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A Method for Designing the Supplying Method of Parts to an Assembly Line

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We propose a method to design the supplying method of parts to an assembly line. Three types of supplying model (Serial, Parallel, and Mixed) are proposed based on the relation between the area of part and that of the transportation equipment. The part is supplied by the pallet on which the all parts of one product are arranged or by the lot of one part. AGV or conveyor are used to transport the pallet.

The supplying model is evaluated from the total transportation cost calculated from the price of the transportation equipment and of land.

1. INTRODUCTION

The flow of part from warehouse to assembly station by transportation equipment is primary important for designing an assembly line to produce multi-item product efficiently. In the conventional method designing the assembly line, the flow of part among stations was considered mainly and the supplying method of the part to the station is treated secondly. (1) But the transportation from warehouse to assembly station is very important in FA assembly system to save the investment cost. (2)

In this paper, we propose the supplying method to supply the part in the assembly line. The parts of one product or one kind of part are arranged on one pallet. The pallet is transported by AGV or conveyor from the warehouse to the assembly station. Under these conditions, three types of supplying model is evaluated from the transportation cost .

2. PROPOSED METHOD

2. 1 Assumption

(1) The assembly station comprizes an assembly machine and buffer. The buffer is divided in two areas. One area is used to receive the part from the transportation equipment and the other to supply the part to the assembly machine.

(2) The parts of one product or one kind of part are arranged on one pallet. Each pallet is transported by the transportation equipment.

(3) There are k assembly stations. The parts of a product is supplied from the warehouse by some transportation method. The parts assembled are transported to the next station by the conveyor with the same speed (pitch time).

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(4) The transportation equipment from warehouse to assembly station is AGV, belt conveyor or other handling equipment.

(5) The sequence of assembly station is given by the other method.

The following notation is used to formulate the supplying model.

G_i : The kind of product (1, 2, …, N)

M_j : The assembly station (j = 1, 2, …, k)

P_{ij} : The part of product Gi which is assembled in an assembly station M_j

B_j : Size of buffer (m^2)

VV_{ij} : Size of P_{ij} (m^2)

P : Pitch time of the assembly line

ℓ_j : Distance between the assembly station M_j and the warehouse

d : Distance between the consecutive assembly stations

V_j : Speed of transportation equipment from the assembly station M_j to the warehouse.

$L_1 \cdot L_2$: Area of transportation equipment (L_1 : width, L_2 : length)

2. 2 Number of parts in a buffer and supplying interval

The number (IN_j) of the same kind parts in a buffer of the assembly station (M_j)is given by equation (1).

$$IN_j = \frac{B_j}{2 \cdot VM_j} \tag{1}$$

$$\text{where}, \quad VM_j = \max_{1 \leq i \leq N} VV_{ij}$$

The speed (V_j) of transportation equipment from the warehouse to each assembly stations is determined from the distance (ℓ_j) and the service time ($IN_j \cdot P$) by eq. (2).

$$V_j = \ell_j \cdot / (IN_j \cdot P) \tag{2}$$

From the relation between speed (V_j) and the allowable speed (V_0) of transportation equipment, the supplying interval (NP_{0j}) is put as the maximum value of n_j which is satisfied the eq. (3) .

$$\frac{V_j}{(n_j + 1)} \leq V_0 \tag{3}$$

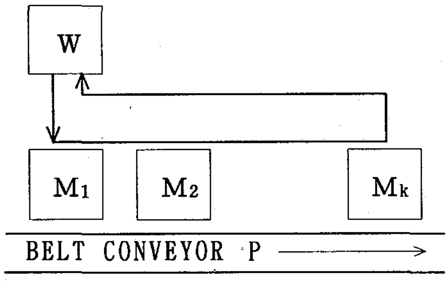
2. 3 The case that all parts of one product are set on one pallet

The part of each product should be stored in the buffer. Therefore, the size of buffer is satisfied the eq. (4) . And it is assumed that the parts of one product are arranged on the pallet.

$$B_j / 2 \geq \max_{1 \leq i \leq N} VV_{ij} \tag{4}$$

(1). Serial Mode

In this case, the area of the transportation equipment is larger than that of all parts



