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# Tradeoffs between Working Capital and Production Capacity for Multi-Stage Manufacturing

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# Agenda

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  - Inventory
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# Company/Background

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## Company:

- Pharmaceutical company with a multi-stage manufacturing process



## Background:

- Many SKU's with different production stages.
- Focusing on one SKU and one production process



## Primary Objective:

- Overall objective to reduce inventory



## Secondary Objective:

- Increase flexibility & reduce risk



## Proposal:

- Invest in new production facilities

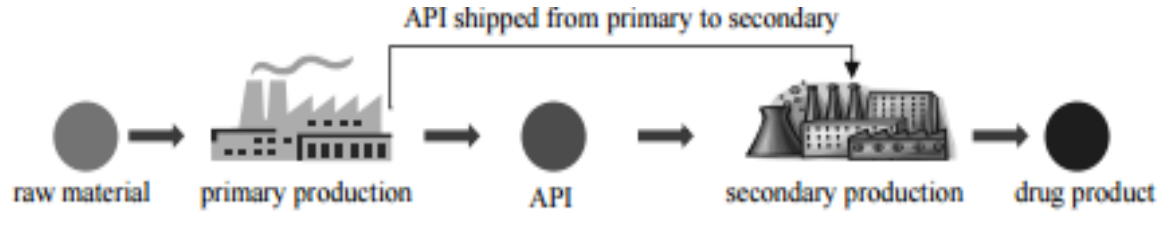


## Methodology:

- Scenario test different investments

# Introduction

# Introduction— Manufacturing Process



a) Traditional two-echelon production scheme



b) Novel integrated production scheme

Source: (Arul Sundaramoorthy, Xiang Li, James M.B. Evans, Paul I. Bartona, 2012)

# Introduction— Production Schedule

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	c/o	c/o	c/o	c/o
Stage	1	2	3	4
Quarter	Q1	Q2	Q3	Q4

Figure: Production schedule for ONE production facility

2

	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o
Stage	1	2	1	2	1	2	1	2	1	2	1	2	
Quarter	Q1		Q2		Q3		Q4						

