Identifying Risks and Mitigating Disruptions in the Automotive Supply Chain

William Schmidt, David Simchi-Levi, Yehua Wei, Peter Yun Zhang
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Talk Outline

- Introduction
- The Risk Exposure Index
- The Mathematical Model
- Ford’s implementation
- The Impact
Risks in Today’s Supply Chains

- Significant increase in supply chain risk
  - Outsourcing and offshoring
    - Supply chain is geographically more diverse
  - Lean manufacturing
    - Just-in-time (JIT) manufacturing and low inventory levels

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Intel Sales are down
Giant blames Thai flood for $1B drop in sales goals. Toyota, Honda, Goodyear, Canon, Nikon, Sony... have cut production and lowered financial forecasts because of the flooding in Thailand.

*The Wall Street Journal, 2011*

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General Motors truck plant was shutting down
General Motors truck plant in Louisiana announced that it was shutting down temporarily for lack of Japanese-made parts because of the earthquake and tsunami had struck Japan.

*New York Times, 2011*
Risks in Today’s Supply Chains

- Significant increase in supply chain risk
  - Outsourcing and offshoring
    - Supply chain is geographically more diverse
  - Lean manufacturing
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![Chart showing Natural Disasters 2011 Cost ($B)]
Worldwide Natural Disasters 1980-2011 Source: Munich Re


Hurricane Katrina, 2005
Supply Chain Disruption and Stock Performance

- Mattel, the world’s largest toy maker;
- Recalled 18 million toys made in China on August 2007;
- The reason: hazards such as lead paint

![Graph showing stock performance with product recall highlight]
Many Sources of Risks

- Natural disasters
- Geopolitical risks
- Epidemics
- Terrorist attacks
- Environmental risks
- Volatile fuel prices
- Rising Labor costs
- Currency fluctuations
- Counterfeit parts and products
- Port delays
- Market changes
- Suppliers’ performance
- Forecasting accuracy
- Execution problems

Unknown-Unknown

Uncontrollable

Known-Unknown

Controllable
Many Sources of Risks

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  - Terrorist attacks
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- Port delays
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- Suppliers’ performance
- Forecasting accuracy
- Execution problems

Unknown-Unknown:
- Counterpart
- Uncontrollable

Known-Unknown:
- Corresponding counterpart
- Controllable
Managing Supply Chain Risk: The Challenge

• Very difficult to predict many sources of risk, especially the unknown-unknown
• Impact of disruption can be devastating
• Large investment in identifying every possible risk in the supply chain
• Existing tools and techniques have been inadequate
  ◆ Mostly ad-hoc, intuition, gut feeling
  ◆ Exposure to risk may reside in unlikely places
  ◆ May lead to the wrong actions and waste resources
  ◆ No ability to prioritize mitigation investment
Ford’s Supply Chain: The Challenge

West Coast

East Coast

North American Assembly Plants

APA Suppliers

EU Suppliers

NA Suppliers

NA Steel Bar Suppliers

Forging Plants

Casting Plants

NA Sheet Steel Suppliers

North American Engine Plants

Transmission Plants

Stamping Plants

APA Suppliers

EU Suppliers

NA Suppliers

NA Suppliers

North American Assembly Plants

Train

Truck

Dealers
Ford’s Supply Chain: The Challenge

Large multi-tier supply chain network

- Complex bill of materials and supply chain structure
- Over 50 manufacturing plants
- 10 tiers of suppliers
- 1400 tier 1 supplier companies with 4,400 manufacturing sites in over 60 countries
- 55,000 different parts
- 6 million vehicles produced annually
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- Introduction
- The Risk Exposure Index
  - The Mathematical Model
  - Ford’s implementation
  - The Impact
• **Time-To-Recover (TTR):** The time it takes to recover to full functionality after a disruption
**Illustrating Our Approach**

- **Steel Bar Suppliers**
- **Raw Chemical Suppliers**
- **Sheet Steel Suppliers**

Contrasting colors: Green

**Contract Manufacturers**

**Stamping Plants**

**Engine Plants**

**Assembly Plants**

- **Time-To-Recover (TTR)**: The time it takes to recover to full functionality after a disruption