W : Warehouse, Mj : Assembly station

Fig. 1 Serial model

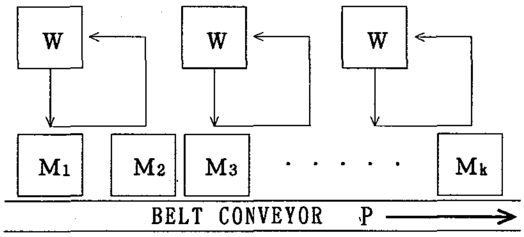
($\sum_{j=1}^{k} VM_j < L_1 \cdot L_2$). Then the transportation equipment is able to carry all parts by one pallet. The pallet is supplied serially from the warehouse to assembly stations along the assembly line. This type of transportation method is called as the serial model. (Fig. 1)

(2). Serial Model with Block

In this case, the area of transportation equipment is smaller than that of all parts ($\sum_{j=1}^{k} VM_j > L_1 \cdot L_2$). The transportation equipment is not able to carry all parts by one pallet. Therefore the assembly stations are grouped into some blocks (NB) based on the area ($L_1 \cdot L_2$) of transportation equipment by eq. (5). The pallet arranged parts is supplied serially to assembly stations in each block. (serial model with block). (Fig. 2)

$$NB = \left[\frac{\sum_{j=1}^{k} VM_j}{L_1 \cdot L_2} \right] + 1 \quad (5)$$

Where : [ ] Notation is the Gauss operation.

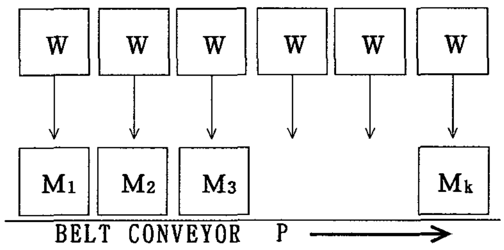


W : Warehouse, Mj : Assembly station

Fig. 2 Serial model with block

(3) Parallel Model

In this case, the condition that $MV_j = L_1 \cdot L_2$ for all assembly station is satisfied. One transportation equipment can carry only one part. Then the part is carried directly from the warehouse to an assembly station.



W : Warehouse, Mj : Assembly station

Fig. 3 Parallel model

(4) Mixed Model

In this case, the area of some parts is equal to that of transportation equipment ($VM_{jp} = L_1 \cdot L_2$, $p = 1, 2, \cdots, PN$). These parts should be supplied by the parallel model.

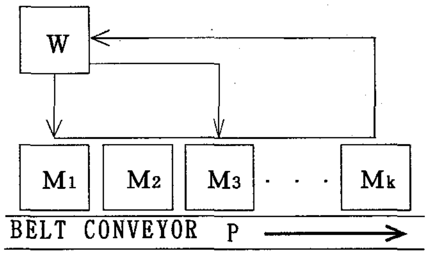
For the other assembly stations (k−PN), parts are supplied in the serial model or the serial model with block. This model is called as the mixed model (Fig. 3).

2. 4 Estimation of the total transportation cost

2. 4. 1 The case that the transportation equipmentent is AGV

(1) Number of AGV

As the number of AGV is depend on the investment cost directly, the number of AGV for each models are estimated as follows.



W : Warehouse, Mj : Assembly station

Fig. 3 Mixed model

(a) Serial model

As all parts are supplied by one AGV, then the number of AGV is calculated by eq. (3) at the first station (M_1) and the last station (M_k). The number of AGV for the first station (M_1) is equal to (NP_{01} + 1), and NP_{0k} is the number of AGV from the last station (M_k) to the warehouse. Further each station is needed one AGV. The total number (NT_0) of AGV is given by eq. (6).

$$NT_0 = (NP_{01} + 1) + k + NP_{0k} \tag{6}$$

(b) Serial model with block

The assembly stations are grouped into NB blocks by eq. (5). As the number (NT_r) of AGV is calculated by eq. (6) in r–th block, the total number (NT_0) of AGV is given by eq. (7).

$$NT_0 = \sum_{r=1}^{NB} NT_r \tag{7}$$

(c) Parallel model

As the part is supplied to an assembly station from the warehouse, it is assumed that the going speed (V_{1j}) of AGV is not equal to the returning speed (V_{2j}) speed. The number of AGV for going and returning are calculated as (MP_{j1}, MP_{j2}) by eq. (3). Then the number of AGV for each assembly station is given as follows.

$$NT_j = (MP_{1j} + 1) + (MP_{2j} + 1) \tag{8}$$

The total number (NT_0) of AGV is given by eq. (9).

