Journal of Advanced Mechanical Design, Systems, and Manufacturing

Vol.1, No.2, 2007

Simultaneous Optimization of Storage Allocation and Routing Problems for Belt-conveyor Transportation*

Masatoshi AGO**, Tatsushi NISHI*** and Masami KONISHI**

** Okayama University, The Graduate School of Natural Science and Technology
3-1-1 Tsushima-naka, Okayama 700-8530, Japan
E-mail: {ago, konishi}@cntr.elec.okayama-u.ac.jp

*** Osaka University, Graduate School of Engineering Science
1-3 Machikaneyama, Toyonaka city, Osaka 560-8531, Japan
E-mail: nishi@sys.es.osaka-u.ac.jp

Abstract

Raw materials for industrial steel-making plants need to be stored in material yards in order to satisfy various production requirements. The stored materials are supplied to production plants by belt-conveyors with multiple alternative transportation routes. The simultaneous optimization of the storage allocation and transportation routing for the raw materials yard is required for achieving production that is flexible to changes in demand. In this paper, we propose a Lagrangian decomposition and coordination approach for storage allocation and routing for a belt-conveyor transportation system to handle demand changes. The overall problem is decomposed into an allocation planning subproblem and a transportation routing subproblem. A near-optimal solution for allocation planning and transportation routing is derived by repeating each optimization of subproblems and multiplier updates. The effectiveness of the proposed approach is confirmed in numerical experiments.

Key words : Belt Conveyor Transportation, Raw Materials Yard, Storage Allocation, Transportation Routing, Lagrangian Decomposition and Coordination.

1. Introduction

Integrated production and distribution planning is a significant problem for effective supply chain management to deliver products quickly and to maintain low inventories[3]. For the steel industry, efficient operations in the raw materials yard are needed to improve the production rate due to increasing demand for worldwide steel production. Because of sudden requests for production demand, the production rate in steel plants is always changing, especially for blast furnaces at production plants. Therefore, stabilizing the amount of raw materials supplied is an important problem for raw-materials yard systems. The raw materials are delivered to the yard by a fleet of ships at a limited shipping frequency, after that they are delivered to appropriate storage areas by belt-conveyor transportation. The stored materials are then continuously supplied to production plants to satisfy changing demand.

For such situations, simultaneous optimization of storage allocation and routing of materials to belt-conveyor is strongly demanded. Hayashi et al.[5] studied an optimization method for transportation systems for port logistics, focusing mainly on task assignment problems or routing problems for automated guided vehicles (AGVs) under a set of transportation requests. Expert systems are often used to derive routing of AGV systems[9]. Nishimura et al.[11] proposed a genetic algorithm to solve multi-trailer transportation routing problem, and Avella et al.[2] proposed a mathematical programming approach using a branch and price algorithm to solve routing for a fleet of trucks with different capacities. However, the optimization of storage allocation and routing has not been considered simultaneously for dynamic environ-

*Received 30 Nov., 2006 (No. 06-0232)
[DOI: 10.1299/jamdsm.1.250]

ments where requests are given in real time. A number of operational issues for yard logistics systems are concerned with port container terminals. Zhang et al.[12] studied a mathematical programming model for storage-space allocation problem that employs a two-level optimization approach, while Kim et al.[7] proposed a beam-search algorithm for container allocation and the straddle-carrier routing problem.

Most conventional studies on the allocation and transportation problem deal with it by adopting the hierarchical decomposition approach, where allocation problems are initially solved and the routings are generated for transportation requests to satisfy the storage allocation goal derived by solving the allocation problem. In this paper, we propose a simultaneous optimization method for the storage allocation and routing problem using Lagrangian decomposition and coordination approach. This method replaces the complicating constraints with a penalty term in the objective function so that the problem can be decomposed into solvable subproblems[4]. The entire problem is successfully decomposed into a storage allocation planning problem and transportation routing problem for belt-conveyor lines by duplicating decision variables.

This paper is organized into the following sections. In Section 2, the storage allocation and routing problem is formulated as a mixed integer programming problem. The original problem is decomposed into storage allocation problem and routing problem in Section 3. Numerical results and the effectiveness of the proposed method for static cases are shown in Section 4. The results for dynamic cases are discussed in Section 5. Section 6 mentions conclusion and future works.

