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조동원, 이영해
한양대학교, 산업공학과

목차

- 서론
  - 연구배경 및 목적
  - 기존연구
- 본론
  - Two phase method
  - 수치예제
- 결론

연구배경

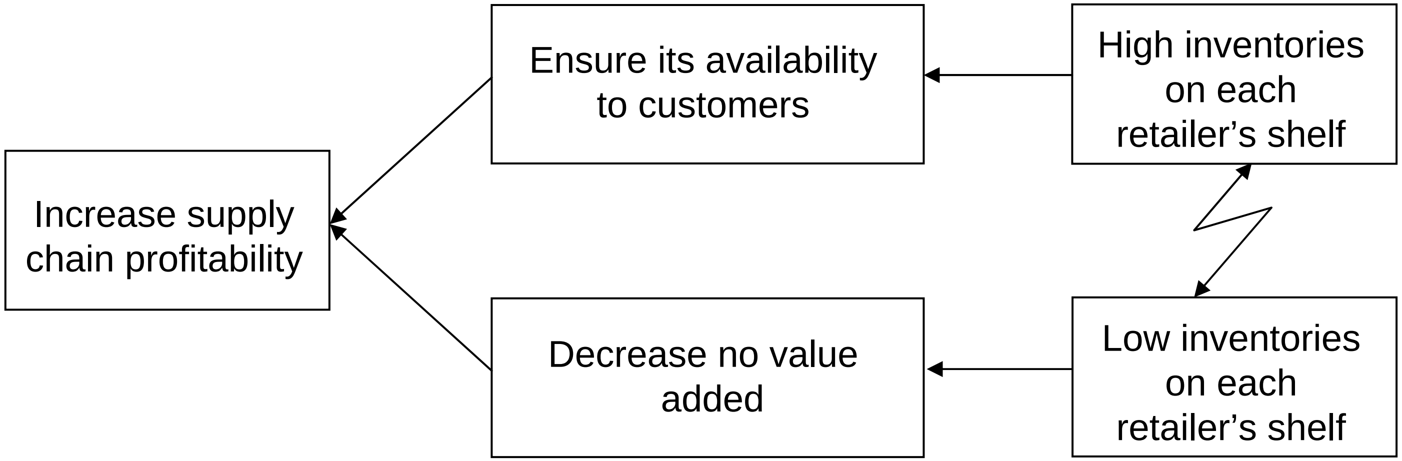
✪ Integrated inventory and distribution model (IIDM)

⇨ It is concerned with the situations in which inventory control and routing decisions have to be made simultaneously.

- Importance of IIDM in supply chain
  - IIDM is one of the core problems that have to be solved when implementing the emerging business practice called VMI.
  - In VMI environments, a supplier monitors the inventory levels at its retailers and decides when, how much inventory and which of route to replenish at each retailer.
  - This has given rise to the special interest of studying IIDM.
  - Inventory control and routing decisions have conventionally been treated separately, but their integration can provide an extremely important source for maximizing supply chain profitability.

연구배경

- Dilemma of a supply chain concerned with inventory
  - Hold high levels of inventory in order to meet a very highly service level for customer request.
  - Hold low levels of inventory in order to decrease no value added.



  - We settle these conflicts through buffer management procedure.

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연구목적

- Suggestion of a new method for solving IIDM – Two phase method
  - The first phase
    - Buffer management procedure of theory of constraints (TOC), which is applied to inventory control, determines when and how much to replenish at each retailer per period.
    - The objective of buffer management procedure settles dilemma on inventory control at each retailer and improves supply chain revenue.
  - The second phase
    - Tabu search (TS) algorithm, which can find routes with the limited number of capacitated vehicles, is applied to the set of retailers to be replenished per period.
    - The objective of TS algorithm minimizes the total cost across the supply chain by using economy of scale for delivery from supplier to each retailer.
- Enhancement of supply chain profitability
  - After all, two phase method can improve supply chain profitability in VMI environment.

