Hierarchical Decision-Making Model in Smart Supply Chain

Yonsei University, Yonsei Engineering Research Institute

Dept. of Information and Industrial Engineering

Jisoo Oh, Bongju Jeong

Research Abbreviation

- SC: Supply Chain
- SCM: Supply Chain Management
- SSC: Smart Supply Chain
- CSC: Conventional Supply Chain
- ICPT: Information Communication and Production Technology
- DMM: Decision Making Model
- DM: Decision Making
- MFG: ManuFacturinG

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Introduction

- **Research Background**
  - Changing SC environment
    - *Demand aspect:* various segmented customer needs, diffusion of internet and mobile device, showrooming & webrooming appearance, customer participation
    - *Supply and Economy:* emerging mobile business, more complexity, 3D printing development, introduction of hyper-connected, decline industrial competitiveness, economic polarization
    - *Society and culture:* decline manpower, avoiding MFG industry, resource limit
  - Introducing ICPT
    - *ICT*: Internet of Things, Big data analysis, Cloud computing, Cyber Physical System
    - *PT*: Artificial Intelligence and Robotics, 3D Printing, Virtual Reality and Augment Reality
  - Enlargement of Converging ICPT
    - Smart Manufacturing and Factory, Smart Logistics, Smart Retail or Omnichannel
    - Securing the strengthen Competitiveness, in order…
      - To collect and share data based real time and anywhere, To establish flexible system, To satisfy customer satisfaction, To detect and respond variability

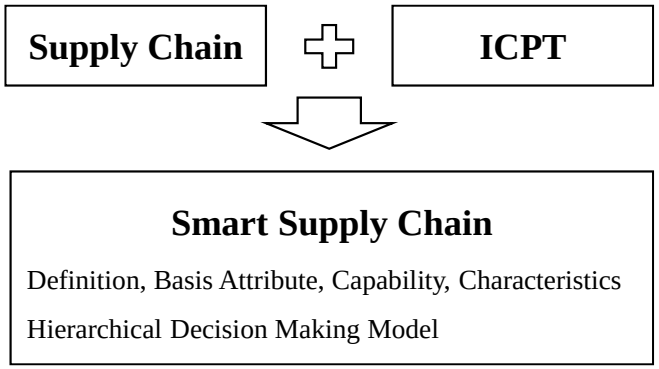
Introduction

- **Research Background**
  - **What is 'Smart'?**
    - (Google) 사리를 분명하게 가릴 줄 알거나, 사물을 확실히 이해하고 처리할 줄 아는 슬기를 가진 상태
    - (국립국어원) 또렷하고 분명하다. 사리에 밝고 총명하다. 정확하다.
    - (고려대 한국어대사전) 인지하고 이해하는 능력이 뛰어나다. 또렷하고 분명하다

    - The smart means that a subject can know own purpose, understand tasks, do well and efficiently, and flexibly respond to variability.
    - To be smart,
      - Using ICT, information of all components are efficiently managed
        - » For information system: real time monitoring, information delivery, share, and integration
      - Using PT, all components perform multiple function
        - » For multifunctional system: automaticity, realization, and flexibility

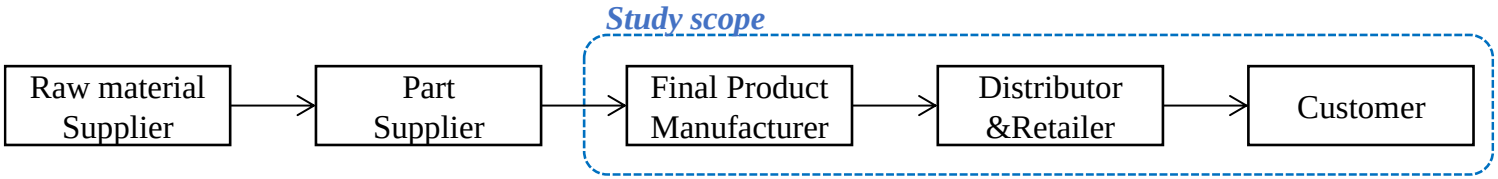
Introduction

- **Research Topic**
  - What is ***Smart Supply Chain*** and its ***Properties***?
  - How does hierarchical ***Decision Making Model*** in Smart Supply Chain represent mathematically?



Research topic

- **Research Scope of SC environment**



SC in this study

Introduction

- **Research Purpose**
  - **(I).** *To define Smart Supply Chain*, **(II).** *To identify Properties* of Smart Supply Chain, **(III).** *How to apply to Decision Making Model*, **(IV).** *How to establish Mathematical Programming*

- **Hierarchical Decision Making Model in Research**
  - Strategic Decision Making Model
    - Profit analysis: Demand and Profit function
  - Planning Decision Making Model
    - Supply planning model
  - Operational Decision Making Model
    - Inventory model

Literature Review

- **Industry 4.0**
  - Glas et al., 2016; Schmidt et al., 2015; Ivanov et al., 2014; Schuh et al., 2014, Lee et al., 2015; Frazzon et al., 2015; Sokolov et al., 2015.
- **Smart Factory**
  - Goryachev et al., 2012; Dhungana et al., 2015; Veza et al., 2015; Talhi et al., 2015; Munera et al., 2015; Chang, 2015; Shellshear et al., 2015; Choi et al., 2015; Kievit et al., 2015; Sooyoung et al., 2016; Bauer et al., 2004.
- **Future Supply Chain**
  - Dawid et al., 2016; Christopher, 2014; Ivanov et al., 2016; He and Lai, 2012; He et al., 2011; Tachizawa et al., 2015;

We found…

1) *Attributes* of ICPT and *Conceptual Approach*

2) Necessity and Requirement of *future Supply Chain*

3) *Trend* of the convergence between ICPT and industries

Literature Review

- **Distribution Channels**
  - Gensler et al., 2007; Coelho et al., 2003; Melis et al., 2015; Verhoef et al., 2015; Erik et al., 2013; Hubner et al., 2016, etc.

- **Strategic Decision Making Model**
  - **Profit function**
    - Chongchao et al., 2006; Avinadav et al., 2013; Fang et al., 2015; Esmaeili, 2009, etc.

We found…

1) Each research studied their own profit functions for market

2) *Channel strategy* is the significant to increase profit and market size

3) Absence of *customized product, cannibalization and omnichannel*

Literature Review

- **Planning Decision Making Model**

  – **Planning model**

    - Fahimnia et al., 2015; Esmaeilikia et al., 2015; Kim et al., 2006; Wang et al., 2016; You et al., 2009; Minner, 2002; Chung et al., 2004; Munson and Rosenbaltt, 1997; Vidal and Goetschalckx, 2001; Vidal and Goetschalckx, 2002; Li, et al., 2008; Sim et al., 2013; Oh and Jeong, 2014, 2016.

We found…

1) Absence of smart attributes and smart supply chain

2) Necessary of integrated DMM

3) Absence of *omnichannel*

Literature Review

- **Operational Decision Making Model**

  – **Inventory model**

    - Teksan, 2016; Digiesi, 2014; Taleizadeh et al., 2013; Sana, 2013; Huang, 2016; Cárdenas-Barrón, 2010, Dobos and Richter, 2004; El Saadany and Jaber, 2008; Konstantaras and Skouri, 2006; Omar and Yeo, 2009; Chung, 2008, and so on.

We found…

1) Absence of integration with DMM, and omnichannel

2) To derive unit cost for each channel and member

Literature Review

1) Attributes of ICPT, Conceptual Approach and Trend

2) Necessity and Requirement of future Supply Chain

3) Channel strategy is the significant to increase profit and market size

4) Absence of cannibalization for customized product and omnichannel

5) Necessary of integrated DMM

SSC and DMM

- **SSC Concept**
  - Supply Chain *converged ICPT*
  - Smart + Supply Chain

    = Information Management & Multifunctional + Purpose of Supply Chain
    - Smart ⊃ {Information Management, Multifunctional}

      cf) multifunctional: realization, flexibility, automation
    - Supply Chain
      - Purpose of SC
        - » Balance of demand and supply
        - » To maximize customer satisfaction and total value of SC

SSC and DMM

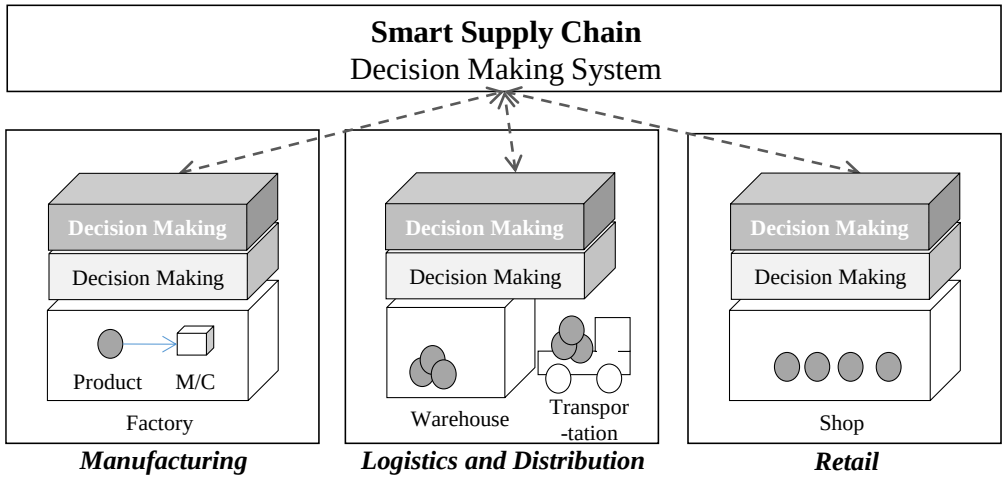
- **SSC Definition**
  - To achieve the **Purposes** of SC, SSC is more effective, responsive, and agile SC.

