Strategic Design of Robust Global Supply Chains

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Credits

- **Interdisciplinary systems engineering**
  - ✓Virtual Factory Lab (VFL), Leon McGinnis
  - ✓Manufacturing Research center (MARC), Russell Peak
  - ✓Ph.D. students, Huang, Megahed, Tang

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Overview

- Supply Chains
- Modeling Based Systems Engineering (MBSE)
- Strategic Supply Chain Design
- Strategic and tactical model
- Algorithm
- Conclusions

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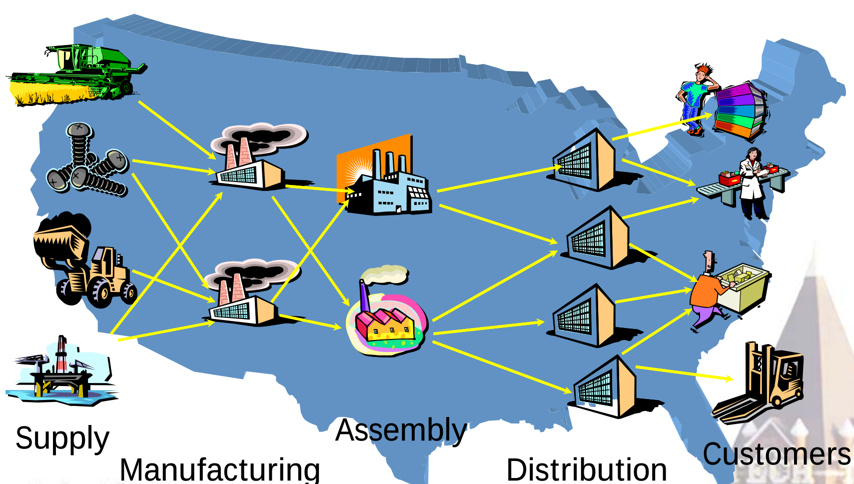
Supply Chain



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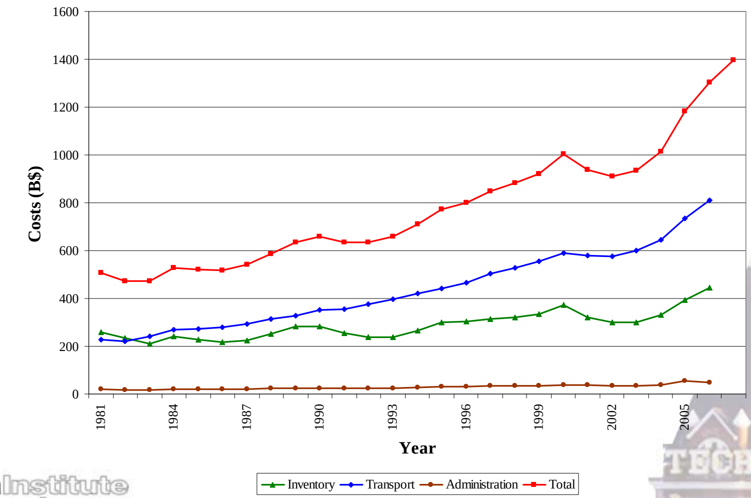
US Logistics Costs by Activity: 1981-2007



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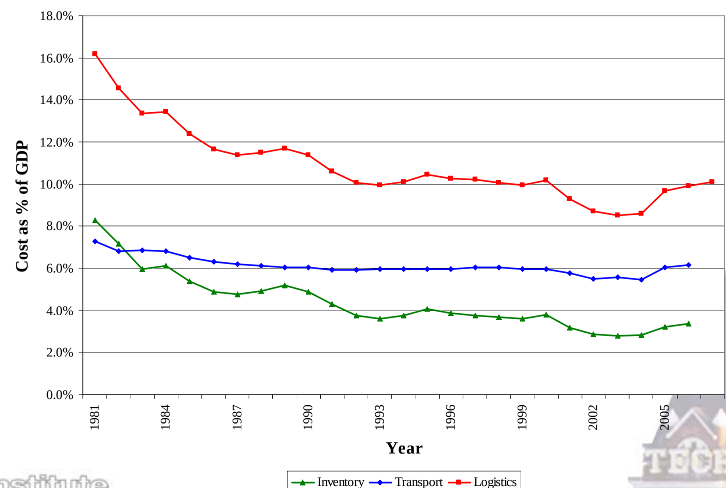
US Logistics Costs as Fraction of GDP: 1981-2007