2. Simultaneous Storage allocation and routing problem

2.1. Modeling raw materials yard system

The storage area allocation and routing problem in the storage yard is explained in this section. Figure 1 illustrates the outline of a transportation system for raw materials yard system.

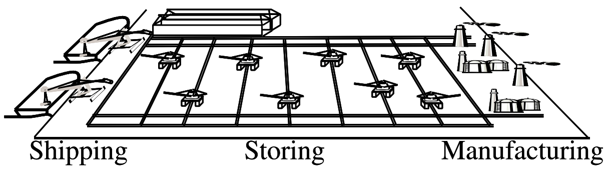

Fig. 1 Outline of raw materials yard system

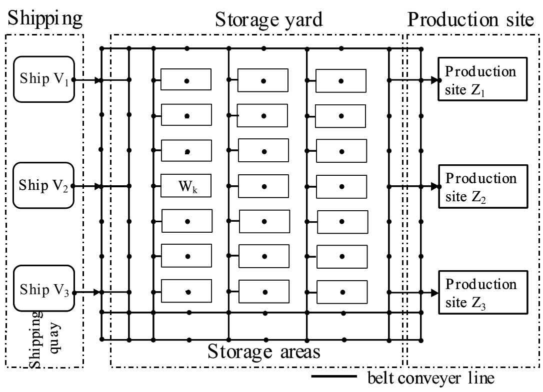

Fig. 2 Raw materials yard model with belt-conveyor transportation system

The raw materials yard model is shown in Fig. 2. The set of raw materials $\{M_i\}$ are unloaded from the ships $\{V_j\}$ at shipping quay, and then transported to the set of storage areas $\{W_k\}$ and they are kept temporarily. These raw materials are transported to production plant $\{Z_l\}$ by belt-conveyor line according to production demand rate. There are several storage areas in the materials yard. Each area has capacity constraints that the raw materials cannot be allocated over a pre-specified capacity. The layout model for raw materials yard consists of several nodes and edges. The nodes represent the points where the raw materials are uploaded from ship, storage areas in storage yard, production sites that are the destination of raw materials, and points where transportation route of raw materials can stop or turn on belt-conveyor. The edges represent the belt-conveyor line. The belt-conveyor can transport only one type of raw material at once. Collisions of a transportation of a raw material on the nodes with other transportation are not permitted. The problem treated in this paper is described as follows. The simultaneous storage allocation and routing problem is to decide the storage allocation of raw materials and the transportation routing for several requests in the raw materials yard system without collisions between product delivery on belt-conveyor lines when the procurement amount of raw materials to ship at each period and the demand amount to production sites are given.

2.2. Formulation of simultaneous storage allocation and routing problem

For raw materials yard system, procurement amount to shipping and transportation demands are given from production sites. The situation in material systems may change every one hour. Thus, it is required to solve dynamic planning problem where requests are given in real time. Conventional planning system is configured to create storage allocation and routing sequentially. The solution for the dynamic problem can be derived by solving the static problems for each time period. However, it is very difficult to derive a feasible routing to satisfy the storage allocation planning for conventional planning system. Therefore, the simultaneous optimization of storage allocation and routing is necessary. The simultaneous storage allocation and routing problem for a set of requests are formulated as a mixed integer linear programming (MILP) problem.

[Indices]

i : raw material
t : time period
j : ship
k : storage area
l : production site

[Sets]

M_i : raw materials $(\forall i=1, 2 \cdots, N_M)$
T_t : time periods $(\forall t=1, 2, \cdots, N_T)$
V_j : ships $(\forall j=1, 2, \cdots, N_V)$
W_k : storage areas $(\forall k=1, 2, \cdots, N_W)$
Z_l : production sites $(\forall l=1, 2, \cdots, N_Z)$

[Decision variables]

$\delta_{i,t}^{k}$: 0-1 binary variable indicating whether material i is stored at area k in time period t or not
$d_{i,t}^{k,l}$: amount of raw material i that is transported to production site l from storage area k in time period t
$E_{i,t}^{l}$: amount of shortage of supply to production site l for raw material i in time period t
$F_{h,t}$: transportation time for request h in time period t
$I_{i,t}^{k}$: amount of raw material i that is stored at storage area k in time period t
N_H^t : number of transportation requests allocated in time period t
$p_{i,t}^{j,k}$: amount of raw material i that is transported to storage area k from ship j in time period t
$S_{i,t}^{j}$: amount of holding raw material i at ship j in time period t