    A smart supply chain converged with ICPT based on 4 **Basis Attributes**, has 5 **Capabilities** and 4 **Characteristics**.
    - Basis Attributes: Connection, Convergence, Collaboration, and Customization
    - Capabilities: Visibility, Flexibility, Responsibility, Integrity, Automaticity
    - Characteristics: Real-time based, End-to-end, Demand-driven, and Omnichannel

※ *Comparison between conventional and smart SC*

- √ Conventional SC vs. SSC: SSC includes agile, adaptive, flexible, response, integrative SC
- √ Green SC vs. SSC: Difference objective, performance measure, and methodologies
- √ Closed loop SC, Recovery SC vs. SSC: Difference performance measure, and SC environment
- √ Robust SC vs. SSC: Difference of management way about variability

SSC and DMM

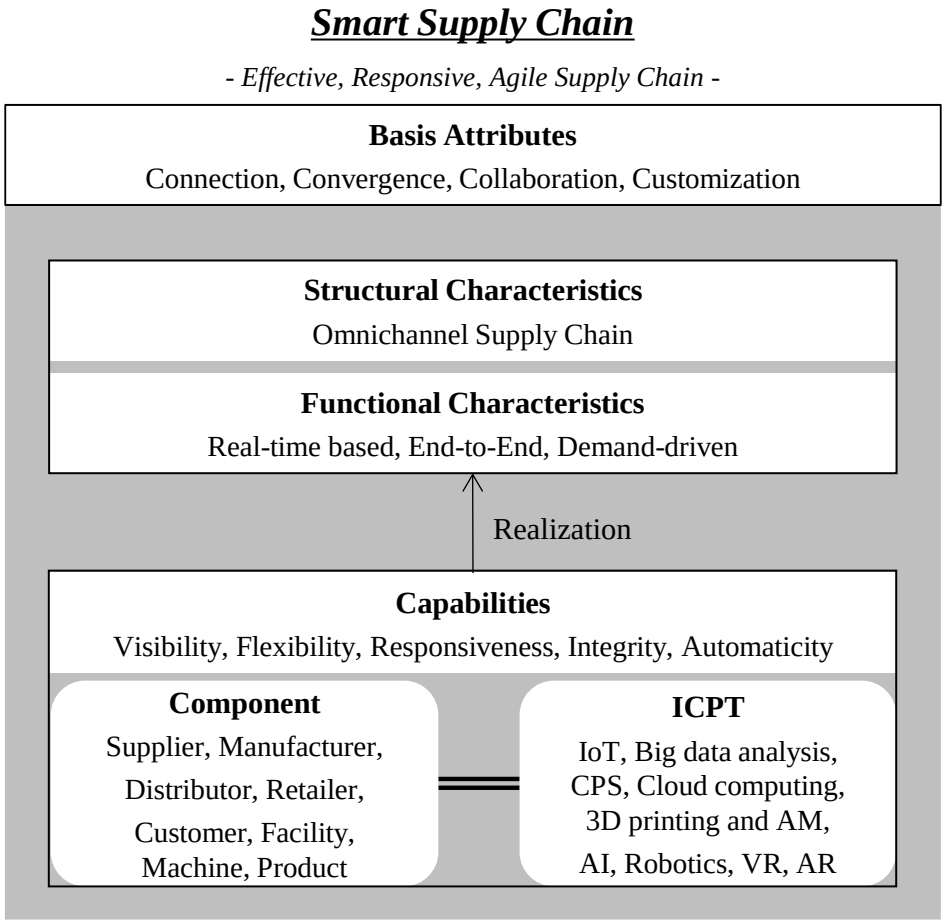


Smart supply chain and industries

- The SSC shares the management area of factory, logistics, and retail
- The SSC connects, converges, collaborates with factory, logistics, and retailer to maximize the purpose of SC
- The scope of SSC does not include detailed operation management (automation, scheduling, process control, etc.)

SSC and DMM

- **Conceptual Framework of SSC**



Framework of SSC

- **Basis Attributes of SSC**

Basis Attribute of Smart Supply Chain

Connection, Convergence, Collaboration, Customization

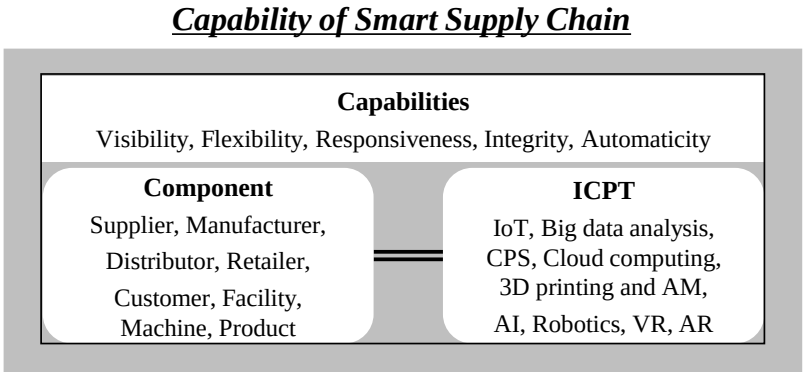
– ***Connection***
  - All components are connected by ICT, and SSC collects and shares their information, and control.
  - *Difference:* All components are connected and connection can collect and control in real time

– ***Convergence***
  - The entire supply chain behaves like a single organization
  - *Difference:* End-to-end approach, not top down or bottom up approach,
    Combination of each channel and supply like omnichannel

– ***Collaboration***
  - All components collaborate to response the changes
  - *Difference:* Quick response in real time, Expanded collaboration component: M/C to M/C, M/C to System,
    The driving force of omnichannel

– ***Customization***
  - SSC is able to supply customized products on customized channels.
  - *Difference:* Quick response for customer requirements, Unconstrained an existing product design,
    Available any channels to sell

- **Capabilities of SSC**
  - *Visibility:* Ability to monitor the status and the change at anytime, anywhere
  - *Flexibility:*
    - Ability to change, and to produce a variety of outcomes utilizing the same resources
    - Machine, material handling, operation, process, product, routing, volume, expansion, and market
  - *Responsibility:* Ability to adopt and respond to the change
  - *Integrity*
    - Ability to share information, to set up a same objective, to assign task
    - Ability to possible end-to-end approach
  - *Automaticity:* Ability to operate automatically

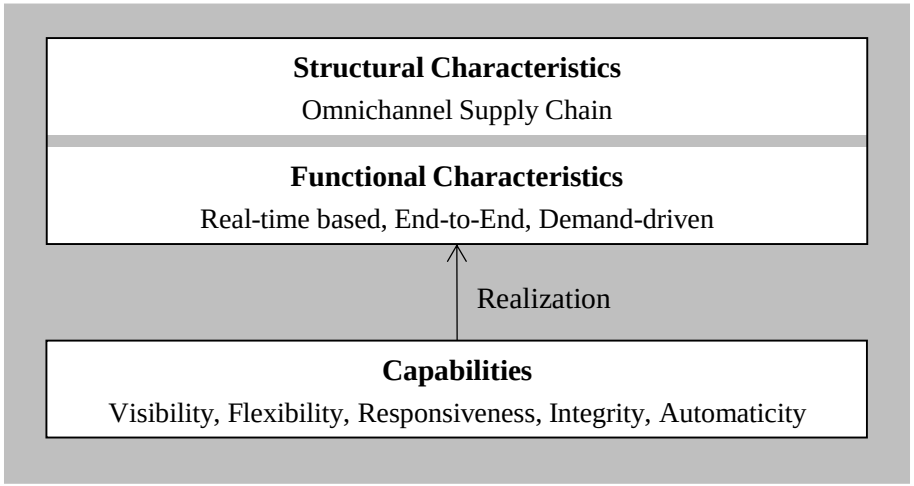


Capabilities of SSC

SSC and DMM

- **Functional and Structural Characteristics**

Characteristics of Smart Supply Chain



Characteristics of SSC

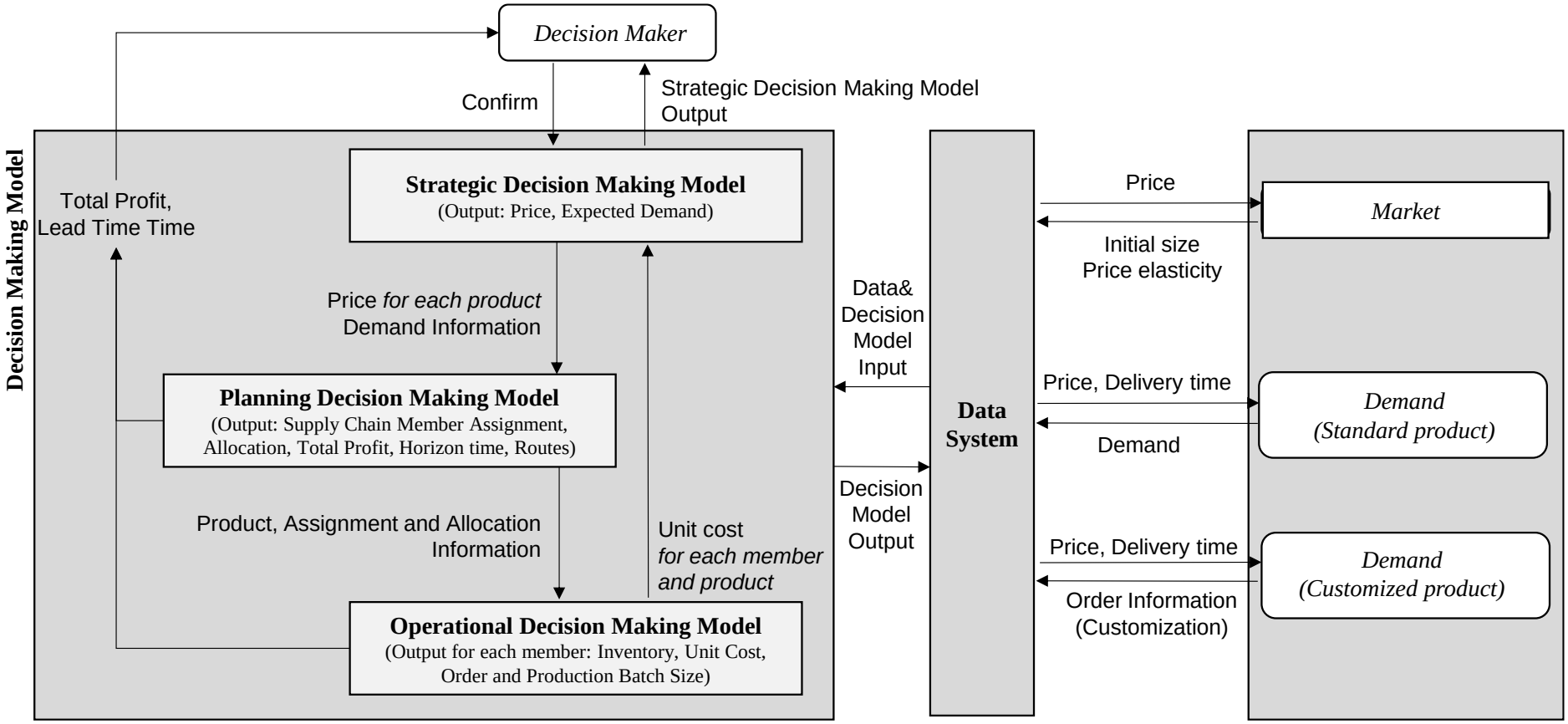
- Characteristics implies the basis attributes, and are realized by capability
- Characteristics is reflected in DMM
  - Proposed DMM is based real time, end-to-end approach, and demand driven on omnichannel

SSC and DMM

- **Functional and Structural Characteristics**
  - *Real time based*
    - Basis attribute and capability: Connection, Visibility, Responsibility, Automaticity
    - It is represented in *minimization of planning horizon of Planning DMM as semi-real time*
  - *End-to-end*
    - Basis attribute and capability: Convergence and Collaboration, Visibility, Integrity
    - It is represented in *Integrated DMM*
  - *Demand-driven*
    - Basis attribute and capability: Connection, Collaboration, and Customization, Visibility, Flexibility, and Responsibility
    - It is represented in *all DMMs at each planning horizon as coexistent SC with standard and customized product*
  - *Omnichannel*
    - Basis attribute and capability: all attributes, all capabilities
    - It is represented for each DMM as *omnichannel SC*

- **Purpose of DMM**
  - Strategic DMM (high level)
    - Strategic DMM deals with standard or customized product, and market (initial market, price elasticity of demand)
    - Solution of 'What to sell, Price, and Expected Demand'
  - Planning DMM (medium level)
    - Planning DMM deals with production, transportation, capacity, and lead time
    - Solution of 'When, Where and How to Supply'
  - Operational DMM (low level)
    - Operational DMM deals with production and transportation batch size, and Inventory for facility
    - Solution of 'How to operate'

- **DMM Structure**



DMM Structure

- **Assumption and Environment**
  - Supply Chain Member: Manufacturer, Retailer and Demand
    - Online (manufacturer → demand) and Offline (retailer → demand)
    - Horizon time of manufacturer and retailer is the same
  - Product: Standard product and Customized product
    - Customized product is ordered or scheduled, Freely changing price
    - BOM structure, a unit of material → a unit finished product
  - Cost Categories: Material cost and Operation Cost
  - Infinite transportation and inventory capacity, order cost by number of order, receivers pay for transportation
  - Operating based on Visibility, Automaticity, Real-time
  - In omnichannel, customer have the same experience from offline and online

- **Supply Channel**
  - Omnichannel
    - Omnichannel is a business model that companies use to increase customer experience, and to support the same value and experience, anywhere, anytime. All process need to be integrated and connected when customer want to purchase products.
    - Companies that use omnichannel that a customer values the ability to be in constant contact
    - Role of ICPT
      - Sensing, IoT and Bigdata analysis (monitoring), AR (Purchase Simulation), Cloud computing (data management), etc.

