디지털 어소팅 시스템에서 제품들의 분할 및 묶음 최적화에 관한 연구

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Introduction

- Digital Assorting System (DAS) is the logistics system that automatically handles the various items assorting by each destination via the digital indicator (*Put-to-Light* (PTL) technology, Kim and Hong, 2020)
- We consider distribution centers which assort the products to retail stores

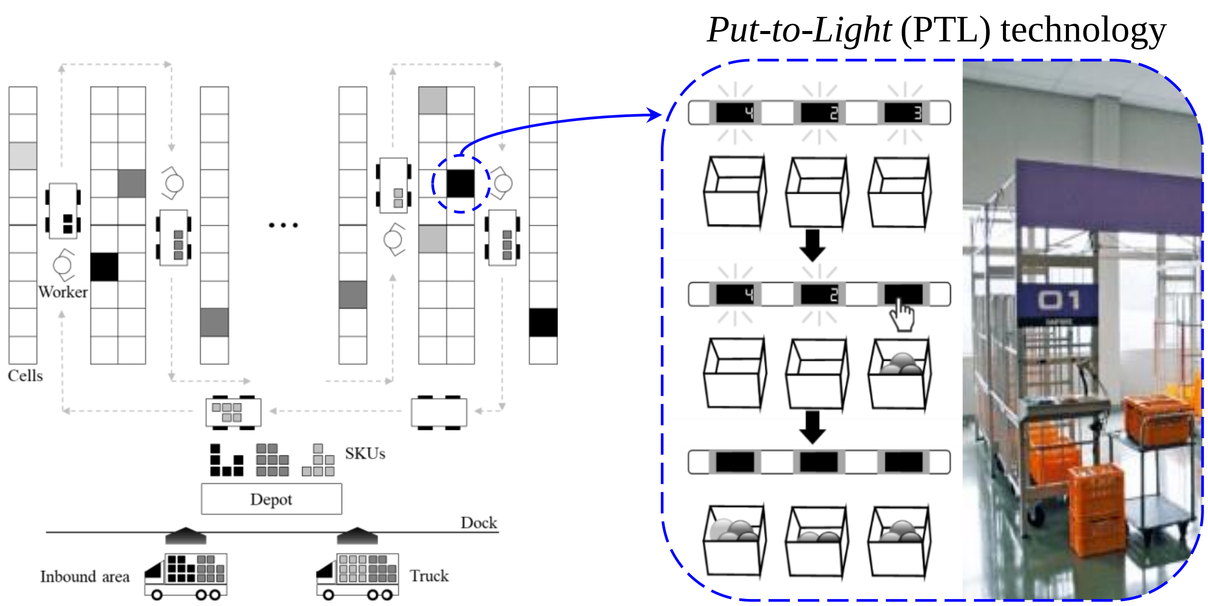


Figure 1. The DAS system using PTL technology (modified from Lee et al., 2019, Kim and Hong, 2020)

Introduction

- Many company are interested in introducing automation systems (Song et al., 2020; Park and Kim, 2020;)
  – Coupang, Market kurly, SSG, etc.
- Distribution centers (DCs) are required to assort products quickly
  – Operators in DCs try to apply automation system to improve productivity to meet the requirement of 1 or 2 delivery schedules everyday, and workload with large fluctuations in demand (Boysen et al., 2019)
  – Convenience stores of urban areas, especially convenience stores in urban areas, have minimal inventory due to short life cycles and lack of storage space (Hong, 2021)

출처(https://magazine.hankyung.com
/business/article/201904169108b)

(a) (b)