$$NT_0 = \sum_{j=1}^{k} NT_j \tag{9}$$

(d) Mixed model

As the assembly station of parallel model is put as M_{jq}, $q = 1, 2, \cdots, k_2$, the number (NT_{jq}) of AGV for each station (M_{jq}) is given by eq. (8) and total number of AGV is calculated by eq. (10).

$$NT_{01} = \sum_{q=1}^{k_2} NT_{jq} \tag{10}$$

For assembly stations ($k_1 = k - k_2$) showing the serial model or the serial model with block, the number (NT_{02}) of AGV is calculated by eq. (6) or eq. (7). The total number of AGV for mixed model is given by eq. (11).

$$NT_0 = NT_{01} + NT_{02} \tag{11}$$

(2) Area of the transportation path

As the area of path is influenced to the investment cost directly, the area of path is estimated as follows.

(a) Serial model; The width (L_1) of AGV is put as the same width of the transportation area. The transportation area of AGV is given by eq. (12).

$$AP_0 = L_1 \cdot (\ell_1 + (k-1)d + \ell_k) \tag{12}$$

(b) Serial model with block; The area of path is given by eq. (13).

$$AP_0 = \sum_{r=1}^{NB} AP_r \tag{13}$$

where : AP_r is the area of path in r th block.

(c) Parallel model; As AGV goes to a station and returns to warehouse on the different path, the area of path is given by eq. (14).

$$AP_0 = 2 \cdot L_1 \sum_{j=1}^{k} \ell_j \tag{14}$$

(d) Mixed model; The area of path is put as AP_{01} in the serial model, and as AP_{02} in the parallel model. The area of path is given by eq. (15).

$$AP_0 = AP_{01} + AP_{02} \tag{15}$$

(3) Total cost (CT) of transportation

From the number of AGV and the area of path, the total cost (CT) is given by eq. (16).

$$CT = C_1 \cdot NT_0 + C_2 \cdot AP_0 \tag{16}$$

Where : C_1 : the price of AGV (¥ / unit)

C_2 : the price of land (¥ / m^2)

2. 4. 2 The Case that the transportation equipment is conveyor

The supplying area on a conveyor is put as the width (L_1) and length (L_2). The pallet puts in this area. The handling equipment acts on this area ($L_1 \cdot L_2$).

(1) Serial Model

The equation ($\sum_{j=1}^{k} VM_j < L_1 \cdot L_2$) is satisfied. As all parts of a product are arranged on the pallet, then the parts are supplied to each assembly station with the pitch time, and the area of path is given by eq. (17).

$$AP_0 = NT = L_1 \cdot (\ell_1 + (k-1)d + \ell_k) \tag{17}$$

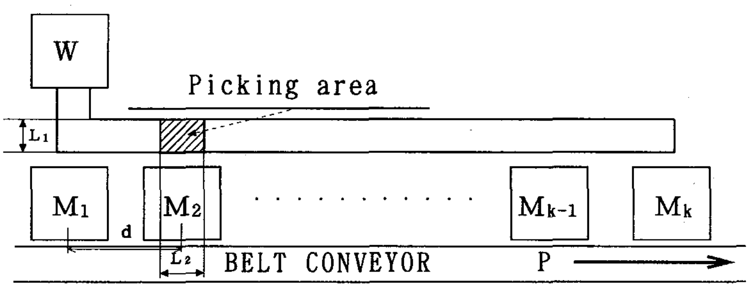


Fig. 5 Serial model

(2) Serial Model with block

As the equation ($\sum_{j=1}^{k} VM_j > L_1 \cdot L_2$) is satisfied, the assembly stations are grouped into blocks.

The number of blocks is given by eq. (18).

$$NB = \left[\frac{\sum_{j=1}^{k} VM_j}{L_1 \cdot L_2} \right] + 1 \tag{18}$$

The area of path is given by eq. (19).

$$AP_0 = NT_0 = \sum_{\ell=1}^{NB} AP_{0\ell} \tag{19}$$

where $AP_{0\ell}$ is put as the area of path in ℓ −th block.

(3) Total transportation cost (CT)

Total transportation cost (CT) is estimated from the price of equipment (C_1) and of land (C_2) by eq. (20)

$$CT = (C_1 + C_2)\, AP_0 \tag{20}$$

2. 5 The case that parts are supplied by lot

As the number of parts stored in the buffer of the station (M_j) is equal to IN_j, the supplying model is evaluated under the condition that the part is supplying by the lot to reduce the traffic intensity.

