

PRODUCTION SIMULATION MODELING

Mid-Hudson Chapter APICS

October 8, 2003

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2 Examples

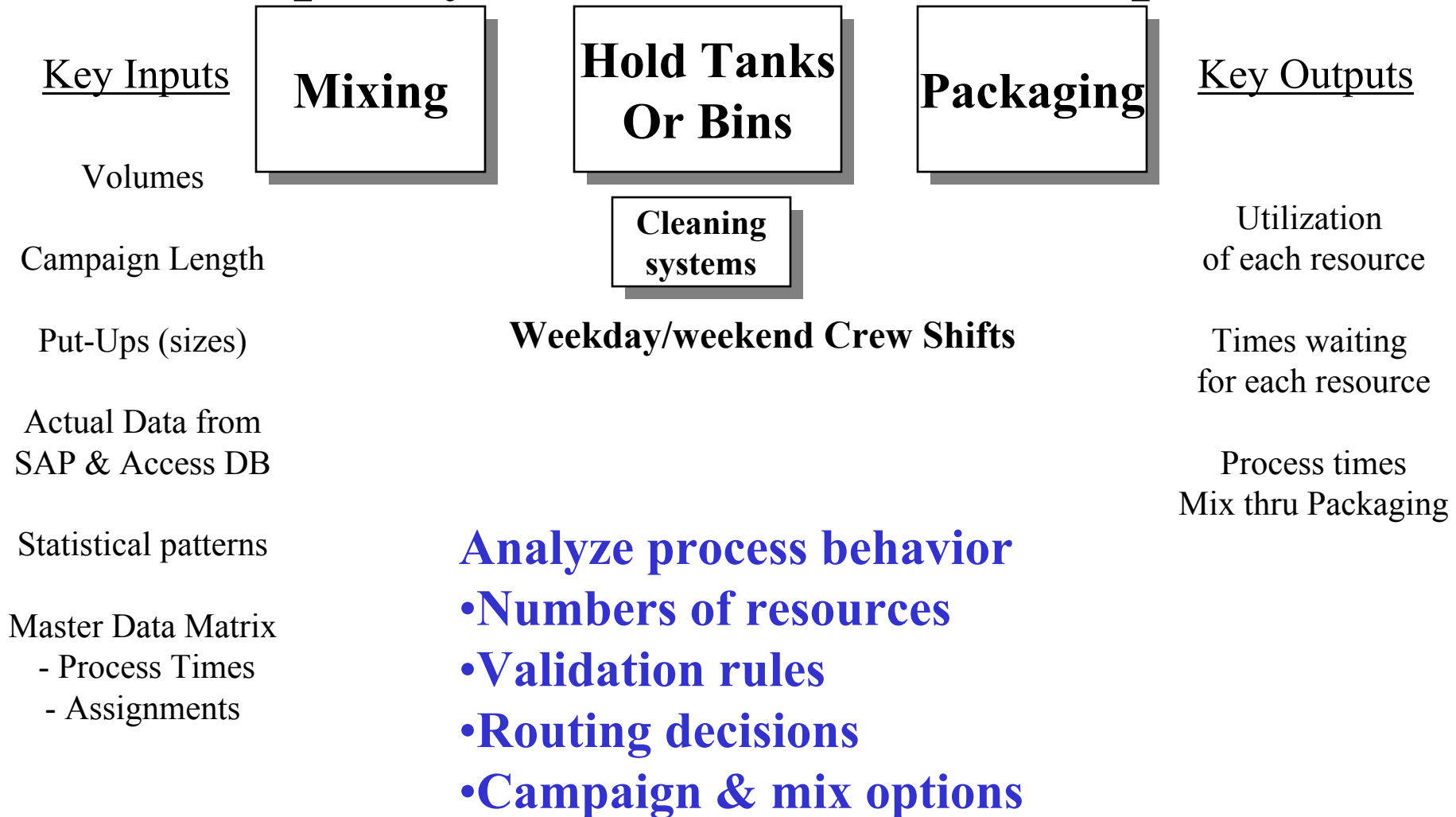
- Consumer goods plant expansion
- Pharmaceutical supply chain

Consumer Goods Plant Expansion

- Consumer cold remedies
- ~95 Liquids products – in bottles
- Subject to FDA validation regulations

SC Issues: Capacity Management

Plant Capacity – varied numbers of products



SC Issues: Capacity Management

Manufacturing Campaign Patterns

Patterns from the 18month sample of production history (1290 batches) were used to segment the inputs, as follows:

- Single batches - ~ 45 products
- Truck shipments out of plant - 3 products
- Campaigns in 3 categories:
 - Long & infrequent campaigns - 6 products (~ 40 campaigns)
 - High runners - 6 products (~ 140 campaigns)
 - Medium & low volume - ~ 30 products (~ 80 campaigns)
- Each of the 5 categories use empirical statistical distributions based on product & campaign length history
- Inputs can be changed across the board, or individually by category to simulate changes in volume / mix

Consumer Goods Plant Expansion Project Objectives

- Confirm capability of:
 - New mixing manufacturing area, &
 - Additional packaging lines
- Specifically address Clean-In-Place System & Hold Tank capacity concerns with FDA product validation plan

Simulation Methodology - Modeling Approach

Current Configuration

- **Created Master Data Matrix**
 - planning times,
changeover standards,
equipment assignments
- **Used Access DB to get variability**
- **Used SAP history for batch detail & campaigns**
- **Validated logic by running actual production**

New Configuration

- **Modified Master Data Matrix for new manufacturing environment with resource validation plan**
- **Added 5th packaging line with incremental large size volume**
- **Ramped up volume based on statistical patterns in SAP history**

Model Overview

Feed Statistical Input

CIP Mixing Hold Tanks Packaging

Line /
Campaign
Mix

Volume

Campaign Length

Bottle size

Statistics of
Campaigns

Med/Low
Volume

Bypass Packaging

Statistical
Intervals
Between Each
Batch



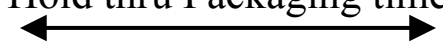
A buildup
before Mixing
indicates a
bottleneck
somewhere

Measure & Report Utilization
of each resource

Measure & Report times each
resource is unavailable

Examine individual Resource
backlogs

Measure & Report
Hold thru Packaging times



Conclusions

- Clean-In-Place systems – varying the number of systems did not affect the results
- Hold Tank & Packaging Line assignments can have a significant effect depending on the bottle size mix and sequence

Demonstration

Monte Carlo Simulation in High Volume Operations

Customized Input / Output Screen

Volume Adjustments:
Set these parameters to see how changing the volume (either on individual put-ups or overall) affects performance

1.1 Vol Total 1.8 Vol 2Oz
 2.0 Tot Volume Fact 2.0 2 Oz Vol Fact
 1.7 Vol Small 1.5 Vol 4 Oz
 Small Vol Fact 4.0 4 Oz Vol Fact
 1.2 Vol 1Oz 1.0 Vol Large
 1 oz Vol Fact Large Vol Fact

Additional Hold Tanks:
Set this constant to 1 route line 5 volume through new hold tanks

0 NewHoldTanks
NewTanks

Mix/Clean Parameters:
These parameters set the number of simultaneous mixings and cleanings, and the duration of the cleaning.

2 MaxMixing 0.82 MaxNbrOfMixings CleaningTime
 NOTE: YOU NEED TO CHANGE BOTH OF THESE
 CleanUnitsAvail
 CIP Batch Waiting - E U # #
 2 MaxCleanings MaxNbrOfCleanings CleaningEqu
 change
 CleaningUnits

Monday - Friday 8 hr Crews 3
 7 Day 12 hr Crews 2

Line 13 Conversion:
Set this parameter to 1 to route selected 4 oz. volume through the sixth line; 0 to use only existing line

1 Line13Conv
Line13Conv

Monthly Seasonality Factors

	Time	Y Output
0	0	0.82
1	730	0.74
2	1460	1.08
3	2190	0.57
4	2920	0.79
5	3650	0.83
6	4380	1.5
7	5110	1.58
8	5840	1.17
9	6570	0.88
10	7300	0.89
11	8030	1.16

Resource Activity

Mix Tanks

2000 gal 1
0

1000 gal 0

500 gal 1

Hold Tanks

1000 gal 1
1

2000 gal 0
0

4000 gal 1
1

Packaging Lines

1 1
2 1
3 0
4 1
Bulk Truck 0
6 0
7 0

Batch Routing

	Arrival time	Priority	ProductCode	BulkResourceN	HoldTankNumbe	PackagingLine
0	29.8996931919		12303	1	9	3
1	40.8151038061		12303	2	9	3
2	61.6082820285		60304	2	3	1
3	77.8054928939		60304	1	4	1
4	81.9768670231		12304	2	5	7
5	91.9750241619		44803	1	9	3
6	100.436473239		12304	1	5	7
7	102.337090564		37204	2	10	3
8	103.290958427		12240	4	1	2
9	112.640765135		90304	1	8	3
10	116.9004624		90304	1	9	3