TTR = 2 Weeks
• **Time-To-Recover (TTR):** The time it takes to recover to full functionality after a disruption
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• **Performance Impact (PI):** Impact of a disruption for the duration of TTR on a given performance measure
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- **Performance Impact (PI):** Impact of a disruption for the duration of TTR on a given performance measure.
- **Risk Exposure Index (REI):** Normalizes the PI by the maximum PI over all disruption scenarios.
Illustrating Our Approach

- **Time-To-Recover (TTR):** The time it takes to recover to full functionality after a disruption
- **Performance Impact (PI):** Impact of a disruption for the duration of TTR on a given performance measure
- **Risk Exposure Index (REI):** Normalizes the PI by the maximum PI over all disruption scenarios
Key features captured in our risk exposure model:

- Ford and its supplier sites’ production portfolio and volume of production
- Bill of materials for each vehicle and its corresponding parts
- Volumes and profit margins of different vehicle lines
- Pipeline inventories
- Time duration of a disruption
- **Firm‘s response after a disruption**
  - The response is simulated via optimization
• Introduction

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Visualizing a Simple Model

Plants

Parts

Nodes (conceptual)

Transition (between nodes)

Bill of Materials Diagram

P1 → P6

P2 → P7

P3 → P7

P4 → P8

P5 → P8
Model Formulation:

\[
\begin{align*}
\text{minimize} & \quad \sum_{j \in \mathcal{V}} f_j l_j \\
\text{s.t.} & \quad u_j - \sum_{i \in \mathcal{P}_{jk}} y_{ij} / r_{kj} \leq 0, \quad \forall k \in \mathcal{N}^- (j), \forall j \in \mathcal{D} \\
& \quad \sum_{j \in \mathcal{N}^+ (i)} y_{ij} - u_i \leq s_i, \quad \forall i \in \mathcal{U} \\
& \quad u_j = 0, \quad \forall j \in \mathcal{S}^{(n)} \\
& \quad l_j + \sum_{k \in \mathcal{V}_j} u_k \geq d_j t^{(n)}, \forall j \in \mathcal{V} \\
& \quad \sum_{k \in \mathcal{A}_\alpha} u_k \leq c_\alpha t^{(n)}, \forall \alpha \in \mathcal{A} \\
& \quad l_j, u_j, y_{ij} \geq 0.
\end{align*}
\]

- Each optimization problem corresponds to a single disruption scenario
- The optimization problems are linear programs
  - important because Ford is looking at tens of thousands of possible disruption scenarios
Model Formulation:

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\end{align*}
\]

Bill of Material Constraint

Total production at node j (corresponding to a part at a particular facility) is bounded by the volumes allocated from its upstream nodes.
Model Formulation:

minimize \( \sum_{j \in \mathcal{V}} f_j l_j \)

s.t. \( u_j - \sum_{i \in P_j k} y_{ij} / r_{kj} \leq 0, \quad \forall k \in \mathcal{N}^{-}(j), \forall j \in \mathcal{D} \)

\( \sum_{i \in \mathcal{N}^{+}(i)} y_{ij} - u_i \leq s_i, \quad \forall i \in \mathcal{U} \)

\( u_j = 0, \quad \forall j \in \mathcal{S}^{(n)} \)

\( l_j + \sum_{k \in V_j} u_k \geq d_j t^{(n)}, \quad \forall j \in \mathcal{V} \)

\( \sum_{k \in A_\alpha} u_k \leq c_\alpha t^{(n)}, \quad \forall \alpha \in \mathcal{A} \)

\( l_j, u_j, y_{ij} \geq 0. \)

Parts Allocation Constraint

Total allocation volume of node i is constrained by its production and its pipeline inventory.
Model Formulation:

\[
\begin{align*}
\text{minimize} & \quad \sum_{j \in \mathcal{V}} f_j l_j \\
\text{s.t.} & \quad u_j - \sum_{i \in \mathcal{P}_{jk}} y_{ij} r_{kj} / r_{kj} \leq 0, \quad \forall k \in \mathcal{N}^{-}(j), \forall j \in \mathcal{D} \\
& \quad \sum_{j \in \mathcal{N}^{+}(i)} y_{ij} - u_i \leq s_i, \quad \forall i \in \mathcal{U} \\
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Disruption Constraint
Production of node \( j \) is halted due to disruption
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Demand loss constraints

