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Trends in Aerospace Supply Chains

Presented at TRAM 2009

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University of Alabama in Huntsville

Massachusetts Institute of Technology

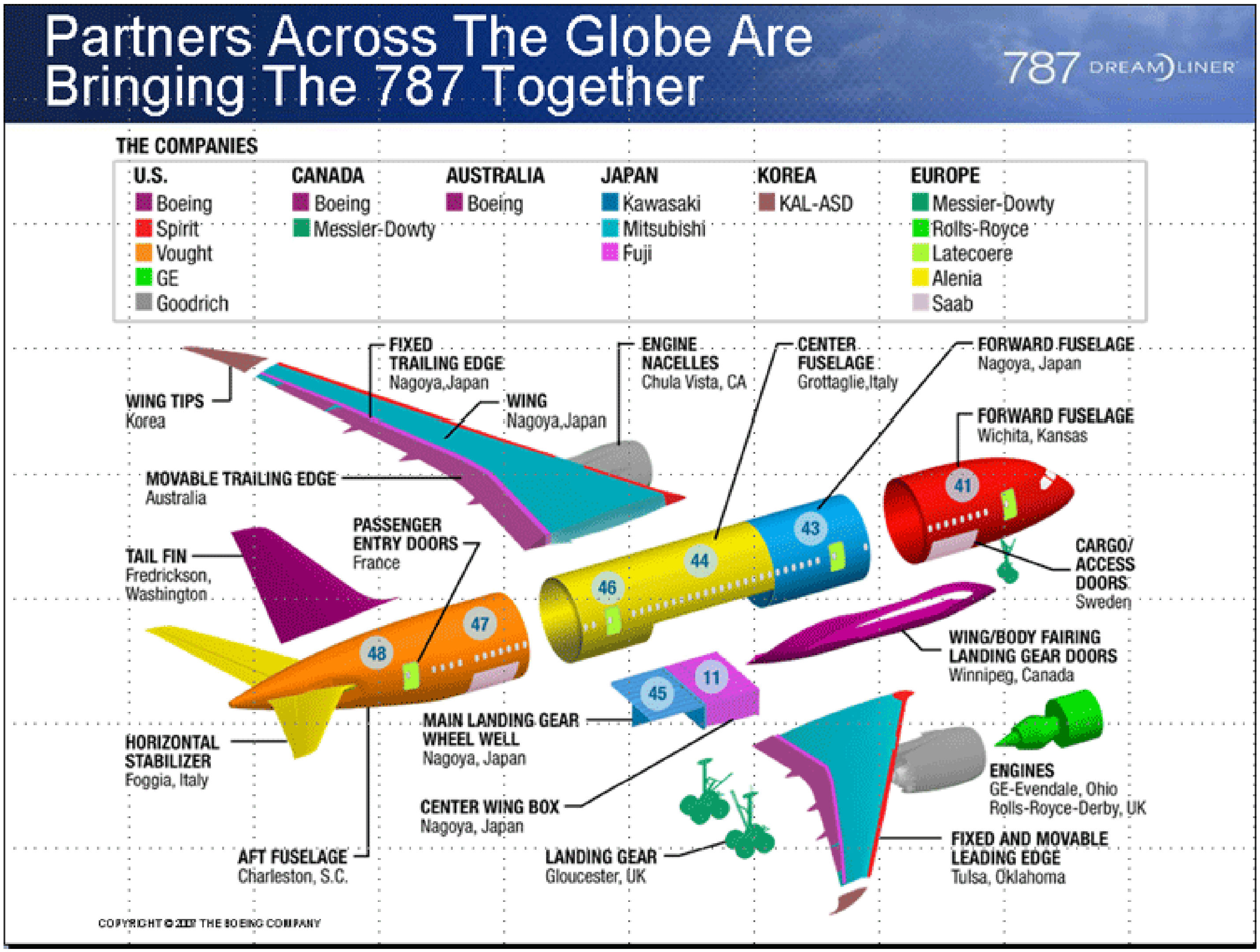
10 September 2009

Managing The Extended Supply Chain

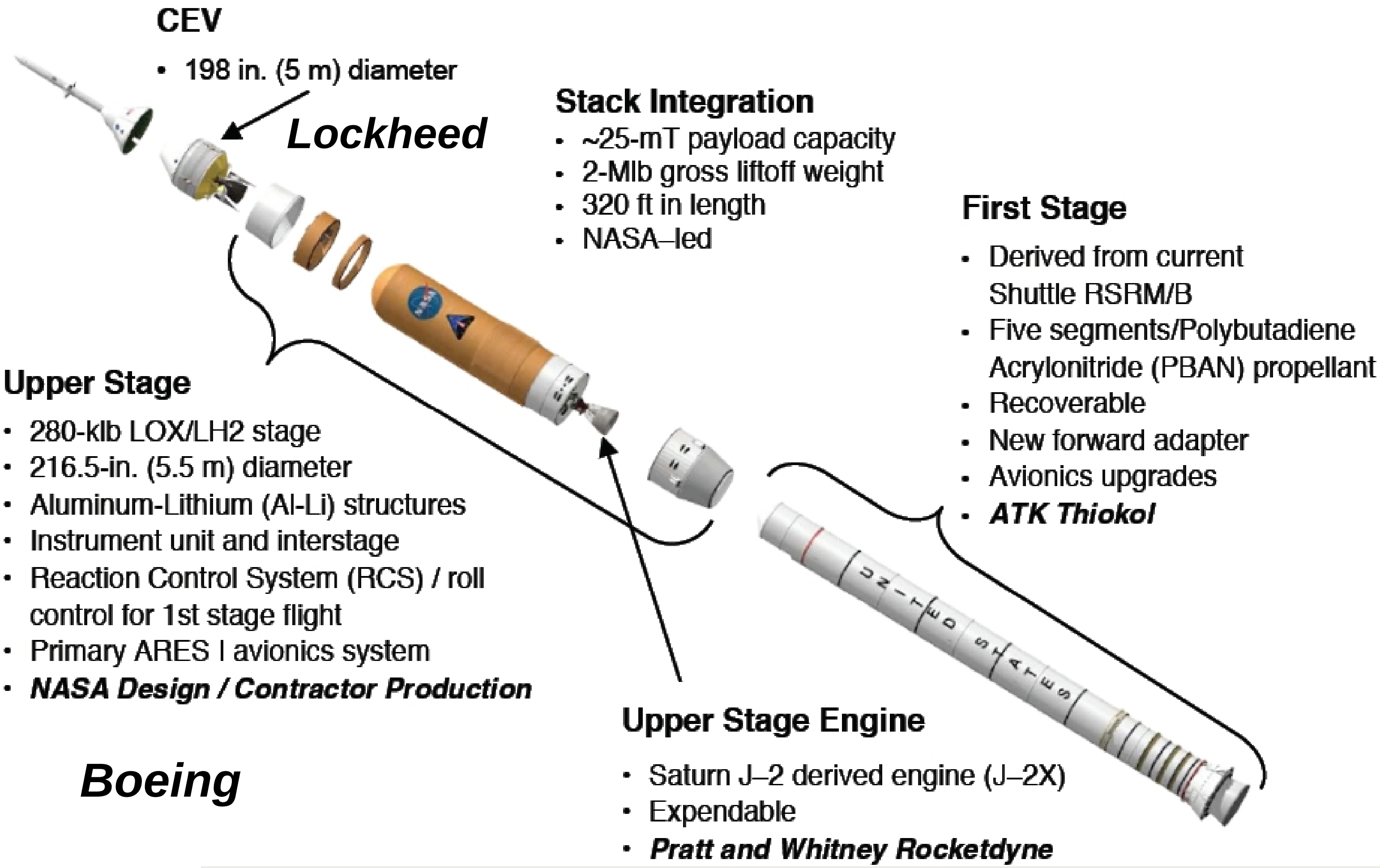
- **Strategic Trends Shaping Industry and Government**
  - **Growing Specialization and Focus on Core Competencies;**
  - **Outsourcing in the Search for Lower Costs;**
  - **Continuing Movement Towards Globalization and the Capture of Market Share in Global and Emerging Markets**

- **Resulting Enterprise Structure and Challenges**
  - **Manufacturers and Prime Contractors Have Become Integrators, Assemblers & Business Managers;**
  - **Hundreds of Companies and Organizations Now Work Together to Deliver Value to the Customer;**
  - **Critical Need for Integrated Management, Visibility, Coordination and Collaboration**

The Boeing 787: An Example of a Global Supply Chain



The NASA Ares I Enterprise



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Challenges & Risks in Enterprise Supply Chain Management

- **Rapidly Changing Customer Requirements and Demands**
- **Fast Moving Technologies and Competitors**
- **Growth of Complex Multi-Tier, Multi-Channel Supply Chains**
- **Technologies Often Developed by Lower Tier Suppliers**
- **Management and Verification of Quality and Processes**
- **Lack of Communication & Visibility in Supply Chains**
- **Shrinking Supplier Base & Industrial Capacity**
- **Long Lead Times for Many Materials and Components**
- **Long Lifetimes and Obsolescence of Parts**
- **Increasingly Tight Schedules and Deadlines – Time is Money**
- **Material and Parts Assurance -- Counterfeits**

Four Important Trends in Aerospace Supply Chain Management

- Detailed Mapping of Extended Supply Chains
- Use of Push-Pull Boundaries & Optimization for Cost Effective Responsiveness
- Modeling and Simulation of Dynamic Performance
- Track and Trace for Supply Chain Visibility, Material and Parts Assurance, and Configuration Management

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Supply Chain Maps

Identifying Waste, Bottlenecks & Risks

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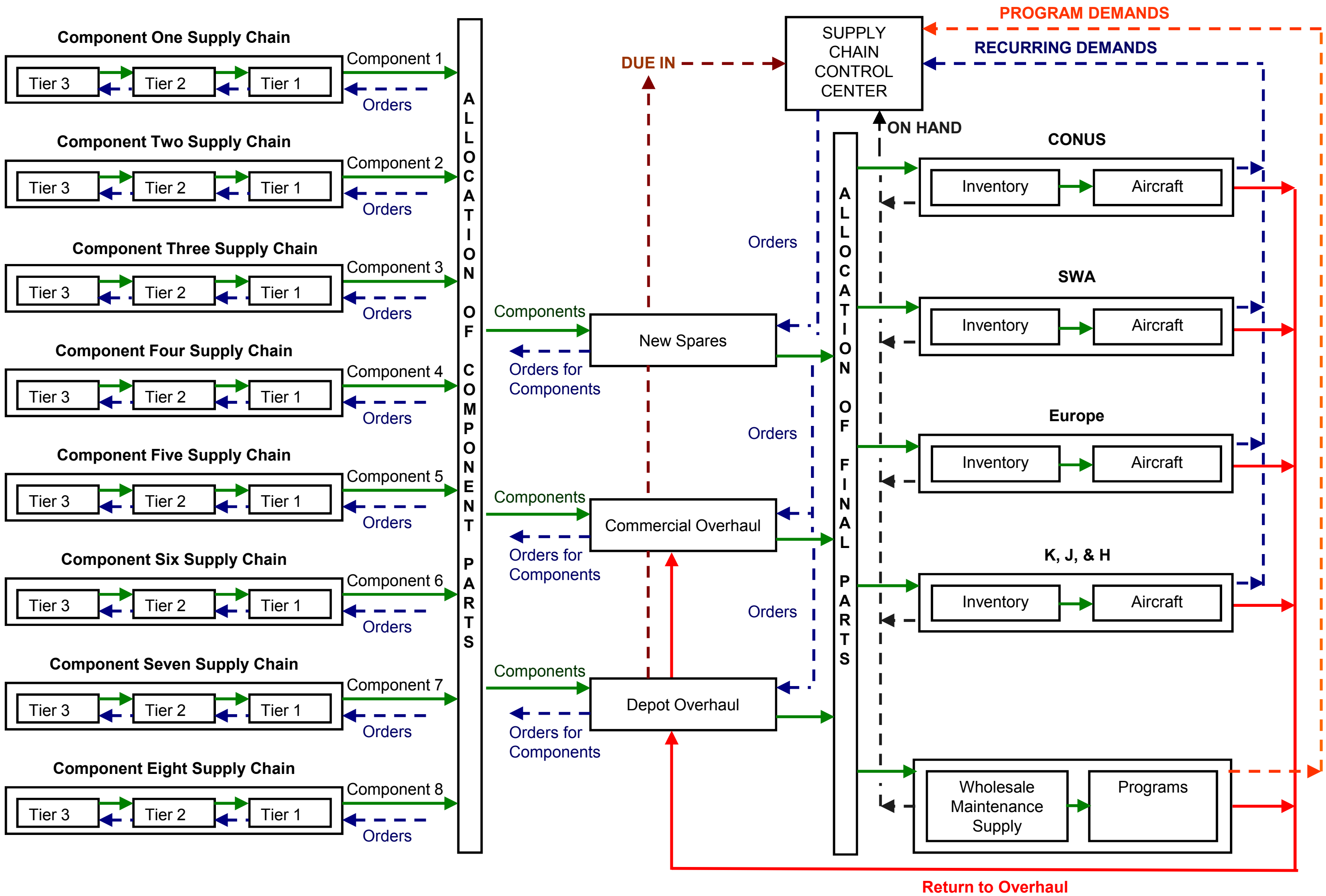
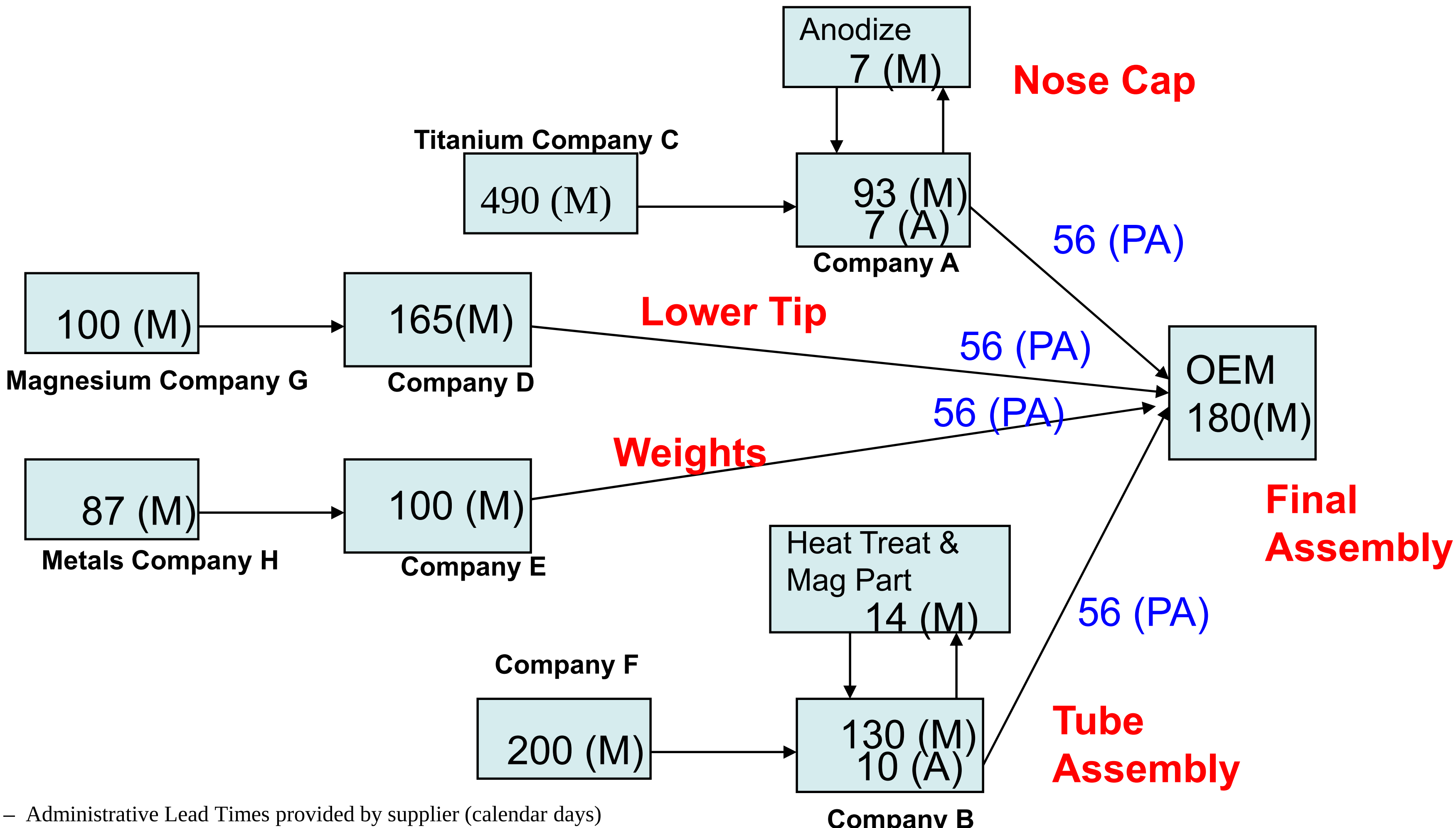
Overview of Global Enterprise Supply Chain