[Parameters]
$\alpha^j_{i,t}$: unit holding cost for raw material i at ship j in time period t
$\beta^k_{i,t}$: unit holding cost for raw material i at storage area k in time period t
$\gamma^l_{i,t}$: penalty cost for shortage of raw material i to production site l for raw material i in time period t
ϵ_k : unit fixed cost for using storage area k
$\eta_{h,t}$: unit transportation cost for belt-conveyor line for request h in time period t
$D^l_{i,t}$: demand of raw material i to production site l in time period t
$P^j_{i,t}$: procurement amount of raw material i to ship j in time period t
I^k_{max} : maximum capacity of storage area k
H : time length in time period t

$$\min \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{j=1}^{N_V}\alpha^j_{i,t}S^j_{i,t} + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\beta^k_{i,t}I^k_{i,t}$$

$$+\sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\epsilon_k\delta^k_{i,t} + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{l=1}^{N_Z}\gamma^l_{i,t}E^l_{i,t} + \sum_{t=1}^{N_T}\sum_{h=1}^{N^t_H}\eta_{h,t}F_{h,t} \tag{1}$$

$$S^j_{i,t} = S^j_{i,t-1} + P^j_{i,t} - \sum_{k=1}^{N_W} p^{j,k}_{i,t} \quad (\forall i, \forall t, \forall j) \tag{2}$$

$$I^k_{i,t} = I^k_{i,t-1} + \sum_{j=1}^{N_V} p^{j,k}_{i,t} - \sum_{l=1}^{N_Z} d^{k,l}_{i,t} \quad (\forall i, \forall t, \forall k) \tag{3}$$

$$I^k_{i,t} \le I^k_{max}\delta^k_{i,t} \quad (\forall i, \forall t, \forall k) \tag{4}$$

$$E^l_{i,t} = D^l_{i,t} - \sum_{k=1}^{N_W} d^{k,l}_{i,t} \quad (\forall i, \forall t, \forall l) \tag{5}$$

$$\sum_{h=1}^{N^t_H} F_{h,t} \le H \quad (\forall t) \tag{6}$$

(routing constraints)

$$d^{k,l}_{i,t} \ge 0,\ E^l_{i,t} \ge 0,\ I^k_{i,t} \ge 0,\ p^{j,k}_{i,t} \ge 0,\ S^j_{i,t} \ge 0,\ \delta^k_{i,t} \in \{0,1\} \quad (\forall i, \forall t, \forall j, \forall k, \forall l) \tag{7}$$

The first term in Eq. (1) represents the materials holding costs for each ship. The materials holding costs are imposed with respect to the amount of raw materials holding at each ship which are not delivered to raw materials yard. The second term represents the materials holding costs for each storage area, and the third term represents the fixed costs for using storage area k, and the fourth term indicates the shortage cost for supplying to each production site, and the last term represents the transportation time for request h on belt-conveyor system. Equation (2) ensures the raw material balancing constraints for each ship. Equation (3) shows the raw material balancing constraints for each storage area. Equation (4) represents the storage capacity constraints of storage area. Equation (5) describes the shortage penalty cost for violating production demand from each production site. Equation (6) restricts the available time for transportation at each time period. Equation (7) defines variable constraints. The above representation allows the allocation planning problem to be formulated as a mixed integer linear programming problem (MILP). Therefore, if the problem size is increased, it takes too much computation time to derive a near-optimal solution.

3. Solution methodology

Lagrangian decomposition and coordination method is applied to solve the problem in this section.