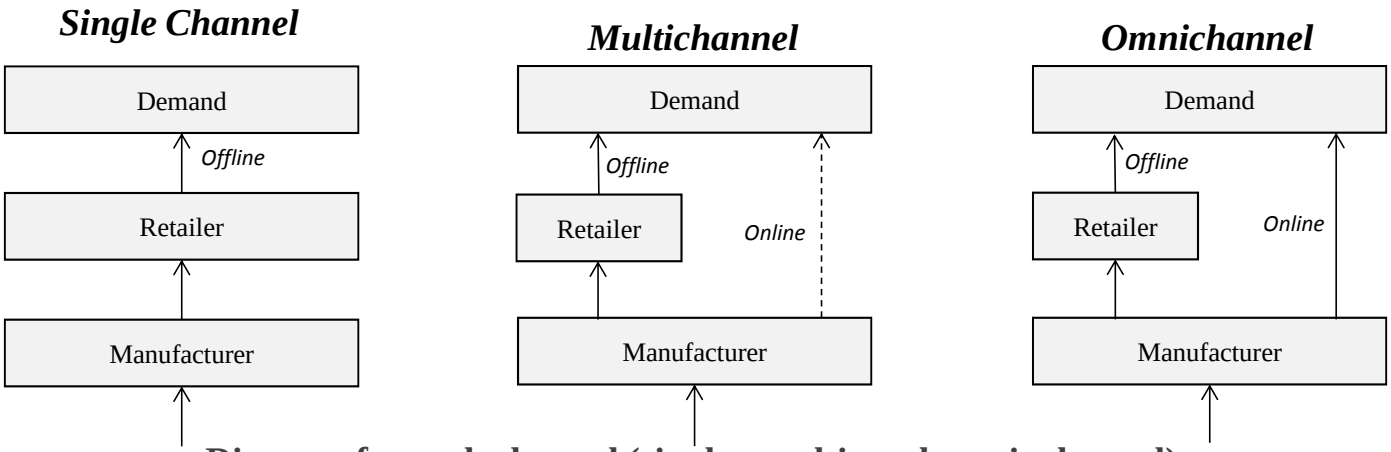


Diagram for each channel (single-, multi- and omni- channel)

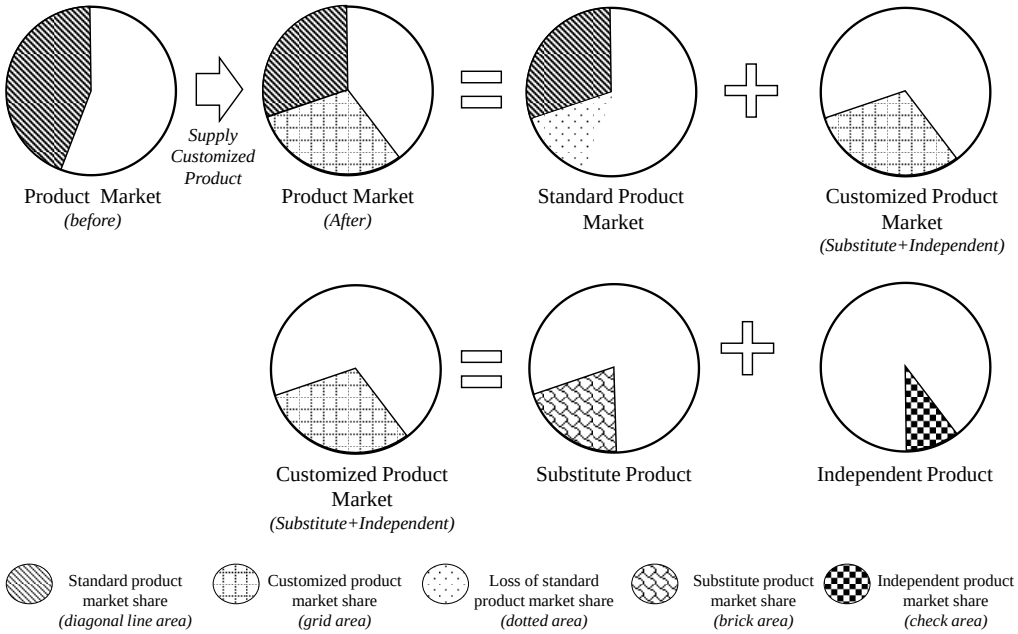
- Methodology of Strategic DMM
  - Decision Variables: Price and Expected Demand
  - Demand and Profit Function
    - Demand function: $D = a - bp$ (a: initial market size, b: price-demand sensitivity, p: price)
    - Profit function: $Profit = D(p - c)$ (c: unit cost = operation unit cost + material cost)
    - Profit function for SC = Profit function of manufacturer + Profit function of retailer

※ DMM based Profit Function

- Profit function is to understand easily and intuitively, and everyone can empathize function.
- Profit function is simple to calculate, analyze, and understand.
- Price is the significant factor to determine demand quantity.

- **Product Criteria**
  - Standard product (economic goods),

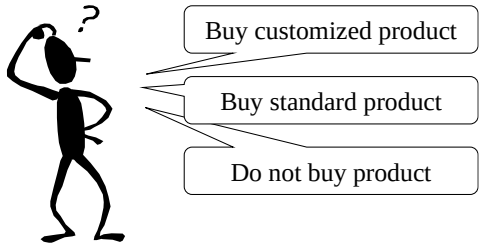
    and customized product (substitute and/or independent goods)



Market sharing for each product

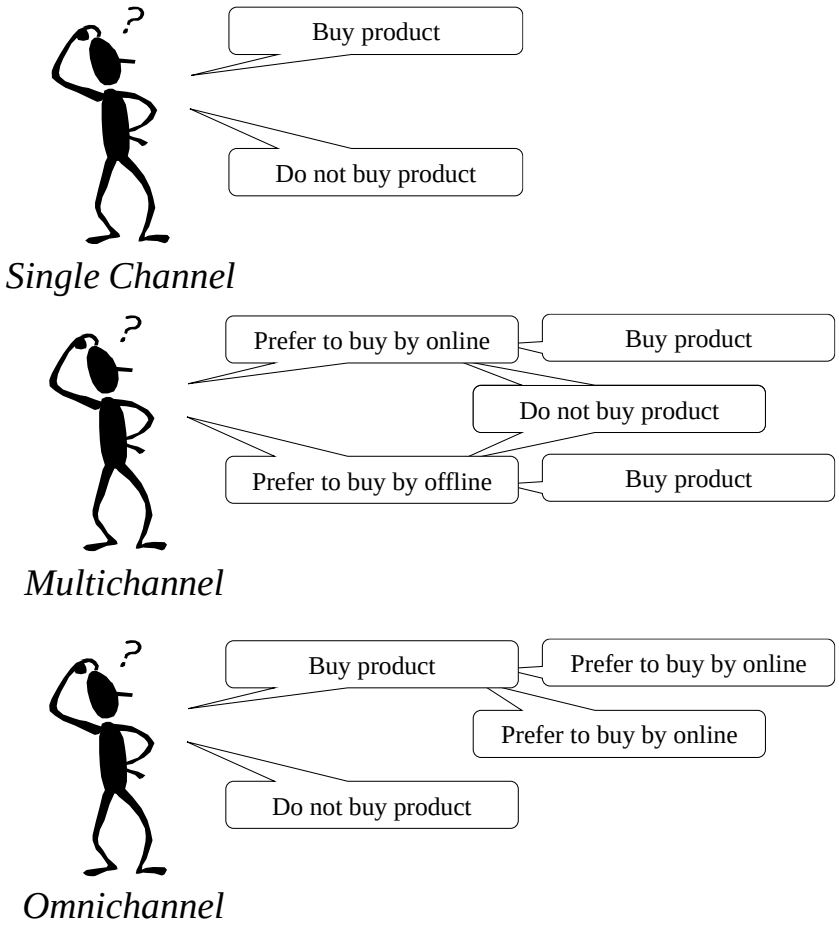
Customer is able to select three choices

Buy standard or customized product or Do not Buy

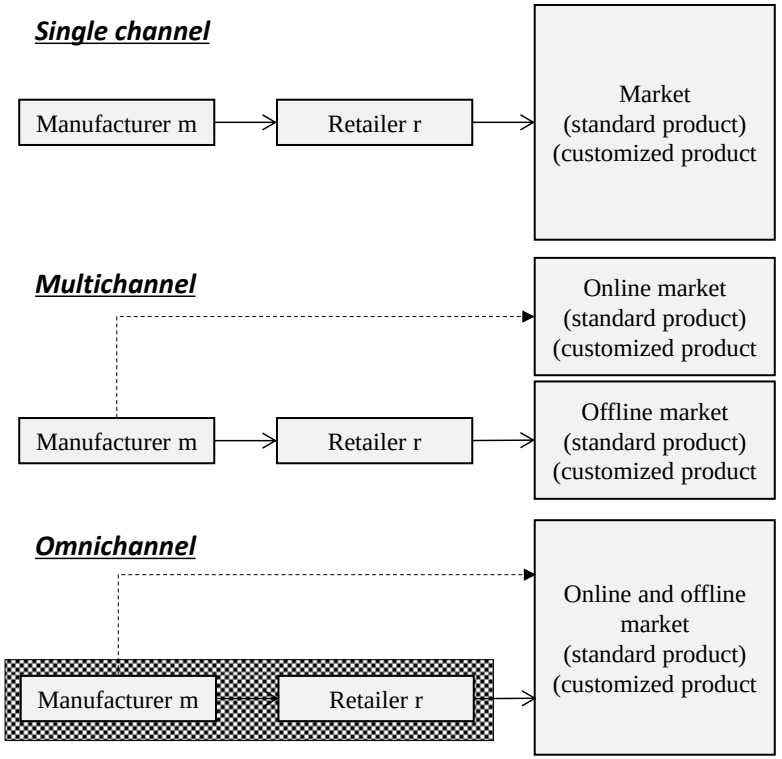


Customer behavior of each product

- **Channel Criteria**



Customer behavior of each channel



Market segmentation for each channel

- Notation
  - Index

s, c	Index of standard product s, and customized product c
S, M, O	Index of single channel S, multichannel M, and omnichannel O.
r, m	Index of retailer r ($r = 1, 2, 3, \dots, I$), and manufacturer m ($m = 1, 2, 3, \dots, J$).
w	Index of wholesale from manufacturer to retailer on multichannel ($w = 1, 2, 3, \dots, W$)

