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MULTIOBJECTIVE OPTIMIZATION AND ANALYSIS OF PICKING/CONVEYANCE SYSTEMS

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ABSTRACT

A method of multiple objective optimization is proposed in an attempt to determine the optimal job-assignment and conveyor systems for a digital picking/conveyance system. A digital picking/conveyance system considered in this paper consists of operators, conveyor lines, racks containing items to be picked. Four particular types of conveyor systems are analyzed to examine their performance under various picking conditions. In addition, a multiple objective optimization problem is formulated in terms of goal programming by using simulation technique. A procedure for obtaining the solution for multiple objective systems is presented with a numerical example.

1. INTRODUCTION

In many industries such as automobiles the product is assembled or operated on a continuous conveyor line. The elemental tasks making up the assembly operation must be assigned to operators along the line. Line balancing for a case of continuous mass production, where the items are assembled or operated on a single conveyor line, is a basic problem. A number of approaches including heuristics have been proposed [Tonge 1961]. The following two approaches to the assembly-line-balancing problem are used: (1)finding the optimal number of work stations under a fixed cycle time, (2) minimizing the cycle time.

The operators along the conveyor line perform picking operation. The picking/conveyance systems considered in this paper are a single container/continuous conveyor system, a multiple containers/continuous conveyor system, a single container/discontinuous system, and a bypassed conveyor system. For these four picking/conveyance systems the physical characteristics are examined through computer simulation.In addition, the selection problem is referred from the physical and economic standpoints.

This paper presents a procedure for obtaining a solution of multiple objective decision problems, by applying an approach of multiobjective optimization as well as simulation. In addition, the procedure is presented, by using a numerical example based on an actual case.

2. PROBLEM STATEMENTS

The digital picking/conveyance system considered in this paper consists of operators, the conveyor line, the rack providing items to be picked, and containers. Operators, who are standing in line along the conveyor, are awaiting picking instructions. In case one item is to be picked at a station, the corresponding digital display is turned on at the station by the installed computer. Then, the operator picks up the exact item from his responsible cell of the rack, and he puts it on the container being routed on the conveyor. After all operators complete their operations, the conveyor resumes to convey containers to the next stations in the continuous types of conveyor systems.

Four particular types of conveyor systems are examined for performance under various picking conditions: (1) a single container/continuous conveyor system, (2) a multiple containers/continuous conveyor system, (3) a single container/discontinuous conveyor system, and (4) a bypassed conveyor system. By performing simulation experiments considering picking conditions such as the frequency of picking operations at each station, the performance is examined for four picking/conveyance systems.

For these types of picking/conveyance systems, several different evaluation criteria are considered, such as maximum production rate, minimum number of operators. A multipleobjective optimization problem is formulated in terms of goal programming. In this paper, a procedure for obtaining solutions for multiple objective systems is proposed by using a simulation technique.

3. PICKING/CONVEYANCE SYSTEMS

3.1 Material Flow

Before considering the models in detail, it is essential to specify the general features of picking/conveyance systems. A general layout for a picking/conveyance system is depicted in Figure 1. Any type of picking/conveyance system to be analyzed comprises four major factors, i.e., the conveyor line, the rack, the operators, and containers. There are four types of picking/conveyance systems based on adopted conveyor systems, as shown in Figure 1.

3.2 Single Container/Continuous Conveyor System (Type 1)

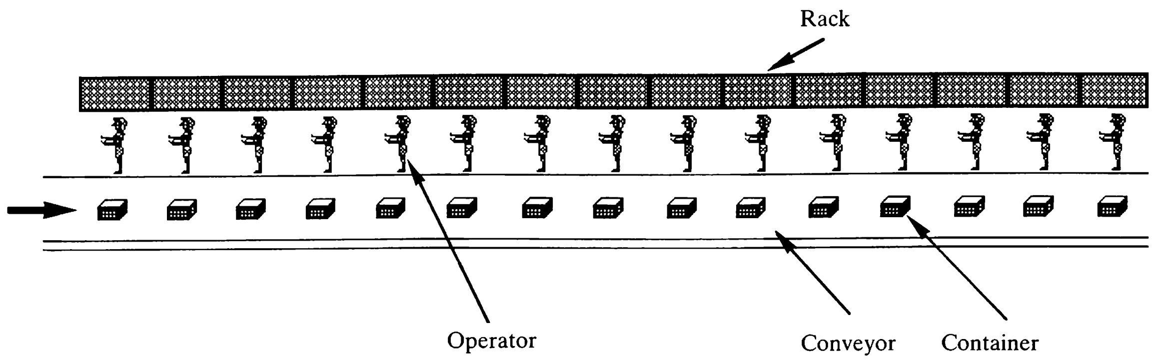
Figure 1(a) shows a single container/continuous conveyor system. Fifteen operators are standing in line along the conveyor (i.e., a belt conveyor). When the conveyor starts, the corresponding digital display lamps turn on to indicate the specific items to be picked. After an operator picks the item, he pushes the button to turn off the display lamp. This action means the completion of his current operation. If any operator is still picking items after the corresponding container arrives, then the conveyor stops. After all operators finish their operations, the conveyor resumes to convey containers.

