Aggregate Production Planning for Engineer-to-Order Products

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Content

Supply Chain MANAGEMENT

Contract Manufacturing

OEM Factories
In-House Manufacturing

Alternative:
Supply by a contract manufacturer

OEM Engineering
Design and Prototype

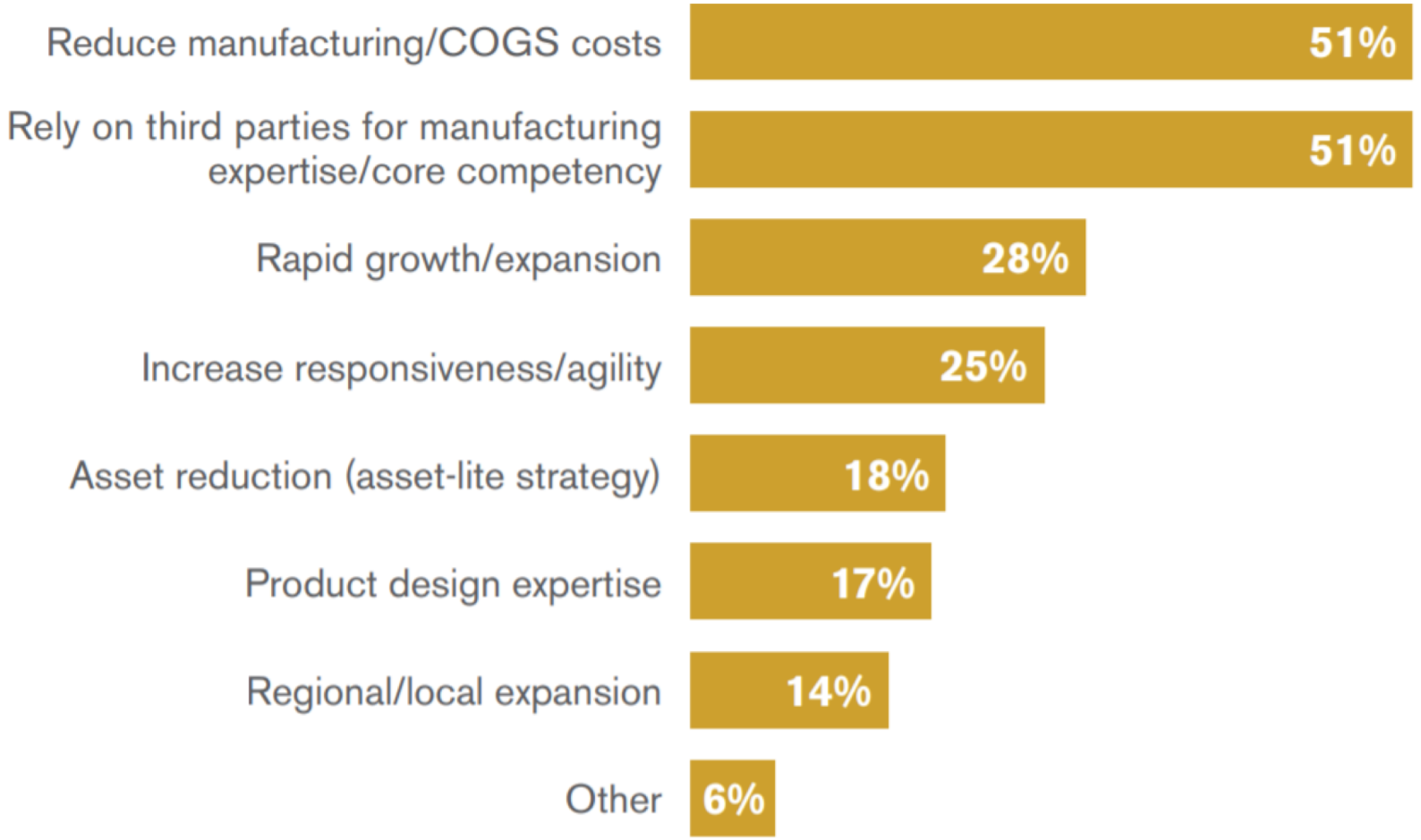
OEM Factories
Purchase
Assembly the Equipment

Sales Channels
Distribute the Equipment

Logistics Company
Transportation

3PL
Provide the Warehouse Solution

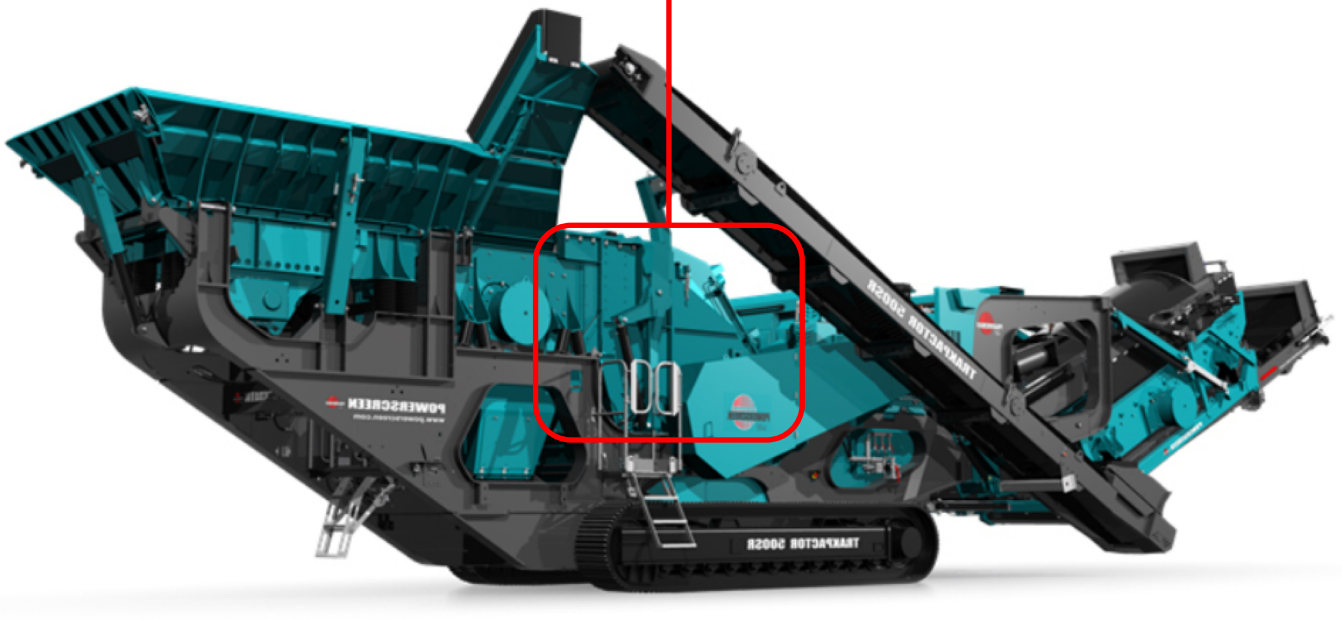
Benefits of Buying from Contract Manufacturers