  - Parameters and Variables (Capital letters are variables)

Profit function for product	
ED_s, ED_c	Expected demand of standard and customized product
ED_T	Total expected demand ($D_T = D_s + D_c$)
a	Initial market size
b_s, b_c	Price-demand sensitivity coefficient of standard and customized product, $b_s, b_c \geq 0$
P_s, P_s	Unit price of standard and customized product
τ	Cannibalization degree for demand of standard product by customized ($0 \leq \tau \leq 1$)
OC_s, OC_c	Unit operation cost of standard and customized product, calculated by operation decision making model

Profit Function on Smart Supply Chain: Omnichannel			
EOD^O	Expected demand of omnichannel	b^O	Price-demand sensitivity coefficient of omnichannel, $b^O \geq 0$
ED_r^O, ED_m^O	Expected demand of retailer and manufacturer on omnichannel	P^O	Unit price of omnichannel
a^O	Initial market size on omnichannel	Π^O	Total profit of omnichannel
Π_r^o, Π_m^o	Profit of retailer and manufacturer on omnichannel		

Strategic Decision Making Model	
$a_s^O,$	Initial market size of omnichannel
b_s^O	Price-demand sensitivity of standard product on omni channel
$SEOD^O, CEOD^O$	Expected demand of standard and customized product on omnichannel
OSP, OCP	Unit price of standard and customized product on omnichannel
RSC^O	Operation cost of standard product for retailer on omnichannel, calculated by operational decision making model
MSC^O	Operation cost of standard product for manufacturer on omnichannel, calculated by operational decision making model
RCC^O	Operation cost of customized product for retailer on omnichannel, calculated by operational decision making model
MCC^O	Operation cost of customized product for manufacturer on omnichannel, calculated by operational decision making model

- Profit function for product
  - Demand function

$$ED_s = a - b_s P_s - \tau ED_c$$
$$ED_c = a - b_c P_c$$
$$ED_T = ED_s + ED_c = a - b_c P_s + (1-\tau)(a - b_c P_c)$$

  - Optimal price for customized product

$$\Pi_c = (a - b_c P_c)(P_c - OC_c)$$
$$P_c^* = (a + b_c OC_c)/2b_c$$

  - Optimal price for standard product

$$\Pi_s = (a - b_s P_s - \tau ED_c)(P_s - OC_s)$$
$$P_s^* = \frac{1}{4b_s}\left((2-\tau)a + \tau b_c OC_c + 2b_s OC_s\right)$$

  - Optimal profit function

$$\Pi_c(P_c^*) = \frac{(a - b_c OC_c)^2}{4b_c} \rightarrow Customized\ product$$
$$\Pi_s(P_s^*) = \frac{\left((2-\tau)a + \tau b_c OC_c - 4b_s OC_s\right)^2}{16b_s} \rightarrow Standard\ product$$

- Profit function for omnichannel
  - Expected demand function

$$EOD^O = a^O - b^O P^O$$
$$ED_m^O = \beta(a^O - b^O P^O)$$
$$ED_r^O = (1-\beta)(a^O - b^O P^O)$$

  - Profit function

$$\Pi_m^o = \beta(a^O - b^O P^O)(P^O - rc_m - OC_m)$$
$$\Pi_r^o = (1-\beta)(a^O - b^O P^O)(P^O - rc_m - OC_m - OC_r)$$
$$\Pi^O = (a^O - b^O P^O)(P^O - rc_m - OC_m - (1-\beta)OC_r)$$

  - Optimal price

$$P^{O*} = \left(a^O + b^O(rc_m + OC_m + (1-\beta)OC_r)\right)/2b^O$$

  - Optimal profit function

$$\Pi^O\left(P^{O*}\right) = \left(a^O - b^O(rc_m + OC_m + (1-\beta)OC_r)\right)^2/4b^O$$

cf) Single channel demand function

$$ED_r^S = a^S - b_r^S P_r^S$$
$$ED_m^S = a^S - b_m^S P_m^S$$

cf) Multichannel demand function

$$ED_r^M = (1-\beta)a^M - b_r^M P_r^M$$
$$EWD_m^M = (1-\beta)a^M - b_w^M W_m^M$$
$$ECD_m^M = \beta a^M - b_m^M P_m^M$$
$$ED_m^M = \beta a^M - b_m^M P_m^M + (1-\beta)a^M - b_w^M W_m^M$$

- Profit function for product and omnichannel
  - Expected demand function
    - Standard product $SEOD^O = a_s^O - \tau CEOD^O - b_s^O OSP$
    - Customized product $CEOD^O = a_c^O - b_c^O OCP$
  - Profit function
    - Standard product $\Pi_s^o = SEOD^O\left(OSP - rc_m - MSC^O - (1-\beta)RSC^O\right)$
    - Customized product $\Pi_c^o = CEOD^O\left(OCP - rc \quad - MCC^O - (1-\beta)RCC^O\right)$
  - Optimal price
    - Standard product $OSP = \left(a_s^O - \tau CEOD_c^O + b_s^O\left(rc_m + MSC^O + (1-\beta)RSC^O\right)\right)/2b_s^O$
    - Customized product $OSP = \left(a_c^O + b_c^O\left(rc_m + MCC^O + (1-\beta)RCC^O\right)\right)/2b_c^O$

Planning DMM

- Methodology of Planning DMM
  - DMM based Supply Planning Model
    - Decision Variables: Manufacturer and retailer selection, production and transportation quantity, capacity for each facility, and planning horizon time
    - Mixed integer linear programming
      - Objective function: Maximize profit and Minimize horizon time
        - » Total profit of single channel and multi channel: Revenue for each member – operation cost for each member – material cost – fixed cost for each facility – change cost of capacity
        - » Total profit of omnichannel: Revenue for omnichannel – operation cost for omnichannel – material cost – fixed cost for each facility – change cost of capacity
        - » Total horizon time: Production time + lead time
    - Constraints: supply planning model included with market segmentation for each channel
      - » Demand satisfaction, balance equation, run of facility and flow, capacity constraints, binary variables and non-negative variables

- Assumption
  - Capacity of manufacturer: free or alternative way
- Notation

Z	Index of channel, Z = S, M or O, single channel S, multichannel M, or omnichannel O.
$r, m,$ d	Index of retailer r ($r = 1, 2, 3, \dots, I$), manufacturer m ($m = 1, 2, 3, \dots, J$), and demand d ($d = 1, 2, 3, \dots, D$).
a	Index of alternative capacity a ($a = 1, 2, 3, \dots, A$)

- mcap_{alt}: manufacturer selects alternative capacity. m ∈ mcap_{alt}, $\text{mcap}_{\text{free}}$: manufacturer selects capacity, freely. m ∈ $\text{mcap}_{\text{free}}$, $\text{rcapa}_{\text{alt}}$: retailer selects alternative capacity. r ∈ rcap_{alt}, $\text{rcapa}_{\text{free}}$: retailer selects capacity, freely.r ∈ $\text{rcap}_{\text{free}}$

  - Decision variable

SQ_{mr}^{Z}	Transportation quantity of standard product from manufacturer to retailer for each channel
SQ_{rd}^{Z}	Transportation quantity of standard product from retailer to demand for each channel
SQ_{md}^{Z}	Transportation quantity of standard product from manufacturer to demand for each channel
CQ_{mr}^{Z}	Transportation quantity of customized product from manufacturer to retailer for each channel
CQ_{rd}^{Z}	Transportation quantity of customized product from retailer to demand for each channel
CQ_{md}^{Z}	Transportation quantity of customized product from manufacturer to demand for each channel
X_m^Z, X_r^Z	1: if production occurs at facility of manufacturer or retailer for each channel
	0: otherwise
Y_{mr}^{Z}, Y_{md}^{Z}	1: if transportation occurs from manufacturer to retailer or demand for each channel
	0: otherwise
E_m, E_r	Planned capacity of manufacturer or retailer

- Notation
  - Dependent variable

TP^Z	Total profit of each channel Z
H^Z	Horizon time of each channel Z
$TP_m^{Z=S\ or\ M}$	Total profit of manufacturer on single or multi- channel
$TP_r^{Z=S\ or\ M}$	Total profit of retailer on single or multi- channel
CA_{ma},CA_{ra}	1: if capacity is changed of alternative capacity for manufacturer or retailer 0: otherwise
CE_m, CE_r	The changed level of capacity for manufacturer or retailer
ACP_{ma}, ACP_{ra}	1: selection of alternative capacity for manufacturer or retailer 0: otherwise

  - Parameters

f_m, f_r	fixed cost to operate facility of manufacturer or retailer
caa_{ma}, caa_{ra}	The capacity cost of changed selection of alternative capacity for manufacturer or retailer
cal_m, cal_r	The capacity cost of changed capacity level for manufacturer or retailer
st_m, st_r	Unit operation time of standard product for manufacturer or retailer
ct_m, ct_r	Unit operation time of customized product for manufacturer or retailer
lt_{mr}, lt_{md}	Transportation lead time from manufacturer to retailer or demand
SD_d, CD_d	Real demand of standard or customized product
M	Large number
cap_m, cap_r	current capacity of manufacturer or retailer
alt_{ma}, alt_{ra}	alternative capacity degree of each alternative capacity for manufacturer or retailer
$lcap_m$, $lcap_r$	Minimum capacity of manufacturer or retailer
$hcap_m$, $hcap_r$	Maximum capacity of manufacturer or retailer
ACP_{ma}^0, ACP_{ra}^0	Selected alternative capacity for manufacturer or retailer at previous horizon time
E_m^0, E_r^0	Planned capacity of manufacturer or retailer at previous horizon time
rc_m	Material cost for manufacturer
β	Market ratio for online channel from manufacturer to demand ($0 \leq \beta \leq 1$)

- Objective functions

$Max\ TP^O$m

$Min\ H^O$n

- Constraints

< The sum of profit for each member>

$$TP_m^O = \sum_{mrd} OSP\left(SQ_{md}^O + SQ_{rd}^O\right) + \sum_{mrd} OCP\left(CQ_{md}^O + CQ_{rd}^O\right) - \sum_{mrd} MSC^O\left(SQ_{mr}^O + SQ_{md}^O\right) - \sum_{mrd} MCC^O\left(CQ_{mr}^O + CQ_{md}^O\right) - \sum_{rd} RSC^O SQ_{rd}^O -$$

$$\sum_{rd} RCC^O CQ_{rd}^O - \sum_{mrd} rc\ \left(SQ_{mr}^O + SQ_{md}^O + CQ_{mr}^O + CQ_{md}^O\right) - \sum_m f_m X_m^O - \sum_{ma} caa_{ma} CA_{ma} - \sum_m cal_m CE_m - \sum_r f_r X_r^O - \sum_{ra} caa_{ra} CA_{ra} - \sum_r cal_r CE_r$$

< The sum of lead time >

$$H^M = \sum_{mrd} st_m\left(SQ_{mr}^O + SQ_{md}^O\right) + \sum_{rd} st_r SQ_{rd}^O + \sum_{mrd} ct_m\left(CQ_{mr}^O + CQ_{md}^O\right) + \sum_{rd} ct_r CQ_{rd}^O + \sum_{mr} lt_{mr} Y_{mr}^O + \sum_{md} lt_{md} Y_{md}^O$$

