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SIMULATION STUDIES OF PHYSICAL DISTRIBUTION SYSTEMS FOR AIRPORTS

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Abstract: This paper is concerned with the simulation studies for three large-scale physical distribution systems for airports which are stochastic transient simulations with the arrival process of objectives. The authors present the idea to make simulation models separately for the arrival process and for the equipment motion. Then the antithetic variate method which is one kind of the variance reduction method, is examined especially how to apply the method for multivariable simulation experiments. Moreover, a guideline for the optimum number of vehicles in a large scale AGV system is also presented.

Keyword: Simulation, Discrete-event systems, Modelling, Queuing, Stochastic systems, Automated guided vehicle, Variance reduction method.

1 INTRODUCTION

Recently large-scale physical distribution systems have been planned for several airport projects. For these systems, simulation studies are indispensable to evaluate and confirm the system performance. In this paper, two examples of simulation studies for the baggage handling system and the cargo handling system in the Kansai International Airport (coded as KIX) and an example for a large-scale automated guided vehicle (AGV) system for an airport are presented.

The first example shows the simulation modeling and results for an automatic transportation and sorting system for passengers' baggage. The simulation has been made for around 10,000 passengers a day using passengers arrival time distribution, baggage number distribution, and other presumed information for stochastic distributions and also equipment dynamics with designed control logic. It gives us capacity evaluation results for this system in the form of baggage processing time histograms before it's operation.

The second example includes simulation modeling for ASRS with complicated control logic for elevating transfer vehicles. Also in this model, the process of loading cargo into containers by workers has been included. The result enables us peak-time capacity evaluation. Moreover, it gives us evaluation for future expansion of facilities.

The third example shows that the simulation study can give us the optimum vehicle number criterion for the transporting system with around 40 to 70 AGVs taking account of the interference among vehicles and their transporting routes. Also, the formula for a guideline is derived to estimate the optimum number of vehicles for a given route.

Lastly, it is shown that the above examples, which are stochastic transient simulations, require us to take a systematic variance reduction approach. This paper shows a study of adopting the antithetic variate (AV) method to reduce the variances of the simulation results. A technique to use the AV method for multiple stochastic variables is presented and evaluated with these examples and also with a transient M/M/1 queuing system.

2 BAGGAGE HANDLING SYSTEM (BHS)

2.1 Configuration of KIX BHS

Figure 1 shows an overall view of this system. This system is symmetrical in the north-south direction and consists of four sub-systems: the domestic arrival, the international arrival, the domestic departure, and the international departure system. The international departure system is the most complicated one and

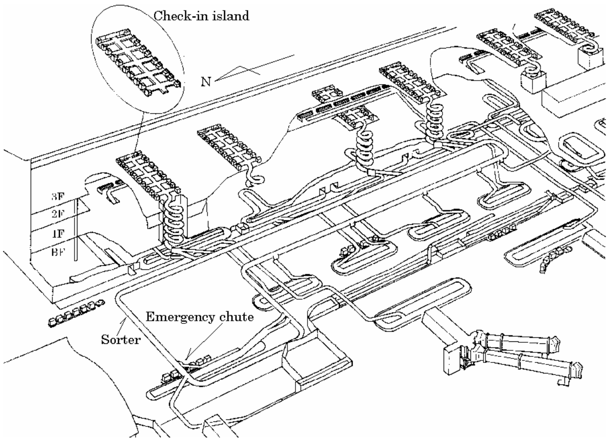

Fig. 1. Whole view of Baggage Handling System in KIX.

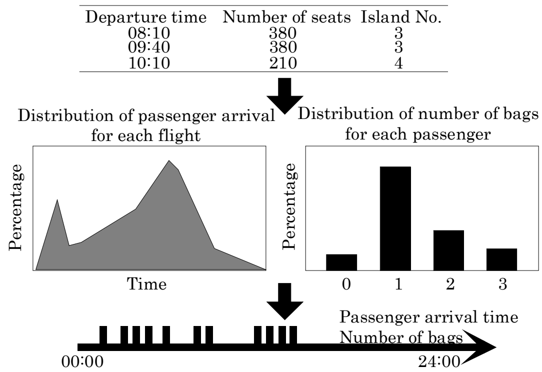

Fig. 2. Schematic of BHS arrival model.

the main target for this simulation study.