기존연구

- Baita et al.(1998) has divided IIDM into two approaches.
  - Frequency domain approaches determine the replenishment frequencies from supplier to each retailer (Zhao et al., 2007; Daganzo, 1999).
  - Time-domain approaches make a decisions on how much inventory and which of route to replenish each retailer at fixed time intervals using discrete time models (Abdelmaguid an d Dessouky, 2006; Bertazzi et al., 2002; Campbell and Savelsbergh, 2004).
  - The methodology of solving two approaches is applied to heuristic algorithm because the complexity of most IIDM is NP-hard.

- Drawbacks of early studies
  - Few studies existed considering customer service level under stochastic demand.
  - Revenue generated from the customer is ignored with focusing most studies on saving overall cost of supply chain (Abdelmaguid and Dessouky, 2006; Bertazzi et al., 2002; Campbell and Savelsbergh, 2004; Daganzo, 1999).
  - The method for settling dilemma on inventory control at each retailer was not proposed.

Proposed IIDM

- Problem description
  - Supply chain is made up of single supplier and multi-retailer under VMI environments.
  - The problem has the following characteristics:
    - A discrete time period is used;
    - One product is distributed;
    - Demand per period at each retailer is independently and normally distributed;
    - Demand between each retailer is independent;
    - The limited number of capacitated vehicle is based at the supplier's warehouse;
    - Customer service level at each retailer is determined by buffer management procedure based on service level in remaining period (SLRP) which means the probability that stock-out will not occur for retailer from an arbitrary period within present reorder cycle to the beginning of new reorder cycle;
    - All costs occurring to the supplier's warehouse are not considered.

Proposed IIDM (Cont'd)

- **Notation**

$i,\ j,\ k =$ index of retailer, $i,j,k \in \{1,\ldots,n\}$

$n\ =$ number of retailers

$m =$ number of maximum available vehicle

$l\ =$ number of maximum vehicle allowed to be used

$t\ =$ number of time periods

$v\ =$ index of vehicles, $v = 1,\ldots,l$

$D_i =$ demand at retailer i per period

$\mu_i =$ expected demand at retailer i per period

$\sigma_t\ =$ standard deviation of demand at retailer i per period

$I_{it}\ =$ inventory at retailer i in period t

$SLRP_{iRP(t)}\ =$ probability that stock - out does not occur for retailer i in $RP(t)$

$EC\ =$ emergency replenishment cost per unit at retailer

$S_{it}\ =$ replenishment quantity at retailer i in period t

$$e_{ij\,vt} = \begin{cases} \text{1: if vehicle } v \text{ moves between retailer } i \text{ and retailer } j \text{ in period } t\left(i \neq j\right) \\ \text{0: otherwise} \end{cases}$$

Proposed IIDM (Cont'd)

- **Notation**

R_i = replenishment cycle of retailer i

$D_{iRP(t)}$ = demand at retailer i during $RP(t)$

$\mu_{iRP(t)}$ = expected demand at retailer i during $RP(t)$

$\sigma_{iRP(t)}$ = standard deviation of demand at retailer i during $RP(t)$

OH_{it} = holding inventory at retailer i in period t

$SO_{iRP(t)}$ = stockout at retailer i during $RP(t)$

$RP(t)$ = remaining period until reorder point after the period t

c_{ij} = transportation cost per distance between retailer i and retailer j $(i \neq j)$

IC = total inventory cost

Z_α = $z-$value with proportion α of the area under the normal curve

Z_β = $z-$value with proportion β of the area under the normal curve

Z_γ = $z-$value with proportion γ of the area under the normal curve

N_t = set of retailers to replenish in t period

x_{ijvt} = transportation quantity by vehicle v between retailer i and retailer j in t period $(i \neq j)$

The First Phase - Buffer Management Procedure

✪ Definition of buffer

- ⇨ Called stock buffer, available inventory which can instantaneously meet uncertain customer request. Buffer level is the same as inventory level.

- Literature review related with buffer management
  - Buffer management can be used in an situation where the durm-buffer-rope(DBR) method has been executed (Goldratt, 1986; Schragenheim and Ronen, 1991).
  - The buffer is generally divided into three controlled zones: green (safety), yellow (tracking) and red (expedite) (Srikanth and Umble, 1997; Yuan et al. 2003).
  - Yuan et al. (2003) apply buffer management to inventory replenishment. But they only studied the application of buffer management to inventory control of supplier.
  - Umble and Umble (2006) used buffer management to improve performance in health care systems.