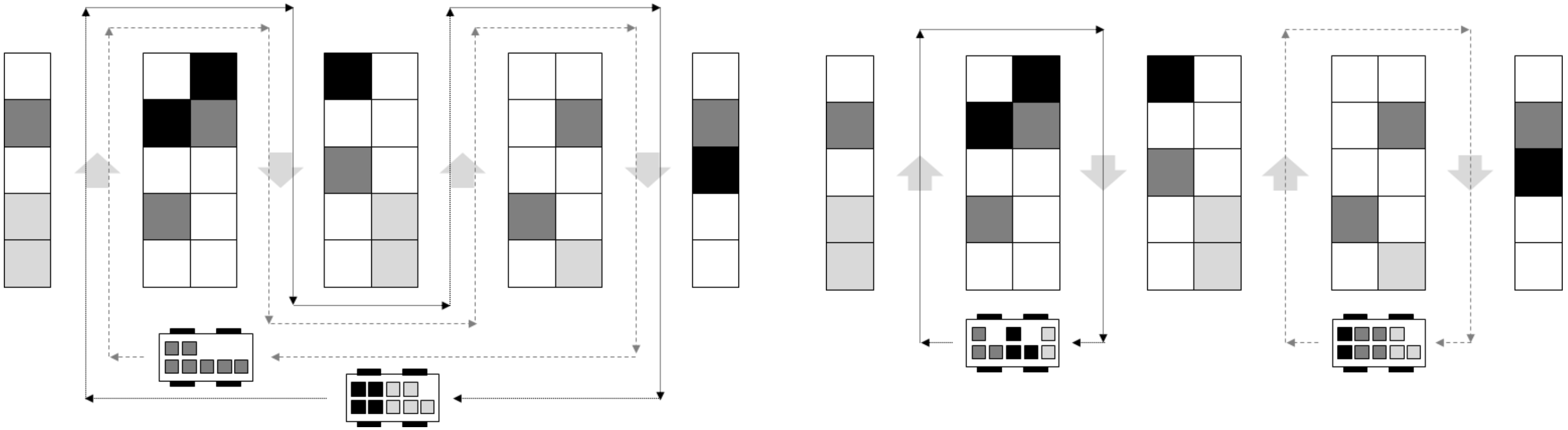
Figure 2. Technologies in the digital assorting system (modified from Lee et al. (2019)): (a) PTL and (b) Worker-following carts

Literature review

- Several studies have been conducted in the field of sorting systems
  - **Hong (2020)** introduced an order sorting system and evaluated the mean and variance of worker process time in a two-worker collaboration situation that includes sorting times, walking times, empty walking times, and blocking delays
  - **Fedtke and Boysen (2017)** introduced design alternatives for closed-loop tilt tray sortation conveyors in a parcel DC
  - **Johnson and Meller (2002)** developed analytical models to evaluate the performance of a circular sorting conveyor system that sorts orders from a particular customer or retail store
- Cross-docking has a distribution mechanism associated with the sorting operation
  - **Nassief et al. (2018)** presented two MIP (Mixed-integer programming) formulations for the cross-docking assignment problem
  - **Enderer et al. (2017)** developed mathematical models that minimize both material handling cost and transportation cost in the cross-docking system
  - **Yu et al. (2016)** conducted a study on the vehicle routing problem between inbound and outbound routes related to cross-docking and proposed a simulated annealing (SA) based heuristic algorithm

Binning and batching problem

- **Binning and batching operations has two problems; 1) binning, 2) batching**
- **The binning** refers to splitting products according to the demand of the customer boxes according to each aisle
- **The batching** refers to grouping bins into a batch to minimize travel distance
- The complexity: binning is NP-Complete (Garey and Johnson, 1979), batching is NP-Hard (Gademann and Velde, 2005)



(a) (b)

Figure 3. Two examples of the batch assorting: (a) without binning and (b) with binning

Binning and batching model (BBM)

Indices and sets

P, p = the set of products and its index $p \in P$.

A, a = the set of aisles and its index $a \in A$.

B, b = the set for batches and its index $b \in B$.

R, r = the set of routes and its index $r \in R$.

Parameters

$CAPA_V$ = the capacity of a cart's volume.

V_{pa} = the volume of product p assigned to aisles a.

$$PA_{pa} = \begin{cases} 1 & \text{if product } p \text{ passes through aisle } a, \\ 0 & \text{otherwise.} \end{cases}$$

LT_r = the length of route r.

$$RA_{ra} = \begin{cases} 1 & \text{if route } r \text{ passes through aisle } a, \\ 0 & \text{otherwise.} \end{cases}$$