Machinery Parts Contract Manufacturer

ZY Machining and Distributions. Ltd

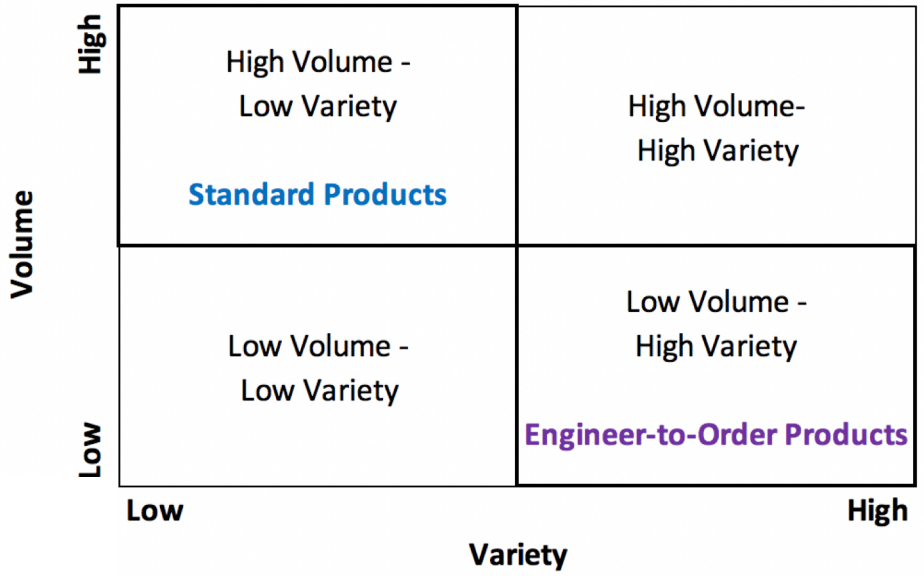
Product

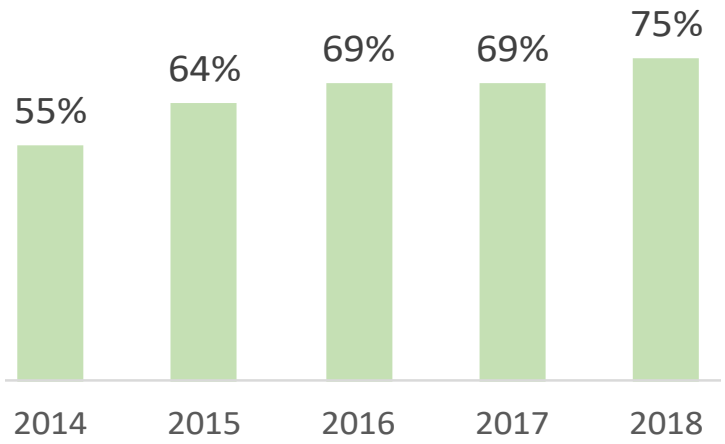


Supply Chain MANAGEMENT

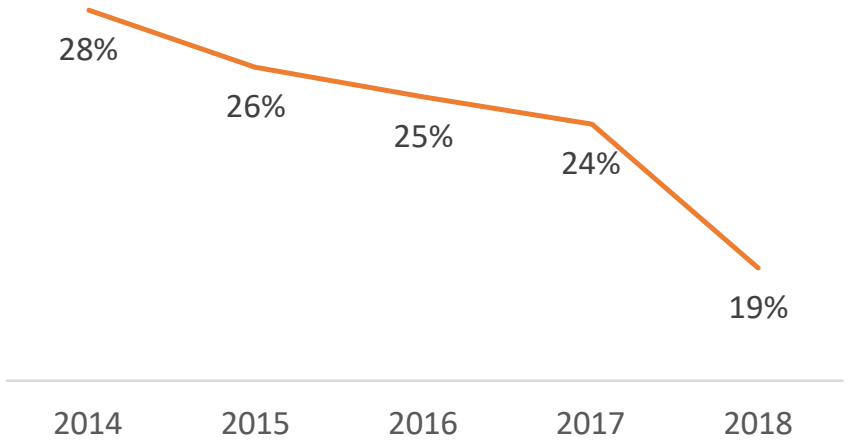
ETO Products: Increasing Share – Decreasing Profit Margin

Contract manufacturing industry is becoming more competitive with the market leaning towards ETO products





Share of ETO orders



Profit margin for ETO products

Problem Statement

Production Cost Increased

WHY?

Isolated, inaccurate planning and production process uncertainty

Actual production schedule doesn't stick to initial plan

Increased Costs

- Labor resources
- Short-notice outsourcing
- WIP inventory holding
- Penalties for late deliveries

How to Plan Production with Minimum Cost?

Feasible Production Plan for ETO Products

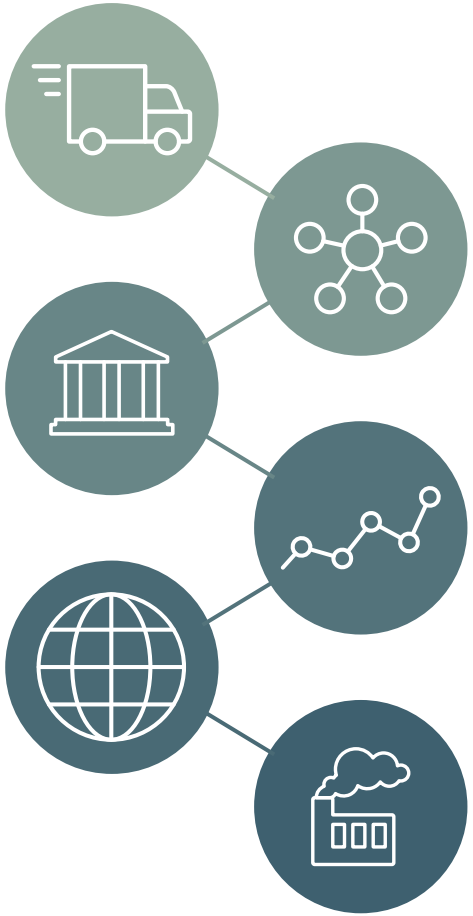
Under Process Uncertainty with Minimum Cost

Methodology Outline

Process Map

Analysis Setting
Production planning options
Scenarios of different production times

