Moving towards Custom Manufacturing:

comparing different order fulfilment strategies

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Contents

- Introduction / background
- Models:
  - Production inventory model
  - Market demand model
  - Integrated model
- Numerical results
- Concluding remarks

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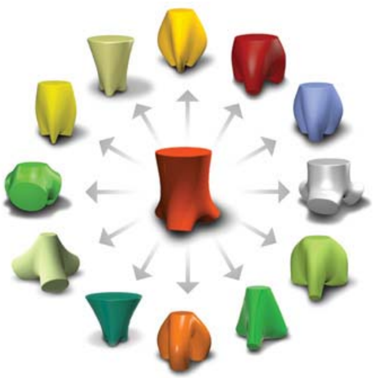
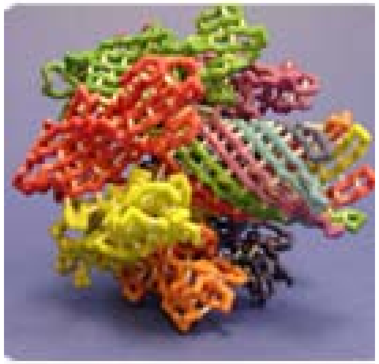
Project: Ultimate Customisation

Crafts

Mass Production



Mass Customisation



Ultimate Customisation

Enabled by advanced manufacturing technology such as **Rapid Manufacturing**

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Rapid Manufacturing Technologies

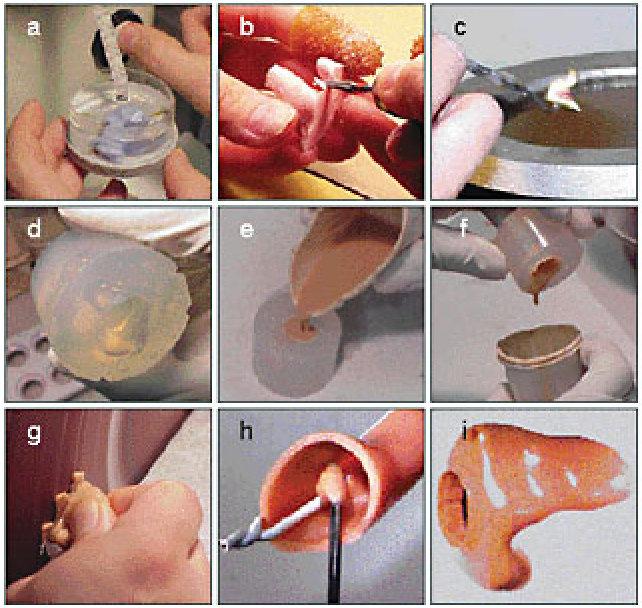

- Evolved from Rapid Prototyping
- Also known as *direct manufacturing*, *layer manufacturing, or 3D printing*

- No need for tooling; is not constrained by any complexity geometry; **can accommodate one-off highly customised products (Custom Manufacturing - CM)**

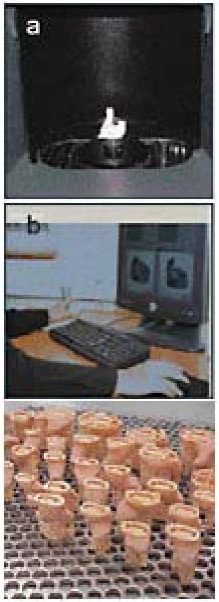
CM – a growing industrial application

Comparing Hearing aids manufacturing

(conventional vs. RM enabled)



- a. Cast
- b. Trim
- c. Wax
- d. Cast #2
- e. Pouring of Shell Material
- f. Drain/Drip
- g. Trim #2
- h. Vent
- i. Attaching Faceplate & Buffing Shell



- a. Scan
- b. Model
- c. Print

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Objective

- To evaluate the relative performance of Custom Manufacturing as an alternative order fulfilment strategy to the more conventional strategies (e.g. make-to-stock, build-to-order / postponement)

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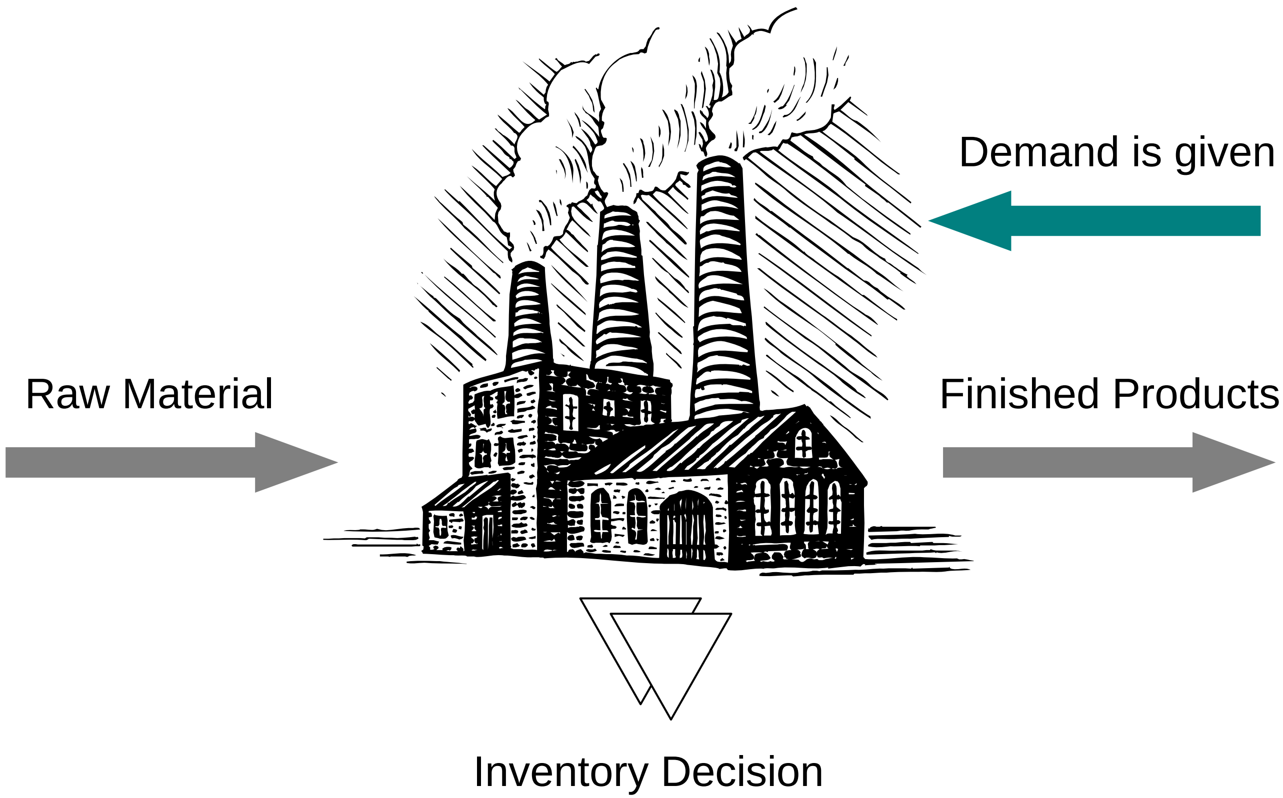
Manufacturing-based analysis (cost oriented)