- Drawbacks of early studies
  - Few studies are not applied to inventory control at each retailer under VMI environments.

The First Phase - Buffer Management Procedure (Cont'd)

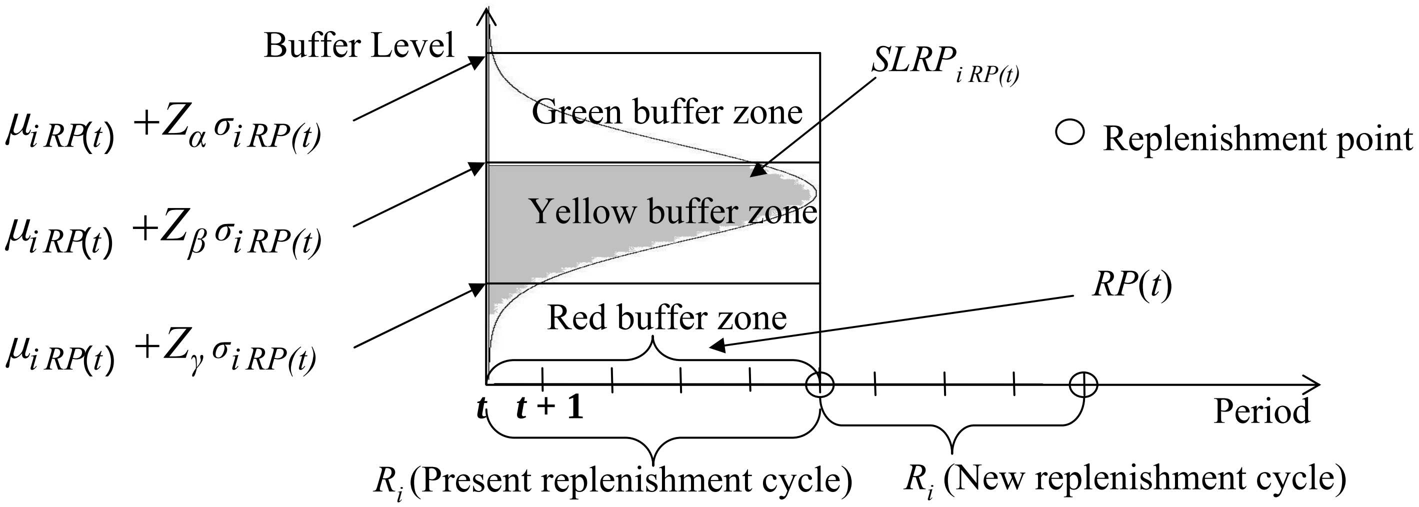
✪ Definition of SLRP

⇨ The probability that stock-out will not occur for retailer from an arbitrary period within present replenishment cycle to the beginning of new replenishment cycle.

$$RP(t) = R_i - t$$

$$SLRP_{i\,RP(t)} = P(D_{iRP(t)} < I_{i\,t}) = \Phi\left(\frac{I_{i\,t} - \mu_{i\,RP(t)}}{\sigma_{i\,RP(t)}}\right)$$

where $D_{i\,RP(t)} \sim N\left(\mu_{i\,RP(t)}, \sigma_{i\,RP(t)}\right)$, for $\mu_{i\,RP(t)} = \mu_i \times RP(t)$, $\sigma_{i\,RP(t)} = \sqrt{\sigma_i^2} \times RP(t)$



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The First Phase - Buffer Management Procedure (Cont'd)

- The steps of buffer management

Step 1. Increase one unit period and go to step 2.

Step 2. After calculating inventory quantity and SLRP at each retailer, check which zone the buffer level belongs by using SLRP. If that drops into green buffer zone, go to step 3. If that penetrates yellow buffer zone, go to step 4. If that penetrates red buffer zone, go to step 5. Otherwise, go to step 6.

$$I_{it} = \begin{cases} OH_{it} - D_{iRP(t)}, & OH_{it} \geq D_{iRP(t)} \\ 0, & OH_{it} < D_{iRP(t)} \end{cases}$$

Step 3. Check the number of continuously visiting the buffer level to green buffer zone. If this is the second visiting, decrease green buffer zone considering SLRP. Since SLRP decreases more than before, delay existing replenishment point to one unit period. If this is the first visiting, no action is taken. Go to step 1.

