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Profit Sharing Method and Virtual Factory System to Decide Parts Layout in Parts Storage Racks

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Abstract. To carry out assembly line production seamlessly, all necessary parts must be prepared at each assembly station beforehand. For this, effective picking-up operation is necessary for efficient assembly line work. This study aims to develop a system for the determining the locations of parts for the picking-up operations to collect parts from the storage racks and deliver them to the assembly lines. The study proposes a new system called Storage Optimization of Assembly Parts (SOAP) to determine the locations of parts locations in the racks. SOAP consists of a module for evaluating operator movements in three dimensions during operations, a module for Profit Sharing method and a module for virtually modeling a factory system. The usefulness of SOAP is ascertained when applied to determine the locations of parts in a real car assembly production line.

1. Introductions

To carry out assembly line production without stopping the line, all necessary parts must be prepared at each assembly station beforehand. The picking-up operation involves an operator picking up the necessary parts from the parts racks located near the assembly line. The parts are then transferred to each assembly station on assembly line by another operator. The necessary parts to be picked up are different according to the products on the line, the ratios of the parts required to assemble the products are also different. Because of this, current decisions about where to locate each part in the racks are made by past experience. Thus, the most efficient arrangement of parts within the racks is never determined. This study tries to develop a system to solve this problem.

The authors previously developed a system called the Virtual Assembly Cell-Production System (VACS) [1]. VACS consists of a virtual factory system and a genetic algorithm (GA) [2]. VACS, which was designed for cellular production lines, determines optimal parts locations in racks for small industrial products that have short life cycles. These types of products are usually assembled in cellular-production lines. In an assembly cellular-production, an operator picks up the parts and takes them to an assembly table where the operator assembles the parts into the finished product. The picking-up operations are considered into two dimensions, and VACS decides the two-dimensional locations of parts in the racks. That is, VACS considers the parts locations decisions as horizontal arm movements.

This study aims to develop a system for determining the locations of parts for wider piking-up operations in order to collect parts from the racks and deliver the parts to the assembly lines. The picking-up operations need to consider three-dimensional operations because multi-layered racks mean some parts have to be collected by stretching or bending the body to upper or lower shelves. Even if the two-dimensional coordinates of racks are same, the picking-up operations are different because the racks have the different vertical locations. To more closely model picking-up operations, this study considers picking-up as a three-dimensional operation including not only the walking distances of an operator but also the operations of the collecting parts from both upper and lower shelves, and finds the better parts locations by adopting the difficulty of various aspects of three-dimensional operations as evaluation guidelines.

To consider the picking-up operations as three-dimensional operations, the study proposes a new system called Storage Optimization of Assembly Parts (SOAP) in order to determine the optimal location of parts in the racks. SOAP consists of a module for evaluating operator movements in three dimensions during operations, a module for Profit Sharing, and a module for virtually modeling a factory system.

In Industrial Engineering, method-time measurement (MTM) [3] and Modular Arrangement of Predetermined Time Standards (Modapts) [4] [5] are often used in movements analyses. However, these methods are actually too detailed to apply in this system. For example, they measure movements in unit of 0.00001 h. This study analyzes the operations specific to picking-up operations and by using these analyses, provides the quantitative values for the three-dimensional picking-up operations. Although studies exist for seeking the picking routes [6]~[8], these studies report methods that seek the routes among the racks by using scheduling analyses to determine efficient operations based on operational flows. Moreover, study to evaluate picking-up operations, which is closer to real picking-up operations, and to determine the locations of parts in the racks, does not exist.