3.3 Multiple Containers/Continuous Conveyor System (Type 2)

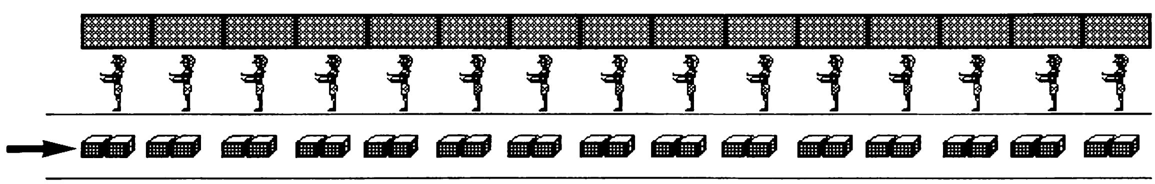
In a multiple containers/continuous conveyor system, multiple (2 to 5) containers are routed together on the belt conveyor. In this system, the operator must pick all designated items for the specific number of containers on the conveyor. In case one operator is responsible for more than one part (one station) of the rack, he may walk around within his responsible region. As in a single container/continuous conveyor system, the conveyor may resume to convey containers after all picking operations have been done. A multiple containers/continuous conveyor system is illustrated in Figure 1(b).

3.4 Single Container/Discontinuous Conveyor System (Type 3)

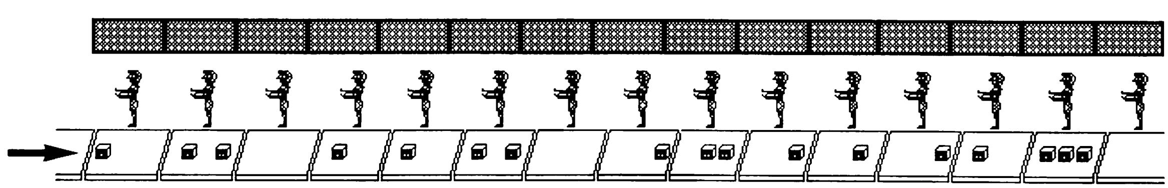
In a single container/discontinuous conveyor system, one container is routed independently on the conveyor. That is, a container may be conveyed if there is space for it at the next station. Otherwise, it must be kept at the current station. The maximum capacity of the buffer at each station on the conveyor is five for the discontinuous type of conveyor systems. The free-flow type of the conveyor is installed for a single container/discontinuous conveyor system. A single container/discontinuous conveyor system is shown in Figure 1(c).



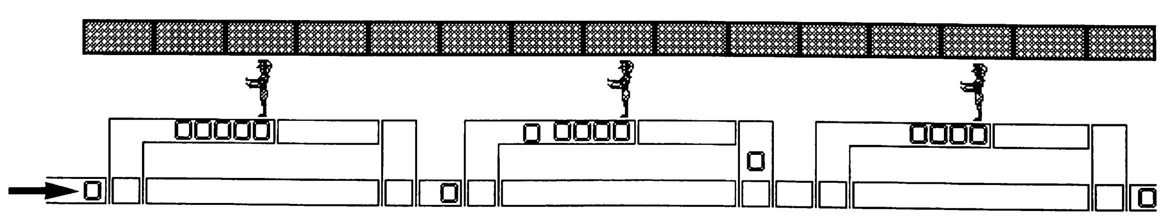
(a) Single Container/Continuous Conveyor System



(b) Multiple Containers/Continuous Conveyor System



(c) Single Container/Discontinuous Conveyor System



(d) Bypassed Conveyor System

Figure 1. Picking/Conveyance Systems

3.5 Bypassed Conveyor System (Type 4)

In a bypassed conveyor system, some additional conveyors are installed besides the main conveyor. A typical bypassed conveyor system is shown in Figure 1(d). In this particular system three operators are responsible for five successive stations respectively. This type of system is suitable for low amount of picked items. The operator must walk around within his responsible stations much more than in the other types of systems.