Random Seed

Resource Stats
 Update

Activity Stats
 Update

Units Produced 116956994

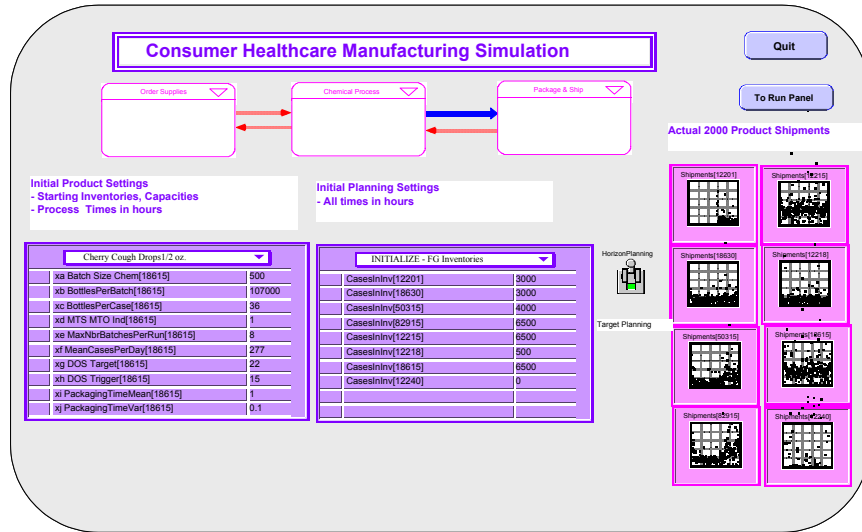
Packaging Capability Performance Index Ppk 1.36

Start Exploring - D:\All_My_Doc... Extend 4:12 AM

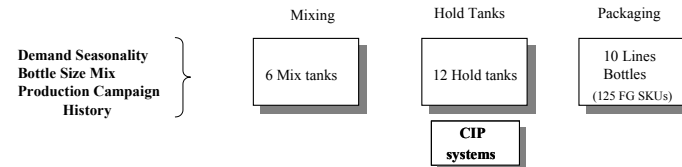
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Monte Carlo Simulation in High Volume Operations

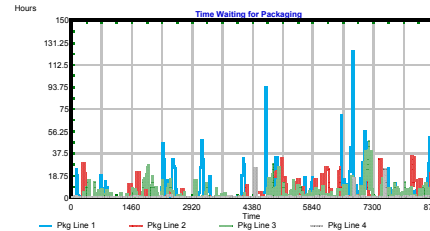
Inventory Balancing



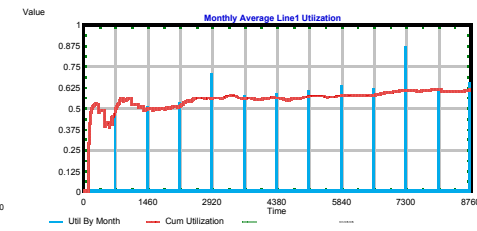
Liquids Products



Wait times recorded for all batches

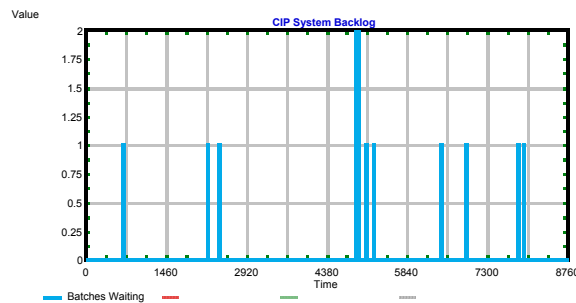


Utilizations of all resources computed vs. scheduled time

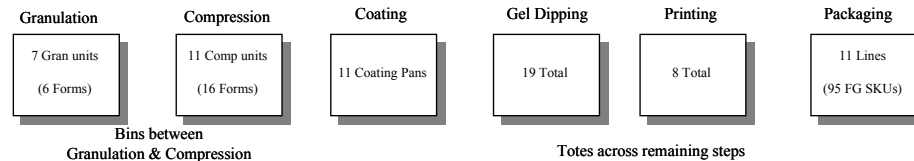


Shared Resources Utilization & Backlogs

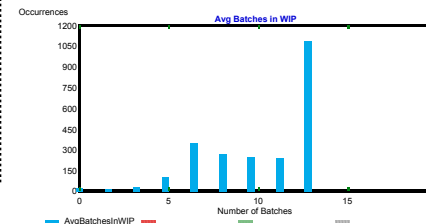
Resource	Type	Number	Utilization (95% confidence int)
CleaningUnits	Resource Pool	2	0.2431±0.04727
TotalCrewsAvail	Labor	5	0.4347±0.02713