Further Analysis
Buffer capacity
Shadow price analysis



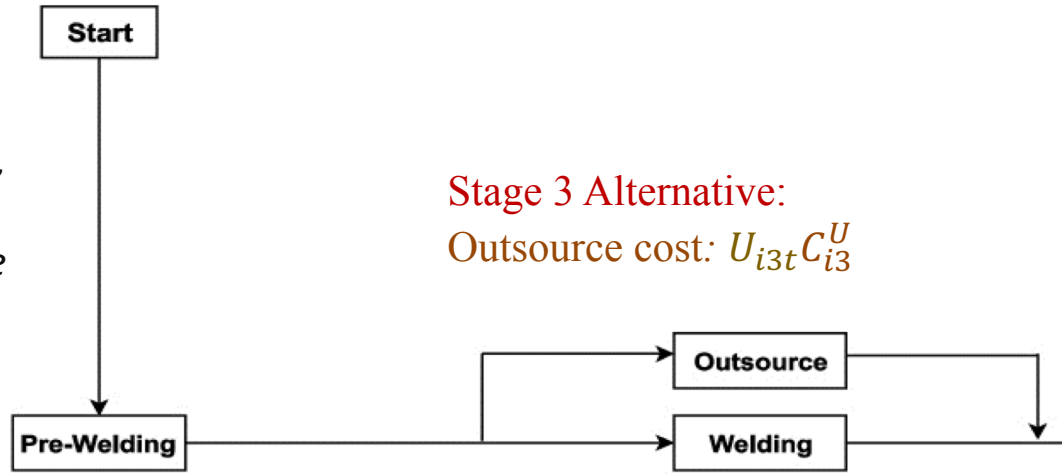
Deterministic APP LP Model

Initial Analysis
Cost drivers
Total expected costs

Deliverables
Resources Change Recommendation
Aggregate Production Plan

Process for Modelling and Cost Minimization

**Stage 1 – procurement, raw materials delivery and holding – out of the scope*



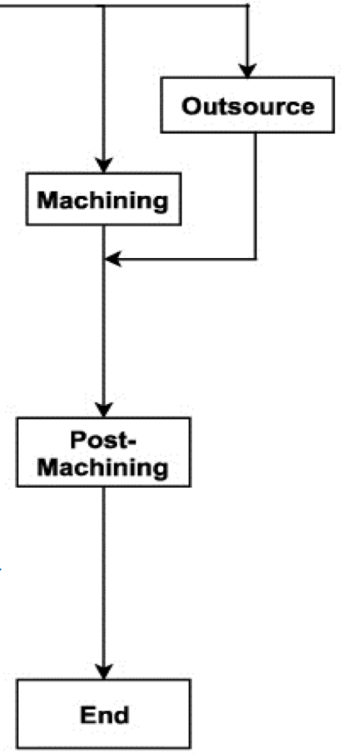
Stage 2:
Variable production cost: $P_{i2t}C_{i2}^{P}L_{i2}$
Labor cost: $W_{2t}C_{2}^{W} + O_{2t}C_{2}^{ov}$
Inventory holding cost: $I_{i2t}C_{i2}^{In}$

Stage 3 Alternative:
Outsource cost: $U_{i3t}C_{i3}^{U}$

Stage 3:
Variable production cost: $P_{i3t}C_{i3}^{P}L_{i3}$
Labor cost: $W_{3t}C_{3}^{W} + O_{3t}C_{3}^{ov}$
Inventory holding cost: $I_{i3t}C_{i3}^{In}$

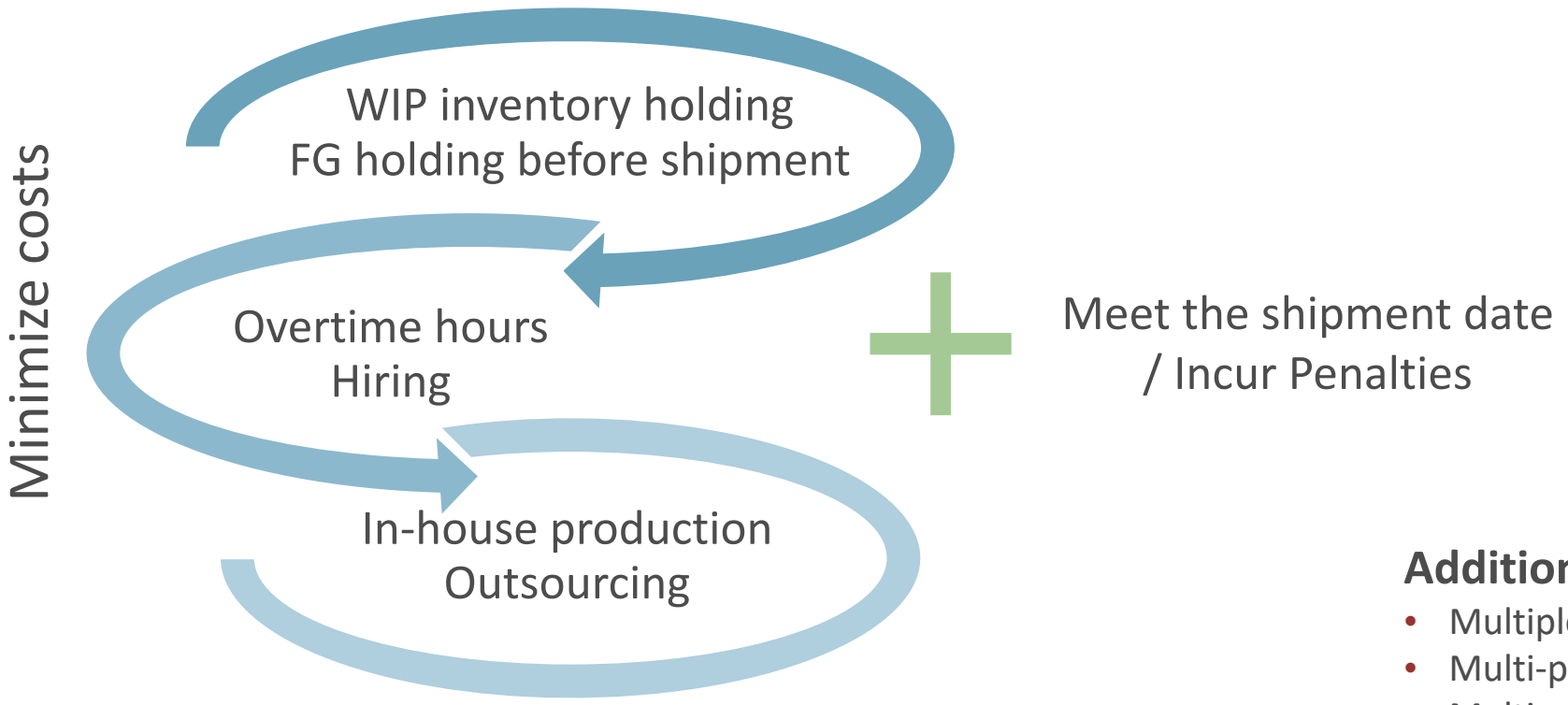
Stage 4:
Variable production cost: $P_{i4t}C_{i4}^{P}L_{i4}$
Labor cost: $W_{4t}C_{4}^{W} + O_{4t}C_{4}^{ov}$
Inventory holding cost: $I_{i4t}C_{i4}^{In}$

Stage 4 Alternative:
Outsource cost: $U_{i4t}C_{i4}^{U}$



Stage 5:
Variable cost: $P_{i5t}C_{i5}^{P}L_{i5}$
Labor cost: $W_{5t}C_{5}^{W} + O_{5t}C_{5}^{ov}$
Inventory holding cost: $I_{i5t}C_{i5}^{In}$
Backorder penalty: $B_{i5t}C_{5}^{Pen}$

