

Cooperation of Production, Product Handling and Transfer Scheduling for Semiconductor Fabrication

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(Received December 12, 2007)

Various kind of productions are made in semiconductor fabrications, where it employs the production system with multiprocesses and multiple Automated Guided Vehicles (AGVs) for transportation. It is difficult to optimize planning of production and transportation simultaneously because of the complicated flow of semifinished products. This paper describes the formulations of production scheduling, transportation routing and sequence planning of material handling system, and algorithm for simultaneous optimization of plannings by using solution space reduction and simulated annealing method. In this paper, all production system is decomposed to the production scheduling problem, transportation routing problem by AGVs and sequence planning of material handling system with managing stockers and buffers. Production scheduling problem and transportation routing problem are solved by the optimization algorithm using the decomposition routing problem. Sequence planning of material handling robot problem is solved by the algorithm using simulated annealing method.

1 INTRODUCTION

In semiconductor industry, where severe competitions between makers exist, decrease in operation energy and keeping environment are required from society to improve production line effectively.

Automated Guided Vehicles (AGVs), that are controlled by the computers, transport the half-finished

products between processes. In semiconductor fabrication, because of difference permissible density of dusts by a place, AGVs use inside of production equipment and other AGVs use outside of production equipment. Half-finished products are transferred by using stocker between inside and outside of production equipment. Material handling robot pickups and delivers half-finished products between stockers and production equipment. Stocker can keep several half-finished

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products temporarily. Many methods for FMS have been made to attain improvement of production efficiency. The method, Constraint-Based Genetic Algorithm (CBGA) to handle a complex variety of variables and constraints in a typical FMS-loading problem, is proposed [1]. A hybrid algorithm based on tabu search and simulated annealing is employed to solve the FMS-loading problem [2]. To utilize the bottleneck machines at the maximum level, vehicle dispatches are decided using a vehicle dispatching procedure based on the theory of constraints [3]. Ant colony optimisation-based software system is proposed to solve FMS scheduling in a job-shop environment with routing flexibility, sequence-dependent setup and transportation time [4]. Realtime scheduling method by using genetic machine learning and reactive scheduling method are proposed to optimize production scheduling and transportation routing simultaneously [5]. To attain optimum transportation route, an autonomous distributed route planning method [6] [7] is proposed. This method is that each AGV plans its own route, communicate each other and plan no conflict route. To attain optimum dispatching and transportation routing simultaneously, the hybrid method by using constraint programming mixed integer linear programming and cutting method if infeasible solution solved, is proposed [8]. In the decomposition method, production system, transportation system and handling plan its own schedule and exchange their plans, is proposed [9]. In the past, the simultaneous optimization problem of production schedule and transportation routing was rarely treated because there are many complex variables of FMS needed to decide.

2 PROBLEM OF PRODUCTION, TRANSPORTATION AND HANDLING SYSTEM PLANNING

This chapter indicates production, transportation planning and sequence planning of material handling problem description and formulation as an integer linear problem.

2.1 Problem Description

The object of this research is FMS that is the construction of number of production processes, two dimensional transportation system and material handling

system. In the following, production process will be stated. The number of Jobs, processes and AGVs are decided previously. It is impossible to transport until process finished after the process machine begin to start. It is impossible to transport more than 2 products by one AGV. Process span includes setup span of processing. Sequence of production process is given beforehand. Fig.1 indicates transportation system. Node is the place that AGV can stop or turn, and Edge, AGV's route, is connecting route between nodes.

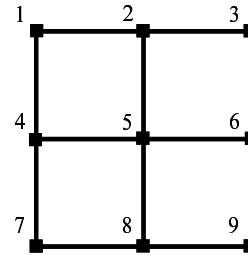


Fig. 1: Transportation Model

To digitize, transportation routing problem is defined below. All of the length of edges are assumed to be equal. AGV's velocity are set to be equal. AGV can stop or turn only on nodes. Transportation requests rise on nodes. And to avoid collisions, following constraints are added.

- Two AGVs cannot exist on a node in the same time period.(Constraint for collision avoidance on node)
- Two AGVs cannot travel on an edge at the same time period.(Constraint for collision avoidance on edge)

And each AGV must synchronize with production processing, so AGV must reach the reserved node until the schedule time is over.

To digitize, sequence planning of material handling robot problem is also defined below.

- Material handling robot's velocity is set to be equal.
- Material handling robot can stop or turn only on nodes.
- Transportation requests rise on nodes which are stocker node, production machine's node and buffer's node.

Fig.2 is the example of gantt chart. In Fig.2, the brack borders is the situation of the production process and AGV. The internal number of the brack borders is the products number. Horizontal axis is time axis. Production scheduling problem determine the process

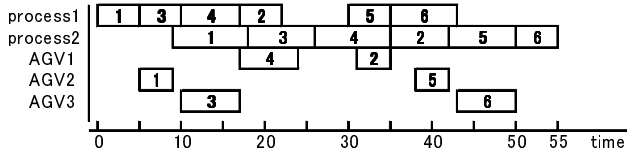


Fig. 2: Example of Gantt chart

turn and start time of processing product in the each processes. It may happen late in reach to reserved node if there isn't enough time to transport even if production is optimal. And if there is much time to transport, it may extend the makespan because of waiting time is longer. Transportation problem determines the assignment of request to AGVs and their routing. Depending to AGV routing, it may extend the assumed time to transport. So it may influence the production schedule. And depending on the assignment of request to AGV, it may prolong the time to transport. So it is needed to determine optimal assignment for all system. Material handling robot is the machine to transport half-finished product between production equipment and AGVs. Planning of material handling system problem is determine when it is carried in or taken out. And this problem determines the buffer to store half-finished product transported by material handling robot temporarily according to the processing situation of production equipment. In this research, the problem of cooperative of production, transportation plannings of AGV and one of material handling robot is to decide the production scheduling and transportation routing to minimize the makespan.