Passengers with baggage arrive at the international check-in counters located on the third floor of the terminal building. There are twenty check-in counters in each of eight check-in islands. At the check-in counter, an operator places the passenger's baggage on a weighing conveyor during the check-in procedure. After being weighed, the baggage is transferred to a queuing conveyor and at the same time, a dedicated segment on the following collecting conveyor, which we call "window", is reserved and the baggage waits for the reserved window to arrive. When the window arrives, the baggage is put onto the window and is transferred to a spiral conveyor. The spiral conveyor transfers the baggage from the third floor to the first underground floor, where there are sorting machines. Arriving at the underground floor, the baggage is put onto an empty tray of the sorter via an induction conveyor. The tray of the sorter rotates and discharges the baggage down to the make-up conveyor designated for the flight. The discharged baggage runs around on the make-up conveyor, waiting to be picked up by a worker and then it is loaded onto the aircraft container. An emergency discharging chute is also provided for wrongly transferred baggage and for safety when the make-up conveyor is fully occupied.

2.2 Objectives of simulation

The performance requirements for this system were given by the customer as follows.

–the capacity of one sorting machine is 3,000 pieces of baggage per hour and the capacity of the collecting conveyor is 980 pieces per hour.
–the transfer time from the weighing conveyor to the designated make-up conveyor is less than 11.5 minutes.

This system is composed of many devices and several branches and junctions. In order to obtain the precise figures of their performances as an entire system, therefore, we must take account of the imbalance of load and the difference in the timing of motion among several devices; they cannot be statically calculated. The authors also need to confirm the performance figures including the necessary number of buffers and also to confirm the control logic to satisfy the desired performances. As a consequence of this, the authors have carried out discrete system simulation with the following objectives:

–capacity evaluation of devices including their control logic for the sorter, collecting conveyor, make-up conveyors, and so on,
–confirming the transfer time of baggage to be less than a predetermined value, and
–checking the equality of availability of check-in counters.

2.3 Outline of simulation model

It is necessary to make a BHS model taking account of the arrival process of baggage in order to evaluate the performance through a day. Therefore, the authors have made two models separately. One is an "arrival model", which generates the arrival process of baggage as shown in Figure 2, and the other is a "main model", which represents all movements through the constituent devices. The arrival model calculates the passenger and baggage arrival process for one day according to a flight schedule and several stochastic distributions of: the number of passengers on each flight, the number of baggage brought in by each passenger, arrival time of passengers on each flights and so on. In the equipment model, the service process at the check-in counter is calculated using a random number stream. The equipment model represents weighing, collecting, spiral and induction conveyor motions, taking account of each control logic like "window"

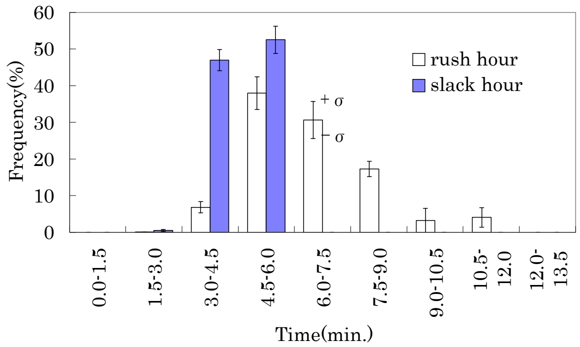

Fig. 3. Baggage processing time histogram.