Deterministic APP LP Model



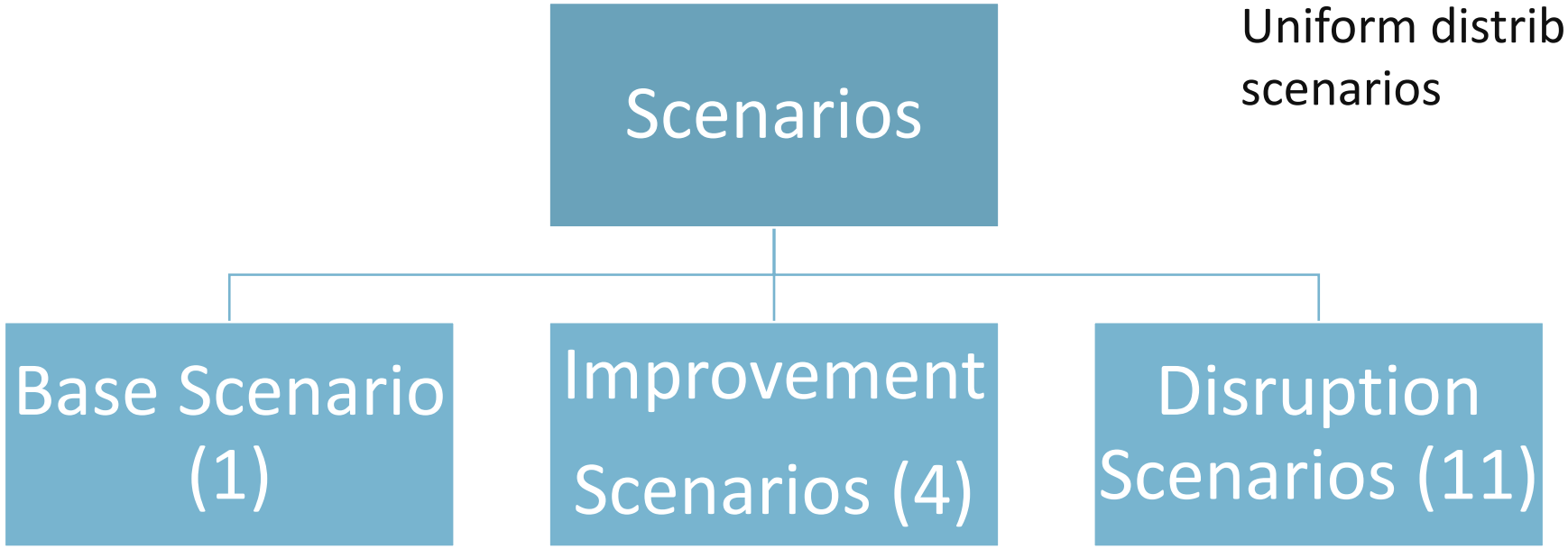
Additional Model Characteristics:

- Multiple production stages
- Multi-product model
- Multi-period model
- ETO products
  - no stock
  - deterministic demand = order

Three Model Options

	New Employees Hiring	Overtime Hours	Outsourcing
			
Option 1: (Both in-house and outsourcing)	✓	✓	✓
Option 2: (In-house regular hours only)	✓	✗	✗
Option 3: (Emergency response without planning)	✗	✓	✓

Multiple Scenarios



Uniform distribution for the 16 scenarios

Analysis Plan

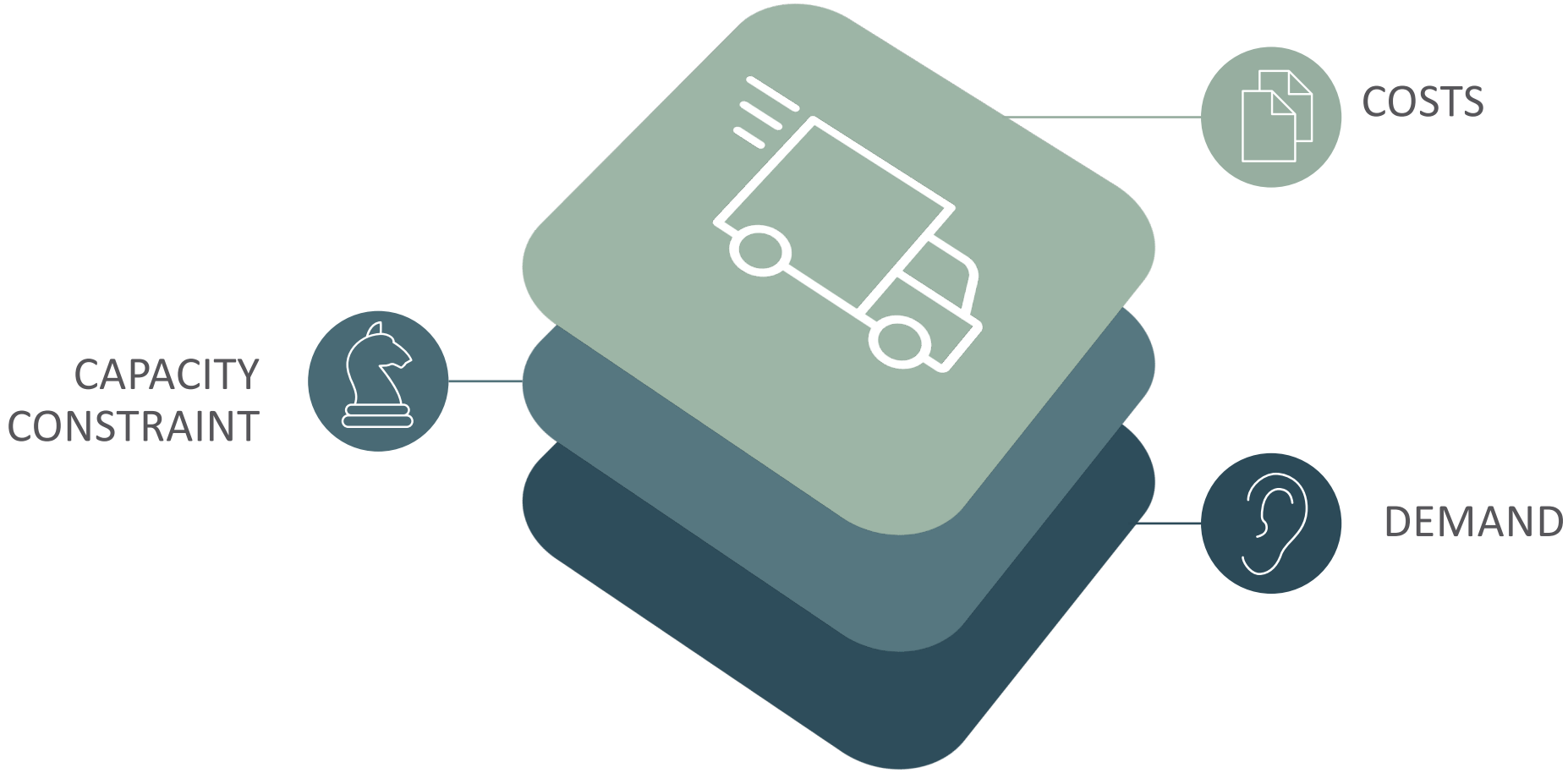
STAGE 01

- Run Model under 3 options and all scenarios
- Identify the cost drivers
- Compare costs for different production planning options