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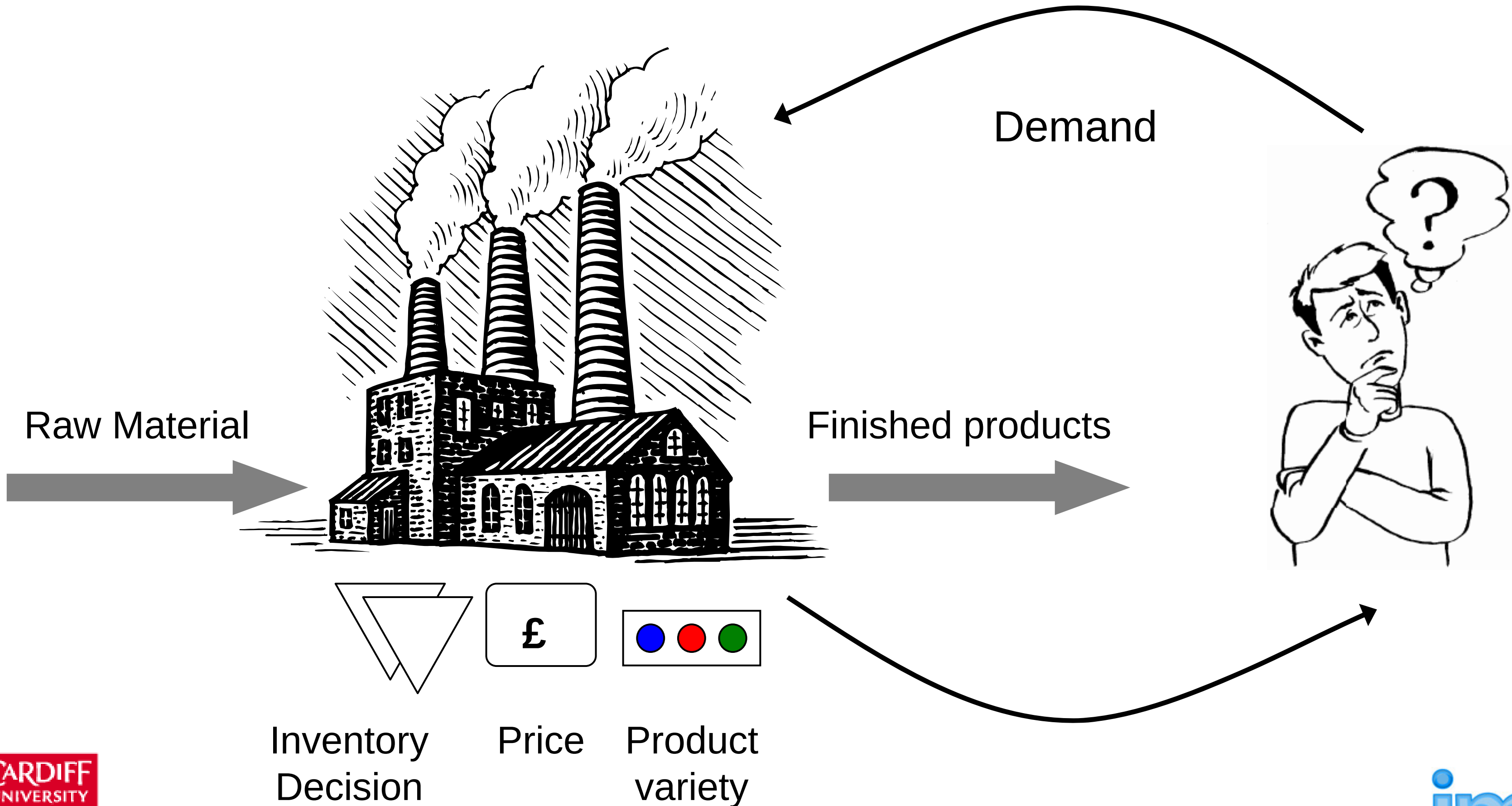
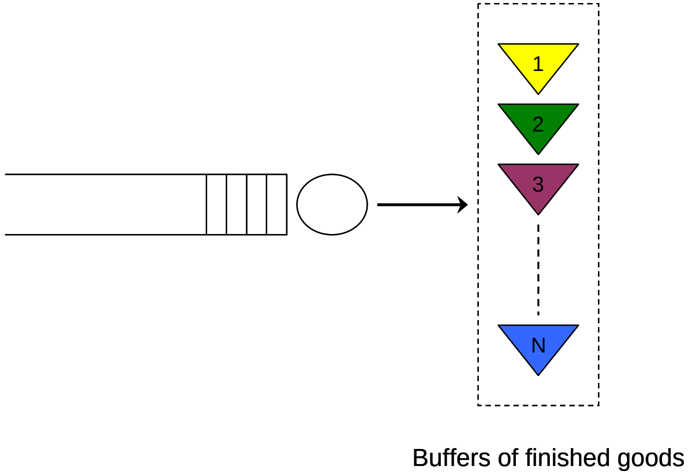
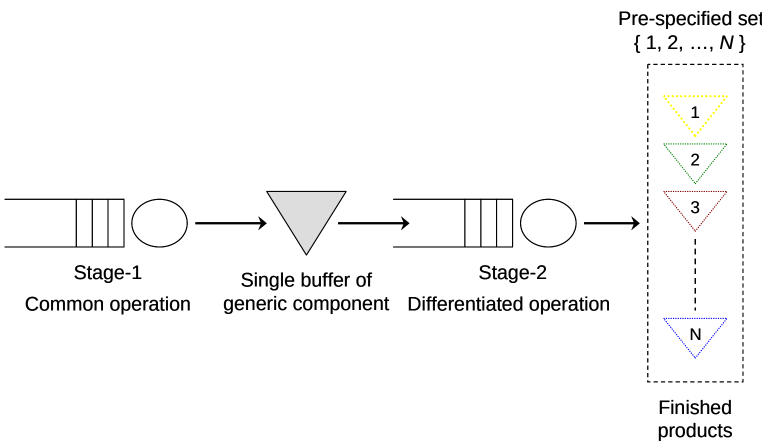
Manufacturing-Marketing Based Analysis (profit oriented)





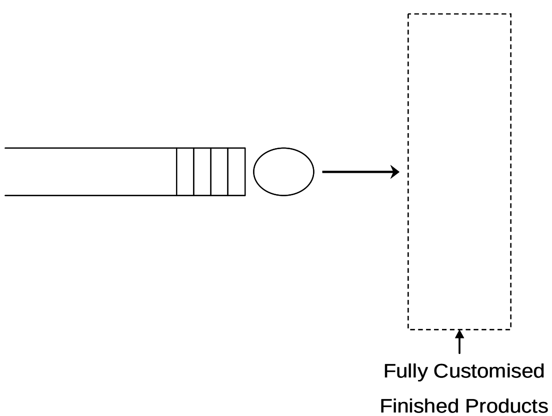
Configuration 1

Make-To-Stock (MTS)



Configuration 2

BTO with Delayed Differentiation (DD)



Configuration 3

Custom Manufacturing (CM)

Literature Review

- Models comparing MTO vs. MTS vs. ATO

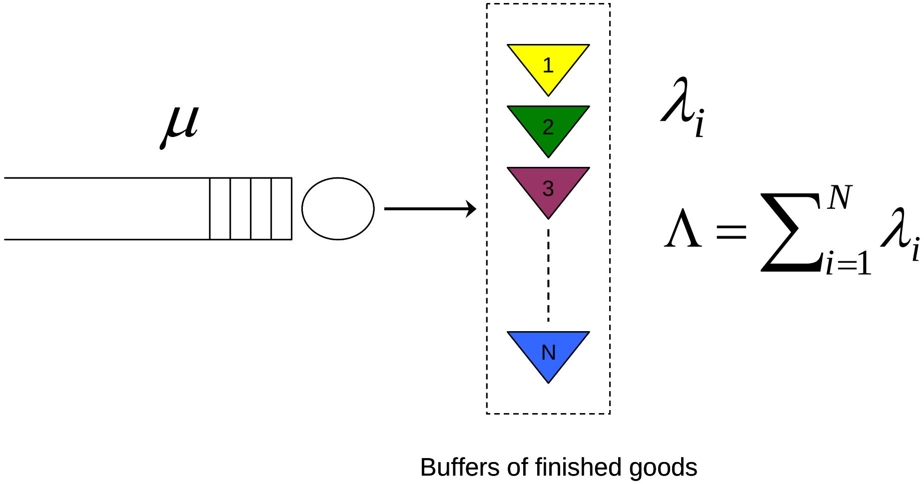
  Arreola-Risa and DeCroix (1998); Rajagopalan (2002); Gupta and Benjaafar (2004); Su et al. (2005), Wong et al. (2008)

- Models incorporating price and lead time & sensitive-demand

  Li (1992); Palaka (1998); Webster (2002); Yang and Geunes (2007)