Example Maps of Multi-Tier, Multi-Channel Supply Chains for Aerospace Parts

Detailed Supply Chain Map for Blade Assembly (1 of 2)



Notes:

(A) – Administrative Lead Times provided by supplier (calendar days)
(M) – Manufacturing Lead Times provided by supplier (calendar days)
(PA) – Prime Administrative Lead Times including dock to stock time (calendar days)

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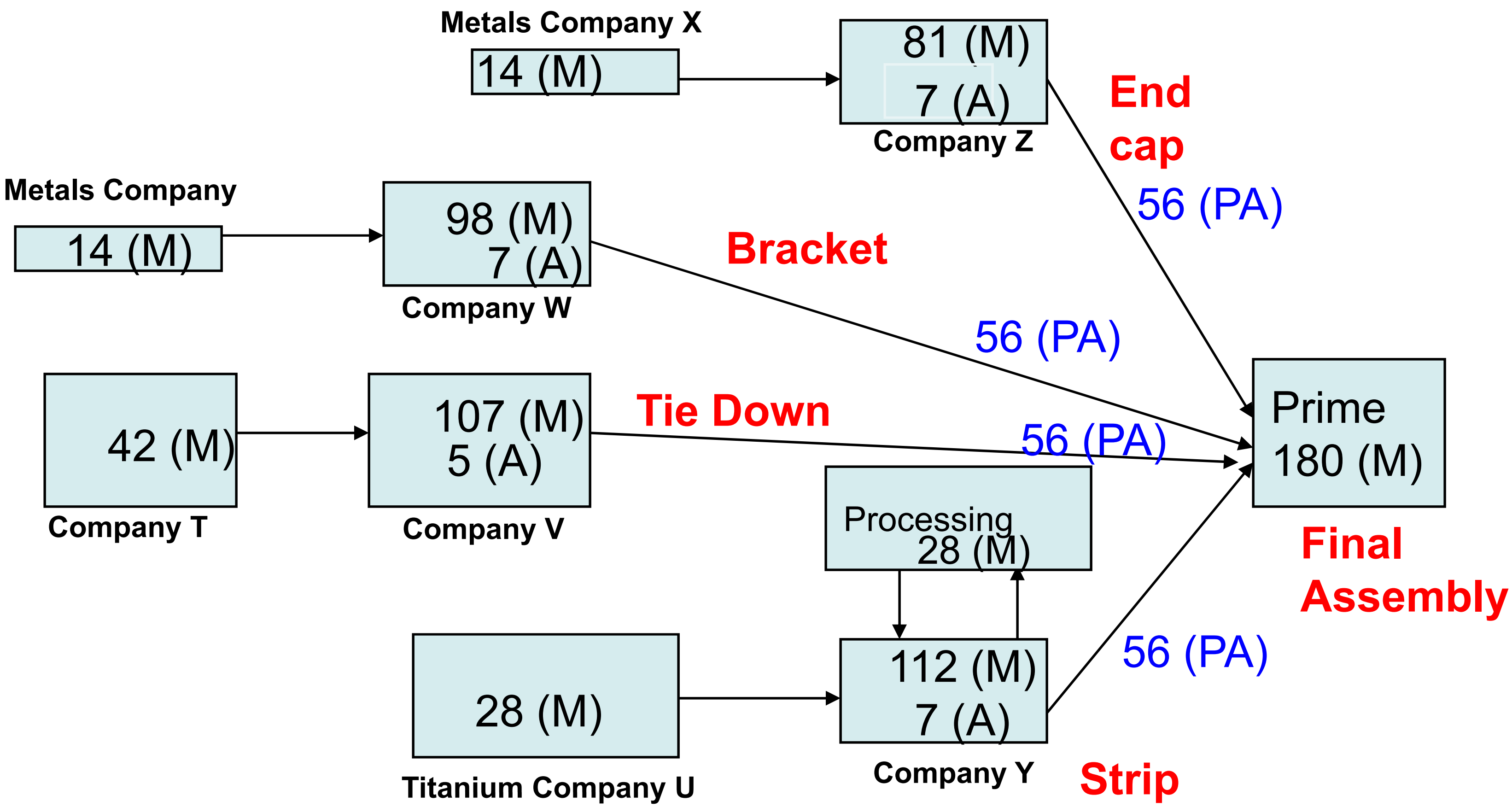
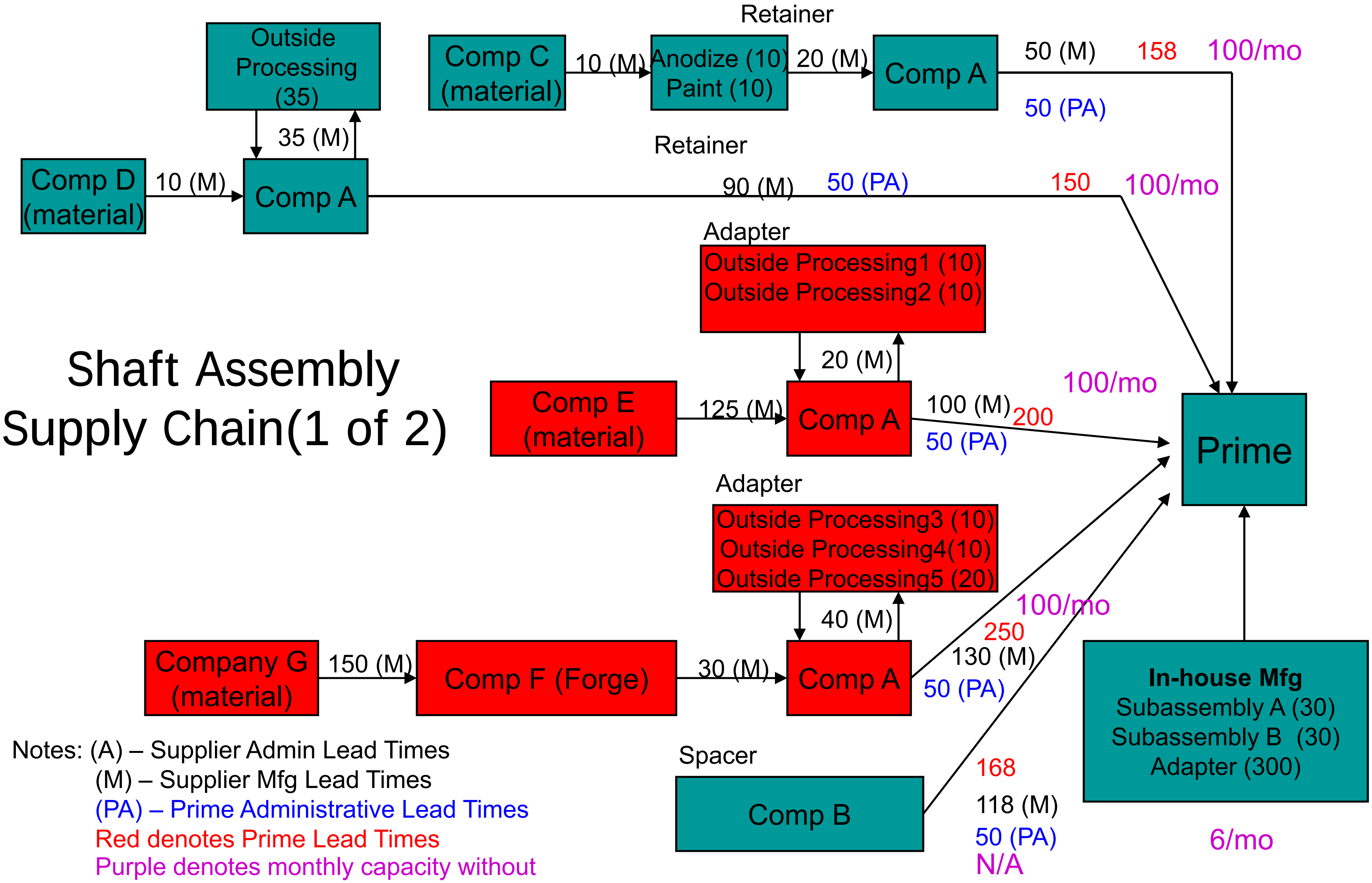
Detailed Supply Chain Map for Blade Assembly (2 of 2)



Notes:

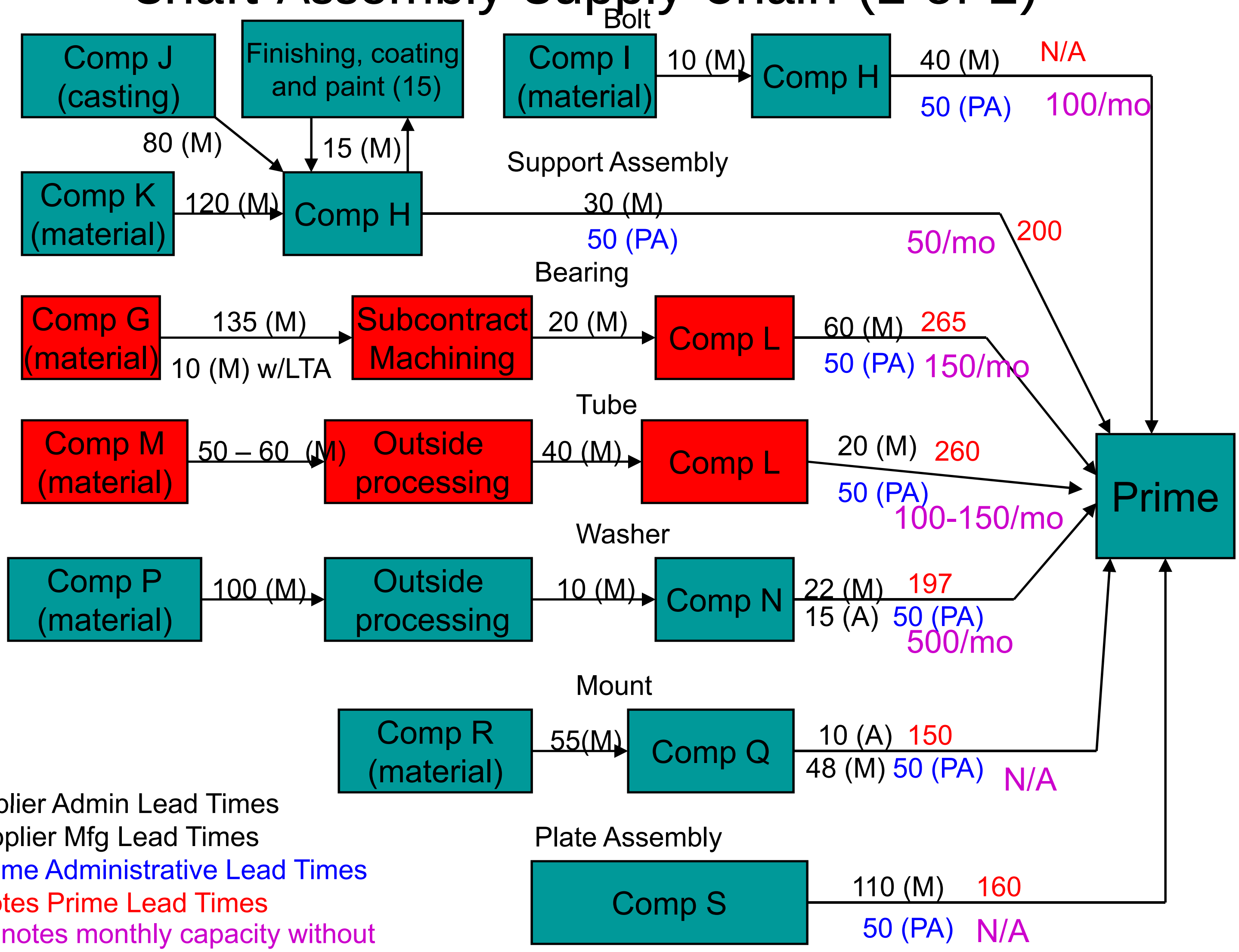
(A) – Administrative Lead Times provided by supplier (calendar days)
(M) – Manufacturing Lead Times provided by supplier (calendar days)
(PA) – Prime Administrative Lead Times including dock to stock time (calendar days)