3.1. Decomposition into storage allocation subproblem and routing subproblem

To apply Lagrangian decomposition, the original problem is reformulated by creating the copy of variables $p^{j,k}_{i,t}$ and $d^{k,l}_{i,t}$. The following constraints (8), (9) are imposed to the original problem.

$$p_{i,t}^{j,k} = \overline{p_{i,t}^{j,k}} \quad (\forall i; \forall t; \forall j; \forall k) \tag{8}$$

$$d_{i,t}^{k,l} = \overline{d_{i,t}^{k,l}} \quad (\forall i; \forall t; \forall k; \forall l) \tag{9}$$

The Lagrangian function can be written as:

$$\begin{aligned} L = &\sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{j=1}^{N_V} \alpha_{i,t}^j S_{i,t}^j + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W} \beta_{i,t}^k I_{i,t}^k \\ &+ \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W} \epsilon_k \delta_{i,t}^k + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{l=1}^{N_Z} \gamma_{i,t}^l E_{i,t}^l + \sum_{t=1}^{N_T}\sum_{h=1}^{N_H^t} \eta_{h,t} F_{h,t} \\ &+ \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{j=1}^{N_V}\sum_{k=1}^{N_W} \lambda_{i,t}^{j,k}(p_{i,t}^{j,k} - \overline{p_{i,t}^{j,k}}) + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\sum_{l=1}^{N_Z} \phi_{i,t}^{k,l}(d_{i,t}^{k,l} - \overline{d_{i,t}^{k,l}}) \end{aligned} \tag{10}$$

The Lagrangian relaxation of constraints leads to decompose the original problem into the following two subproblems.

(Storage allocation planning subproblem)

$$\min \ L_{AP}$$

$$\begin{aligned} L_{AP} = &\sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{j=1}^{N_V} \alpha_{i,t}^j S_{i,t}^j + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\left(\sum_{j=1}^{N_V} \lambda_{i,t}^{j,k} p_{i,t}^{j,k} + \sum_{l=1}^{N_Z} \phi_{i,t}^{k,l} d_{i,t}^{k,l}\right) \\ &+ \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W} \epsilon_k \delta_{i,t}^k + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W} \beta_{i,t}^k I_{i,t}^k + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{l=1}^{N_Z} \gamma_{i,t}^l E_{i,t}^l \end{aligned} \tag{11}$$

s. t. (2), (3), (4), (5)

(Routing subproblem)

$$\min L_{RP}$$

$$L_{RP} = \sum_{t=1}^{N_T}\sum_{h=1}^{N_H^t} \eta_{h,t} F_{h,t} - \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\left(\sum_{j=1}^{N_V} \lambda_{i,t}^{j,k} \overline{p_{i,t}^{j,k}} + \sum_{l=1}^{N_Z} \phi_{i,t}^{k,l} \overline{d_{i,t}^{k,l}}\right)$$

s. t. (6), (routing constraints) (12)

3.2. Solving dual problem

The dual problem can be formulated as

$$\max_{\{\lambda,\phi\}} \quad q(\lambda, \phi) \quad \text{where} \quad q = \min(L_{AP} + L_{RP}) = \min L_{AP} + \min L_{RP} \tag{13}$$

To solve dual problem, the steps of solving subproblems and the multiplier updating are repeated until the solution of dual problem has not been updated. The transportation routing must be generated so that the transportation is completed in the time period to satisfy the solution of storage allocation planning problem. If the routing plan derived by solving routing problem is not completed in the time period derived by storage allocation planning, $(p_{i,t}^{j,k} - \overline{p_{i,t}^{j,k}})$ and $(d_{i,t}^{k,l} - \overline{d_{i,t}^{k,l}})$ are not zero and a feasible solution cannot be obtained. Furthermore, if the subproblems are solved independently, the solution oscillation makes the convergence of the algorithm difficult. To help the convergence of the algorithm, the penalties for violating material balancing constraints are included in the objective function for each subproblem. Then, the Lagrangian multipliers $\lambda_{i,t}^{j,k}$ and $\phi_{i,t}^{k,l}$ representing the price of storage allocation are updated. Each subproblem is written as follows.

$$\min \left(L_{AP} + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{j=1}^{N_V}\sum_{k=1}^{N_W} w_p |p_{i,t}^{j,k} - \overline{p_{i,t}^{j,k}}| + \sum_{i=1}^{N_M}\sum_{t=1}^{N_T}\sum_{k=1}^{N_W}\sum_{l=1}^{N_Z} w_d |d_{i,t}^{k,l} - \overline{d_{i,t}^{k,l}}|\right) \tag{14}$$

By increasing weighting factors w_p and w_d for allocation planning problem, the transportation requests which may lead to large transportation time cannot not be generated at storage allocation planning level. The storage allocation planning and transportation route planning are repeatedly executed until a feasible solution for the entire planning is derived. To ensure the generation of feasible solution, a feasible solution is derived at each iteration by modifying the dual solution into a feasible solution by a heuristic procedure. The flow chart of coordination of allocation and route planning problem is shown in Fig. 3.