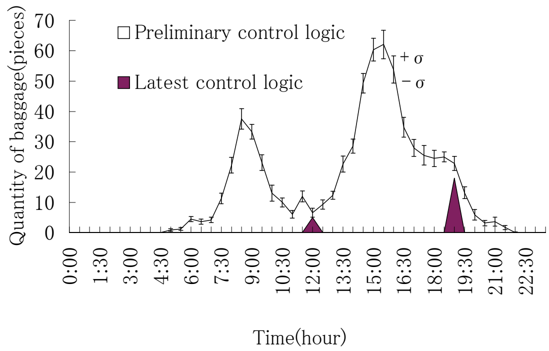

Fig. 4. Quantity of discharged baggage to emergency chute for one day.

control as explained previously. After be sorted, the baggage is picked up and put into a container by the service process which is an Erlang distribution with a mean time of 6 sec.

The results of simulation experiments will now be explained. These results have been obtained, using the variance reduction technique mentioned in section 5.

2.4 Simulation results

Figure 3 shows the histograms of processing time for baggage, which is the duration from baggage check-in on the weighing conveyor to arrival at the make-up conveyor. The mean processing time for slack time was 5.8 min. and the transfer to the make-up conveyor was finished in 6.6 min. at the latest. Nevertheless, the processing time for rush time became longer than that for slack time because of the increase in waiting time at the queuing conveyor and at the induction conveyor. Moreover, when the make-up conveyor is full, the baggage on the sorter tray may run around again and it will cause an increase in the processing time. These results show that the total transfer time in this system was less than 11.5 min, satisfying the required performance mentioned previously. Figure 4 shows a change in the amount of baggage discharged to the emergency chute through a day. According to this result, the amount of baggage discharged to the emergency chute was larger than expected at the beginning stage of planning. By the previous control logic, two pieces of baggage on successive trays with the same destination failed to be discharged successively to the same outlet and the second one was discharged to the emergency chute. Therefore the control logic was modified by this simulation result. The result of this modification gives us satisfactory performance.

3 CARGO HANDLING SYSTEM(CHS)

3.1 Configuration of KIX CHS and its function

Figure 5 shows an overall view of CHS in KIX. In this terminal, export goods received from forwarders are classified into three categories and stored in bulk storage. Export goods stored in bulk storage are retrieved at an appropriate time before the flight departure and made up on a pallet or in a container at one of twelve workstations. There are open spaces also to make up bulk goods in the case all workstations are fully occupied. Pallets or containers made up are called unit load devices “ULDs”. ULDs are transferred to an ASRS, using two transfer vehicles (TVs) and then stored in the shelves with two elevating transfer vehicles (ETVs). This ASRS has an induction conveyor to transfer made-up ULDs coming directly from forwarders. From two to three hours before the flight departure time, the containers or pallets for the corresponding flight are retrieved through the lowest shelves at lamp side and carried to the airplane by dollies.

This ASRS is completely controlled by a computer and has high functions as follows;

–One ASRS shelf for ULDs can store one 20-foot or two 10-foot containers or pallets.

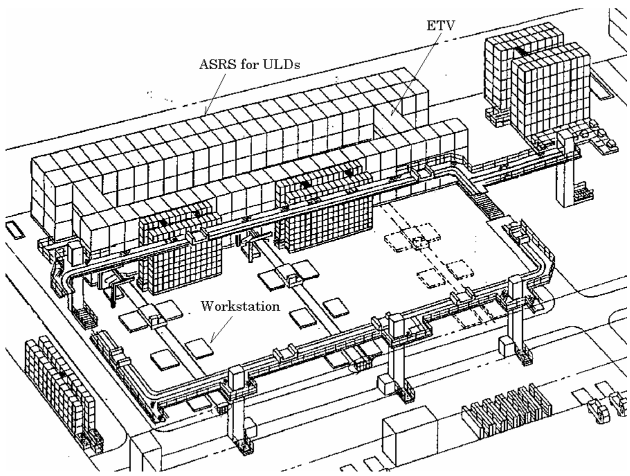

Fig. 5. Whole view of KIX Cargo Handling System (CHS).