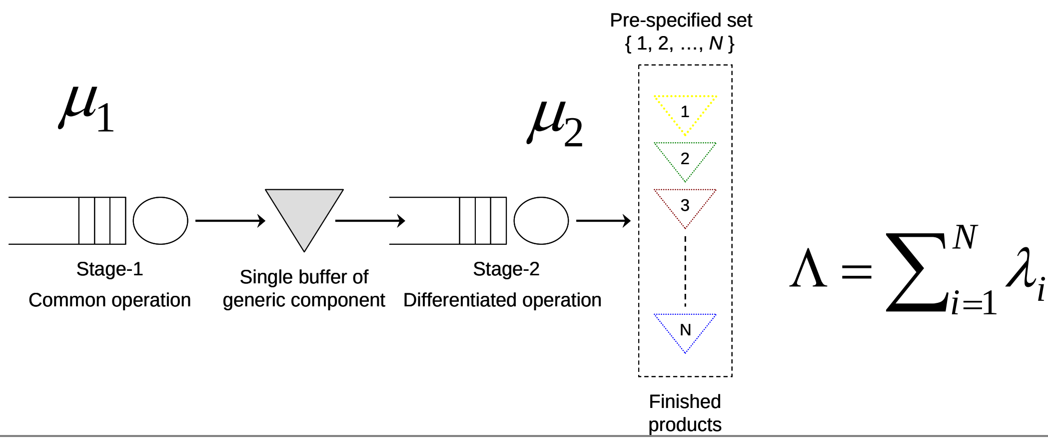
- Models incorporating marketing-manufacturing decisions in line with this paper

  De Groote (1994); Jiang et al. (2006); Alptekinoglu and Corbett (2007)



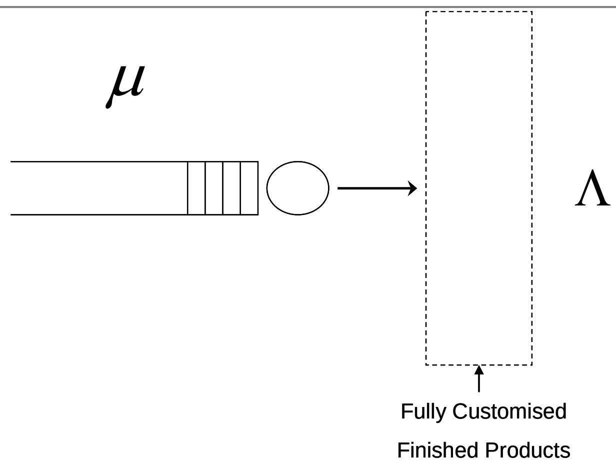
Costs:

- Holding cost h
- Production cost c_{MTS}
- Proliferation cost K



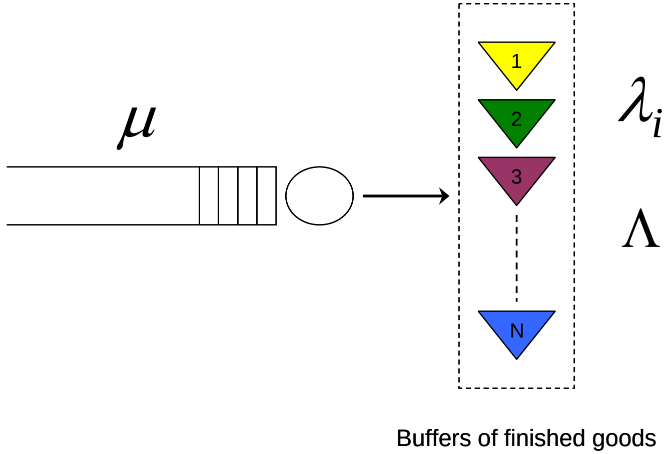
Costs:

- Holding cost h_o
- Production cost c_{DD}
- Proliferation cost K



Costs:

- Production cost c_{CM}
- Flexible $K = 0$



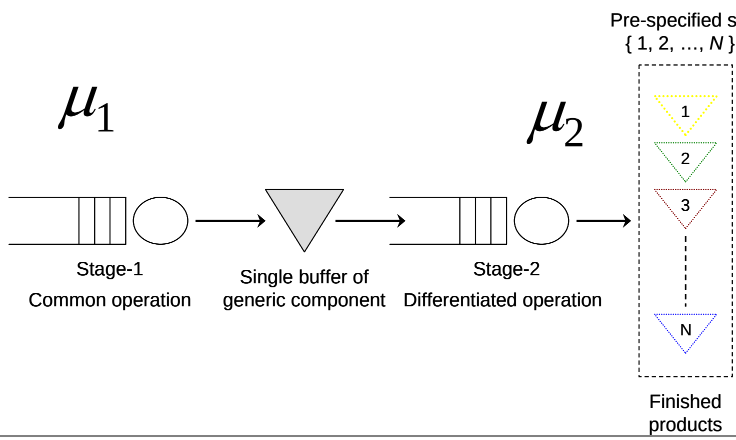
$$\Lambda = \sum_{i=1}^{N} \lambda_i$$

Marketing decisions:

- Number of product lines N
- Characteristic of each product line x_i
- Price p

Manufacturing decision

- Base stock level (FG) S_i



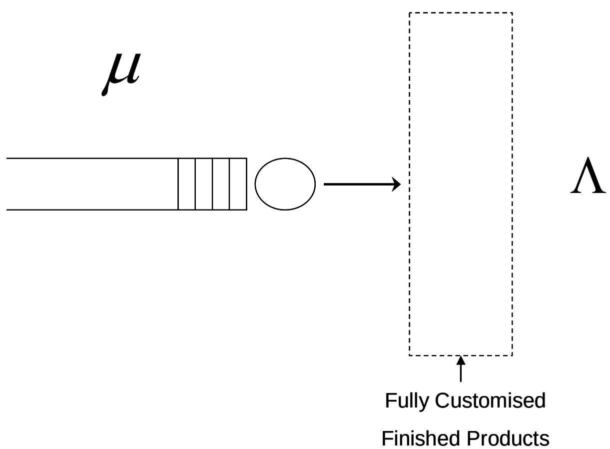
$$\Lambda = \sum_{i=1}^{N} \lambda_i$$

Marketing decisions:

- Number of product lines N
- Characteristic of each product line x_i
- Price p

Manufacturing decision

- Base stock level (GC) S_0



Marketing decisions:

- Price p

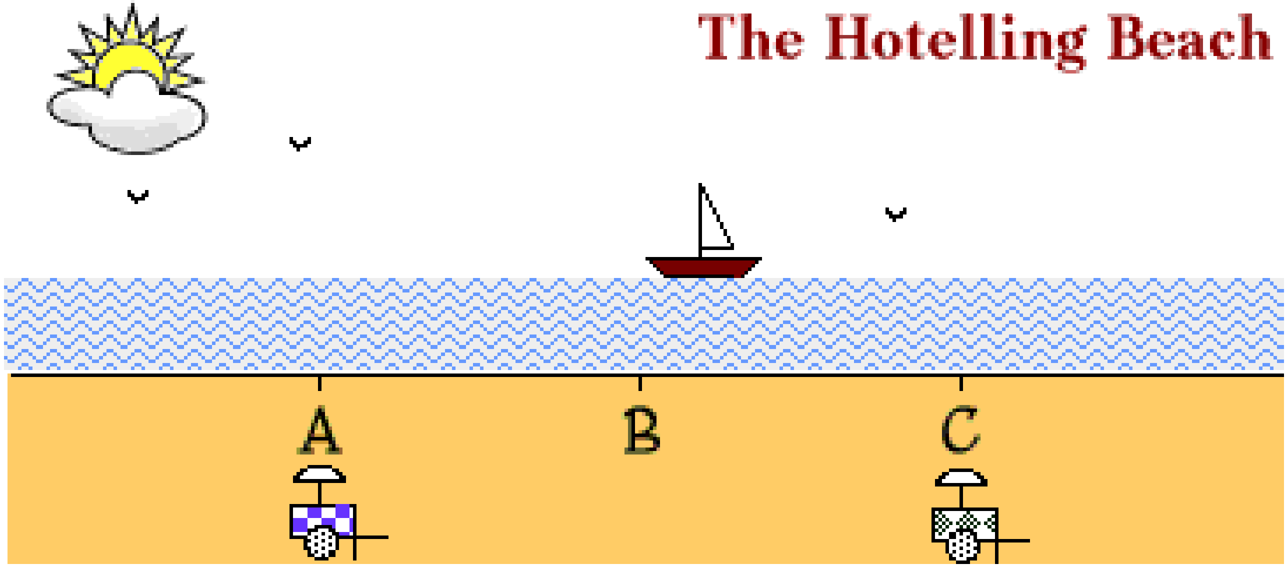
Main Assumptions

- Monopolistic setting
- Product lines are horizontally differentiated $\rightarrow$ same price is reasonable
- Customer demand follows a Poisson process
- Manufacturing processing times are exponentially distributed