Decision variables

$$X_{pab} = \begin{cases} 1 & \text{if product } p\text{'s bin that should visit aisle } a \text{ is assigned to batch } b, \\ 0 & \text{otherwise.} \end{cases}$$

$$Z_{pb} = \begin{cases} 1 & \text{if at least one product } p\text{'s bin is assigned to batch } b, \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{br} = \begin{cases} 1 & \text{if batch } b \text{ takes route } r, \\ 0 & \text{otherwise.} \end{cases}$$

Binning and batching model (BBM)

Formulation

$$\text{BBM: } \min \textstyle\sum_{b\in B}\sum_{r\in R} LT_r \cdot Y_{br}, \tag{1}$$

subject to

$$\textstyle\sum_{b\in B} X_{pab} \geq 1, \quad \forall p\in P,\ \forall a\in A, \tag{2}$$

$$X_{pab} \leq Z_b, \quad \forall p\in P,\ \forall a\in A,\ \forall b\in B, \tag{3}$$

$$\textstyle\sum_{p\in P}\sum_{a\in A} V_{pa}\cdot X_{pab} \leq CAPA, \quad \forall b\in B, \tag{4}$$

$$\textstyle\sum_{r\in R} Y_{br} \leq Z_b, \quad \forall b\in B, \tag{5}$$

$$X_{pab}\cdot PA_{pa} \leq \textstyle\sum_{r\in R} RA_{ra}\cdot Y_{br}, \quad \forall p\in P,\ \forall a\in A,\ \forall b\in B, \tag{6}$$

$$X_{pab}\in\{0, 1\}, \quad \forall p\in P,\ \forall a\in A,\ \forall b\in B,$$

$$Y_{br}\in\{0, 1\}, \quad \forall b\in B,\ \forall r\in R,$$

$$Z_b\in\{0, 1\}, \quad \forall p\in P,\ \forall b\in B.$$

Batching only model (BOM)

Formulation

$$\text{BOM: } \min \textstyle\sum_{b\in B}\sum_{r\in R} LT_r \cdot Y_{br}, \tag{7}$$

subject to

$$\textstyle\sum_{b\in B} X_{pb} = 1, \quad \forall p\in P, \tag{8}$$

$$X_{pb} \leq Z_b, \quad \forall p\in P,\ \forall b\in B, \tag{9}$$

$$\textstyle\sum_{p\in P}\sum_{a\in A} V_{pa}\cdot X_{pab} \leq CAPA, \quad \forall b\in B,\ \forall a\in A, \tag{10}$$

$$\textstyle\sum_{r\in R} Y_{br} \leq Z_b, \quad \forall b\in B, \tag{11}$$

$$X_{pab}\cdot PA_{pa} \leq \textstyle\sum_{r\in R} RA_{ra}\cdot Y_{br}, \quad \forall p\in P,\ \forall a\in A,\ \forall b\in B, \tag{12}$$

$$X_{pb}\in\{0, 1\}, \quad \forall p\in P\ \forall b\in B,$$

$$Y_{br}\in\{0, 1\}, \quad \forall b\in B,\ \forall r\in R,$$

$$Z_b\in\{0, 1\}, \quad \forall b\in B.$$

Route packing-based binning-then-batching procedure

- The route packing-based binning-then-batching procedure (RPBB) consists BBM-RP model for binning and BP_r model for batching to solve the large-sized problems.
- The BBM-RP model based on the Route-bin packing reformulation
- The procedure is modified from **Hong *et al.* (2012b)**, **Hong & Kim (2017)**.