< Demand satisfaction constraints >

$$SD_d = \sum_m SQ_{md}^O + \sum_r SQ_{rd}^O \qquad \forall d$$

$$CD_d = \sum_m CQ_{md}^O + \sum_r CQ_{rd}^O \qquad \forall d$$

< Network balance equation constraints >

$$\sum_m SQ_{mr}^O = \sum_d SQ_{rd}^O \qquad \forall r$$

$$\sum_m CQ_{mr}^O = \sum_d CQ_{rd}^O \qquad \forall r$$

< Run of facility and transportation constraints >

$$\begin{pmatrix} \sum_r SQ_{mr}^M + \sum_d SQ_{md}^M \\ + \sum_r CQ_{mr}^M + \sum_d CQ_{md}^M \end{pmatrix} \le MX_m^M \qquad \forall m$$

$$\sum_d SQ_{rd}^M + \sum_d CQ_{rd}^M \le MX_r^M \qquad \forall r$$

$$SQ_{mr}^M + CQ_{mr}^M \le MY_{mr}^M \qquad \forall m, r$$

$$SQ_{md}^M + CQ_{md}^M \le MY_{md}^M \qquad \forall m, d$$

< Maximum capacity constraints >

$$\begin{pmatrix}\sum_{rd} st_m\left(SQ^O_{mr}+SQ^O_{md}\right)\\ +\sum_{rd} ct_m\left(CQ^O_{mr}+CQ^O_{md}\right)\end{pmatrix} \le cap_m E_m \qquad \forall m$$

$$\sum_d st_r SQ^O_{rd} + \sum_d ct_r CQ^O_{rd} \le cap_r E_r \qquad \forall r$$

< Changes of maximum capacity constraints >

$$E_m = \sum_{a \subset mcap_{cap}} alt_{ma} ACP_{ma} \qquad \forall m \in mcap_{alt}$$

$$\sum_{a \subset mcap_{cap}} ACP_{ma} = 1 \qquad \forall m \in mcap_{alt}$$

$$lcap_m \le E_m \le hcap_m \qquad \forall m \in mcap_{free}$$

$$E_r = \sum_{a \subset rcap_{cap}} alt_{ra} ACP_{ra} \qquad \forall r \in rcap_{alt}$$

$$\sum_{a \subset rcap_{cap}} ACP_{ra} = 1 \qquad \forall r \in rcap_{alt}$$

$$lcap_r \le E_r \le hcap_r \qquad \forall r \in rcap_{free}$$

< Changing capacity or not constraints >

$$-CA_{ma} \le ACP_{ma} - ACP^0_{ma} \le CA_{ma} \qquad \forall m \in mcap_{alt}, a$$

$$-CE_m \le E_m - E^0_m \le CE_m \qquad \forall m \in mcap_{free}, a$$

$$-CA_{ra} \le ACP_{ra} - ACP^0_{ra} \le CA_{ra} \qquad \forall r \in rcap_{alt}, a$$

$$-CE_r \le E_r - E^0_r \le CE_r \qquad \forall r \in rcap_{free}, a$$

< Binary variables constraints >

$$X^O_m, X^O_r, Y^O_{mr}, Y^O_{md}, CA_{ma}, CA_{ra}, ACP_{ma}, ACP_{ra} \in \{0,1\} \qquad \forall \text{ all indices}$$

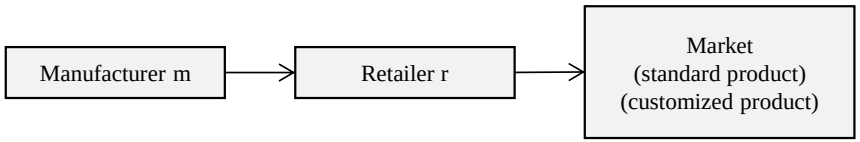
< Non-negative variables constraints >

$$SQ^O_{mr}, SQ^O_{md}, CQ^O_{mr}, CQ^O_{md}, SQ^O_{rd}, CQ^O_{rd}, E_m, E_r, CE_m, CE_r \in R \qquad \forall \text{ all indices}$$

Planning DMM

Production planning model

Single channel



Objective function: maximize profit

$$\boldsymbol{TP_m^S} = \sum_{mr}(MSP_m^s - MSC_m^s)SQ_{mr}^s + \sum_{mr}(MCP_m^s - MCC_m^s)CQ_{mr}^s - \sum_{mr} rc_m(SQ_{mr}^s + CQ_{mr}^s) - \sum_m f_m X_m^S - \sum_{ma} caa_{ma} CA_{ma} - \sum_m cal_m CE_m$$

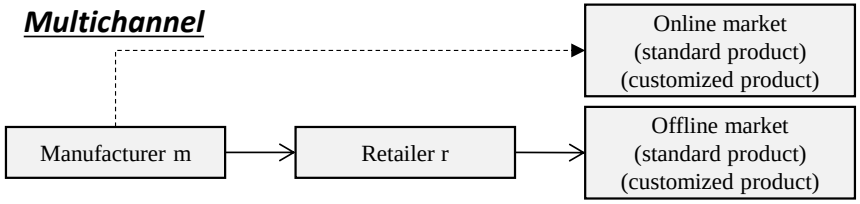
$$\boldsymbol{TP_r^S} = \sum_{rd}(RSP_r^s - RSC_r^s)SQ_{rd}^s + \sum_{rd}(RCP_r^s - RCC_r^s)CQ_{rd}^s - \sum_{mr} MSP_m^s SQ_{mr}^s - \sum_{mr} MCP_m^s CQ_{mr}^s - \sum_r f_r X_r^S - \sum_{ra} caa_{ra} CA_{ra} - \sum_r cal_r CE_r$$

Demand constraints

$$\boldsymbol{SD_d} = \sum_r SQ_{rd}^S$$

$$\boldsymbol{CD_d} = \sum_r CQ_{rd}^S$$

Multichannel



Objective function: maximize profit

$$\boldsymbol{TP_m^M} = \sum_{mr}(MRSP_m^M - MSC_m^M)SQ_{mr}^M + \sum_{md}(MDSP_m^M - MSC_m^M)SQ_{md}^M + \sum_{mr}(MRCP_m^M - MCC_m^M)CQ_{mr}^M + \sum_{md}(MDCP_m^M - MCC_m^M)CQ_{md}^M - \sum_{mrd} rc_m(SQ_{mr}^M + SQ_{md}^M + CQ_{mr}^M + CQ_{md}^M) - \sum_m f_m X_m^M - \sum_{ma} caa_{ma} CA_{ma} - \sum_m cal_m CE_m$$

$$\boldsymbol{TP_r^M} = \sum_{rd}(RSP_r^M - RSC_r^M)SQ_{rd}^M + \sum_{rd}(RCP_r^M - RCC_r^M)CQ_{rd}^M - \sum_{mr} MRSP_m^M SQ_{mr}^M - \sum_{mr} MRCP_m^M CQ_{mr}^M - \sum_r f_r X_r^M - \sum_{ra} caa_{ra} CA_{ra} - \sum_r cal_r CE_r$$

Demand constraints

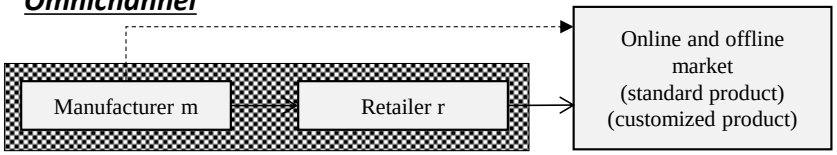
$$\boldsymbol{(1-\beta)SD_d} = \sum_r SQ_{rd}^M$$

$$\boldsymbol{(1-\beta)CD_d} = \sum_r CQ_{rd}^M$$

$$\boldsymbol{\beta SD_d} = \sum_m SQ_{md}^M$$

$$\boldsymbol{\beta CD_d} = \sum_m CQ_{md}^M$$

Omnichannel



Objective function: maximize profit

$$\boldsymbol{TP_m^O} = \sum_{mrd} OSP(SQ_{md}^O + SQ_{rd}^O) + \sum_{mrd} OCP(CQ_{md}^O + CQ_{rd}^O) - \sum_{mrd} MSC^O(SQ_{mr}^O + SQ_{md}^O) - \sum_{mrd} MCC^O(CQ_{mr}^O + CQ_{md}^O) - \sum_{rd} RSC^O SQ_{rd}^O - \sum_{rd} RCC^O CQ_{rd}^O - SQ_{md}^O + CQ_{mr}^O + CQ_{md}^O) - \sum_m f_m X_m^O - \sum_{ma} caa_{ma} CA_{ma} - \sum_m cal_m CE_m - \sum_r f_r X_r^O - \sum_{ra} caa_{ra} CA_{ra} - \sum_r cal_r CE_r$$

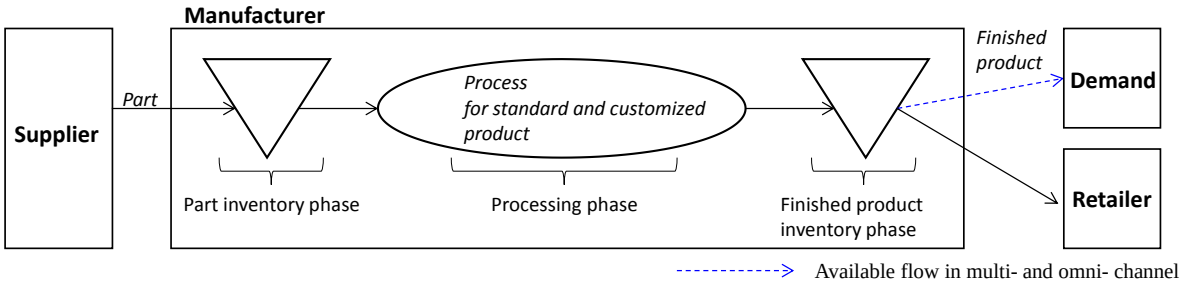
Demand constraints

$$SD_d = \sum_m SQ_{md}^O + \sum_r SQ_{rd}^O$$

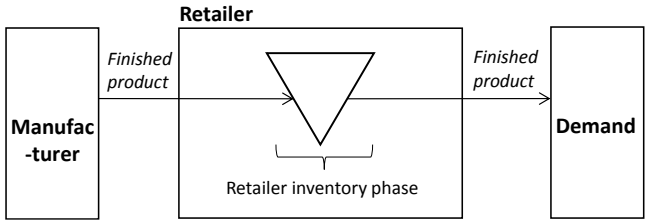
$$CD_d = \sum_m CQ_{md}^O + \sum_r CQ_{rd}^O$$

Operational DMM

- Methodology of Operational DMM
  - Decision Variables: Order and Production Batch Size, Inventory, Unit Cost
  - DMM based Inventory Model
    - Operation DMM is dealt with allocated quantity of planning DMM
    - Cost composition: setup cost, production cost, order and transportation cost, inventory cost
  - Calculation of unit cost for strategic and planning DMM