(1) For the part that shows the $IN_{jq} = 1$, $q=1, 2, \cdots, k_2$, the number ($NP_{0j}+1$) of transportation equipment is determined as the maximum value (n_j+1) which is satisfied eq. (21).

$$P \geq \frac{\ell_{jq}}{n_j + 1} \tag{21}$$

(2) For the part that shows the $IN_j \neq 1$. The assembly stations are classified into blocks by eq. (22) considering IN_j. Hereafter we denote IN_j as the lot size of part.

$$NB = \left[\frac{\sum_{j=1}^{k} IN_j \cdot MV_j}{L_1 \cdot L_2} \right] + 1 \tag{22}$$

The assembly stations in some block are denoted as M_{jq}, $q=1, 2, \cdots pp$.

As the supplying interval ($IN_{jq} \times P$) is different in each station, the assembly work can not do under the serial model. Then the lot size of part is determined in block as follows.

The minimum value of IN_{jq} puts as IN_{j0}.

$$IN_{j0} = \min_{1 \leq q \leq pp} IN_{jq}$$

As the supplying interval puts as $IN_{j0} \cdot P$ in a block, the lot size in assembly station (M_{jq}) is determined by eq. (23).

$$IIN_{jq} = \left[\frac{IN_{jq}}{IN_{j0}} \right] \times IN_{j0} \tag{23}$$

(3) Estimation of efficiency and total cost in a case of supplying by lot.

The estimation of transportation equipment cost for AGV or conveyor are given by eq. (15) or eq. (20).

As the part is supplied by lot, the interval of supplying is $IN_{j0} \cdot P$. Then the efficiency (E) of utilization of the transportation equipment is evaluated by the rate that the total cost of transportation equipment (CT) is divided by amount (NT) (total number of AGV, or of loading area on the conveyor) of the transportation equipment by eq. (24).

$$E = \frac{CT}{NT} \tag{24}$$

3. APPLICATION EXAMPLE

We tried to apply the proposed method to determine the supplying method of 5 kinds of home electronic products.

3.1 Preconditions

The number of assembly stations is 8 ($M_1 \sim M_8$). The distance (d) among assembly stations is 2.0 m. The area of buffer (B_i) is 1.2 m^2. Pitch time (P) is 2 m / sec.. The distance (ℓ_1) from the warehouse to the assembly station M_1 is 10 m. The distance (ℓ_8) from the assembly station (M_8) to the warehouse is 23 m. The maximum area of part supplied to each assembly station is shown in Table 1.

Table 1. The Maximum area of part and Lot size

Assembly Parts	P1	P2	P3	P4	P5	P6	P7	P8
VMj(m²)	1701	50	25	4	45	1575	50	1625
Lot size (INj)	3	120	240	720	133	3	120	3

3.2 The case that parts of one product are arranged on one pallet

Total area of parts is 5072 cm^2. The number of blocks becomes 2 ([5072/5000] +1), as the area of pallet put as 0.5 m^2. And it is greater than 0.6 m^2, all parts can be arranged on one pallet, and supplied by the serial model.

(1) Transportation cost of AGV

(a) Number of AGV

(i) The number of AGV is 9, as the area of AGV is equal to 0.6 m^2. (Fig. 6)

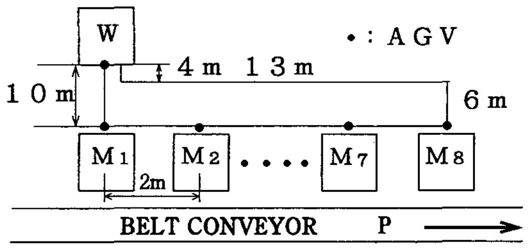


Fig. 6 Serial model

(ii) As the area of AGV is equal to 0.5 m^2, 8 stations can be grouped into 2 blocks, and the number of AGV is 10 by eq. (10). (Fig. 7)

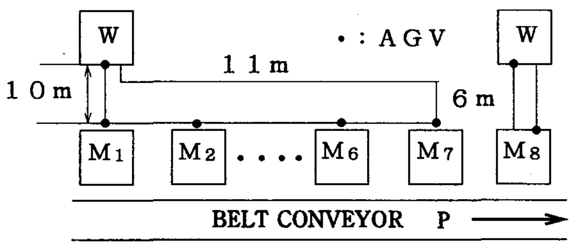


Fig. 7 Serial model with block

(b) Area of path of AGV

It is assumed that the length of AGV is put as 1 m. As the area of AGV is varied from 0.5 m^2 to 1 m^2, the area of path in Table 2 is calculated by eq. (11) and (12).

