Determining Economic Production Quantities in a Continuous Process

IIE Process Industries Webinar

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Agenda

The Basics

- EPQ Overview
- Getting Started / Gaining Alignment

Understanding the Model

- Influence of Input Variables on EPQ & EPQ on other Factors
- Sensitivity Analysis

A Case Study

- Objectives
- Case Description
- EPQ Results
- Run Strategy
- Implementation

The Basics - EPQ Overview

- A basic decision every production facility must make is how much product to produce (the order quantity) and how frequently to produce it.
- When deciding on an order quantity, 2 costs need to be considered:
  - Changeover costs – the cost to change from product to the next
  - Inventory holding costs – the costs associated with carrying finished goods
- EPQ in continuous process differs from discrete/batch manufacturing
  - Discrete manufacturing will likely have EPQs for fabricated parts, assemblies and finished goods, continuous processes will likely have 1 EPQ for each finished good
  - Cleaning and sanitation requirements often dictate the duration of a changeover in the process industries
  - Quantifying changeover costs in discrete manufacturing is very different than in continuous processes.
  - There may be a limited number of “available” PQs in a continuous process as determined by:
    - Ingredient or pre-blend batch sizes (e.g. use full tanker quantities)
    - Regulatory run length restrictions (e.g. FDA, USDA)
    - Shift schedule
    - Traceability

EPQ Overview (cont'd)

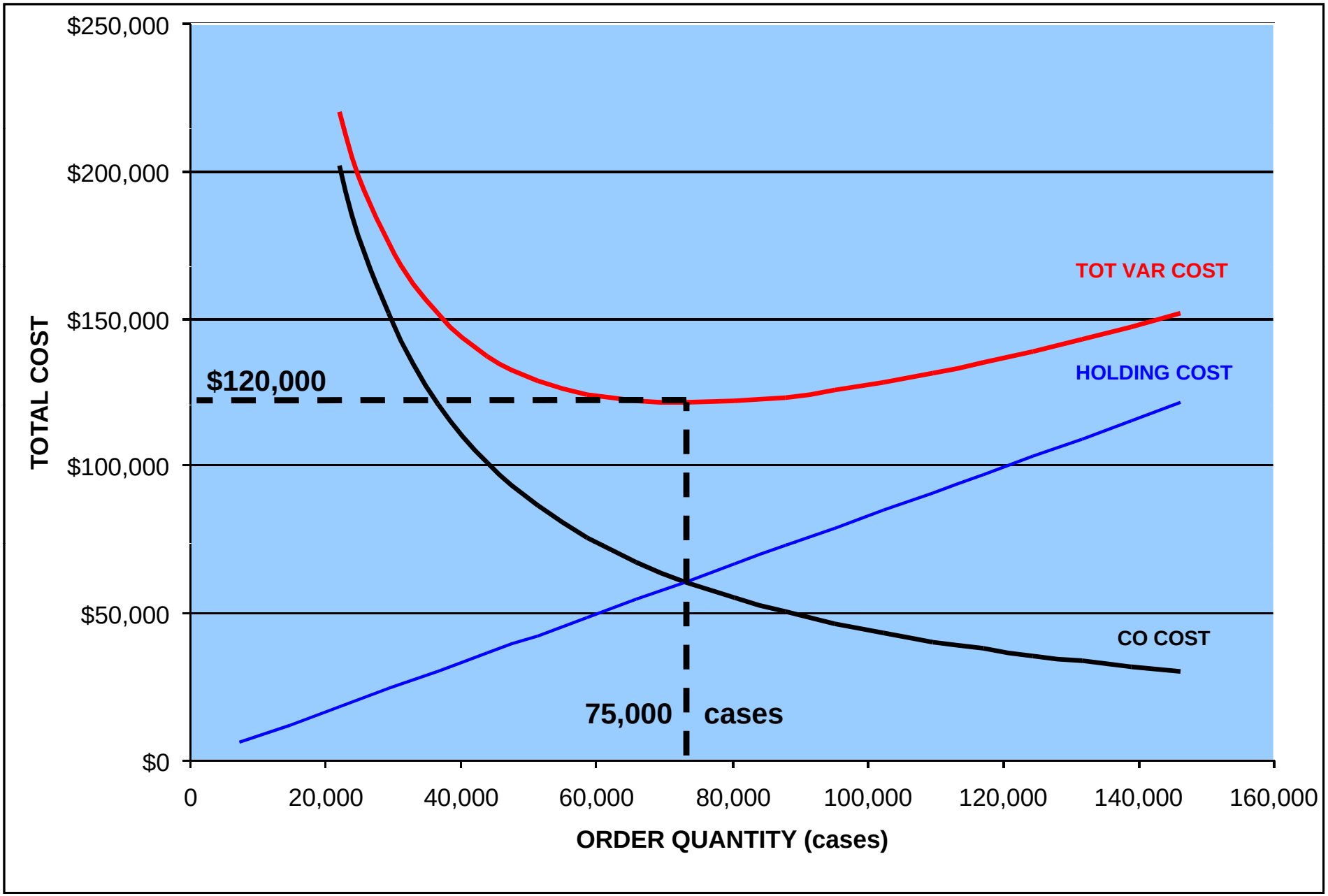
- A high order quantity:
  - low changeover costs per production unit
  - high inventory holding costs
  - fosters higher production efficiencies
  - increases capacity / reduces utilization
- A low order quantity:
  - high changeover costs per production unit
  - low inventory holding costs
  - can negatively impact production efficiencies
  - decreases capacity / increases utilization
- The EPQ Model identifies an order quantity which minimizes the sum of the changeover costs and inventory holding costs, i.e. the model balances the two opposing costs.