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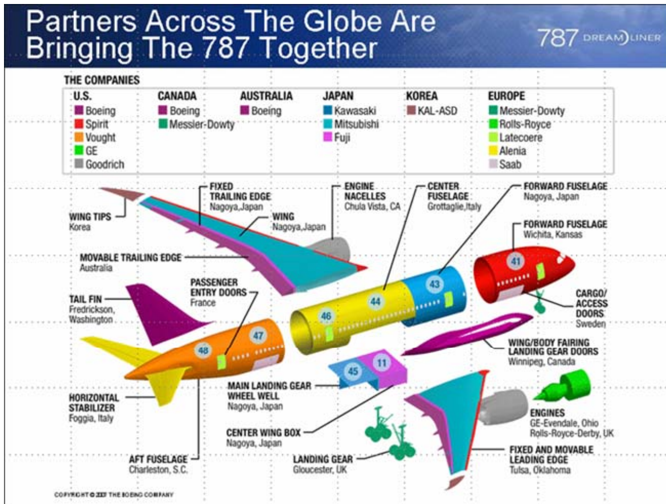
Global Supply Chain Example: Boeing 787 Dreamliner



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Global Supply Chains

- **Nearly all supply chains are global**
- **Longer chains in space and time**
- **Influenced by policies of two or more governments**
  - ✓Exchange rates
  - ✓Local content
  - ✓Protectionism of goods and jobs
  - ✓Political and property rights stability

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Modeling Based Systems Engineering (MBSE)

- **Design and management of systems**
- **Formalized, holistic, interdisciplinary**
- **Systems have structure and behavior**
- **Large variety of systems**
  - ✓international space station, Florida wetlands management, healthcare system, supply chains…
- **Systems Modeling Language (SysML)**
  - ✓Open standard, commercial implementation
  - ✓Descriptive
  - ✓INCOSE, UML,…

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Mathematical Models in Strategic Design Process

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Logistics Meta Model (1)

- **Decide Structure**
  - ✓Network / Facilities + Channels
  - ✓IT support Systems
- **Decide Behavior**
  - ✓Transportation
  - ✓Inventory
  - ✓Transformation

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Logistics Meta Model (2)

- **With as Objective**
  - ✓Minimize total system cost
  - ✓Maximize total system NPV(NCF)
  - ✓Maximize expected profit
  - ✓Tradeoff expected profit and profit variability

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Logistics Meta Model (3)

- **Subject to**
  - ✓Capacity constraints (infrastructure, budget, demand, time)
  - ✓Service level constraints (demand)
  - ✓Conservation of flow constraints (time, space, BOM)
  - ✓Linkage or consistency constraints
  - ✓Substitution constraints (calculation of intermediate variables)
  - ✓Extraneous special conditions

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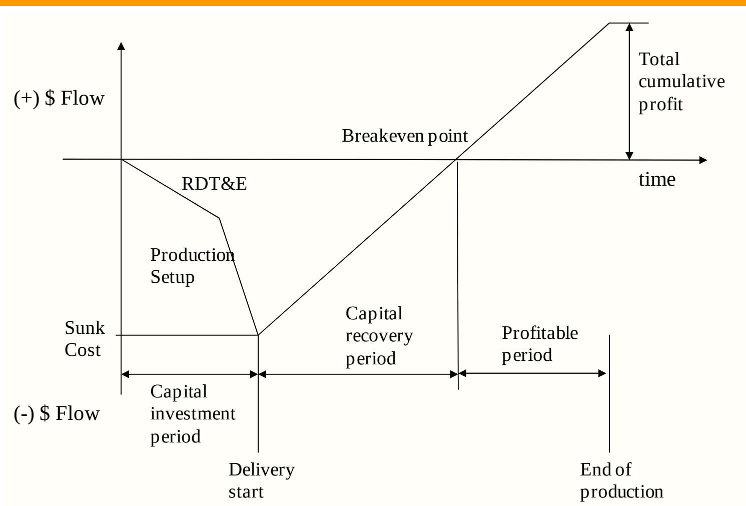
Program Lifecycle Cash Flow Diagram



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Matrix Organization of Planning Modules

Strategic	Strategic Enterprise Planning			Strategic Demand Planning
Tactical	Master Production and Distribution Planning			Tactical Demand Planning
Operational	Material Requirem. Planning	Production Planning	Distribution Planning	Operational Demand Planning
Execution	Purchasing	Scheduling	Vehicle Dispatching	Demand Monitoring

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Strategic Planning and Design