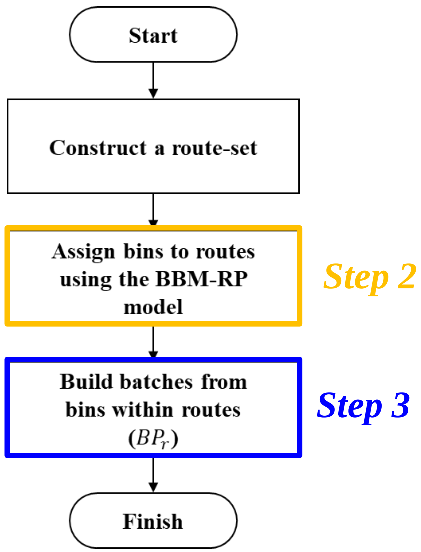


Figure 4. The flowchart of RPBB

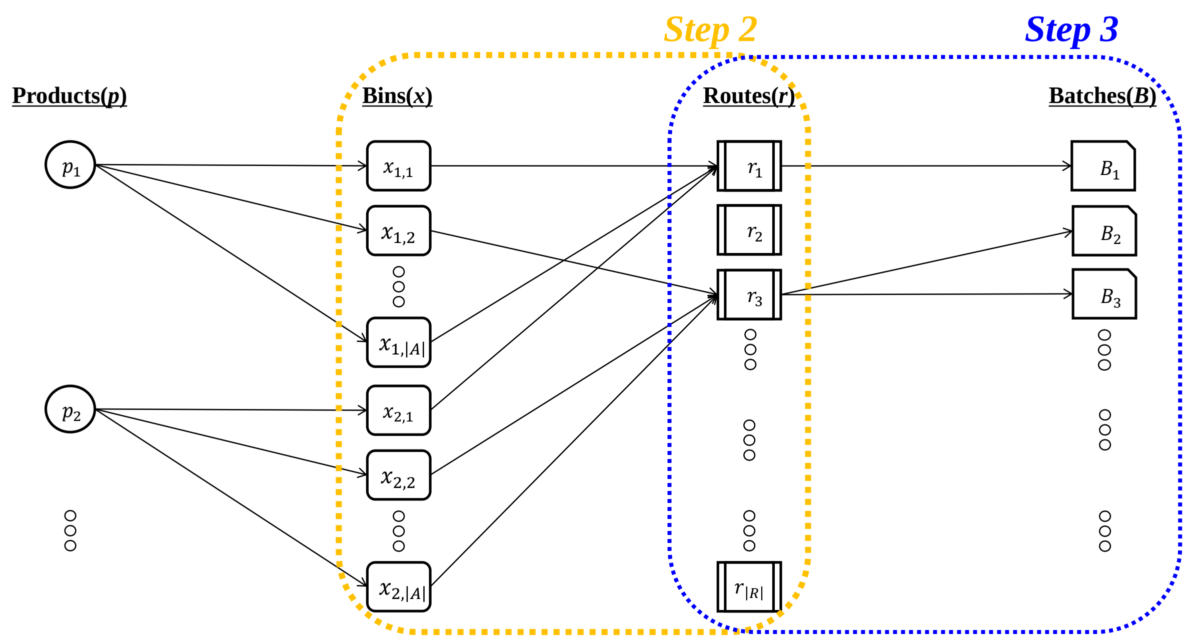


Figure 5. Route packing-based binning-then-batching procedure

Route packing-based binning-then-batching procedure

- Route-bin packing reformulation

Decision variables

$$x_{par} = \begin{cases} 1 & \text{if product } p\text{'s bin that should visit aisle } a \text{ is assigned to route } r, \\ 0 & \text{otherwise.} \end{cases}$$

y_r = the number of batches assigned to route r.

Formulation

$$\min \sum_{r \in R} LT_r \times y_r,$$

Subject to

$$\sum_{r \in R} x_{par} = 1, \qquad \forall p \in P, \forall a \in A, \qquad (13)$$

$$\sum_{p \in P} V_{pa} \times x_{par} \leq CAPA_V \times y_r, \qquad \forall p \in P, \forall a \in A, \forall r \in R, \qquad (14)$$

$$x_{par} \times PA_{pa} \leq RA_{ra} \times y_r, \qquad \forall p \in P, \forall a \in A, \forall r \in R, \qquad (15)$$

$$x_{par} \in \{0,1\}, \qquad \forall p \in P, \forall a \in A, \forall b \in B,$$

$$y_r \in \{0,1, \dots,\}, \qquad \forall r \in R.$$

Experimental design

- Performance measures

  1) Number of batches, 2) Total travel distance of all batches , 3) CPU times

- Computational Environment
  - IBM CPlex 12.60, the MIP models were implemented using Concert Technology in IBM JAVA
  - Intel® Core™ i5-7600 @ 3.50GHz, 32GB memory, window 10 education version

Table 1. Profile of experiments

	Parameters
Number of products (|P|)	Small: 10, 20, 30; large: 360, 720
Volume of products	Uniform (0.5, 5.0)
Routing policy	One-way traversal
Number of aisles (|A|)	4, 6, 8
Length of an aisle (LT)	15 m
Distance between two adjacent aisles	4 m
Capacity of a worker-following cart (CAPA)	6, 12, 24, 36 liters

Experimental results

- We consider 10, 20, and 30 products in 4 and 6 aisles
  - In table 2, the BBM obtains the shortest total travel distance for 10 ~ 30 products in 4 and 6 aisles
  - The RPBB obtains 0.50 ~ 10.87% optimal (Opt) gap solutions for the cases in the Table 2.