Loss of production for vehicle $j$ is lower bounded by the demand minus the production over the TTR duration.
Model Formulation:

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\begin{align*}
\text{minimize} & \quad \sum_{j \in \mathcal{V}} f_j l_j \\
\text{subject to} & \quad u_j - \sum_{k \in \mathcal{P}_{jk}} y_{ij} / r_{kj} \leq 0, \quad \forall k \in \mathcal{N}^-(j), \forall j \in \mathcal{D} \\
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Production capacity constraints
Total production of all nodes at site/plant \( \alpha \) is bounded by its capacity
Performance Impact of Different Supplier’s Sites

Another 2773 sites with No Impact
Performance Impact and Total Spent at Supplier Site
Supplier Sites Segmentation

- Long Term Contracts
- Track Inventory
- Partnership
- Risk Sharing Contracts
- Track Performance
- Require Multiple Sites
- Inventory
- Dual Sourcing
- New Product Design
Time-to-Recover (TTR): The time for a node in the supply chain to return to full functionality after a disruption.

Time-to-Survive (TTS): The maximum duration that the supply chain can match supply with demand after a node disruption.

\[ TTR(j) < TTS(j) \text{ for all nodes } (j) \]

Robust Supply Chain
In the TTS formulation, $t^{(n)}$ changes from a constant to a variable, and is being maximized.
Time-to-Survive across all Ford Tier 1 suppliers
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Development of a Decision Support System for Risk Management

- **Risk Analysis--Strategic**
  - Identify Exposure to Risk associated with parts and suppliers
  - Prioritize and allocate resources effectively
  - Segment suppliers and develop mitigation strategies
  - Identify opportunities to reduce risk mitigation cost

- **Track changes in Risk Exposure--Tactical**
  - Alert procurement executives to changes in their risk position

- **Respond to a Disruption--Operational**
  - Identify an effective way to allocate resources after a disruption
System Architecture

- Central Repository (SQL Server)
  - Supply chain mapping (Java Graph ETL)
  - Model interface
    - Risk exposure model (Java-CPLEX)
- Data Visualization (Tableau)
- Vehicle Volume Planning System
- Materials Planning & Logistics
- Purchasing System
- Vehicle Profit Margins
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Materials Planning & Logistics

Supply chain mapping (Java Graph ETL)

Central Repository (SQL Server)

Model interface

Risk exposure model (Java-CPLEX)

Data Visualization (Tableau)
# Generating Critical Supplier List

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Vehicle Impacted</th>
<th>Total Part Cost</th>
<th>Financial Impact</th>
<th>Volume Impact</th>
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Critical Suppliers in Japan

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Benefits to Ford

- Provided an internal proactive tool for risk management

- Generated critical supplier list / part list
  - Previously, Ford monitored 1500 supplier sites
  - The model identified 2600 suppliers’ sites, up to $2.5 billion risks on revenue
  - Among the 2600 sites, 1100 sites were monitored by Ford
    - Identified 1500 new sites that are not currently monitored
    - About 400 sites has been assessed as low risks

- Examples of the model in practice
  - Risk model identified a sensor that has high vehicle exposure and is being supplied by two sites globally. The commodity team acknowledged the sourcing concentration and has investigated alternatives
  - For the fastener commodity, the model enabled Ford to prioritize parts based on exposure level and triggered further investigation. Our investigation segment industry standard parts with short TTR into low-risk while special or unique fasteners into potential high-risk category
  - Ford Supply Risk Specialists use the model routinely to prioritize commodities and supplier sites that represent the highest level of exposure during potential disruption events (i.e. Natural disasters, Labor Strikes, Political Unrest, etc.), enabling efficient use of resources
Acknowledgement

- Ford Purchasing – Steve Faraci
- Ford IT – John Knowles and Dong Ruan
- Ford Research – John Ginder
- Ford – MIT Alliance
Thank you!

Any Questions?