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Transfer Routing of Ore Yard by Decentralized Agent Method

Junji Kikuchi *
Dept. of Electrical and Electronic Engineering
Okayama University
3-1-1, Tsushima-Naka, Okayama, 700-8530

Masami Konishi
Dept. of Electrical and Electronic Engineering
Division of Industrial Innovation Sciences
The Graduate School of
Natural Science and Technology
Okayama University
3-1-1, Tsushima-Naka, Okayama, 700-8530

Jun Imai
Dept. of Electrical and Electronic Engineering
Division of Industrial Innovation Sciences
The Graduate School of
Natural Science and Technology
Okayama University
3-1-1, Tsushima-Naka, Okayama, 700-8530

Tatsushi Nishi
Dept. of Electrical and Electronic Engineering
Division of Industrial Innovation Sciences
The Graduate School of
Natural Science and Technology
Okayama University
3-1-1, Tsushima-Naka, Okayama, 700-8530

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In steel works, iron ores are stored in ore yard and sent to various plants of down stream accoding to transfer requests. To attain stable operation, it is neccesary to keep a certain allowable stock level in ore tanks of all plants. To this purpose, ore transfer routing method has been developed based on decentralized agent method. In case of disaster such as a big earthquake or a big fire, damages in the facilities of industrial complex may be unavoidable. In this paper, decentralized optimization method is tested to cope with such emergencies. Decentralized agents corresponding to kind of ore make their own transfer route plan exchanging information with others. As the application of the proposed method, transfer scheduling in ore yard in steel works are made in case of destruction of transfer facilities.

1 Introduction

In Japan, there are many industrial complexes in seashore area. Iron ores are imported by sea and stored in ore yard of steel works. To attain the stable production, it is needed to transfer required volume of ore from ore yard to ore tanks of plants. In cace of disaster such as an earthquake and a big fire, there may occur destruction of transfer facilities and manufacturing plants in steel work of industrial complex. In such occasions, transfer scheduling should be modified to cope with such troubles. In this paper, an agent based production scheduling method is proposed for the transfer control in steel work. In transfer routing, decentralized agent method is considered to be promising because of its fastness in calculation. In the routing, each ore is treated as an agent. Between agents, necessary information to make transfer routing are exchanged in each other. Cooperative planning is possible through these

*kikuchi@cntr.elec.okayama-u.ac.jp

information exchanges. In case of disaster, production circumstances and planning situation may greatly be changed from its proper conditions. However, the same planning procedure by decentralized agents can be applied to such situations. An autonomous decentralized optimization by agents are proposed in 1999 by an Italian scientist and after that mainly applied to transfer routing problems by plural researchers.[1][2] Examples of the application is routing of multi mobile robots in semiconductors manufacturing line.[3] Recently, in the other field such as production scheduling the decentralized agent method is studied and its effectiveness was revealed having an appropriate solution with high speed convergence characteristics.

In this paper, the method is newly applied to the problem of transfer of iron ores in steel works. In the problem, it is necessary to determine transfer planning for ores from ore yard to plants such as blast furnaces. Base on the decentralized agent method, transfer routing is made for these processes. Further, its applicability to emergency condition is checked. In the following, the structure of transfer routing method by decentralized agents is presented together with its experimental results.