4. COMPUTER SIMULATION

4.1 Data Input

As mentioned in the previous section, the controllable variables are the number of pickers, the station assignment, the conveyor speed, operators' walking speed, and so on for each type of the conveyor systems. The simulation program is written in SIMAN [Pegden 1986]. The data input for the simulation program is:

- number of containers to be treated.
- number of operators.
- station assignment for each operator.
- number of picked items for each container at each station.
- distance between two consecutive stations.
- time of picking each item.
- walking speed.
- conveyor speed.
- number of containers to be routed jointly on the conveyor (for Multiple Containers/Continuous Conveyor Systems).
- capacity of the buffer at each station (for Single Container/Discontinuous Conveyor Systems).
- bypassed conveyor speed (for Bypassed Conveyor Systems).
- capacity of the buffer on the bypassed conveyors (for Bypassed Conveyor Systems).

4.2 Output

The simulation model provides a number of outputs. These includes:

- completion time.
- throughput time.
- time between departure.
- initial idle time.
- last idle time.
- number in queue waiting for being picked completely.
- operator utilization.
- conveyor utilization.
- walking time.
- number of picked items.
- number of passing containers.

4.3 Model Verification

Verification is concerned with determining if the simulation program is working as intended. The animation provides a visual means to rapidly and easily be sure that a model correctly represents the actual system [Miles et al. 1988]. By monitoring the movement of entities and the state of resources and conveyors, the analyst can quickly identify any error in logic which would be difficult to detect with only standard summary statistics.

In this study, a Cinema model was developed for animation since Cinema animation is driven by the SIMAN simulation language as in the previous paper. Summary statistics for the number of pieces handled were compared to model statistics for deriving input probability distributions.

5. ANALYSIS OF PICKING/CONVEYANCE SYSTEMS

5.1 Evaluation Criteria

The simulation study for this paper has two major objectives. One is to find which conveyor system is the most suitable to meet the system requirements considering the various constraints such as the frequency of picking items. Another is to identify the optimal job-assignment or the optimal buffer size on a day-by-day basis. In either case,the common evaluation criteria are to be considered for multiobjective optimization and analysis of the picking/conveyance systems in this paper. The following evaluation criteria may be utilized in the picking/conveyance systems.

(1) the production rate.
(2) the throughput time.
(3) the operators utilization.
(4) the cost.

5.2 Simulation Analysis

Simulation analyses are performed on four types of picking/conveyance systems described in 3.2 through 3.5. Experimental conditions are summarized in Table 1. Figure 2 shows the production rate in relation to the selected rates of picking. The production rate (pcs/min) refers the amount of products in a unit time interval. In this numerical experiment, the rate of picking is assumed to be the same for all stations. The production rate in the single container/continuous conveyor system decreases as the rate of picking at each station increases. Due to the constraint of the conveyor speed, the production rate never exceed 20 pcs/min in this system.

Figure 3 shows the production rate and the mean flowtime in relation to the rate of picking. The production rate is found to be much higher by adopting the multiple containers/continuous conveyor systems than by adopting the single container/continuous system. It is observed that the production rate is much improved at lower rate of picking. On the contrary, the mean flowtime of the products increases as the number of containers increases in the multiple containers/continuous conveyor systems.

Figure 4 shows the production rate in relation to the buffer capacity at each station in the single container/discontinuous conveyor system. It is found to be sufficient to convey the maximum number of products, by setting 3 pieces as the buffer capacity under the above-mentioned picking and conveyance conditions.

Figure 5 shows the production rate in relation to the rate of picking in the logarithmic form. Three operators perform picking operation in the bypassed conveyor system. This type of the picking/conveyance system is suitable for low amount of picked items because of stationary containers for wider range of the rack.

5.3 Cost Comparison among Alternative Investments

An economic analysis of alternatives would be necessary to select the most economical, considering the picking conditions. When performing cost comparisons among alternatives it is necessary to collect the following information:

(1) initial cost.
(2) annual maintenance cost.
(3) any irregular expense.
(4) expected life.
(5) salvage value.