Shaft Assembly Supply Chain(1 of 2)



Notes: (A) – Supplier Admin Lead Times
(M) – Supplier Mfg Lead Times
(PA) – Prime Administrative Lead Times
Red denotes Prime Lead Times
Purple denotes monthly capacity without impact to normal through put

Shaft Assembly Supply Chain (2 of 2)



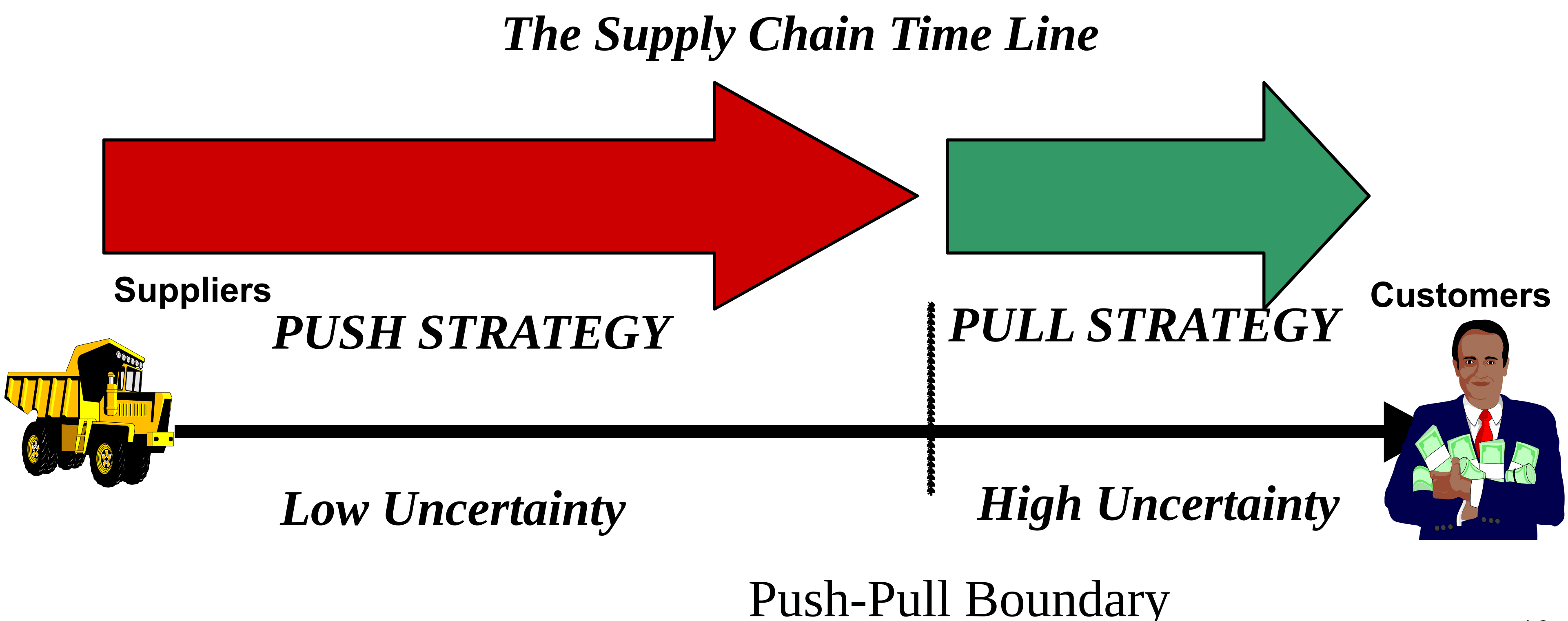
Notes: (A) – Supplier Admin Lead Times
(M) – Supplier Mfg Lead Times
(PA) – Prime Administrative Lead Times
Red denotes Prime Lead Times
Purple denotes monthly capacity without impact to normal through put

Summary Comments: Mapping the Supply Chain

- Identifies Bottlenecks and Constraints
- Reveals Wastes at the Interfaces
- Serves as Foundation for Supplier Conferences and Collaborative Planning
- Enables Creation of Lean Supply Chains
- Highlights Risks and Opportunities for Risk Management

Use of Push-Pull Boundaries and Optimizaton for Cost Effective Responsiveness

A Key Supply Chain Strategy:
Establishing a Push-Pull Boundary



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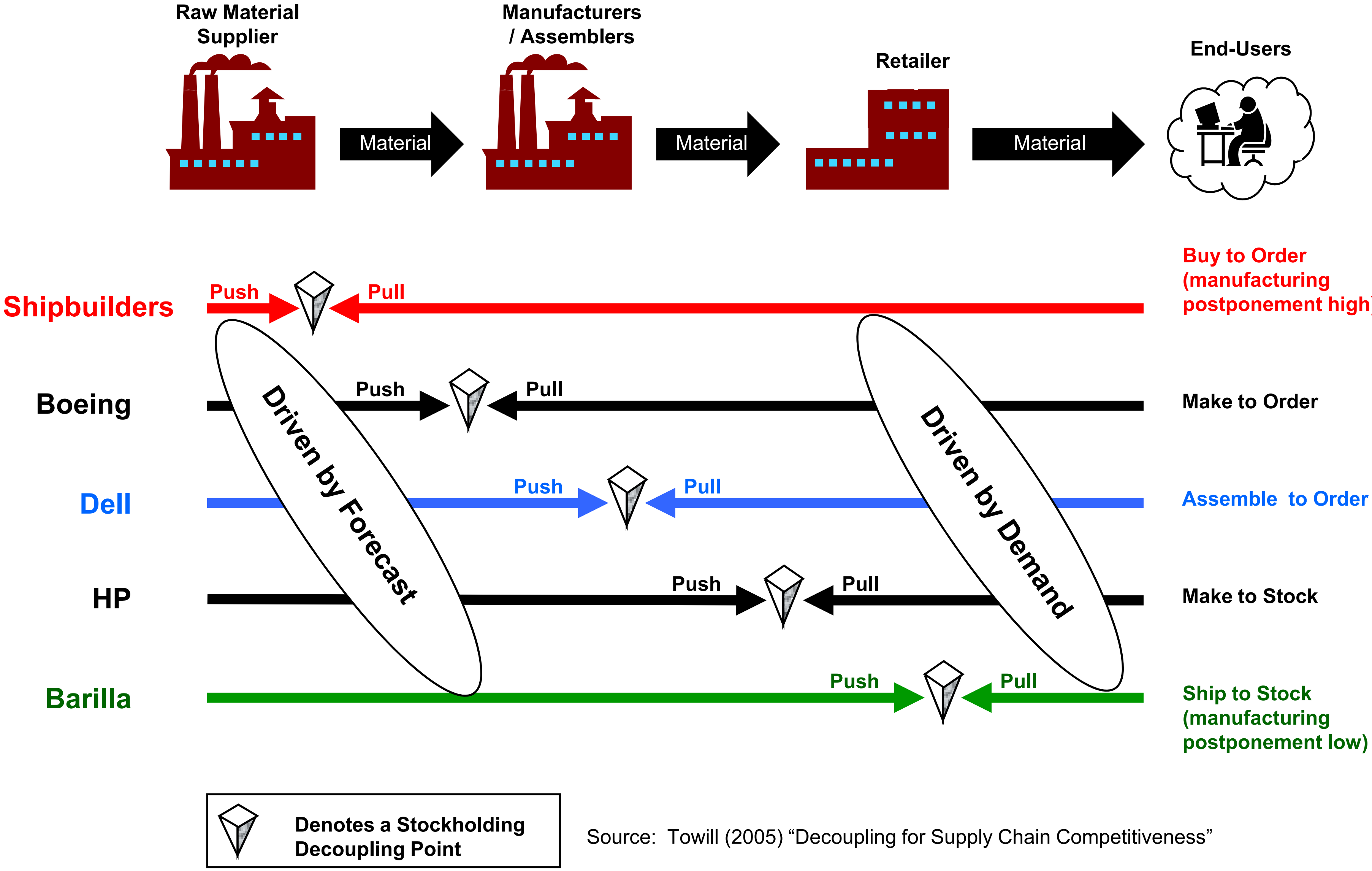
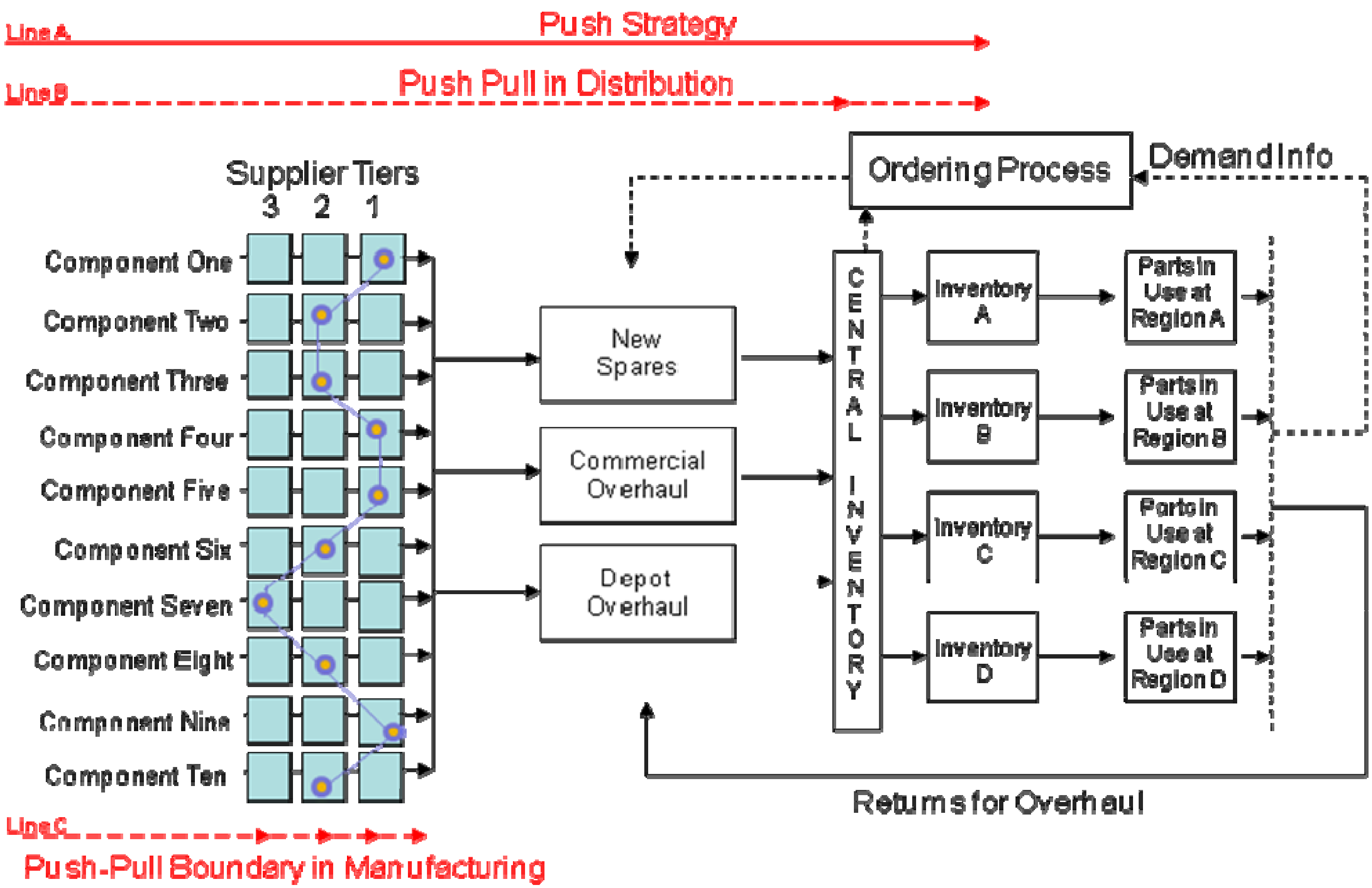
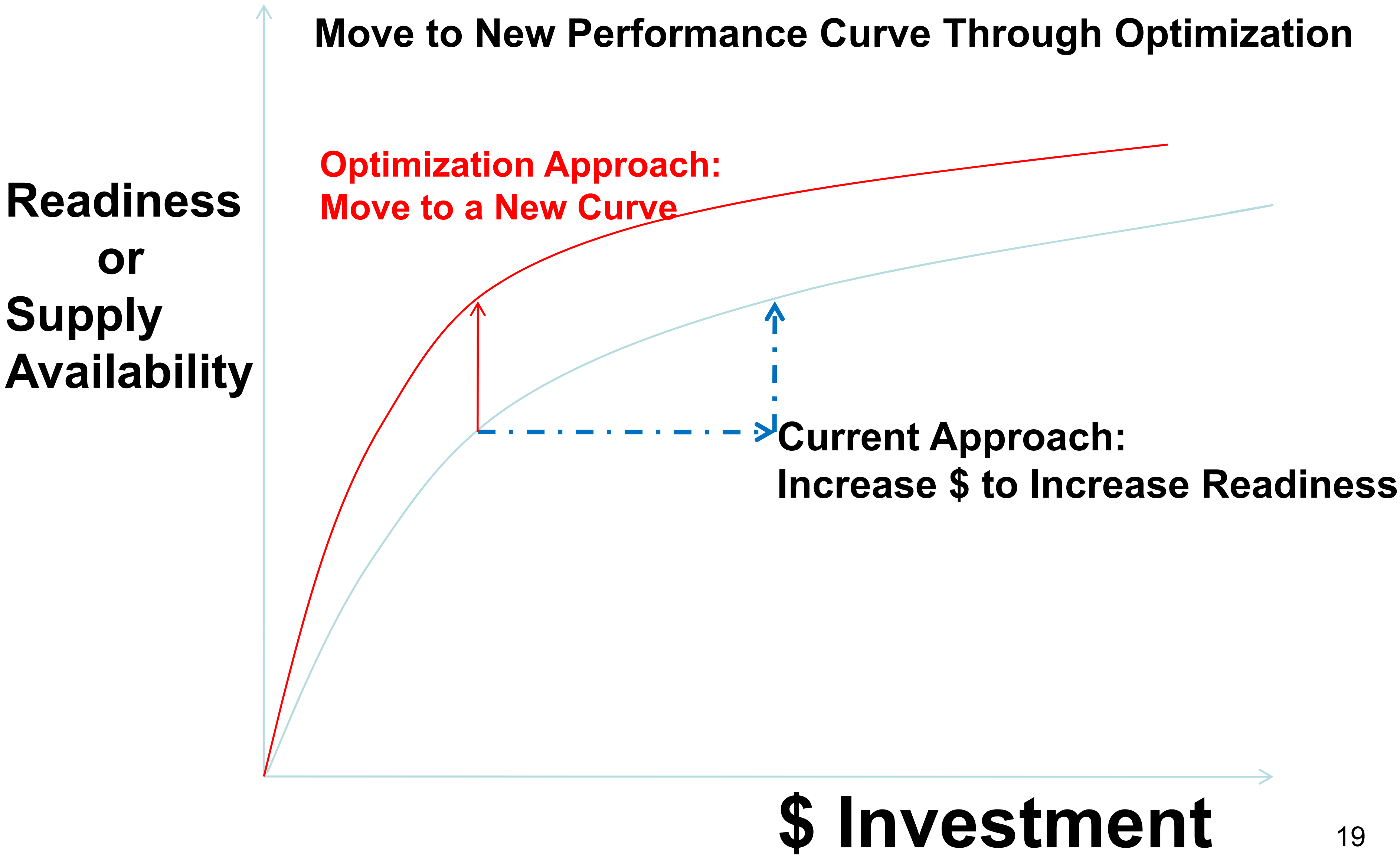
PUSH – PULL SUPPLY CHAINS