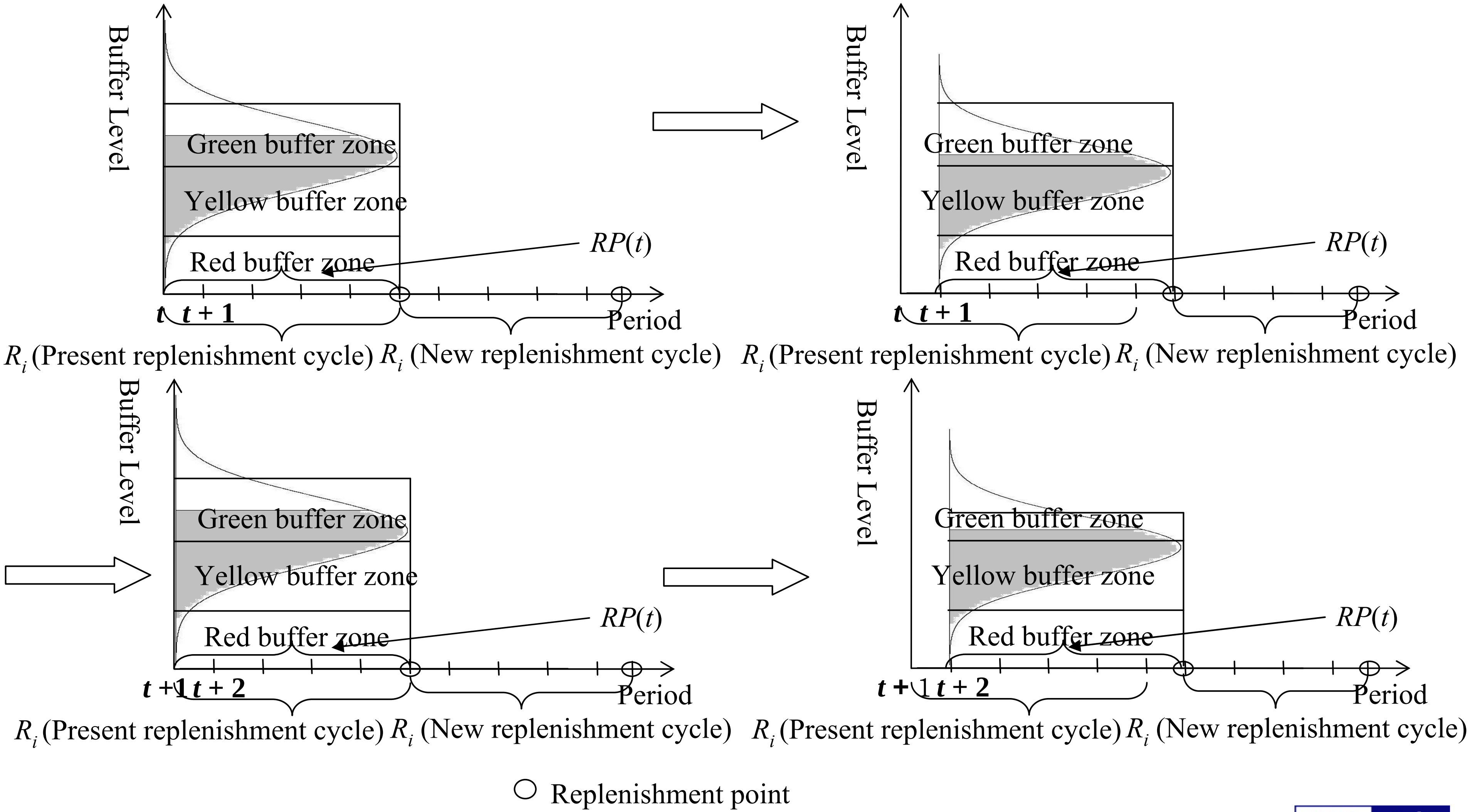
Step 4. As the buffer level drops into yellow buffer zone, tracking is requested. This means that the buffer level is needed to be tracked in the future. Maintain existing replenishment point and go to step 1.