–Two elevating transfer vehicles (ETVs) move on the same rails. Each ETV has an exclusive zone and a cooperation zone to store in and retrieve from.
–ASRS can store empty containers or transit cargoes, which can be retrieved to work-stations at land side.

3.2 Objectives of simulation

The following performance figures were determined at the beginning stage of the project, taking account of the increase in cargo demand;

–handling capacity of cargoes should be 134,000t per year or more.
–time limit for receipt of export goods is 2 hours before the flight departure.
–minimum time from retrieval of stored ULD to flight departure is 30 minutes.

To confirm these figures, the authors have carried out simulations, paying attention to the following;

–performance of ASRS at peak time,
–activity rate of ETVs, and
–cycle time of each moving machine and each worker's operation.

To examine operation performances, the following figures were also considered:

–container or pallet build-up time,
–necessary open-space build-up area, and
–future expansion capability.

3.3 Outline of simulation model

The authors made two models for this CHS based on the same idea as that of BHS, one was a CHS equipment model and the other was an arrival model which generates the process of bulk material arrival at the build-up workstation and also ULD arrival directly from forwarders. For the equipment model, complicated control logic has been taken into account in order to simulate the precise movement of each device. The distribution of build-up time for bulk material is presumed to follow Erlang distributions with a mean time of 45 min. for a pallet and 30 min. for a container according to results actually measured at another airport. Moreover in order to study future expansion possibilities, several devices and shelves of the ASRS for expansion were also taken into account within the equipment model.

Table 1 Simulation result of CHS capacity and activity rate of ETV

	ETV1	ETV2
max. activity rate	71.8%	87.3%
mean activity rate	34.7%	24.0%

Table 2 Evaluation result for future expansion

Year	Future facilities	Build-up efficiency	100%	200%
1994	no	Necessary	8.2	3.6
2000	no	build-up	14.2	9.8
2000	yes	space	15.5	11.1

3.4 Simulation results

Table 1 shows an example of the CHS simulation results. In the initial stage of this project, the authors estimated that the activity rate of ETV should be 78 % and that the quantity of ULDs handled should be 37 units in an hour by static calculation. By the simulation, the activity rate of ETVs was 77.1 % and the quantity was 32 units in an hour at peak-load time. Next, the authors carried out a simulation for checking the performance of the entire CHS with facilities for future expansion. Simulation experiments with or without facilities for future expansion and with various efficiencies of building-up work were carried out. The results of these experiments are shown in Table 2. This table shows the result of the comparison of the maximum number of necessary open-space areas between the year of opening (1994) and the year 2000. This result means that it is important for future operation by the client to consider not only an expansion of facilities but also how to improve the efficiency of building-up work.

4 LARGE-SCALE AGV SYSTEM

4.1 Example of system

As a third example, a simulation experiment will be introduced as one method for designing large-scale AGV transportation systems for transporting bulk cargo in boxes between the bulk storage ASRS and several points inside a cargo terminal. Figure 6 shows a schematic layout of the transporting route. This layout itself was determined according to results of several simulation experiments for some candidate layout designs. The vehicles run on rails having branches and junctions which facilitate efficient loading and unloading without much interference with other vehicles running on the main line. This system has also a special feature that the necessary number of vehicles becomes very large to meet capacity demand which amounts to 320 boxes per hour during the peak time. The optimum number of vehicles to meet the capacity demands has also been obtained by the

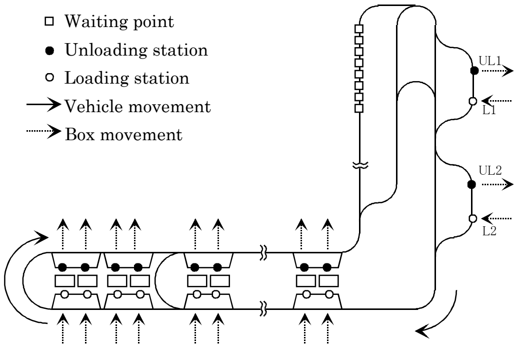

Fig. 6. Schematic layout of AGV system.

simulation experiments.