Table 1. Experimental Conditions of Simulation

Number of Containers to be Treated	100 (pcs.)
Number of Operators	15 (pcs.)
Number of Picked Items for Each Container at Each Station	1 (pc.)
Distance between Two Consecutive Stations	1.50 (m.)
Picking Time	N(3,1) (sec.)
Walking Speed	45 (m/min.)
Conveyor Speed	30 (m/min.)

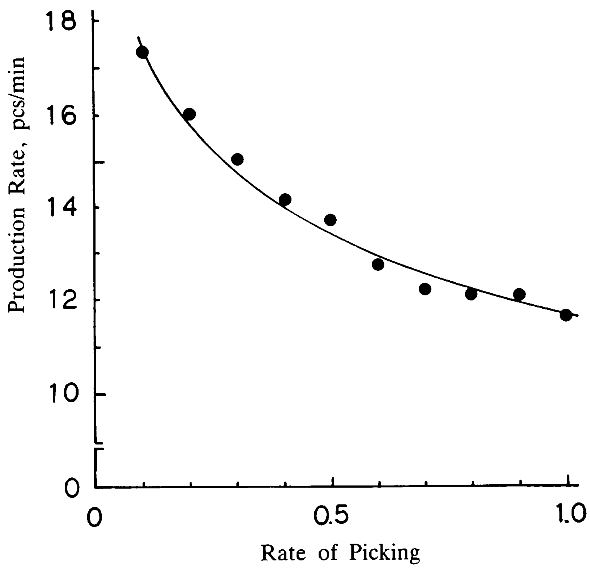


Figure 2. Production Rate in Relation to Rate of Picking (Single Container/Continuous Conveyor System)

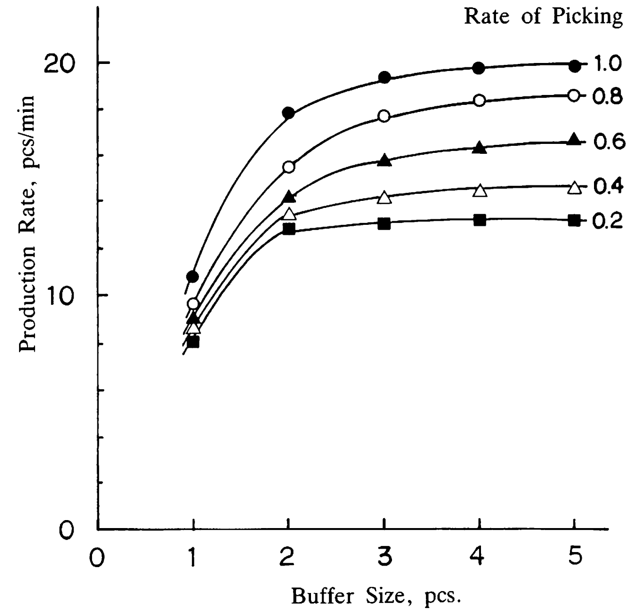


Figure 4. Production Rate in Relation to Buffer Size (Single Container/Discontinuous Conveyor System)

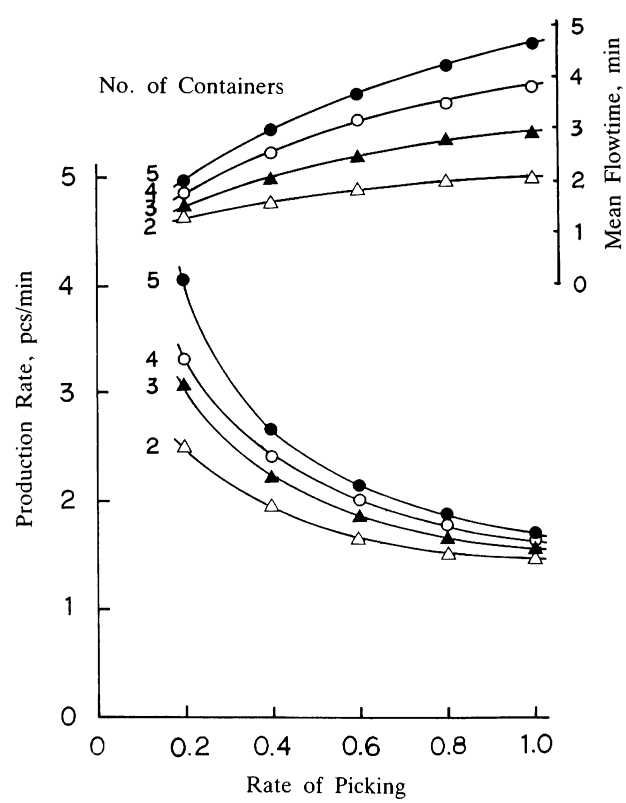


Figure 3. Production Performance in Relation to Rate of Picking (Multiple Containers/Continuous Conveyor system)

