PepsiCo’s Practical Application of Supply Chain Resilience Strategies and Inventory Optimization

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Irma

Tuesday Morning Forecast

Wednesday Morning Forecast

Thursday Morning Forecast
Agenda

- Overview / Background
- Supply Chain Resilience
- Inventory Deep Dive
- Case Studies
PepsiCo Overview

PepsiCo is a global food and beverage powerhouse. Our broad range of delicious products offers consumers convenient, nutritious and affordable options in nearly every country around the world.

Global Beverages

Global Snacks

Global Nutrition

Performance

Brands

Scale

People

More than $63 billion revenue

22 billion-dollar brands

>200 countries & territories

More than 250,000 employees
PepsiCo Overview

Good For You

Better For You

Fun For You
Specialized Supply Chain

- Global Nutrition Segment
- Good for You Products
- Chilled Supply Chain

As PepsiCo proactively adapts to emerging market trends for healthy & nutritious beverages, our supply chain becomes more global and complex
Case Study - International Supply

- Natural, Functional Beverage
PepsiCo Coconut Water Supply Chain

- Copackers in Southeast Asia
- Packaging Materials from Germany, Pakistan, Serbia, Singapore
- Warehouses near East/West ports
- Redistributed to regional DCs
- Backup US Copackers
Supply Chain Starts Here
Supply Chain Resilience Concepts

Presented at 2013 APICS International Conference (Orlando)

Supply Chain Resilience – The ability of a supply chain to anticipate, create plans to avoid or mitigate, and/or to recover from disruptions to supply chain functionality


Supply Chain Resilience – Conceptual Framework

Resilience

- Resistance
  - Avoidance
  - Containment
- Recovery
  - Stabilization
  - Return

Time Series Display of Supply Chain Resilience Factors

- Avoidance
- Containment
- Return
- Stabilization
## Supply Chain Resilience Strategies

<table>
<thead>
<tr>
<th>Investment Strategies</th>
<th>Investment Strategies Summarized</th>
<th>Examples of Investments</th>
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<tbody>
<tr>
<td><strong>Discovery</strong></td>
<td>Investing in the ability of the firm to identify potential problems in the supply chain as close to the event occurrence as possible.</td>
<td>• Information technology/Information sharing • Early warning by supply chain partners • Forecasting • Demand sensing • Monitoring of performance in the supply chain</td>
</tr>
<tr>
<td><strong>Information</strong></td>
<td>Investments in improving the quantity, speed, and quality of information flowing within the supply chain.</td>
<td>• Improved information technology • Effective communication • Information visibility</td>
</tr>
<tr>
<td><strong>Supply Chain Design</strong></td>
<td>Designing and implementing supply chains that can be configured and reconfigured quickly in response to changes within the supply chain.</td>
<td>• Supplier base management (strategies for better managing suppliers at the major, minor, and scouting levels) (Melnyk, Griffis, Cooper, Macdonald &amp; Phillips, 2010). • Supplier base configuration • Supplier base reconfiguration</td>
</tr>
<tr>
<td><strong>Buffers</strong></td>
<td>The creation of excess cushions in the form of inventory, capacity or lead times.</td>
<td>• Human resources – capacity • Human resources – capability/experience • Inventory • Operating flexibility • Excess operating capacity • Redundancy • Excess/safety lead time</td>
</tr>
<tr>
<td><strong>Operating Flexibility</strong></td>
<td>The ability of the system to change either flows or product specifications in response to supply chain problems.</td>
<td>• Transportation alternatives • Variable bills of material</td>
</tr>
<tr>
<td><strong>Security</strong></td>
<td>Ability to protect the system from supply chain shocks,</td>
<td>• Firewalls • Quarantine • Strengthened physical systems</td>
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<tr>
<td><strong>Preparedness</strong></td>
<td>Designing contingency plans for dealing with possible supply chain shocks and in carrying out drills</td>
<td>• Planning for contingencies • Training/rehearsal • Risk assessment</td>
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Application to Coconut Water Supply Chain

Several strategies for SC Resilience: a) early warning, b) buffers, c) supply chain configuration d) brand equity…etc.