2. SOAP

2.1 Picking-up Operations

The parts storage area, including the racks where the parts to be used in the final assembly are located, is itself located near the final assembly line where many parts are needed, similar to an automotive assembly line, as shown in Fig.1. In the parts storage area, an operator pushes a cart <1> and put an empty container on the cart from container rack <2>. The operator collects various parts by walking between the racks and placing different parts in the parts container <3>. The operator then pushes the cart to the ejection rack after collecting all the parts and puts the part container on the ejection rack <4>. The movements from <1> to <4>

correspond to the one cycle of the picking-up operation. Because many products are assembled on the final assembly lines, this cycle of the picking-up operation is repeated continuously throughout the day. The multi-variety production that occurs to assemble variety of products means that wide variety of parts need to be picked up, and the quantity of parts required is different. As a result, the problem is that it is difficult to decide beforehand which part is to put on which rack. Fig.2 shows an image of the cart, the parts container on the cart, and the operator who pushes the cart.

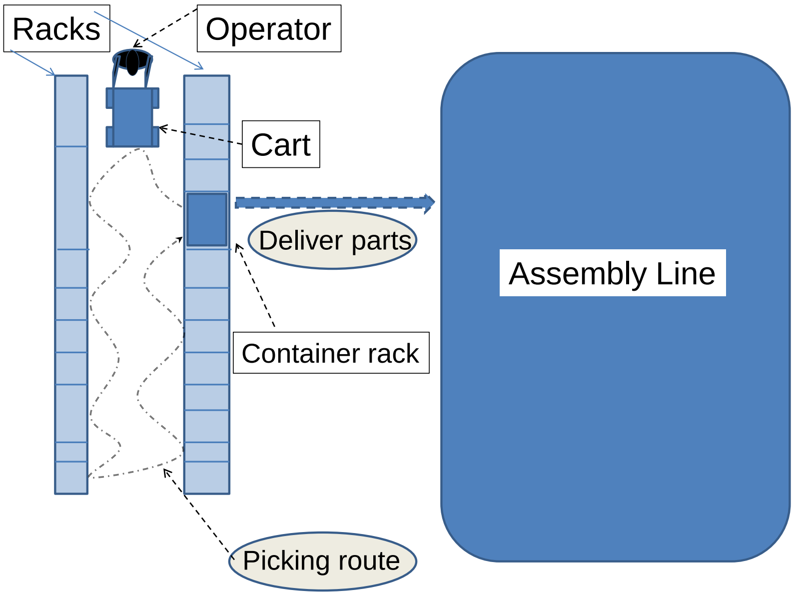


Fig.1 Assembly line and its parts storage area

2.2 Previous System - VACS

The virtual factory system, VACS, which we previously developed, is a system that determines the locations of parts, similar to the goal of this study. The VACS system composed of the two modules:, the virtual factory module and the parts layout module, as shown in Fig.3. The parts layout decision module has two sub-module:, the intelligent system sub-module (IS sub-module) and the walking evaluation sub-module (WE sub-module). The purpose of the WE sub-module is to calculate the distances that an operator walks to collect all parts. The function of the IS sub-module is to select the shortest route that an operator can walk by evaluating the above distances. The IS sub-module uses a GA to find the shortest route.