Step 5. As the buffer level drops into red buffer zone, expedite action must be taken. Replenish emergency inventory quantity using SLRP in order to receive after one unit period and go to step 1.

Step 6. if stock-out occurs, increase the buffer level of red buffer zone. Replenish emergency inventory quantity using SLRP in order to receive after one unit period and go to step 1.

The First Phase - Buffer Management Procedure (Cont'd)

- From step 2 to step 3



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The Second Phase – VRP

- Objective function includes transportation costs.

  Minimize $\sum_t \sum_v \sum_i \sum_j c_{ij} x_{ijvt}$

- Constraints is as follows:

  - Balance equations for the number of inbound and outbound vehicle at retailer *j*

    $$\sum_{i \in N_t} e_{ijvt} - \sum_k e_{jkvt} = 0 \qquad \text{for } t \in T,\ v \in V,\ j,k \in N_t$$

  - The equations which establish vehicle routing by one vehicle

    $$\sum_j \sum_v e_{ijvt} = 1 \qquad \text{for } i \in N_t,\ t \in T$$

    $$\sum_i \sum_v e_{ijvt} = 1 \qquad \text{for } j \in N_t,\ t \in T$$

  - Constraint concerned with the limiting number of vehicle at supplier's site

    $$\sum_i \sum_v e_{0ivt} \le vm \qquad \text{for } t \in T$$

The Second Phase – VRP (Cont'd)

- Constraints is as follows:
  - Constraint concerned with the total amount delivered in a given period to the available capactitated vehicle

    $$x_{jkt} \le \sum_{v} vc \cdot e_{jkvt} \qquad \text{for } j,k \in N_t,\ t \in T,\ v \in V$$

  - The amount delivered in a given period for retailer *j*

    $$\sum_{i} x_{ijt} - \sum_{k} x_{jkt} = S_{jt} \qquad \text{for } t \in T,\ j \in N_t$$