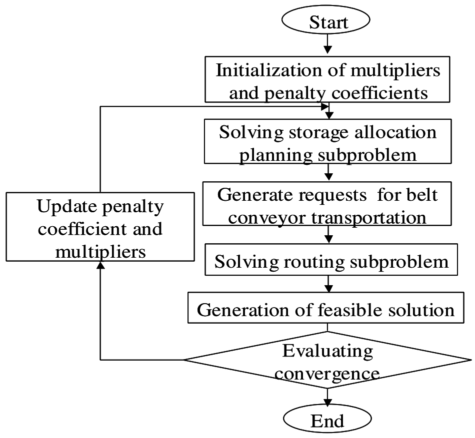

Fig. 3 Flow chart of coordination for storage allocation planning and transportation route planning

At the first step of the algorithm in Fig. 3, the information for materials storage yard layout, the amount of procurements for raw materials and production demand for production site are given. Then, the weighting factors and Lagrangian multipliers are initialized according to the situation of the storage yard. At the second step, the storage allocation planning is generated by solving MILP problem and the transportation requests are created by the results of storage allocation problem. At the third step, the transportation routing is generated to satisfy the transportation requests. If the transportation routing is infeasible, the multipliers and penalty weighting factors w_p and w_d are updated according to Eqs. (15), (16) and return to storage allocation planning. Here, $\Delta\lambda$ and $\Delta\phi$ are constants of updating multipliers in sub-gradient direction of $q(\lambda, \phi)$. n represents the number of times of allocation and routing. If a feasible solution satisfying the relaxed constraints of Eqs. (8), (9) is derived, the algorithm is completed and the tentative optimal solution is regarded as a final solution.

$$\lambda^{j,k}_{i,t}(n+1) = \lambda^{j,k}_{i,t}(n) + \Delta\lambda \tag{15}$$

$$\phi^{k,l}_{i,t}(n+1) = \phi^{k,l}_{i,t}(n) + \Delta\phi \tag{16}$$

3.3. Solving routing problem

The transportation requests $r \in R$ $(r = 1, \cdots, N_R)$ are generated by $p^{j,k}_{i,t}$ and $d^{k,l}_{i,t}$ obtained by solving storage allocation planning problem. A transportation request consists of the set of a pair of an initial node and an ending node having no duplicate nodes. $p^{j,k}_{i,t}$ is related to the transportation requests from the ship j to the storage area k. Similarly, $d^{k,l}_{i,t}$ is related to the transportation requests from the storage area k to the production site l. Therefore, an initial node and an ending node for transportation are represented by shipping node, storage area node and production site node. The set of transportation request are generated at the beginning of time period t. The transportation routing problem is solved when the requests for transportation are given. The collision-free routing for transportation of raw materials by belt-conveyor is generated. The algorithm for the routing problem is explained in the following. A distributed routing method[1] is used for route planning problem for belt-conveyor transportation. However, the number of nodes that each transportation request occupies according to the amount of transportation is different in transportation by the belt-conveyor. The amount of transportation must be considered in this problem. Therefore, collisions with other transportations are checked according to the amount of transportation.

4. Numerical experiments

The effectiveness of the proposed method is investigated by numerical experiments in this section.

4.1. Example problem

In the numerical example problem, the raw materials yard system model consists of 3 ships, 21 storage areas and 3 production sites as shown in Fig. 4. It is assumed that 1 time period is composed by 15 hours. The weighting factors $\alpha^j_{i,t} = 50$ $(\forall i; \forall t; \forall j)$, $\beta^k_{i,t} = 1$ $(\forall i; \forall t; \forall k)$, $\epsilon_k = 5$ $(\forall k)$, $\gamma^l_{i,t} = 100$ $(\forall i; \forall t; \forall l)$, $\eta_{h,t} = 1$ $(\forall h; \forall t)$ are used for example problems. A commercial LP solver CPLEX 8.0[6] was used to solve the allocation planning problem. The simulations are conducted on a PC with a Pentium IV 2.53 GHz processor with 512MB memory. The heuristic to generate a feasible solution is that the transportation

