula is converted into an actual "production" formula, or batch recipe.

- Both can be aided by *Linear Programming*, or *Optimization* (a.k.a., *Least Cost Formulation, Least Cost Optimization*)

II. Formula Optimization

Linear Programming Defined

- Definition
  - 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.
  - Because linear models can involve a very large number of calculations, their solution relies on the use of optimization computer software.
- Formula Optimization Objective
  - To arrive at <u>the</u> formula that represents the most economical (i.e., least cost) allocation of raw materials and ingredients that meets all formula design requirements, i.e., the least cost formula (LCF)

Basic Elements of an LP Model

- Objective function
  - Value to be optimized (maximized or minimized)
  - Mathematically represented as $c_1, c_2, c_3, \ldots, c_n$
  - In most food formulation models the objective function is *formula cost*, and the objective is to *minimize* it, hence the term *least cost formulation*
- Decision (or *problem*) variables
  - Values to be determined by LP problem as it seeks to optimize the objective function (i.e., minimize cost)
  - Represent amounts or usage levels (i.e., allocation) of resources, (e.g., RMs/ingredients), product chemical and nutritional composition, and other calculated values, such as regulated values (e.g., added water, PFF, etc.)
  - Mathematically represented as $x_1, x_2, x_3, \ldots, x_n$

Basic Elements of an LP Model

- Parameters (Inputs)
  - Fixed, uncontrollable values (i.e., constants) inherent to each variable, e.g., RM/ingredient composition, prices, etc.
  - A change in parameters changes the assumptions of the model and requires it to be re-run
  - Precision of model's solution is directly related to completeness and accuracy of parameter data
  - Mathematically represented as $a_1, a_2, a_3, \ldots, a_n$
- Constraints
  - Mathematical expressions that place restrictions on the values that decision variables (and, hence, the solution) may take
  - Expressed as equalities (=, ≤, ≥) or inequalities (≠)
  - Constraints used during formula development are <u>not</u> the same as the *rules* of a standard formula, although the rules are mathematical constraints

Basic Elements of an LP Model

- Solution (Output)
  - *Feasible solution*
    - Set of values for decision variables that satisfies all constraints
    - There may be many of these sets of values and, hence, multiple feasible solutions
  - *Optimal solution*
    - Feasible solution where the objective function is optimized
    - In the vast majority of 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	$\left\{ \begin{array}{l} a_{11} x_1 + a_{12} x_2 + \ldots + a_{1j} x_n \leq b_1 \\ a_{21} x_1 + a_{22} x_2 + \ldots + a_{2j} x_n \leq b_2 \\ a_{31} x_1 + a_{32} x_2 + \ldots + a_{1j} x_n \leq b_3 \end{array} \right\} \quad \sum_{i=1}^{n} a_{ji} x_i \leq b_j \quad j = 1,2,\ldots,m$

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

Simplistic Example of an LP Model

- Constraints

  Total Fat = 28–30% (28% ≤ Fat ≤ 30%); Moisture ≤ 56%; Protein ≥ 11.5%

- Objective Function: minimize cost
- Parameters

Raw material	Price /lb	Fat, %	Moisture, %	Protein, %
Beef 90 Trim	$2.15	10.0	69.5	20.0
Beef 85 Trim	$1.90	15.0	65.7	18.6
Beef 50 Trim	$0.80	50.0	35.6	13.7