Source: Towill (2005) “Decoupling for Supply Chain Competitiveness”


Line A
Push Strategy
Line B
Push Pull in Distribution
Supplier Tiers
3 2 1
Component One
Component Two
Component Three
Component Four
Component Five
Component Six
Component Seven
Component Eight
Component Nine
Component Ten
New Spares
Commercial Overhaul
Depot Overhaul
Ordering Process
Demand Info
CENTRAL INVENTORY
Inventory A
Inventory B
Inventory C
Inventory D
Parts in Use at Region A
Parts in Use at Region B
Parts in Use at Region C
Parts in Use at Region D
Returns for Overhaul
Line C
Push-Pull Boundary in Manufacturing

Move to New Performance Curve Through Optimization



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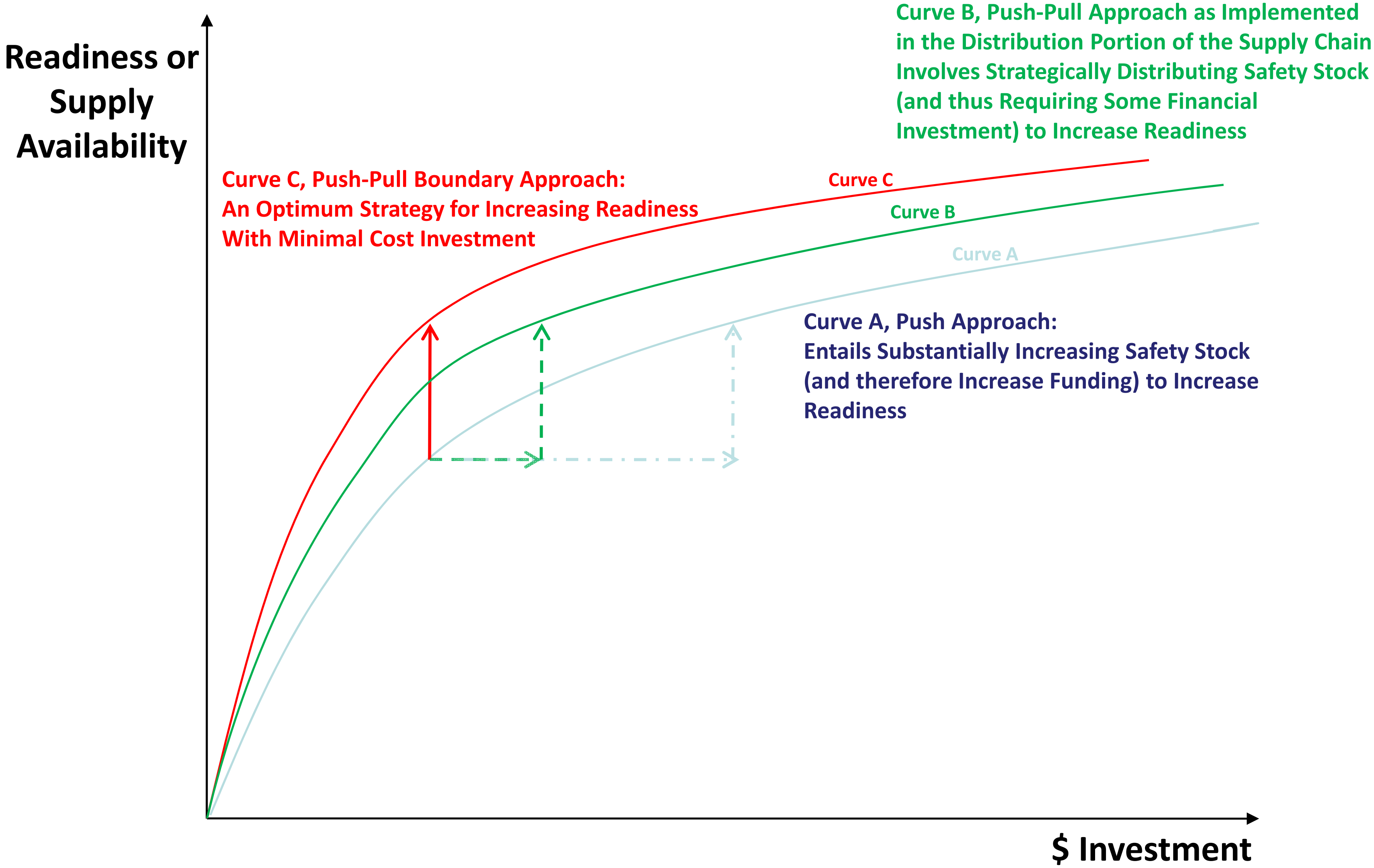
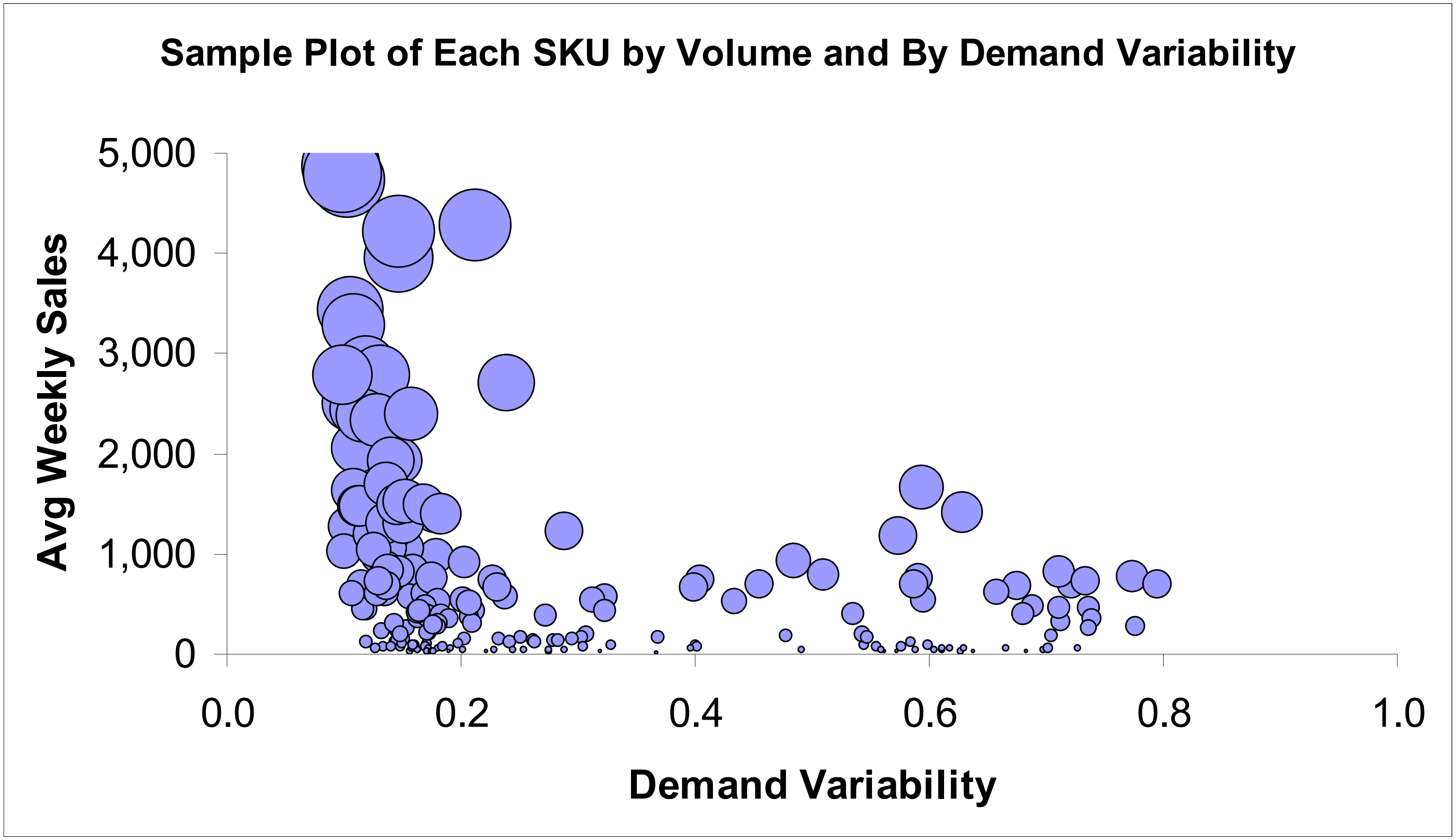
Dollars Invested versus Readiness/Supply Availability

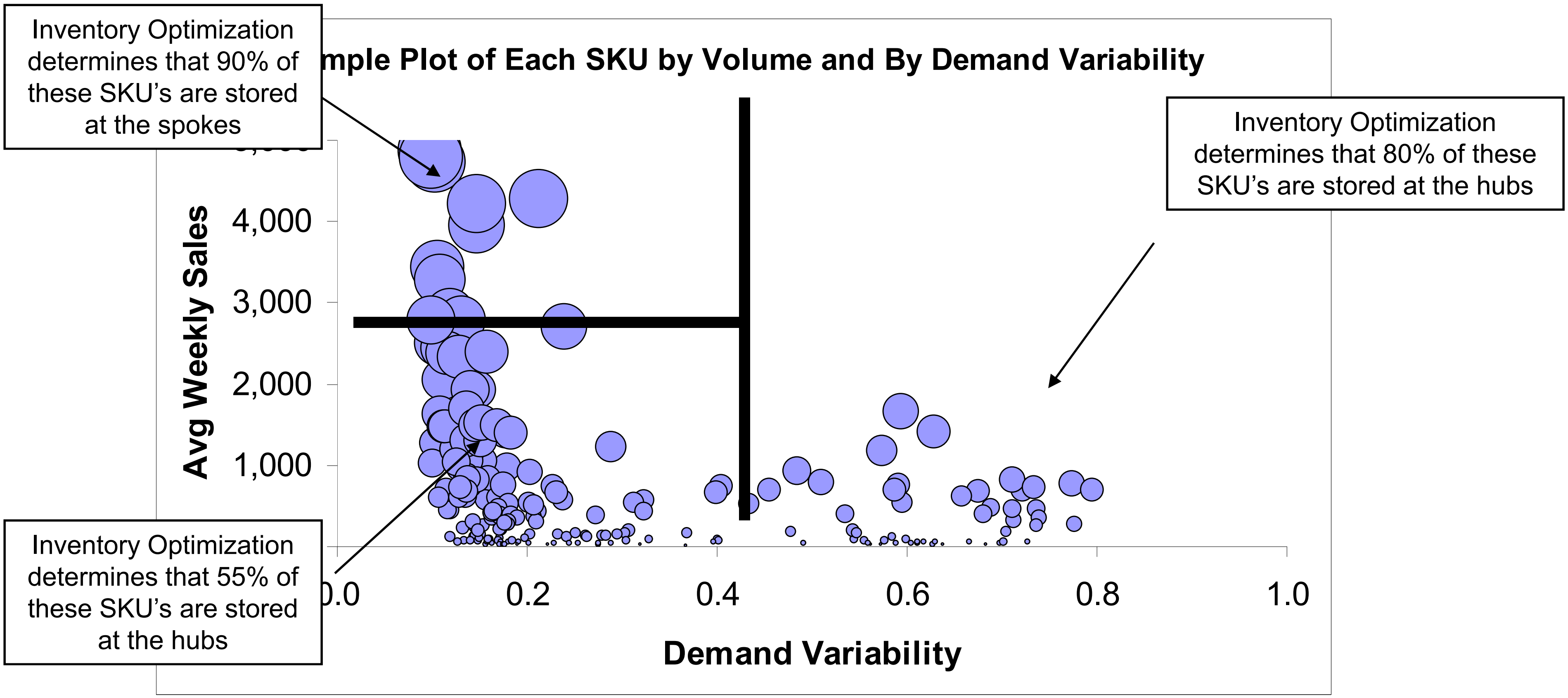


Push-Pull in Distribution

Demand Variability for Typical Product



Inventory Optimization Can Even Determine Specific Hub and Spoke Strategies by SKU