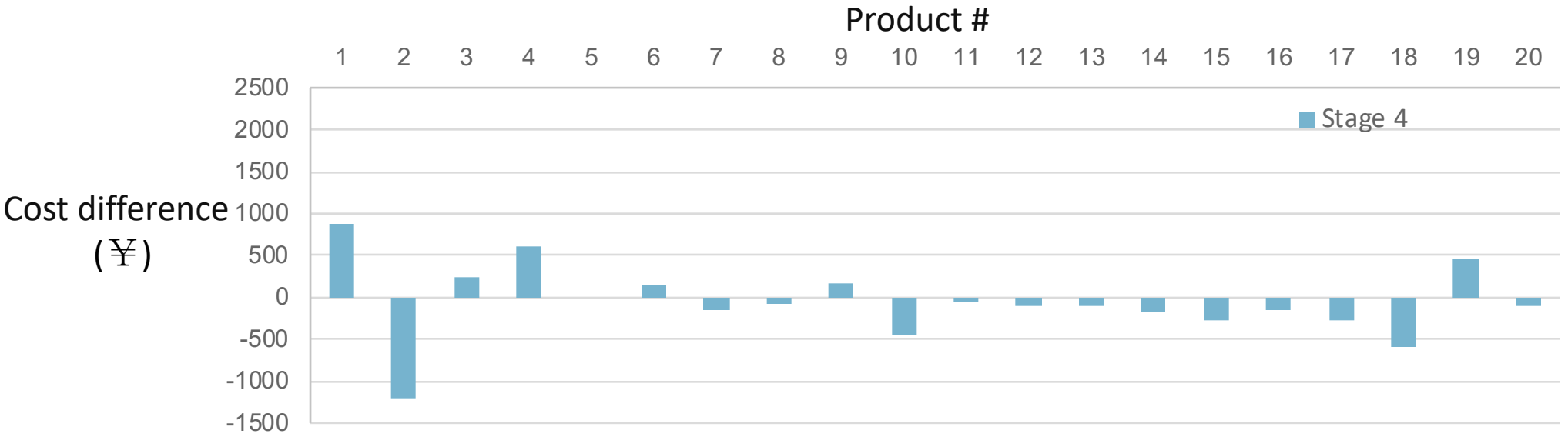
STAGE 02

- Conduct shadow price analysis
- Calculate final production plan using buffer capacity

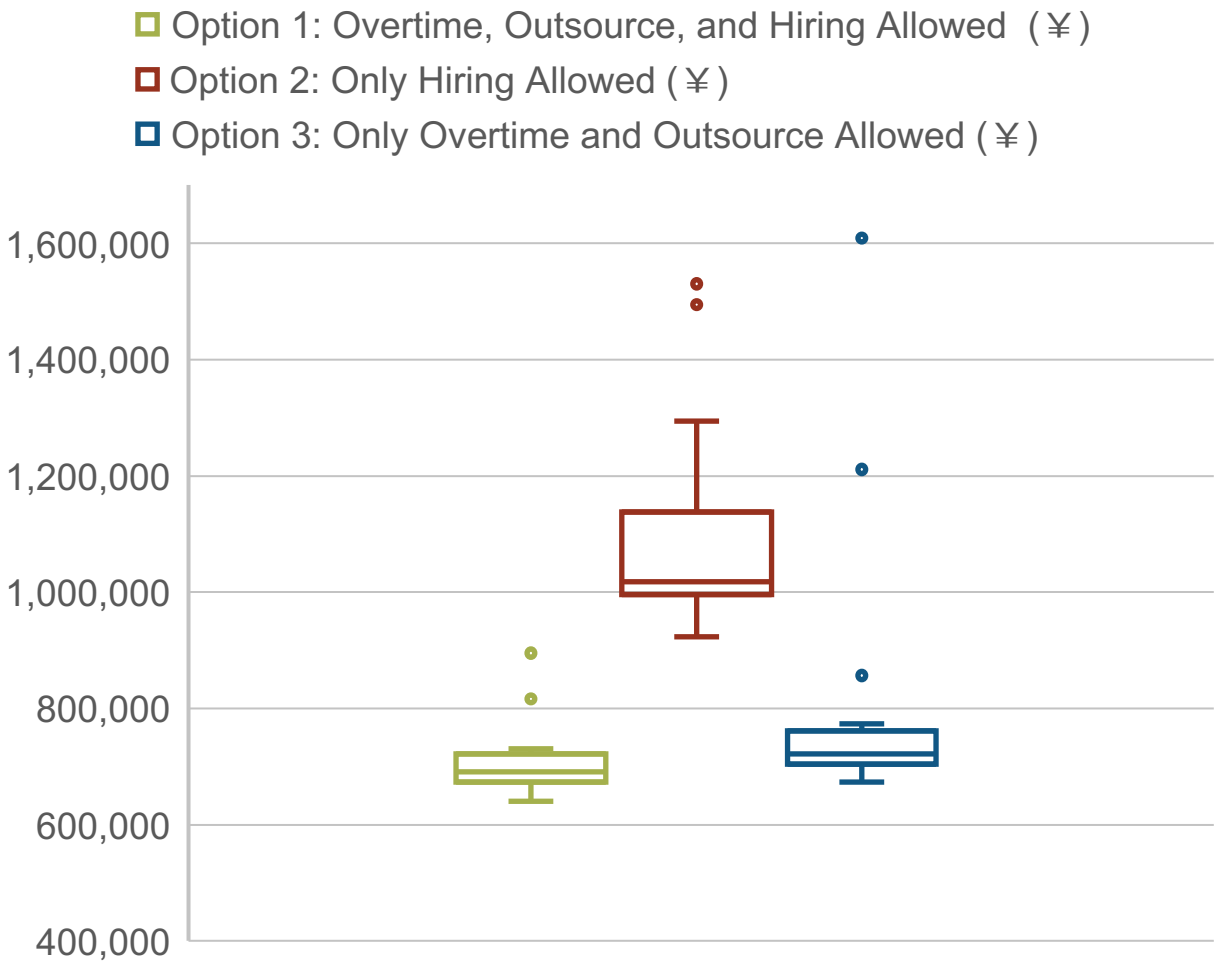
Data Input



Outsourcing Costs vs In-House Production Cost



Total Expected Costs for All the Scenarios



Total Expected Costs (for All Scenarios) under the Three Model Options

Option 2 is the most expensive:

1. Outsourcing is cheaper for some product / stages
2. Employees can't be fired
3. Not enough capacities to produce on-time ➔ penalties