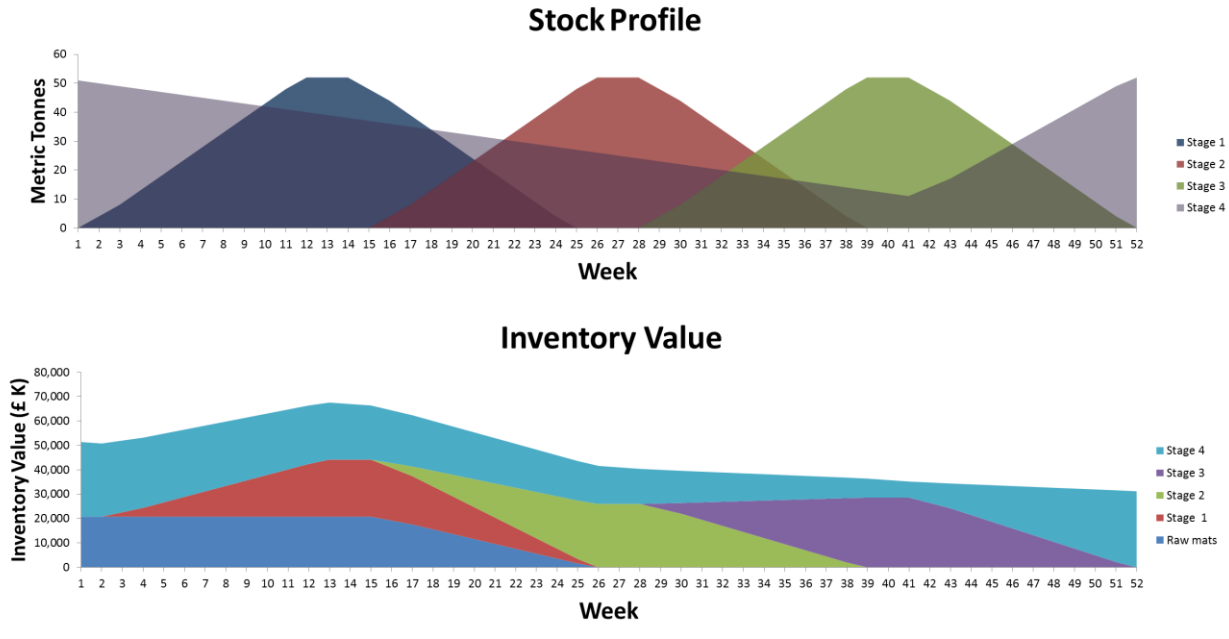
  

	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o	c/o
Stage	3	4	3	4	3	4	3	4	3	4	3	4
Quarter	Q1		Q2		Q3		Q4					

Figure: Production schedule for TWO production facility

# Introduction – Inventory (One production facility)

1



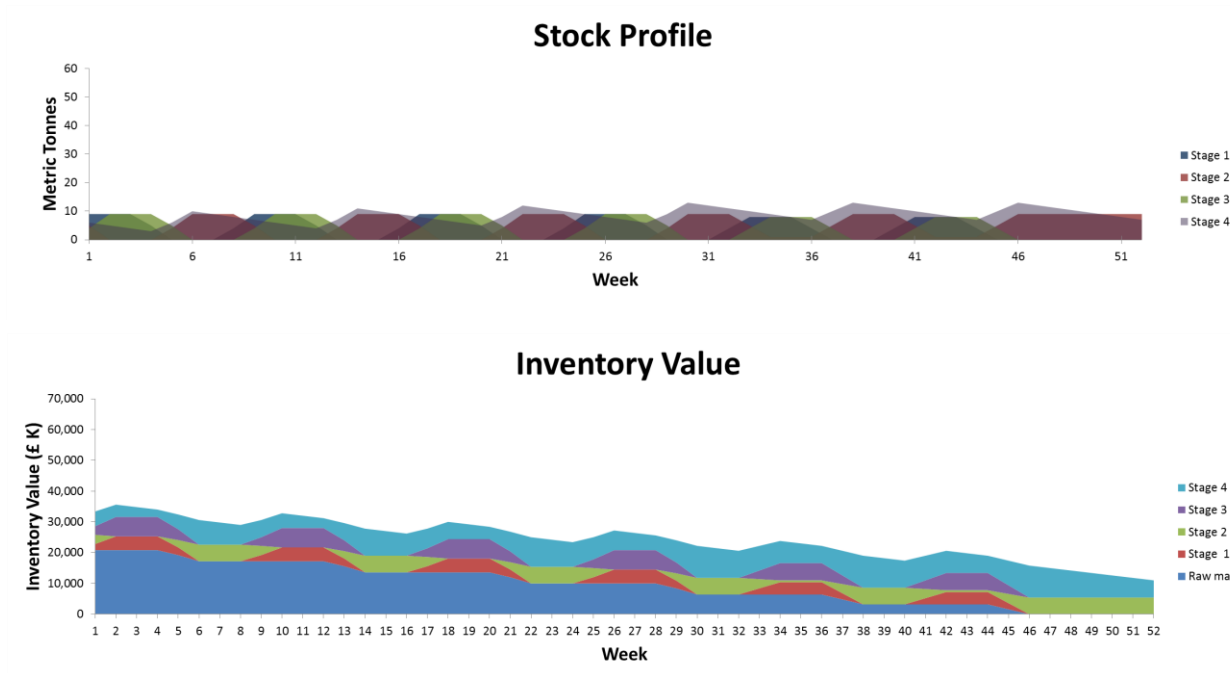
## Characteristics:

- Big batches
- Low frequency of changeovers
- Long lead-times
- Low CAPEX investment



# Introduction – Inventory (Two production facilities)

2



## Characteristics:

- Smaller batches
- Higher changeovers
- Short lead-times
- High CAPEX investment