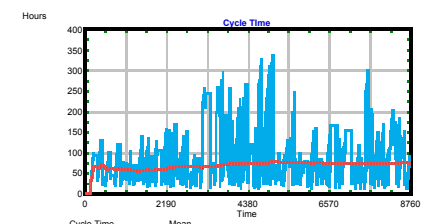
Solids Products



WIP measured across entire process

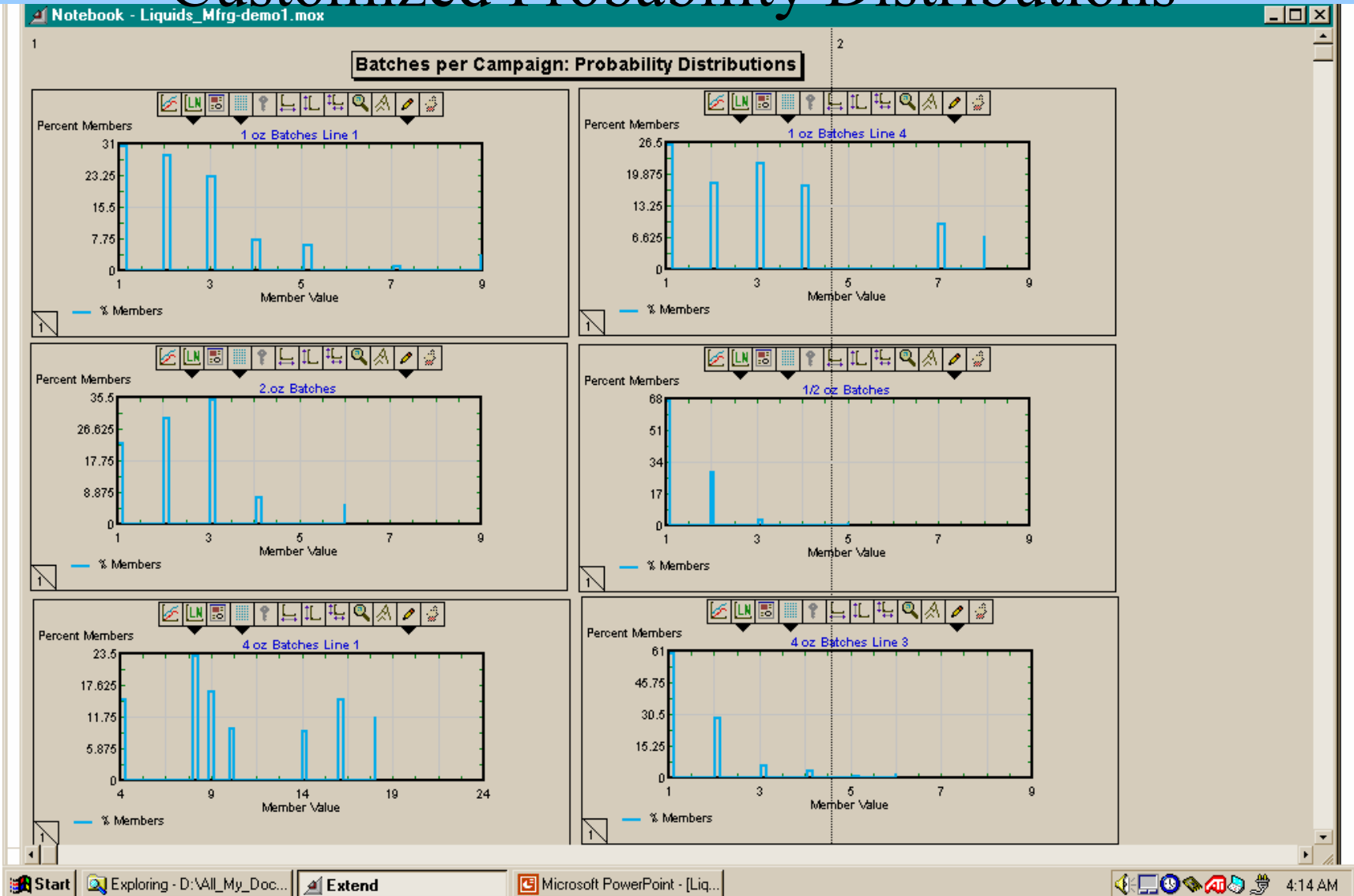


Cycle time of every batch recorded



Monte Carlo Simulation in High Volume Operations

Customized Probability Distributions



Example of Master Matrix

2	A	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AO	AP	AU
3	Finished Good SKU	Primary Line Used	Secondary Line Used	Put-Up	BatchSize	Existing Batch Size	Pkg PV (pkgs/lift)	Pkg Time (hrs/batch)	New Liquids Batch Size	Tank Clean Time (min)	New Liquids Clean Time (min)	Annual Finished Good Demand	Equivalent Bulk Demand (Kg)	Bulk Batch Size (gal)	Bulk Batch Size (kg)	Density (Kg/L)	Pkg Freq	
5	12201	4	4	1	500	51,000	23,600	17.29		30	55	1,273,752	60,990	500.08	2,442	1,290	0.205	
6	12215	2	4	0.5	500	107,028	35,400	24.19		30	55	3,322,164	75,800	500.08	2,442	1,290	0.205	
7	12218	2	4	0.5	500	107,028	35,400	24.19		30	55	1,479,744	33,763	500.08	2,442	1,290	0.205	
8	12240	2	4	0.25	500	207,000	35,400	46.78		30	55	7,102,404	83,788	500.08	2,442	1,290	0.205	
9	12301	1	4	1	1000	113,000	43,680	20.70		30	55	672,936	29,073	999.76	4,882	1,290	0.205	
10	12302	1	4	2	1000	60,543	38,080	12.72		30	55	1,452,330	117,111	999.76	4,882	1,290	0.205	
11	12303	3	1	4	2000	61,200	45,000	10.88		30	55	1,396,980	222,878	1,999.52	9,764	1,290	0.205	
12	12304	3	1	4	2000	60,000	40,000	12.00		30	55	3,053,256	496,867	1,999.52	9,764	1,290	0.205	
13	12311	1	4	1	1000	113,000	43,680	20.70		30	55	112,104	4,843	999.76	4,882	1,290	0.205	
14	12312	3	1	4	2000	60,000	40,000	12.00		30	55	60,000	9,764	1,999.52	9,764	1,290	0.205	
15	12313	3	1	4	2000	60,000	40,000	12.00		30	55	60,000	9,764	1,999.52	9,764	1,290	0.205	
16	12314	3	1	4	2000	60,000	40,000	12.00		30	55					1,290	0.205	
17	12316	1	4	2	1000	60,543	38,080	12.72		30	55	235,098	18,958	999.76	4,882	1,290	0.205	
18	12330	1	4	1	1000	113,000	43,680	20.70		30	55					1,290	0.205	
19	12332	3	1	4	2000	60,000	40,000	12.00		30	55	657,960	107,072	1,999.52	9,764	1,290	0.205	
20	12337	1	4	1	1000	113,000	43,680	20.70		30	55	348,975	15,077	999.76	4,882	1,290	0.205	
21	12340	3	1	4	2000	60,000	45,000	10.67		30	55			1,999.52	9,764	1,290	0.205	
22	12352	1	4	2	1000	60,543	38,080	12.72		30	55					1,290	0.205	
23	12357	1	4	1	1000	113,000	43,680	20.70		30	55					1,290	0.205	
24	12360	1	4	2	1000	60,543	38,080	12.72		30	55	121,086	9,764	999.76	4,882	1,290	0.205	
25	18602	2	2	0.5	500	104,000	29,500	28.20		30	55	107,028	2,513	500.08	2,442	1,290	0.205	
26	18603	2	2	0.5	500	104,000	29,500	28.20		30	55	107,028				1,290	0.205	
27	18604	2	2	0.5	500	104,000	29,500	28.20		30	55					1,290	0.205	
28	18605	2	2	0.5	500	104,000	29,500	28.20		30	55					1,290	0.205	
29	18612	2	2	0.5	500	104,000	29,500	28.20		30	55	477,132	11,199	499.88	2,441	1,290	0.205	
30	18615	2	4	0.5	500	104,000	29,500	28.20		30	55	3,388,368	79,529	499.88	2,441	1,290	0.205	
31	18617	2	2	0.5	500	104,000	29,500	28.20		30	55					1,290	0.205	
32	18630	4	4	1	1000	111,024	23,600	37.64		30	55	1,983,312	87,211	999.76	4,882	1,290	0.205	
33	18643	2	2	0.5	500	104,000	29,500	28.20		30	55					1,290	0.205	
34	18645	2	2	0.25	500	207,000	29,500	56.14		30	55					1,290	0.205	
35	18662	2	2	0.5	500	104,000	29,500	28.20		30	55	624,152	14,656	500.08	2,442	1,290	0.205	
36	18667	2	2	0.5	500	104,000	29,500	28.20		30	55			500.08	2,442	1,290	0.205	
37	18675	2	2	0.25	500	207,000	29,500	56.14		30	55	1,044,828	12,326	500.08	2,442	1,290	0.205	
38	18676	2	2	0.25	500	207,000	29,500	56.14		30	55	204,624	2,414	500.08	2,442	1,290	0.205	
39	18677	2	2	0.5	500	104,000	29,500	28.20		30	55					1,290	0.205	
40	18904	3	1	4	2000	60,000	45,000	10.67		30	55	1,615,212	122,810	934.23	4,562	1,290	0.205	
41	19201	1	4	1	1000	113,040	43,704	20.69		30	55	2,148,696	82,116	1,000.20	4,320	1,141	0.232	
42	19202	1	4	2	2000	116,325	38,080	24.44		30	55	2,226,192	82,675	1,000.20	4,320	1,141	0.232	
43	19204	3	1	4	2000	58,290	45,000	10.36		30	55	6,392,244	947,487	2,000.39	8,640	1,141	0.232	
44	19220	1	4	2	2000	116,325	38,080	24.44		30	55	2,226,192	82,675	1,000.20	4,320	1,141	0.232	
45	19231	1	4	1	1000	113,000	43,680	20.70		30	55	2,148,696	82,145	1,000.20	4,320	1,141	0.232	
46	19801	4	4	1	500	51,000	20,000	20.40		30	55	867,000	41,514	565.39	2,442	1,141	0.232	
47	29604	3	1	4	2000	60,000	40,000	12.00		30	55	60,000	9,764	1,999.52	9,764	1,290	0.205	
48	29612	3	1	4	2000	60,000	40,000	12.00		30	55	60,000	9,764	1,999.52	9,764	1,290	0.205	
49	29613	3	1	4	2000	60,000	40,000	12.00		30	55	60,000	9,764	1,999.52	9,764	1,290	0.205	
50	30178	1	4	2	1000	58,000	38,080	12.18		30	55	116,000	8,640	1,000.20	4,320	1,141	0.232	
51	30179	3	1	4	2000	58,290	40,000	11.66		30	55	117,762	17,455	2,000.39	8,640	1,141	0.232	
52	30294	2	2	0.5	500	104,000	29,500	28.20		30	55	50,328	1,052	499.83	2,174	1,149	0.230	
53	30295	2	2	0.25	500	207,000	29,500	56.14		30	55					1,149	0.230	
54	37204	3	1	4	2000	60,000	45,000	10.67		30	55	4,846,476	788,683	1,999.52	9,764	1,290	0.205	
55	40700	1	4	1	1000	113,000	43,680	20.70		30	55	3,043,984	131,511	999.76	4,882	1,290	0.205	

New Configuration

2001 volume + New Line large size volume

Mean Results of 5 Runs

Ann. Volume		1,467 Batches		100 mil. Pkgs				Tot. Loading
Mean Utilizations								w/Inc. PF's
Mix Tanks	%	Hold Tanks	%	Pkg Lines	Total %	Incl. Chngover %		
2000 (2)	46%	1000 (2)	35%	1	57%	10%		67%
1000 (1)	6%	2000 (4)	31%	2	55%	5%		65%
500 (1)	7%	4000 (2)	56%	3	80%	9%		90%
				4	34%	5%		44%
				New Line	23%	2%		33%
CIP Systems (2)		23%						