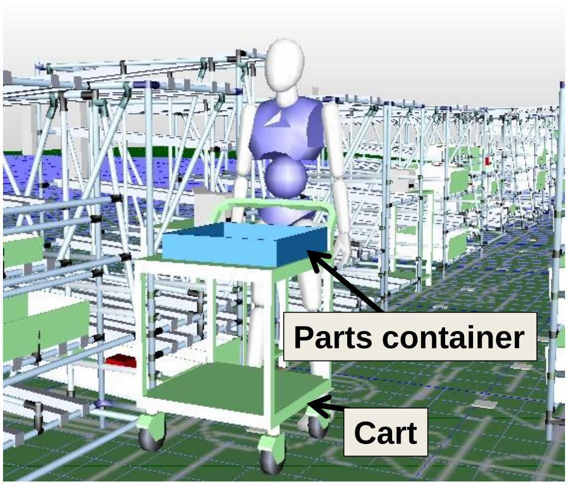


Fig. 2 Example of parts storage area drawn by SOAP

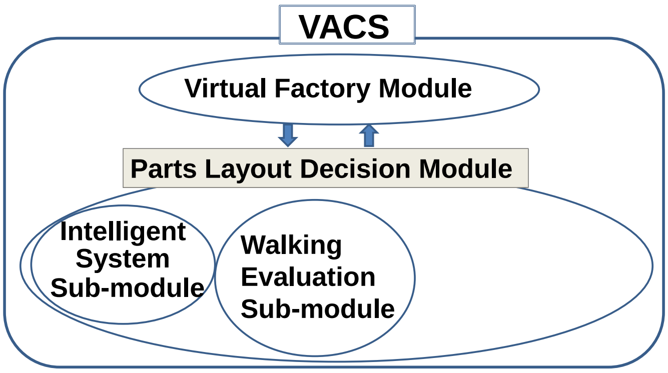


Fig.3 VACS construction

2.3 Module Construction of SOAP

SOAP is a system that determines the locations of parts by considering the job of the picking-up operator as three-dimensional movements, including not only walking but also up-and-down body movements, and by evaluating and modeling the difficulty of the two types of movements. As shown in Fig.4, SOAP's unique characteristic is to add the difficulty evaluation sub-module for three-dimensional operations to the basic VACS construction.

Again, SOAP has two modules:, the virtual factory module (V module) and the parts layout decision module (PL module). The PL module has three sub-modules:, the IS sub-module, the WE sub-module and the 3DE sub-module. The function of the 3DE sub-module is to quantify the difficulty of particular three-dimensional operations. The function of the IS sub-module function is to select the parts locations so that an operator is not worn out by evaluating the difficulty of their three dimensional-operations. The WE sub-module calculates the distances that an operator walks.

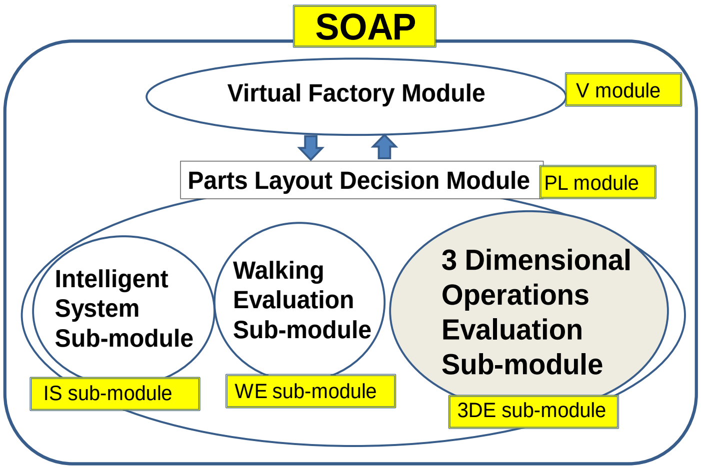


Fig.4 SOAP construction

The overall function of SOAP is to draw the layout of the parts storage area including the racks, using the V module; to calculate the walking distances using production simulations in the WE sub-module; and then to decide the most efficient rack layout using the learning function of the IS sub-module. Then the acquired data is transferred into the V module and a visualization of the picking-up operations is created by the V module. Each of the three sub-modules is indispensable in determine the locations of parts in the three-dimensional parts picking-up operation.

Each module function of SOAP is described as follows.

[a] By using the virtual factory drawing functions of the V module, the virtual parts storage area is drawn and the coordinates of all the racks are set.

[b] Parts are randomly set on each rack of the virtual parts storage area in the V module.

[c] The coordinate information of all parts is transferred from the V module to the PL module.

[d] By using the coordinate information of all the parts, the 3DE sub-module calculates quantitative values representing the degree of difficulty of the three-dimensional operations.

[e] The IS sub-module selects better coordinates for the locations of parts.

[f] The selected coordinates are transferred back to the V module and the virtual picking-up operation is carried out again. This corresponds to the visibility of the picking-up operations.