This is for a product family of SKU's within the 40,000 SKU's.
Each circle represents a SKU
Other drivers include supplier lead time, lead time variability, review period

Inventory Optimization for Performance Based Logistics

Inventory Maintained at Central Hub Distribution Center

Base Assumptions for Operations

- **Unit is installed on 98 aircraft;**
- **41 Flight Hours per Month;**
- **MTBF equals 700 Hours;**
- **Customer Specified Base Fill Rate is 85%;**
- **Repair Time Equals 6 Weeks;**
- **New Spare Price Equals Overhaul price, $250,000;**
- **New Spare Production Cost Equals New Spare Price, $250,000;**
- **Overhaul Cost is $20,000;**
- **Shipping Time = 1 Day;**
- **Carcasses are Readily Available for Repair when Needed;**
- **Holding Cost = 10%;**
- **Demand Uncertainty (σ) is Equal to Monthly Demand.**

Optimum Inventory for Alternative Cases

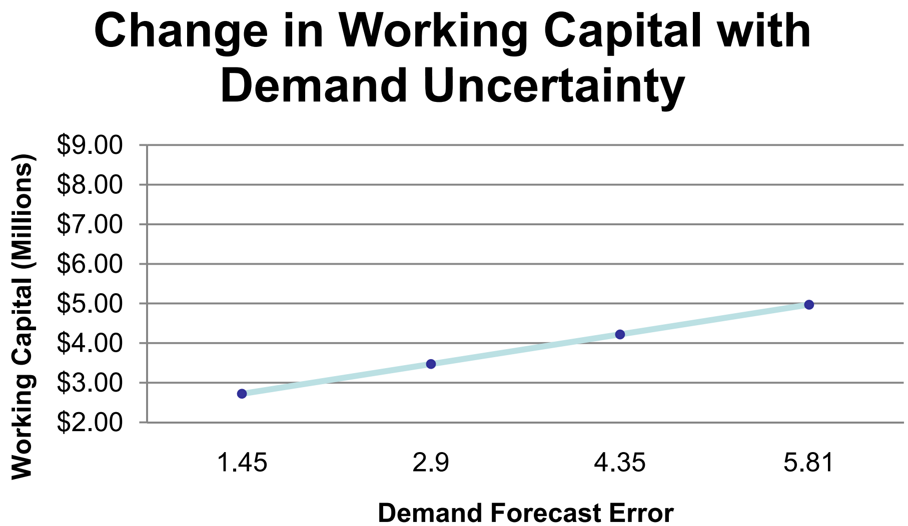
Higher Demand Value

	Low	Medium	High
Table A			
MTBF (hours)	800	700	569
Fill Rate (%)	80	85	95
Optempo (hours)	25	41	50
Cost (M)	200	225	265
CONUS Demand σ	2.98	5.69	8.56
Demand σ/μ	1	1	1
RRLT (weeks)	6	10	12
Working Capital (M)	$1.94	$6.50	$14.86
Safety Stock	4.83	14.7	31.41
Base Inventory	3.04	5.81	8.56
WIP Repair	1.83	8.38	16.09

Lower Demand Value

	Low	Medium	High
Table B			
MTBF (hours)	800	700	569
Fill Rate (%)	80	85	95
Optempo (hours)	25	41	50
Cost (M)	200	225	265
CONUS Demand σ	1	3.75	8.56
Demand σ/μ	0.33	0.66	1
RRLT (weeks)	6	10	12
Working Capital (M)	$1.14	$5.37	$14.86
Safety Stock	0.83	9.7	31.41
Base Inventory	3.04	5.81	8.56
WIP Repair	1.83	8.38	16.09

Sensitivity Analysis for Demand Forecast Error (σ)



Demand Forecast Error	Working Capital (M)	Safety Stock	Base Inv	WIP Repair
1.45	$2.72	2.06	5.81	3.02
2.9	$3.47	5.06	5.81	3.02
4.35	$4.22	8.06	5.81	3.02
5.81	$4.97	11.06	5.81	3.02

Key Assumptions

FH/month	Fill Rate	MTBF	Repair LT	Repair Cost	New Spare Cost	Holding Cost
41	85	700	6 weeks	$20K	$250K	10%

Push-Pull in Manufacturing

Key Assumptions

- There are nine critical items in the blade supply chain (Nose Cap, Two Tube Assemblies, Tip Lower, End Cap, Strip, Tie Down, Weight, Bracket)
- All other items are categorized as "Remaining Items"
- The cost of the blade is $175,790
  - The OEM pays 50% of that cost for the parts needed to assemble a blade, broken down as follows:
    - The Nose Cap and End Cap each comprise 15% of the OEM's's cost for the entire blade
    - The two Tube Assemblies and the Tip Lower each comprise 10% of the OEM's cost for the entire blade
    - The Strip, Tie Down, Weight, and Bracket each comprise 5% of the OEM's cost for the entire blade
    - The remaining 20% is the cost of the "remaining items"
  - First tier suppliers pay 50% of the OEM's cost for the parts needed to assemble their products

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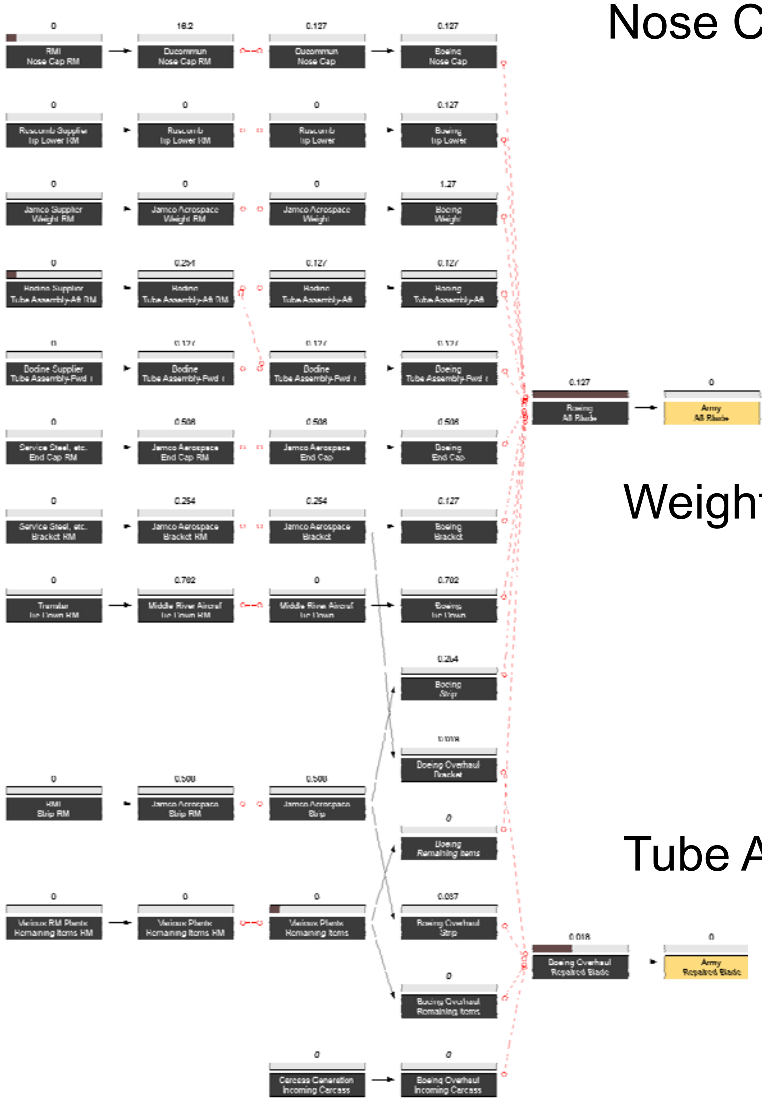
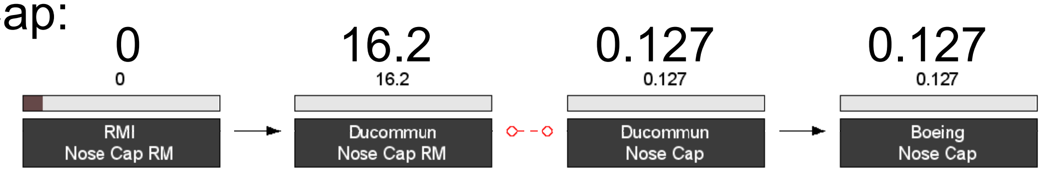
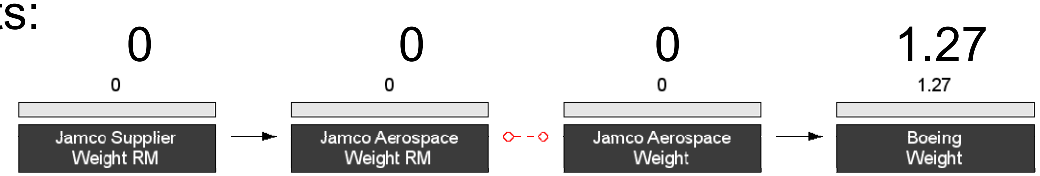
Committed Service Time: 750 days



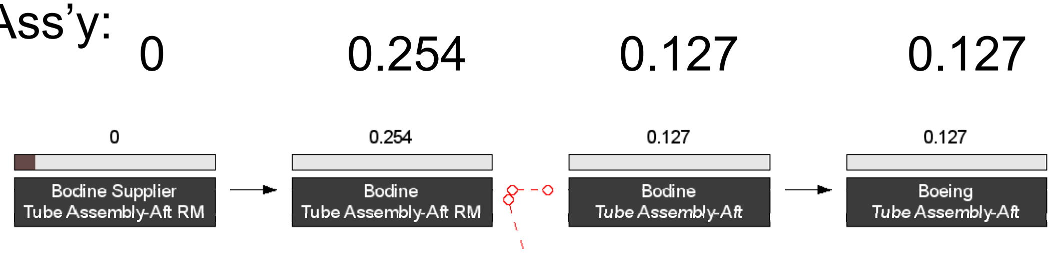
Nose Cap:



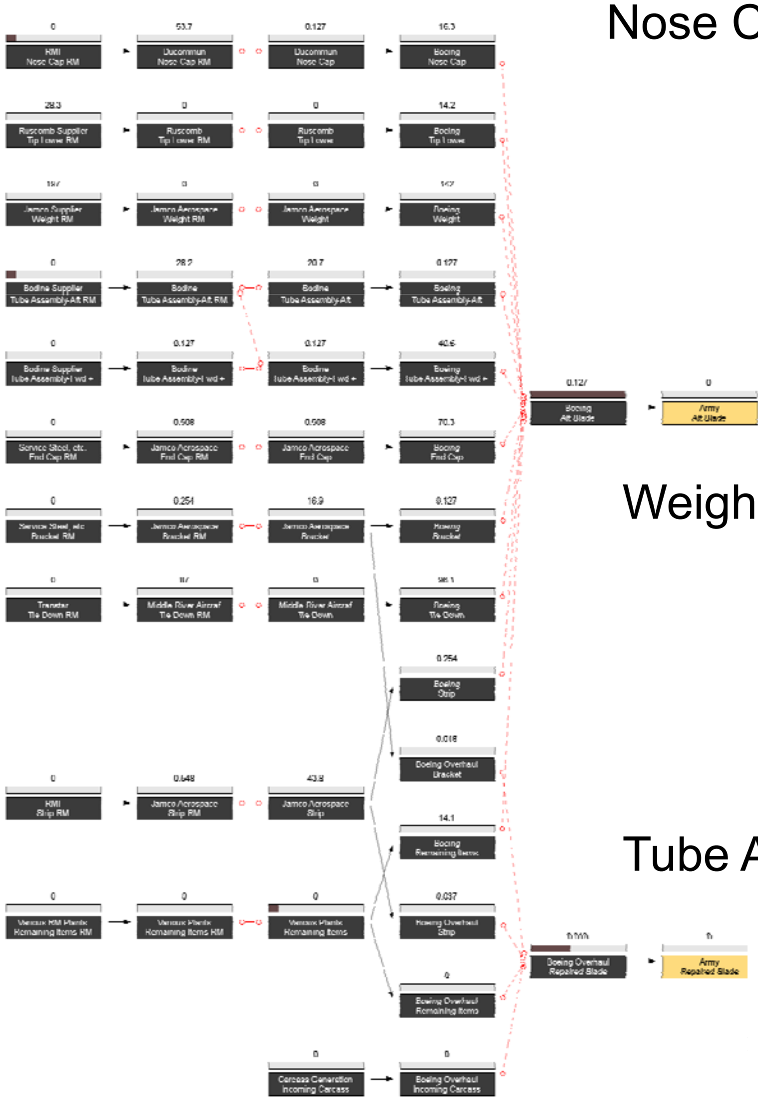
Weights:



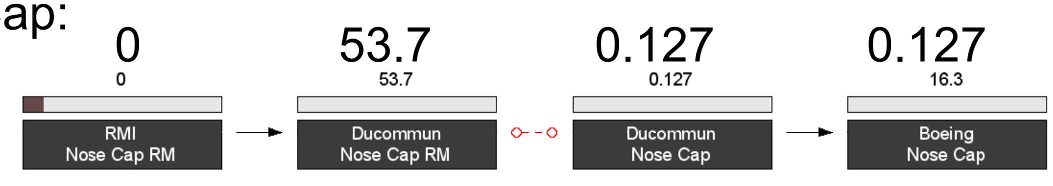
Tube Ass'y:



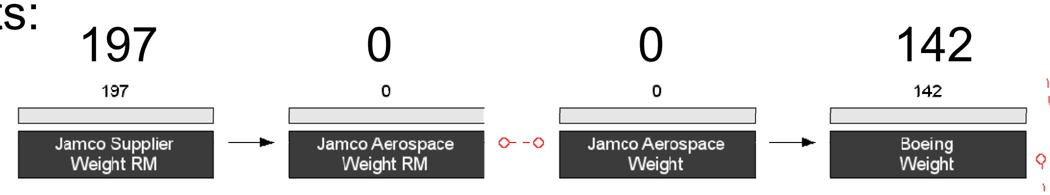
Committed Service Time: 240 days



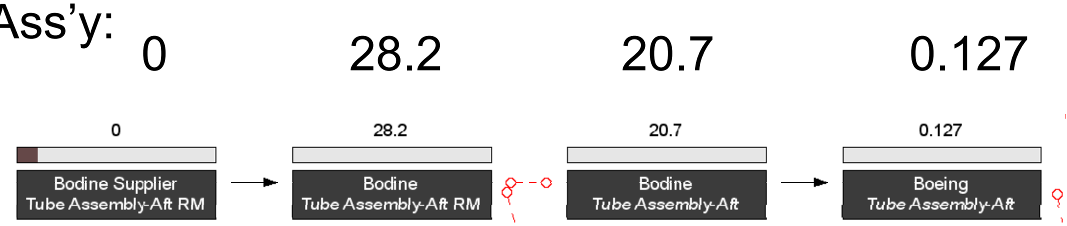
Nose Cap:



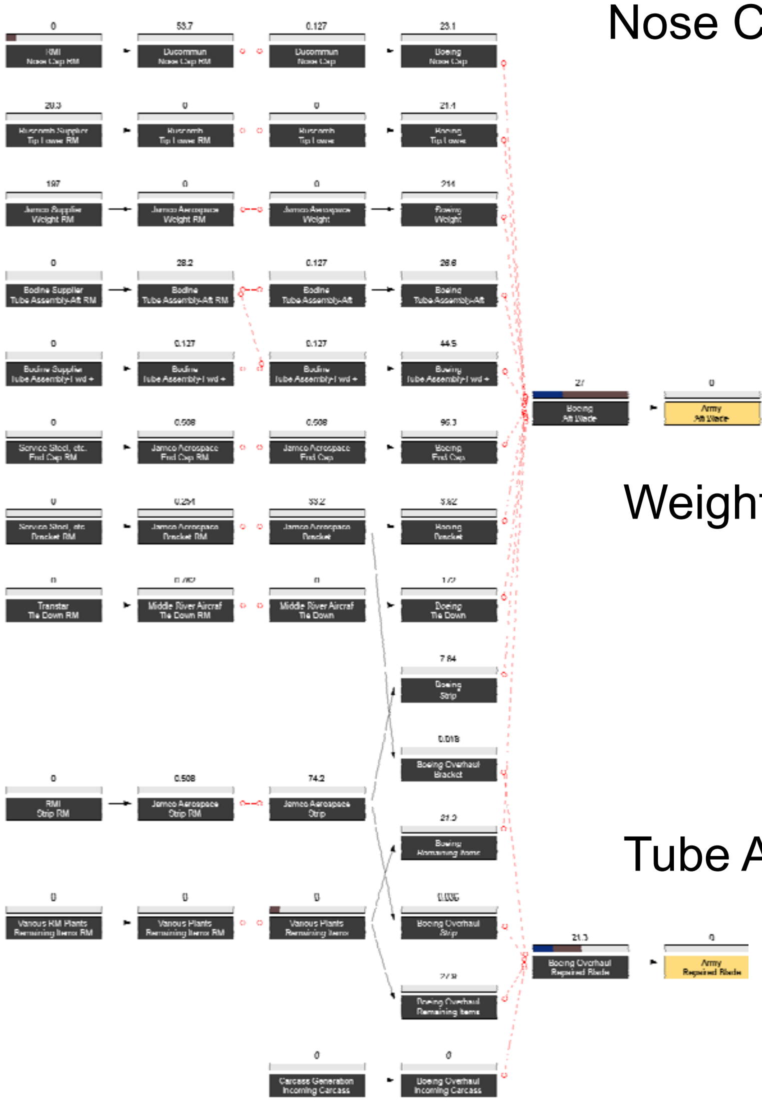
Weights:



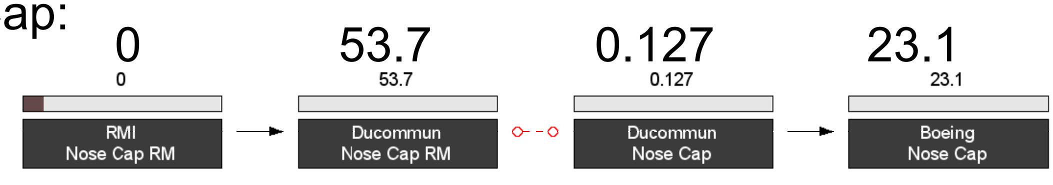
Tube Ass'y:



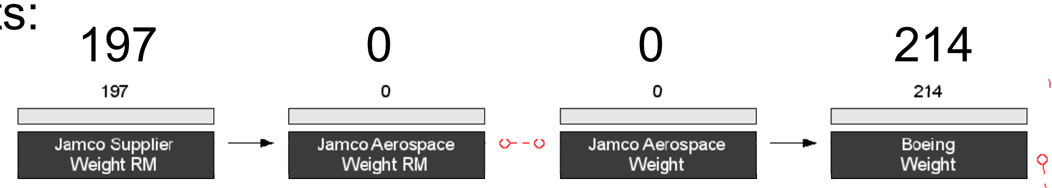
Committed Service Time: 30 days



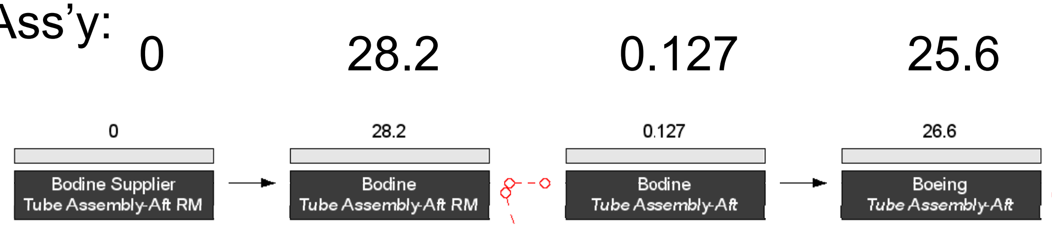
Nose Cap:



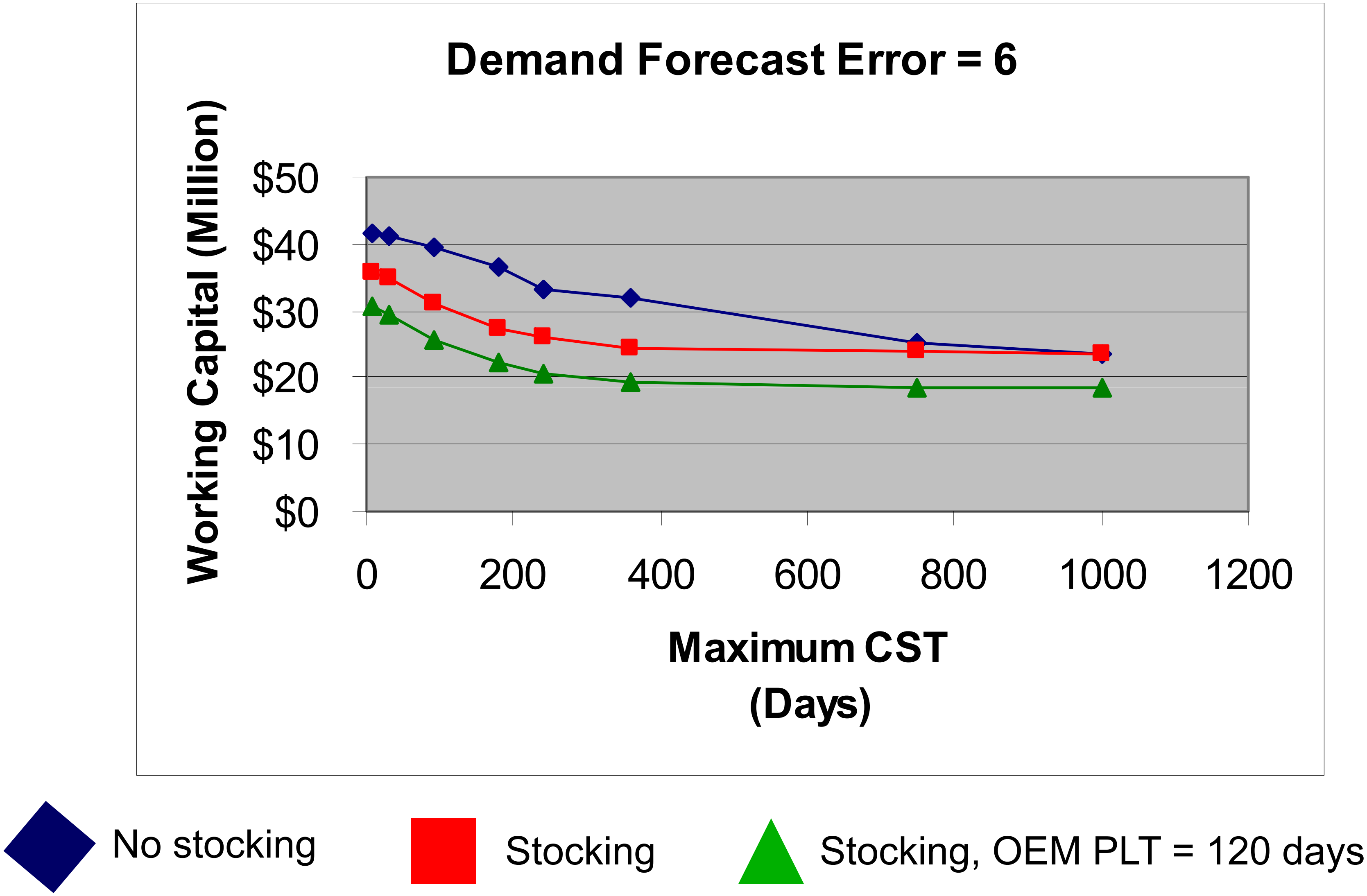
Weights:



Tube Ass'y:



Working Capital Vs. Customer Service Time



Inventory Analyst Conclusions

- Increasing safety stock levels in the manufacturing supply chain can both reduce lead times and reduce the amount of working capital invested to achieve desired service times;
- Increasing safety stock levels even for the one component with the greatest lead time produces noteworthy results;
- Increasing safety stock levels furthermore reduces the risk of shortages and longer lead times in the event of an unexpected increase in demand, a problem that has existed for aviation spares.

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Use of Dynamic Models to Evaluate Supply Chain Strategies