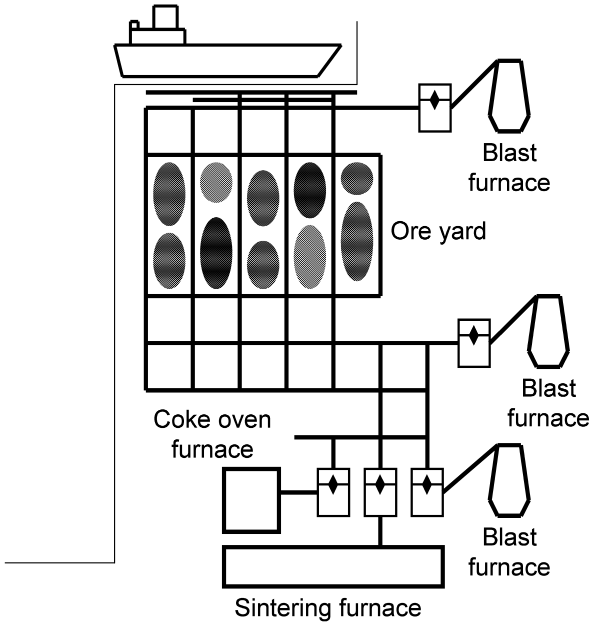

Fig. 1: Production facilities in steel work

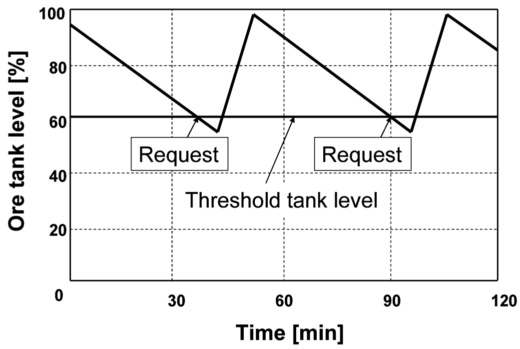

Fig. 2: Ore stocking tank level in blast furnace

2 Ore transfer routing in steel work

In steel work of Japan, raw materials are transported by ships and unloaded on ore yard as shown in Fig.1. According to the request from down stream plants such as blast furnaces and coke oven furnaces, raw materials are transferred through conveyer lines. After processed in blast furnace, the raw material, iron ore, is reduced and processed as pig iron. Basically, cost minimization is the object of transfer routing satisfying constraints in the operation.

For the operation of ore yard, it is required to supply necessary volume of ores to ore stocker in down stream plant such as blast furnace. There occur frequent and simultaneous requests of ore transfer from plural furnaces. Ores are transferred to the corresponding plants mounted on belt conveyers. The routing of conveyers from ore yard to furnaces are the problem to be solved.

As shown in Fig.2, ore tank level in blast furnace moves according to time due to consumption in furnace and to supply of ore from ore yard. After elapse of time, the stock tank level may become beneath the allowable lowest one, then the request for ore supply is to be occurred. To cope with the request, route scheduling of ore transfer will be made. An example of ore transfer is shown in Fig.3. In the routing, decentralized agent corresponding to transfer requested ore searches its appropriate route to minimize the transportation cost. During the transportation, routes for different requests are constructed so as to avoid crossing or collision in transportations. Ore yard model in our study is shown in Fig.4. As shown in Fig.4, all node are numbered from one to fifty two. The problem consists of 52 nodes along the conveyers and 5 plants

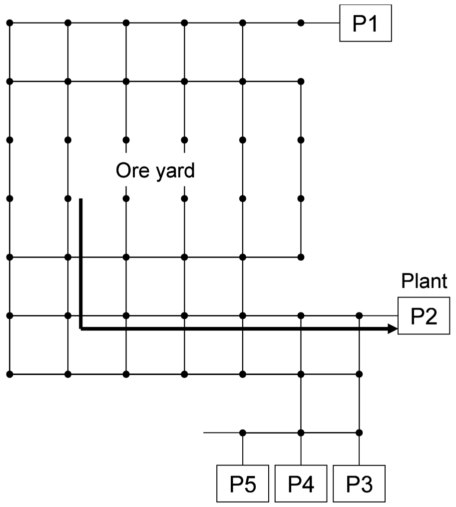

Fig. 3: Example of ore transfer route

which generate transfer requests.