The EPQ Model Formula

- EPQ Variables:
  - A = annual demand (units/yr)
  - S = set up or changeover costs ($/changeover)
  - H = inventory holding cost penalty (%/unit/year)
  - C = standard unit cost
  - Q = order quantity
- Changeover Cost per Year = [(A/Q) X S]
- Holding Cost per Year = [(Q/2) X (HXC)] where Q/2 is the average inventory level.
- Total Cost = [(A/Q) X S] + [(Q/2) X (HXC)]
- Economic Order Quantity (Q_0) can be determined by setting changeover costs = holding costs and solving for Q (this is where the 2 cost curves intersect) or by taking the first derivative of the total cost curve, setting = 0 and solving for Q, this is the minimum of the curve.

$$Q_0 = [(2 \text{ X } S \text{ X } A) / (H \text{ X } C)]^{1/2}$$

The EPQ Model Graph



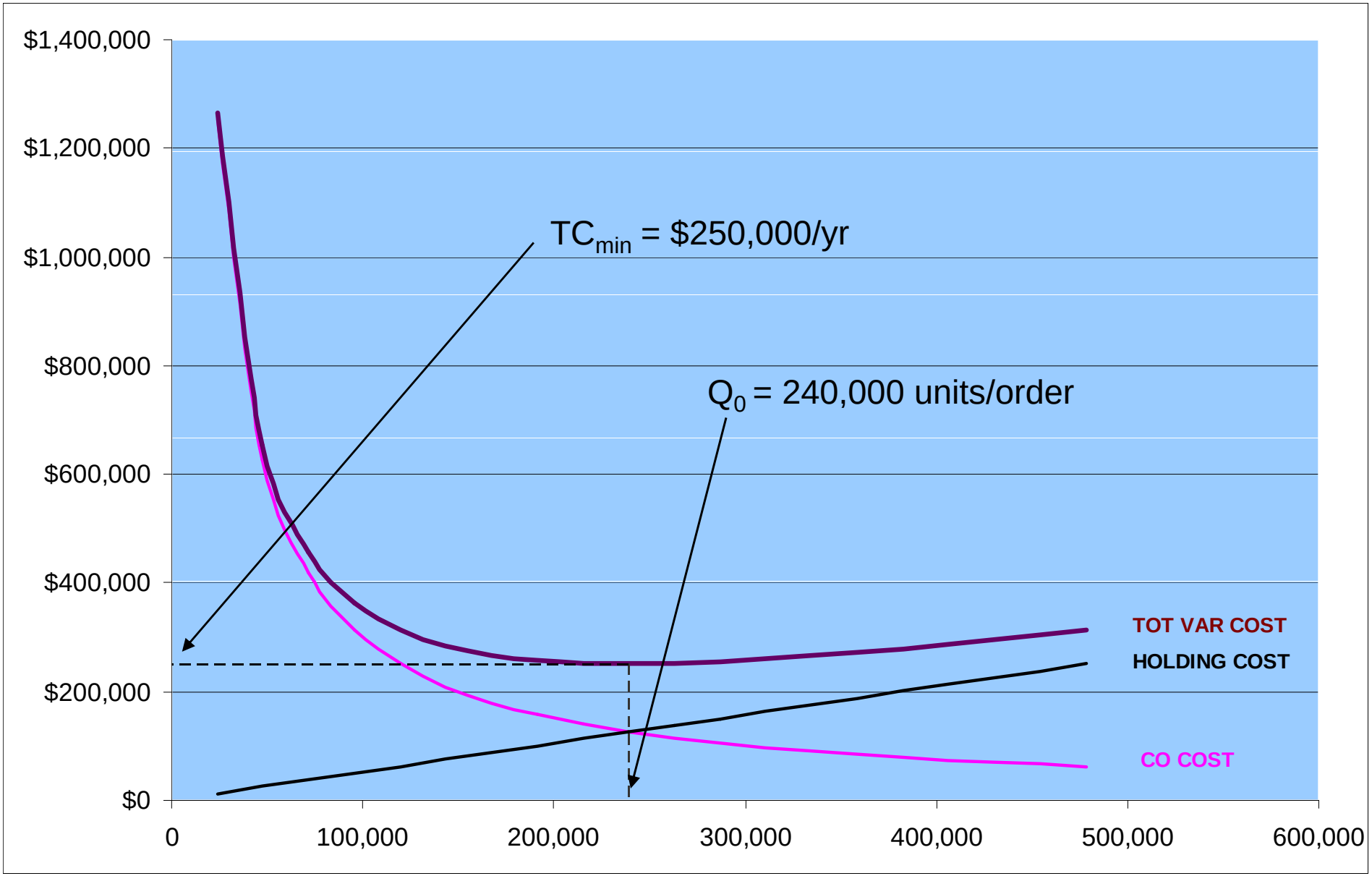
Sample Calculation: $Q_0 = [(2 \text{ X } S \text{ X } A) / (H \text{ X } C)]^{1/2}$

- EPQ Variables:
  - A = annual demand (units/yr) = 3.0MM
  - S = set up or changeover costs ($/changeover) = $10M
  - H = inventory holding cost penalty (%/unit/year) = 21%
  - C = standard unit cost = $5.00

$$Q_0 = [(2 \text{ X } S \text{ X } A) / (H \text{ X } C)]^{1/2} = 240{,}000 \text{ units/order}$$

- Order Cost per Year = [(A/Q) X S] = $125M
- Holding Cost per Year = [(Q/2) X (HXC)] where Q/2 is the average inventory level
  = $125M
- Total Cost = [(A/Q) X S] + [(Q/2) X H] = $250M

The EPQ Model (cont'd)



Getting Started / Gaining Alignment

- Determine what factors effect the duration of a changeover – item last produced, item produced next or a combination
- Identify how many changeover types there are in the process being studied, e.g.:
  - Push – color change going from light to dark
  - Simple – few raw materials used, not a lot of equipment to clean
  - Complex – many raw materials used, a lot of equipment to clean
  - Special Cases
    - hard to clean materials
    - packaging change vs. formula change vs. both
    - long runs = more cleaning
    - nature of process doesn't allow for getting a 'head start' at cleaning front end

Getting Started / Gaining Alignment (cont'd)