# Methodology

# Methodology – Scenario Analysis

Scenario	Number of Modules	Number of Stages in Production	Changeover Frequency (times/year)	Changeover Time (Weeks)
Base Scenario	One Module	4	4	8
Base Scenario	Two Modules	4	12	24
Scenario 2	Two Modules	4	8	16
Scenario 3	Two Modules	4	4	8
Scenario 4	One Module	2	12	24
Scenario 5	One Module	2	8	16
Scenario 6	One Module	2	6	12
Scenario 7	One Module	2	4	8
Scenario 8	One Module	2	2	4
Scenario 9	Two Modules	2	4	8
Scenario 10	Two Modules	2	2	4
Scenario 11	Two Modules	2	0	0
Scenario 12	Two Modules	2	0	0

# Methodology - Production Planning

## Constraints

- Demand
  - Number of Stages
- ➔  $APQ = \frac{\text{Total Production Quantity (Tons/Stage)}}{\text{Number of Batches/Stage}}$
- Changeover time
  - Changeover frequency
- ➔  $PT^+ = \frac{52 - CF * 2}{CF}$

**Equipment Capacity** ➔  $EC = \text{roundup}\left(\frac{APQ}{PT}\right)$

- 5 tons per week ~ equipment costs £30 million
- 4 tons per week ~ equipment costs £24 million
- 3 tons per week ~ equipment costs £18 million

# Methodology - KPIs

## NPV

$$FCF = NOPAT + Depreciation - Net Capital Expenditures - Net Working Capital Investment$$

## Work-in-process Inventory (WIP)

$$IOH = \text{Initial Inventory} + \text{Inventory Produced} - \text{Inventory Consumed}$$

$$\text{Inventory value} = \frac{\sum(\text{average weekly inventory values})}{52 \text{ weeks/year}}$$

## Flexibility:

- Finished goods lead time
- Production utilization rate
- Allowable demand fluctuation