2.2 Problem Formulation

In this section, problem formulation will be described.

2.2.1 Constants and Variables

It indicates the constants and variables used in this paper.

[Constants]

- R : Set of jobs
- P : Set of production processes
- M : Large number
- L_i^l : Span of processing product $\#i$ in process $\#l$
- A : Span to transport next request
- N : Set of nodes
- N_i : Set of nodes which directly connect to node $\#i$
- V : Set of AGV
- R_T : Set of transportation request
- H : Time horizon
- S_k : Initial node of AGV $\#k$
- S_r : Loading node of transport request $\#r$
- F_r : Unloading node of transport request $\#r$
- O_r : Set of operations for job $\#r$

[Variables]

- s_i^l : Start time of job $\#i$ in process $\#l$
- T_i : Span of transport request $\#i$
- V_r : AGV number to transport request $\#r$
- t_{S_r} : Start time of transportation request $\#r$
- t_{F_r} : Finish time of transportation request $\#r$
- f_{INr}^l : Start time of loading for request $\#r$ in process $\#l$
- g_{INr}^l : Finish time of loading for request $\#r$ in process $\#l$
- f_{OUTr}^l : Start time of unloading for request $\#r$ in process $\#l$
- g_{OUTr}^l : Finish time of unloading for request $\#r$ in process $\#l$
- T_{INr}^l : Loading time of request $\#r$ in process $\#l$
- T_{OUTr}^l : Unloading time of request $\#r$ in process $\#l$

The span $\#t$ defines from the time $\#(t-1)$ to the time $\#t$. The explanation of binary variables is below.

The definition of binary variable $\epsilon_{i,j}^l$ that indicate precedence relation about job $\#i$ and job $\#j$ in the process $\#l$, is below.

$$\epsilon_{i,j}^l = \begin{cases} 1 & (\text{In process } \#l, \text{ job } \#i \text{ precedes job } \#j) \\ 0 & (\text{other}) \end{cases}$$

The binary variable $\gamma_{i,j,k}$ that indicate precedence relation about transportation request $\#i$ and $\#j$ to assigned AGV $\#k$ is defined below.

$$\gamma_{i,j,k} = \begin{cases} 1 & (\text{At AGV } \#k, \text{ request } \#i \text{ precedes } \#j) \\ 0 & (\text{other}) \end{cases}$$

The binary variable $\delta_{i,k}$ that indicate transportation request $\#i$ assign to AGV $\#k$, is defined below.

$$\delta_{i,k} = \begin{cases} 1 & (\text{when transportation request } \#i \\ & \text{assign to AGV } \#k) \\ 0 & (\text{other}) \end{cases}$$

The variable $x_{i,j,t}^k$, that indicate the condition of AGV's movement, is defined below.

$$x_{i,j,t}^k = \begin{cases} 1 & (\text{AGV } \#k \text{ moves from node } \#i \text{ to } \#j \\ & \text{in span } \#t) \\ 0 & (\text{other}) \end{cases}$$

The variable $\eta_{r,t}^k$, that indicate the condition of transportation request $\#r$, is defined below.

$$\eta_{r,t}^k = \begin{cases} 1 & (\text{When AGV } \#k \text{ transports request } \#r \\ & \text{in span } \#t) \\ 0 & (\text{other}) \end{cases}$$

The variable $z_{r,r'}^l$, that indicate the relationship between the request r and r' , is defined below.

$$z_{r,r'}^l = \begin{cases} 1 & (\text{request } \#r \text{ precedes } \#r') \\ 0 & (\text{other}) \end{cases}$$

2.2.2 Problem Constraints

When job $\#i$ finishing processing in the process $\#l$ is transported to the reserved process, the start time of transportation t_{S_i} must be later than the completion of process in the process $\#l$. The finish processing time is sum of s_i^l , that is the variable of the start time of process in the process $\#l$, and L_i^l that is the variable of the span. So the relation of s_i^l and L_i^l is given formulation(1).

$$t_{S_i} \geq s_i^l + L_i^l \quad (\forall i \in R; \forall l \in P) \quad (1)$$

When job $\#i$ is processed in the next process $\#(l+1)$, the variable of start time of process s_i^{l+1} must be later than the finish time of transportation. Because the finish time of transportation is related to the start time of transportation and the span, the start time of process

in the next process s_i^{l+1} , the start time of transportation t_{S_i} and the span T_i are given formulation(2).

$$s_i^{l+1} \geq t_{S_i} + T_i \quad (\forall i \in R; \forall l \in P) \quad (2)$$

The relation between the finish time of transportation of job $\#i$, t_{F_i} and the start time of process in the process s_i^{l+1} are given formulation(3).

$$s_i^{l+1} \geq t_{F_i} \quad (\forall i \in R; \forall l \in P) \quad (3)$$

The decision variable $\epsilon_{j,i}^l$ indicates the process precedence about job $\#i$ and $\#j$ in the process $\#l$. The one is decided, the other is decided simultaneously, so the constraint is given formulation(4).

$$\epsilon_{i,j}^l + \epsilon_{j,i}^l = 1 \quad (\forall i, \forall j \in R; \forall l \in P) \quad (4)$$