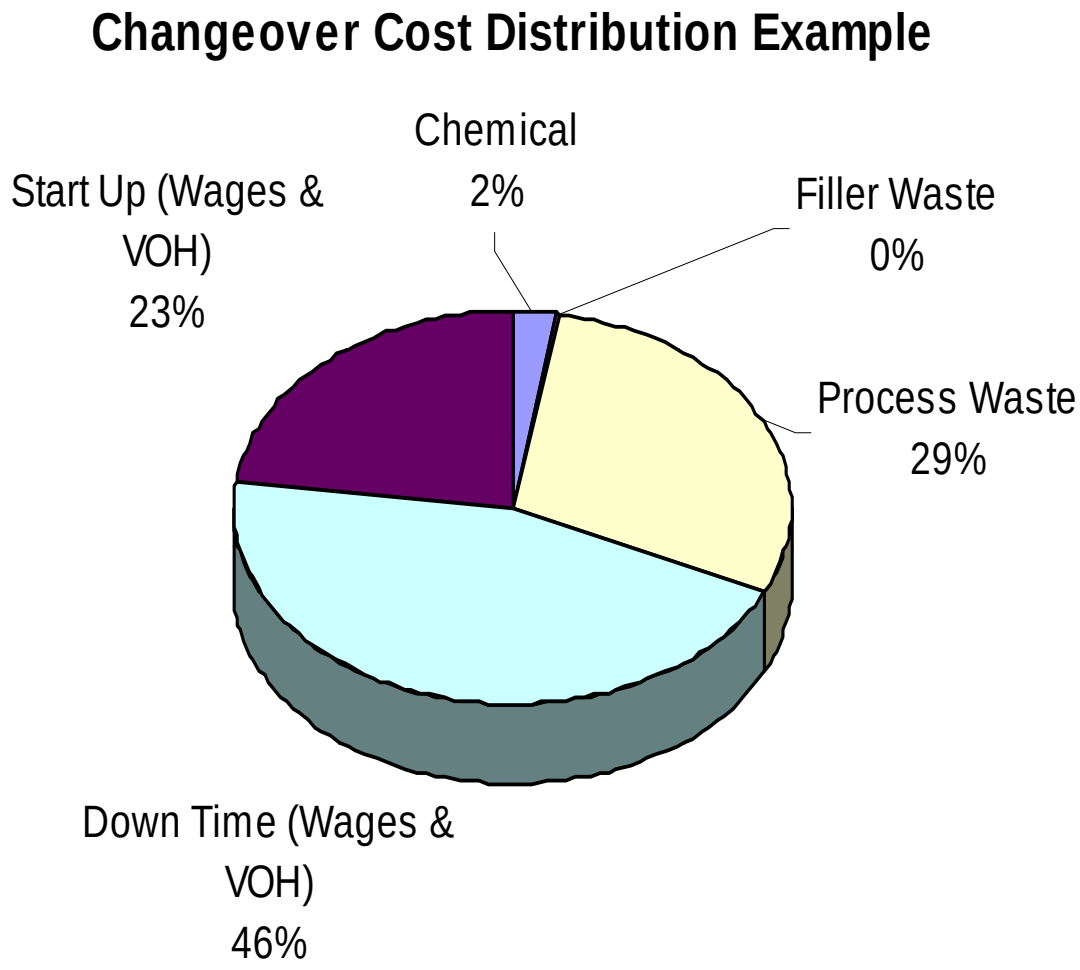
- Establish what costs will be included in changeover costs:
  - Labor – direct & indirect
  - Variable overhead
  - Cleaning chemicals and supplies
  - Product waste – in processing, in packaging
  - Start-up costs
- Determine how changeover costs will be quantified
  - Actual vs. standard – time, losses, crewing
  - Product losses – material costs vs. variable costing
  - Start-up costs – labor and losses, need diligence to quantify
  - Validate the numbers!

Getting Started / Gaining Alignment (cont'd)

- Determine what will be included in holding costs:
  - Finished good cost
    - Benefits and fixed overhead are included in the finished good cost portion of holding costs. Benefits and fixed overhead are excluded from the changeover costs. This is a standard EPQ procedure.
  - Inventory holding penalty is typically around 21%:
    - Cost of capital - 9%
    - Cost of obsolescence – 4%
    - Actual warehousing cost – 6%
    - Cost of complexity/seasonality – 2%

Questions on The Basics

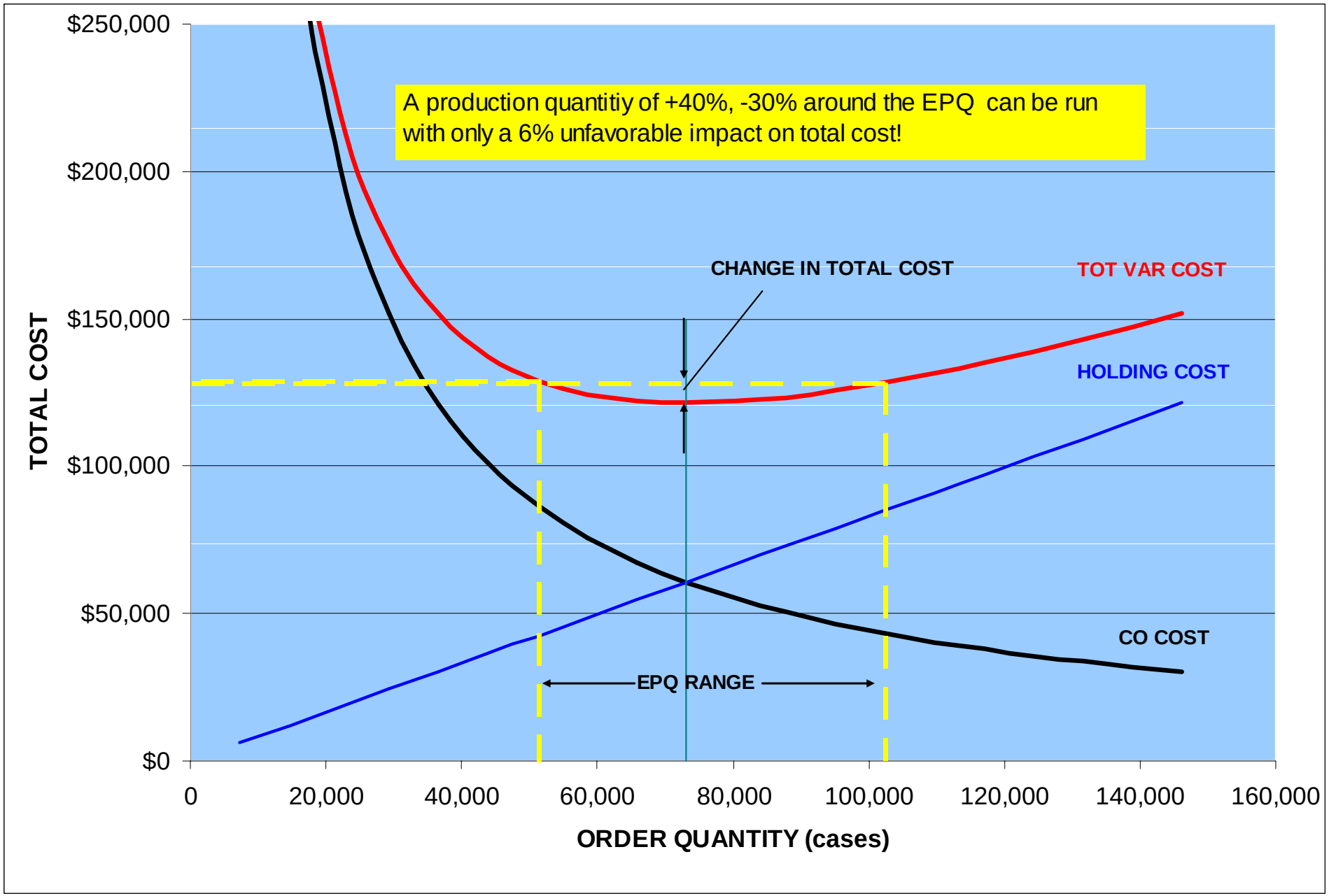
Understanding the Model - Changeover Costs Distribution