- **Strategic Decisions (configure, structure)**
  - ✓Supply chain capital assets, capacity, and technology configuration
  - ✓5-15 year schedule (planning horizon)
- **Tactical Decisions (evaluate, behavior)**
  - ✓Purchasing, production allocations, transportation flow quantities, inventory
  - ✓Transfer prices
  - ✓Yearly or seasonal flows

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Common Goal for Supply Chain Design

- **Maximize the**
  World Wide
  Long Term
  After Tax
  Net Cash Flow

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Net Cash Flow Calculations

$$EBITDA = SALES - FIXEDCOSTS - VARIABLECOSTS$$

$$NIBT = EBITDA - INTEREST - DEPRECIATION$$

$$NCF_{ct} = NIBT_{ct} \cdot (1 - TAXRATE_{ct}) + DEPRECIATION_{ct} - AMORTIZATION_{ct}$$

$$NCF_t = \sum_{c=1}^{C} \frac{NCF_{ct}}{EXRATE_{ct}}$$

$$NPV\left(NCF\right) = \sum_{t=1}^{T} \frac{NCF_t}{\prod_{j=1}^{t}\left(1 + df_j\right)}$$

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Objectives Incorporating Uncertainty

- **Ignore uncertainty**
  - ✓mean value problem (MVP), best guess, deterministic

$$\max\left\{NPV\left(NCF\right)\right\}$$

- **Expected value**
  - ✓Expected value problem (EVP), stochastic problem (deterministic equivalent problem DEP)

$$\max\left\{\mathbf{E}\left[NPV\left(NCF\right)\right]\right\}$$

- **Robust configuration**
  - ✓Minimize worst case value (WCVP)

$$\max\left\{\min\left[NPV\left(NCF\right)\right]\right\}$$

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Objective Incorporating uncertainty

- **Bi-criteria: central tendency minus dispersion times penalty**
  - ✓Pareto optimality
  - ✓Penalty from risk profile
  - ✓Risk analysis graph
  - ✓Central tendency = expected value, dispersion = standard deviation

$$\max\left\{\begin{array}{l}\mathbf{E}\left[NPV\left(NCF\right)\right]- \\ \kappa\cdot\mathbf{STDEV}\left[NPV\left(NCF\right)\right]\end{array}\right\}$$

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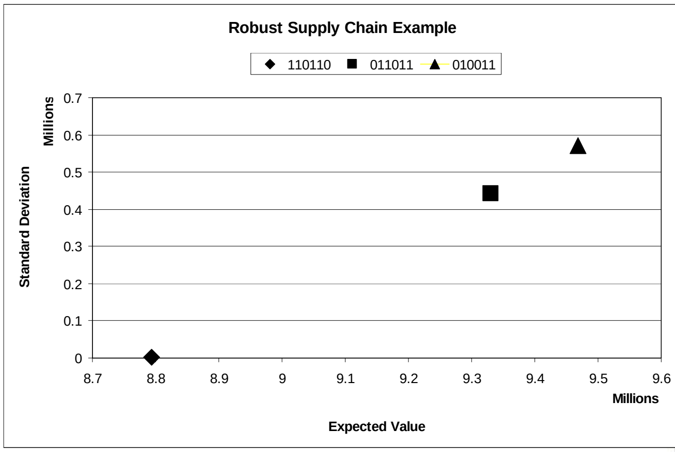
Risk Analysis Graph



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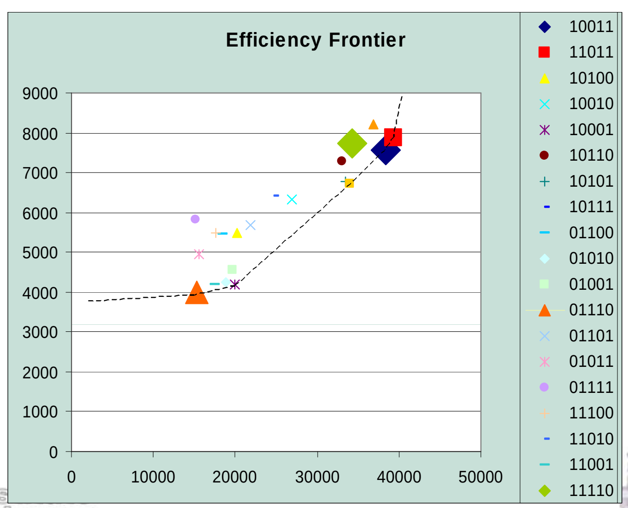
Multi-objective Criteria and Efficiency Envelope



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Number of Scenarios and Configuration Robustness