Market demand model

- The spatial locational model of Hotteling (1929)
- Customers' tastes are uniformly distributed over a closed interval of the product space [0,1]
- N product lines are horizontally differentiated
- Each product's characteristic $x_i \in [0,1]$
- Customer demand is sensitive to product characteristic x_i , price p, and promised lead time w

Hotelling's location model



Market demand model

The utility of customer at θ derives from buying a product with price p, characteristic x_i, and promised lead time w :

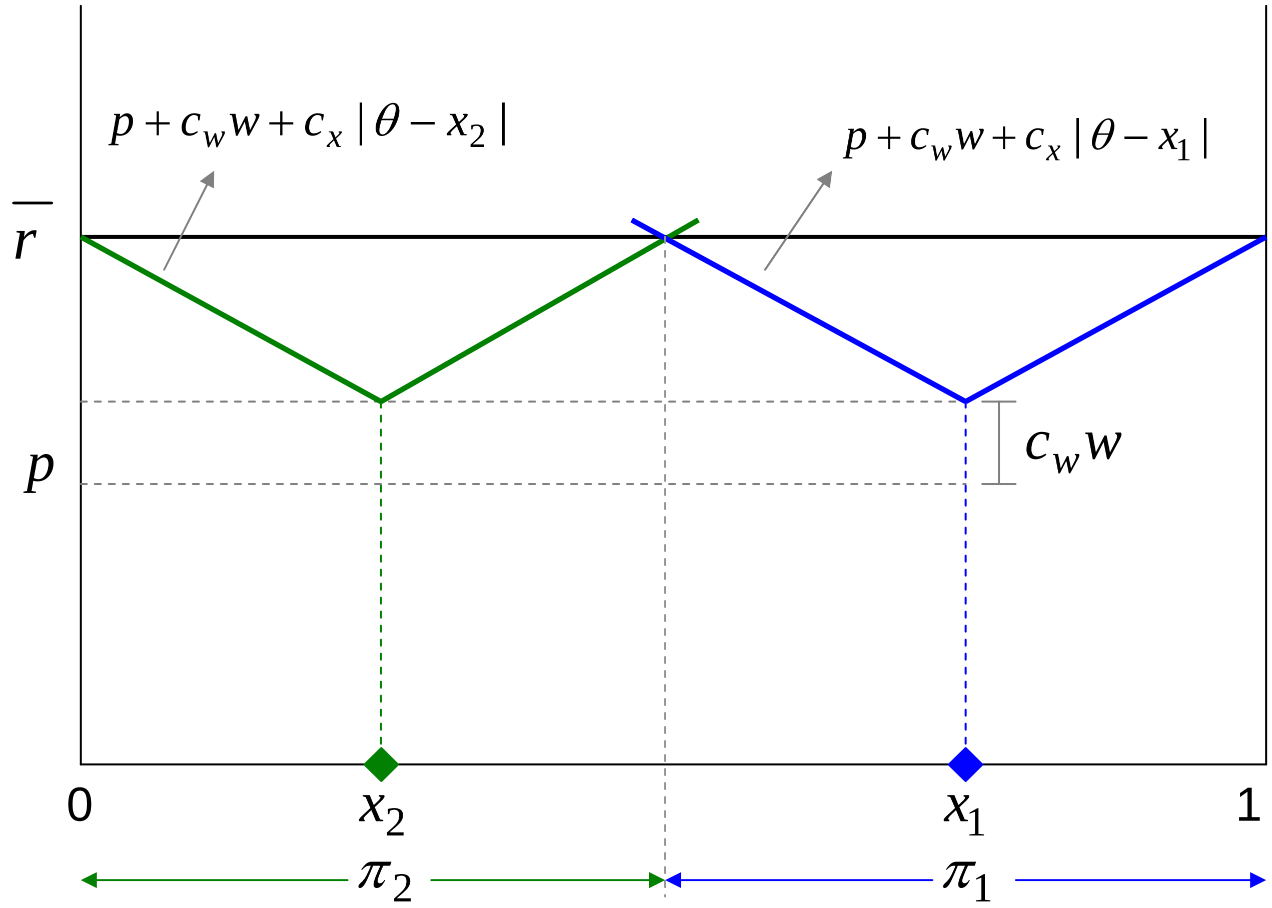
$$U(\theta, x_i, p, w) = r - p - c_w w - c_x \left| \theta - x_i \right|$$

Reservation price

Cost of waiting

Cost of deviation from the ideal preference

Market demand model



Market demand model

Given that N, w, c_w, and c_x are fixed, we obtain full market coverage with the maximum revenue by setting:

- $$x_i^* = \frac{2i-1}{2N} \qquad i = 1, 2, \ldots, N$$

- $$p^* = \bar{r} - c_w w - \frac{c_x}{2N}$$

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Production-Inventory model

The MTS system (Buzacott and Shanthikumar, 2003)

Expected inventory:

$$I_i(S_i) = S_i - \left(\frac{\lambda_i}{\mu - \Lambda}\right)\left(1 - \hat{\rho}_i^{S_i}\right)$$, where $$\hat{\rho}_i = \lambda_i / (\mu - \lambda_{-i})$$

$$\lambda_{-i} = \sum_{j \neq i} \lambda_j$$

Max lead time:

$$\Pr\left[T_i(S_i) \leq w\right] = 1 - \hat{\rho}_i^{S_i} \cdot e^{-(\mu - \Lambda)w}$$

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The DD system (Gupta and Benjaafar, 2004)

$$I_0(S_0) = S_0 - \left(\frac{\rho_1(1-\rho_1^{S_0})}{1-\rho_1} \right)$$

$$\Pr(T(S_0) \geq w) \approx \begin{cases} (1+\rho^{S_0}(1-\rho)\mu w)e^{-\mu(1-\rho)w} & \text{if } \rho_1 = \rho_2 = \rho, \\ e^{-\mu_2(1-\rho_2)w} + \left(\frac{(1-\rho_2)\rho_1^{S_0+1}}{\rho_2 - \rho_1} \right) \cdot \left(e^{-\mu_2(1-\rho_2)w} - e^{-\mu_1(1-\rho_1)w} \right) & \text{otherwise} \end{cases}$$

The CM system

Use the MTS model with zero stock

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Profit functions

MTS

$$Z(N, \mathbf{x}, \mathbf{S}, p) = \sum_{i=1}^{N} (p - c_{\mathrm{MTS}}) \cdot \lambda_i (x_i, S_i, p) - h \cdot I_i (S_i) - K \cdot N$$

DD

$$Z[N, \mathbf{x}, S_0, p] = \sum_{i=1}^{N} (p - c_{\mathrm{DD}}) \cdot \lambda_i [x_i, S_0, p] - h_0 \cdot I_0 [S_0] - K \cdot N$$