Sensitivity Example – Changeover Costs Affect on EPQ

AFFECT OF CHANGEOVER VARIABLES ON EOQ (negative % represents a reduced EOQ)		
Variable	Reduce Variable by 50%	Increase Variable by 100%
Changeover Downtime	-11%	18%
Processing Waste	-5%	9%
Start Up Time	-4%	8%
Chemical Costs	0%	1%
Barrel Waste	0%	0%

Sensitivity Example – The Flat Spot on the EPQ Curve



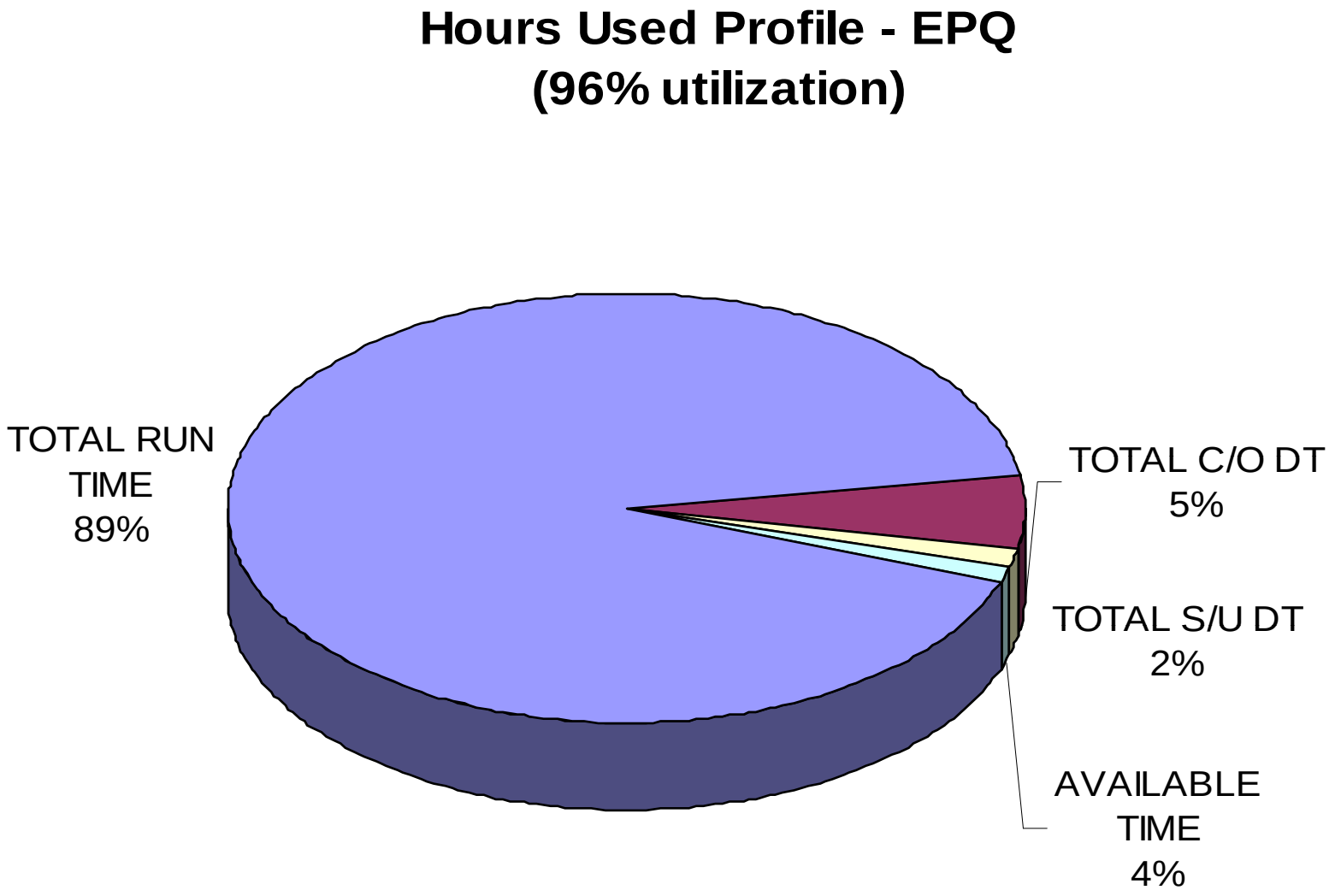
Sensitivity – The Flat Spot on the EPQ Curve

- The total cost curve is relatively flat on either side of the EPQ.
- This results in a very forgiving EPQ.
- In the this case, for each SKU, the EPQ can vary up to +40%, -30% with only a 6% penalty in total cost.
- Increasing the EPQ will increase inventory levels and increase holding costs while decreasing changeover costs and decreasing utilization.
- Decreasing the EPQ will decrease inventory levels and decrease holding costs while increasing changeover costs increasing utilization.
- This is evident in data as well as the graph.