- Linear Functions

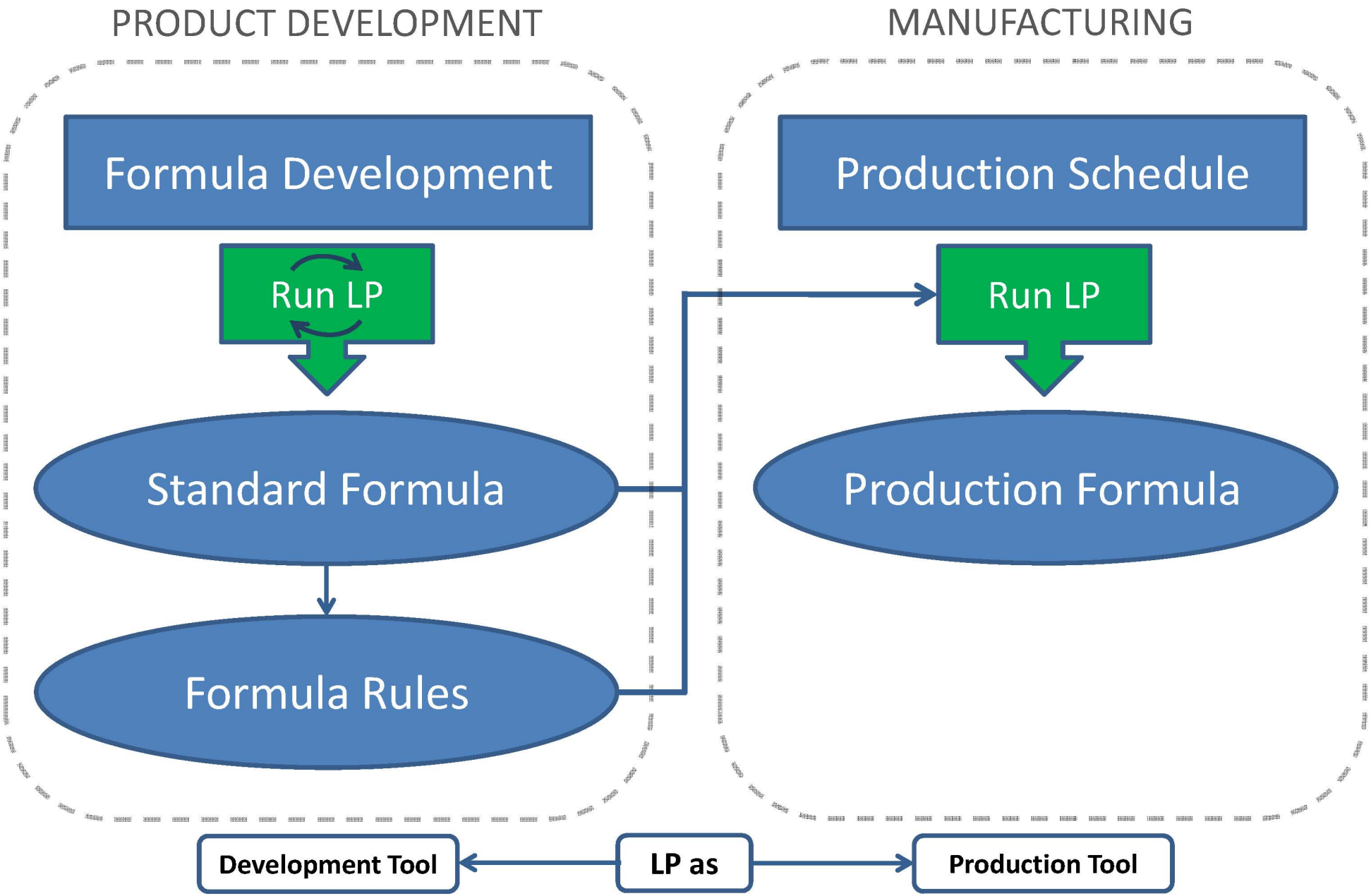
C = $2.15/lb (% Beef 90) + $1.90/lb (% Beef 85) + $0.80/lb (% Beef 50)

F = 0.100 (% Beef 90) + 0.150 (% Beef 85) + 0.500 (% Beef 50)

M = 0.695 (% Beef 90) + 0.657 (% Beef 85) + 0.356 (% Beef 50)

P = 0.200 (% Beef 90) + 0.186 (% Beef 85) + 0.137 (% Beef 50)

Role of Linear Programming in Formula Optimization



Key Characteristics of Formulation Linear Programs

	Product Development	Manufacturing
Inputs	• Product design requirements	• Master production schedule • Production volumes • Standard formula(s) • Formula rules • Yield factors • Raw material prices • Raw material inventory
Outputs	• Standard formula • Formula rules	• Production formula, or recipe (batch sheet)
Type of Model	• Single formula	• Composite formula • Multi-formula • Multi-site
Responsible Function	• R&D	• Production Scheduling or Operations, and/or Purchasing
Frequency	• Unspecified; based on product development needs	• As specified by production planning cycle; generally weekly