  - The equations for forming one direction routing

    $$\sum_{v} (e_{ijvt} + e_{jivt}) \le 1 \qquad \text{for } i,j \in N_t, t \in T$$

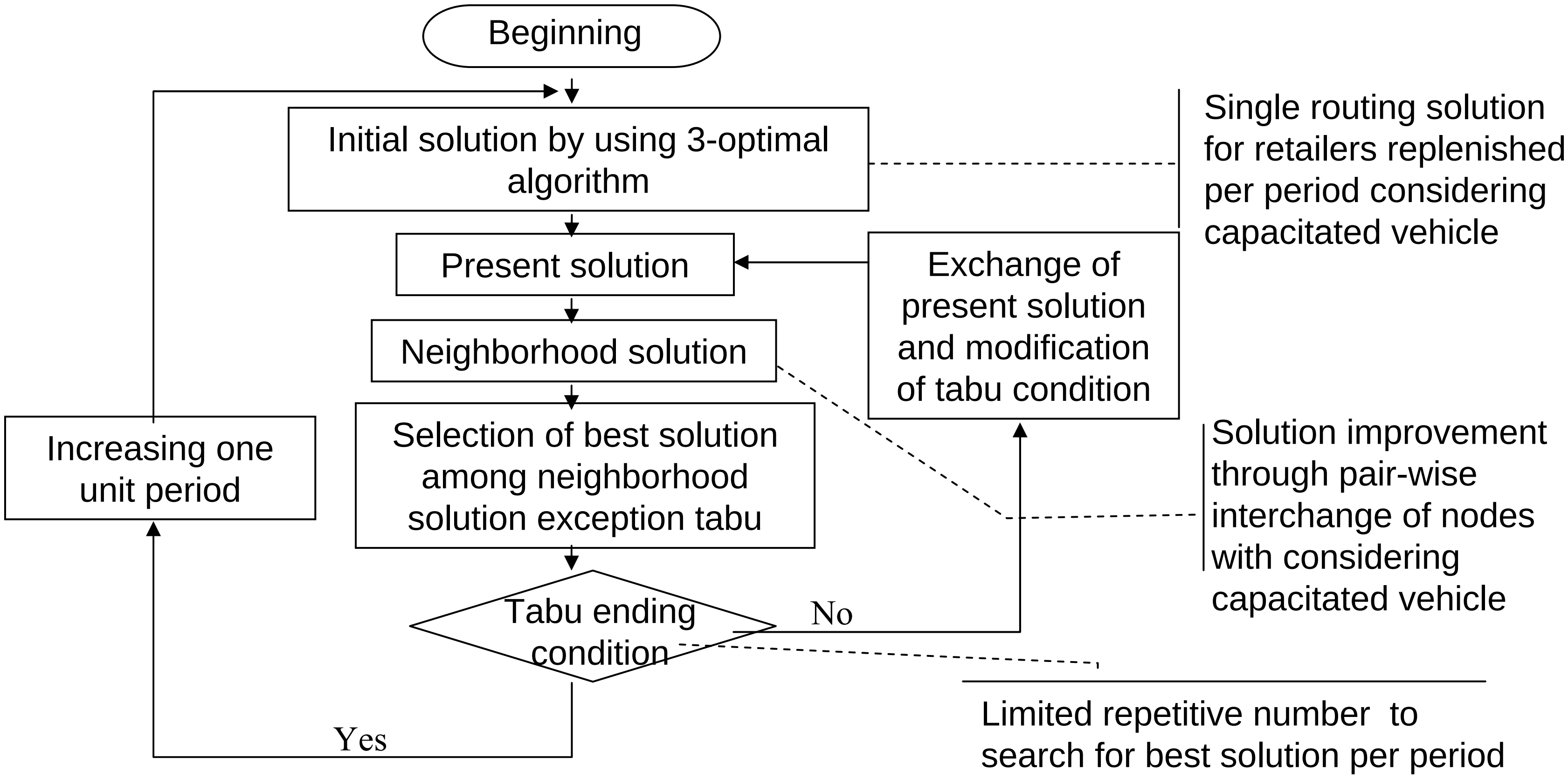
  - The domain constraints.

    $$x_{ijt} \ge 0,\ e_{jkt} \in \{0,1\}$$

- Research question
  - Since the problem is NP-hard, it is reasonable that heuristic algorithm should be developed (Salhi and Rand, 1993).

The Second Phase – TS Algorithm

- Salhi and Rand's algorithm modification (Salhi and Rand, 1993)



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The Second Phase – TS Algorithm (Cont'd)

- Comparison of the TS algorithm
  - Parameters of problems in order to compare the proposed TS algorithm with CPLEX and Saving method (Barlow, 2003)