Job $\#i$ is transported to the reserved process after finishing processing. So to transport by AGV, they must be assigned. The constraint formulation(5) is added below.

$$\sum_{k \in V} \delta_{i,k} = 1 \quad (\forall i \in R; \forall k \in P) \quad (5)$$

If the transportation request $\#i$ and $\#j$ aren't assigned to AGV $\#k$, AGV $\#k$ need not to regard them. So the variable $\gamma_{i,j,k}$ that indicate the precedence of process sequence about request $\#i$ and $\#j$, are assigned to AGV $\#k$, and variable $\delta_{i,k}$ indicated the situation about the assignment to AGV $\#k$ are given formulation(6), (7).

$$\gamma_{i,j,k} \leq \delta_{i,k} \quad (\forall i, \forall j \in R; \forall k \in P) \quad (6)$$

$$\gamma_{i,j,k} \leq \delta_{j,k} \quad (\forall i, \forall j \in R; \forall k \in P) \quad (7)$$

When the variable $\gamma_{i,j,k}$, that indicate the precedence about transportation request $\#i$ and $\#j$, is decided, the variable of start time of transportation, t_{S_i} and t_{S_j} , are decided. The relation of $\gamma_{i,j,k}$, t_{S_i} and t_{S_j} is given below.

$$\gamma_{i,j,k} = \begin{cases} 1 & (t_{S_j} \geq t_{S_i} + T_i + A) \\ 0 & (t_{S_i} \geq t_{S_j} + T_j + A) \end{cases}$$

The constraint about route planning of AGV $\#k$ is given below.

$$\sum_{j \notin N_i} x_{i,j,t}^k = 0 \quad (k \in V, i \in N; t = 1, \dots, H) \quad (8)$$

$$\sum_{j \in N_i} x_{i,j,t}^k \leq 1 \quad (k \in V, i \in N; t = 1, \dots, H) \quad (9)$$

$$\sum_{j \in N_i} x_{j,i,t}^k = \sum_{n \in N_i} x_{i,n,t+1}^k \quad (10)$$

$$(k \in V, i \in N; t = 1, \dots, H-1)$$

$$\sum_{j \in N_{S_k}} x_{S_k,j,0}^k = 1 \quad (k \in V) \quad (11)$$

The formulation(8) indicates that AGV $\#k$ cannot travel from node $\#i$ to node $\#j$ which is not directly connected to node i . The formulation(9) indicates that AGV $\#k$ can take only one edge in a same time span. The formulation(10) indicates the time continuity constraints of the movement of AGVs. On span $\#t$, it indicates that AGV $\#k$ in node $\#i$, can move only the node connected node $\#i$. The formulation (11) indicates the initial condition of the place of AGV.

The constraint of AGV not to collide is given below.

$$\sum_{k \in V} \sum_{j \in N} x_{j,i,t}^k \leq 1 \quad (i \in N; t = 1, \dots, H) \quad (12)$$

$$\sum_{k \in V} (x_{i,j,t}^k + x_{j,i,t}^k) \leq 1 \quad (13)$$

$$(i \in N, j \in N_i; t = 1, \dots, H)$$

The formulation(12) indicates that more than one AGV cannot travel from a node to the connected node in a same time span, The formulation(13) indicates that more than one AGV cannot travel on an edge in a same time span. The constraints about the variables of start time of transportation request $\#r$ t_{S_r} , the finish time t_{F_r} , the start node of transportation node S_r and the goal node of transportation node F_r are the formulation (14) and (15).

$$\sum_{j \in N_{S_r}} x_{S_r,j,t_{S_r}}^{V_r} = 1 \quad (14)$$

$$\sum_{i \in N_{F_r}} x_{i,F_r,t_{F_r}}^{V_r} = 1 \quad (15)$$

The formulation(14) indicates that AGV $\#V_r$ assigned the request $\#r$ must reach the start node S_r at the start time t_{S_r} . The formulation(15) indicates that AGV $\#V_r$ assigned the request $\#r$ must reach the goal node F_r at the goal time F_r . The constraint of each AGVs are limited products to transport at the same time are given formulation(16).

$$\sum_r \eta_{r,t}^k \leq 1 \quad (16)$$

The formulation(16) indicates the constraint which AGV $\#k$ can transport only one request on the span t .

The constraint about route planning of Material Handling is given below. Formulation(17) indicates that the loading motion must start after the completion of transportation by AGVs.

$$t_j^l + T_j^l \leq f_{INj}^l \quad (17)$$

Formulation(18) expresses that the loading motion must

be completed before the start of processing in the process equipment.

$$s_j^l \geq g_{INj}^l \quad (18)$$

Formulation(19) indicates that the unloading motion must start after the completion of processing in the process equipment.

$$s_j^l + L_j^l \leq f_{OUTj}^l \quad (19)$$

Formulation(20) indicates that the unloading motion must be completed before the starting of transportation for the succeeding product.

$$t_i^l \geq g_{OUTj}^l \quad (20)$$

Formulation(21) and (22) indicate that loading time and unloading time.

$$T_{IN,o}^l = g_{IN,J(o,l)}^l - f_{IN,J(o,l)}^l \quad (o \in O_j; j \in J; l \in P) \quad (21)$$

$$T_{OUT,o}^l = g_{OUT,J(o,l)}^l - f_{OUT,J(o,l)}^l \quad (22)$$

Formulation(23) and (24) indicate that precedence relationship between handling operations.

$$g_{OUT,J(o,l)}^l \leq f_{IN,J(o',l)}^l + M(1 - z_{o,o'}^l) \quad (23)$$

$$g_{OUT,J(o,l)}^l \geq f_{IN,J(o',l)}^l + Mz_{o,o'}^l \quad (24)$$

Note that the unloading and loading time for handling robots may change if the sequence of handling operations is different.