In this way, SOAP generates a tentative parts storage area layout using the V module, and at the same time, sets the tentative parts, which are needed for the final assembly line, into racks. Based on this information, the PL module decides the coordinates for more efficient placement of parts and transfers these coordinates back to the V module. Finally, SOAP starts the virtual production simulations and, in the real world, the production engineers can see the visibility of the picking-up occur.

3. Evaluation of Difficulty of Three-Dimensional Operations

3.1 Previous Operations Evaluations

VACS, whose aim was to find the optimal locations of parts in an assembly cell-production line, used the distances between the assembly table and the points that the operator took parts from the racks in the evaluation of difficulty. For example, Fig.5 shows an assembly cell-production line. When an operator makes a round trip from the rack to the assembly table, if the one-way distance is *b*, 2*b* becomes the difficulty value. That is, when an operator assembles a product, if the number of times he or she makes a round trip to pick up all parts in order to assemble the product is *n* and the one way distance is *b*(*n*), the summed up walking distance *L* is the evaluation value that is calculated in the equation (1). VACS chooses the smaller evaluation to decide parts locations. Other study has also adopted the same method of comparing the walking distances.

$$L = \sum_{n=1}^{n} 2\mathrm{b}(\mathrm{n}) \qquad (1)$$

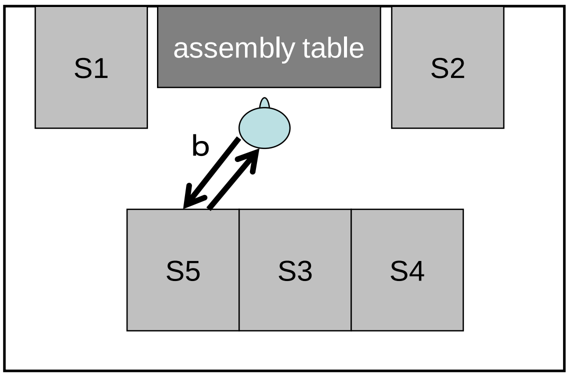


Fig.5 Assembly cell-production line

3.2 SOAP Operations Evaluations

Conventional systems for determining the locations of parts, including VACS, decide the parts locations by using evaluations representing the operator's walking distance. These systems assume that an operator moves along a flat floor in the cell-production shop. In other words, the systems evaluate the picking-up operations as two-dimensional operations, treating the operations as movements on the floor. By treating the operations as two-dimensional movements, these conventional systems attempt to minimize the summed-up walking distance L from among the many possible paths between the assembly table and the racks. However, the difficulty of time spent in real picking-up operations do not depend just on the walking distances. They also depend on how parts are collected and the posture required to collect the parts. Because the racks have many shelves, merely approaching the shelves is not the end of the operator's movements. For example, the operator must take parts from the bottom shelf of the rack by bending down and take parts from the upper shelf by stretching their arm and body. In this way, the difficulty of operations changes depending on which shelf in the rack the required parts are placed. Although common sense dictates that the parts that an operator uses frequently are put on the middle shelves directly beside the operator and the parts that an operator rarely uses are put on the upper or lower shelves, we do not have a systematic way to calculate or find the frequency that a part is taken by an operator. To develop a systematic way to determine a real operator's movements in their picking-up operations, SOAP uses the difficulty of the three-dimensional operations, which combines the difficulty of reaching the two-dimensional coordinates, (on the x axis and y axis of the shop floor), with the difficulty of reaching the parts on the vertical axis of the racks.

We analyze one cycle of the picking-up operations and define the results and the evaluation values with the following five movements, A-E.