Advantages of Least Cost Formulation

Product Development	Manufacturing

Advantages of Least Cost Formulation

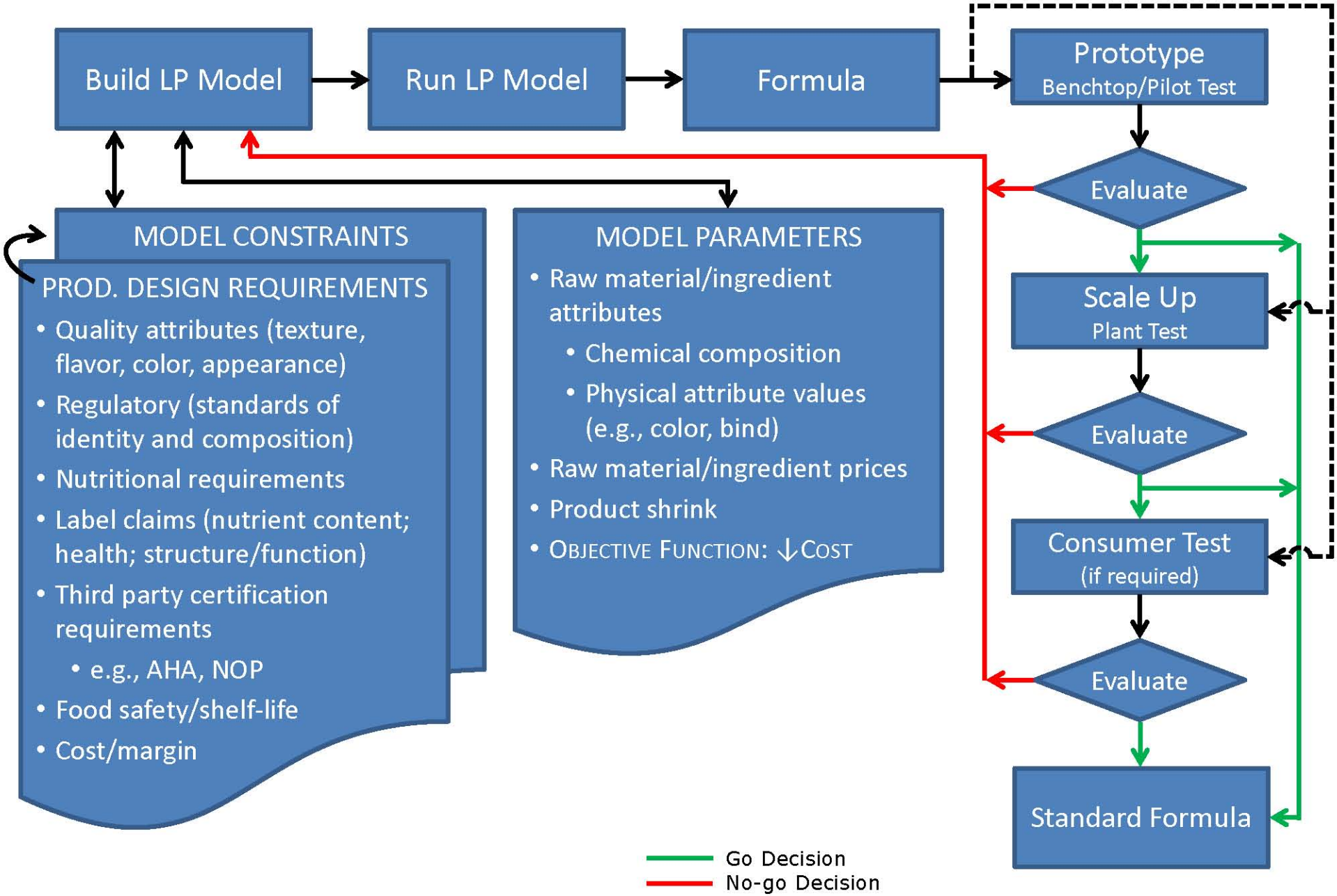
Product Development	Manufacturing
• Permits rapid generation of multiple "what if" scenarios, which helps: - shorten development time - develop deeper and more thorough knowledge and understanding of formula and product - make more efficient use of R&D resources	