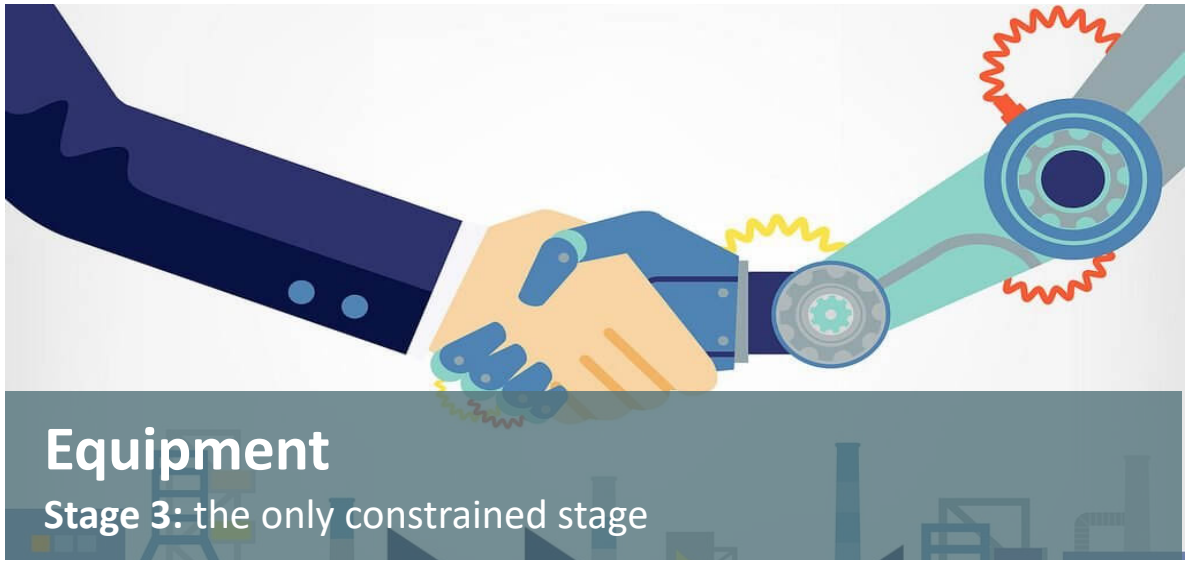
Option 1 achieved a cost reduction of **11.9%** compared to Option 3.

Model Option	Option 1, ¥	Option 3, ¥	Cost Change, %
Total Expected Cost	714,247	810,364	-11.86%

Shadow Price Analysis

Workforce

Stage 3: Excessive labor | **Stage 5**: the most constraint



Equipment

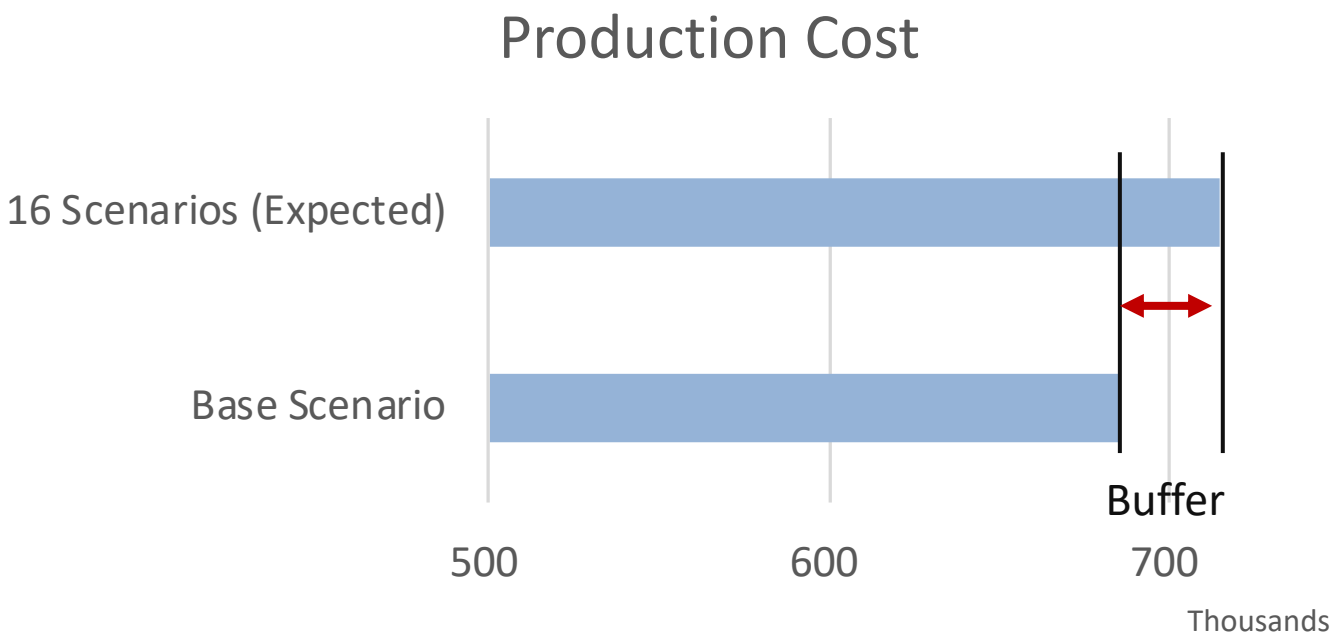
Stage 3: the only constrained stage

Workforce re-allocation:

0.52% total expected cost reduction without headcount increase

Adding 1 equipment unit gives only 0.18% total expected cost reduction while investments required

Final Plan Calculation with the Buffer Capacity



A single plan for execution:

We add buffer capacity to the base plan until production cost is equal to the total expected cost

7% capacity buffer is required for the data provided (for 4.3% additional cost vs base scenario)

Recommendation for the Sponsor Company

1

APP LP MODEL
Use the model with hiring, outsourcing, and overtime hours

2

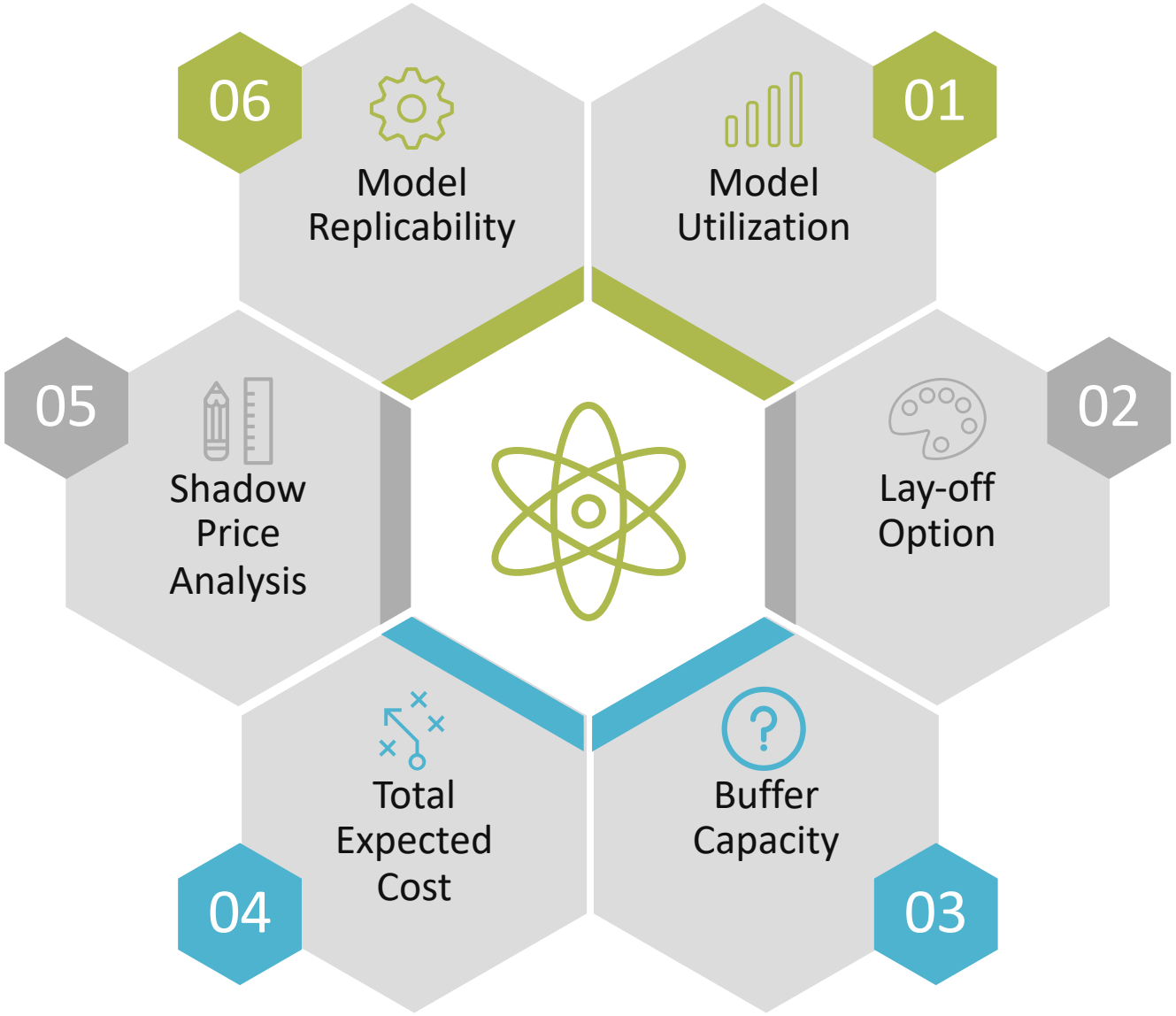
BUFFER CAPACITY
Add 7% buffer capacity across all stages to the base scenario