2.2.3 Objective function

In this paper, the objective function aims to minimize the makespan that imply all requests finish their processing.

$$\min Q \quad (25)$$

$$Q = \max\{s_i^l + L_i^l\} \quad \forall i \in R, \forall l \in P \quad (26)$$

3 COOPERATION OPTIMIZATION OF PRODUCTION, TRANSPORTATION AND SEQUENCE OF HANDLING SYSTEM

Production scheduling, transportation routing and sequence planning of material handling system problem are described in the following.

- Production Schedule Problem
 - Decision of production turn in the each processes
 - Decision of the start/finish time of production process
- Transportation Routing Problem
 - Decision of the start/finish time of transportation request
 - Decision of the assignment of request to AGV
 - Decision of the transportation routing
- Sequence Planning of Material Handling Robot Problem
 - Decision of the sequence process of material handling robot
 - Decision of the start/finish time of sequence of material handling robot
 - Decision of use stocker or buffer

It is needed to set the production schedule to decide the transportation routing which AGV transport the products and where process. So the master problem decide the production schedule, the assignment of transportation request and the start/finish time of transportation request simultaneously. Sub problem checks the possibility of transportation based on the production plan decided in the master problem.

3.1 Cooperation Algorithm for Production System

The flow chart of the simultaneous optimal algorithm of production schedule, transportation routing and sequence planning of material handling is shown in Fig.3. Steps in Fig.3 are described in the following.

Step1 Master Problem:Production Schedule and Assignment of Request to AGV

To minimize the makespan, it decides the production schedule and assignment of request and the start/finish time of transportation based on the required products, the span of products to process and the span to transport. The span to transport equal to the minimum span to move the goal node from start node. The master problem is formulated as Mixed Integer Linear Programming, and solve the optimal solution. In this research, it takes one span to move neighbor node

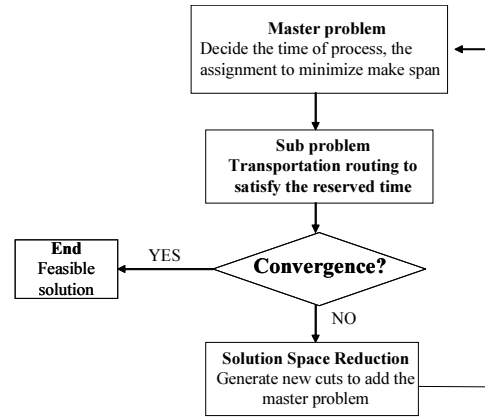


Fig. 3: The algorithm of all production system

and the minimum span to transport is defined by the formulation(27).

$$\min T_r = \sum_t x_{S_r, F_r, t}^k \tag{27}$$

Step2 Sub Problem:Transportation Routing

Based on them decided by master problem, it decides the transportation route to reach the reserved node without late from the reserved time. It uses the autonomous decomposition optimal distributed routing method[6] regarded the start/finish time to transport. This method is that it add the penalty, calculated from the delay span between the reserved time T_k and the now time T_{due}^k , to objective function using transportation routing if AGV don't reach the reserved node till the reserved time.

$$D_k = \max\{0, T_k - T_{due}^k\} \tag{28}$$

Step3 Convergence

If the transportation routing in Step2 can be decided the transportation routing without delay, calculation is finished. Even if it can not plan the delay routing, go to Step4.

Step4 Solution Space Reduction

To eliminate the area including the infeasible solution, it generates the reduction about extension of transportation span, the change of assignment of transportation request and change of turn process.

3.1.1 Master Problem

The master problem decides the start/finish time of products in the processes, the assignment of request to AGV and the start/finish time of transportation. In this paper, it solves the master problem by using the formulation about production schedule and transportation routing that are formulated in Chapter 2.

At first, the formulation about the constraint of production schedule and assignment of transportation. The formulations are described from formulation (29) to (37) as follows.

$$t_{S_i} \geq s_i^l + L_i^l \quad (\forall i \in R; \forall l \in P) \quad (29)$$

$$s_i^{l+1} \geq t_{S_i} + T_i \quad (\forall i \in R; \forall l \in P) \quad (30)$$

$$s_i^{l+1} \geq t_{F_i} \quad (\forall i \in R; \forall l \in P) \quad (31)$$

$$\epsilon_{i,j}^l + \epsilon_{j,i}^l = 1 \quad (\forall i, \forall j \in R; \forall l \in P) \quad (32)$$

$$\sum_{k \in V} \delta_{i,k} = 1 \quad (\forall i \in R; \forall k \in P) \quad (33)$$

$$\gamma_{i,j,k} \leq \delta_{i,k} \quad (\forall i, \forall j \in R; \forall k \in P) \quad (34)$$

$$\gamma_{i,j,k} \leq \delta_{j,k} \quad (\forall i, \forall j \in R; \forall k \in P) \quad (35)$$

$$t_{S_j} \geq t_{S_i} + T_i + A \quad (36)$$

$$\text{when } i \prec j \quad (\forall i, \forall j \in R)$$

$$t_{S_i} \geq t_{S_j} + T_j + A \quad (37)$$

$$\text{when } j \prec i \quad (\forall i, \forall j \in R)$$

Following formulations are rewritten become because there isn't regarded assignment of request $\#i$ and $\#j$ to AGV $\#k$ about the constraint formulation(36) and (37) that precedence $\#i$ and $\#j$ that assigned AGV $\#k$.

$$t_{S_j} + M(1 - \gamma_{i,j,k}) + M(2 - \delta_{i,k} - \delta_{j,k}) \geq t_{S_i} + T_i + A \quad \text{when } i \prec j \quad (38)$$

$$t_{S_i} + M\gamma_{i,j,k} + M(2 - \delta_{i,k} - \delta_{j,k}) \geq t_{S_j} + T_j + A \quad \text{when } j \prec i \quad (39)$$

3.1.2 Transportation Routing Problem

The transportation routing problem decides using the autonomous distributed route planning method regarded the delay penalty. The explain of autonomous distributed route planning method regarded the delay penalty is given in below and the flow chart indicates Fig.4.

