LINEAR MODELING FOR SUPPLY CHAIN OPTIMIZATION

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All models are wrong;
some are useful.

George Box

The map is not the territory.

Alfred Korzybski

OUTLINE

Analytics Applications in Supply Chains

Introduction to Linear Optimization

Case Study: Sourcing Optimization for a Global Supply Chain

- Overview of supply chain challenges
- Modeling process
- Key data: manufacturing cost / capacity / duties & transfer pricing
- Model output & lessons learned

Introduction to Mixed-Integer Models

WHAT IS A SUPPLY CHAIN?

Complete sequence of entities and steps needed to provide a good or service, including sourcing raw materials and components, manufacturing / assembly, storage / warehousing, and transportation / logistics.

Raw Material Supplier → Manufacturer (Plant / Factory) → Warehouse / Distribution Center → Retailer → Customer

How are analytics used in supply chains?

<u>Prescriptive Analytics:</u>

- Linear Programming (network design, et al)
- Discrete-event simulation (stochastic)
- Finite scheduling
- Routing optimization

<u>Predictive Analytics</u>

- Predictive maintenance
- IoT in factories, transportation
- Sales forecasting models
- Commodity price models / hedging / futures contracts

LINEAR PROGRAMMING INTRODUCTION

Goal: find values of inputs (x's) that optimize (i.e. maximize or minimize) a linear objective function

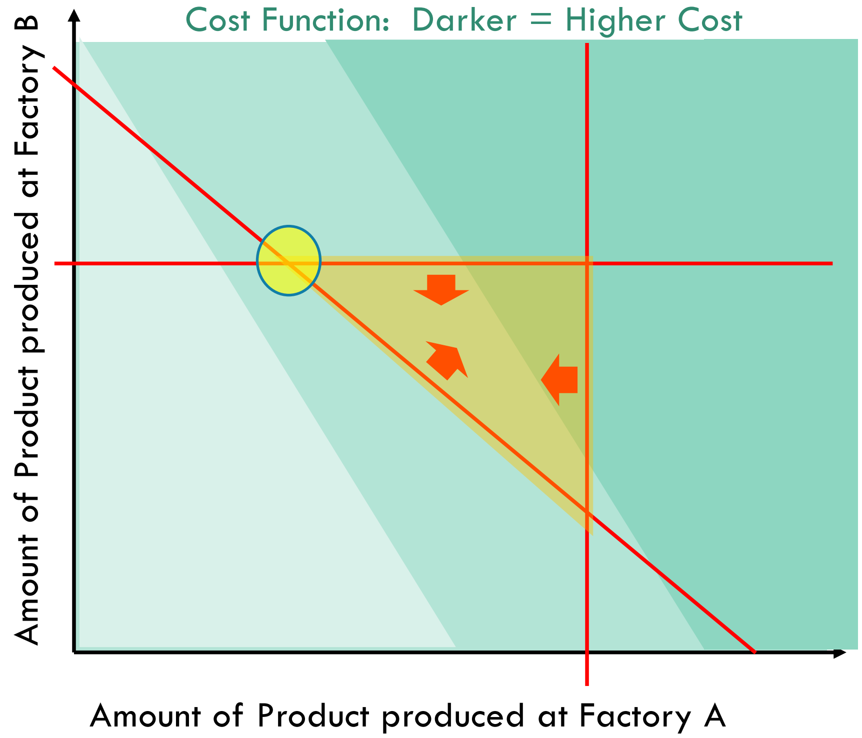
$$\mathrm{Y} = \sum_{i=1}^{n} a_i\, x_i$$

subject to one or more linear constraints of the form

$$\sum_{i=1}^{n} b_i\, x_i \; = k \; or$$

$$\sum_{i=1}^{n} b_i\, x_i \; \leq k, etc.$$

Note: solution will always be on a vertex or edge of the polygon formed by the constraints



CASE STUDY:
NUTRITIONAL PRODUCTS SUPPLY CHAIN

Complex:

- Several thousand products (SKUs)
- Global markets
- Plants in US, Europe, Asia
- Unique capability (plants not interchangeable)
- Multi-step manufacturing process (see below) → multiple types of capacity

Dynamic

- Changing sales forecasts and different market dynamics
- Dairy ingredients → seasonality of supply
- Mix-dependent capacity
- Geopolitical / trade

Difficult Solutions:

- Transferring products among plants: 3-24 months
- Hiring additional crew: 3-12 months
- New packaging line: $5-10 million, 1-2 years
- New plant: $150+ million, 3-4 years

Wet Processing → Drying → Dry Blending → Packaging

Which products should be made in which plants for which customers?

Need process to 1. **optimize** costs and 2. **anticipate** future capacity constraints and capital needs!