Structure of manufacturer in operational DMM

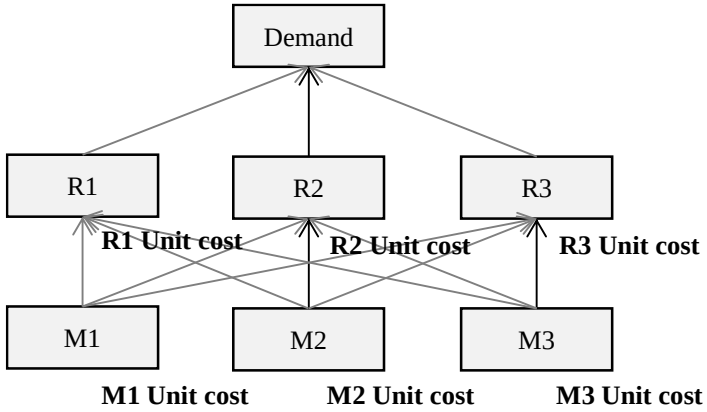


Structure of retailer in operational DMM

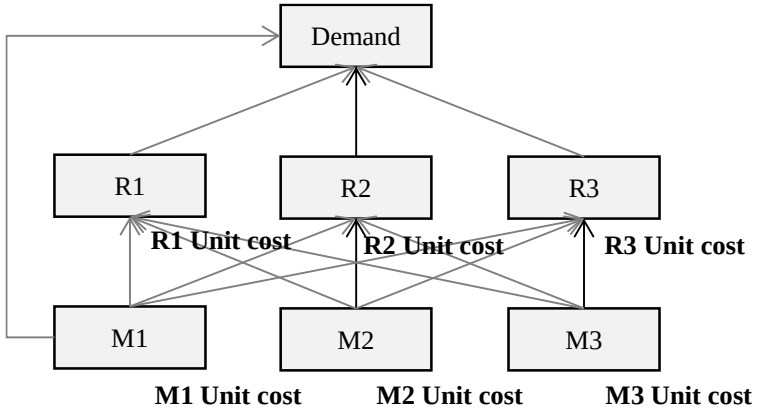
Operational DMM

- The basic form of operational DMM
  - *Manufacturer: part inventory phase*
    - Cost of part inventory phase = order and transportation cost + inventory cost
    - **Optimal order batch size** is derived from cost of part inventory phase
  - *Manufacturer: processing phase*
    - Cost of processing phase = setup cost + processing cost + WIP inventory cost
  - *Manufacturer: finished product inventory phase*
    - Finished product inventory cost
    - **Optimal production batch size** is derived from costs of processing and finished product inventory cost
  - *Retailer: retailer inventory phase*
    - Cost of retailer inventory phase = order and transportation cost + inventory cost
    - **Optimal order batch size** is derived from cost of retailer inventory phase
- Assumption
  - Transportation and inventory capacity is unconstrained

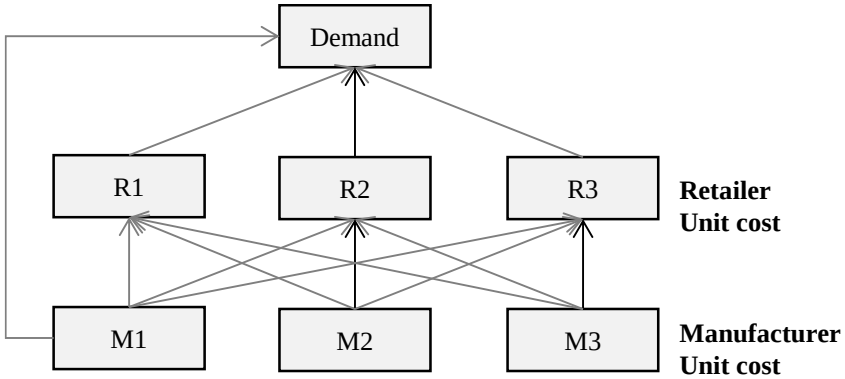
Operational DMM



Single Channel



Multichannel



Omnichannel

- Notations
  - Index

Z	Index of channel, $Z = S, M \ or \ O$ single channel S, multichannel M, or omnichannel O.
r, m, d	Index of retailer r ($r = 1, 2, 3, \dots, I$), manufacturer m ($m = 1, 2, 3, \dots, J$), and demand d ($d = 1, 2, 3, \dots, D$).

  - Variables

PTC_m^Z	Total cost of part inventory phase for manufacturer
STC_m^Z	Total cost of processing of standard product for manufacturer
CTC_m^Z	Total cost of processing of customized product for manufacturer
SFC_m^Z	Inventory cost of finished standard product for manufacturer
CFC_m^Z	Inventory cost of finished customized product for manufacturer
$PU_m^{S \ or \ M}$	Unit part cost for manufacturer on single or multi- channel
PU^O	Unit part cost on omnichannel
$SU_m^{S \ or \ M}$, $CU_m^{S \ or \ M}$	Unit production cost of standard and customized product for manufacturer on single or multi- channel
SU^O, CU^O	Unit production cost of standard and customized product on omnichannel
$SFU_m^{S \ or \ M}$, $CFU_m^{S \ or \ M}$	Unit inventory cost of standard and customized product for manufacturer on single or multi- channel
SFU^O, CFU^O	Unit inventory cost of standard and customized product on omnichannel
PB_m^Z	Ordering batch size of part for manufacturer on single, multi- and omni- channel
SB_m^Z, CB_m^Z	Production batch size of standard and customized product for manufacturer on single, multi- and omni- channel
RTC_r^Z	Total operation cost of retailer on single, multi- and omni- channel
RBC_{mr}^Z	Ordering batch size cost from manufacturer to retailer on single, multi- and omni channel
SCR_{mr}^Z	Ordering and transportation cost from manufacturer to retailer on single, multi- and omni channel
HR_{mr}^Z	Holding cost from manufacturer to retailer on single, multi- and omni channel
$SSCR_{mr}^Z$, $CSCR_{mr}^Z$	Ordering and transportation cost of standard and customized product from manufacturer to retailer on single, multi- and omni channel
SHR_{mr}^Z, CHR_{mr}^Z	Holding cost of standard and customized product from manufacturer to retailer on single, multi- and omni channel
RB_{mr}^Z	Ordering batch size from manufacturer to retailer on single, multi- and omni channel

- Operational Model for Omnichannel
  - Manufacturer

Manufacturer's part inventory phase

<Total cost of part inventory phase>

$$PTC_m^O = \left[\left(\sum_{rd} \frac{SQ_{mr}^O + SQ_{md}^O + CQ_{mr}^O + CQ_{md}^O}{PB_m^O}\right)(po_m + pt_m) + ph_m \frac{PB_m^O}{2}\right] X_m^O \qquad \forall m$$

<Optimal order batch size of part>

$$PB_m^{O*} = \sqrt{\frac{2(po_m + pt_m)\left(\sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O + CQ_{mr}^O + CQ_{md}^O\right)\right)}{ph_m}} \qquad \forall m$$

<Unit cost of part>

$$PU^O = \frac{\sum_m PTC_m^O}{\sum_{mrd}\left(SQ_{mr}^O + SQ_{md}^O + CQ_{mr}^O + CQ_{md}^O\right)}$$

Manufacturer's processing phase

<Total cost of processing of standard product>

$$STC_m^O = \left[\left(\frac{\sum_{rd}\binom{SQ_{mr}^O}{+SQ_{md}^O}}{SB_m^O}\right) ssc_m + spc_m \sum_{rd}\binom{SQ_{mr}^O}{+SQ_{md}^O} + shw_m \sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O\right)\right] X_m^O \qquad \forall m$$

$$spc_m \sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O\right) = spc_m SB_m^O \frac{\sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O\right)}{SB_m^O} \qquad \forall m$$

$$shw_m \sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O\right) = shw_m SB_m^O \frac{\sum_{rd}\left(SQ_{mr}^O + SQ_{md}^O\right)}{SB_m^O} \qquad \forall m$$

<Total cost of processing of customized product>

$$CTC_m^O = \left[\left(\frac{\sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}{CB_m^O}\right) csc_m + cpc_m \sum_{rd}(CQ_{mr}^O + CQ_{md}^O) + chw_m \sum_{rd}(CQ_{mr}^O + CQ_{md}^O)\right] X_m^O \quad \forall m$$

$$cpc_m \sum_{rd}(CQ_{mr}^O + CQ_{md}^O) = cpc_m CB_m^O \frac{\sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}{CB_m^O},\ chw_m \sum_{rd}(CQ_{mr}^O + CQ_{md}^O) = chw_m CB_m^O \frac{\sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}{CB_m^O} \quad \forall m$$

<Operational unit cost of production for each product>

$$SU^O = \frac{\sum_m STC_m^O}{\sum_{rd}(SQ_{mr}^O + SQ_{md}^O)},\ CU^O = \frac{\sum_m CTC_m^O}{\sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}$$

Manufacturer's finished product inventory phase

<Inventory cost of finished standard product>

$$SFC_m^O = shf_m \left(\frac{SB_m^O}{2}\right) X_m^O,\ CFC_m^O = chf_m \left(\frac{CB_m^O}{2}\right) X_m^O \quad \forall m$$

<Optimal production batch size of standard product>

$$SB_m^{O*} = \sqrt{\frac{2ssc_m \sum_{rd}(SQ_{mr}^O + SQ_{md}^O)}{shf_m}},\ CB_m^{O*} = \sqrt{\frac{2csc_m \sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}{chf_m}} \quad \forall m$$

<Unit cost of finished product inventory for each product>

$$SFU^O = \frac{\sum_m SFC_m^O}{\sum_{rd}(SQ_{mr}^O + SQ_{md}^O)},\ CFU^O = \frac{\sum_m CFC_m^O}{\sum_{rd}(CQ_{mr}^O + CQ_{md}^O)}$$

- Operational unit cost of manufacturer for each product

$$MSC^O = PU^O + SU^O + SFU^O$$

$$MCC^O = PU^O + CU^O + CFU^O$$

– Retailer

<Operational cost for each retailer>

$$RTC_r^O = \sum_m RBC_{mr}^O \qquad \forall r$$

$$RBC_{mr}^O = SCR_{mr}^O + HR_{mr}^O \qquad \forall m, r$$

<Order and transportation cost>

$$SCR_{mr}^O = SSCR_{mr}^O + CSCR_{mr}^O \;,\; SSCR_{mr}^O = \frac{SQ_{mr}^O}{RB_{mr}^O}\left(roc_{mr} + rtc_{mr}\right) \;,\; CSCR_{mr}^O = \frac{CQ_{mr}^O}{RB_{mr}^O}\left(roc_{mr} + rtc_{mr}\right) \qquad \forall m, r$$

<Inventory holding cost>

$$HR_{mr}^O = SHR_{mr}^O + CHR_{mr}^O \;,\; SHR_{mr}^O = rsh_r \left(\frac{SQ_{mr}^O}{SQ_{mr}^O + CQ_{mr}^O}\right)\frac{RB_{mr}^O}{2} \;,\; CHR_{mr}^O = rch_r \left(\frac{CQ_{mr}^O}{SQ_{mr}^O + CQ_{mr}^O}\right)\frac{RB_{mr}^O}{2} \qquad \forall m, r$$