- 5 runs completed all batches successfully without buildup

Monte Carlo Simulations with Increasing Volumes

8% Increase

10% Increase

Batches

Backup*

Batches

Backup

1595

0

1562

8

1552

7

1596

61

1514

8

1585

75

1537

5

1581

56

1551

11

1582

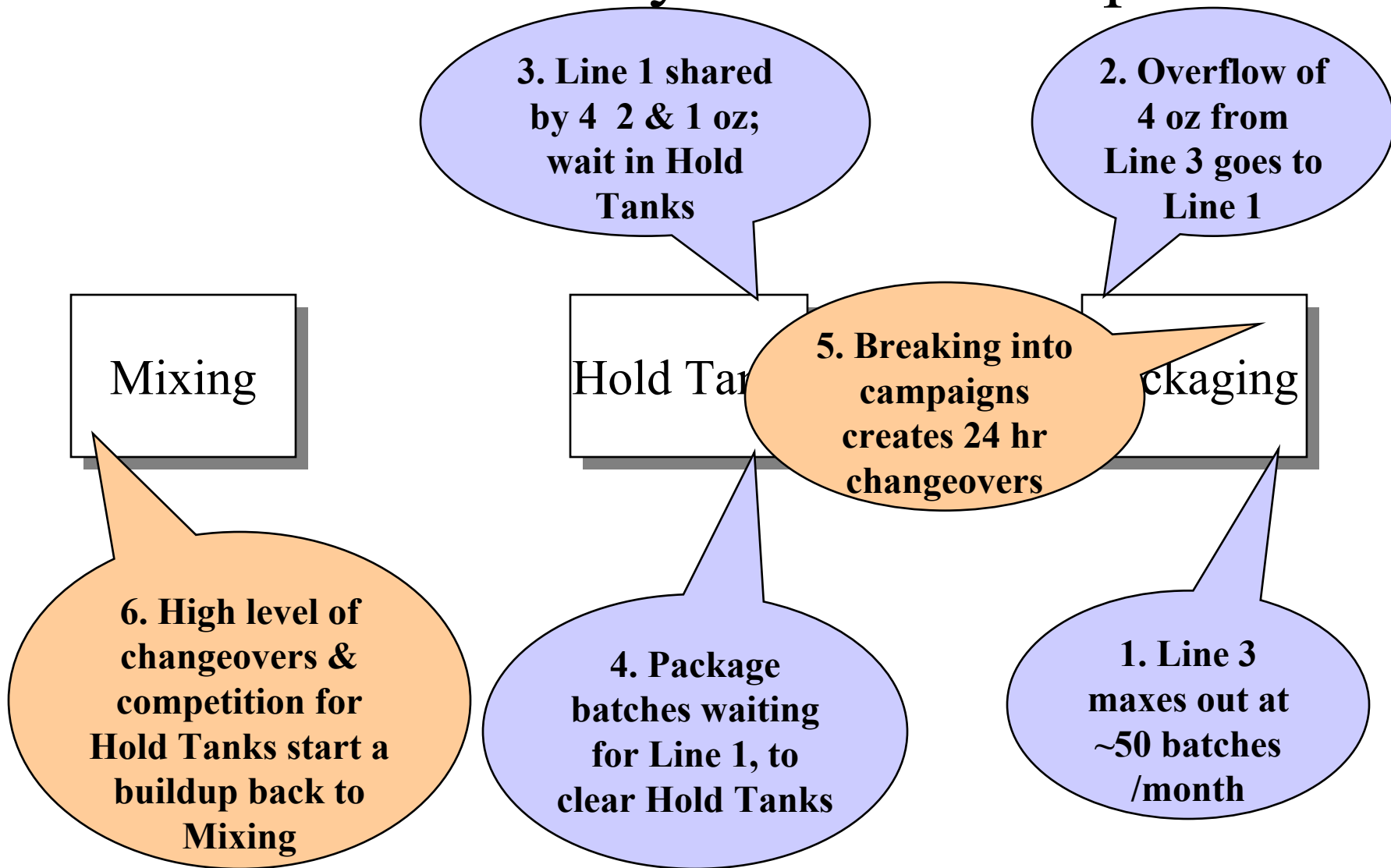
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* There can be in process batches in process at the end of a run

Learnings on Key Drivers

- Bottle size mix / campaign pattern is a key driver
 - Product is secondary to bottle size
- Hold Tank – Packaging Line linkages are complex, and are also key drivers
 - Balance flexibility vs. repetitive process

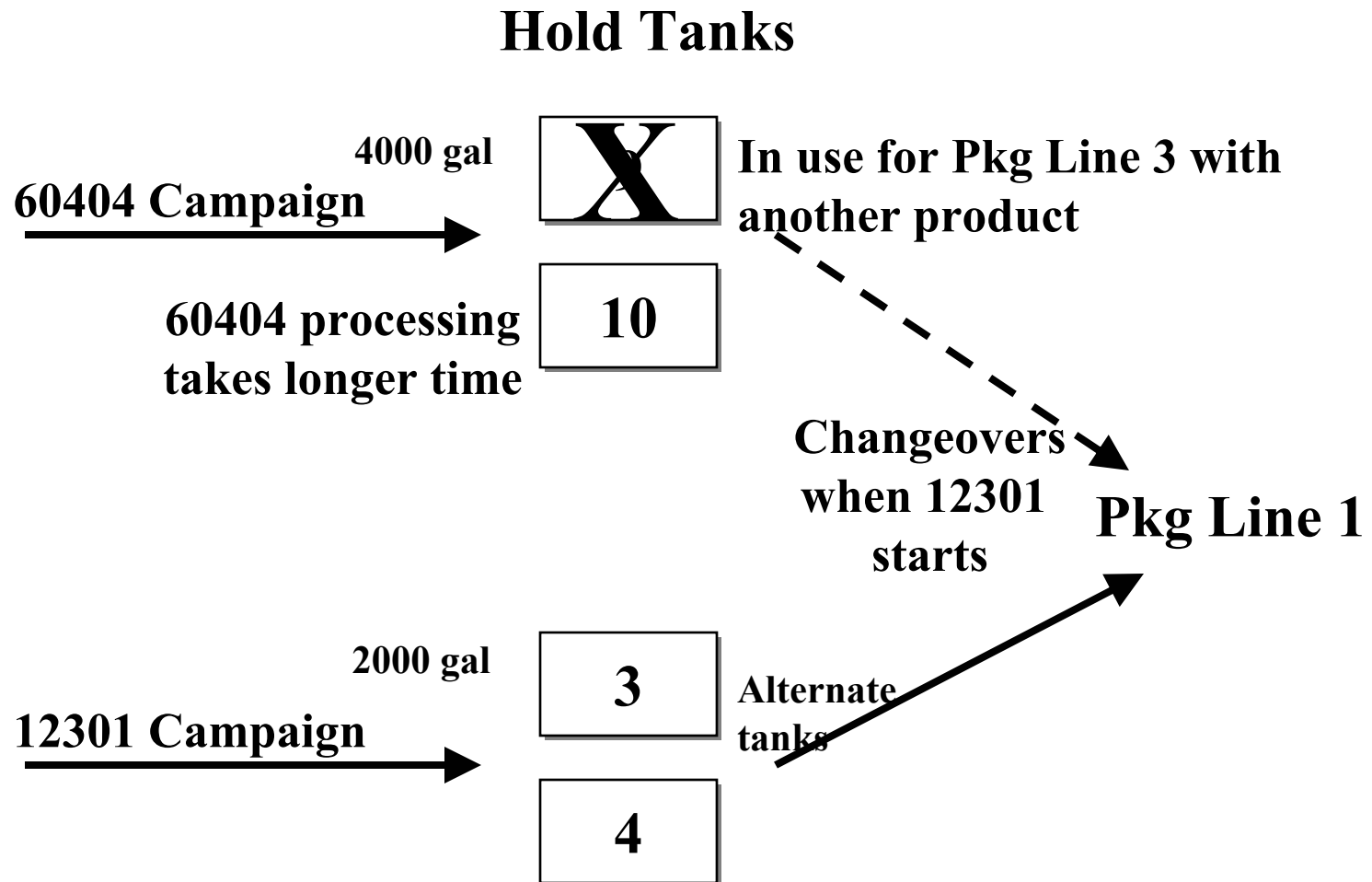
Conclusions: some dynamics in the process



Example of Hold Tank Assignment Impact

- Hold tanks – 2 4000gal. & 4 2000gal.
 - 26 products can use either 4000 or 2000 gal.
 - 6 products can use only 4000 gal.; they account for ~10% of volume
- In the example that follows:
 - Product 60404 can only use tanks 9 & 10, and has a campaign is running on Packaging #1
 - Product 12301 starts up in different tanks, but also scheduled for Packaging #1 when 60404 completes

Example of Hold Tank Assignment Impact



Model Runs for 10% Increase Flexibility of 2000 gal. Tanks Eliminates the Bottleneck

Mean Results of Runs @10% Vol. Increase - 4000 gal. Hold Tanks only

Ann. Volume		1,535 Batches		115 mil. Pkgs		Backup - 40 batches		Tot. Loading w/Inc. PF's	
Mean Utilizations									
Mix Tanks	%	Hold Tanks	%	Pkg Lines	Total %	Incl. Chngover %			
2000 (2)	49%	1000 (2)	65%	1	68%	13%	78%		
1000 (1)	18%	2000 (4)	41%	2	73%	6%	83%		
500 (1)	26%	4000 (2)	60%	2	86%	9%	96%		
				3	45%	3%	55%		
				New Line	20%	2%	30%		
CIP Systems (2)		24%							

Mean Results of Runs @10% Vol. Increase - 4000 & 2000 gal. Hold Tanks

Ann. Volume		1,608 Batches		118 mil. Pkgs		Backup - 11 batches		Tot. Loading w/Inc. PF's	
Mean Utilizations									
Mix Tanks	%	Hold Tanks	%	Pkg Lines	Total %	Incl. Chngover %			
2000 (2)	44%	1000 (2)	61%	1	66%	10%	76%		
1000 (1)	6%	2000 (4)	41%	2	73%	6%	83%		
500 (1)	28%	4000 (2)	53%	2	88%	9%	98%		
				3	45%	3%	55%		
				New Line	23%	2%	33%		
CIP Systems (2)		25%							