Advantages of Least Cost Formulation

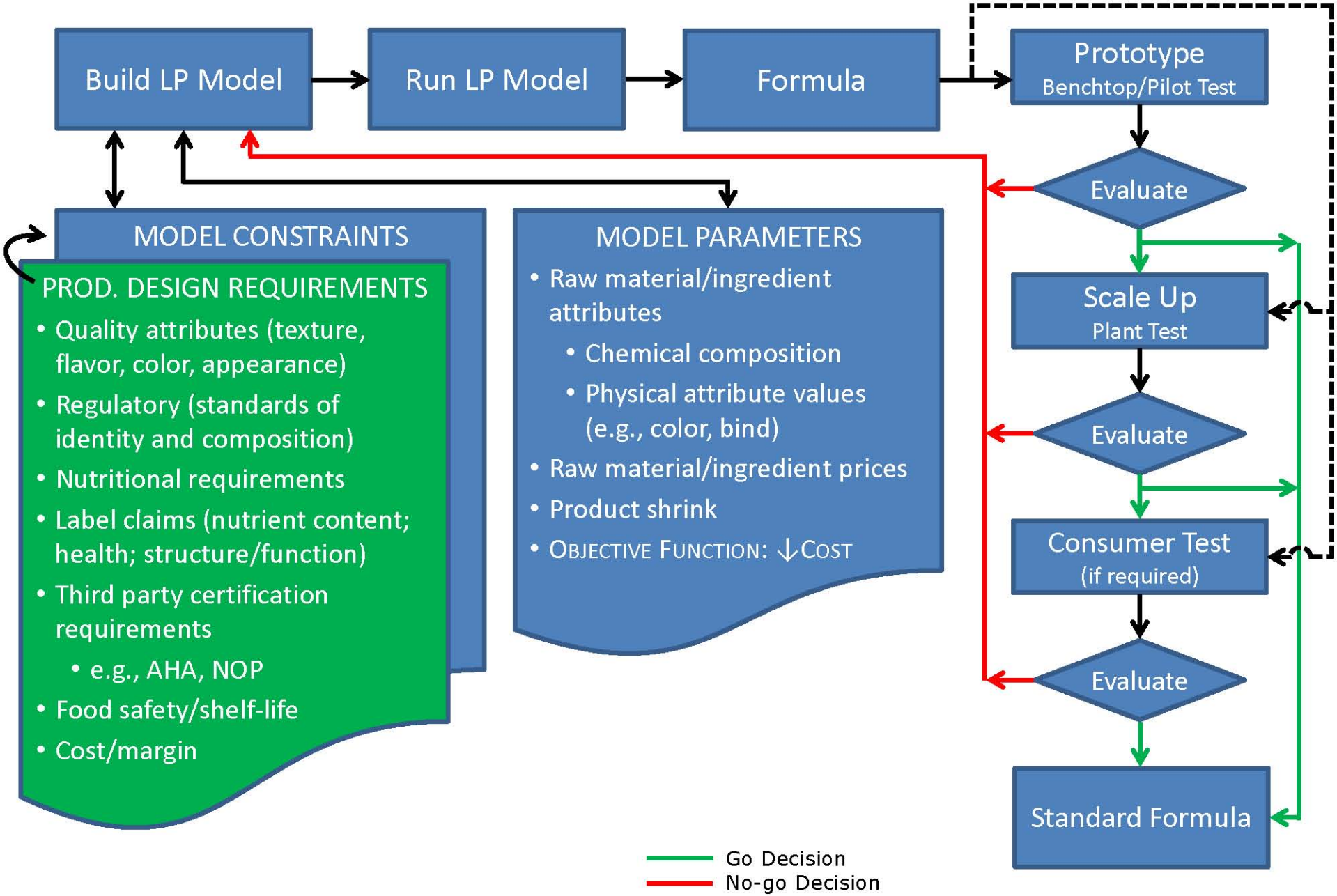
Product Development	Manufacturing
• Permits rapid generation of multiple "what if" scenarios, which helps: - shorten development time - develop deeper and more thorough knowledge and understanding of formula and product - make more efficient use of R&D resources	• Results in most economical combination/allocation of RMs and ingredients that meets all constraints (i.e., least cost formula) • Yields predictable and consistent finished product quality • Helps optimize RM utilization • Helps optimize inventory levels • Provides useful and accurate procurement information • Saves time over more traditional formulation methods