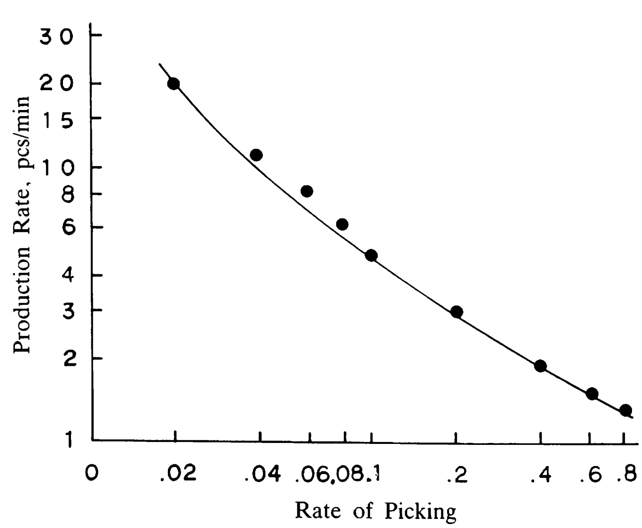


Figure 5. Production Rate in Relation to Rate of Picking (Bypassed Conveyor System)

Table 2. Cost Comparison among Alternative Investments

Picking/Conveyance System	Initial Cost (Yen 1 million)	Uniform End-of-Year Expense (Yen 1 million)	Salvage Value (Yen 1 million)	Service Life (years)	Unacost (Yen 1 million)
Single Container/ Continuous Conveyor System	25.00	2.45	2.50	6	7.866
Multiple Containers/ Continuous Conveyor System	30.00	2.70	3.00	6	9.199
Single Container/ Discontinuous Conveyor System	40.00	3.20	4.00	6	11.866
Bypassed Conveyor System	50.00	3.70	5.00	6	14.532

These estimates should be collected for all of the conveyance systems to be considered. When this information has been collected, cost comparisons can then be made among the alternative systems on a before tax basis. Then, recommendations can be made to management regarding the most economical system to install. Cost information on the specific systems considered in this paper is summarized in Table 2. Initial cost comprises a conveyor system, a rack, containers, and FA computers. Annual interest rate of 10 % was selected for this case. The term "unacost", as used here implies uniformity from year to year with the end of the year as part of the definition [Jelen and Black 1983]. The exact picking/conveyance system to be selected will depend on whether the management is emphasizing low cost or high rate of production.

6. MULTIOBJECTIVE OPTIMIZATION OF PICKING/CONVEYANCE SYSTEMS

6.1 Multiobjective Decision Problem

In case the number of operators is less than the number of stations in the rack,it is necessary to determine the allocation of the specified number of operators to the stations, i.e., the positions in the rack. In addition, the optimal number of containers should be determined for the multiple containers/continuous conveyor system.The optimal buffer sizes at each stations should be determined for the single container/discontinuous conveyor system as well. Furthermore, the conveyor speed might be a decision variable in some cases. In this section, a multiple objective decision problem is formulated and solved for such problems. In case of a single decision variable [Takakuwa 1989], a simple approach can be applied effectively.

In this paper, an approach of a modified pattern search is proposed for achieving the multiple objective optimization to meet a general situation.

6.2 Assigning Operators to Stations

For specific conveyor systems considered in this paper it is necessary to assign the possible number of operators to stations. In case one operator is responsible for multiple stations (i.e., sections) of the rack, he must walk around within his responsible stations. In performing stations assignment on a day-by-day basis, the amount of picked items at each station should be known or estimated in advance. Hence, station assignment must be determined for every possible value of the number of operators.

The expected value of the picking time is assumed to be the same for all operators. Firstly, the number of operators, which is denoted by n, is let to be equal to that of stations. Denoting the expected or estimated value of picking rate at station i (i=1,2,...,n) by b_i, the minimum (b_j+b_{j+1}) for j=1,2....,n−1 can be found by comparison. The j th operator are to be assigned to the j th and j+1 th stations. Then, assigning j th operator to the j th and j+1 th stations, a station assignment can be obtained for n−1 operators. An example of this problem is shown in Table 3. In this case, fifteen operators are responsible initially for fifteen stations. According to the procedure described earlier, a station assignment is obtained for fourteen operators shown in the second column of Table 3. In other words, The 14th operator denoted by N in Table 3 is responsible for both the 14th and 15th stations. Similarly, a set of station-assignments may be obtained step-by-step for each possible number of operators. The detailed operation is illustrated in Table 3.