# Results

# Results – 4-Stage Production

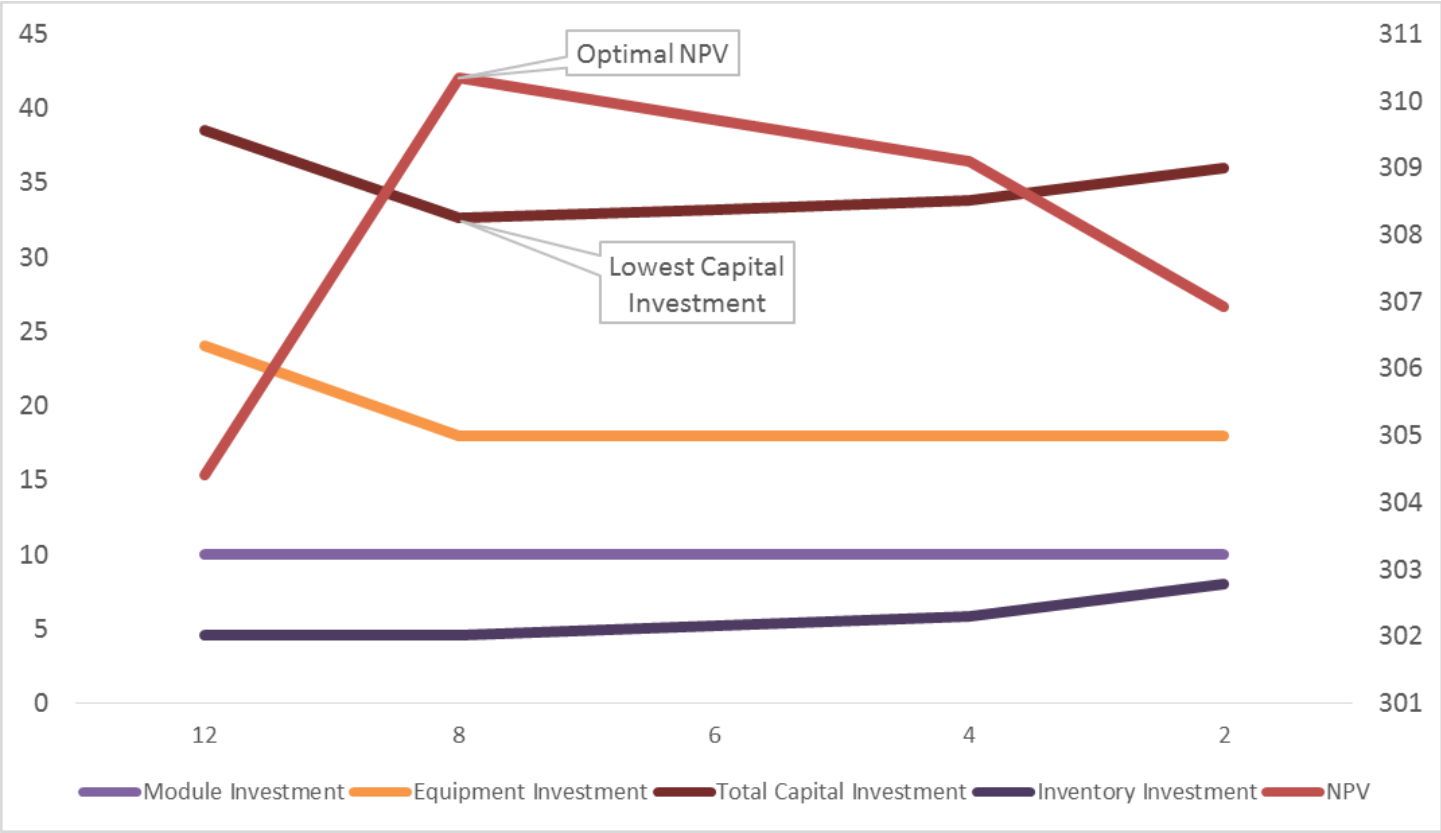
	4 Stages			
	One Module	Two Modules		
	Base Scenario	Base Scenario	Scenario 2	Scenario 3
Changeover Frequency (CF) (times/year)	4	12	8	4
Total Production Time	44	28	36	44
AVG production quantity for each batch	52.0	8.7	13.0	26.0
Production time for each batch (Week/batch)	11.0	2.3	4.5	11.0
Equipment Capacity (Tons/week)	5	4	3	3
Production Utilization Rate (%)	80%	50%	67%	67%
Machine Operating Time Rate (%)	85%	54%	69%	85%
Allowable Demand Fluctuation %	6%	8%	4%	27%
Lead Time (weeks)	39	14	20	41
Inventory Investment (£M)	8.24	3.68	4.32	6.22
Module Investment (£M)	10	10	10	10
Equipment Investment (£M)	30	48	36	36
Total Capital Investment (£M)	48.24	61.68	50.32	52.22
NPV	294.70	276.18	287.53	285.64