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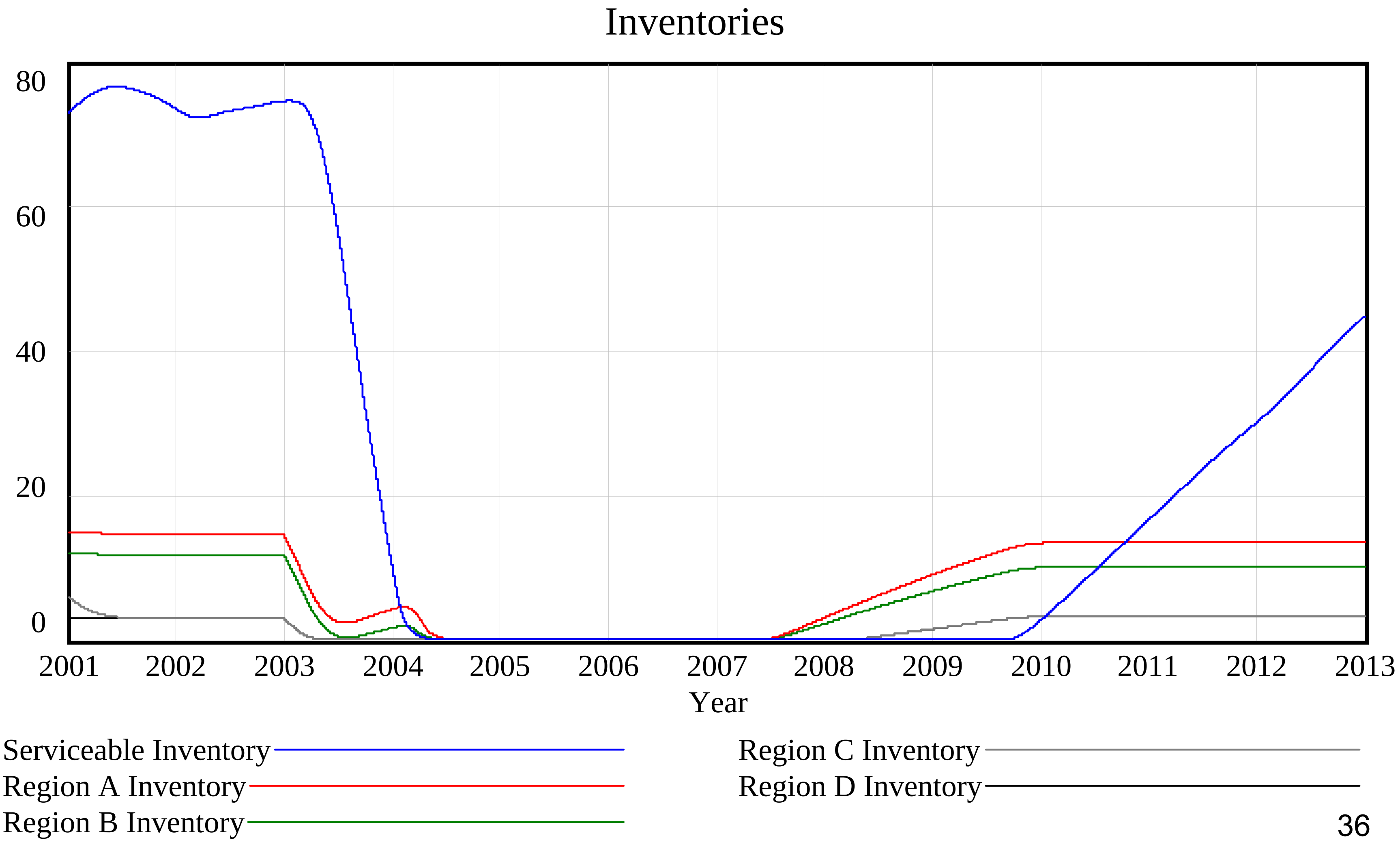
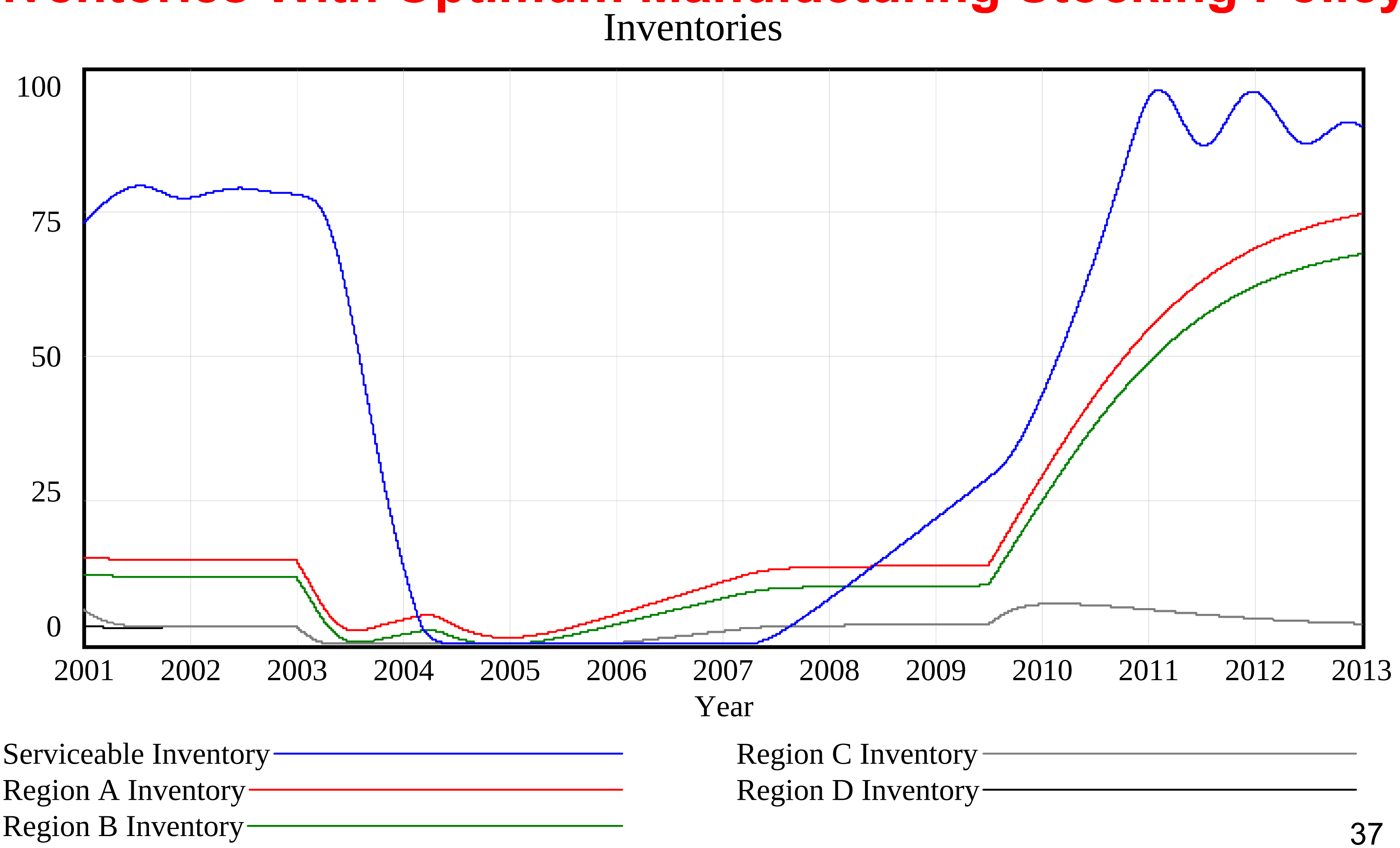
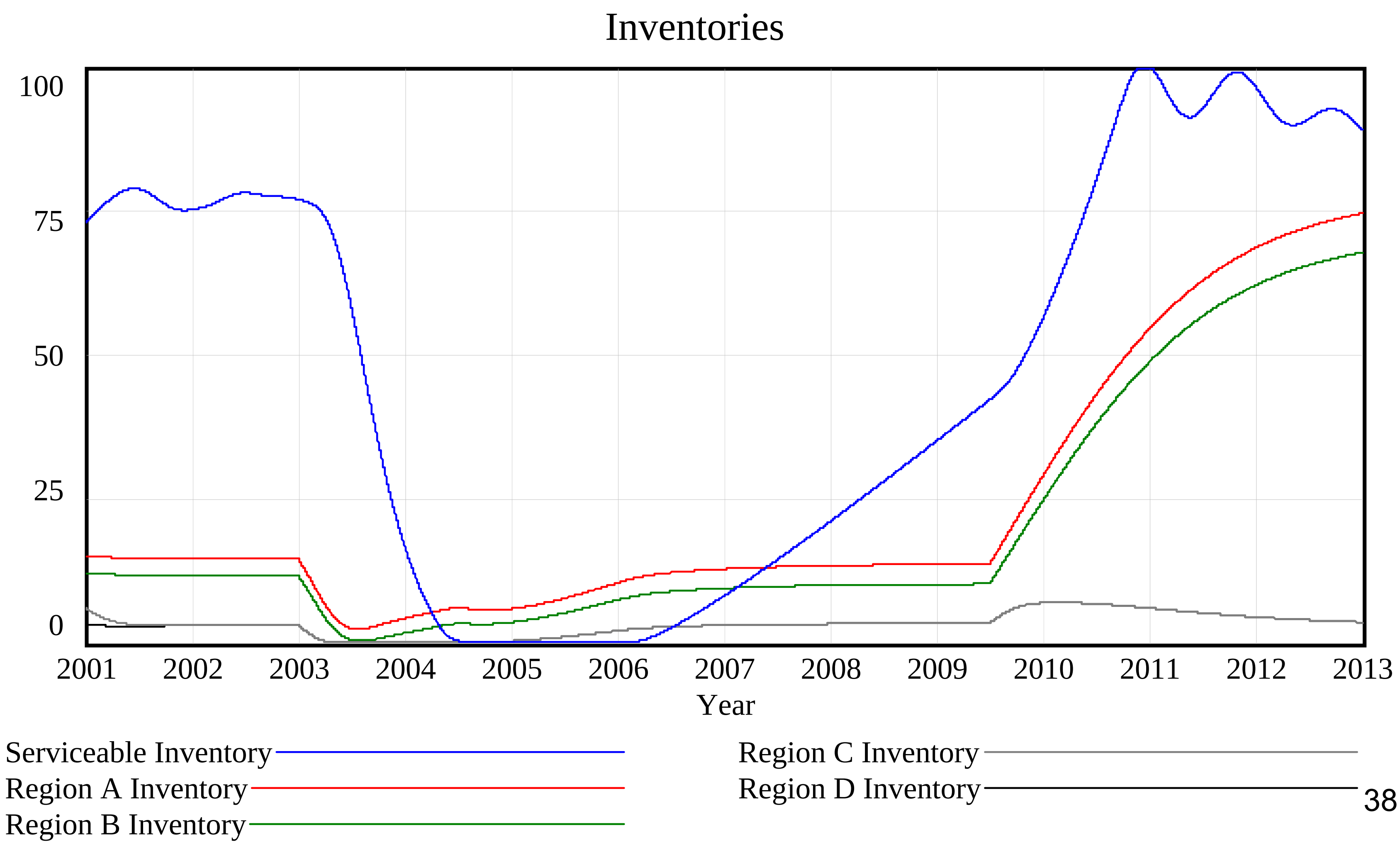
Base Case Simulation: Blade Inventories



Alternative Simulation:
Inventories With Optimum Manufacturing Stocking Policy



Alternative Simulation B: Inventories With Stocking Policy & OEM PLT Reduction



Summary & Conclusions

- **Forecasts Are Always Wrong;**
- **The Longer the Forecast Horizon, the Worse the Forecast;**
- **Holding Inventory of Final Goods is a Very Expensive Way of Dealing with Uncertainty;**
- **Push-Pull Boundaries Enhance Abilities to be Adaptive and Responsive and Efficiently Mitigate Risks of Forecast Errors**

Track and Trace for Supply Chain Visibility, Material & Parts Assurance, and Configuration Management

Overview of Approach

- Two Pronged Attack Builds On IUID;
- 2D Barcode Data Matrix and/or RFID;
- Track and Trace System with Search Capability;
- ePedigree for Backup Assurance of Historical Path.

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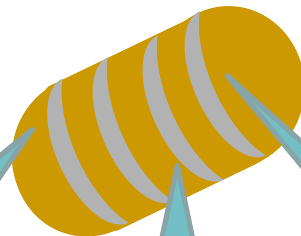
Basic Concept

The basic concept is for every object in the program to be uniquely identified and maintained



Widget #110056

Physical Information
Bill of Materials
Manufacturing work centers
Raw material used
Sub-components used
Location
Condition
Testing results
Certifications

Component Information
Production routing
Component heritage
Raw materials heritage
Certification BOMs
Manufacturing SPC / SQC data
Manufacturing video
Design documents
Version controls

Programmatic Information
Timeline / schedule
Budget
Dependencies
Sourcing
Certifications
Contractual deliverables

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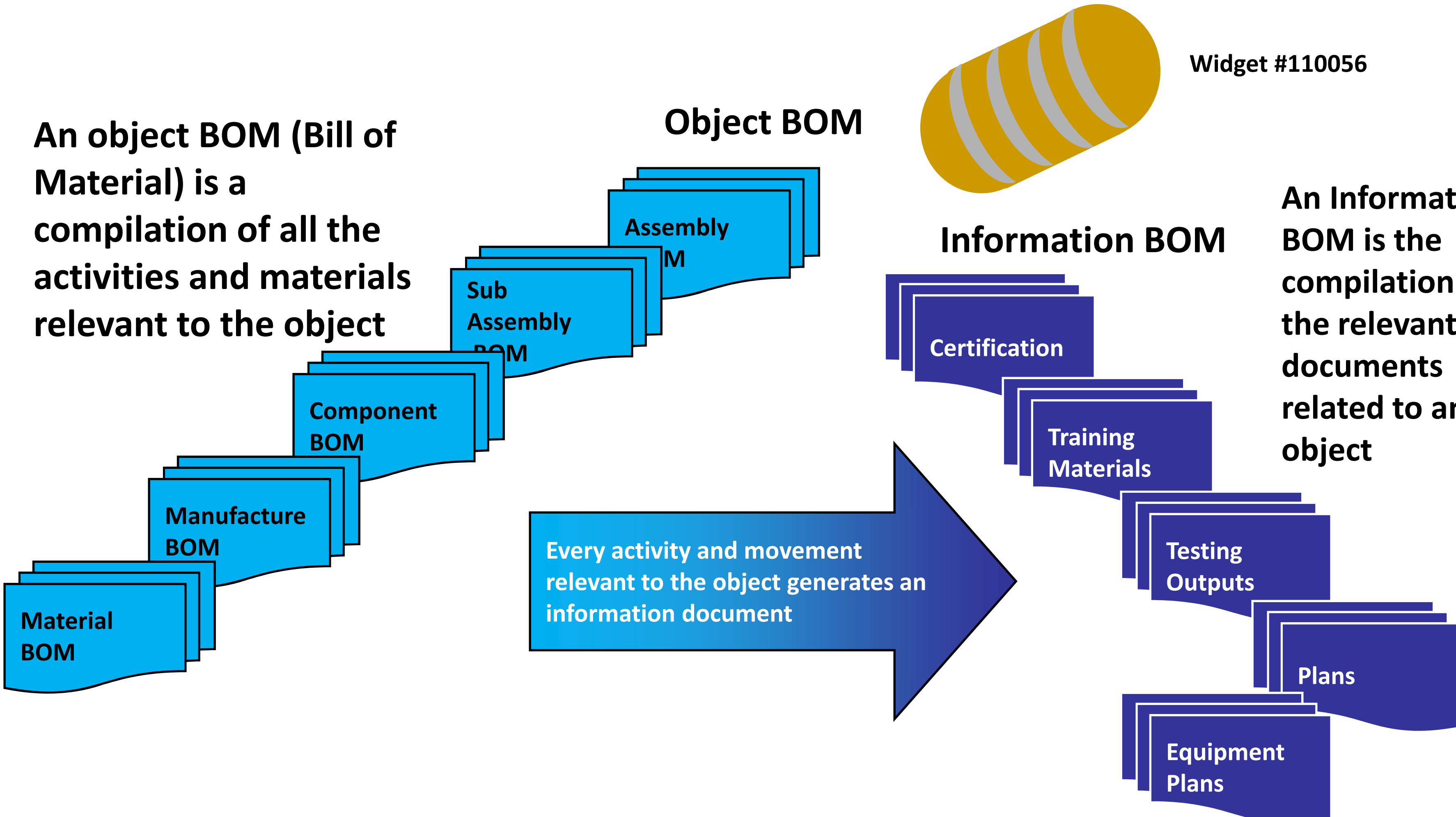
Enterprise Operating Model Master Scenarios

An object BOM (Bill of Material) is a compilation of all the activities and materials relevant to the object

An Information BOM is the compilation of all the relevant documents related to an object