6.3 Problem Formulation

The multiple-objective decision problem in this paper is described in terms of 'chance-constrained' goal programming. 'Chance-constraint' goal programming proposed in this paper is a modified approach of goal programming [Ignizio 1982]. The general form of this model is:

lexicographic-min $\mathbf{a}=\{g_1(\mathbf{n},\mathbf{p}), g_2(\mathbf{n},\mathbf{p}),\ldots,g_K(\mathbf{n},\mathbf{p})\}$
such that:

$$G_i:\quad f_i(x) + n_i - p_i = b_i, \qquad i = 1,2,\ldots,N$$

$$\text{and:}\quad \mathbf{x},\ \mathbf{n},\ \mathbf{p} \geq 0$$

where **a** is an achievement function of this problem. In the goal of G_i, b_i is an aspiration level on G_i. n_i and p_i are negative and positive deviation variables. In case $f_i(x)$ is to be obtained through the simulation experiment, it may be necessary to set b_i with some probability.

6.4 The Algorithm

Step 1: Select $\mathbf{B}_1$, the first base point and **d**, the initial set of variable perturbation values. Specify: R_{max} = the maximum

Table 3. Assigning Operators to Stations

	Station	A =	B =	C =	D =	E =	F =	G =	H =	I =	J =	K =	L =	M =	N =	O =
15 Operators	Assignment	{ 1 }	{ 2 }	{ 3 }	{ 4 }	{ 5 }	{ 6 }	{ 7 }	{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13 }	{ 14 }	{ 15 }
	Expected Rate of Picking	.45	.16	.33	.32	.64	.10	.48	.28	.52	.74	.30	.56	.13	.09	.06
	Sum of Two Consecutive Rates	(.61)	(.49)	(.65)	(.96)	(.74)	(.58)	(.76)	(.80)	(1.26)	(1.04)	(.86)	(.69)	(.22)	(.15)*	
14 Operators	Assignment	{ 1 }	{ 2 }	{ 3 }	{ 4 }	{ 5 }	{ 6 }	{ 7 }	{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13 }	{ 14, 15 }	
	Expected Rate	.45	.16	.33	.32	.64	.10	.48	.28	.52	.74	.30	.56	.13	.15	
	Sum of Two Rates	(.61)	(.49)	(.65)	(.96)	(.74)	(.58)	(.76)	(.80)	(1.26)	(1.04)	(.86)	(.69)	(.28)*		
13 Operators	Assignment	{ 1 }	{ 2 }	{ 3 }	{ 4 }	{ 5 }	{ 6 }	{ 7 }	{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13, 14, 15 }		
	Expected Rate	.45	.16	.33	.32	.64	.10	.48	.28	.52	.74	.30	.56	.28		
	Sum of Two Rates	(.61)	(.49)*	(.65)	(.96)	(.74)	(.58)	(.76)	(.80)	(1.26)	(1.04)	(.86)	(.84)			
12 Operators	Assignment	{ 1 }	{ 2, 3 }		{ 4 }	{ 5 }	{ 6 }	{ 7 }	{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13, 14, 15 }		
	Expected Rate	.45	.49		.32	.64	.10	.48	.28	.52	.74	.30	.56	.28		
	Sum of Two Rates	(.94)	(.81)		(.96)	(.74)	(.58)*	(.76)	(.80)	(1.26)	(1.04)	(.86)	(.84)			
11 Operators	Assignment	{ 1 }	{ 2, 3 }		{ 4 }	{ 5 }	{ 6, 7 }		{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13, 14, 15 }		
	Expected Rate	.45	.49		.32	.64	.58		.28	.52	.74	.30	.56	.28		
	Sum of Two Rates	(.94)	(.81)		(.96)	(1.22)	(.86)		(.80)*	(1.26)	(1.04)	(.86)	(.84)			
10 Operators	Assignment	{ 1 }	{ 2, 3 }		{ 4 }	{ 5 }	{ 6, 7 }		{ 8, 9 }		{ 10 }	{ 11 }	{ 12 }	{ 13, 14, 15 }		
	Expected Rate	.45	.49		.32	.64	.58		.80		.74	.30	.56	.28		
	Sum of Two Rates	(.94)	(.81)*		(.96)	(1.22)	(1.38)		(1.54)		(1.04)	(.86)	(.84)			
9 Operators	Assignment	{ 1 }	{ 2, 3, 4 }			{ 5 }	{ 6, 7 }		{ 8, 9 }		{ 10 }	{ 11 }	{ 12 }	{ 13, 14, 15 }		
	Expected Rate	.45	.81			.64	.58		.80		.74	.30	.56	.28		
	Sum of Two Rates	(1.26)	(1.45)			(1.22)	(1.38)		(1.54)		(1.04)	(.86)	(.84)*			
8 Operators	Assignment	{ 1 }	{ 2, 3, 4 }			{ 5 }	{ 6, 7 }		{ 8, 9 }		{ 10 }	{ 11 }	{ 12, 13, 14, 15 }			
	Expected Rate	.45	.81			.64	.58		.80		.74	.30	.84			
	Sum of Two Rates	(1.26)	(1.45)			(1.22)	(1.38)		(1.54)		(1.04)*	(1.14)				