III. Formulation in Product Development

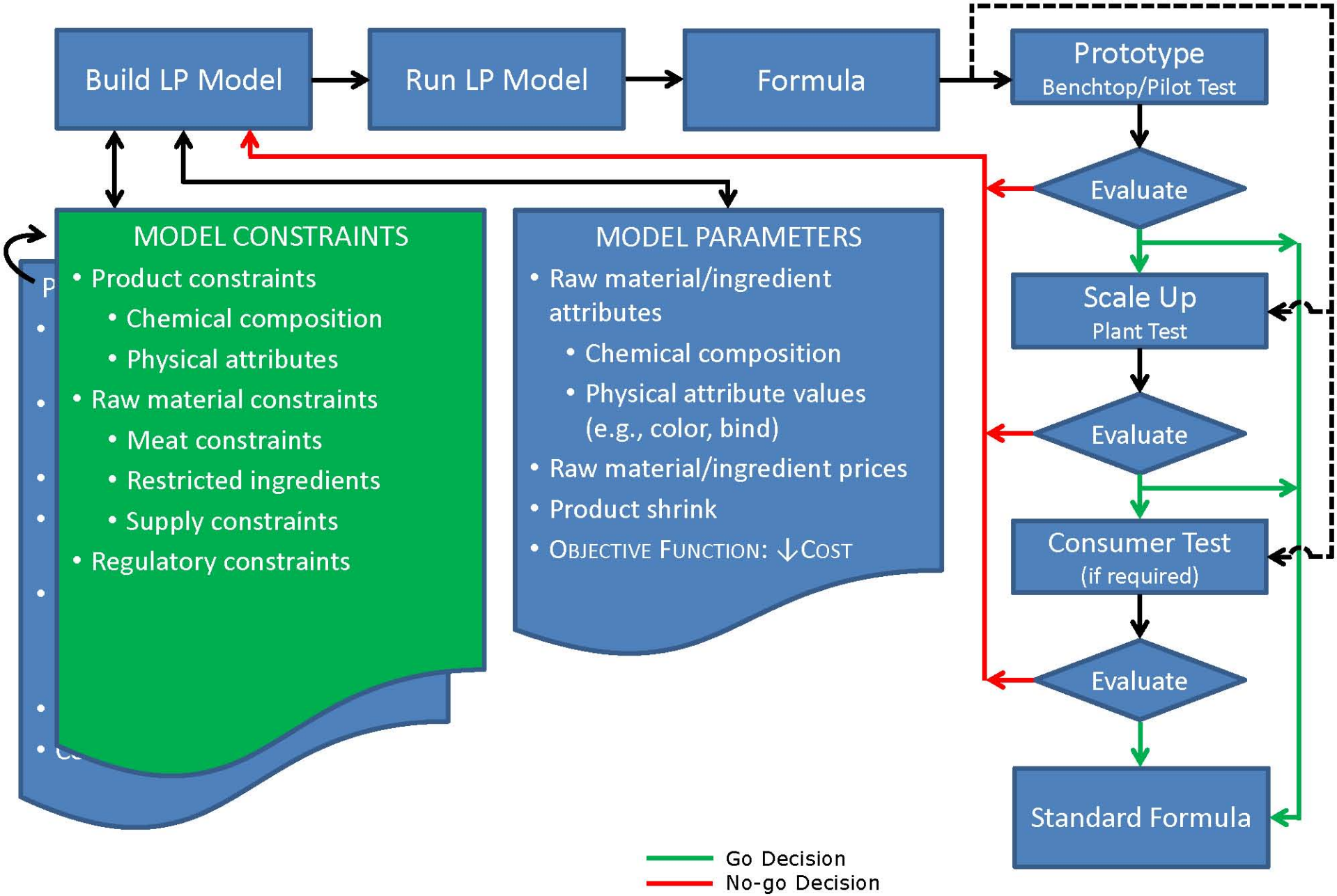
Formula Development Flowchart



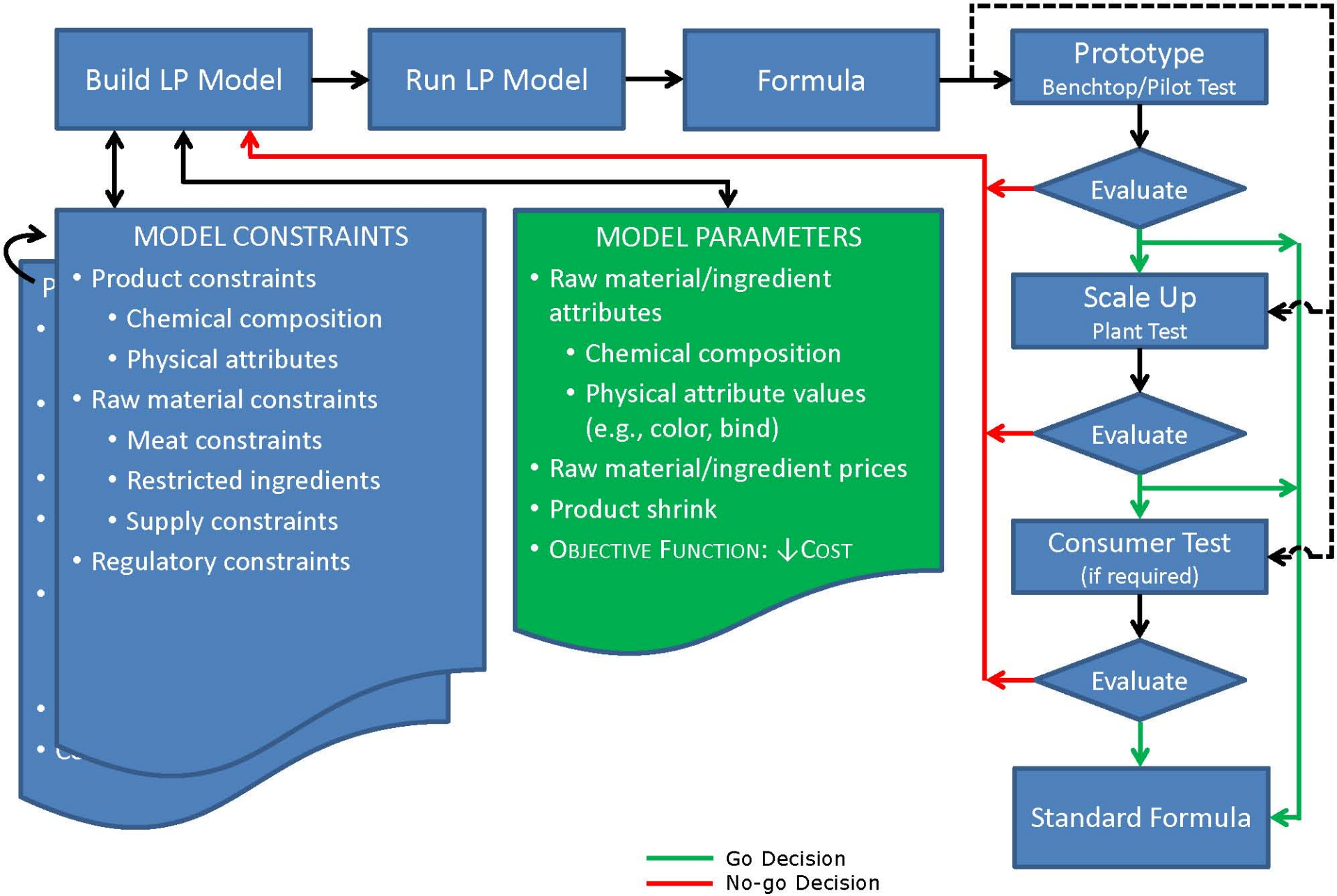
Formula Development Flowchart



Formula Development Flowchart



Formula Development Flowchart



Key Elements of a Formula Development LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, bind) • Raw material/ingredient prices • Product shrink (actual or estimated) – Cook – Chill (chilling water/brine vs. air chilling) • Objective Function defined – Minimize Cost	• Raw material/ingredient constraints – Meat (e.g., species, breast /white meat, shank meat, poultry, skin, MDM/MDP, FTB/FTP, frozen) – Restricted ingredients – Supply constraints • Product constraints – Chemical composition: moisture, fat, protein, sodium, salt, etc. – Physical attribute values (e.g., color, bind) • Regulatory constraints – PFF, Added Water, Fat, Fat + Added Water, Moisture/Protein ratio, poultry skin, restricted ingredients	• Optimal RM/ingredient allocation (i.e., Formula) • Formula (least) cost • Actual product attributes – Chemical composition – Physical attribute values (e.g., color, bind) – Nutritional information

Key Elements of a Formula Development LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, bind) • Raw material/ingredient prices • Product shrink (actual or estimated) – Cook – Chill (chilling water/brine vs. air chilling) • Objective Function defined – Minimize Cost	• Raw material/ingredient constraints – Meat (e.g., species, breast /white meat, shank meat, poultry, skin, MDM/MDP, FTB/FTP, frozen) – Restricted ingredients – Supply constraints • Product constraints – Chemical composition: moisture, fat, protein, sodium, salt, etc. – Physical attribute values (e.g., color, bind) • Regulatory constraints – PFF, Added Water, Fat, Fat + Added Water, Moisture/Protein ratio, poultry skin, restricted ingredients	• Optimal RM/ingredient allocation (i.e., Formula) • Formula (least) cost • Actual product attributes – Chemical composition – Physical attribute values (e.g., color, bind) – Nutritional information

Key Elements of a Formula Development LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, bind) • Raw material/ingredient prices • Product shrink (actual or estimated) – Cook – Chill (chilling water/brine vs. air chilling) • Objective Function defined – Minimize Cost	• Raw material/ingredient constraints – Meat (e.g., species, breast /white meat, shank meat, poultry, skin, MDM/MDP, FTB/FTP, frozen) – Restricted ingredients – Supply constraints • Product constraints – Chemical composition: moisture, fat, protein, sodium, salt, etc. – Physical attribute values (e.g., color, bind) • Regulatory constraints – PFF, Added Water, Fat, Fat + Added Water, Moisture/Protein ratio, poultry skin, restricted ingredients	• Optimal RM/ingredient allocation (i.e., Formula) • Formula (least) cost • Actual product attributes – Chemical composition – Physical attribute values (e.g., color, bind) – Nutritional information