 Relevant strategies applied to managing our coconut water supply chain

a) Early Warning
   1) The earlier you are aware of the disruption, the sooner you can start working on the recovery
   2) Improve frequency of communications and data quality

b) Buffers – 3 kinds of buffers
   1) Stock Buffers
      - Pre-build prior to high risk SE Asia supply timeframe and prior to peak seasonal demand in US
      - Optimize inventory targets to balance fill rate and expiration risk
   2) Capacity Buffers
      - SE Asia: how much more can we get above the contractual commitments when needed
      - US copack: how much can we get from US copackers when needed
   3) Lead Time Buffers
      - SE Asia – flexibility to change short term schedule; dual sourcing where possible (500ml Pure)
      - US copackers – stage long lead time materials for quicker response when SE Asia supply disrupted (or demand spikes)
Understand and Address Seasonal Risks

Seasonal Inventory DOH Targets

Max Limit
Max Target
Avg
Min Target
Min Limit

Month

Supply & Demand

Demand

Low Sales
Moderate Sales
Peak Sales
Moderate Sales
Low Sales

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Supply

Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct

Typhoons

Moderate Risk
Low Risk
Moderate Risk
Peak Risk

Holidays

Holidays
Chinese NY
Holy Week
Ramadan
Decompose Lead Times and Optimize

Example Supply Scenario and Lead Times (weeks)

- FG lead time from SE Asia is **20 weeks**
- 2nd SE Asia copacker * improves reliability**, but same **20 week** lead time
- US contingency lead time is **8 weeks** (less if line time & ingredients available)

* Dual SE Asia sourcing currently applies only to 500ml Pure. For others, scheduler will increase plan at Copack #1 in subsequent months after disruption has subsided.

** It is important to quantify (and optimize) both average (µ) and standard deviation (σ) of supply (lead time and quantity). For example, transit and port clearance times continually change; monitor and update as needed.
Brand Equity and Reputational Resilience

- Certification

- Supply – stable, on shelf, fresh

- Promotion – new channels, drive awareness
INVENTORY DEEP DIVE
Inventory Policy is Part of SC Resilience

− Our work on applying these Supply Chain Resilience strategies within PepsiCo’s global supply chain is leading to groundbreaking research, particularly in the area of inventory buffers.
− International supply has long lead times and high variability. Inventory required to meet customer service targets begins to introduce risk of expiration, especially with organic products with shorter shelf lifes.
− We have derived formulas in conjunction with industry experts and academia (and validated with historical data) to predict both the percentage of stockouts as well as the percentage of expired product, and implemented the solution that strikes the optimal balance.
− In doing so for the coconut water business, we found opportunities to reapply this to other emerging product categories with supply challenges such as probiotic beverages. These probiotic beverages have the unique challenge of very short shelf life compared to other items in the portfolio of premium juice beverages.
− Adapting the formulas for the product-specific characteristics of probiotic beverages (supply & demand variability, lead time and shelf life) allowed us to find the optimal balance for that product group as well and implement the results to improve our supply.
The Sawtooth

Inventory vs Time

Place order and the reorder quantity (ROQ) arrives one lead time later. Safety stock buffers against uncertainty of supply and demand.
Widely Documented: Correlate Inventory Level with Percent Backorders/Cuts

\[
\sum \text{backorders/cuts}(\text{cycles throughout the year given variable demand and supply})
\]

divide by annual demand to get percent backorders/cuts

fill rate % = 1 – percent backordered/cut
Emerging Area of Research: Correlate Inventory Level with Percentage Expired

\[ \sum \text{amount leftover at the end of the replenishment cycles} \times \left( \frac{1}{\text{annual demand}} \right) \]

\[ \text{Expected inventory (safety stock) prior to receiving next replenishment} \]

\[ \text{Expected amount of each production lot leftover at the end of its shelf life} \]

* "Shelf Life" in this context is viewed from an internal perspective, subtracted from the "remaining shelf life" guaranteed to external customers upon receipt. It is otherwise known as "Warehouse Life".
Consider the Boundary Cases

Scenarios of expected inventory at the end of product shelf life assuming no demand or supply variability

1. **100% expired, 0% backordered/cut**
   - ROQ

2. **50% expired, 0% backordered/cut**
   - $\frac{1}{2}$ ROQ

3. **0% expired, 0% backordered/cut**
   - Zero

4. **0% expired, 50% backordered/cut**
   - $-\frac{1}{2}$ ROQ

5. **0% expired, 100% backordered/cut**
   - ROQ

#APICS2016
Illustration of the Symmetric Relationship

- ROQ  -½ROQ  Zero  ½ROQ  ROQ

- Green: percent backordered/cut (no variability)
- Blue: percent expired (no variability)
Layer in Variability
Definition of Terms

Safety Stock (SS) = Expected inventory position when reorder arrives

Lead Time (LT) = Time it takes from the point an order is placed until it arrives and is available to sell to customers. Lead Time Demand (LTD) is the demand during lead time

Lock = Time required by manufacturer that production schedule be locked and no more changes accepted

Make = Time allotted for manufacturer to produce the scheduled quantity and product to clear incubation (if required)