LONG-RANGE PLANNING & MODELING PROCESS

Solution: long-range planning (LRP) process:

- 2x / year; project demand & capacity for next 5 years
- Minimize: Variable Mfg Cost + Freight + Duties, subject to constraints
- Key assumptions: existing network footprint (usually), buffer %, approved capital projects

Demand

- 5-yr growth rates (family / region)
- Current mix + key launches / conversions

Capacity

- Gross rate
- OEE
- Current crewing
- Max possible hours
- Buffer

Costs

- Mfg Costs
- Freight
- Duty (incl rate & transfer price)
- Tax
- ESTIMATION

Constraints

- Mfg capability
- Kosher / halal
- Regulatory
- Commercial & political

Pre-Processing (Excel)

Model (SAILS)

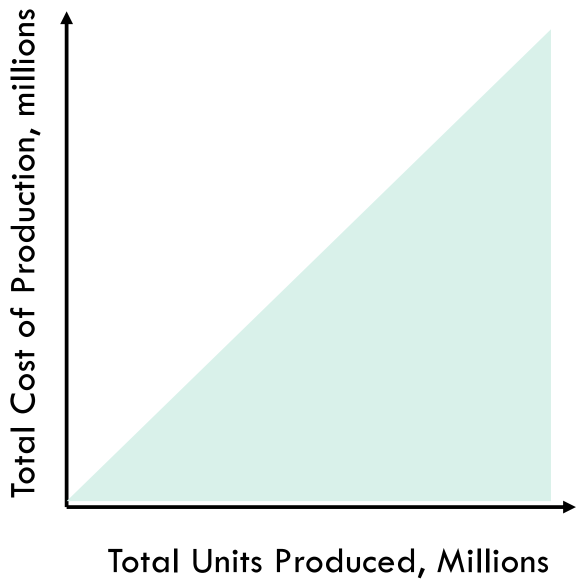
Output (Excel)

- Plant / product assignment
- Plant utilization
- Capital timing

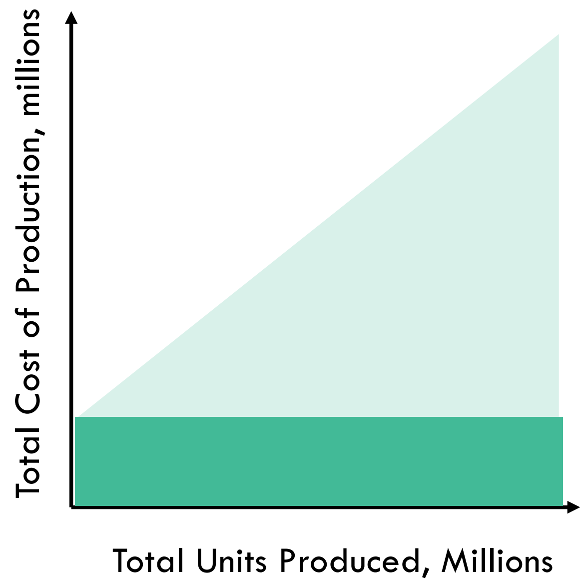
Executive Presentation (PPT)

3-4 Months | 2-3 Wks | 2-3 Wks

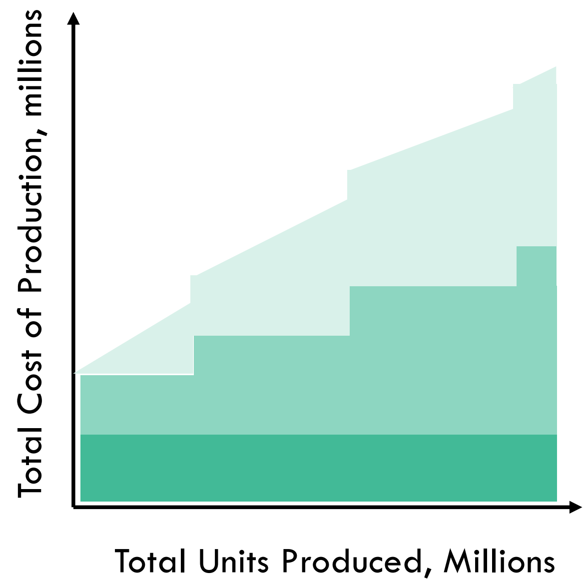
MANUFACTURING COSTS



Full Standard Cost



Traditional Cost Accounting



Detailed Cost Model

What method is correct? What questions are you trying to answer?

Fixed costs are sunk costs!!!