Key Elements of a Formula Development LP Model

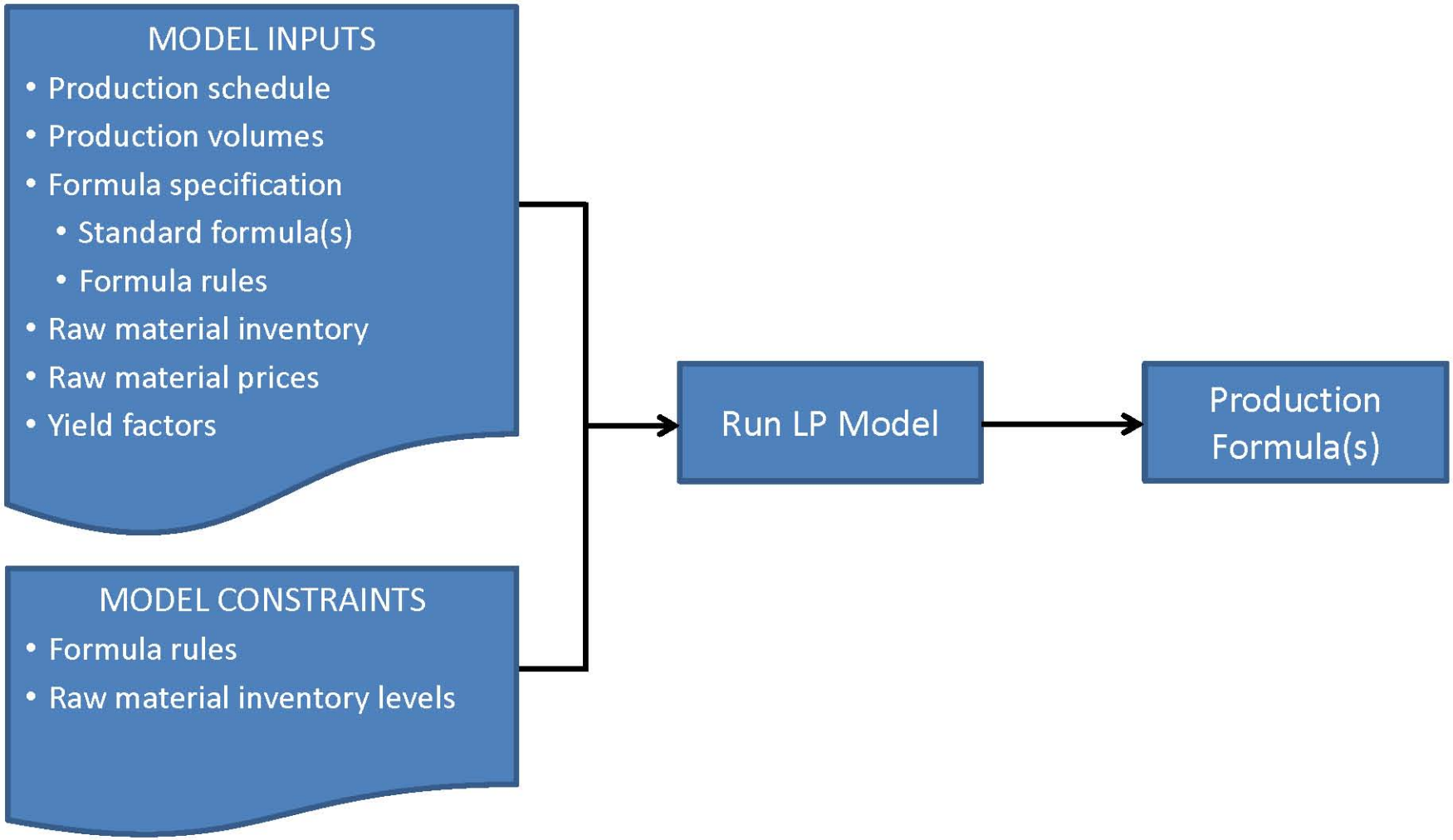
Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, bind) • Raw material/ingredient prices • Product shrink (actual or estimated) – Cook – Chill (chilling water/brine vs. air chilling) • Objective Function defined – Minimize Cost	• Raw material/ingredient constraints – Meat (e.g., species, breast /white meat, shank meat, poultry, skin, MDM/MDP, FTB/FTP, frozen) – Restricted ingredients – Supply constraints • Product constraints – Chemical composition: moisture, fat, protein, sodium, salt, etc. – Physical attribute values (e.g., color, bind) • Regulatory constraints – PFF, Added Water, Fat, Fat + Added Water, Moisture/Protein ratio, poultry skin, restricted ingredients	• Optimal RM/ingredient allocation (i.e., Formula) • Formula (least) cost • Actual product attributes – Chemical composition – Physical attribute values (e.g., color, bind) – Nutritional information