Step1 Initial Routing

Each AGV plans own most optimal route without thinking other AGVs.

Step2 Exchange Information

It exchanges with the transportation route $x_{i,j}^l$ of AGV $\#l$.

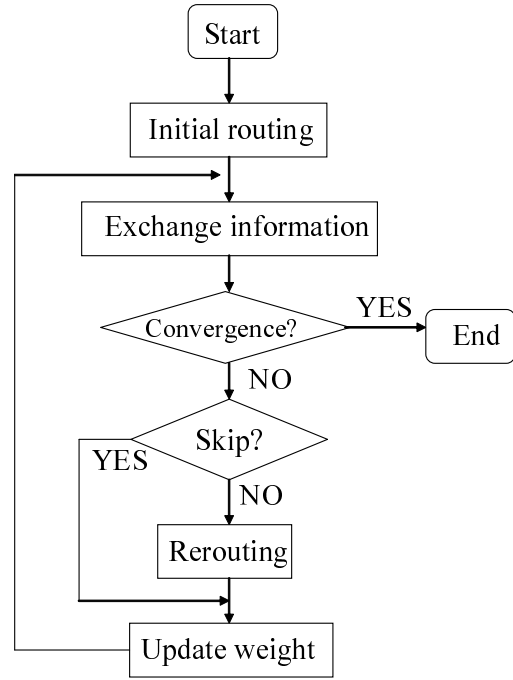


Fig. 4: The algorithm of route planning

Step3 Convergence

This step judges convergence based on route gotten from Step2. If it is convergence, the calculation is finished. Judgment of convergence is that all AGV's route don't update in rerouting without collision.

Step4 Skip

Not to plan route having collision at interval, skip rerouting and go to Step6 by certain odds.

Step5 Rerouting

Based on the information from the Step2, it plans rerouting. To minimize the objective function indicates the formulation(40), it plans the routing. This problem is applied the Dijkstra algorithm because of the shortest route problem of each AGV added the penalty of collision and delay as cost.

$$I_k = \sum_t \pi_{k,t} + \sum_{l \in V, l \neq k} \alpha_{k,l}(r)(C_{k,l}^1 + C_{k,l}^2) + \beta D_k \quad (40)$$

The variable $\pi_{k,t}$ is that, when AGV $\#k$ reach the reserved node in span t , equal 0, the other ,equal 1. This

variable's constraint is given below.

$$\sum_{i \in N_{G_k}} x_{i,G_k,t}^k \leq (1 - \pi_{k,t}) \quad (41)$$

$$\begin{aligned} & (k \in V; t = 1, \dots, H) \\ \sum_{i \in N_{G_k}} x_{i,G_k,t}^k & \geq 1 - \pi_{k,t} \quad (42) \\ & (k \in V; t = 1, \dots, H) \end{aligned}$$

At once, because AGV reaching the reserved node stop there, the added constraint is given below.

$$\begin{aligned} -\pi_{k,t} + \pi_{k,t+1} & \leq 0 \quad (43) \\ & (k \in V; t = 1, \dots, H-1) \end{aligned}$$

The variable $C_{k,l}^1, C_{k,l}^2$ indicate the times of collision of AGV $\#k$ and AGV $\#l$.

Step6 Update of Weighting Factor of Penalty Function

If the route from rerouting is infeasible, for AGV collision according to the formulation(44), update of weighting factor of penalty function $\alpha_{k,l}(r+1)$ and go back to Step2. The variable r indicates the times of rerouting.

$$\alpha_{k,l}(r+1) = \alpha_{k,l}(r) + \Delta\alpha \sum_{l \neq k} (C_{k,l}^1 + C_{k,l}^2) \quad (44)$$

3.2 The Constraints of Reduction and Formulation

When the master problem solution find infeasible assessed from the sub problem, by adding the constraint generating from reduction, it is method to eliminate the area including infeasible solution and to solve efficiency. This section explains the logic to eliminate the solution area. When reduction do is that when it is impossible to plan the route to satisfy the start or finish time of transportation request. So it is thought that the condition about transportation decided by the master problem is bad. So, by doing the reduction, the constraints about sub problem are relaxed and the constraint of the master problem constrain is added. By those constraint, logic is defined to change the factor of master and sub problem the assumption that noted previously. In this paper, following the three types of logic are checked.

- Extension of transportation span
- Change in assignment of request to AGV
- Change of processing turn

The explain of formulation of each logic is given below.