CM

$$Z[p] = (p - c_{\mathrm{CM}}) \cdot \Lambda$$

Constraint: $\Pr\left[T \leq w\right] \geq 1 - \beta$

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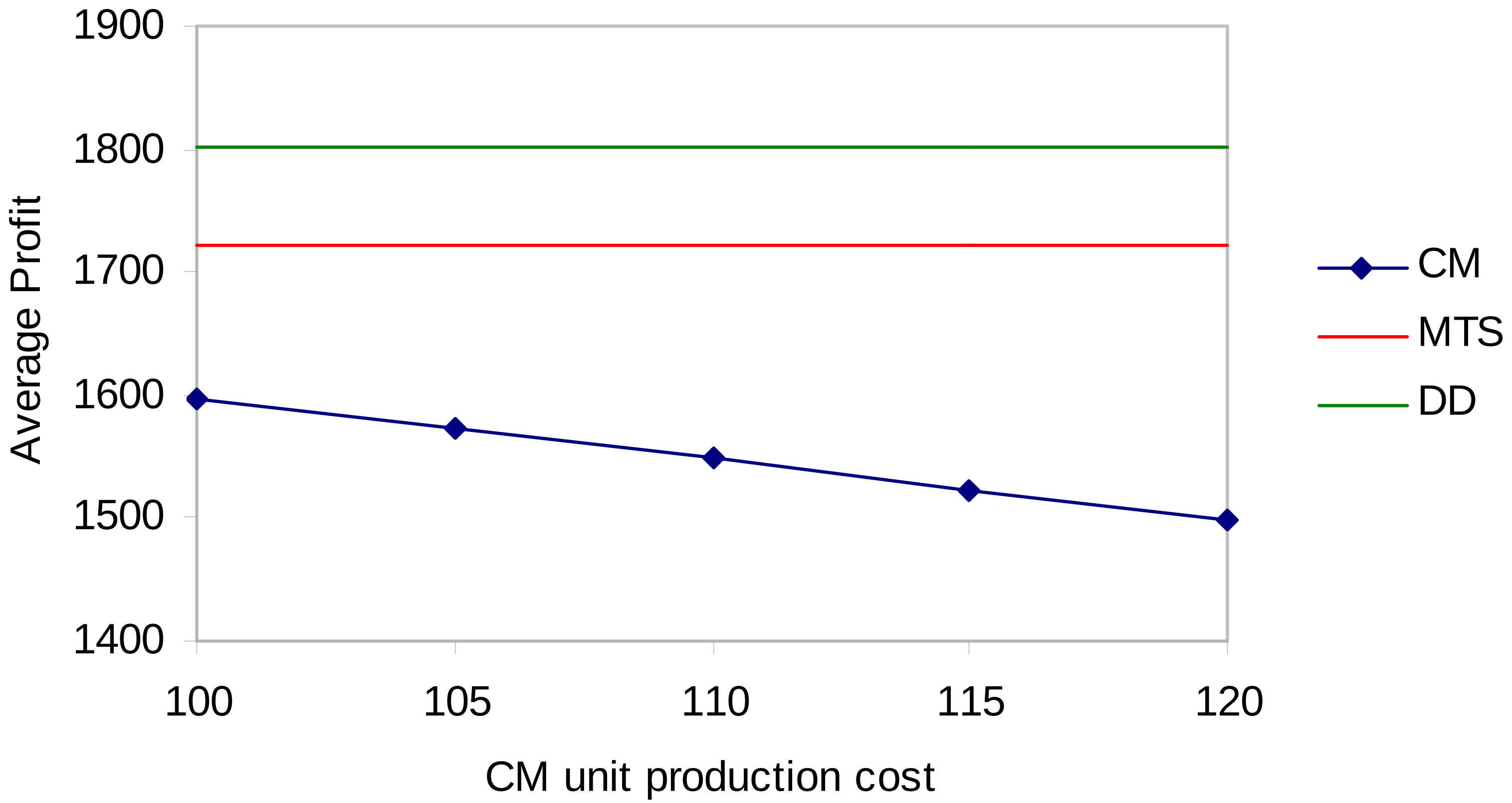
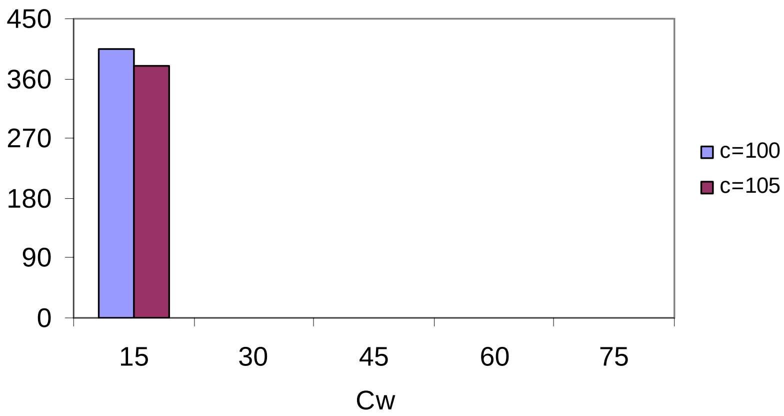
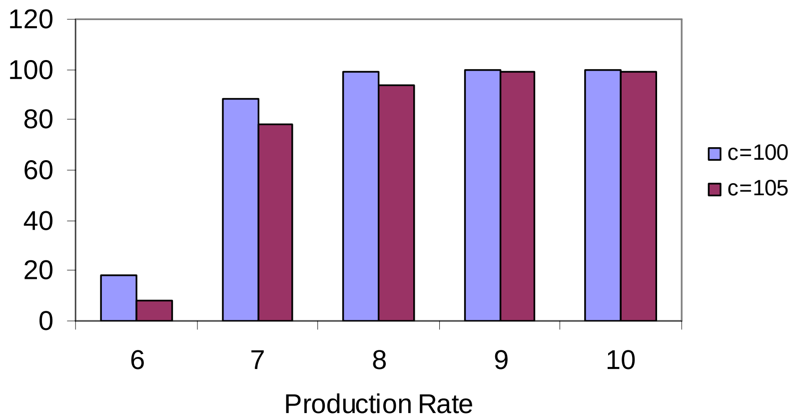
Numerical Experiment

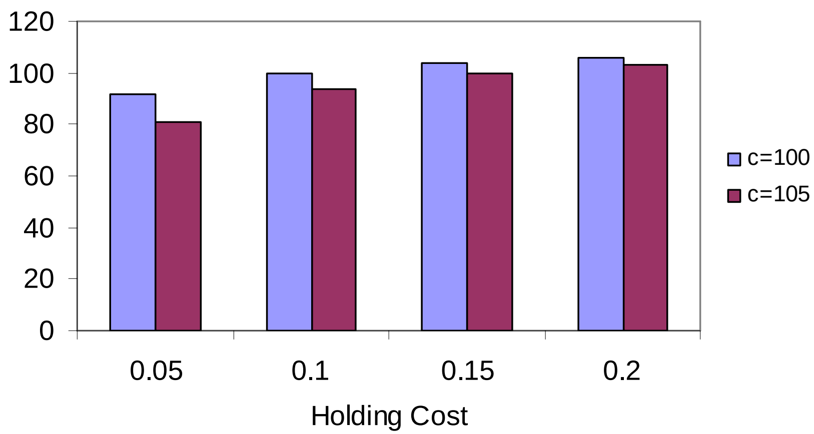
- Total demand rate : $\Lambda = 5$
- Production cost $c_{\text{MTS}} = c_{\text{DD}} = 100$
- Reservation price $r = 500$
- Production rate = μ = [6 / 7 / 8 / 9 / 10]
- Waiting cost = c_w = [15 / 30 / 45 / 60 / 75]
- Preference deviation cost = c_x = [40 / 80 / 120 / 160 / 200]
- Holding cost = h = [5 / 10 / 15 / 20]
- Product proliferation cost = K = [5 / 10 / 15 / 20 / 25]
- CM Production cost = c_{CM} = [100 / 105 / 110 / 115 / 120]