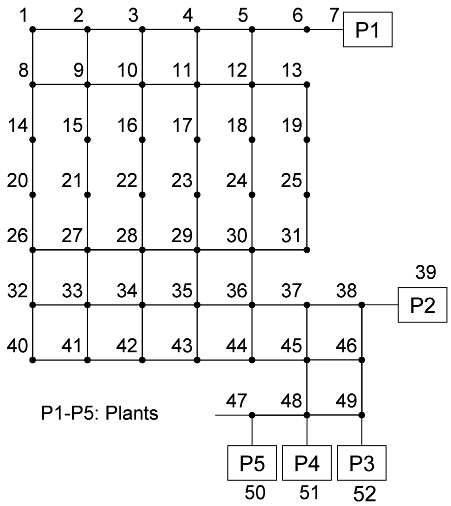

Fig. 4: Ore yard model for study

In our study, the autonomous decentralized agent method is employed. In Fig.5, the structure of decentralized agent production planning system is shown. The system consists of simulation part and agent part. The simulation part consists of facility simulators of conveyers. In the simulation part effect of disaster on the operation in steel work and estimation of calculated results by production plans by agents are made. On the other hand, in the transfer route planning part consists of transfer routing agent. The transfer routing agent corresponding to specified iron ore determines an appropriate transfer route to reach the required ore stock tank of a blast furnace.

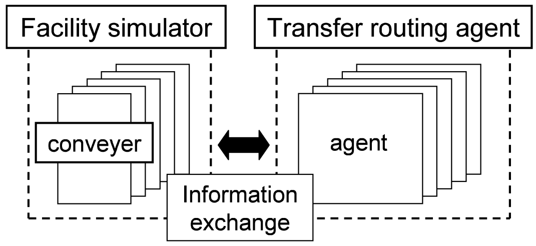

Fig. 5: Construction of decentralized transfer routing system

3 Mathmatical formulation of routing problem

3.1 Constraints

A binary variable $x^k_{i,j,t} \in \{0,1\}$ denotes whether transfer routing agent k travels from node i to node j in time period t. As constraint of operation in transfer, relations (1) to (5) are provided.

$$\sum_{j \notin N_i} x^k_{i,j,t} = 0 \qquad (\forall k, \forall i, \forall t) \qquad (1)$$

$$\sum_{j \in N_i} x^k_{i,j,t} \leq 1 \qquad (\forall k, \forall i, \forall t) \qquad (2)$$

$$\sum_{j \in M_i} x^k_{j,i,t} = \sum_{m \in N_i} x^k_{i,m,t+1} \qquad (\forall k, \forall i, \forall t) \qquad (3)$$

$$\sum_{j \in N_{S_k}} x^k_{S_k,j,0} = 1 \qquad (\forall k) \qquad (4)$$

$$\sum_{k \in V} \sum_{j \in M_i} x^k_{j,i,t} \leq 1 \qquad (\forall i, \forall t) \qquad (5)$$

Here, M_i is the set of up stream nodes which directly connect to node i , N_i is the set of down stream nodes which directly connect to node i, V is the set of transfer routing agents, S_k is the loading node given for agent k. Eq.(1) indicates that agent k cannot travel from node i to node j which is not directly connected to node i. Eq.(2) indecates that agent k can take only one arc in a same time period. Eq.(3) indecates the time continuity constraints of the movement of transfer routing agents. Eq.(4) indicates the initial condition of the place of agent. Eq.(5) indicates that more than an agent cannot travel to a node in a same time period.

3.2 Objective Function

The route plan problem is formulized as a problem which minimizes the following objective function against the given request.

$$I = \sum_k I_k \rightarrow \min \quad (6)$$

$$I_k = n_k + \alpha C_k \quad (7)$$

Where, I is the value of objective function, n_k represents the total transportation time of transfer routing agent k, C_k is the number which transfer routing agent k changes its direction and α is combining weight for scaling.

4 Algorithm for transfer routing

The algorithm for transfer routing is shown as follows.

STEP1 Preparation of initial data

Each transfer routing agent obtains the starting node and the goal node of the request.

STEP2 Generation of an initial route

Each agent independently generates its route with avoiding the routes of other agents.

STEP3 Sprinkle of initial pheromone information

The value of the pheromone information $ph^k_{i,t}$ is updated using the Eq.(8).

$$ph^k_{i,t} = W \sum_{j \in M_i} x^k_{j,i,t} \quad (8)$$

Here, W is the amount of pheromone information.

STEP4 Generation of a new route

(a) Each agent randomly generates a candidate of the node i traveling in time period $(t+1)$ from the node in time piriod t.