Extension of transportation span

The extension of span of transportation request T_r is add more one span. T_r^* is the previous span of transportation request $\#r$. The variable ζ_r , indicate the previous span of request $\#r$ is changed as following.

$$\zeta_r = \begin{cases} 1 & T_r = T_r^* + 1 \\ 0 & T_r = T_r^* \end{cases}$$

The variable ζ_r about the follow constraint is formulated describe the formulation(45) to (48).

$$T_r + M(1 - \zeta_r) \geq T_r^* + 1 \quad (45)$$

$$T_r \leq M\zeta_r + T_r^* \quad (46)$$

$$T_r + M\zeta_r \geq T_r^* \quad (47)$$

$$T_r \leq T_r^* + 1 + M(1 - \zeta_r) \quad (48)$$

Change in Assignment of Request to AGV

The explain of change assignment in transportation request is given below. The binary variable $\delta_{r,V_r}^{*(k)}$ that indicate the assignment of request is changed define below. Here $\#V_r$ indicate the previous assignment of request $\#r$ to AGV.

$$\delta_{r,V_r}^{*(k)} = \begin{cases} 1 & \text{(Iteration } k \text{ of request } \#r \\ & \text{assigned to AGV } \#V_r) \\ 0 & \text{(other)} \end{cases}$$

$$\sum_{r \in R_T} \delta_{r,V_r}^{*(k)} \leq |R_T| - 1 \quad (49)$$

$$\text{when } \delta_{r,V_r}^{*(k)} = 1 \quad (\forall i \in R; \forall l \in P)$$

Change of Processing Turn

It describes that the constraint of change turn of process. The binary variable $\epsilon_{i,j}^{*(k),l}$ that indicate the turn process is changed as follows.

$$\epsilon_{i,j}^{*(k),l} = \begin{cases} 1 & \text{(At iteration } k, \#i \prec \#j \text{ in the process } \#l) \\ 0 & \text{(other)} \end{cases}$$

$$\sum_{i \in R} \sum_{j \in R} \epsilon_{i,j}^{*(k),l} \leq |R^2| - |R| - 1 \quad (50)$$

$$\text{when } \epsilon_{i,j}^{*(k),l} = 1$$

Formulation(50) is introduced to derive solution different from that obtained before.

Change in assignment of transportation request to AGV and Change of processing turn are integer cut.

So formulation(49) and (50) are transformed into formulation (51).

$$\sum_{r \in R_T} \delta_r^{*(k)} + \sum_{i \in R} \sum_{j \in R} \epsilon_{i,j}^{*(k),l} \leq |R^2| - |R| + |R_T| - 1$$

when $\delta_r^{*(k)}, V_r = 1, \quad \epsilon_{i,j}^{*(k),l} = 1 \quad (51)$

3.3 Planning of Handling robot's Sequence Problem

Material handling robot transports half-finished product between production equipment and stocker or buffers. Fig.5 indicates the layout of material handling system.

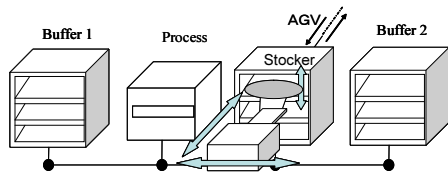


Fig. 5: Material Handling System

3.3.1 Definition of Handling robot's Sequence

Table1 indicates the defined sequence of material handling robot. Fig.6~11 indicate the operation of sequence of material handling robot.

Sequence ID	Robot motion
S1	Pickup from stocker
S2	Transportation to equipment
S3	Transportation from equipment
S4	Delivery to stocker
S5	Keeping in buffer
S6	Pickup from buffer

- S1:Pickup from stocker
S1 is a sequence that pickup a half-finished product from stocker.

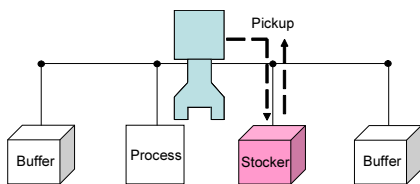


Fig. 6: Operation of Sequence S1

- S2:Transportation to equipment
S2 is a sequence that deliver a half-finished product to equipment.

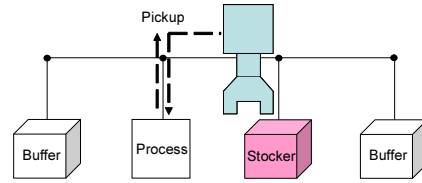


Fig. 7: Operation of Sequence S2

- S3:Transportation from equipment
S3 is a sequence that pickup a product from equipment.

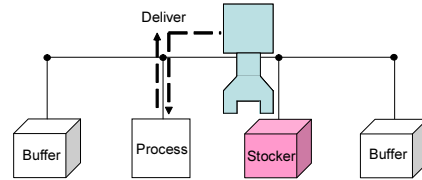


Fig. 8: Operation of Sequence S3

- S4:Delivery to stocker
S4 is a sequence that deliver a half-finished product to stocker.

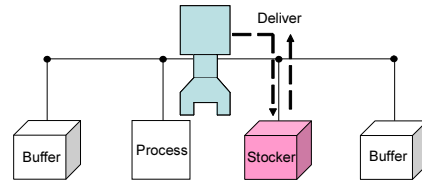


Fig. 9: Operation of Sequence S4

- S5:Keeping in buffer
S5 is a sequence that deliver a half-finished product to a buffer.

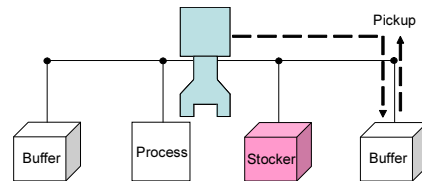


Fig. 10: Operation of Sequence S5

- S6:Pickup from buffer
S6 is a sequence that pickup a half-finished product from a buffer.