Additional Considerations

- During product development, the formula developed must:
  1. Represent the lowest cost solution to the problem given the model's constraints and parameters
  2. Be an adequate mathematical expression of a technically- and financially-viable product. Just because a solution is mathematically feasible or optimal does not mean that it will result in a desirable product
- Therefore, while LP is a most useful tool, it can never replace the knowledge, experience and judgment of an experienced product development scientist. A knowledgeable and experienced product developer who understands LP should be able to (1) understand how a formula on paper relates to a real finished product and (2) know how to effectively leverage this understanding.
- The quality of the model can only be as good as the quality of the data fed into it.

IV. Formulation in Manufacturing

Manufacturing Formulation Flowchart



Key Elements of a Manufacturing Formulation LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Production schedule • Production volumes • Standard formula(s) • Formula rules • Raw material inventory • Raw material/ingredient attributes – Chemical composition – Physical attribute values (e.g., color, bind) • Raw material prices • Yield factors	• Formula rules • Raw material inventory levels	• Production formula(s) – Batch sheets or batch recipes

Key Elements of a Manufacturing Formulation LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Production schedule • Production volumes • Standard formula(s) • Formula rules • Raw material inventory • Raw material prices • Yield factors	• Formula rules • Raw material inventory levels	• Production formula(s) – Batch sheets or batch recipes

Key Elements of a Manufacturing Formulation Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Production schedule • Production volumes • Standard formula(s) • Formula rules • Raw material inventory • Raw material prices • Yield factors	• Formula rules • Raw material inventory levels	• Production formula(s) – Batch sheets or batch recipes

Key Elements of a Manufacturing Formulation LP Model

Parameters (Inputs)	Constraints (Limits)	Solution (Outputs)
• Production schedule • Production volumes • Standard formula(s) • Formula rules • Raw material inventory • Raw material prices • Yield factors	• Formula rules • Raw material inventory levels	• Production formula(s) – Batch sheets or batch recipes

Formula Rules

- Most are mathematical constraints applied to standard formula, but are not the same as formula development constraints.
- Derived from knowledge and restrictions of the standard formula, product composition and regulatory specifications, as well as process capabilities.
- Provide flexibility for the LP model to reach its optimal solution.
- Specify values such as composition, regulatory limits and alternate raw materials (i.e., raw materials permitted to be used when primary raw materials are unavailable).

When to use LCF in Manufacturing

- LCF can be used at one or more of several business stages
  - Purchasing
    - LCF used to optimize purchasing decisions based on formula and production requirements, and raw material pricing and availability
    - Most effective and powerful stage at which to use LCF, since it is the point at which raw material costs are truly controlled; once they're purchased, they must be used
  - Production scheduling
    - LCF used to optimize allocation of existing inventories and guarantee formula targets are met for consistent quality
    - Limited usefulness, but still valuable
  - Batch adjustments and corrections
    - LCF used in individual batches to correct deviations from formula targets caused by compositional variations in raw materials
    - Little to no value in terms of controlling costs

V. Reformulation

Definition

- What it's not
  - Normal and expected variations in raw material and ingredient allocations that occur during formula optimization at the manufacturing level according to the requirements of the standard formula and formula rules, i.e., change in production formula or recipe
- What it is
  - Change in formula beyond the requirements of the standard formula and formula rules
  - Implies a need to return to formula development stage

Common Reasons to Reformulate

Product Quality

Reason:
Quality, or some aspect of it, no longer acceptable

- Consumer/customer feedback
- Product performance issues
- Quality improvement initiative

Financial

Reason:
Change in actual or desired product cost

- Significant change in RM/ingredient pricing (cost avoidance)
- Improve contribution margin (cost improvement)

Supply

Reason:
Change in RM/ingredient situation

- Change in RM/ingredient availability
- Change in RM/ingredient functional quality (e.g., new supplier, new ingredient SKU)

Operational

Reason:
Formula and process no longer "aligned"

- Change in process capabilities (e.g., equipment change, process modification, changes in standard yields)

Should be done carefully and with clearly-stated objectives in mind.

Thank You