(b) Each agent obtains the pheromone information and calculate Δph using the Eq.(9).

$$\Delta ph = ph^k_{i,t+1} - \sum_{k' \neq k} ph^{k'}_{i,t+1} \quad (9)$$

(c) If Δph satisfies the following Eq.(10), the candidate node is accepted, and otherwise rejected and return to (a).

$$d \leq P \quad (10)$$

$$P = \begin{cases} 1 & ; \Delta ph \geq 0 \\ \exp(\Delta ph / T_p) & ; \Delta ph < 0 \end{cases} \quad (11)$$

d is a random number with probability of uniform distribution on the interval [0,1).

(d) If the candidate node does not reach the goal node, the time is updated such as $t \leftarrow t+1$ then return to (a).

STEP5 Judgemet whether the new route is adopted or not

The different value of objective function, ΔI_k is calculated using the Eq.(12).

$$\Delta I_k = I_{k1} - I_{k2} \quad (12)$$

Here, I_{k1} represents the value of objective function by previous solution for agent k, I_{k2} represents the value of objective function by new solution for agent k. And the new route is adopted if the new solution satisfies the following Eq.(13).

$$d \leq Q \quad (13)$$

$$Q = \begin{cases} 1 & ; \Delta I_k \geq 0 \\ \exp(\Delta I_k / T_q) & ; \Delta I_k < 0 \end{cases} \quad (14)$$

STEP6 Update of pheromone information

The pheromone information is updated using Eq.(15).

$$ph^k_{i,t} = (1-\rho) ph^k_{i,t} + W \sum_{j \in M_i} x^k_{j,i,t} \quad (15)$$

Here, ρ is the pheromone evaporation factor.

STEP7 Judging the convergence

If the new route generated at STEP4 is considered as the final solution, the algorithm is terminated, otherwise, return to STEP4.

STEP8 Occupation of nodes

T_k calculated using Eq.(16) is the period during which transfer routing agent k occupies the node on its route.

$$T_k = \left[\frac{A_k}{U_0} \right] \quad (16)$$

Here, A_k is the transfer amount by agent k, U_0 is the amount which a belt conveyer can carry ores. And the pheromone information on route does not evaporate during period T_k using Eq.(17).

$$ph^k_{i,t+1} = ph^k_{i,t+2} = \cdots = ph^k_{i,t+T_k} = ph^k_{i,t} \qquad (17)$$

5 Numerical Experiment

To check the applicability of the decentralized agent method, numerical experiments are made both in proper occation and in emergency situation.

Parameters for decentralized agent method are given as shown in Table.1. Values of T_p and T_q are determined experimentally as described in the appendix A.

Table. 1: Prameters in algorithm

W	ρ	T_p	T_q
6	0.2	3	0.02

5.1 Ore transfer in proper occation

As shown in Fig.6, ore transfer routes are made by each transfer agent corresponding to requested ore transfer. On route, pheromone information corresponding to each transfer agent is disperced. As shown in Fig.7, accumulated amount of pheromone increased with iteration. Each transfer agent occupy nodes on route for a certain period as shown in Fig.8.

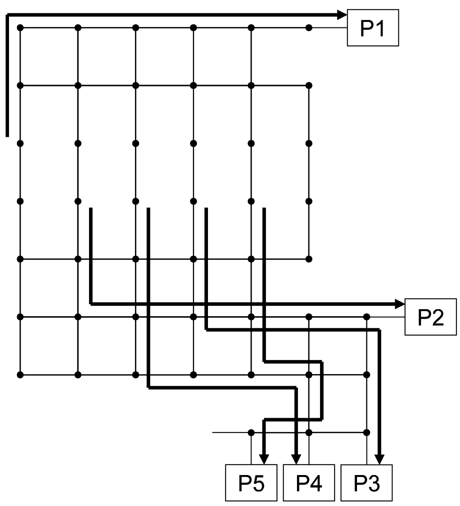

Fig. 6: Result of transfer routing

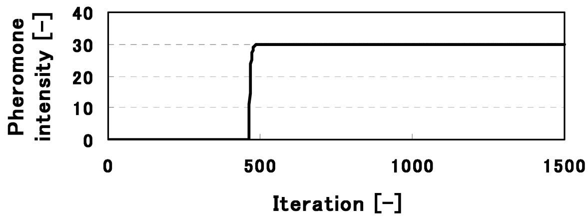

Fig. 7: Change of pheromone accumulation (Ore ♯4, Node ♯36, 34min)