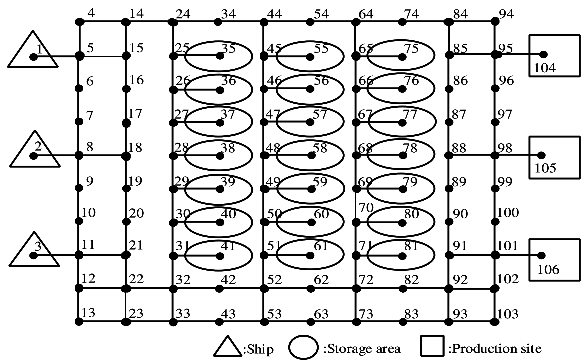

Fig. 4 Layout model of raw materials yard system

requests which are not completed in a given time period are modified to store at ships or storage areas. The transition of each cost function for iterative calculations of the proposed method is shown in Fig. 5 when the amount of procurement and demand for one time period are given. As the number of iterations is increased, the total costs gradually decreases even though the allocation costs are gradually increased. This is because the materials holding costs for ships can decrease the total costs.

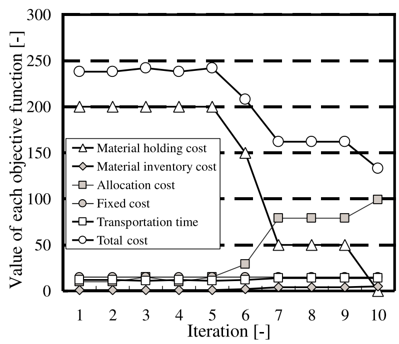

Fig. 5 Transition of each cost function for one time period

4.2. Computational results

For the numerical experiments, the total planning horizon is set to 3 time periods (45 hours). Three types of raw materials are treated. The multiplier updating parameters $|\Delta\lambda| = |\Delta\phi| = 10$ and $\Delta\theta$=1.8 are used for computation. The amount of procurement for each ship is shown in Table 1, and the demand for each production site is shown in Table 2. The transportation requests obtained by solving allocation planning problem are shown in Table 3. For the proposed method, a feasible allocation and transportation plan have been derived after ten times of iterations. The solution for each transportation requests is shown in Fig. 6. There exists no collision or interferences between raw material transportations. As a result, the derived solution is feasible because all of transportations are completed in the time period to satisfy the storage allocation plan.

Table 1 Procurement amount of raw materials to shipping

Time period	1			2			3		
Materials	1	2	3	1	2	3	1	2	3
Node 1	200	0	0	200	0	0	0	100	0
Node 2	100	0	0	0	0	200	0	0	100
Node 3	0	200	0	0	100	0	100	0	0

Table 2 Amount of demand to production site

Time period	1			2			3		
Materials	1	2	3	1	2	3	1	2	3
Node 104	0	0	0	0	0	0	0	0	0
Node 105	0	0	0	0	100	0	100	0	100
Node 106	0	0	0	100	0	0	0	0	0

Table 3 Transportation requests

Request ID	Initial node	Goal node	Start time of transportation	Amount of transportation
1	1	60	0	200
2	2	60	0	100
3	3	36	0	200
4	1	56	15	100
5	1	60	15	100
6	3	55	15	100
7	2	40	15	200
8	60	106	15	100
9	55	105	15	100
10	3	60	30	100
11	1	36	30	100
12	2	57	30	100
13	60	105	30	100
14	57	105	30	100

4.3. Comparison with a hierarchical planning method

The effectiveness of the proposed method (LDC) is investigated by comparing the performance with a hierarchical planning method (HPM). For numerical experiments, two cases of situations are assumed. Case 1 is for normal operation, and Case 2 is for frequently-ordered operation. Five instances of problems are created randomly. One of the data for procurement amount to ship and demand from production site for each case are shown in Tables 4 and 5. The total planning horizon is 3 time periods and three types of raw materials are treated. For the hierarchical planning method, the transportation route is created sequentially from the result of storage allocation planning and the feasibility of transportation is checked. The storage allocation planning is generated so as to satisfy the constraints of transportation again. The two types of methods are compared for two cases for five instances. The average results of 5 times of calculations are shown in Table 6.