A. An operator walks to a rack to take a part (walking movement): The walking movement is classified as the movement in which an operator pushes the cart to move to the rack where the required part is located. The walking step is expressed as W steps.
B. An operator stretches his or her arm and takes a part from a rack (arm and lower back movements): The arm and lower back movements are classified in terms of the level of arm stretching. As shown in Fig. 6, there are five classifications for when an operator stretches his or her arm, A(3) : stretch an arm directly at his or her side, A(2) : stretch an arm slightly upward, A(1) : stretch an arm while stretching their body, A(4) : stretch an arm slightly downward, A(5) : stretch an arm while bending their body.
C. An operator grasps a part (finger movement): The finger movement is classified in terms of the difficulty of grasping a part. The difficulty has two classifications, G(1) : grasp with one hand and G(2) : grasp with both hands.
D. An operator places a part into the parts container (placement movement): The placement movement classifies the difficulty for the operator to place the part in the parts container. The difficulty has two classifications based on whether it is easy or hard to place. Easy placement is expressed as P(1) and difficult placement is expressed as P(2).
E. An operator collects a heavy part (revised weight): The revised weight evaluation is for the collection of heavy parts. According to the weight of the part, the degree of difficulty changes. For weights from 0 to 2 kg, the revised weight is equal to 0, and for every part heavier than 2 kg, the value of H is increased by 1.

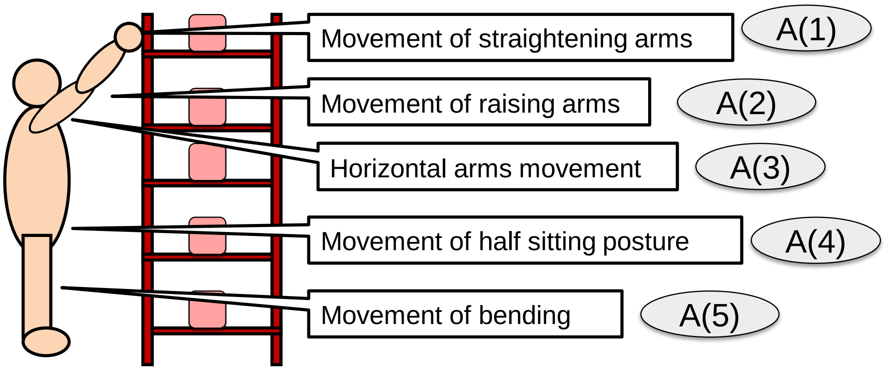


Fig.6 Five possible arm and lower back movements to collect a part

The movement difficulty (MD) of one three-dimensional picking-up operation cycle is expressed as the sum of the above degrees of difficulty, A ~ E, as shown in the equation (2).

$$MD=W+A+G+P+H \quad (2)$$

4. IS Sub-Module

The IS sub-module selects better coordinates for the location of parts by using the MD of one cycle, as quantified in the 3DE sub-module. VACS, the previous system, made decisions using a GA. Because the assembly line in this study is closer to a real one since both the operator's walking distances and the operator's postures are included in the evaluations, it is difficult to implement the individual expressions into a GA and SOAP cannot easily use GAs to evaluate the difficulty of the movements. For this reason, SOAP decides better parts locations by using Profit Sharing, which is a Reinforcement Learning method. The SOAP decision-making process has three procedures, as follows.

1. Selection of parts locations by a roulette selection
2. Calculation of the difficulty of one cycle of operations based on the parts locations.
3. Give rewards to excellent parts locations.

After repeating the above three procedures for the amount of time it takes to find the minimum, the layout that corresponds to the minimum difficulty of movement becomes the solution and the solution is transferred to the V module.

4.1 Parts Location Selection by Roulette Selection

To decide the quality of various layouts, a learning method that is used in which good parts locations are given rewards by Profit Sharing. During the learning process, to decide whether the location of a parts is given a reward or not, roulette selection of parts locations is carried out.

For example, let us consider the values for the locations of parts ①－⑤ after (n－1) learning rounds, as shown in Table 1. For *n* rounds learning, the location of part ①－(rack A), as shown in Fig.7, is selected with the probability 5/80, in which the numerator is the value of each location and the denominator is all values of part ①. The locations of other parts are selected in the same way.