- **A robust supply chain configuration has a high quality for (many) simultaneous scenarios**
- **The more scenarios, the better**
- **Every scenario grows the model size**
- **Scenario probabilities (sampling, black swans)**

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Tactical Model: Problem Assumptions

- **Medium term, master planning**
- **Material Flow and Storage Decisions**
  - ✓Continuous variables
- **Given Supply Chain Configuration**
  - ✓Given capacities and resource capacities

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Tactical Model: Objective

Variable Costs = Sum of sales revenue minus procurement, transportation, production, resource, inventory, and backorder costs

$$\max \sum_{k\in C}\sum_{p}\sum_{t} sr_{kpt}\cdot sq_{kpt}$$
$$-\sum_{i\in S}\sum_{p}\sum_{t} pc_{ipt}\cdot pq_{ipt} - \sum_{i\in O}\sum_{j\in D}\sum_{p}\sum_{t} tc_{ijpt}\cdot x_{ijpt} - \sum_{j\in TR}\sum_{p}\sum_{t} ac_{jpt}\cdot aq_{jpt}$$
$$-\sum_{j\in TR}\sum_{p}\sum_{r\in AR}\sum_{t} arc_{jrt}\cdot ares_{jprt}\cdot aq_{jpt} - \sum_{j\in TR}\sum_{p}\sum_{r\in IR}\sum_{t} irc_{jrt}\cdot ires_{jprt}\cdot iq_{jpt}$$
$$-\sum_{j}\sum_{p}\sum_{r\in R}\sum_{t} rc_{jrt}\cdot res_{jprt}\cdot otq_{jpt}$$
$$-\sum_{k\in C}\sum_{p}\sum_{t\in T, t\geq 2}\sum_{u\in T, u<t} bc_{kptu}\cdot bq_{kptu} - \sum_{j\in TR}\sum_{p}\sum_{t} hc_{jpt}\cdot iq_{jpt}$$

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Tactical Model: Suppliers

Individual and joint-product capacities
Procurement = outgoing flow
Supplier selection decision

$$\sum_{p} res_{ip}\cdot pq_{ipt} \leq cap_{it} \qquad \forall i, \forall t$$

$$pq_{ipt} \leq cap_{ipt} \qquad \forall i, \forall p, \forall t$$

$$pq_{ipt} = \sum_{j} x_{ijpt} \qquad \forall i, \forall p, \forall t$$

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Tactical Model: Transformers

- **Component product inventory and incoming flow**
- **BOM manufacturing flow balance**
- **Individual and joint-product capacities**
- **Assembled product inventory and outgoing flow**

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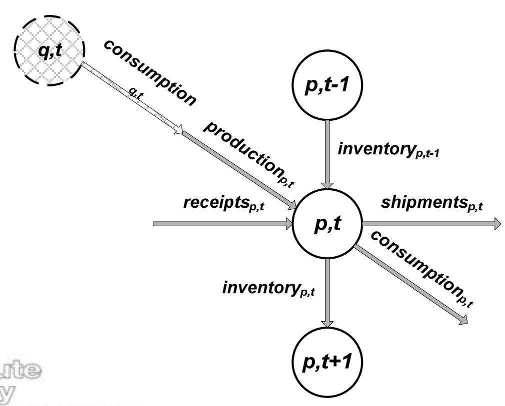
Tactical Model: Transformers Conservation of Flow Graph

General conservation of flow with transportation, inventory, production



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Tactical Model: Transformers Conservation of Flow Equations

$$\sum_{i} x_{ijpt} = itq_{jpt}$$

$$itq_{jpt} + aq_{jpt} + init\_inv_{jp} - iq_{jpt} - cq_{jpt} - otq_{jpt} = 0 \quad (t=1)$$

$$itq_{jpt} + aq_{jpt} + iq_{jpt-1} - iq_{jpt} - cq_{jpt} - otq_{jpt} = 0 \quad (t=2..T-1)$$

$$itq_{jpt} + aq_{jpt} + iq_{jpt-1} - cq_{jpt} - otq_{jpt} = 0 \quad (t=T)$$

$$\sum_{k} x_{jkpt} = otq_{jpt}$$

$$cq_{jpt} = \sum_{v} 1bom_{jpvt} \cdot aq_{jvt} \qquad \forall p \in 1BOM_{v}$$

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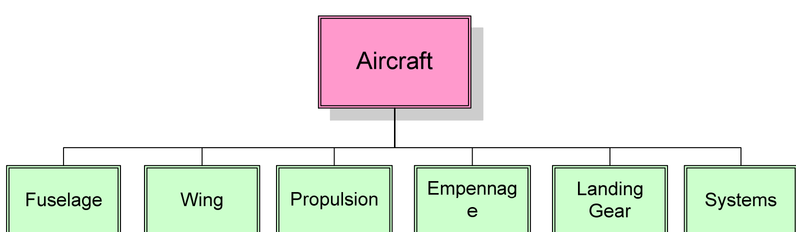
Tactical Model: Transformers Production with 1BOM