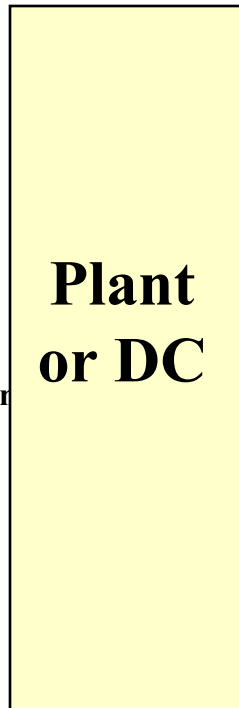
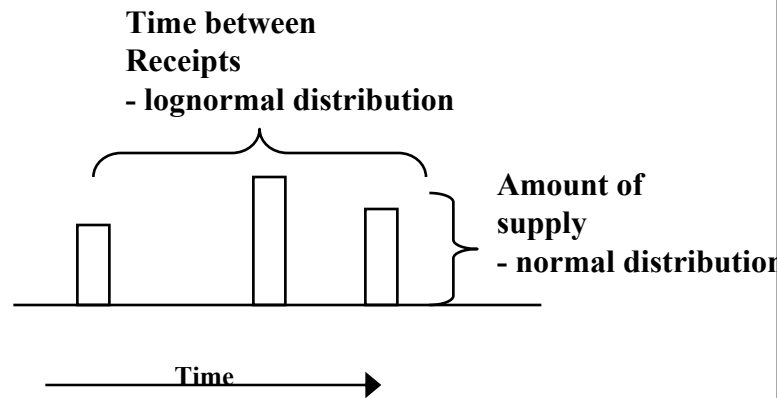
Service Channel™ Segmentation