The MD for one part is calculated using equation (2). When all *k* parts are picked up to assemble a product, the total MD (TMD) of the parts locations is given by equation (3).

$$\mathrm{TMD}=\sum_{k=1}^{k}\mathrm{MD} \quad \cdot\cdot\cdot (3)$$

Table 1 Value examples of Profit Sharing

Rack names	**A**	**B**	**C**	**D**	**E**	**F**
part ①	5	10	20	15	10	20
part ②	5	5	10	5	5	10
part ③	5	10	10	5	5	5
part ④	5	5	5	15	5	5
part ⑤	5	10	5	5	5	10

Rack names	**A**	**B**	**C**	**D**	**E**	**F**
Values of part ①	5	10	20	15	10	20

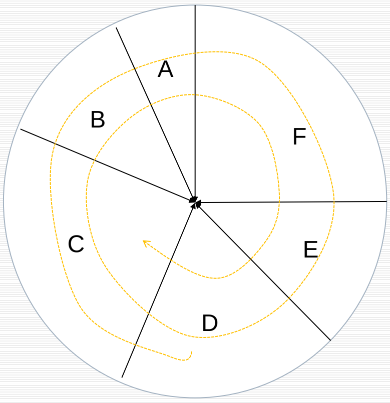


Fig.7 Roulette selection example

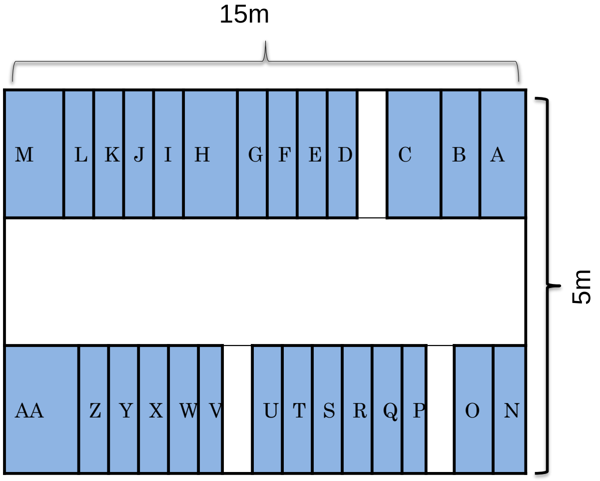
4.2 Rewards

Let us consider a complicated picking-up operation being carried out, in which *k* parts are located at *p* locations. In a case where k = 5 and p = 6, 30(5×6) values are needed to be given, as shown in Table 1. The initial values for each of the (k×p) location combinations is randomly chosen, and a reward *R* is added to the initial value if the value for the parts locations selected in section 4.1 is superior to a standard value. Repeating step 1-3 from section4.1 to 4.3 as many times as necessary, the parts layouts with the maximum values so far are adopted as the practicable parts locations and are transferred to the V module.

5. Application Example to Automotive Final Assembly Line

SOAP was applied to the picking-up operations of a real automobile assembly line to ascertain the usefulness of SOAP. Fig.8 shows the final assembled vehicle. As shown in Fig.9, the parts storage area has 27 racks (A~Z and AA) in a rectangular space with dimensions 15m×5m. Each rack has multiple shelves on which parts are located. For example, rack A has five shelves vertically. The table on the right of Fig. 9 shows the height of each shelf in rack A, namely 20, 40, 60, 80, and 100 cm from the bottom. A total of 56 parts must be located on the racks, as shown in Fig.10.