MANUFACTURING CAPACITY

$$x_i = units\ of\ product\ i\ produced$$
$$r_i = machine\ speed\ for\ product\ i\ (units\ per\ minute)$$
$$e_i = OEE\ (efficiency\ factor)$$
$$Constraint\colon \sum_{i=1}^{n} \left(\frac{x_i}{r_i e_i}\right) \leq Total\ Available\ Hours * Buffer$$

Overall Equipment Effectiveness (OEE): measure of efficiency

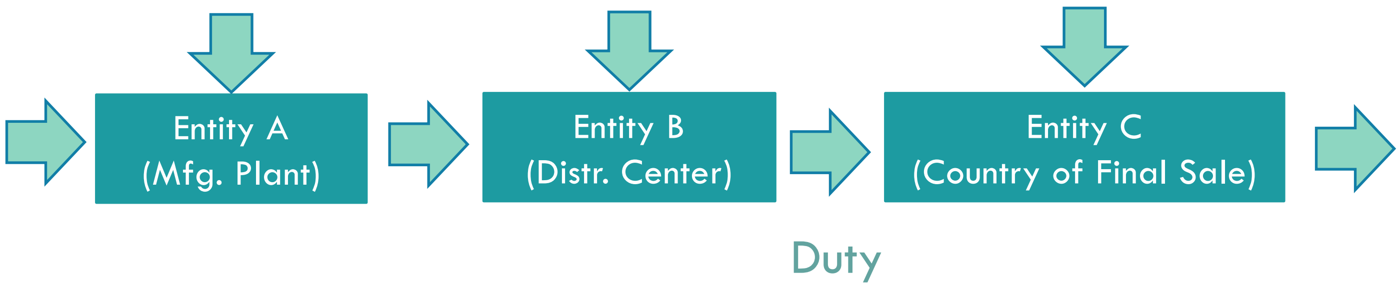
Measure at both current crewing and at theoretical max crewing (24-7 operation)

Challenges

- Inconsistency of definitions / metrics; hidden activity
- Unforeseen bottlenecks when approaching max capacity
- Mix- and sequence-dependent:

vs.

TRANSFER PRICING, DUTIES AND TAX



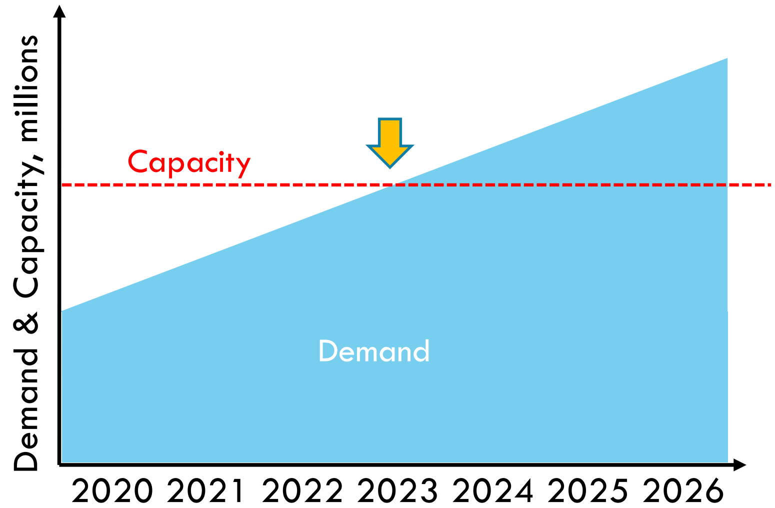
Transfer Price: price charged among different entities in same company

- Need not be same as the manufacturing standard cost!
- Considerations: treasury, tax, currency hedging

Duty Cost = Duty Rate * (Transfer Price + Freight) + Fixed Element (if applicable)

Duty regulations and free trade agreements are complex!

MODEL OUTPUT & LESSONS LEARNED



Output:

- Where (and when) will we have a problem?
- What are the key risks / sensitivities?

Lessons Learned - Technical

- Cost structure drives ideal network structure
- Be aware of the trade-offs among speed, quality and level of detail. Is the extra precision needed?
- Understand sensitivity to key assumptions

Lessons Learned - Organizational

- Align early and often!
- Must speak the language of (the) business; aka NO ONE CARES ABOUT YOUR STUPID MODEL
- Executive presentations are a special skill! Come with clearly articulated recommendations
- **Model must not be a black box;** must articulate WHY the model is making a particular recommendation

OTHER TOPICS: NETWORK FOOTPRINT ANALYSIS

Network footprint analysis answers:
- Where should our factories and distribution centers be located? How large each should be?
- Risk / scenario analysis

Key challenges:
- Finding desired balance of "blue sky" with "practical"
- Aligning on macro / strategic assumptions, questions, and scenarios; managing "scope creep"
- Developing financial and other detailed assumptions
- Confidentiality / sensitivity
- Understanding and being willing to make decisions in the face of uncertainty

Mixed-Integer Linear Programming: involves binary / "on-off" decisions
- Example: "plant A is open" vs. "plant A is closed"
- Warning! This is more difficult computationally; solver time increases exponentially with the number of on-off decisions!

QUESTIONS & COMMENTS ?

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