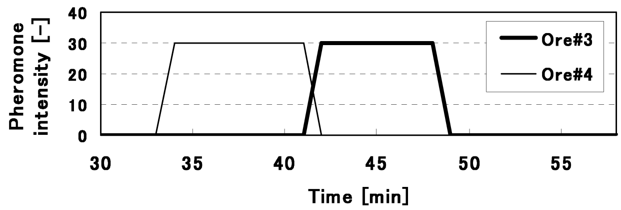

Fig. 8: Occupation of node ♯36

For comparison, deceentralized agent method and SA, which is a centralized optimization method, are applied to the transfer routing problem. The result shows that decentralized agent method can calculate the same transfer route by that of SA method. The comparison of transportation time obtained by the two algorithm is shown in Fig.9. At the same time, high speed computing ability of the decentralized agent method is ascertained compared with SA method.

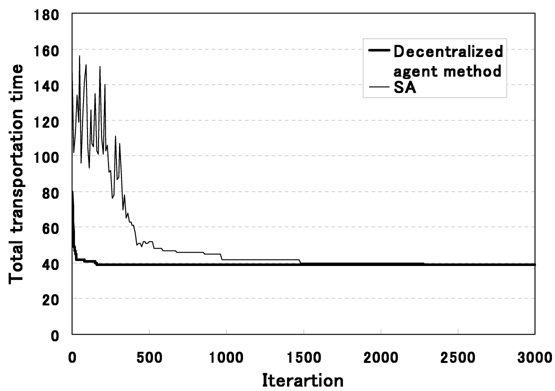

Fig. 9: Compariosn with decentralized agent method and SA

To check the performance of this simulator, request level is changed from 60% to 50% of full amount of

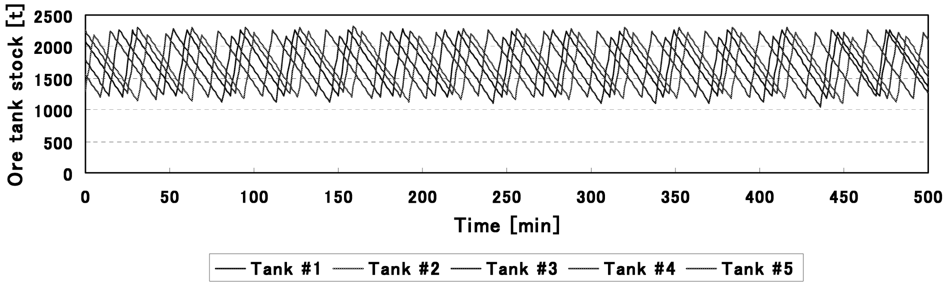

Fig. 10: Change of each ore tank stock (request level 60%)

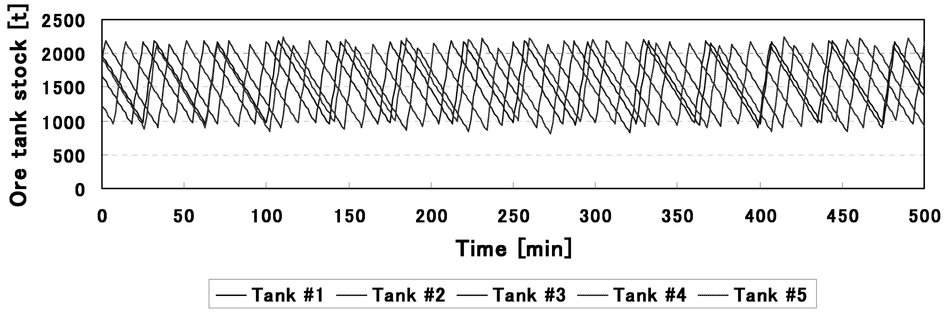

Fig. 11: Change of each ore tank stock (request level 50%)

stock level. The results are shown in Fig.10 and Fig.11. In both cases, ore stock levels are kept in stable states which shows the practicability of the proposed routing method.