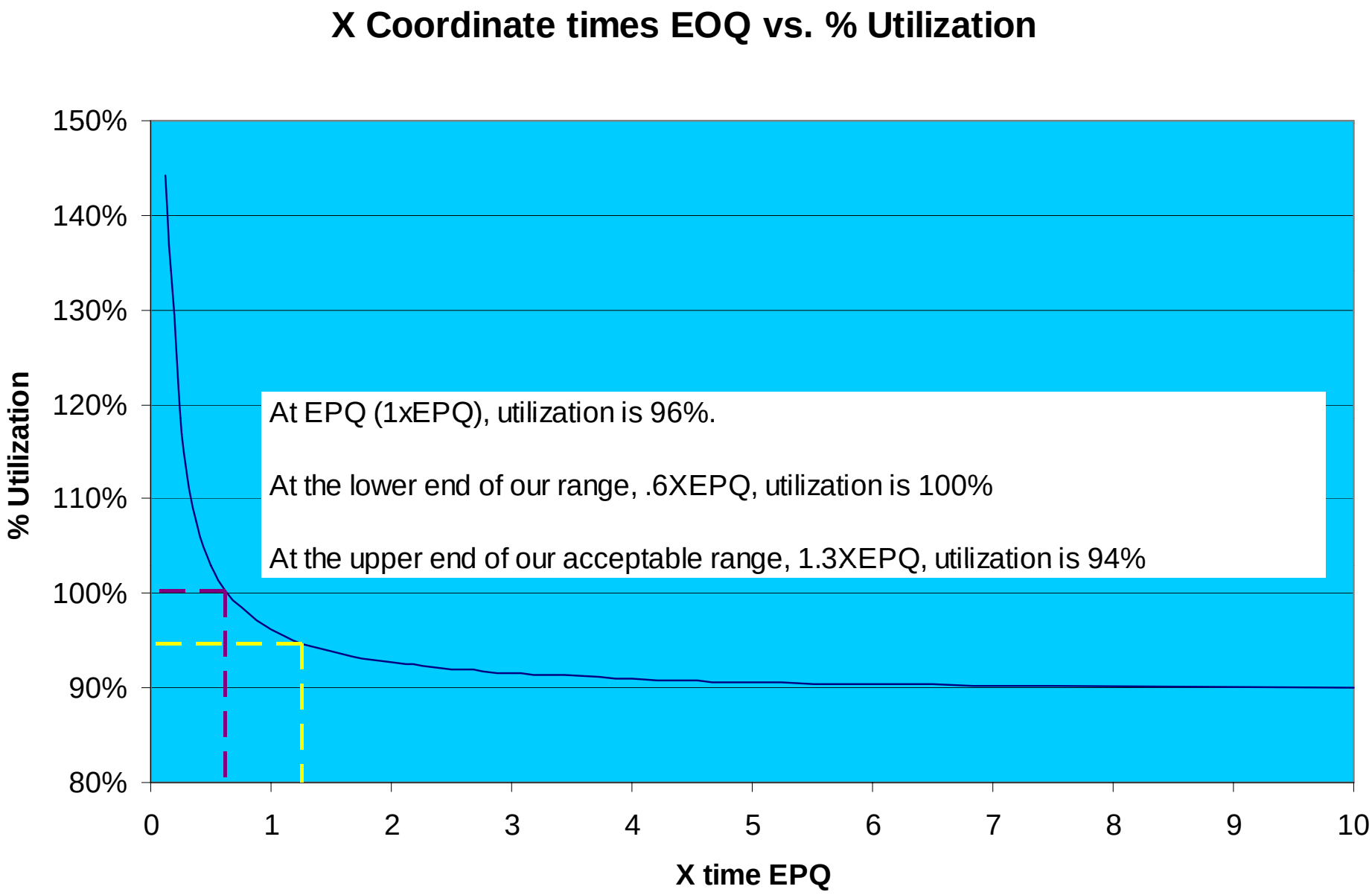
EPQ Effect on Capacity

- On an annual basis, hours required per SKU can be divided into 3 categories:
  - Changeover hours
  - Start-up hours
  - Run hours
- Annual run hours
  - Fixed
  - Annual run hours required are equal to the units required divided by the expected units per hour
- Annual start up and changeover hours
  - Start up and changeover hours per occurrence are fixed, but the occurrences are dependant on the order quantity.
- The lower the order quantity, the higher the occurrence of changeovers and start-ups and the higher the total changeover and start-up hours required.
- The higher the order quantity the lower the machine utilization and the higher the capacity.

EPQ Hours Used Profile & Utilization



EPQ - Utilization Sensitivity Graph



Questions on Understanding the Model

The Case Study

The Case Study - Objectives

- To calculate economic production quantities (EPQ) based on actual costs.
- To compare calculated EPQs to minimum order quantities and actual average order quantities.
- To understand how costs affect EPQ & how EPQ affects costs
  - how changeover cost buckets affect the calculated EPQ
  - how the EPQ affects cost
  - how the EPQ affects utilization
  - how the EPQ affects inventory levels.
- To ultimately determine run strategies that minimize total cost subject to the constraints of capacity, customer fill rate and shelf life.

The Case Study

- A production line had a utilization over 100%.
- Customer orders were not being met, service level was low.
- Minimum order quantities had been calculated in the past.
- Actual average order quantities were below minimum order quantities.
- The EPQ was compared to actual average run quantities and to the facility's minimum production quantity.
- The comparison showed that producing at the EPQs would result in a net savings.
- Running calculated EPQs was not practical due to scheduling & other constraints.
- A usable run strategy was developed.

Summary - EPQ vs Minimum PQ vs YTD Average PQ

Comparison - EPQ vs. Minimum PQ and EPQ vs. YTD Ave PQ[3]

	Average Production Quantity[1]	C/O Cost per Year	Holding Cost per Year	Total Cost per Year (C/O & Holding)	Average WFC	C/O per Year	% Ute	Average Inventory (cs)
EPQ vs. Minimum Order	35,000	-$413,000	$331,000	-$82,000	2.1	-38	4%	410,000
EPQ vs. YTD Ave Order	52,000	-$760,000	$485,000	-$275,000	2.9	-65	-3%	595,000