<Order batch size cost for each transportation>

$$RBC_{mr}^O = \left(\frac{SQ_{mr}^O + CQ_{mr}^O}{RB_{mr}^O}\right)\left(roc_{mr} + rtc_{mr}\right) + \frac{RB_{mr}^O}{2}\left(\frac{rsh_r\, SQ_{mr}^O + rch_r\, CQ_{mr}^O}{SQ_{mr}^O + CQ_{mr}^O}\right) + \frac{RB_{mr}^O}{2}\left(\frac{rsh_r\, SQ_{mr}^O + rch_r\, CQ_{mr}^O}{SQ_{mr}^O + CQ_{mr}^O}\right) \qquad \forall m, r$$

<Optimal order batch size>

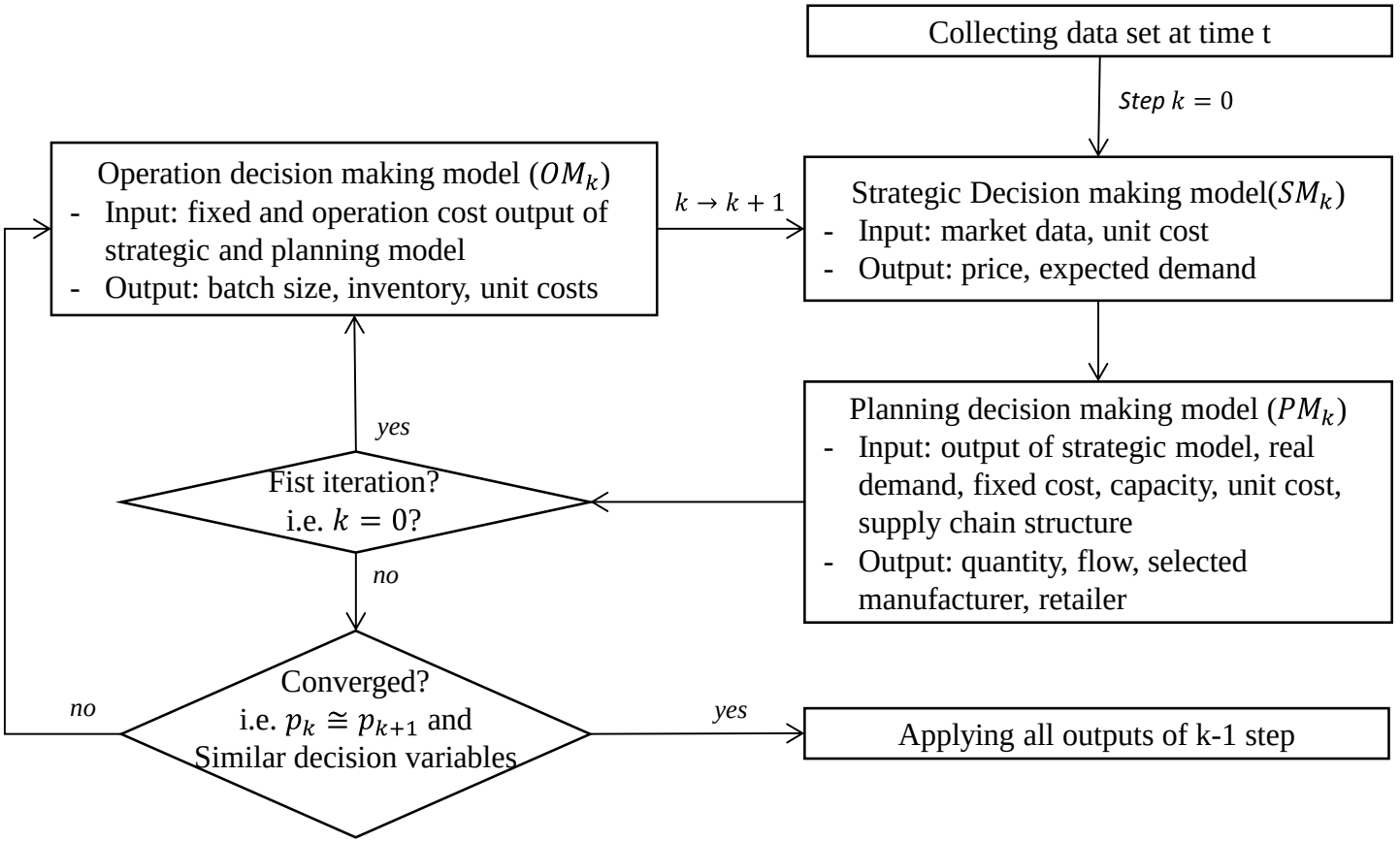
$$RB_{mr}^O = \left(SQ_{mr}^O + CQ_{mr}^O\right)\sqrt{\frac{2\left(\left(roc_{mr} + rtc_{mr}\right)\right)}{rsh_r\, SQ_{mr}^O + rch_r\, CQ_{mr}^O}} \qquad \forall m, r$$

<Operational unit cost of each retailer for each product>

$$RSC^O = \frac{\sum_{mr}\left(SSCR_{mr}^O + SHR_{mr}^O\right)}{\sum_{mr} SQ_{mr}^O} \;,\; RCC^O = \frac{\sum_{mr}\left(CSCR_{mr}^O + CHR_{mr}^O\right)}{\sum_{mr} SQ_{mr}^O} \qquad \forall r$$