For Case 1, the average value of total costs for LDC is smaller than that of HPM. For Case 2, the proposed method generates better solution than the hierarchical planning method because the transportation routes are crowded when a number of transportation requests are given. Even though the storage allocation cost for the proposed method is larger than that of the hierarchical planning method, the holding costs and the shortage penalty costs for LDC are smaller than that of HPM. Thus, it is demonstrated that the LDC can derive better solutions than the HPM without significantly increasing the total computation time compared with that of the HPM.

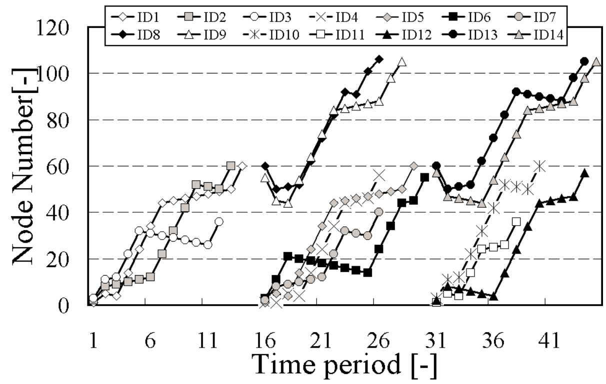

Fig. 6 Results of routing requests for belt-conveyor transportation

Table 4 Procurement amount of raw materials to shipping

					Case 1				
t		1			2			3	
M_i	1	2	3	1	2	3	1	2	3
Node 1	100	0	0	0	0	0	0	0	0
Node 2	0	100	0	100	0	0	0	0	0
Node 3	0	0	100	0	0	0	100	0	100
					Case 2				
t		1			2			3	
M_i	1	2	3	1	2	3	1	2	3
Node1	0	100	0	0	0	100	100	0	200
Node2	100	0	100	100	0	0	0	200	0
Node3	100	100	100	100	0	0	200	0	0

Table 5 Amount of demand to production size

					Case 1				
t		1			2			3	
M_i	1	2	3	1	2	3	1	2	3
Node 104	0	0	0	0	0	0	0	0	0
Node 105	0	0	0	0	100	0	100	0	100
Node 106	0	0	0	0	0	0	0	0	0
					Case 2				
t		1			2			3	
M_i	1	2	3	1	2	3	1	2	3
Node 104	0	0	0	0	0	0	0	0	100
Node 105	0	0	0	0	100	0	100	100	0
Node 106	0	0	0	100	100	0	0	0	0

Table 6 Comparison of the proposed method (LDC) and the hierarchical planning method (HPM)

	Case1		Case2	
	LDC	HPM	LDC	HPM
Holding costs for ship	0	90	150	380
Holding costs for storage	7.2	5.6	14.6	10.2
Penalty of shortage	40	40	200	220
Fixed costs	29	24	46	37
Transportation time	34	41.2	41.0	47.2
Total cost	110.2	200.8	451.6	694.4
CPU time* [s]	2.6	1.0	6.0	3.2

Pentium IV 2.53 GHz processor with 512MB is used.

5. Application to simultaneous optimization problem for dynamic demand case

5.1. Description of problem in dynamic case

In the previous sections, the procurement amount of raw materials to shipping and demand from production site are given a priori. However, in practical situations, these data are not available with respect to time periods. In this section, the proposed method is applied to a simultaneous optimization problem in a real time for dynamic demand case.

5.2. Solution method for dynamic case

It is assumed that future three demands from current planning time are available. Figure 7 shows the solution method for a dynamic case. The rolling planning is executed for each three time periods. To avoid the shortage of transportation to production site, safety stocks for raw materials are stored to raw materials yard. The penalty costs for violating safety stock level are included in the objective function. Even though the transportation routing problem becomes extremely difficult if the number of safety stocks is increased, the safety stocks are stored to minimize the shortage of transportation. The inventory level derived at each time period is set as the initial inventory level for the next time period. The number of safety stock level is determined from numerical simulations.