4.2 *Outline of model*

As illustrated in the figure, this AGV system has along the main transporting route, 18 loading stations and 18 unloading stations each having a dedicated branch route. When running to each station, the vehicle runs to the branch route in order to avoid interference with the other vehicles running on the main route. After the loading or unloading operation, the vehicle returns to the main route after waiting for the proper timing for merging if necessary. Moreover, the distance between two vehicles is checked. The latter one will be automatically decelerated when the distance is less than the predetermined value.

4.3 *Optimum number of vehicles*

The necessary number of vehicles fairly relates to the spending on equipment when the route and the number of branches and junctions are determined. On the other hand, too many vehicles cause a decrease in the total transporting capacity because of the interference among vehicles. It means that we have an optimum number of vehicles for the corresponding layout of the route.

As results of simulation experiments, Figure 7 shows the queue length at the most critical loading point versus the number of vehicles. We can find that the optimum number of vehicles is around 60. This figure also shows that there is an appropriate number of vehicles corresponding to the layout and length of the route, which we can intuitively recognize. On the other hand, we need many simulation experiments to find such characteristics, for example, in this case, the authors need to carry out 40 sets of experiments for accuracy at 5 points of the number of vehicles, i.e. 200 experiments in all. The following formula can be proposed to obtain the optimum number of vehicles, especially taking

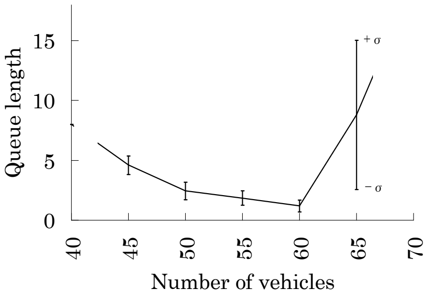

Fig.7. Queue length versus number of vehicles.

account of the interference length among vehicles;

$$N_{opt} \cong \frac{L_{main}}{l_{junc}} + N_{wait} \quad (1)$$

where L_{main} is the length of main route, N_{wait} is sum of empty stand-by vehicles on loading branch, and l_{junc} means the distance between two vehicles which will be come about at the most critical junction points when the latter vehicle will merge from stopping state.

In this example, L_{main}=828.9m, N_{wait}=20, L_{junc}=20.7m.

With this formula, we can obtain $N_{opt} \cong 60$ for this example and this figure is just same as the actual optimum number shown in figure 7. This formula give us an approximate optimum number of vehicles for preliminary design without numerous simulation studies.

5 APPLICATION OF VARIANCE REDUCTION METHOD

The three simulations mentioned earlier are transient stochastic simulations through one day according to the flight schedule. Normally, the coefficient of variance of an observed variable obtained by transient simulation becomes larger than the one for steady-state simulation (Law & Kelton 1991a). This fact requires us to carry out more experiments to obtain reliable results. The authors have examined the antithetic variates (AV) method with an extension to the multivariable system.

Generally, even though the objective system is highly complicated queuing system, we can intuitively select one primary set of arrival and service processes which are dominant in the results. Therefore, we will consider a case with two stochastic variables as the following, but we can easily extend this result to multi-variable cases.

5.1 *Application technique for AV method*

Stochastic simulation using random numbers is described as follows.

$$Z = F(X, U(V)) \quad (2)$$

where Z is one output from an experiment,

$$X=(x_1, x_2, \cdots, x_m) \quad (3)$$

is a deterministic operative variable,

$$U=\{U_1(v_1), U_2(v_2), \cdots, U_n(v_n)\} \quad (4)$$

is an n-set of stochastic variables,

v_i is a random number stream for simulating the i-th stochastic variable U_i.