Dist = Time it takes to distribute product from manufacturer to demand points

ROQ* = Run cycle (or time between replenishments); the timeframe that the reorder quantity (ROQ) is expected to cover

Shelf Life* = Total internal shelf life from the time produced until the last date it can be sold to customer (consumer shelf life minus time guaranteed to customers upon receipt).

eRSL* = Expected inventory remaining at the end of the internal shelf life
Method Derivation

Arranging Terms

\[ X^* = \text{Lock} + \text{Make} + \text{Shelf Life} - \text{ROQt} \]
\[ Y^* = \text{SS} + \text{LTD} - \text{eRSL}^* \]

Where: \( \text{LTD} = \text{Lock} + \text{Make} + \text{Dist} \)
\[ Y^* = \text{Lock} + \text{Make} + \text{Dist} + \text{SS} - \text{eRSL}^* \]

Algebraic Reduction

Set \( X^* = Y^* \)
\[ \text{Lock} + \text{Make} + \text{Shelf Life} - \text{ROQt} = \text{Lock} + \text{Make} + \text{Dist} + \text{SS} - \text{eRSL}^* \]
\[ \text{Lock} + \text{Make} + \text{Shelf Life} - \text{ROQt} = \text{Lock} + \text{Make} + \text{Dist} + \text{SS} - \text{eRSL}^* \]
\[ \text{Shelf Life} - \text{ROQt} = \text{Dist} + \text{SS} - \text{eRSL}^* \]
\[ \text{SS} = \text{Shelf Life} - \text{ROQt} + \text{Dist} + \text{eRSL}^* \]

Procedure

- Specify \( \text{eRSL}^* \)
- Calculate \( \text{SS} \)
- Calculate mean (\( \mu \)) and standard deviation (\( \sigma \)) of \( \text{LTD} \)
- Based on \( \mu, \sigma, q \) (ROQ) and \( \text{SS} \): calculate % backorders/cuts
  (A)
  - Iterate with conventional formula: \( \text{SS} = k\sigma, k = f[L(z) = Aq/\sigma] \)
  - Or calculate explicitly per Zipkin: \( A = (\sigma/q)[F^1(z_r) - F^1(z_r+q)] \)
- Calculate \( \mu^* \) and \( \sigma^* \) of demand over \( X^* \)
- Based on \( \mu^*, \sigma^*, q \) and \( \text{eRSL}^* \): calculate % backorders/cuts
- Determine estimated percentage of expired inventory based on symmetric relationship with percentage backorders/cuts
  (see calculation mechanics on next slide)

* "Shelf Life" in this context is viewed from internal perspective and has subtracted the “remaining shelf life” guaranteed to external customers upon receipt. It is otherwise known as “Warehouse Life”.

#APICS2016
Calculation Mechanics

Start at midpoint (MP), where eRSL=0

- Calculate SS\textsubscript{MP}
- Calculate % backorders/cuts at SS\textsubscript{MP} given $\mu$, $\sigma$, $q$
- Calculate % backorders/cuts at eRSL\textsubscript{MP} given $\mu^*$, $\sigma^*$, $q$

**Ascending**

- Calculate % backorders/cuts at SS\textsubscript{MP+2} given $\mu$, $\sigma$, $q$
- Calculate % backorders/cuts at eRSL\textsubscript{MP+2} given $\mu^*$, $\sigma^*$, $q$
- Set % expired at = eRSL\textsubscript{MP+2} = % backorders/cuts at eRSL\textsubscript{MP+2}
- Calculate % backorders/cuts at SS\textsubscript{MP+4} given $\mu$, $\sigma$, $q$
- Calculate % backorders/cuts at eRSL\textsubscript{MP+4} given $\mu^*$, $\sigma^*$, $q$
- Set % expired at = eRSL\textsubscript{MP+4} = % backorders/cuts at eRSL\textsubscript{MP+4}
- Continue for MP+6, MP+6, etc (or increments other than 2)

**Descending**

- Calculate % backorders/cuts at SS\textsubscript{MP-2} given $\mu$, $\sigma$, $q$
- Calculate % backorders/cuts at eRSL\textsubscript{MP-2} given $\mu^*$, $\sigma^*$, $q$
- Set % expired at = eRSL\textsubscript{MP-2} = % backorders/cuts at eRSL\textsubscript{MP-2}
- Calculate % backorders/cuts at SS\textsubscript{MP-4} given $\mu$, $\sigma$, $q$
- Calculate % backorders/cuts at eRSL\textsubscript{MP-4} given $\mu^*$, $\sigma^*$, $q$
- Set % expired at = eRSL\textsubscript{MP-4} = % backorders/cuts at eRSL\textsubscript{MP-4}
- Continue for MP-6, MP-8, etc (or increments other than 2)
Model Correlates Well with Historical Data