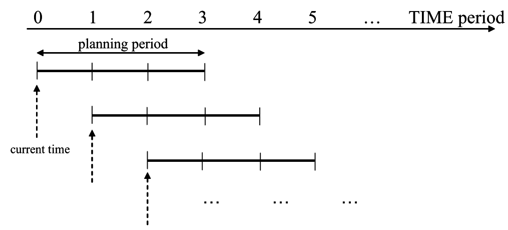

Fig. 7 Rolling planning for dynamic case

5.3. Numerical experiments for dynamic case

The simulation for 20 time periods is executed to determine an appropriate safety stock level. Three types of raw materials are treated. The demand for each time period is set as illustrated in Fig. 8. Figure 9 shows the effect of safety stock level to total costs for 20 time periods. The total costs are minimized when the safety stock level is set to approximately 2. The penalty shortage costs become extremely larger when the safety stock level is less than 2, on the other hand, the inventory holding costs are increased when the safety stock level is more than 2. The appropriate safety stock level can be determined by the simulation results in dynamic cases.

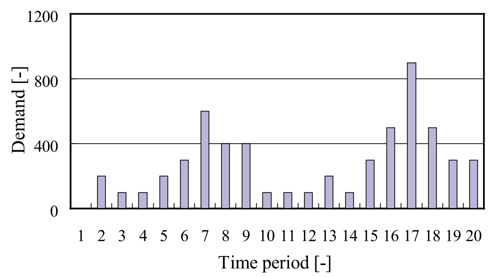

Fig. 8 Production demand given at each time period

Figure 10 shows the transition of storage allocation at period 1, period 10 and period 15 respectively. The storage allocation at period 10 is different from that at period 1. This is because the storage allocation which is easier to transport raw materials is selected at period 10. It is also confirmed that the number of stocks at period 15 is increased to accommodate the increase of the demand at period 17.

The performance derived by the proposed method (LDC) and hierarchical planning method (HPM) is compared for dynamic case. Table 7 summarizes the results of compu-

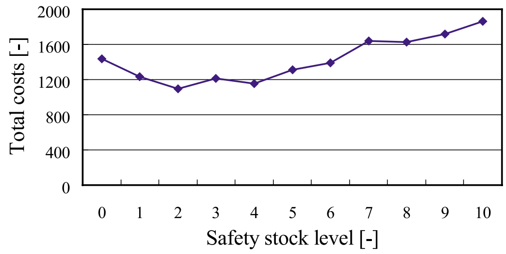

Fig. 9 Effect of safety stock level to total costs

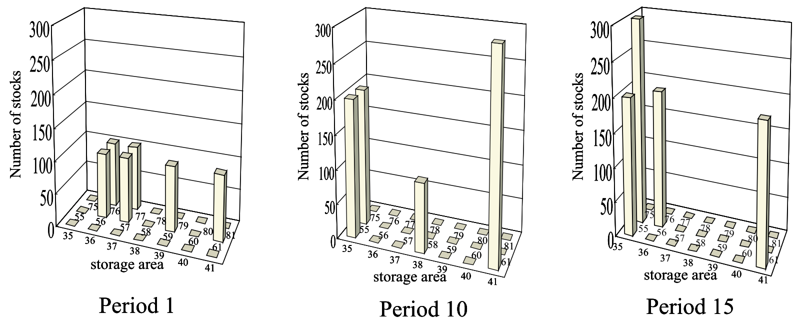

Fig. 10 Transition of storage allocation for dynamic case

tation for 20 time periods. Even though the holding costs for ship for LDC is larger than that of HPM, the holding costs for storage and the penalty shortage costs for LDC are smaller than those of HPM.

Table 7 Comparison of performance between the proposed method (LDC) and hierarchical planning method (HPM) for dynamic case

	LDC	HPM
Holding costs for ship	156	138
Holding costs for storage	180	185
Penalty of shortage	250	650
Fixed costs	245	254
Transportation time	267	267
Total costs	1,098	1,494

6. Conclusion

In this paper, we have proposed a simultaneous optimization model for belt-conveyor transportation system in a raw materials yard. The Lagrangian decomposition and coordination technique has been used to decompose the problem into a storage allocation problem and a routing problem for belt-conveyor line. Numerical experiments demonstrate that the performance derived by the proposed method is better than that of a hierarchical planning method for the cases where the transportation requests are dynamically given to the materials yard. However, the actual storage yard system is operated under more complex situations. It is necessary to create the model with consideration to apply to real plants. For the raw materials yard, the transportation situation is greatly different according to the accidents of machine troubles or weather conditions. To solve planning under several disturbances will be one of future works.

Acknowledgments

The authors gratefully thanks to the support from the funding provided by the JSPS under Grant-in-Aided for Scientific Research (B) No. 18760296.

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