- **1BOM = One-level BOM**
  - ✓1 aircraft has 2 wings as immediate components



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Tactical Model: Transformer Capacities

- **Capacities for throughput, inventory, and production**

$$\sum_p ares_{jprt} \cdot aq_{jpt} \le acap_{jrt} \cdot y_j$$

$$aq_{jpt} \le acap_{jpt} \cdot y_j$$

$$\sum_p tres_{jprt} \cdot otq_{jpt} \le tcap_{jrt} \cdot y_j$$

$$otq_{jpt} \le tcap_{jpt} \cdot y_j$$

$$\sum_p ires_{jprt} \cdot iq_{jpt} \le icap_{jrt} \cdot y_j$$

$$iq_{jpt} \le icap_{jpt} \cdot y_j$$

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Tactical Model: Customers

Deliveries = incoming flow
Deliveries balanced with demand through backorders

$$\sum_j x_{jkpt} = dq_{kpt}$$

$$dq_{kpt} + \sum_{t<u} bq_{kput} = \sum_{u<t} bq_{kptu} + dem_{kpt}$$

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Solution Algorithm

- **Work in progress…**
- **St. Dev. Pareto points subset of variance Pareto points**
- **Solve Mean-Variance Robust Design Problem (MV-RDP) for various values of penalty**
  - ✓Currently monolithic MIQO
  - ✓# iterations (also) dependent on # scenarios

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Solution Algorithm continued

- **MV-RDP**
  - ✓Bound to limit of # penalty values to be examined
  - ✓Few non-trivial test cases available
  - ✓Industrial Case with 30 scenarios
    - 2 minutes computing time
    - 2 optimal configurations (including expected value)
  - ✓If necessary primal Benders decomposition

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Extensions: Local Content

- **Required local content per customer order**
- **Required data**
  - ✓Component costs
  - ✓Local content fraction
- **Assumption of one level of components**
- **Easy single additional constraint**
- **Problem becomes hard if any assumptions are relaxed**

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Challenges for Robust Design by MBSE

- **Immediate Modeling Challenges**
  - ✓Local value-adding
  - ✓Supply chains for strategic partnerships
- **Long-Term Discipline Challenges**
  - ✓Holistic approach and interfacing with other disciplines
  - ✓Economic justification of robust design

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Boeing 747-LCF

LCF: Large Cargo Freighter
Transport B-787 fuselage sections

8 m internal height
150 ton payload

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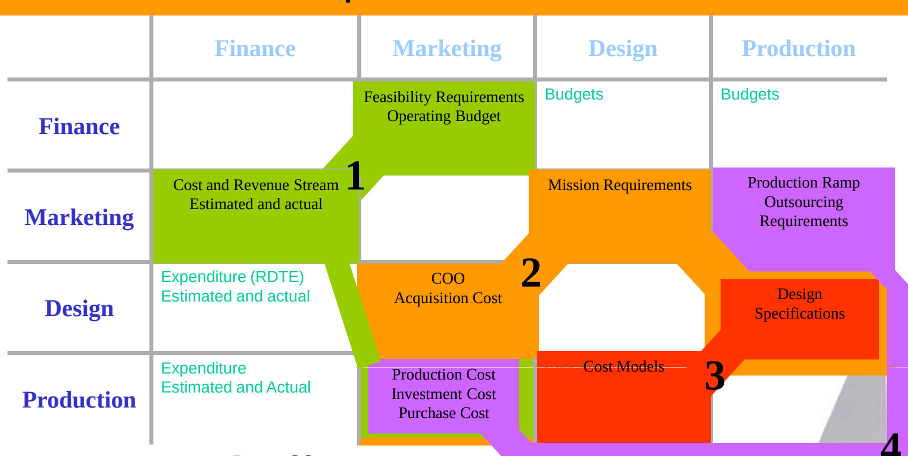
Interactions and Trade-offs between Disciplines



Key Tradeoffs:

1. Financial Discussion
2. Mission/COO & Production Trade-off
3. Product design /Process Cost & Risk Trade-off
4. Marketing/Manufacturing Network Trade-off

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Thank You
Can I Answer Any Questions?

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