3

EMPLOYEES
Remove 1 employee at stage 3 and add 1 employee at stage 5.

12.3% COST SAVINGS

General Recommendations for the Company



THANK YOU!

Questions?

Cheng Cheng

Liz Shafir

Supply Chain MANAGEMENT

Back up slides

APP LP Model

$$Min\ z = \sum_i \sum_s \sum_t \left(P_{ist} L_{is} C_{is}^P I_{ist} + I_{ist} C_{is}^{In} + U_{ist} C_{is}^U\right)$$

$$+ \sum_s \sum_t (W_{st} C_s^W + O_{st} C_s^{Ov}) + \sum_i \sum_t (B_{it} C_i^{Pen}) \qquad \forall i,\ \forall s,\ \forall t \in \{1 \dots T\}\ (1)$$

s.t.

$$\sum_i (P_{ist} L_{is} - (HW_{st} + O_{st}) * z \leq 0 \qquad \forall s,\ \forall t \in \{1 \dots T\}\ (2)$$

$$\sum_i (P_{ist} L_{is} - (P_s^{Max} * 24 * 6) * z \leq 0 \qquad \forall s,\ \forall t \in \{1 \dots T\}\ (3)$$

$$W_{st} - W_{s\,t-1} - A_{st} = 0 \qquad \forall s,\ \forall t \in \{1 \dots T\}\ (4)$$

$$O_{st} - O^{max} W_{st} * z \leq 0 \qquad \forall s,\ \forall t \in \{1 \dots T\}\ (5)$$

$$U_{ist} - U_{is}^{Max} \leq 0 \qquad \forall i,\ \forall s,\ \forall t\ (6)$$

$$I_{is\,t-1} - I_{ist} + P_{ist} + U_{ist} - (P_{is+1\,t} + U_{is+1\,t}) = 0 \qquad \forall i,\ \forall s \in \{1 \dots S-1\},\ \forall t \in \{1 \dots T\}\ (7)$$

$$I_{is\,t-1} - I_{ist} + P_{ist} + U_{ist} - D_{it} - B_{it-1} + B_{it} = 0 \qquad \forall i,\ s=S,\ \forall t \in \{1 \dots T\}\ (8)$$

$$A_{st}\ W_{st}\ I_{ist}\ P_{ist}\ U_{ist} O_{st}\ B_{it} \geq 0 \qquad \forall s,\ \forall t\ (9)$$

$$0 < z < 1 \qquad (10)$$

Indices:

i – product, 1<i<N
s – production stage, 1<s<S
t – time period, 0<t<T

Decision variables:

A_{st} - employees to hire at start of period t, stage s
W_{st} - employees in the end of period t, stage s
O_{st} - overtime hours to work in period t, stage s
I_{ist} - units of inventory, product i, end of period t, stage s
P_{ist} - units to produce internally, period t, stage s, product i
U_{ist} - units to outsource, period t, stage s, product i
B_{it} – units of backlog by product by week

Input data:

D_{it} - demand for product i period t, units
L_{is} - production time for stage s product i, hours/unit
$W_{s\,0}$ - workforce at week 0 stage s, # of employees
H - working hours, hours/person/week
O^{max} - max hours of overtime, hours/person/week
U_{is}^{max} - max outsourcing product i stage s, units/week
P_s^{Max} - production equipment by stage, units
I_{is0} - inventory at week 0 product i stage s, units
C_{is}^P - production cost for product i stage s, ¥/hour
C_s^{Ov} - cost of overtime hour for stage s, ¥/hour
C_s^W - cost of employee for stage s, ¥/person/week
C_{is}^{In} - inventory holding cost product i stage s, ¥/unit/week
C_{is}^U – outsource cost product i stage s, ¥/unit
C_i^{Pen} – late delivery penalty product i, ¥/unit/week

Future Research Recommendation

1) Calculation buffer capacity by every production stage based on scenarios probability derived from historical data (needs to be collected)
2) Adding buffer capacity size to the objective function of the LP model
3) Adding more constraints and inputs to the model

Aggregate Production Plan (extract)

In-House Production Plan Example for the Base Scenario

Product-Stage	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Product 8, Stage 2	0	0	13.1	4.5	0	0
Product 8, Stage 3	1.1	18.1	27.2	16.1	17.5	0
Product 8, Stage 4	0	0	46.4	0	33.6	0
Product 8, Stage 5	0	0	46.4	0	33.6	0