Pharmaceutical example

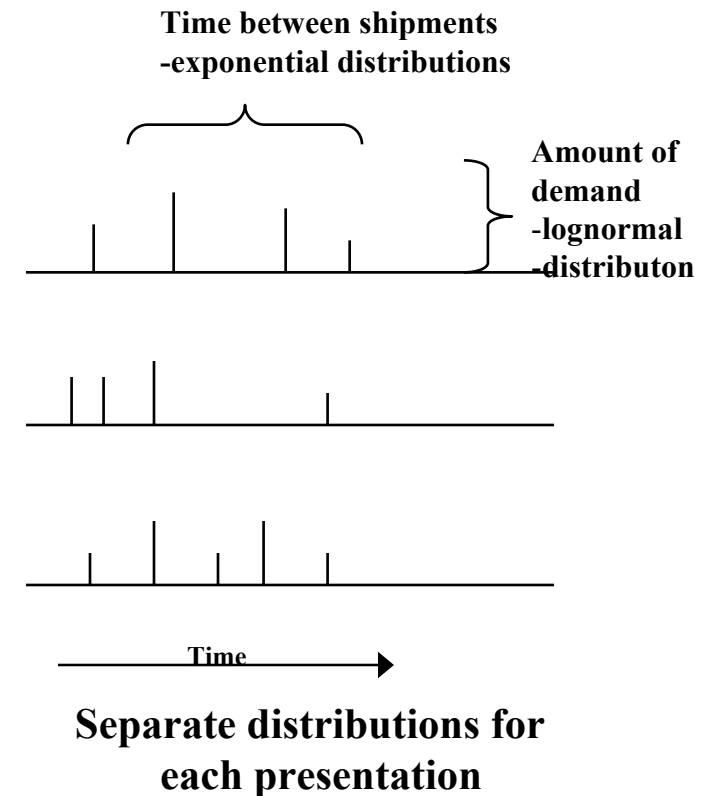
SC Issues – planning across locations

Statistical Patterns

Supply Variability



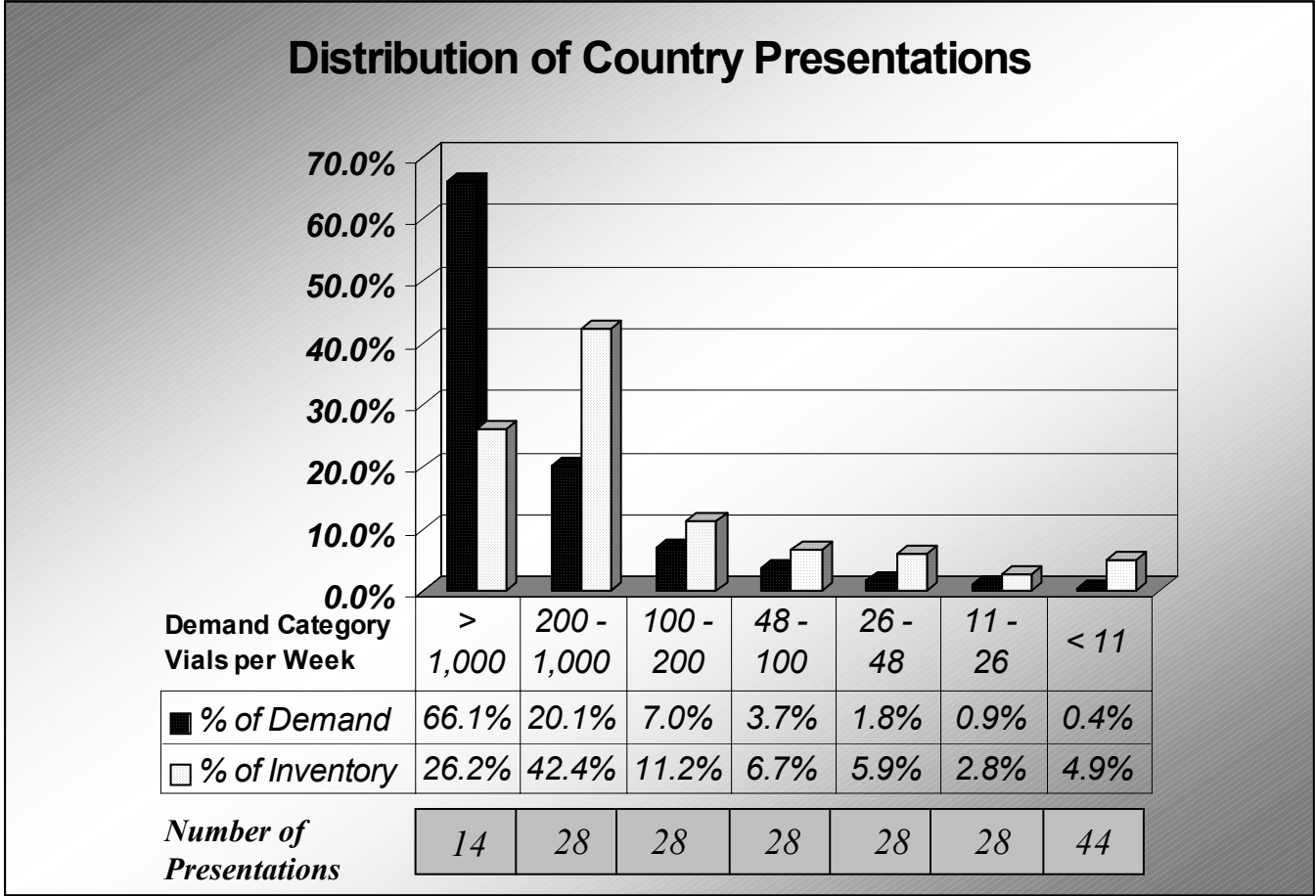
Demand Variability



Service Channel™ Segmentation

- **Overall Product Demand & Inventory**

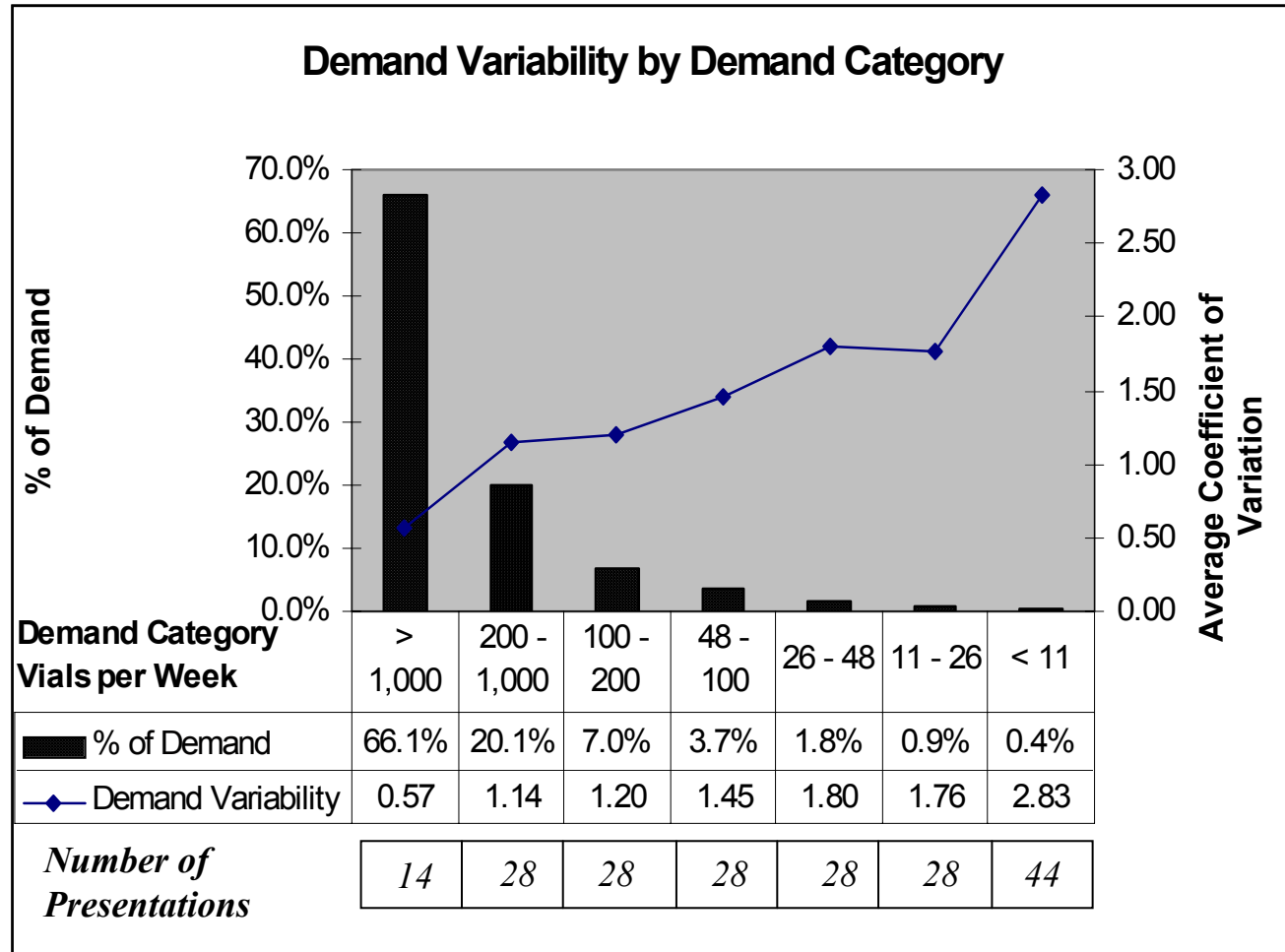
- Demand at the country label presentation level was categorized by average weekly volume levels
- The categories were classified as a % of both demand volume and inventory cost



Service Channel™ Segmentation

• Overall Product Demand & Variability

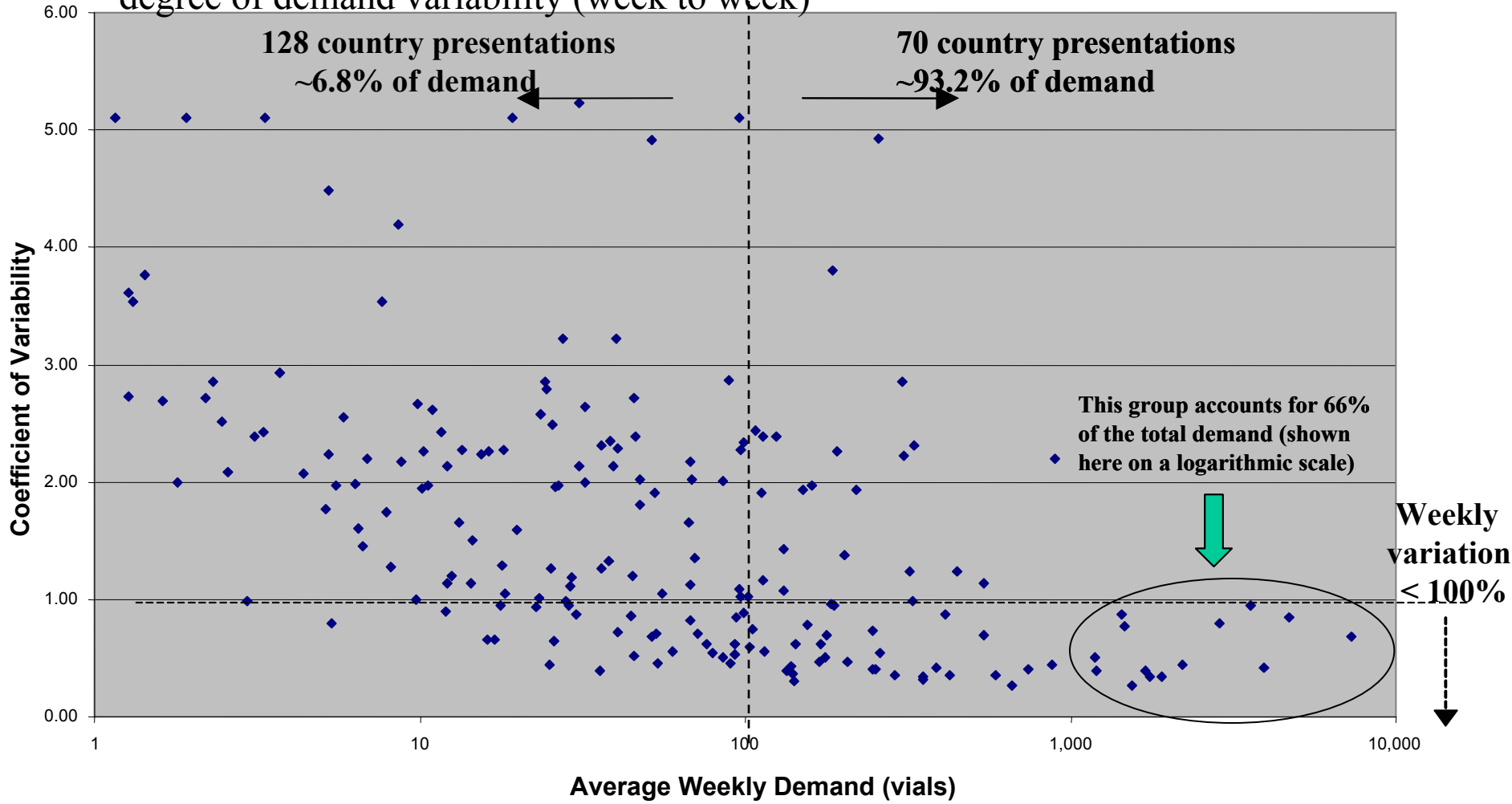
- A good comparative index of variability is the standard deviation of weekly demand divided by the average; it is called the Coefficient of Variation (CofV)
- CofV is a key driver of the amount of inventory required to meet demand
- A CofV > ~.5 indicates demand that is difficult to predict



Service Channel™ Segmentation

- Overall Product Demand and Variability

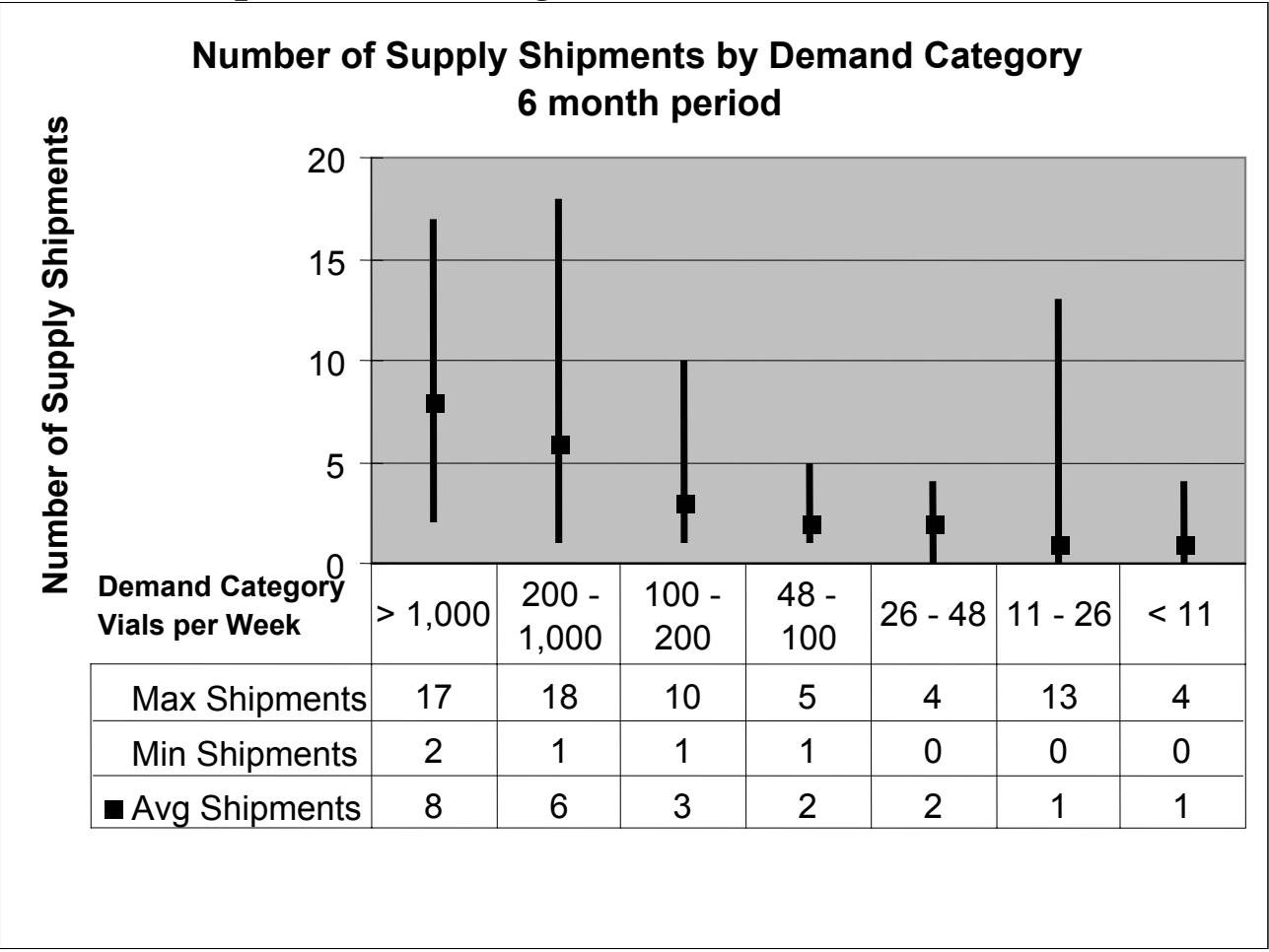
- Combining the variability vs. the weekly demand for all presentations shows the high degree of demand variability (week to week)