Fig.8 Target vehicle



Rack locations

Rack height

Rack name	Height (cm)				
A	20	40	60	80	100
B	20	80			
C	20	80			
D	20				
E	20	50	90	120	
F	20	50			
⋮					
AA	20	40	80	100	

Fig. 9 Shelves examples

	suppliers	S-No	Part numbers	Part names
1	Tokai	661	904800153700	GROMMET
2	Koji	833	827122639100	SUPPORT WIRING HARNESS
3	Tokai-T	618	611812602000	BRACKET INSTRUMENT PANEL SIDE
4	Kode	141	7703795D0190	LOCK SUB-ASSY FUEL FILLER OPE
5	TRW	101	891732202000	SENSOR AIR BAG FR
6	Aisi	726	694702810000	PLATE ASSY SLIDE DOOR RR LOCK
7	Chuo	130	338272601000	BRACKET TRANSMISSION CONT CAB
8	Yaza	746	821552607000	WIRE PILLAR NO.2
9	Hi	65	770352614000	CABLE SUB-ASSY FUEL LID LOCK
10	Siro	362	6807326010A1	MOULDING SUB-ASSY SLIDE RAIL
			⋮	
56	Siro	246	694852602000	STRIKER SLIDE DOOR OPEN RH

Fig. 10 Parts examples

Each degree of difficulty in the operations, as described in section 3.2, was set as the following. W = (number of steps) ×5, A(1) = 10, A(2) = 8, A(3) = 6, A(5) = 19, G(1) = 3, G(2) = 1, P(1) = 0, P(1) = 3. These figures were decided following interviews of some operators. The interviews were done by Paired Comparisons [9][10]; for example, we asked how difficult other operations are if the difficulty with one hand, G(1), is 1.