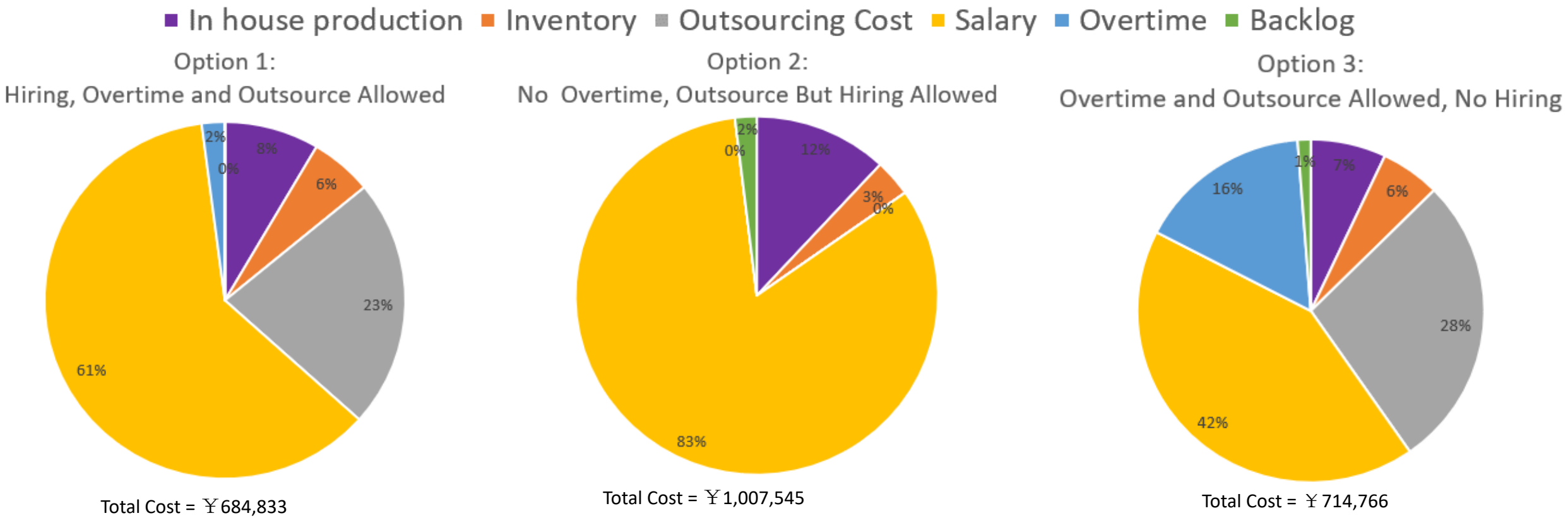
Inventories Level for Work-in-Progress Materials for the Base Scenario

Product-Stage	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Product 8, Stage 2	61.4	43.2	29.1	17.5	0	0
Product 8, Stage 3	1.1	19.2	0	16.1	0	0
Product 8, Stage 4	0	0	0	0	0	0
Product 8, Stage 5	0	0	46.4	46.4	8	0

Overtime Hours Planned for the Base Scenario

Stage	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Stage 1	0	0	0	0	0	0
Stage 2	0	0	0	0	0	0
Stage 3	0	0	0	0	0	0
Stage 4	0	0	45.6	86.2	43.9	0

Base Scenario Cost Breakdown



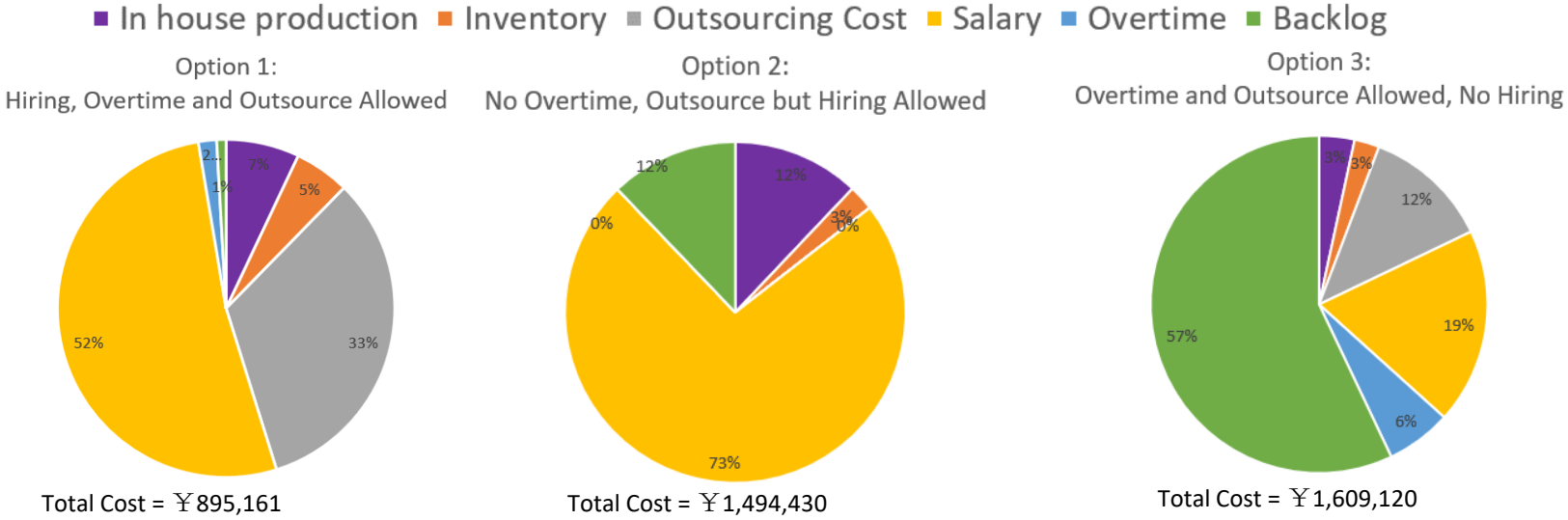
Total Cost = ¥684,833

Total Cost = ¥1,007,545

Total Cost = ¥714,766

Extreme Scenarios Cost Breakdown

Scenario 6

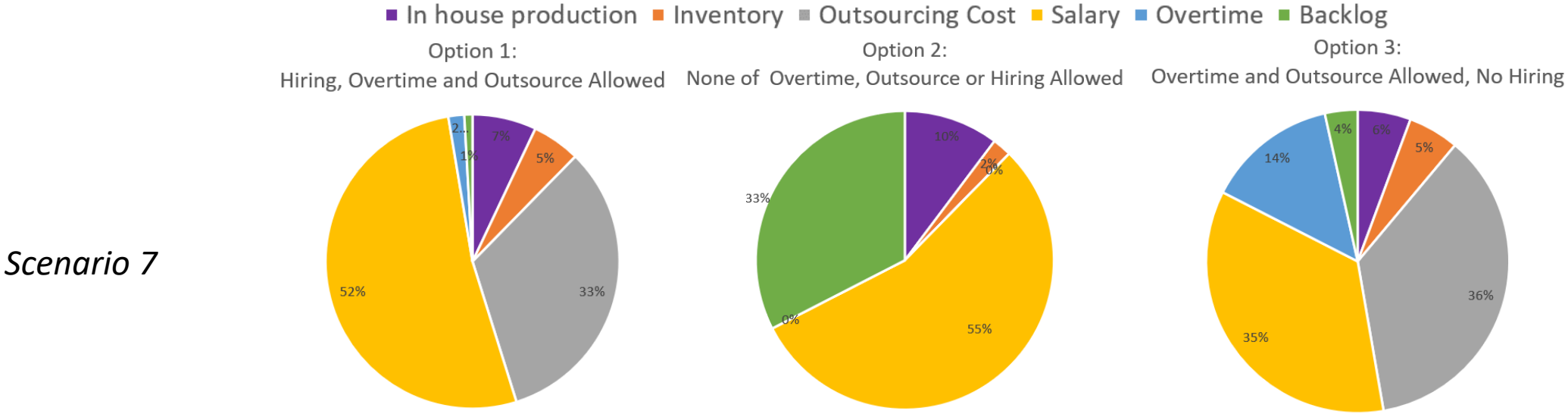


Total Cost = ￥895,161

Total Cost = ￥1,494,430

Total Cost = ￥1,609,120

Scenario 7



Total Cost = ￥822,813

Total Cost = ￥1,530,375

Total Cost = ￥856,347