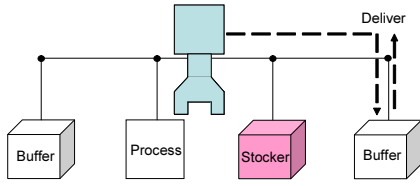


Fig. 11: Operation of Sequence S6

Material handling robot can't keep a number of half-finished product. So if robot pick up product, robot must deliver to other place. From this reason, Table2 indicates the handling sequence motion.

Table. 2: Sequence Motion

Sequence	Motion of Material Handling robot
S1 → S2	Stocker → Production Equip.
S1 → S5	Stocker → Buffer
S3 → S4	Production Equip. → Stocker
S3 → S5	Production Equip. → Buffer
S6 → S2	Buffer → Production Equip.
S6 → S4	Buffer → Stocker

3.3.2 Cooperation Algorithm of Sequence of Material Handling Robot

In this paper, sequence of material handling robot is decided by using simulated annealing method algorithm. It indicates the explanation of algorithm.

Step1 Decision of initial solution

In this step, it determines the pattern of handling sequence of products randomly. Based on this determination, it determines the sequence of material handling robot and the start time of each sequence. The solution is adopted as the temporary solution.

Step2 Derived neighbor solution

Based on the temporary solution, it derives the neighbor solution.

Step3 Adoption of temporary solution

If the value of objective function of neighbor solution is better than the temporary solution, neighbor solution is adopted as the temporary solution. Otherwise, not to solve local area of optimize solution, based on the odds of difference

of objective function and present temperature, it determines whether neighbor solution is adopted as the temporary solution or not.

Step4 Update temperature

If the calculation times is more than setup time in the same temperature, go to Step5. Otherwise go to Setp2.

Step5 Convergence

If present temperature is higher than freeze temperature, update the present temperature, and go to Step2. Otherwise stop the calculation and output the temporary solution as the optimal solution.

Fig.12,13 indicate the solving method of neighbor solution.

- Shuffle of Sequence

A transportation request of handling robot, is picked randomly, shuffle other request. And it determines the sequence of material handling robot again.

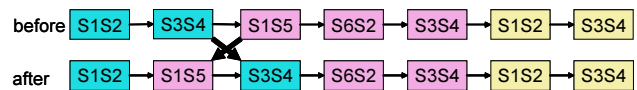


Fig. 12: Shuffle of Sequence

- Change of Sequence

Change the transportation request, it determines the sequence order of material handling robot again.

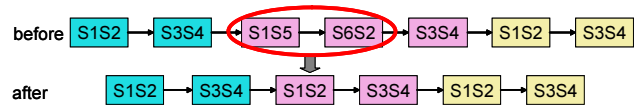


Fig. 13: Change of Sequence

The method of determination of the start time of sequence of material handling robot and the method of determination of the place of buffer to keep the half-finished product temporarily are below. The start time of sequence of material handling robot h_s^i depends on the sum of finish time of adjacent sequence and transportation period or the warehousing time of product.

h_s^i indicates the start time of sequence of material handling robot. The start time of S1,S3 is defined equation(52), and the start time of S2,S4,S5,S6 is defined equation(53).

$$h_s^i = \max\{h_s^{i-1} + U^{i-1}, h_s^i - U^i\} \quad (i = 1, 3)(52)$$

$$h_s^i = h_s^{i-1} + U^{i-1} \quad (x = 2, 4, 5, 6) \quad (53)$$

U^i indicates the period of sequence $\#i$ motion. The method of determination of buffer position is that the most nearest buffer from present position of material handling robot.(Equation(54))

$$\min L = \sum x_{i,j}^l \quad (l \in L) \quad (54)$$

4 NUMERICAL EXPERIMENTS

In this chapter, at first, by using the optimization algorithm for material handling robot, it indicates the numerical experiments of only material handling robot. And by using the algorithm for all production system, it indicates the numerical experiments.

4.1 Material Handling System Problem

By using proposed method for material handling robot, it solves the sequence solution of material handling robot about Table3. Fig.5 indicates the layout of material handling system. In this system, there is one material handling robot. And there are two buffers at the sides, each buffer can keep 4 half-finished products, stoker can keep 3 products. Fig.14 indicates the node layout of material handling system. Table4 indicates

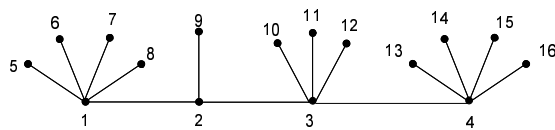


Fig. 14: Node of material handling system

the Parameter of Simulated Annealing in this numerical experiment.

4.2 The Result of Material Handling System Problem

Fig.15,16 indicate the gantt chart when penalty factor of objective function of material handling robot are

Table. 3: The Example Request of Handling Robot

	stoker(in)	start pro.	end pro.	stoker(out)
1	4	10	47	80
2	29	71	102	118
3	60	136	174	180

Table. 4: Parameter of SA

start temp.	100
freeze temp.	0.01
Calc. loop	50
update temp.	0.9

changed. Equation(55) indicates the objective function of material handling robot.

$$J = \kappa \sum_t x_t + \mu \sum_{j \in J} (h_j^i - s_j) + (h_s^i - s_j) \quad (55)$$

κ is the weight factor of penalty of motion of material handling robot, and μ is the weight factor of delay penalty. The number, in the stoker, production equipment and buffer, indicates the production ID, the number, in the handling robot, indicates the sequence ID. Fig.17,18 indicate the root of material handling