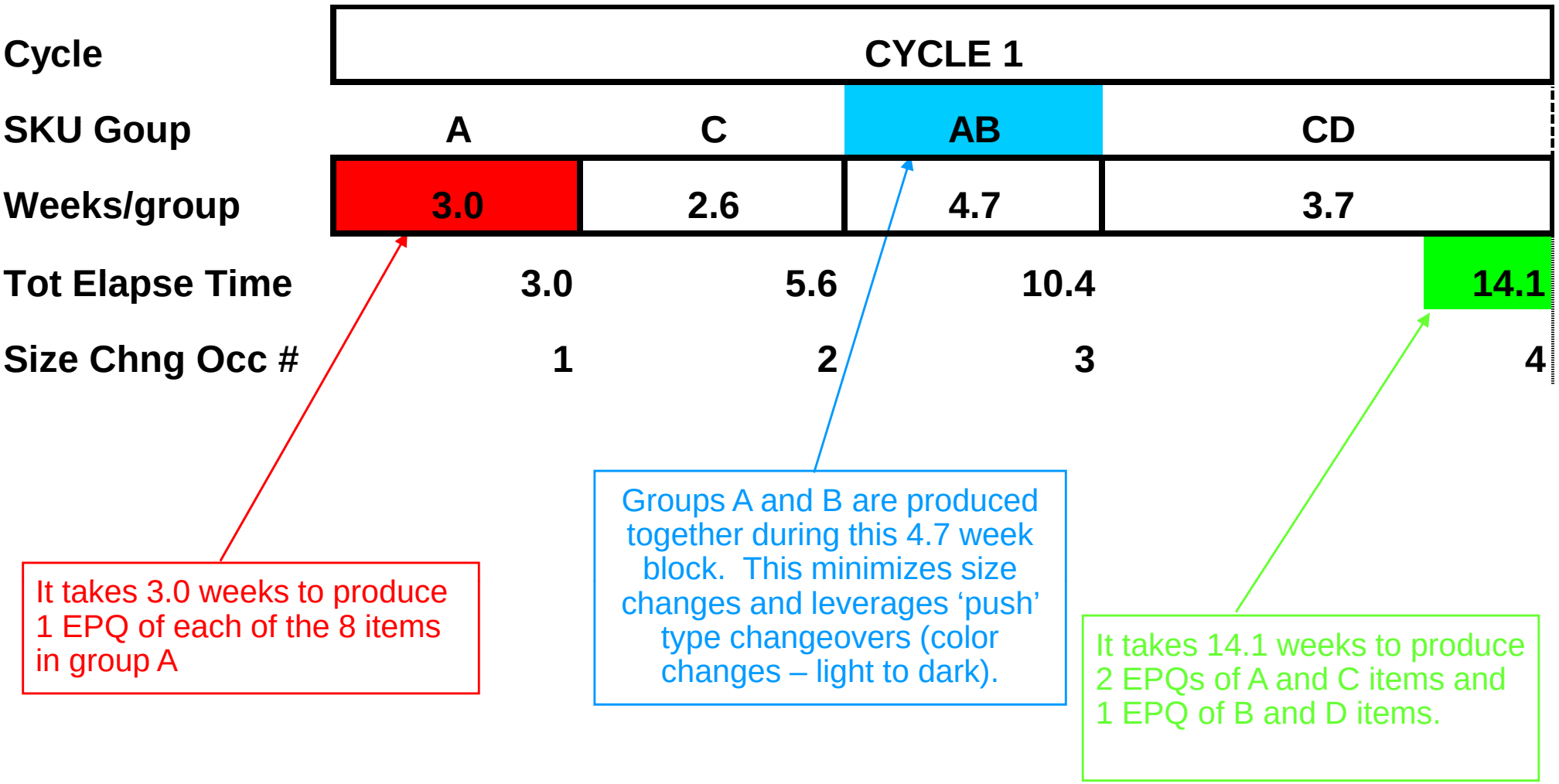
Notes:

1. Average Order Quantity is weighted by orders per year.
2. Average WFC is a straight average over 27 SKUs.
3. Negative numbers indicate a decrease if the EPQ quantity is used. Positive numbers indicate an increase.

Run Strategy 1 – EPQ Runs, All SKUs

SKU GROUP	DESCRIPTION	ANNUAL REQT'S (units)	EOQ	T (frequency in weeks)	N (runs/year)	TOTAL TIME REQ'D (C/O + S/U + run)
A (Size 1)	FG ITEM #1	3,560,000	551,510	8.1	6.5	67
	FG ITEM #2	2,919,756	462,490	8.2	6.3	57
	FG ITEM #3	3,520,205	565,790	8.4	6.2	70
	FG ITEM #4	2,220,369	405,110	9.5	5.5	50
	FG ITEM #5	2,311,231	425,050	9.6	5.4	53
	FG ITEM #6	3,372,191	623,200	9.6	5.4	77
	FG ITEM #7	2,592,466	543,580	10.9	4.8	68
	FG ITEM #8	2,584,143	553,740	11.1	4.7	69
					Total Hrs	510
					Total Wks	3.0
B (Size 1)	FG ITEM #9	899,393	219,310	12.7	4.1	27
	FG ITEM #10	1,789,282	437,590	12.7	4.1	55
	FG ITEM #11	2,049,585	503,990	12.8	4.1	64
	FG ITEM #12	716,525	187,500	13.6	3.8	24
	FG ITEM #13	808,199	212,920	13.7	3.8	26
	FG ITEM #14	765,024	205,000	13.9	3.7	26
	FG ITEM #15	548,607	162,830	15.4	3.4	21
	FG ITEM #16	500,622	169,060	17.6	3.0	21
	FG ITEM #17	481,479	163,730	17.7	2.9	21
					Total Hrs	285
					Total Wks	1.7
C (Size 2)	FG ITEM #18	5,291,405	648,720	6.4	8.2	78
	FG ITEM #19	5,443,472	717,140	6.9	7.6	87
	FG ITEM #20	3,950,128	534,450	7.0	7.4	65
	FG ITEM #21	2,613,426	419,900	8.4	6.2	53
	FG ITEM #22	3,510,930	585,850	8.7	6.0	72
	FG ITEM #23	3,686,244	647,350	9.1	5.7	80
					Total Hrs	435
					Total Wks	2.6
D (Size 2)	FG ITEM #24	2,906,550	576,380	10.3	5.0	72
	FG ITEM #25	2,005,704	416,390	10.8	4.8	52
	FG ITEM #26	1,668,921	362,920	11.3	4.6	46
	FG ITEM #27	697,902	173,130	12.9	4.0	22
					Total Hrs	193
					Total Wks	1.1

Run Strategy 1 – Run Block Example



Run Strategy 1 – EPQ Timeline

Cycle	CYCLE 1				CYCLE 2				CYCLE 3			
SKU Goup	A	C	AB	CD	A	C	AB	CD	A	C	AB	CD
Weeks/group	3.0	2.6	4.7	3.7	3.0	2.6	4.7	3.7	3.0	2.6	4.7	3.7
Tot Elapse Time	3.0	5.6	10.3	14.0	17.1	19.6	24.4	28.1	31.1	33.7	38.4	42.1
Size Chng Occ #	1	2	3	4	5	6	7	8	9	10	11	12

Every 42 weeks:

- Run group A SKUs 6 times, every 7 weeks on average.
- Run group B SKUs 3 times, every 14 weeks on average.
- Run group C SKUs 6 times, every 7 weeks on average.
- Run group D SKUs 3 times, every 14 weeks on average.
- 12 size changes, or 1 size change every 3.5 weeks.
- 123 changeovers (all types) in 42 weeks, or 1 changeover every 2.4 days.