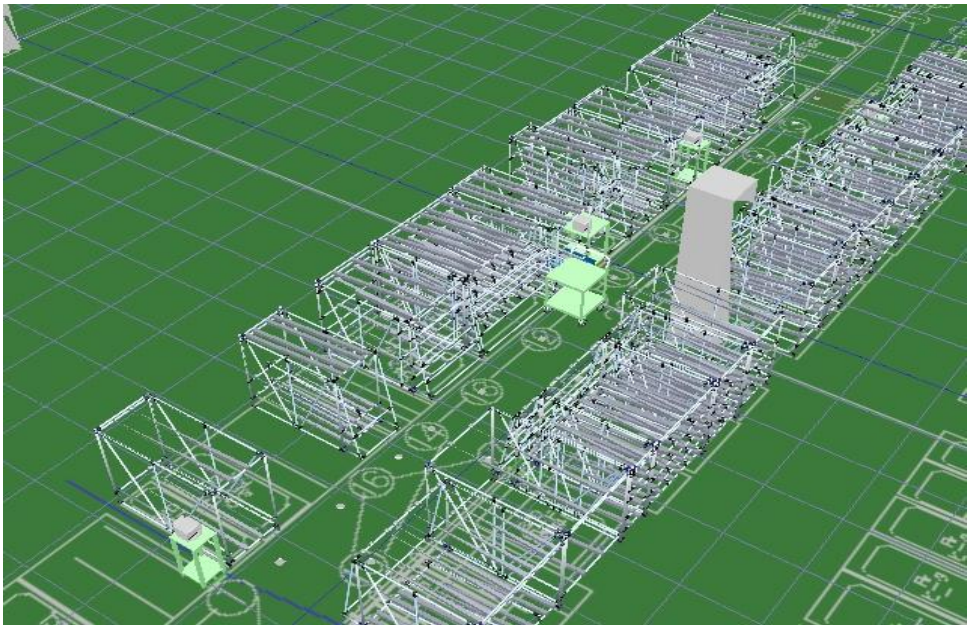


Fig.11 Parts storage are drawn by SOAP

First, using the V module, model was created of the parts storage area, as shown in Fig.11, and each rack coordinate acquired from this model was transferred to the PL module. We found the degree of difficulty for all 56 parts, and using Profit Sharing, the results shown in Table 2 were acquired. The figures in Table 2 show the average of 10 simulations' results, because the simulations need random coefficients to use Profit Sharing. To gain better understanding, the TMDs acquired were arranged by time value. The figures in Table 2 correspond to the arranged values, because the raw values for TMD are hard to interpret simply by inspection. The time conversion is based upon the MTM method, with a difficulty of 1 is set to 0.1 s. As a comparison, the TMD acquired by the random parts locations and the ones corresponding to the current parts locations in the real factory were both put in the table. Examining all the simulation results, SOAP's results are smaller (or better) than those with random parts locations and the actual current parts locations. The usefulness of SOAP was thus ascertained. If the minimum difficulty layout, corresponding to the minimum operation time of , 19,634 s in Table 2, is adopted (after examining the operation visualization in the V module and finding no problems), using the determined parts locations means that working conditions will be improved.

Table 2 Simulation results

Simulation No.	Random layout	Layout by SOAP	Current layout
1	26755	**20201**	23800
2	26780	**20150**	〃
3	26768	**20111**	〃
4	26213	**19930**	〃
5	27348	**19634**	〃
6	26922	**20421**	〃
7	26161	**19672**	〃
8	25619	**20098**	〃
9	26832	**19698**	〃
10	26896	**20459**	〃

6. Conclusions

This study described a new system named SOAP whose key technology is the combination of a virtual production system and Profit Sharing method. SOAP decides the better locations of parts in a parts storage area for parts picking-up operations in an assembly line. SOAP has two modules: the V module that carries out a virtual production simulation and the PL module that finds the better parts location. The PL module consists of a system to calculate the difficulty of the movements in order to evaluate whether the locations of parts location for picking-up operations is good or bad and a learning system to implement a Profit Sharing method using the difficulty of movements. By applying the developed SOAP to find better parts locations in a real vehicle assembly line, the usefulness of SOAP was ascertained.

References

[1] Hidehiko Yamamoto and Takayoshi Yamada, Determine an Efficient Parts Layout for Assembly Cell Production by Using GA and Virtual Factory System, Proceeding of the 3rd International Conference on Intelligent Decision Technologies (IDT 2011), pp.419-428, Editors; Juozo Watada, Gloria Phillips-Wren, Lakhmi G. Jain and Robert J. Huwlett, Greece, July 2011.

[2] Hidehiko Yamamoto, Jaber Abu Qudeiri, Takayoshi Yamada and Rizauddin Ramli, Production Layout Design System by GA with One by One Encoding Method, The Journal of Artificial Life and Robotics, Vol. 13, No.1, 234-237 (2008), Springer.

[3] Karger, Delmar W. & Bayha, Franklin H. *Engineered Work Measurement, Fourth Edition.* Industrial Press. ISBN (0-8311-)1170-4

[4] Adler, Paul S. “Time-and-Motion Regained”. Harvard Business Review. Boston: Jan/Feb 1993. Vol.71, Iss. 1, 12 pgs.
[5] Dossett, Royal J. “Work-measured labor standards – The state of the art.” Industrial Engineering. Apr 1995; 27, 4; ABI/INFORM Global. pg. 22.
[6] Maxwell, W.L. and Muckstadt, J.A., Design of Automated Guided Vehicle System, IIE, Vol.14, No.2, pp.114-124, 1982.
[7] Gaskins, R.J. and Tanchoco, J.M.A., Flow Path Design for Automated Guided Vehicle System, Int. Journal of Production Research, Vol.25, No.5, pp.667-676, 1987.
[8] Kim, K.H. and Tanchoo, J.M.A., Economical Design of Material Flow Path, Int. Journal of Production Research, Vol31, No.6, pp.1387-1407, 1993.
[9] Graßhoff, U., Großmann, H., Holling, H. & Schwabe, R., Optimal paired comparison designs for first-order interactions, Statistics 37: (2003)373–386.
[10] Saaty, Thomas L., Relative Measurement and its Generalization in Decision Making: Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors – The Analytic Hierarchy/Network Process, (2008-06).