Service Channel™ Segmentation

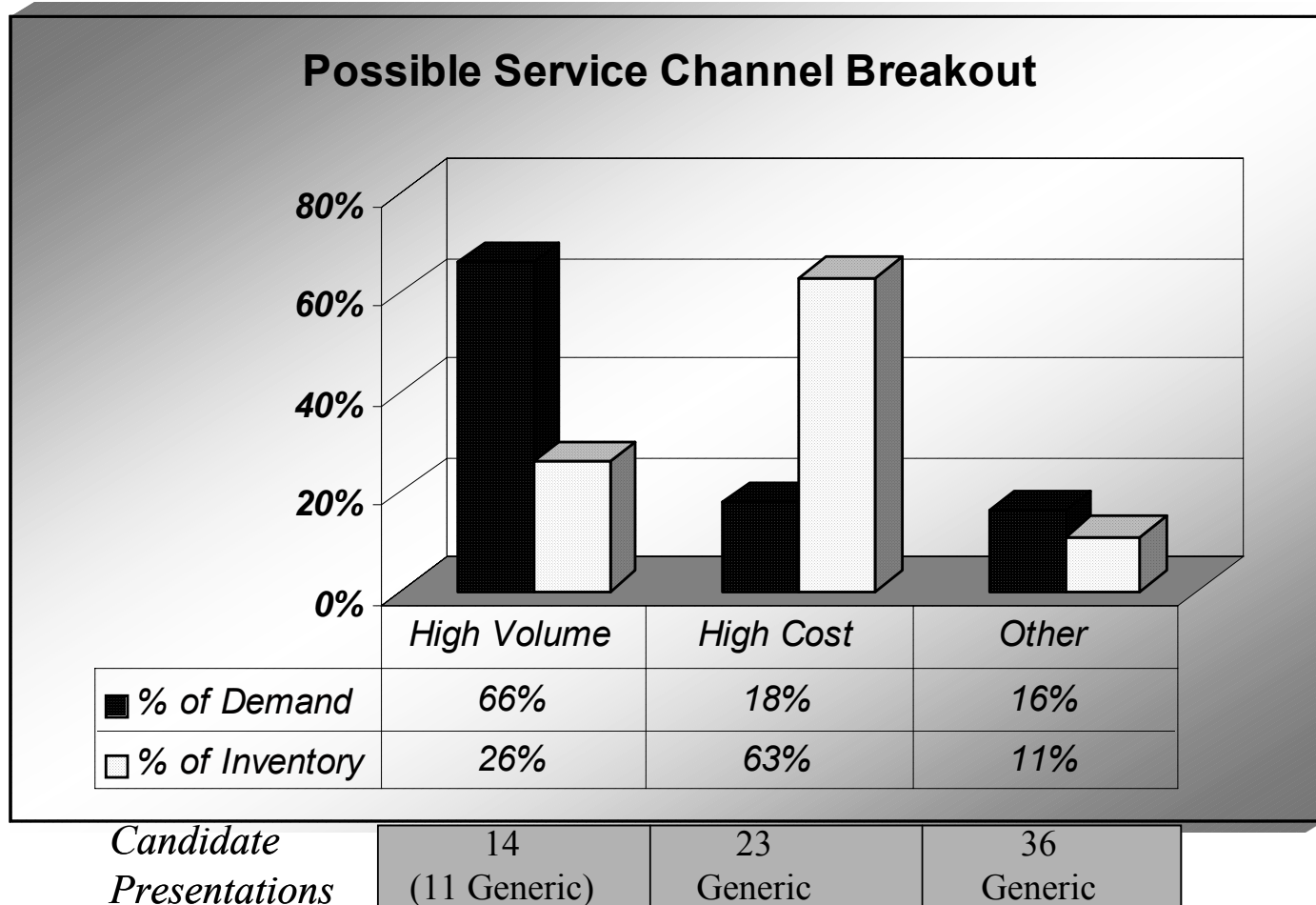
- **Overall Product Supply**

- The number of re-supply shipments for the same demand categories over the 6 months were compared, showing wide variation in the number of shipments.



Service Channel™ Segmentation

- In addition to demand and supply patterns, high unit cost is also a driver of overall inventory cost, with unit costs have a wide range

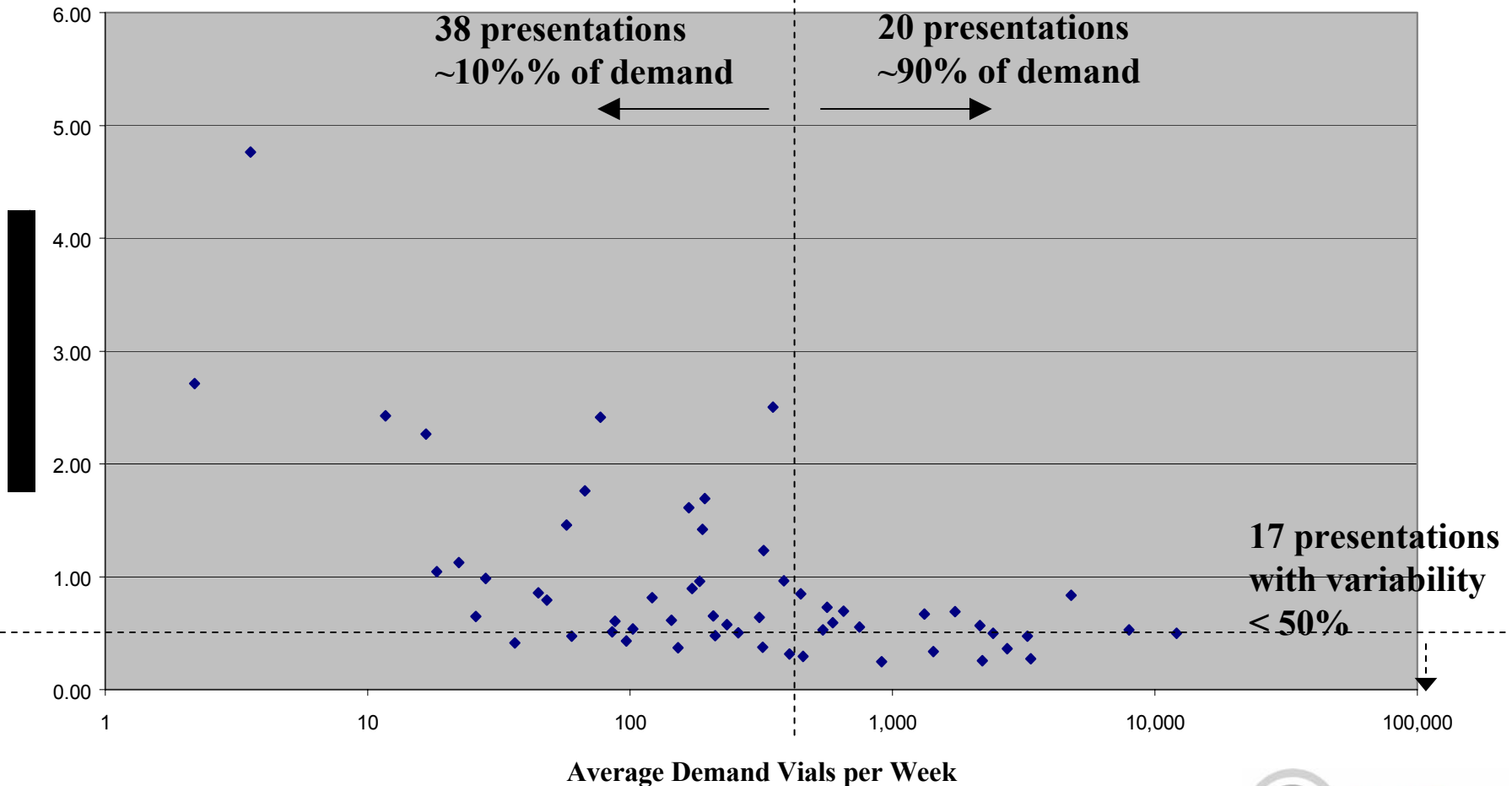


Service Channel™ Segmentation

- **Supply & Postponement Strategy**

- The simulation demonstrates benefits of postponing country labeling. However, there is still significant demand variability even at the generic Europe-wide level.