# Results – 2-Stage Production

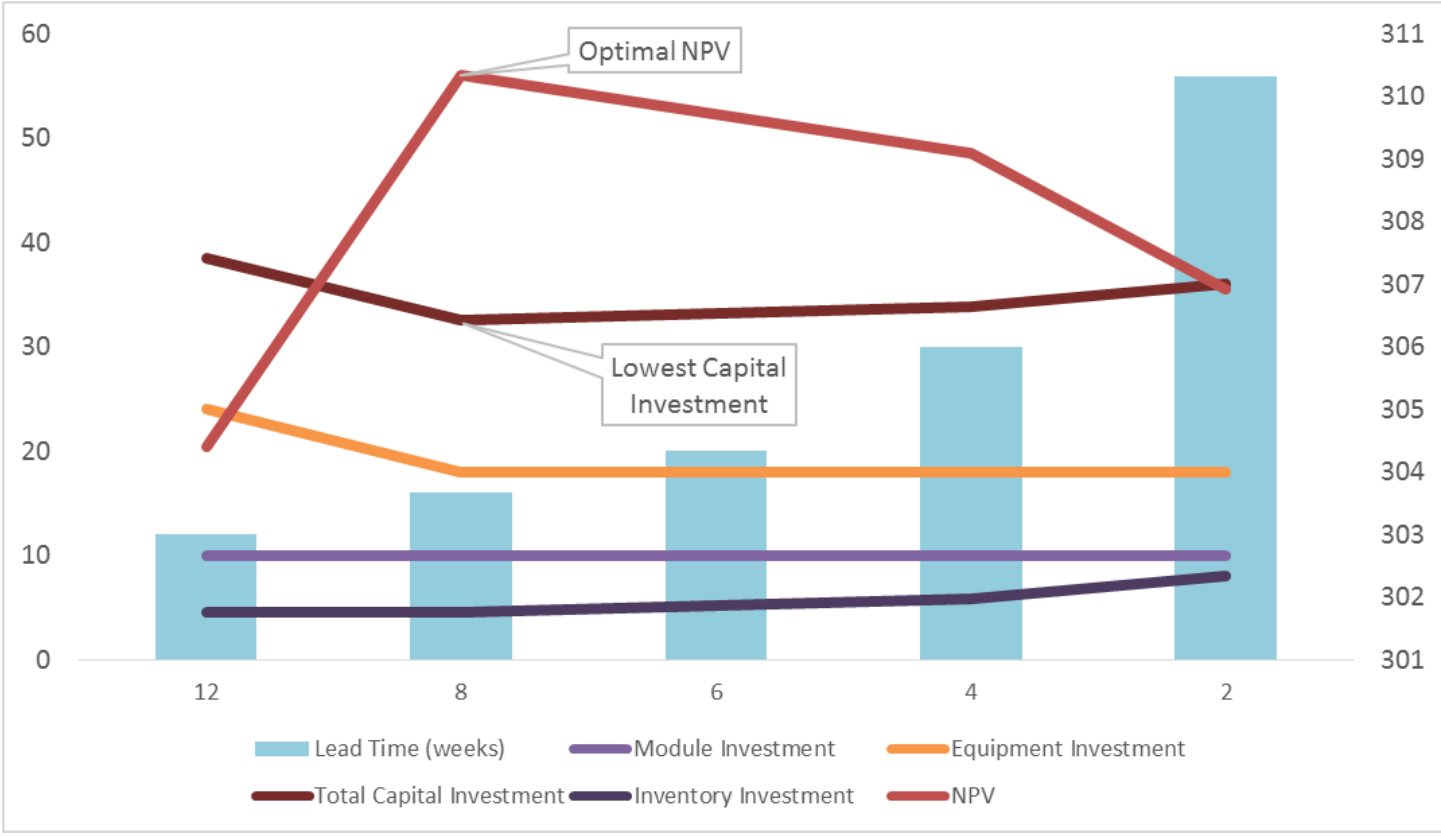
	2 Stages								
	One Module					Two Modules			
	S4	S5	S6	S7	S8	S9	S10	S11	S12
Changeover Frequency (CF) (times/year)	12	8	6	4	2	4	2	0	0
Total Production Time	28	36	40	44	48	44	48	52	52
AVG production quantity for each batch	8.7	13.0	17.3	26.0	52.0	26.0	52.0	+∞	+∞
Production time for each batch (Week/batch)	2.3	4.5	6.7	11.0	24.0	11.0	24.0	+∞	+∞
Equipment Capacity (Tons/week)	4	3	3	3	3	2	2	1	1
Production Utilization Rate (%)	50%	67%	67%	67%	67%	50%	50%	100%	50%
Machine Operating Time Rate (%)	54%	69%	77%	85%	92%	85%	92%	100%	100%
Allowable Demand Fluctuation %	8%	4%	15%	27%	38%	69%	85%	0%	100%
Lead Time (weeks)	6	8	10	15	28	15	28	1	1
Inventory Investment (£M)	4.53	4.60	5.22	5.85	8.01	5.84	7.87	3.40	3.40
Equipment Investment (£M)	24	18	18	18	18	24	24	12	24
Total Capital Investment (£M)	38.53	32.60	33.22	33.85	36.01	39.84	41.87	25.40	37.40
NPV	304.40	310.34	309.72	309.09	306.93	298.01	295.98	312.46	300.46