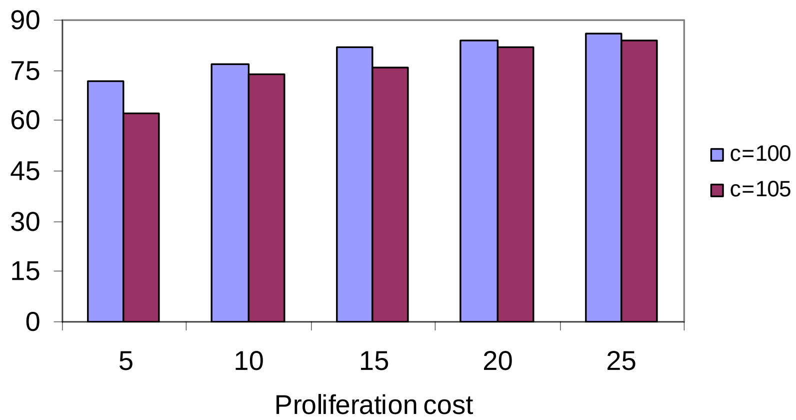
Average profit comparison

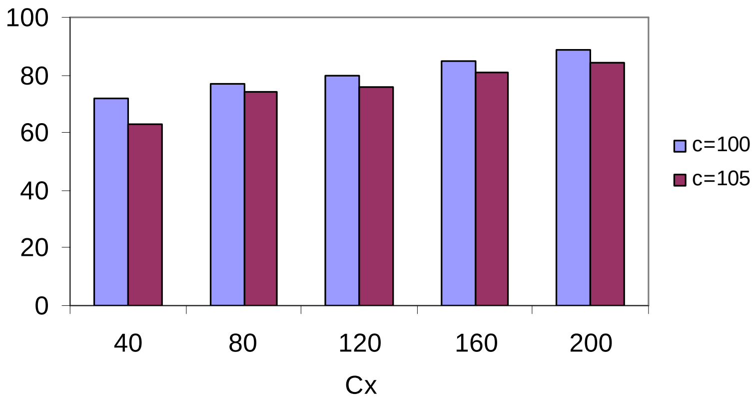










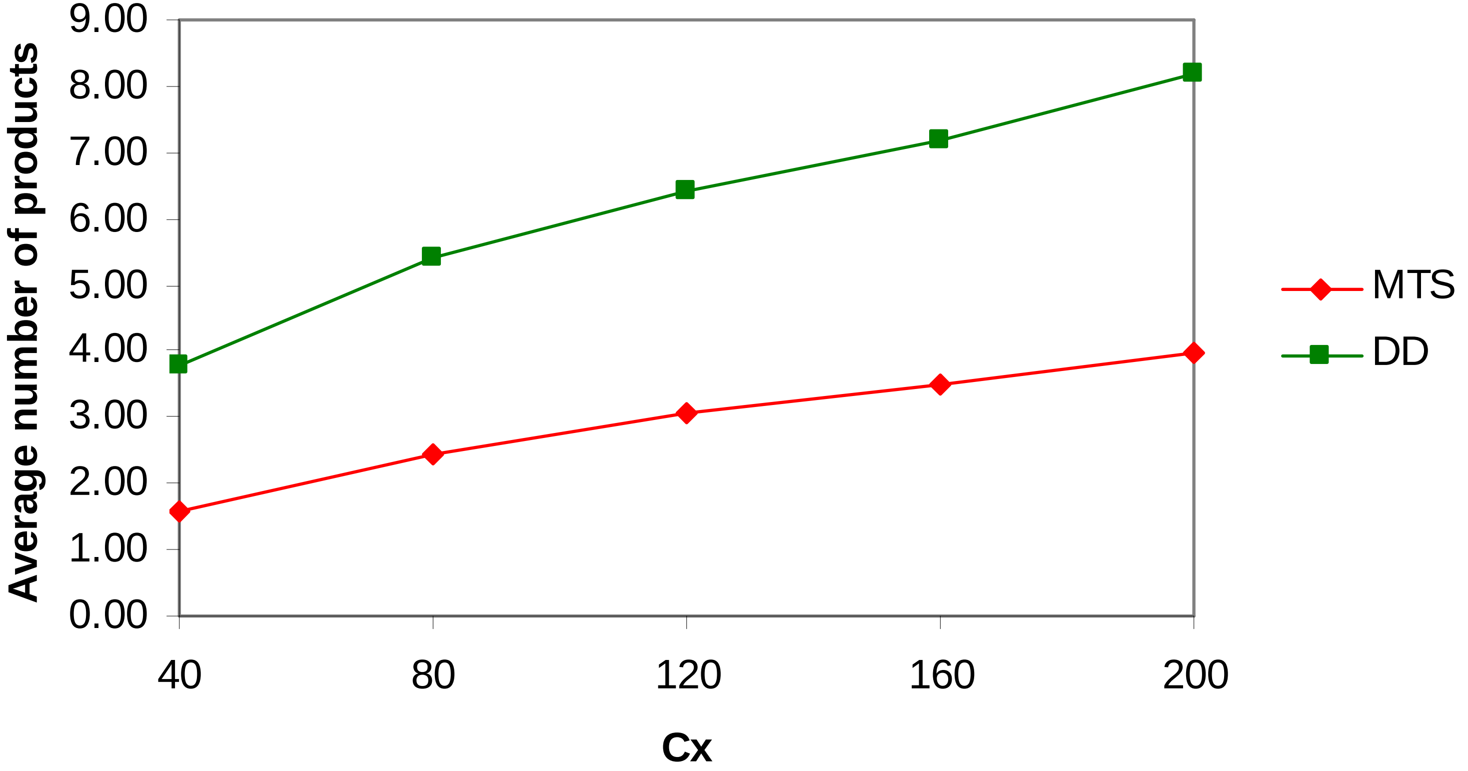


CM outperforms DD:

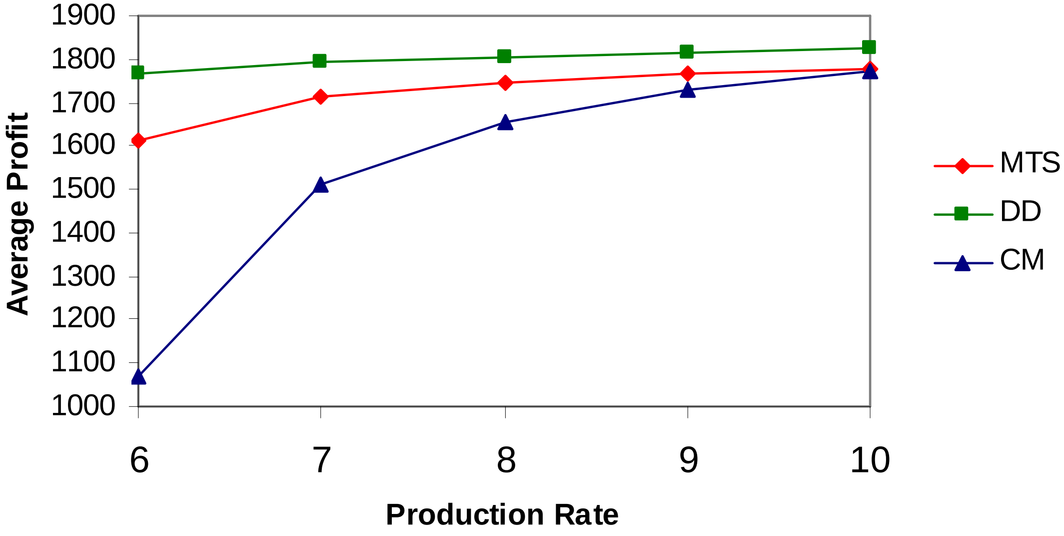
- 405 cases (out of 2500) for c=100

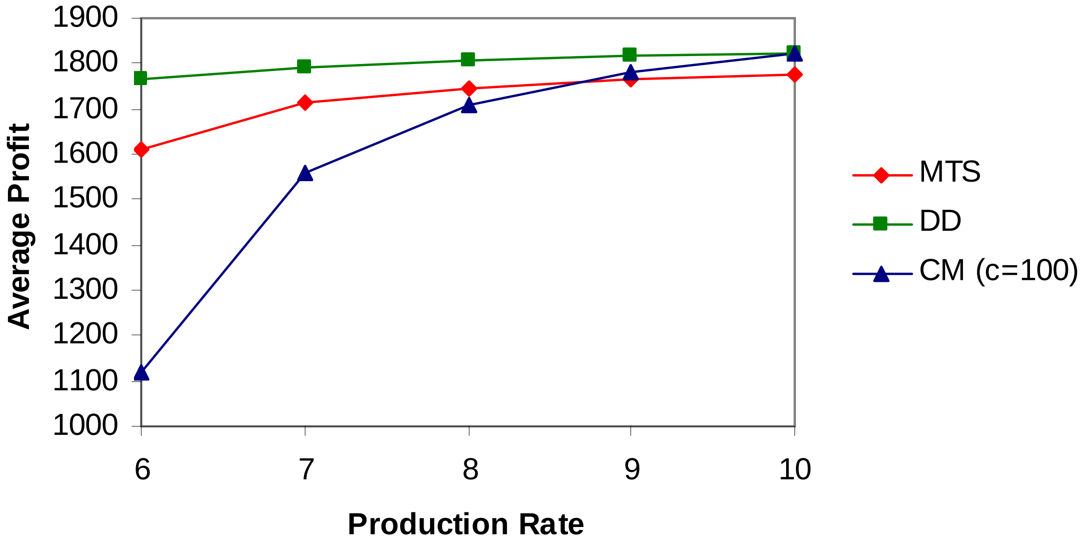
- 378 cases for c=105

Number of product lines

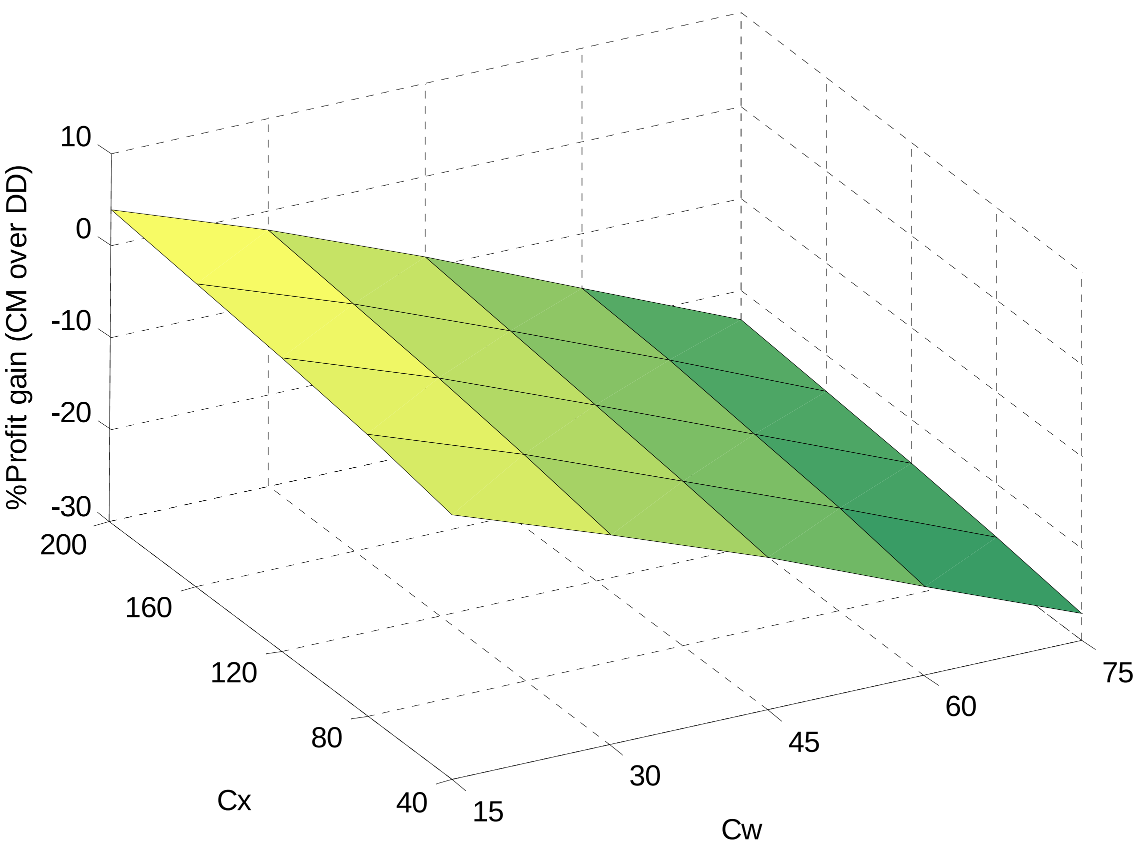


The effect of production rate





CM vs. DD



%Profit gain (CM over DD)
10
0
-10
-20
-30
200
160
120
80
40
Cx
15
30
45
60
75
Cw

Concluding Remarks

- Many issues may inhibit the viability of CM (customers' lead time sensitivity and high production cost)
- Next step - To assess the viability of CM by understanding how CM products may encroach on demand for conventional products
  - Incorporating different market segments
  - Competitive analysis where MTS, DD and CM products co-exist in the market