Table 2. The area and total cost by using AGV

Area of pallet (m^2)	Supplying Model	Area of Path (m^2)	Transportation cost(×10000Yen)
0.5	serial with 2 blocks	31.5	495.5
0.6	serial	28.2	444.6
0.7	serial	32.9	458.7
0.8	serial	37.6	472.8
0.9	serial	42.3	486.9
1	serial	47	501

(c) Total transportation cost

Total transportation cost in Table 2 is calculated under the condition that the price of AGV per unit is ¥400,000 and the price of land (per m^2) is ¥30,000.

As the area of AGV is equal to 0.6 m^2, the transportation cost is shown the minimum value (¥446, 6×10^4).

Table 3. The area of path and total cost by using conveyor

Area of pallet (m^2)	Path Area(m^2)	Transportation cost(×10000 Yen)
0.5	31.5	315
0.6	28.2	282
0.7	32.9	329
0.8	37.6	376
0.9	42.3	423
1	47	470

(2) Transportation cost for conveyor

(a) The area of conveyor

The length (L_2) of conveyor puts as 1 m from the distance (2m) among stations. As the area of pallet is put as 0.6 m^2, the total area of conveyor (AP_0) is 28.2 m^2.

(b) Total transportation cost

As the price of conveyor (per m^2) and land (per m^2) is put as ¥100,000, the transportation cost is shown in Table 3 in various values of the area of pallet. The transportation cost becomes minimum at the 0.6 m^2 of pallet.

3.3 Supplying by a lot

The lot size is shown in Table 1 calculated by eq. (1). The lot size of assembly station M_4 is 1500 parts. However as the operation time per day is 8 hours and pitch time 40 seconds, then the number of product is 720 units in a day. The lot size of assembly station M_4 is put as 720 units. The number of assembly stations in a block is varied with the area of pallet from eq. (22). (Table 4) As the area of pallet is 2 m^2, the lot size (IIN_4) of parts in block is recalculated from eq. (21) as follows.

$$IIN_4 = [133/3] \times 3 = 132 \text{ units.}$$

Table 5 is shown the transportation cost by using AGV, as the area of pallet is equal to 0. 6 m^2, 1. 5 m^2 and 2. 0 m^2, from eq. (20). The total transportation cost is calculated based on the condition that the price of AGV is ¥ 400, 000 / unit and of land is ¥ 30, 000 / m^2. As the efficiency (E) is shown the minimum at 0. 6 m^2 of the area of pallet, AGV having 0. 6 m^2 is the most effective to supply lot of parts.

Table 4. The supplying model for the variation of the area of pallet

<table>
<tr><th rowspan="2">Area of pallet (㎡)</th><th rowspan="2">Supplying Model</th><th colspan="8">Assembly Station in blocks</th></tr>
<tr><th>M1</th><th>M2</th><th>M3</th><th>M4</th><th>M5</th><th>M6</th><th>M7</th><th>M8</th></tr>
<tr><td>0. 6</td><td>Parallel</td><td>S1</td><td>S2</td><td>S3</td><td>S4</td><td>S5</td><td>S6</td><td>S7</td><td>S8</td></tr>
<tr><td>1. 5</td><td>Serial with 4 blocks</td><td colspan="2">S1</td><td colspan="2">S3</td><td colspan="2">S3</td><td colspan="2">S4</td></tr>
<tr><td>2</td><td>Serial with 3 blocks</td><td colspan="3">S1</td><td colspan="3">S2</td><td colspan="2">S3</td></tr>
</table>

where Sq shown q−th block

Table 5. The total transportation cost by supplying the lot of part

Area of pallet (㎡)	0. 6	1. 5	2
Number of Blocks	8	4	3
Path area (㎡)	96	138	154
Number of AGV	11	8	6
Transportation cost (×10, 000Yen)	728	734	702
Utilization Rate (E)	66	91	117

4. CONCLUSIONS

In this paper, we proposed the method to design the supplying part having the following characteristics.

(1) Three types of supplying model are proposed based on the total area of parts and loading area of transportation equipment.

(2) Each model is evaluated from the cost of transportation equipment and the area of land. The parts are supplied by two supplying types, that are, one is the pallet on which the parts of one product are arranged and the other the lot of parts.

(3) The supplying model is determined under the condition that the transportation cost becomes minimum as the area of transportation equipment is varied.

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