Volume / Variability Comparison for "white label" Presentations



Service Channel™ Segmentation

- Replenishment/production design
 - High volume channel with level frequent supply:
 - Produce on a biweekly level cycle
 - High cost channel with postponement:
 - Produce generic product every 4 weeks
 - Kanbans for country labeled stock
 - Low volume/low cost channel with level supply:
 - Produce twice per year on a regular schedule

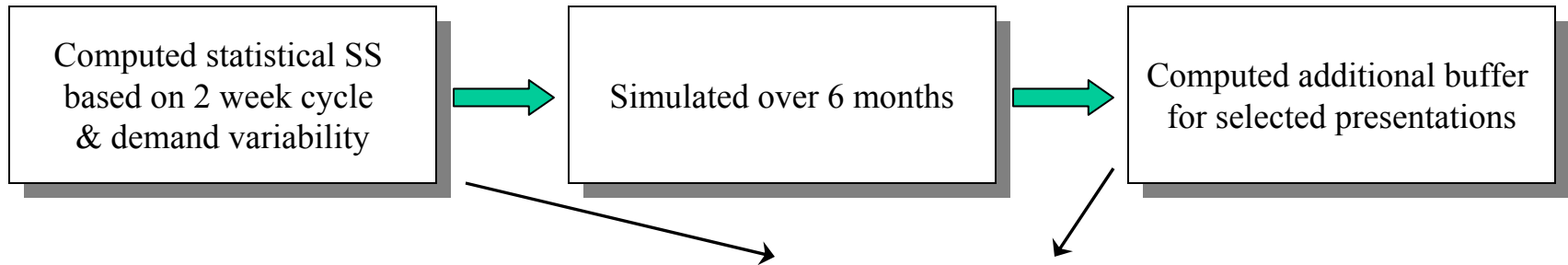
Service Channel™ Segmentation

- Simulation results
 - High volume channel with level frequent supply:
 - 99.9+% service level
 - 60% reduction in inventory
 - High cost channel with postponement:
 - 97+% service level
 - 30% reduction in inventory
 - Low volume/low cost channel with level supply:
 - Improved service levels with same inventory level

Service Channel™ Implementation – Europe

High Volume (flow) channel candidates:

- Simulation for level 2week replenishment w/ 99.9% service
 - Total average inventory - \$7.5mil.



Presentation	Country	Level Load Weeks SS	Extra Buffer Weeks	Total Weeks SS
	DE	2.7	0	2.7
	ES	5.0	0	5.0
	IT	3.1	2	5.1
	DE	2.4	1	3.4
	DE	3.7	3	6.7
	DE	2.5	2	4.5
	IT	2.5	2	4.5
	DE	2.3	2	4.3
	IT	3.9	0	3.9
	DE	2.8	0	2.8
	ES	2.5	1	3.5
	IT	3.1	0	3.1
	DE	3.4	0	3.4
	IT	6.5	0	6.5

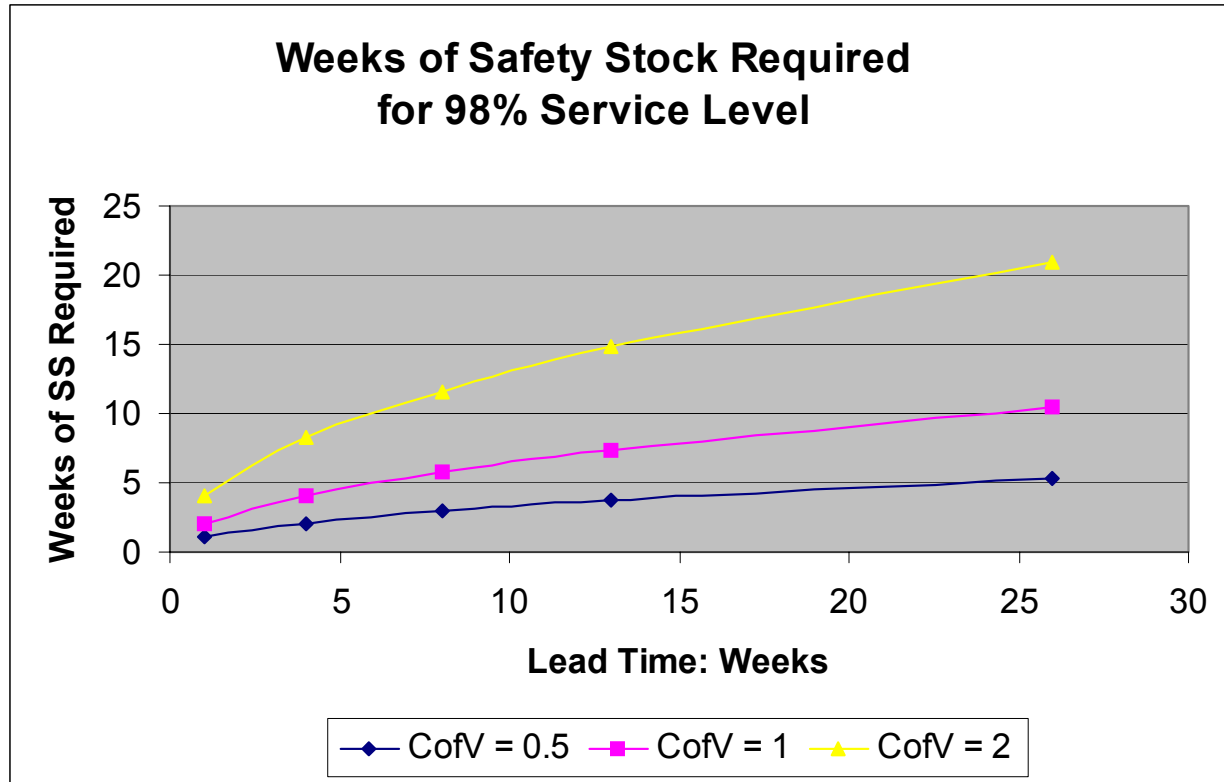
Note: each additional week of SS for this group ~\$1.5mil. in inventory cost

Safety Stock Required: Effect of Demand Variability & Lead-Time

This example demonstrates the additional safety stock requirement as weekly demand variability and supply lead times increase.

Supply variability adds to the safety stock required.

This example uses 98% service level; increasing or decreasing the service level changes the safety stock exponentially.



Coefficient of Variation (CoV) for weekly demand, equal to Standard deviation / mean demand is an indicator of comparative variability

Current Process

	Est Lead-time*		Weekly Demand	CofV	SS Needed
Plant / DC	6 mos.	Spain	102	1.03	1,037
	> 6 mos.	Germany	29	.95	826
	3 mos.	Sweden	27	1.98	535
	2 mos.	France	24	2.85	444
	> 6 mos.	Netherlands	13	2.28	466
	6 mos.	Italy	13	1.20	384
	> 6 mos.	Great Britain	66	2.11	2,287
				Total	

* - Based on nbr of supply shipments in 6 mon. period

Postponement: Reduced inventory

**Shortened &
Consistent Lead times**

+

=

**Reduced CofV of
aggregate demand**

Safety Stock



3,140 vials

**Total Average
Inventory**



4,358 vials

@ \$330 / vial = \$1.43M reduction

Wrap Up

- Experimenting with the inventory / service level analysis available at:

www.OpStat.com

1 Actual Or Stat Demand

1 Actual Or Stat Supply

1 Lean Replenishment

SUPPLY & DEMAND SETUP:
 0 - Actual Run in Calendar Days
 1 - Statistical in Business Days

SUPPLY:
 0 - Use history only
 1 - Use replenishment rules

INITIAL INVENTORY 400

REVIEW PERIOD: Bus Days 5

REORDER QUANTITY 240

BACKORDER: yes=0; no=1 0

CONT FLOW CYCLE (days) 1

CONT FLOW QUANTITY 8

SERVICE LEVEL STND (days) 5

REORDER trigger 0 **Safety Stock** 1 **Target Level** 2

REPLENISHMENT PARAMETERS

0	300	200	500
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REPLENISHMENT EXPECTED LEAD TIME (bus days) 14 **EXPECTED MAX LT (%) VARIABILITY** 8

Totals

Ordered	Fulfilled	Fulfilled > Stnd	Hist Supply	ReSupply Rules
0	1819	2	13	4
0	1819	13	0	1440

Average Inventory Units 225.4 **% Amount Fulfilled** 1

Ending Inventory Units 0 **Nbr Orders/Days** 95