Run Strategy 1 – EPQ Run Frequency & Slack Time

SKU GROUP	DESCRIPTION	ANNUAL REQT'S (A) (units)	EOQ	T (freq In weeks)	AVE FREQ	"PAD" AVE F REQ - T
B (Sz1)	FG ITEM #9	389,737	95,031	12.7	14.0	-1.4
	FG ITEM #10	775,355	189,622	12.7	14.0	-1.3
	FG ITEM #11	888,154	218,392	12.8	14.0	-1.3
	FG ITEM #12	310,494	81,250	13.6	14.0	-0.4
	FG ITEM #13	350,220	92,263	13.7	14.0	-0.3
	FG ITEM #14	331,510	88,831	13.9	14.0	-0.1
	FG ITEM #15	237,730	70,557	15.4	14.0	1.4
	FG ITEM #16	216,936	73,256	17.6	14.0	3.5
	FG ITEM #17	208,641	70,947	17.7	14.0	3.6

Run Strategy 1 – EPQ Run Frequency & Slack Time

SKU GROUP	DESCRIPTION	ANNUAL REQT'S (units)	EOQ	T (frequency in weeks)	N (runs/year)	TOTAL TIME REQ'D (S/U + run + C/O)	FREQUENCY 1	FREQUENCY 2	AVE FREQ	"PAD" AVE FREQ - T
A (Size 1)	FG ITEM #1	3,560,000	551,510	8.1	6.5	67	5.6	8.5	7.1	1.0
	FG ITEM #2	2,919,756	462,490	8.2	6.3	57	5.6	8.5	7.1	1.2
	FG ITEM #3	3,520,205	565,790	8.4	6.2	70	5.6	8.5	7.1	1.3
	FG ITEM #4	2,220,369	405,110	9.5	5.5	50	5.6	8.5	7.1	2.4
	FG ITEM #5	2,311,231	425,050	9.6	5.4	53	5.6	8.5	7.1	2.5
	FG ITEM #6	3,372,191	623,200	9.6	5.4	77	5.6	8.5	7.1	2.6
	FG ITEM #7	2,592,466	543,580	10.9	4.8	68	5.6	8.5	7.1	3.9
	FG ITEM #8	2,584,143	553,740	11.1	4.7	69	5.6	8.5	7.1	4.1
					Total Hrs	**510**				
					Total Wks	**3.0**				
B (Size 1)	FG ITEM #9	899,393	219,310	12.7	4.1	27	14.1	14.1	14.1	(1.4)
	FG ITEM #10	1,789,282	437,590	12.7	4.1	55	14.1	14.1	14.1	(1.4)
	FG ITEM #11	2,049,585	503,990	12.8	4.1	64	14.1	14.1	14.1	(1.3)
	FG ITEM #12	716,525	187,500	13.6	3.8	24	14.1	14.1	14.1	(0.5)
	FG ITEM #13	808,199	212,920	13.7	3.8	26	14.1	14.1	14.1	(0.4)
	FG ITEM #14	765,024	205,000	13.9	3.7	26	14.1	14.1	14.1	(0.2)
	FG ITEM #15	548,607	162,830	15.4	3.4	21	14.1	14.1	14.1	1.3
	FG ITEM #16	500,622	169,060	17.6	3.0	21	14.1	14.1	14.1	3.5
	FG ITEM #17	481,479	163,730	17.7	2.9	21	14.1	14.1	14.1	3.6
					Total Hrs	**285**				
					Total Wks	**1.7**				
C (Size 2)	FG ITEM #18	5,291,405	648,720	6.4	8.2	78	7.3	6.8	7.1	(0.7)
	FG ITEM #19	5,443,472	717,140	6.9	7.6	87	7.3	6.8	7.1	(0.2)
	FG ITEM #20	3,950,128	534,450	7.0	7.4	65	7.3	6.8	7.1	(0.0)
	FG ITEM #21	2,613,426	419,900	8.4	6.2	53	7.3	6.8	7.1	1.3
	FG ITEM #22	3,510,930	585,850	8.7	6.0	72	7.3	6.8	7.1	1.6
	FG ITEM #23	3,686,244	647,350	9.1	5.7	80	7.3	6.8	7.1	2.1
					Total Hrs	**435**				
					Total Wks	**2.6**				
D (Size 2)	FG ITEM #24	2,906,550	576,380	10.3	5.0	72	14.1	14.1	14.1	(3.8)
	FG ITEM #25	2,005,704	416,390	10.8	4.8	52	14.1	14.1	14.1	(3.3)
	FG ITEM #26	1,668,921	362,920	11.3	4.6	46	14.1	14.1	14.1	(2.8)
	FG ITEM #27	697,902	173,130	12.9	4.0	22	14.1	14.1	14.1	(1.2)
					Total Hrs	**193**		**# SKUs w/ Negative Slack**		**11**
					Total Wks	**1.1**		**# SKUs w/ Positive Slack**		**16**
								Minimum Slack		**-4.5**
						`		**Maximum Slack**		**4.1**

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Run Strategy 2 – Adjusted Run Quantities

Slack Weeks

Condition	Meaning	Options	Actions
-	SKU needed before scheduled	Make more	Increase OQ
	(Making it late)	Make sooner	Decrease other OQ
+	SKU needed after scheduled	Make less	Decrease OQ
	(Making it early)	Make later	Increase other OQ

- Hybrid run strategies were developed by increasing or decreasing order quantity based on the condition of the ‘Slack’ weeks.
- Several iterations were performed varying the order quantity while monitoring the time between runs and the slack weeks.
- The objective was to eliminate/minimize negative slack while minimizing time between runs.