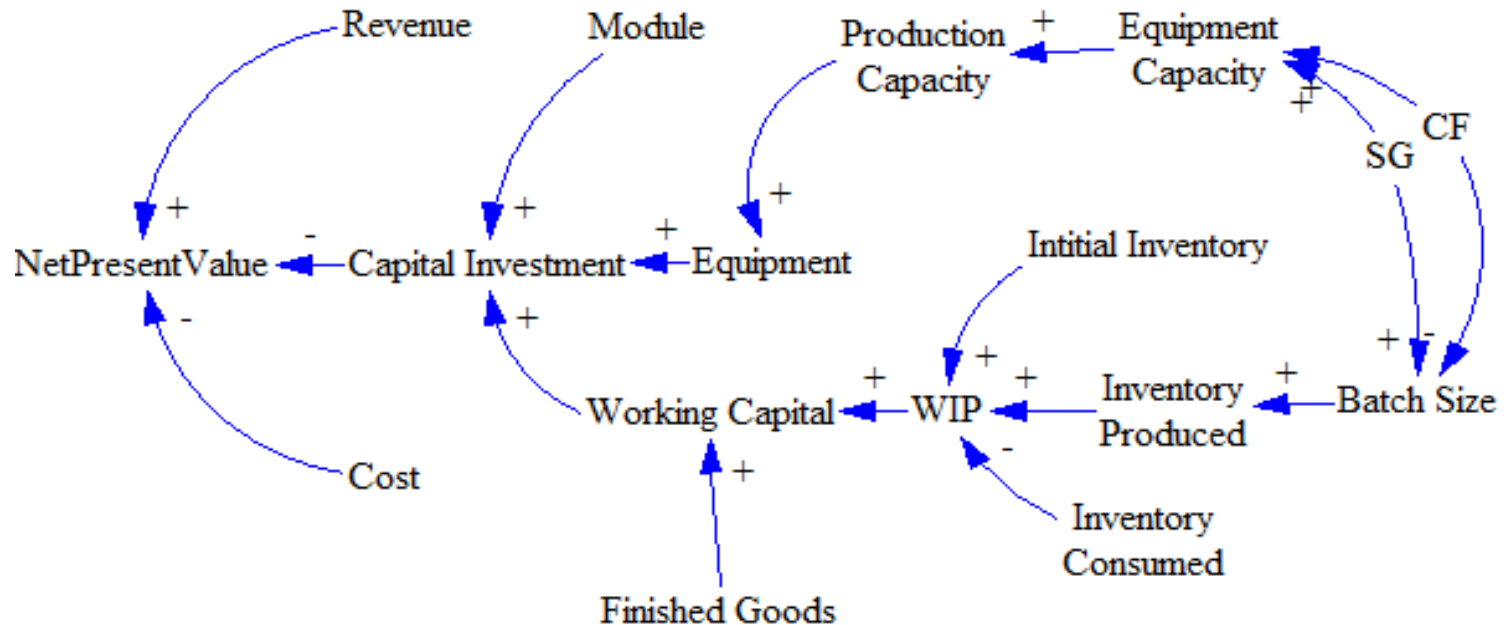
# Results



# Results



# Results



- The higher CF is, the higher production capacity, the lower WIP
- The higher SG is, the higher production capacity, the higher WIP, the lower NPV

# Recommendations

# Recommendation

- There is a trade-off between production capacity and inventory
- Production capacity has a higher impact on the NPV than does inventory
- The best NPV is achieved when the production capacity reaches its tipping point
- Other considerations: flexibility and risk
- Future research opportunities: finished goods inventory reduction, demand variation, multiple SKUs, and/or considering new product introductions

# Q&A