number of iterations, and d_{min} = the minimum values for **d**. In addition, specify the number of simulation runs for obtaining the value of the achievement function. Set $m = 0$ and $k = 0$.

Step 2: Set $k = k + 1$.

Step 3: If $k > R_{max}$, then go to Step 8. Otherwise, go to Step 4.

Step 4: Execute simulation with multiple runs so as to determine $\mathbf{x}_{k,n}$ as follows:

(a) Set $i = 1$.

(b) If $\mathbf{a}(\mathbf{x}_{k,0} + \mathbf{d}_i) < \mathbf{a}(\mathbf{x}_{k,0})$, then $\mathbf{x}_{k,i} = \mathbf{x}_{k,0} + \mathbf{d}_i$ and go to Step 4(d). Otherwise, go to Step 4(c).

(c) If $\mathbf{a}(\mathbf{x}_{k,0} - \mathbf{d}_i) < \mathbf{a}(\mathbf{x}_{k,0})$, then $\mathbf{x}_{k,i} = \mathbf{x}_{k,0} - \mathbf{d}_i$ and go to Step 4(d). Otherwise, go to Step (d).

(d) If $i = n$ (the number of decision variables), then go to Step 4(e). Otherwise, set $i = i + 1$ and go to Step 4(b).

(e) If $\mathbf{a}(\mathbf{x}_{k,n}) < \mathbf{a}(\mathbf{B}_m)$ then go to Step 5. Otherwise, go to Step 6.

Step 5: Set $m = m + 1$ and $\mathbf{B}_m = \mathbf{x}_{k,n}$. Let $\mathbf{x}_{k,0} = 2\mathbf{B}_m - \mathbf{B}_{m-1}$, and go to Step 2.

Step 6: Set $m = m + 1$ and reduce the perturbation step size. Set $j = j + 1$. Let $\mathbf{B}_m = \mathbf{B}_{m-1}$ and $\mathbf{x}_{k,0} = \mathbf{B}_m$.

Step 7: If **d** is less than $\mathbf{d}_{min}$, go to Step 8. Otherwise, go to Step 2.

Step 8: Terminate the search. The solution is $\mathbf{B}_m$.

6.5 Analysis for an Example

Suppose that the production goals are set on the single container/discontinuous conveyor system as the following priorities from the management standpoint.

Priority 1: Set the conveyor speed of 30 m/min. In addition, achieve the production rate of at least 10 (pcs/min) with 95 per cent of probability.

Priority 2: Minimize the number of operators.

Priority 3: Minimize the buffer size (common to all stations) at each station.

Let x_1 = speed of the conveyor

x_2 = number of operators

x_3 = buffer size at each station

Although the conveyor speed can be usually set at some range, the speed of the conveyor is desired to be 30 m/min in this case. Other experimental conditions used in this example are same as those shown in Table 1. Hence, this constraint is given by

$$x_1 = 30$$

The corresponding objective is obtained.

$$G_1: x_1 + n_1 - p_1 = 30$$

Satisfaction of G_1 is achieved by minimizing $(n_1 + p_1)$, actually by setting both n_1 and p_1 to zero.