5.2 Ore transfer in emergency situation

In the experiment, conveyers are destroyed as shown in Fig.12. To cope with the emergency, transfer routing agents determine surrogate transfer routes avoiding destroyed conveyers.

As shown in Fig.13, the minimum of each ore tank stock go down soon after the accident, but the minimum is gradually stabilized. Maximum, minimum and mean of each ore tank stock in Fig.13 are shown in Table.2. As shown in Table.2, stable ore supply is attained even after emergency decreasing mean level of all ore tanks.

These results show the effectiveness of the proposed transfer routing method based on decentralized agent. Basically, the autononomous decentralized method has the excellent features of short computation time to solve a large scale problem with near optimality.

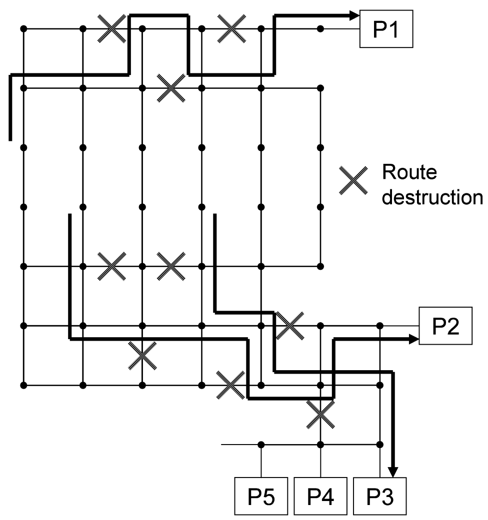

Fig. 12: Change of transfer routing

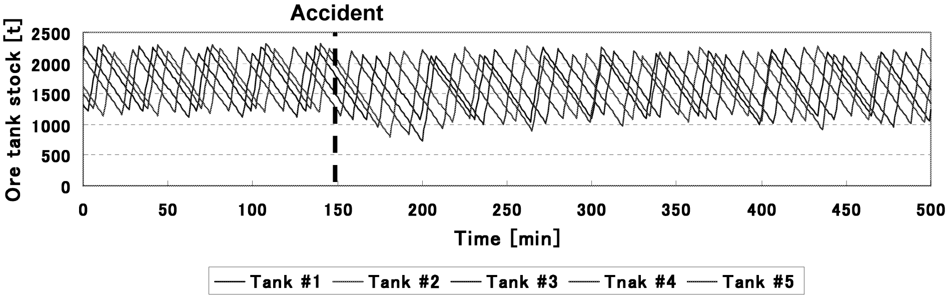

Fig. 13: Change of each ore tank stock when the accident occurs (request level 60%)

Table. 2: Maximum, minimum and mean of each ore tank stock

		Tank ♯1	Tank ♯2	Tank ♯3	Tank ♯4	Tank ♯5
Before accident	max [t]	2270	2239	2275	2261	2314
	min [t]	1210	1139	1115	1165	1254
	mean [t]	1752	1682	1701	1716	1788
After accident	max [t]	2260	2275	2239	2257	2256
	min [t]	992	799	731	825	932
	mean [t]	1614	1610	1594	1595	1613

6 Conclusion

In this paper, the decentralized agent method is newly applied to the problem of transfer routing of products in steel work. The effectiveness of the decentralize agent method is checked and demonstrated through numerical experiments. The method can calculate an appropriate transfer route in a very short time. In the experiments, destructions in transfer facilities are generated. Using the proposed method, surrogate solution with reasonable performance was presented.

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Appendix A:

Determination of parameters T_p and T_q is tried experimentably. In Table.A.1 mean iteration numbers fill convergence are listed for various combinations of T_p and T_q. As shown in Table.A.1, optimal values of T_p and T_q are considered to be 3 and 0.02 respectively which minimize mean iteration numbers before convergence.

Table. A.1: Mean iteration numbers (100 case studies)

		T_p			
		2.8	3	3.2	3.4
T_q	0.02	603.6	512.3	550.9	570.5
	0.06	649.5	579.7	550.9	586.7
	0.1	526.0	567.3	584.3	570.4