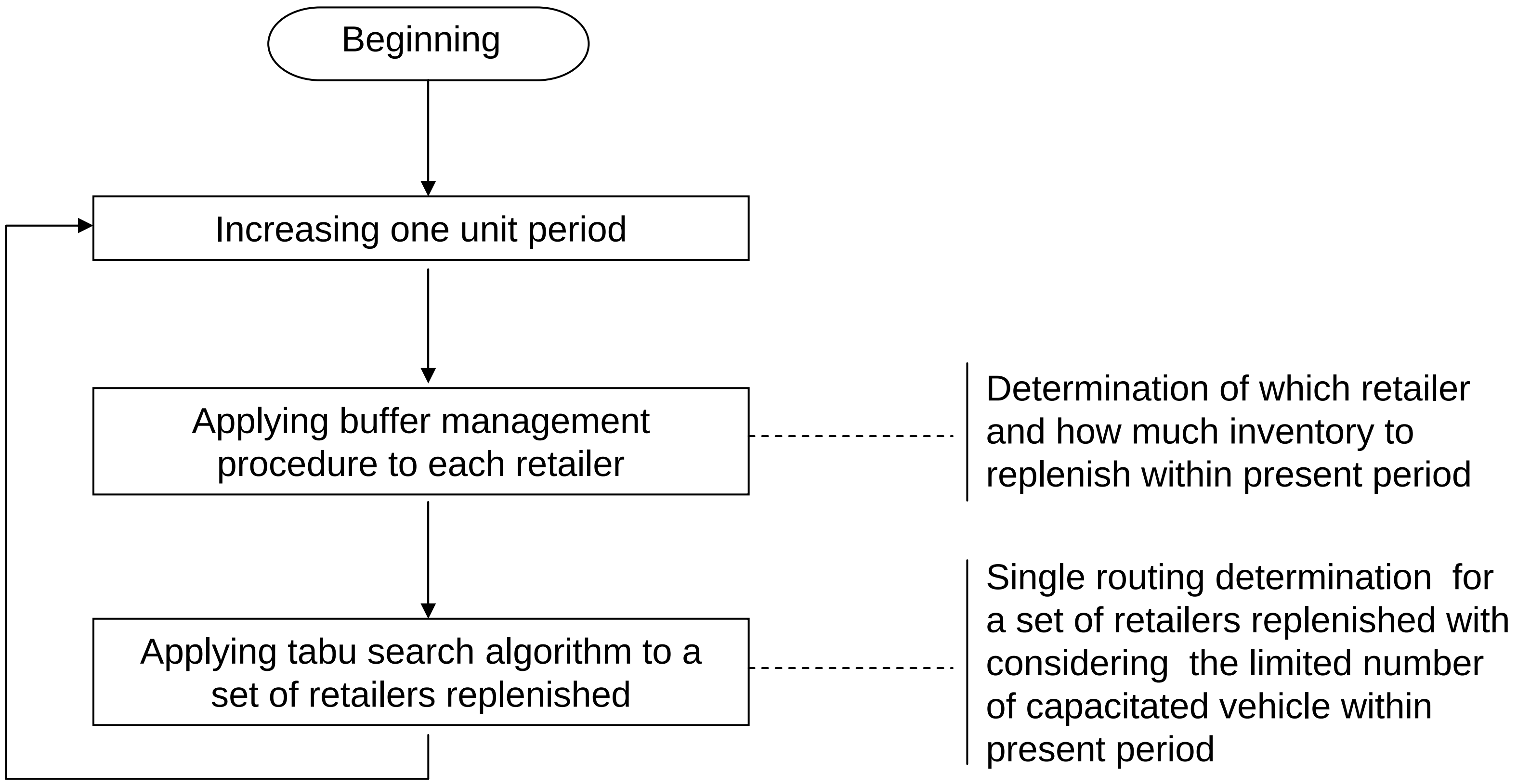
Problem No.	No. 1	No. 2	No. 3
Number of retailer	10	25	50
No. of vehicle	4	6	10
Vehicle Capacity	100	200	200
No. of repetitive experiment	1000	10000	15000
Tabu tenure	100	200	300
Demand	Unif(10, 60)	Unif(10, 60)	Unif(10, 60)

  - Comparison

Problem No.	Saving Method[a]		TS[b]		CPLEX		|b-a| /b*100
	Value	Time(sec)	Value	Time	Value	Time	
No. 1	1350	5	1285	26.84	1285	70264.9	5%
No. 2	7630	15	6650	100.23	No available	-	14.7%
No. 3	16240	30	10700	137.52	No available	-	51.7%

Two Phase Method

- Integration of the first and second phase



Numerical example

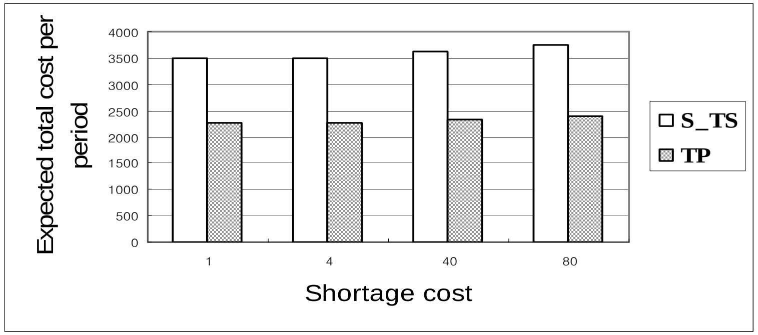
- Parameters for problems for applying two phase method to IIDM