Because it is desired to keep the probability of satisfactory behavior above the level, i.e., 0.95 as the first priority, the production-rate goal may be represented by

$$P\ \{ f_1(x) \geq 10 \} \geq 0.95$$

where $P\ \{ f_1(x) \geq 10 \}$ represents the probability that the production rate will exceed 10 pcs/min. By consulting a table of the normal distribution function $F(t)$ is found when $t = 1.645$. In addition, by using the sample mean and sample standard deviation obtained by simulation experiments as the mean and standard deviation respectively, the following goal is obtained.

$$E\ [f_1(x)] + 1.645\ \{Var\ [f_1(x)]\}^{1/2} \geq 10$$

Then, the corresponding objective is obtained.

G_2: $E\,[\,f_1\,(x)\,] + 1.645\,\{Var\,[\,f_1\,(x)\,]\}^{1/2} + n_2 - p_2 = 10$

Satisfaction of G_2 is achieved by minimizing n_2, actually by setting n_2 to zero.

In the priority 2, the following objective is given.

Minimize x_2

Setting x_2 to the lower limit (3 operators) gives the following objective.

G_3: $x_2 + n_3 - p_3 = 3$

Satisfaction of G3 is achieved by minimizing p_3, actually setting p_3 to zero.

In the priority 3, the following objective is given.

Minimize x_3

Setting x_3 to the lower limit (1 piece) gives the following objective.

G_4: $x_3 + n_4 - p_4 = 1$

Again, satisfaction of G4 is achieved by minimizing p_4, actually setting p_4 to zero.

A resultant achievement function of this problem is expressed as:

lexicographic-min $\mathbf{a} = (n_1 + p_1 + n_2, p_3, p_4)$

s.t.

$$x_1 + n_1 - p_1 = 30$$

$$E\,[\,f_1\,(x)\,] + 1.645\,\{Var\,[\,f_1\,(x)\,]\}^{1/2} + n_2 - p_2 = 10$$

$$x_2 + n_3 - p_3 = 3$$

$$x_3 + n_4 - p_4 = 1$$

$$\mathbf{x},\ \mathbf{n},\ \mathbf{p} \geq 0$$

Applying the procedure described in 6.4 with 5 simulation runs at each time, the following solution is obtained for this problem:

$$x_1{}^* = 30$$

$$x_2{}^* = 13$$

$$x_3{}^* = 3$$

$$\mathbf{a}^* = (0, 10, 2)$$

In this multiobjective optimal solution, priority 1 is completely achieved. In other words, the optimal solution satisfies the conveyor-speed constraint and the production-rate goal. By allocating 13 operators to 15 stations and setting the buffer capacity to 3 (pcs.) at each station, the production rate of 10 pcs/min may be achieved. Actually, the expected value of the production rate is 14.75 pcs/min. As shown in Table 3, the 13th operator will be responsible for the last three stations. The operational problem of picking/conveyance systems is proved to be formulated as a multiple objective decision problem and solved by using a procedure with simulation, based on an actual case.

7. SUMMARY

This paper presents analytical results of four types of picking/conveyance systems. Characteristics of picking/conveyance systems are clarified from the standpoint of the handling requirements. In addition, a general procedure is proposed to find the solution of the multiple objective decision problem, by applying chance-constraint goal programming and simulation.

The procedure is also presented using a numerical example based on an actual case.

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REFERENCES

Ignizio, J.P. (1982), *Linear Programming in Single- & Multiple-Objective Systems*, Prentice-Hall, Inc, Englewood Cliffs, NJ.

Jelen, F.C. and J.H. Black (1983), *Cost and Optimization Engineering*, McGraw-Hill Book Co., New York, NY.

Miles, T., R.P. Sadowski, and B.M. Werner (1988), "Animation with Cinema," In *Proceedings of the 1988 Winter Simulation Conference*, M. Abrams, P. Haigh, and J. Comfort Eds. IEEE, Piscataway, NJ, 180-187.

Pegden, C.D. (1986), *Introduction to SIMAN*, Systems Modeling Corporation, State College, PA.

Takakuwa, S. (1989), "Module Modeling and Economic Optimization for Large-Scale AS/RS," In *Proceedings of the 1989 Winter Simulation Conference*, E.A. MacNair, K.J. Musselman, and P. Heidelberger Eds. IEE, Piscataway, NJ, 795-801.

Tonge, F.M. (1961), *A Heuristic Program for Assembly Line Balancing*, Prentice-Hall Inc., Englewood Cliffs, NJ.