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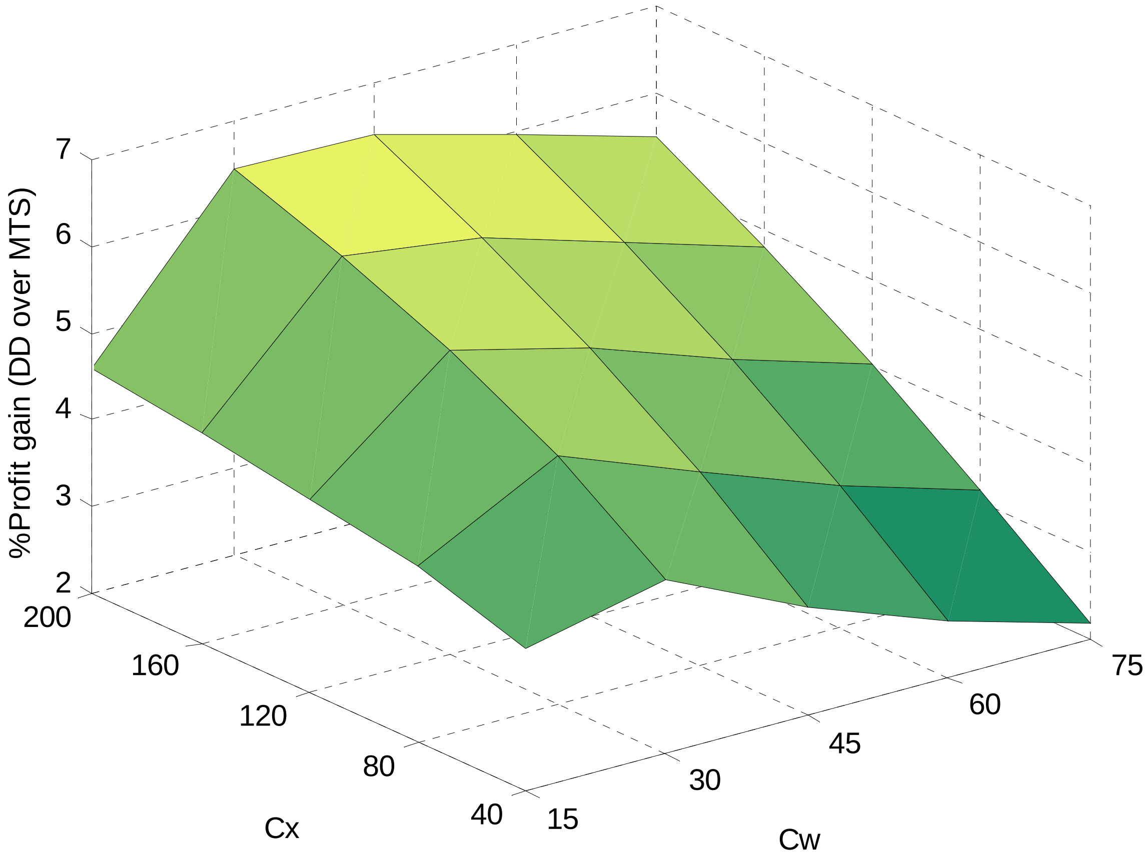
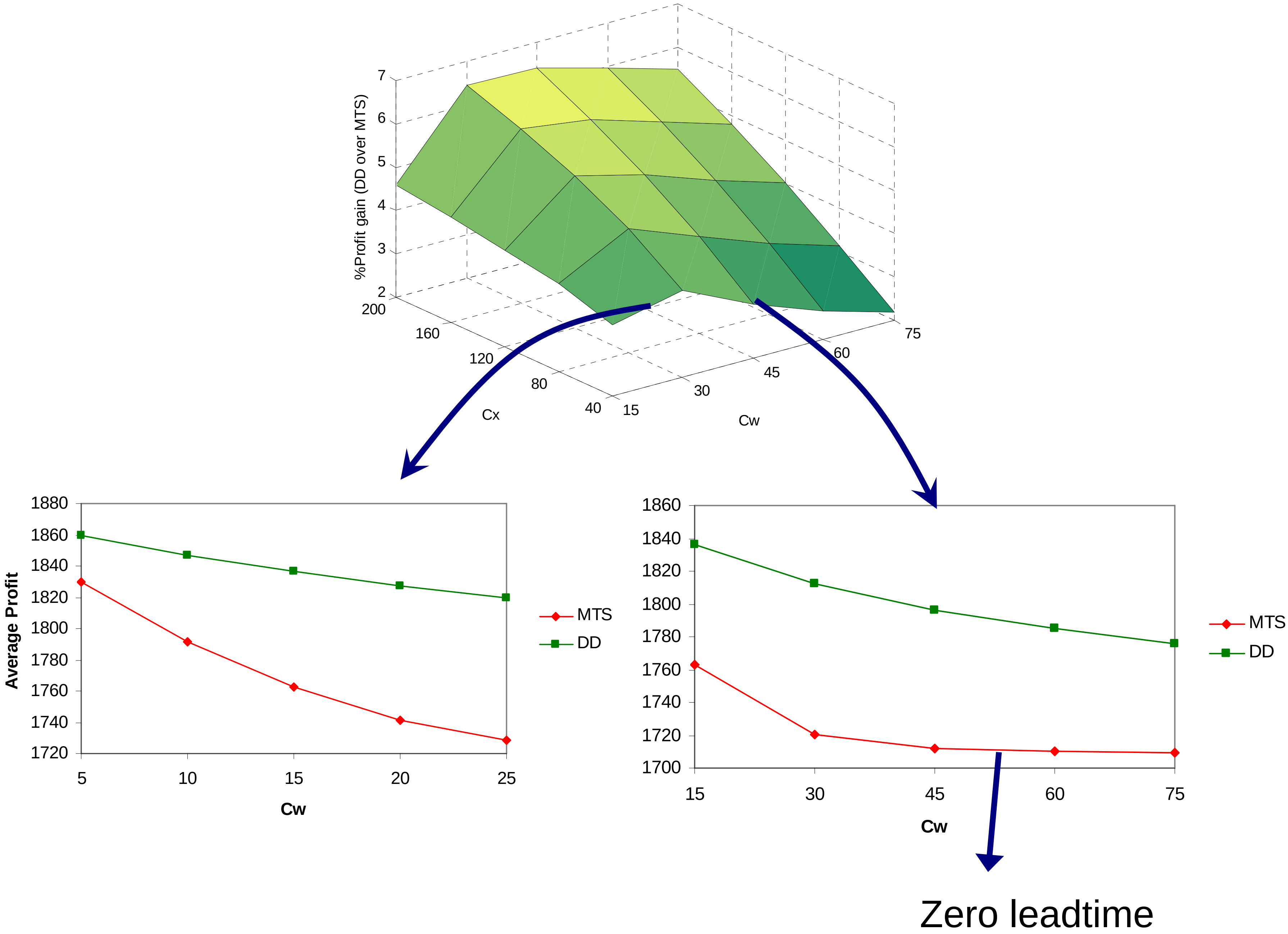
Thank You…

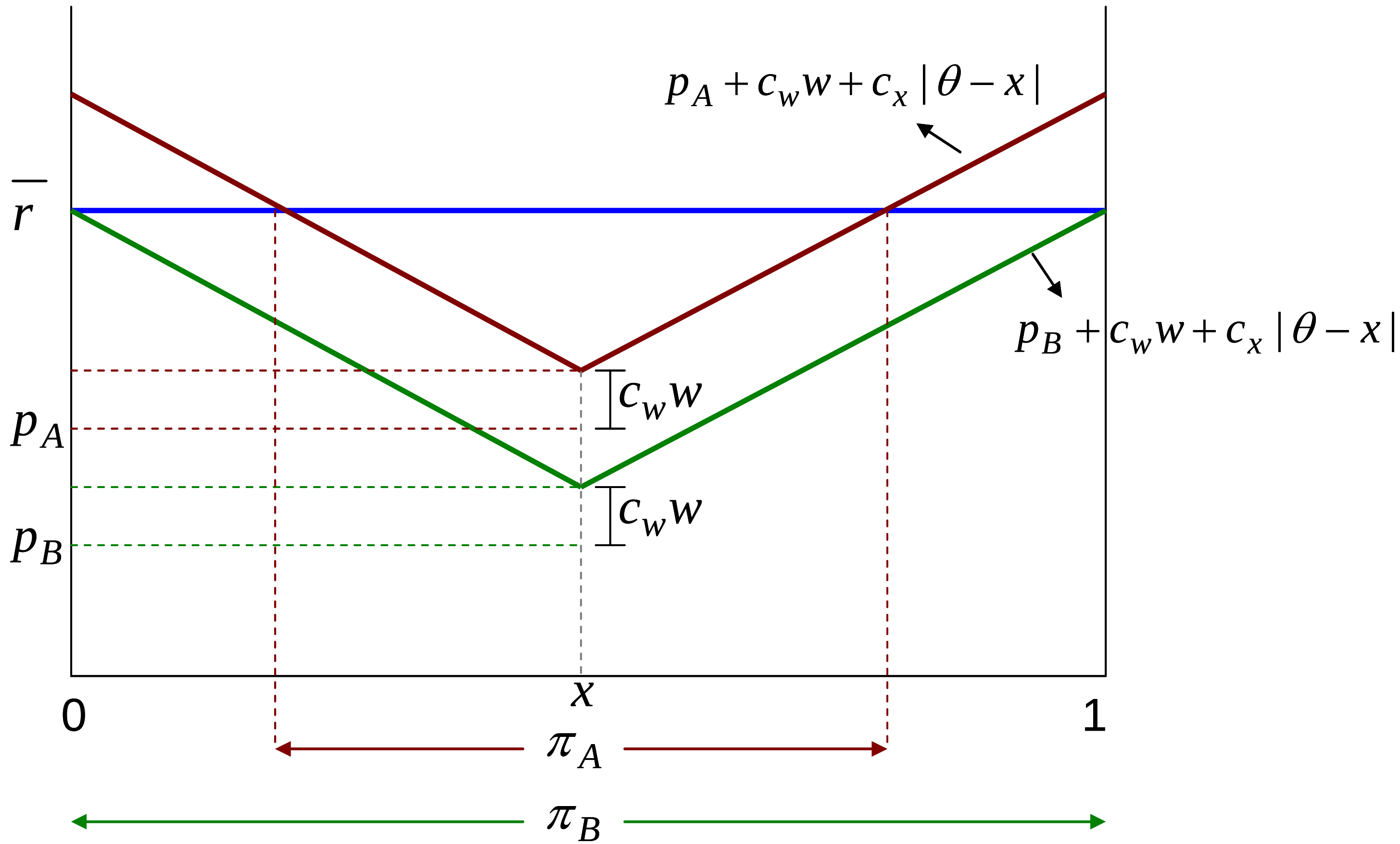
DD vs. MTS



%Profit gain (DD over MTS)
7
6
5
4
3
2
200
160
120
80
40
Cx
15
30
45
60
75
Cw


%Profit gain (DD over MTS)
7
6
5
4
3
2
200
160
120
80
40
Cx
15
30
45
60
75
Cw
Average Profit
1880
1860
1840
1820
1800
1780
1760
1740
1720
5
10
15
20
25
Cw
MTS
DD
1860
1840
1820
1800
1780
1760
1740
1720
1700
15
30
45
60
75
Cw
MTS
DD
Zero leadtime

Market demand model



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Market demand model