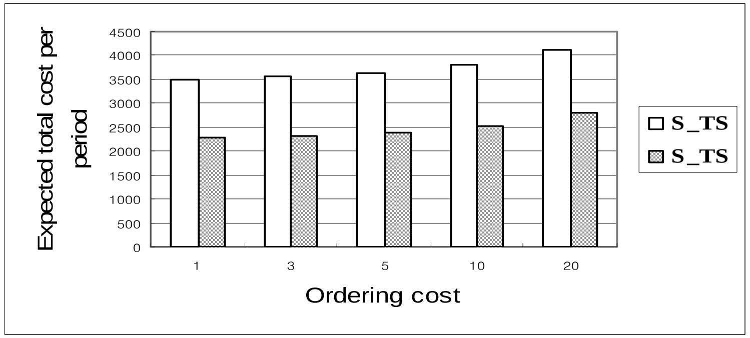
No. of retailer	25
Total period	500
Demand	N(10~50, 0~10)
Unit holding cost	1,5, 10, 20, 30
Unit shortage cost	1, 10, 20, 30, 40
Unit ordering cost	1,3, 5, 10, 20
Unit transportation cost	10,20,30

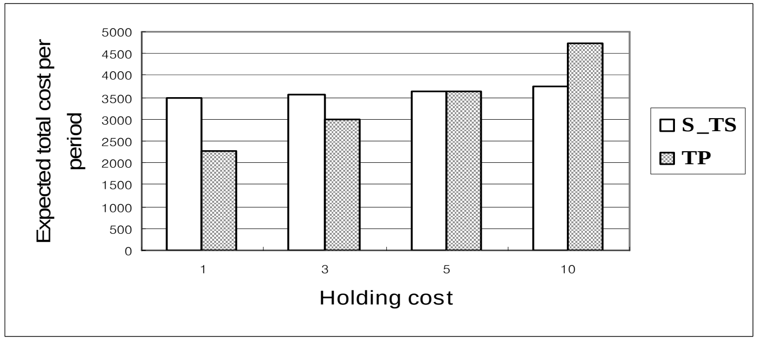
- In order to evaluate and compare the performance of two phase (TP) method, alternative solving approach, which combine (*s*, *S*) inventory policy and the proposed TS algorithm (S_TS), is developed.
- Simulation is used for generating stochastic demand.

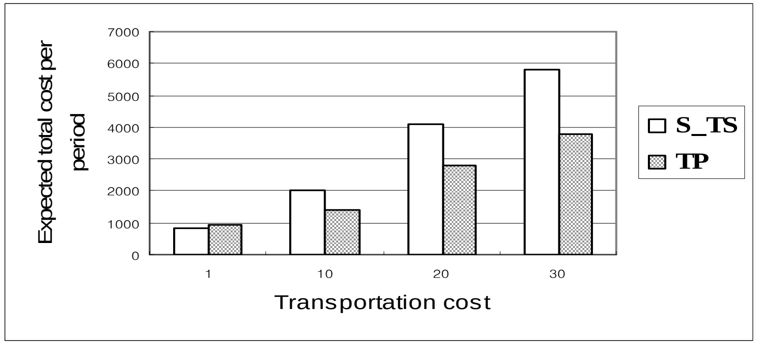
Numerical example (Cont'd)

- Analysis
  - The results of simulation experiments show that TP is more effective than S_TS for the change of holding cost, ordering cost, shortage cost and transportation cost .
  - Expected total cost per period is made up of expected inventory cost and (=holding cost + ordering cost + shortage cost) and expected transportation cost (=emergency cost + regular cost) per period.









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Conclusions

- Two phase method was suggested for improving supply chain profitability.
  - In the first phase, buffer management procedure is applied to inventory replenishment issues. With the control of customer service level through SLRP, the procedure presents a method of monitoring and correcting the inventory of each retailer.
  - In the second phase for settling distribution issues, tabu search algorithm, which is linked with buffer management procedure, proposed.

- TP outperformed S_TS.
  - In various cases, the results showed that TP is more effective than S_TS.
  - Moreover we remarked that expected total cost per period is larger S_TS than TP for the change of shortage cost. This means that TP can improve more supply chain profitability than S_TS.

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