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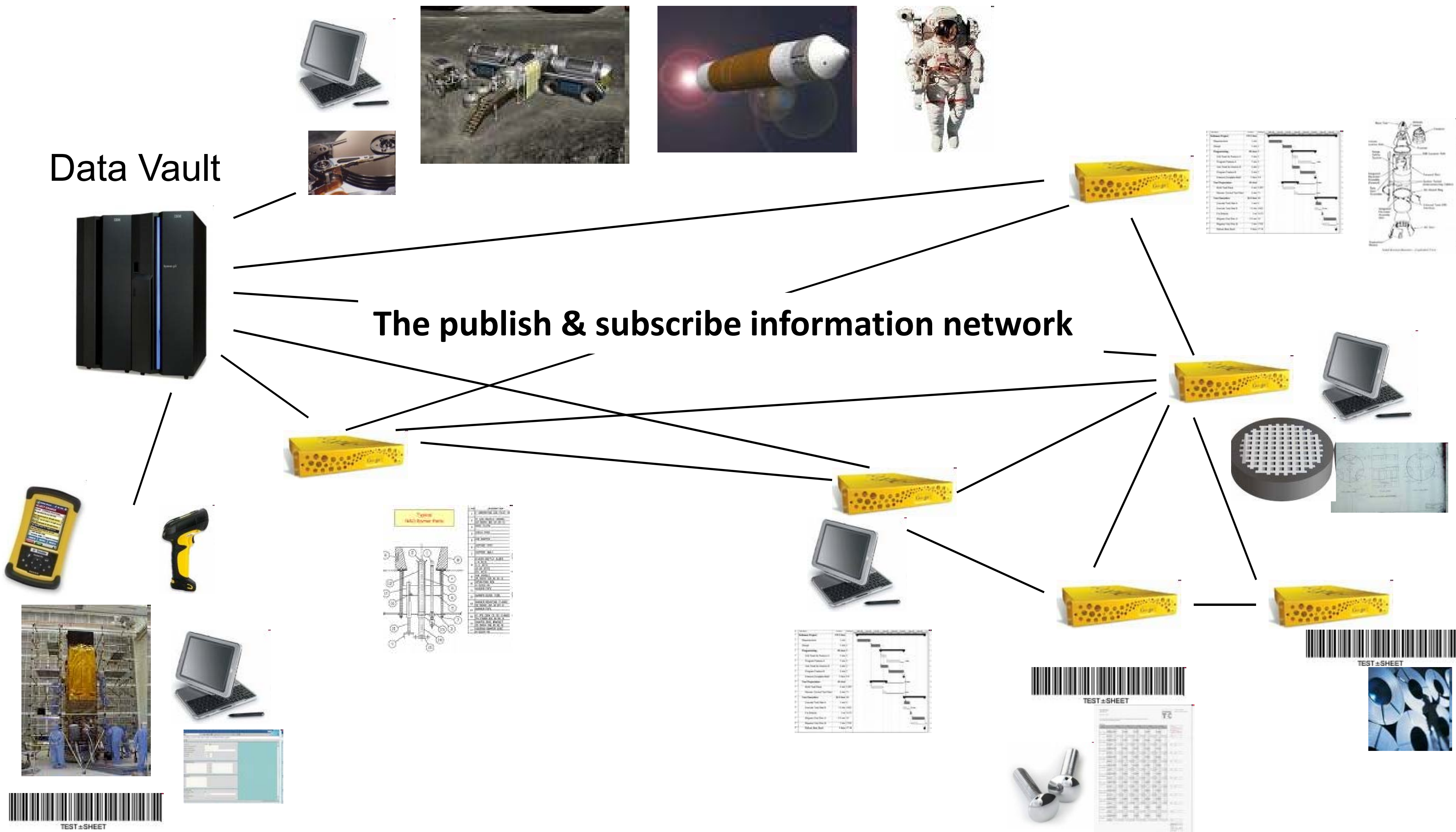
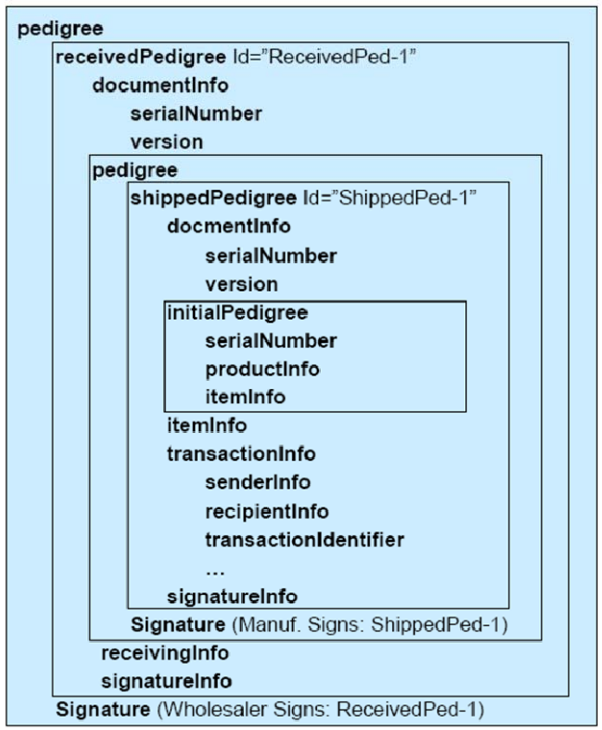
System Structure With Nodes at Suppliers

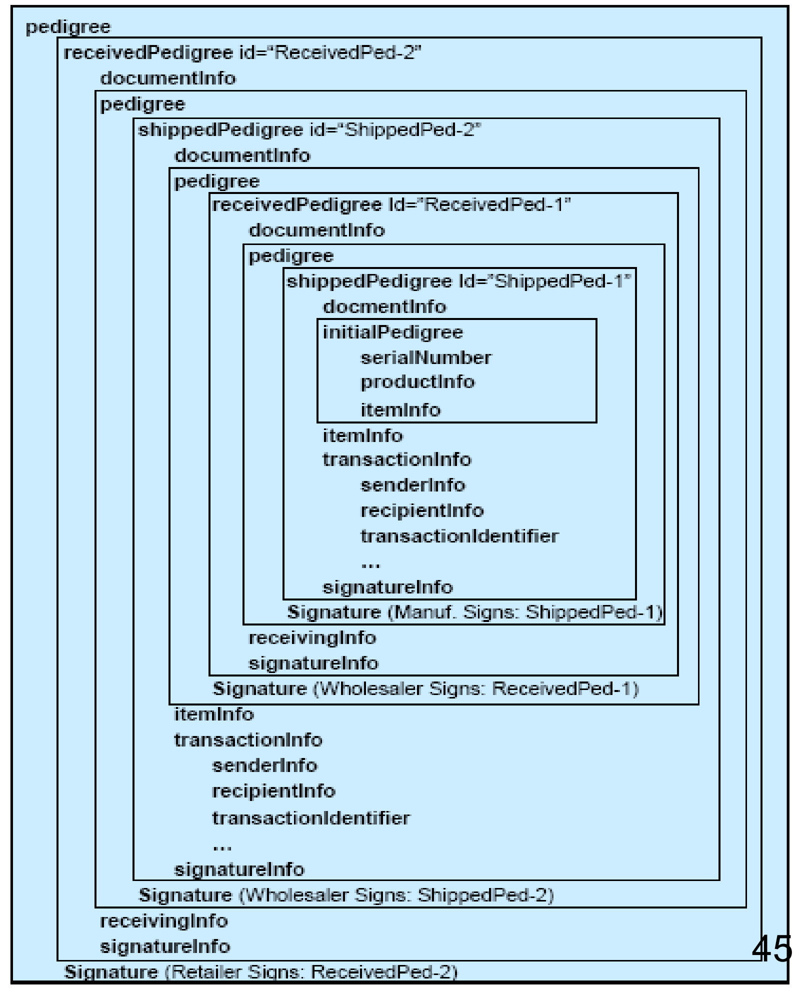


Supplement Track & Trace With Secure Digital ePedigree

Signed manufacturer pedigree

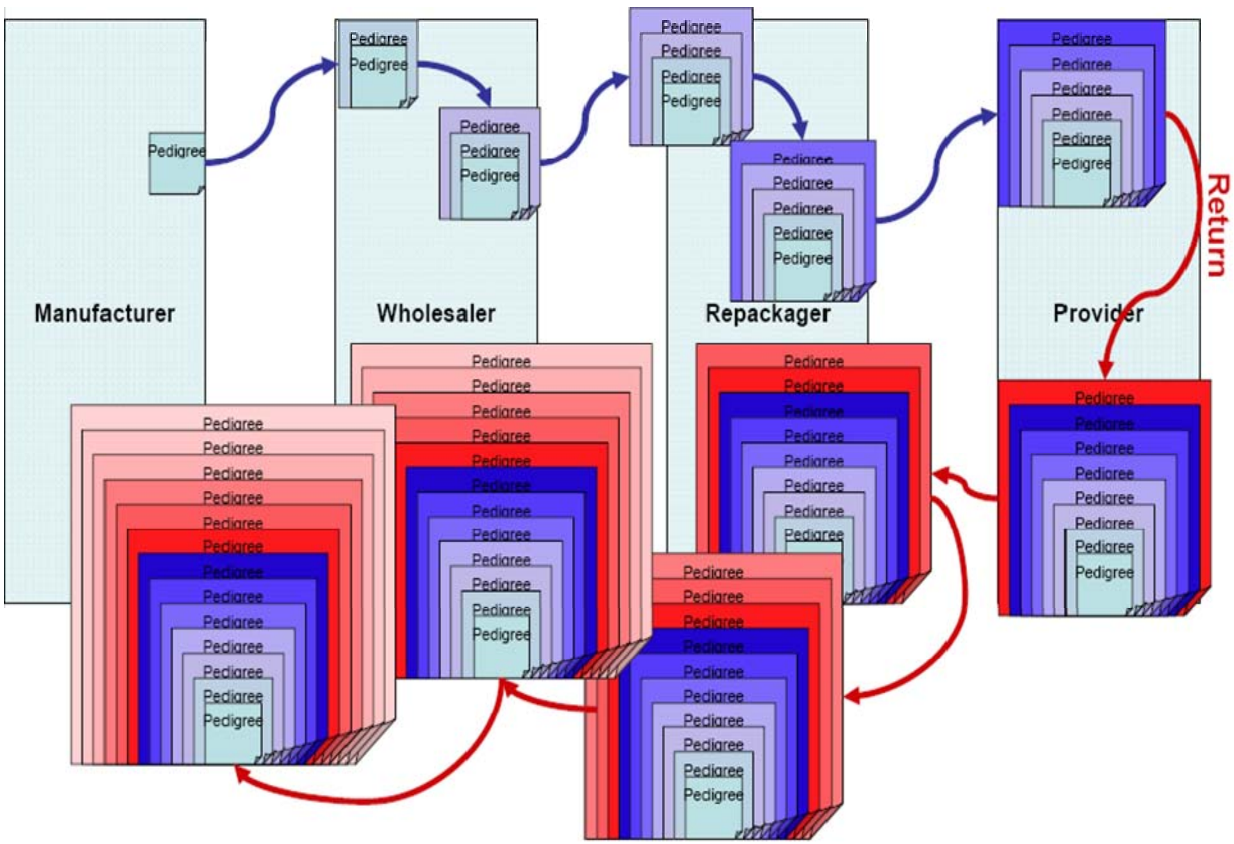
(Initiated by manufacturer, after the wholesale distribution, signed by both manufacturer and wholesaler)





Secure Nested XML Pedigree Standard Established by GS1/EPC Global

ePedigree Is Built Up As Part Moves Through Supply Chain



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Sample Pedigree

Product Information	Pedigree Serial Number
Transistor Terrific Transistors 3 Prong, 100, Test NDC542 33344477771	urn:uuid:47ba1902-c716-4659-b3e0-8fdb1aedc7b6

History

1 | SELLER Terrific Transistors, Ltd. | TRANSACTION Sale | BUYER Quality Missile Parts | TRANSACTION IDENTIFIER 247906670004 | TRANSACTION DATE 02 Oct 2007

Seller: **Terrific Transistors, Ltd.**
1 Elm Street, Sun Lakes, AZ 85248 USA
License Number: 00:00001 NC
Transaction Identifier: 247906670004 InvoiceNumber
02 Oct 2007
Authentication Contact: Jinseok Behr
Boss
800-555-1365
JinseokBehr@terrific.com
http://www.terrific.com
Certified By: dennis fryer
Certifier User
800-555-1234
dfryer@supplyscape.com
Thu Oct 23 17:21:49 EDT 2008

Buyer: **Quality Missile Parts**
1 Spring Street, Portland, ME 04096 USA
License Number: 00:00002 FL
Date Received: 23 Oct 2008
Certified By: dennis fryer
Certifier User
800-555-1234
dfryer@supplyscape.com
Thu Oct 23 17:22:50 EDT 2008

ITEMS IN TRANSACTION

Lot: **DM_20081023_153742** Expiration: **01 Jul 2010** Quantity: **1**

2 | SELLER Quality Missile Parts | TRANSACTION Sale | BUYER Missile R Us | TRANSACTION IDENTIFIER 247906990001 | TRANSACTION DATE 29 Sep 2007

Seller: **Quality Missile Parts**
1 Spring Street, Portland, ME 04096 USA
License Number: 00:00001 NC
Transaction Identifier: 247906990001 InvoiceNumber
29 Sep 2007
Authentication Contact: Jinseok Behr
Boss
800-555-1365
JinseokBehr@quality.com
http://www.quality.com
Certified By: dennis fryer
Certifier User
800-555-1234
dfryer@supplyscape.com
Thu Oct 23 17:24:01 EDT 2008

Buyer: **Missile R Us**
1 School Street, Acton, MA 01720 USA
License Number: 00:00002 FL
Date Received: 23 Oct 2008
Certified By: dennis fryer
Certifier User
800-555-1234
dfryer@supplyscape.com
Thu Oct 23 17:25:12 EDT 2008

ITEMS IN TRANSACTION

Lot: **DM_20081023_153742** Expiration: **01 Jul 2010** Quantity: **1**

3 | SELLER Missile R Us | TRANSACTION Transfer | BUYER Missile R Us | TRANSACTION IDENTIFIER 247907320001 | TRANSACTION DATE 03 Sep 2007

Seller: **Missile R Us**
1 School Street, Acton, MA 01720 USA
License Number: 00:00001 NC
Transaction Identifier: 247907320001 InvoiceNumber
03 Sep 2007
Authentication Contact: Jinseok Behr
Boss
800-555-1365
JinseokBehr@mru.com
http://www.mru.com
Certified By: dennis fryer
Certifier User
800-555-1234
dfryer@supplyscape.com
Thu Oct 23 17:25:53 EDT 2008

Buyer: **Missile R Us**
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Summary Comments on Serialization and Track & Trace

- **Unique ID serialization opens the door for material and parts assurance, supply chain visibility, and configuration management;**
- **Global ePedigree standard offers potential for additional security; and**
- **Data carrier (RFID, 2D matrix barcode, laser marking, etc.) depends on part and business case analysis.**

Overall Conclusions

- **Supply Chain Management Strategies Are Evolving to Meet the Challenges in Global Aerospace Manufacturing;**
- **There Is No Single Strategy that Will Solve the Supply Chain Demands;**
- **A Robust Solution Will Likely Involve Detailed Supply Chain Maps, Close Suppler Relations, Push-Pull Boundaries, Track and Trace Technologies, Optimization and Modeling and Simulation.**

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