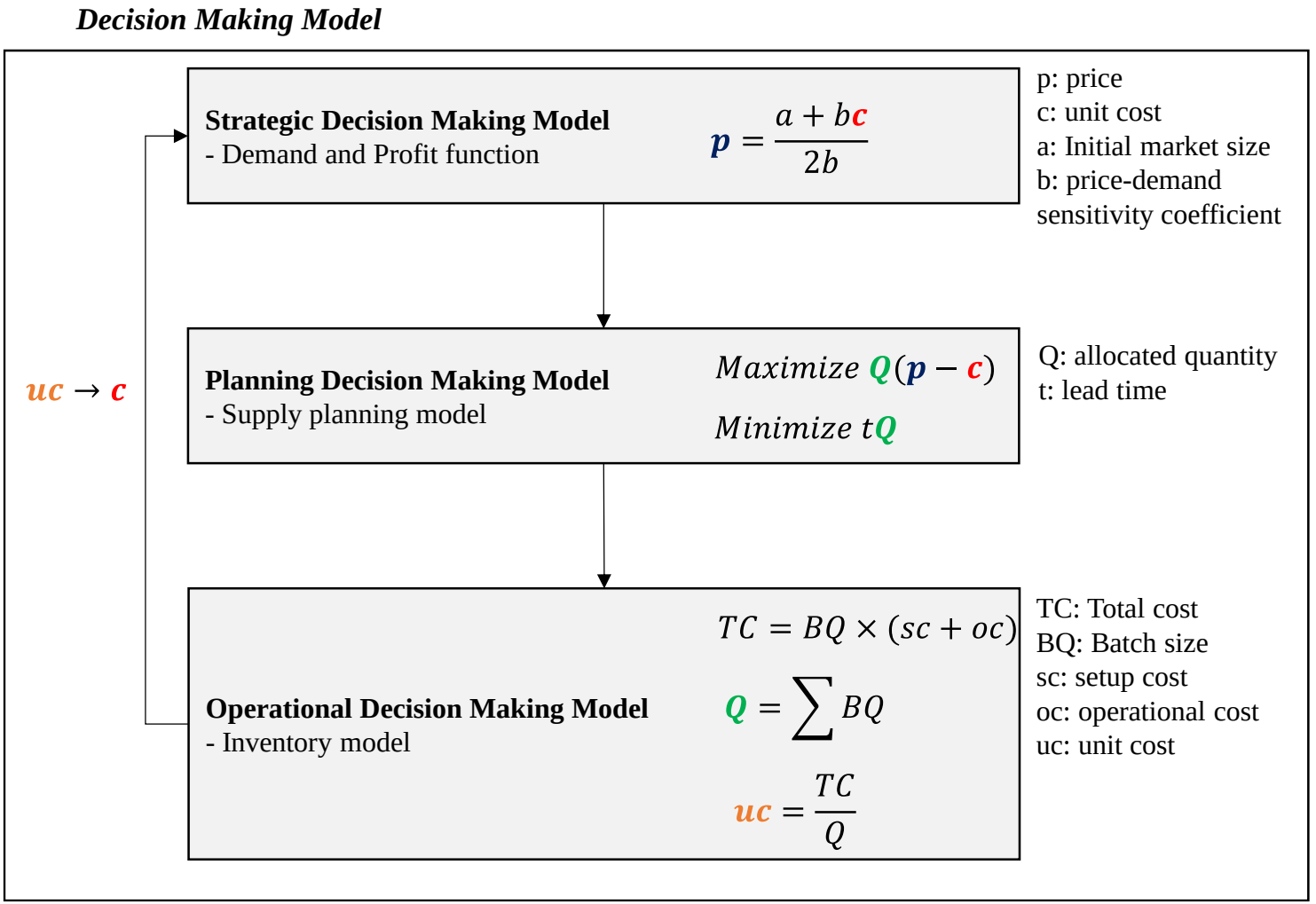
Integrated DMM

- Solution Algorithm



Solution procedure for integrated decision making model

Integrated DMM



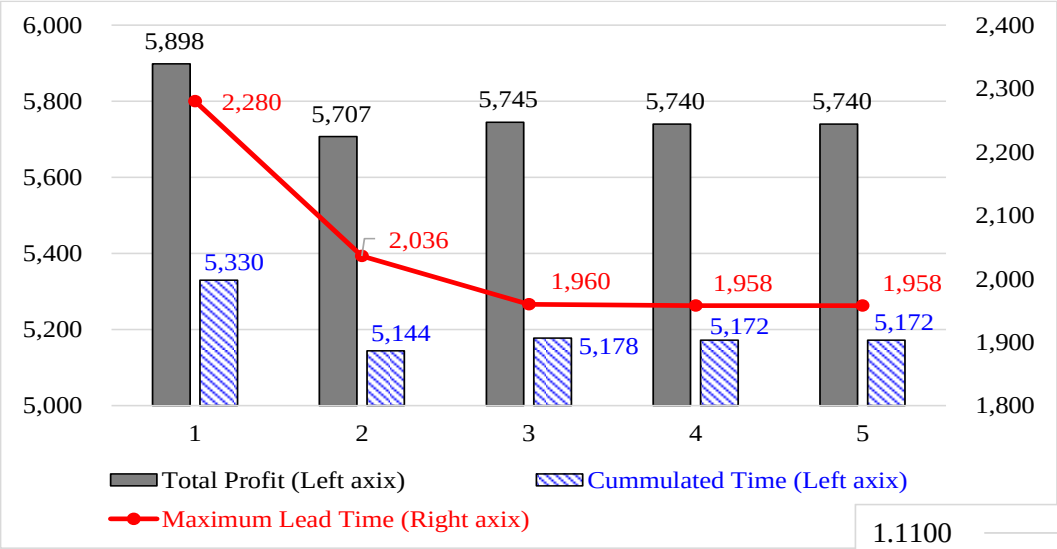
Concept of relation among DMMs

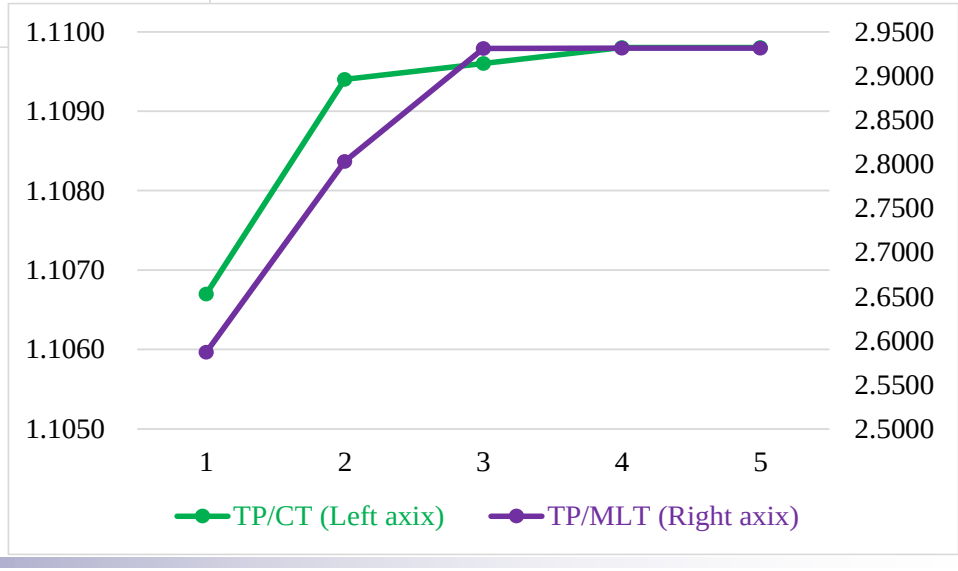
Experimental Analysis

Design and Performance measures

- Experimental Design
  - Numerical experiment
  - Case analysis
    - Multichannel(top-down) vs. multichannel(end-to-end) vs. omnichannel(end-to-end)
    - The changes of weights of the objective (maximizing total profit and minimizing lead time)
  - Performance measures
    - Total Profit (TP): supply chain profit
    - Cumulated Time (CT): total required time
    - TP per CT : measuring increment profit
    - Maximum Lead Time (MLT): The highest lead time on time horizon
    - TP per MLT: Profit velocity per one cycle lead time as planning horizon

- Performance measures for each iteration

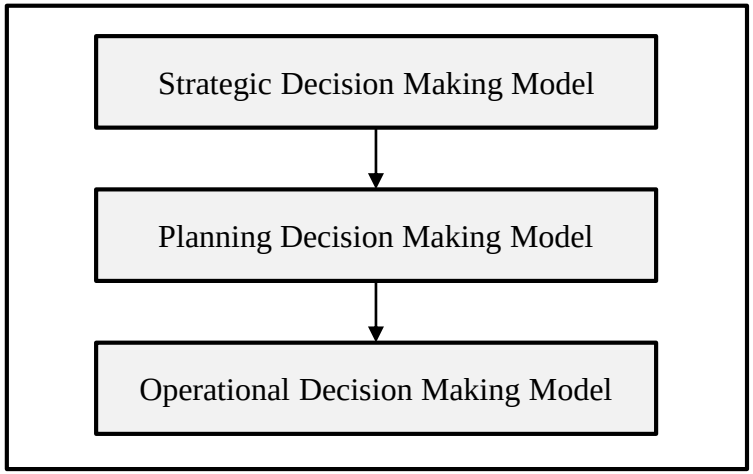




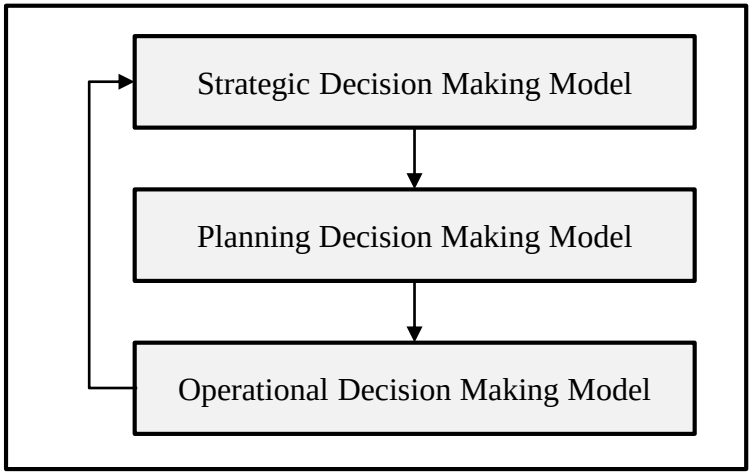
Experimental Analysis

- Comparison between SSC and CSC
  - Multichannel(top-down) vs. multichannel(end-to-end) vs. omnichannel(end-to-end)

Decision Making Model – Top down approach

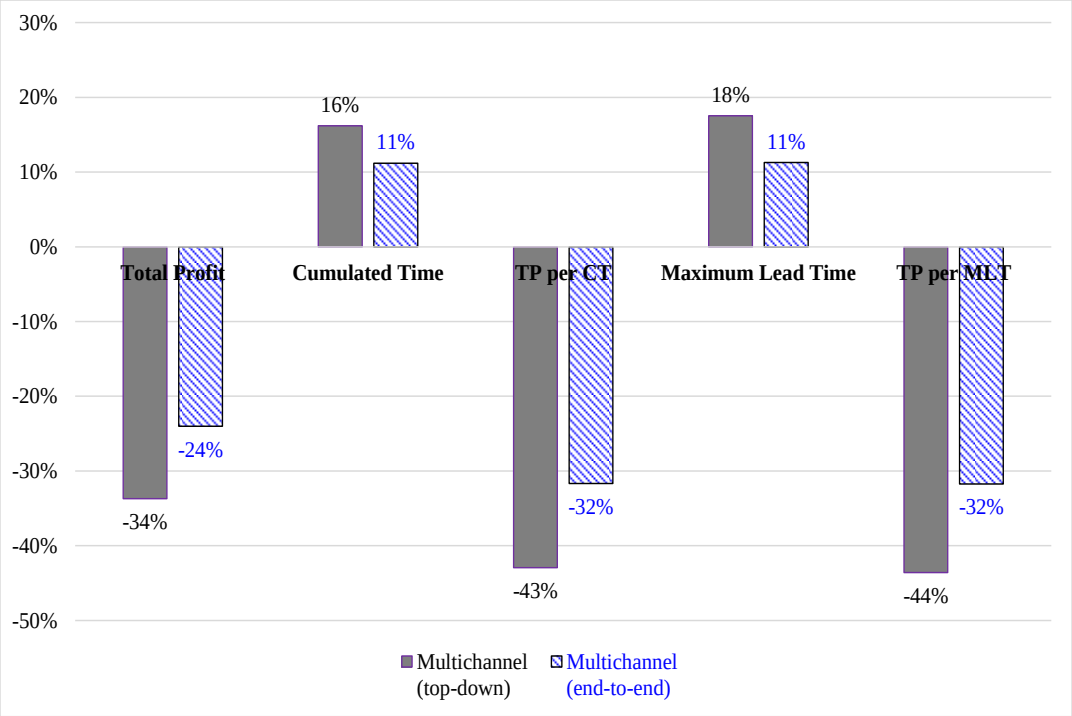


Decision Making Model – End-to-end approach



Experimental Analysis

- Comparison between SSC and CSC



– This case analysis shows that

  - Smart supply chain (omnichannel) is more effective, response, and agile.
  - End-to-end approach is more effective than top-down approach. So the integrity is the significant properties.

- Changing weights of profit and lead time

  – First objective function

$$Max\ {}^{w_P TP^O}\Big/_{w_L H^O}$$

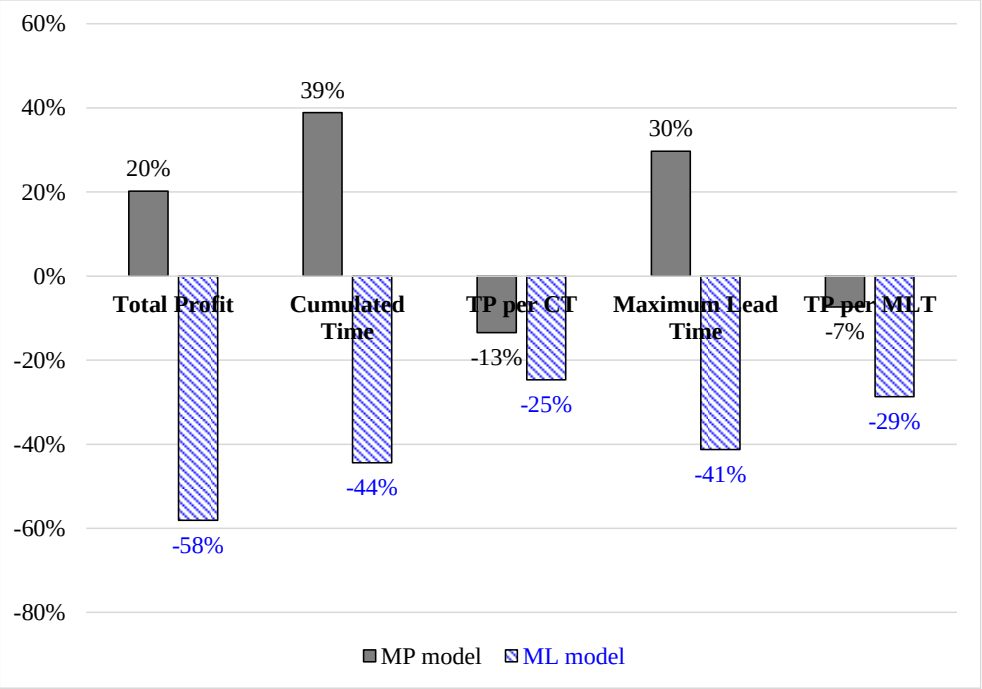
  – Second objective functions

$$Max\ TP^O$$

$$Min\ H^O$$

Experimental Analysis

Case analysis 2



– This case analysis shows that

- Identical weights of profit maximization and lead time minimization is the balance supply chain in terms of profit and lead time.
- At the same lead time, considering two weights case is profitable more than others.
- To accomplish goal of supply chain, supply chain manager can control the weights according to their direction to pursue.

Conclusion

- Research Highlights
  - We define the smart supply chain, and identify its basis attributes and functional, structural characteristics.
  - We describe decision making models – strategic, planning, and operational - of smart supply chain with convergence of ICPT (Information, Communication, and Production Technologies).
  - We attempt to found the method of the market segmentation for product and channels, semi-real time reflected real world, and mathematical decision making models for integration.
  - We make decision making models as profit analysis using demand function, supply planning model using multi-objective mixed integer linear programming, and inventory model for each channel.
  - We represent the excellence of decision making model of smart supply chain through numerical experiment.

Future Research

- Directions of improvement for this research
  - One decision making model for strategic, planning, and operational model
  - Adding various route decision variables
  - Adjustment of the scale of currency unit and time unit
  - Constrained transportation and inventory capacity

- New subject based on this research
  - Development of real time decision making
    - This research considered discrete demand, but it is need to change to continuous demand. Using continuous demand, we can develop the same way of this research for real-time.
  - Using Little's law, the change of capacity is represented by decision variables as cycle time and throughput
  - Development of Customization degree

End

- Jisoo Oh’s email: silverion2@hanmail.net
- Bongju Jeong’s email: bongju@yonsei.ac.kr

- Reference: Integrated Strategic and Production Planning Model for Smart Supply Chain, Ph D. Thesis, Yonsei University, the Republic of Korea, 2017.