SL=40d, Low/Med $\sigma$

SL=40d, Med/High $\sigma$
Deriving Formulas from Scratch

\[ S = \text{the order up to quantity in a periodic review system} \]
\[ p = \text{production lead time (order to produce)} \]
\[ w = \text{warehouse life} \]

\[ f(x) = \text{pdf for weekly demand } x \]
\[ x \sim N(\mu, \sigma) \]

\[ g(x) = \text{pdf for demand } x \text{ over period } p+w \]
\[ x \sim N(\mu(p+w), \sigma\sqrt{(p+w)}) \]

\[ h(x) = \text{pdf for standard normal distribution} \]

For any given \( S \)

\[ E (\text{cases expiring}) = \int_{-\infty}^{S} (S - x)g(x)\,dx \]

Let \( z = (x-\mu')/\sigma' \rightarrow x = z\sigma' + \mu' \) where \( \mu' = \mu(p+w) \)
\[ k = (S-\mu')/\sigma' \rightarrow S = k\sigma' + \mu' \text{ where } \sigma' = \sigma\sqrt{(p+w)} \]

\[ E (\text{cases expiring}) = \int_{-\infty}^{k} \sigma'(k-z)h(z)\,dz \]

\[ = \sigma\sqrt{(p+w)} \int_{-\infty}^{k} (k-z)h(z)\,dz \]

Where: \( h(z) = \frac{e^{-\frac{1}{2}z^2}}{\sqrt{2\pi}} \) (standard normal dist: \( \mu=0, \sigma=1 \))

Solve with Numerical Integration
Other References


8. Figure 1. Sample path (S, τ) models.


Case Study: Coconut Water

Long lead time, long shelf life products

9 month shelf life*  

6 month shelf life*

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* "Shelf Life" in this context is viewed from internal perspective and has subtracted the "remaining shelf life" guaranteed to external customers upon receipt. It is otherwise known as "Warehouse Life".

** Target inventory includes Safety Stock + Avg Cycle Stock + In Transit
Case Study: Coconut Water

Long lead time, long shelf life products

**Shelf Life** in this context is viewed from internal perspective and has subtracted the “remaining shelf life” guaranteed to external customers upon receipt. It is otherwise known as “Warehouse Life”.

Target inventory includes Safety Stock + Avg Cycle Stock + In Transit

* 9 month shelf life*

* 6 month shelf life*

* *Target inventory includes Safety Stock + Avg Cycle Stock + In Transit*
Case Study: Naked Juice Smoothies

Short lead time, short shelf life products

* "Shelf Life" in this context is viewed from internal perspective and has subtracted the "remaining shelf life" guaranteed to external customers upon receipt. It is otherwise known as "Warehouse Life".

** Target inventory includes Safety Stock + Avg Cycle Stock + In Transit
Rules of Thumb

For Example: Max Stock Policy = \( \frac{1}{2} \) Shelf Life*

For the 4 examples studied, this policy will result in less than 10% expired.

* "Shelf Life" in this context is viewed from internal perspective and has subtracted the “remaining shelf life” guaranteed to external customers upon receipt. It is otherwise known as "Warehouse Life".

** Target inventory includes Safety Stock + Avg Cycle Stock + In Transit
For More Info on Inventory Optimization

Essential Inventory Truths

An In-Depth Review of Inventory Optimization at PepsiCo

Tim Rowell
Shawn Batka

2011 APICS International Conference & Expo
October 22-26, 2011, Pittsburgh, Pennsylvania, USA
The Simple Math

Safety Stock = k \sigma

Where:
- k = safety factor
- \sigma = standard deviation of lead time demand

Safety Factor

k = z = standardized variate

Type 1 Service:
- Lookup service level (1-A) in table of Normal Probability Distribution

Type 2 Service:
- L(z) = A^q/\sigma
  Where:  A = (1 - service level)
  q = order quantity
  \sigma = standard deviation of lead time demand
- Lookup L(z) in table of Normal Partial Expectations
- Or calculate explicitly (e.g. \phi(z) = \left(\frac{1}{\sqrt{2\pi}}\right) \exp\left(-\frac{1}{2}z^2\right))

Accounting for Variability

Source of Variability
- Supply
  - Transit
  - Production

Measurement
- Forecast error
- Transit time variability
- Quantity variability

Method Comparisons

Equations
1) \sigma_2 = \sigma_0^2 + \sigma_1^2
2) \sigma_2 = \mu_0^2 + \mu_1^2

Comparisons
Method 1 typically more sensitive and conservative
Except for scenario of high u, low l, low adh
2011 Inventory Optimization excerpt 2

### Continuous vs Periodic Review

#### Continuous Review (r,q)
- Inventory position is continuously reviewed and at the instant the reorder point (r) is reached, an order for a predetermined quantity (q) is placed that arrives one lead time (L) later.