Run Strategy 2 – Adjusted Run Quantities Timeline

Cycle	CYCLE 1				CYCLE 2				CYCLE 3				CYCLE 4			
SKU Goup	A	C	AB	CD	A	C	AB	CD	A	C	AB	CD	A	C	AB	CD
Weeks/group	2.6	2.5	4.3	3.9	2.6	2.5	4.3	3.9	2.6	2.5	4.3	3.9	2.6	2.5	4.3	3.9
Tot Elapse Time	2.6	5.1	9.4	13.3	15.9	18.4	22.8	26.6	29.2	31.8	36.1	39.9	42.6	45.1	49.4	53.3
Size Chng Occ #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Every 53 weeks:

- Run group A SKUs 8 times, every 6.7 weeks on average.
- Run group B SKUs 4 times, every 13.3 weeks on average.
- Run group C SKUs 8 times, every 6.7 weeks on average.
- Run group D SKUs 4 times, every 13.3 weeks on average.
- 12 size changes, or 1 size change every 4.4 weeks.
- 123 changeovers (all types) in 53 weeks, or 1 changeover every 3.0 days.

Run Strategy 2 – Adjusted Run Quantities & Slack Time

SKU GROUP	DESCRIPTION	2008 ANNUAL REQT'S (units)	Adjusted Production Quantity	Total Time Req'd (S/U + Run + C/O)	Freq 1	Freq 2	Ave Freq	Reqd Freq	"SLACK" (AVE FREQ - T)
A (Size 1)	FG ITEM #1	3,560,000	468,801	58	5.3	8.3	6.8	6.9	0.0
	FG ITEM #2	2,919,756	131,044	49	5.3	8.3	6.8	7.0	0.2
	FG ITEM #3	3,520,205	160,313	60	5.3	8.3	6.8	7.1	0.3
	FG ITEM #4	2,220,369	114,785	43	5.3	8.3	6.8	8.1	1.2
	FG ITEM #5	2,311,231	120,435	46	5.3	8.3	6.8	8.1	1.3
	FG ITEM #6	3,372,191	176,580	66	5.3	8.3	6.8	8.2	1.3
	FG ITEM #7	2,592,466	154,020	58	5.3	8.3	6.8	9.3	2.4
	FG ITEM #8	2,584,143	156,899	59	5.3	8.3	6.8	9.5	2.6
			Total Hrs	**439**					
			Total Wks	**2.6**					
B (Size 1)	FG ITEM #9	899,393	263,186	93	13.6	13.6	13.6	15.2	1.6
	FG ITEM #10	1,789,282	525,135	186	13.6	13.6	13.6	15.3	1.6
	FG ITEM #11	2,049,585	604,820	215	13.6	13.6	13.6	15.3	1.7
	FG ITEM #12	716,525	225,012	80	13.6	13.6	13.6	16.3	2.7
	FG ITEM #13	808,199	255,517	90	13.6	13.6	13.6	16.4	2.8
	FG ITEM #14	765,024	246,013	87	13.6	13.6	13.6	16.7	3.1
	FG ITEM #15	548,607	138,411	50	13.6	13.6	13.6	13.1	-0.5
	FG ITEM #16	500,622	143,706	52	13.6	13.6	13.6	14.9	1.3
	FG ITEM #17	481,479	139,176	50	13.6	13.6	13.6	15.0	1.4
			Total Hrs	**809**					
			Total Wks	**4.8**					
C (Size 2)	FG ITEM #18	5,291,405	778,505	272	7.0	6.7	6.8	7.7	0.8
	FG ITEM #19	5,443,472	860,613	301	7.0	6.7	6.8	8.2	1.4
	FG ITEM #20	3,950,128	641,374	225	7.0	6.7	6.8	8.4	1.6
	FG ITEM #21	2,613,426	356,928	128	7.0	6.7	6.8	7.1	0.3
	FG ITEM #22	3,510,930	497,991	177	7.0	6.7	6.8	7.4	0.6
	FG ITEM #23	3,686,244	550,268	195	7.0	6.7	6.8	7.8	0.9
			Total Hrs	**1,298**					
			Total Wks	**7.7**					
D (Size 2)	FG ITEM #24	2,906,550	691,692	245	13.6	13.6	13.6	12.4	-1.3
	FG ITEM #25	2,005,704	499,694	177	13.6	13.6	13.6	13.0	-0.7
	FG ITEM #26	1,668,921	435,527	155	13.6	13.6	13.6	13.6	-0.1
	FG ITEM #27	697,902	207,767	74	13.6	13.6	13.6	15.5	1.8
			Total Hrs	**650**		**# SKUs w/ Negative Slack**			**4**
			Total Wks	**3.9**		**# SKUs w/ Positive Slack**			**23**
							Minimum Slack		**-1.3**
							Maximum Slack		**3.1**

Summary – Adjusted OQ vs Min OQ vs YTD Average OQ

Comparison - EPQ vs. Minimum Order Quantity and EPQ vs. YTD Ave Order Qty[3]

	Average Production Quantity	C/O Cost per Year	Holding Cost per Year	Total Cost per Year (C/O & Holding)	Average WFC[2]	C/O per Year	% Ute	Average Inventory (cs)
Adjusted Production Qty vs. Min Production Qty	14,712	-$247,692	$155,804	-$91,888	0.6	-19	4.4%	191,067
Adjusted Production Qty vs. YTD Ave Production Qty	31,327	-$594,659	$310,194	-$284,464	1.3	-45	-2.5%	376,531

Notes:

1. Average Order Quantity is weighted by orders per year.
2. Average WFC is a straight average over 27 SKUs.
3. Negative numbers indicate a decrease if the EPQ quantity is used. Positive numbers indicate an increase.

Final Steps

- Several iterations were performed to determine acceptable production quantities (within +40%,-30% of EPQ) for each Finished Good Item that resulted in no negative slack.
- These production quantities were used in the actual plant finite scheduling model which accounts for actual schedule downtime, consumption, inventory levels, raw and packaging material availability etc.
- After determining that EPQs do work when considering all ‘real life’ variables, an implementation plan was developed.
- Implementation plan included phasing in acceptable EPQ quantities as production schedules were developed.

QUESTIONS?

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Contact information available through IIE membership directory.