Table 2. Experimental results for small scale problems

$\|A\|$	*Capa*	$\|S\|$	# of batches			Total travel distance			Opt Gap (%)	CPU (sec)		
			BOM	**BBM**	RPBB	BOM	**BBM**	RPBB	**RPBB**	BOM	BBM	**RPBB**
4	6	10	6.96	**6.36**	6.64	393.52	**302.16**	313.52	3.62%	0.07	0.06	**0.04**
		20	12.68	**11.16**	11.92	693.44	**528.16**	555.28	4.88%	0.33	0.26	**0.09**
		30	18.96	**16.52**	17.40	1019.68	**765.28**	801.36	4.50%	0.55	2.99	**0.17**
	12	10	3.16	**3.12**	3.16	192.00	**161.36**	163.52	1.32%	0.08	0.08	**0.03**
		20	5.68	**5.56**	5.72	320.96	**264.24**	272.24	2.94%	0.29	0.25	**0.06**
		30	8.20	**8.20**	8.28	451.12	**380.72**	386.32	1.45%	0.98	3.99	**0.06**
6	6	10	6.76	**6.32**	6.40	452.80	**352.08**	360.40	2.31%	0.07	0.06	**0.05**
		20	12.80	**11.60**	12.92	850.48	**636.80**	700.56	9.10%	0.35	0.75	**0.14**
		30	19.32	**16.88**	18.92	1270.80	**915.68**	1027.36	**10.87%**	0.80	2.41	**0.38**
	12	10	3.24	**3.32**	3.36	245.68	**192.72**	193.68	**0.50%**	0.10	0.07	**0.03**
		20	5.84	**5.76**	5.92	420.56	**325.12**	337.44	3.65%	0.65	0.44	**0.08**
		30	8.36	**8.28**	8.56	584.32	**452.00**	465.20	2.84%	10.56	8.41	**0.19**

Experimental results

- We consider 360 and 720 products in 4, 6, and 8 aisles
  - In Table 3, the RPBB obtains the total travel distance to solve the large scale problems
  - The RBBP obtains 0.5 ~ 10.9% Lower bound (LB) gap solutions for the cases in Table 3.

Table 3. Experimental results for large scale problems

$\|A\|$	*Capa*	$\|S\|$	# of batches	Total travel distance		LB Gap (%)	CPU (sec)
			RPBB	RPBB	LB	RPBB	RPBB
4	24	360	47.82	2204.07	2162.24	1.90%	17.64
		720	95.32	4397.64	4335.42	**1.41%**	76.70
	36	360	31.92	1471.52	1443.12	1.93%	2.12
		720	64.16	2965.61	2906.09	2.01%	67.96
6	24	360	47.72	2569.20	2523.58	1.78%	37.58
		720	95.40	5158.64	5079.66	1.53%	90.99
	36	360	31.76	1715.04	1682.39	1.90%	11.80
		720	63.68	3443.20	3386.44	1.65%	64.64
8	24	360	47.72	2967.92	2910.21	1.94%	45.17
		720	95.46	5917.85	5803.95	1.92%	108.37
	36	360	31.91	1994.61	1951.33	**2.17%**	31.41
		720	63.65	3956.87	3887.00	1.77%	57.16

Conclusion

- **We proposed the RPBB procedure to solve the large scale binning and batching problem in the digital assorting system**

- **We proposed two optimal models and heuristic procedure**
  - Binning and batching model (BBM) and batching only model (BOM)
  - Route packing-based binning-then-batching procedure (RPBB)

- **Future research**
  - To evaluate the congestion with an analysis of bottlenecks in multi-cart operations
  - To develop optimal binning and batching model considering the blocking between carts

THANK YOU

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