#### Periodic Review (u,s)
- Inventory is reviewed and orders placed at predetermined intervals (u) to bring the inventory position back up to a predetermined quantity (s) one leadtime (L) later.

### Zipkin’s Method Mitigates Asymptotic Effect at Low L(z)

#### Zipkin Continuous Review (r,q) Model

\[
A = \left( \frac{\sigma}{q} \right) [\Phi(z_r) - \Phi(z_{r+q})]
\]

Where:
- \( z_r = \frac{r-v}{\sigma} \)
- \( z_{r+q} = \frac{r+q-v}{\sigma} \)
- \( \sigma \) = Mean lead time (LT) demand
- \( v \) = Standard deviation of LT demand
- \( A \) = Average annual fill-rate service level
- \( q \) = Reorder quantity

### Model Comparison

#### Continuous Review

\[
A = \left( \frac{\sigma}{q} \right) [\Phi(z_r) - \Phi(z_{r+q})]
\]

Where:
- \( z_r = \frac{r-v}{\sigma} \)
- \( z_{r+q} = \frac{r+q-v}{\sigma} \)

#### Periodic Review

\[
A = \left( \frac{1}{u} \right) \int_{z_r}^{z_{r+q}} \Phi(\dot{v}) \, dv
\]

Where:
- \( z_r = (s-v)/\sigma \)
- \( z_{r+q} = (s+q)/\sigma \)
- \( \dot{v} = \sigma \Phi(z_r) - \frac{\sigma}{2} \Phi^2(z_r) - \sigma^2 \Phi^3(z_r) \)

### Multi-Echelon Considerations

#### Considerations
- Lead Time = f(iSL)
- Order Quantity = f(iSL)
- Push vs Pull
- Dynamic vs Static iSL
- (iSL = Internal Service Level)

### Illustration

- Safety Stock vs Time
- Illustration of DC SS, Plant SS, and Total SS

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Today’s presenter

Tim Rowell
- Supply Chain Sr. Manager
- 19 years at PepsiCo/Tropicana
- APICS CPIM since 2003

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Fun facts and APICS highlights

- 1991 Bachelors of Science in Mechanical Engineering, University of Florida
- 1991 Started at Westinghouse in Nuclear Safety Analysis
- 1997 MBA (MSIA), Carnegie Mellon Graduate School of Industrial Administration
- 1997 Started at Tropicana, a division of Seagram's
- 1999 PepsiCo acquired Tropicana
- 1999 Began work on Tropicana inventory model with Dr. Sridhar Bashyam (Frito Lay US)
- 2000 consulted with Dr. Steven Nahmias on periodic review and continuous review formulas
- 2000 Established inventory model based on Fill Rate for Tropicana business
- 2003 APICS: became Certified in Production and Inventory Management (CPIM)
- 2003 Presented at APICS International Conference: Tropicana Inventory Planning Methodology
- 2005 Began work on Project OneUp including Multi-Echelon Inventory Optimization for QTG
- 2006 Applied Dr. Paul Zipkin (Duke/Fuqua) models for Continuous Review and Periodic Review
- 2007 PepsiCo acquired Naked Juice
- 2008 Mark Entsminger documented/circulated derivation for quantity-based supply variability
- 2009 PepsiCo implemented Project OneUp Release 4
- 2009 PepsiCo reacquired PBG
- 2010 LSS inventory optimization for ingredients (chilled supply chain)
- 2011 Presented at APICS International Conference: Essential Inventory Truths
- 2012 PepsiCo acquired 100% of ONE
- 2013 APICS International Conference: Michigan State PHD Steven Melnyk presented on SC Resilience
- 2013 Implemented APICS/MS Supply Chain Resilience strategies for coconut water
- 2014 PepsiCo NAB APICS Pilot
- 2015 Performed deep dive optimization and segmentation of Naked Juice business
- 2015 Developed model to correlate % backorders/cuts and % expired as function of target inventory
- 2016 Vetted model with academia and industry, including Terra Technology / E2open
- 2016 PepsiCo Inventory Optimization organization alignment
- 2016 Presented at APICS International Conference: Practical Application of SC Resilience Strategies

Luke 10:27
THANK YOU