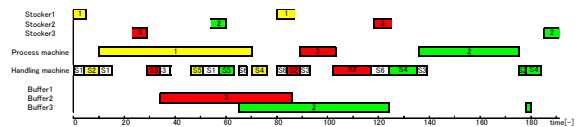


Fig. 15: $\kappa=1, \mu=1$

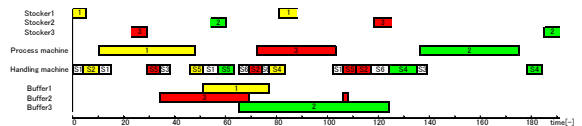


Fig. 16: $\kappa=1, \mu=10$

robot when penalty factor of objective function of material handling robot are changed. Fig.19,20 indicate the changes of the objective function of material handling robot when penalty factor of objective function of material handling robot are changed. Table5 indicates the time delay and sum of distant when penalty

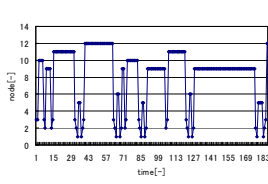


Fig. 17: $\kappa=1, \mu=1$

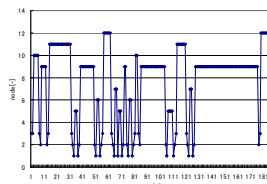


Fig. 18: $\kappa=1, \mu=10$

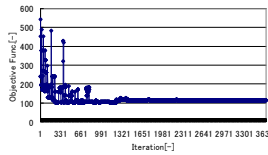


Fig. 19: $\kappa=1, \mu=1$

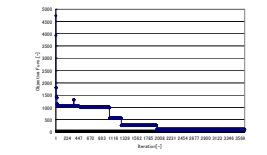


Fig. 20: $\kappa=1, \mu=10$

factor of objective function of material handling robot are changed.

Table. 5: time delay and sum of distant

	time delay	sum of distant
$\kappa = 1, \mu = 1$	22	80
$\kappa = 1, \mu = 10$	1	79

Increase the delay penalty of objective function therefore delay can be decrease. But, each sum of distant is subequal. And, it confirms the wasted sequence for evaluation. To improve these problem, it needs considering the making method of neighbor solution by using SA method.

4.3 Production and AGV routing Problem

In this section, by using the proposed method, it derives the optimization solution of production scheduling and transportation routing of AGVs. Fig.21 indicates the layout of FMS model. The place where take

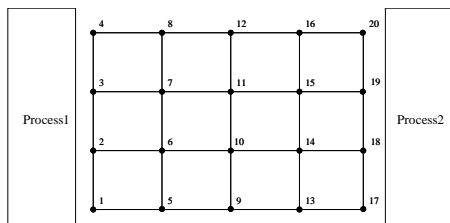


Fig. 21: The FMS model

out products from process #1 is node 1 and node 4, the place bring in them to process #2 is node 17 and node 20. Node 1 and node 4 are called input buffer, node 17 and node 20 are called output buffer. It indicates the result, that when the number of AGV is 3 and the number of request is 6, in Table 6. In addition, the pa-

Table. 6: The input data of example problem

Product ID	pro.1	pro.2	start node	goal node
1	6	9	4	20
2	6	5	1	17
3	8	6	4	17
4	9	7	1	20
5	5	7	1	20
6	6	5	4	17

Table. 7: Initial node of AGV

AGV ID	Initial node
1	17
2	14
3	7

parameter of skip ratio is 30 %, the increment of penalty function is 0.8, the increment of delay penalty is 30 in this calculation.

4.4 The Result of Production and AGV routing Problem

Fig.22,23 indicate the schedule of production equipment and AGV. Fig.22 is the solution of first iteration. Fig.23 is the solution of eighth iteration. Fig.24 in-

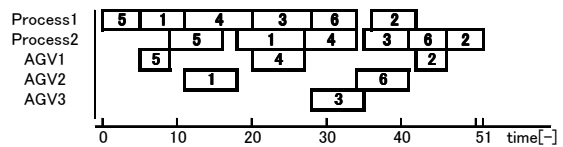


Fig. 22: Ganttchart(iteration0)

indicates the changes of upper bound and lower bound. Lower bound is the period of end of process all request when only the master problem is derived. Upper bound is the period of end of process all request add the amount of delay. From seeing Fig.24, lower bound

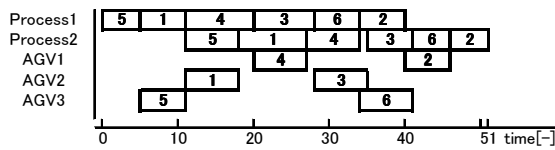


Fig. 23: Ganttchart(iteration8)

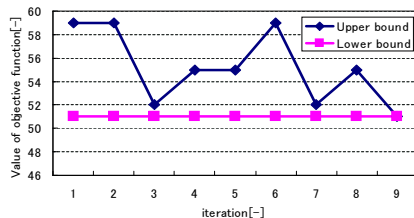


Fig. 24: Change of Upper and Lower Bound

is not changed and upper bound reaches lower bound. So in this problem, it learns that the proposed method can solve the optimal solution.

5 CONCLUSION

In this paper, optimization method of production schedule and transportation routing of AGVs, and the method of sequence planning of material handling robot are proposed. The method determines optimal sequence operation of material handling robot by using simulated annealing. Production equipment scheduling and transportation routing of AGVs are optimized by using solution space reduction algorithm. From the numerical experiments, the optimization method of material handling system can be improved considering wasted sequence for evaluation. And the optimization method of production equipment and transportation routing can derive optimization solution. The optimization method of production equipment schedule, transportation routing of AGVs and sequence planning of material handling robot are left for future works.

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