In case $n=2$, $4p$ sets of simulation results can be obtained by using antithetical variable for each random number stream respectively as follows;

$$\begin{aligned}
Z_{NN}^1 &= F(X, v_1^1, v_2^1), \cdots, & Z_{NN}^p &= F(X, v_1^p, v_2^p) \\
Z_{AN}^1 &= F(X, 1-v_1^1, v_2^1), \cdots, & Z_{AN}^p &= F(X, 1-v_1^p, v_2^p) \\
Z_{NA}^1 &= F(X, v_1^1, 1-v_2^1), \cdots, & Z_{NA}^p &= F(X, v_1^p, 1-v_2^p) \\
Z_{AA}^1 &= F(X, 1-v_1^1, 1-v_2^1), \cdots, & Z_{AA}^p &= F(X, 1-v_1^p, 1-v_2^p)
\end{aligned} \quad (5)$$

Then we have two possibilities for estimation:

$$E_1[Z] = \bar{\xi} = \frac{1}{p}\sum_{i=1}^{p}\xi_i = \frac{1}{2p}\sum_{i=1}^{p}(Z_{NN}^i + Z_{AA}^i) \quad (6)$$

$$E_2[Z] = \bar{\varsigma} = \frac{1}{p}\sum_{i=1}^{p}\varsigma_i = \frac{1}{4p}\sum_{i=1}^{p}(Z_{NN}^i + Z_{AN}^i + Z_{NA}^i + Z_{AA}^i) \quad (7)$$

The authors' idea is that if a strong negative correlation between Z_{NN} and Z_{AA} can be expected beforehand, we may use $\bar{\xi}$ as the case 1 and on the other hand if not, we use $\bar{\varsigma}$ as case 2.

5.2 Result of application to M/M/1 system

Simulation experiments were made for the simplest M/M/1 queuing system with a mean arrival interval of 1 min. and a mean service time of 0.9 min. for the first 100 arrivals from the initial state. Figure 8 shows a comparison between the true value (Law and Kelton 1991b) and three estimated values for the mean waiting time in the queue for the first 100 arrivals. The values $\bar{\xi}$ and $\bar{\varsigma}$ estimated by the AV method have less deviation from the true value than δ, which is a simple mean obtained without using the AV method. We can also recognize that the estimate $\bar{\varsigma}$ has less variance around the true value than $\bar{\xi}$.

5.3 Application to simulation

This technique was applied to BHS and CHS simulations and the necessary number of experiments could be reduced as a result. In the case of BHS, the passenger arrival process and the service process for each flight are primary stochastic variables that affect the performance especially the waiting time for the entire system. In this case, it is difficult to assume a correlation between Z_{NN} and Z_{AA}, and so $\bar{\varsigma}$ was used.

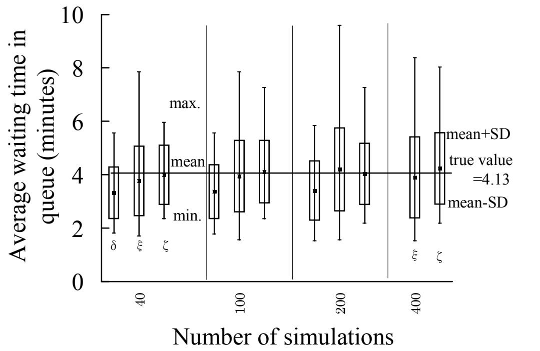

Fig. 8. Comparison of variances for transient M/M/1 system.

On the other hand, in the case of CHS, the stochastic variables affecting the characteristics of the system are the distribution of build-up service time at workstations, which has two different distributions of build-up time for pallets and containers.

Because we can expect a negative correlation between Z_{NN} and Z_{AA} in these two service processes, $\bar{\xi}$ was used.

In both cases, we could satisfactorily obtain the several results after only 40 experiments even though these systems are quite large-scale objectives for simulation.

6 CONCLUDING REMARKS

In this paper, three examples of stochastic simulation studies for large-scale physical distribution systems have been presented especially in order to evaluate the overall system performances before their operations. Through these studies, systematic approaches to obtain accurate results with a minimum number of simulation experiments are recognized to be important especially for such large-scale stochastic simulations.

The authors have presented an application technique to use the antithetic variate method for multi-stochastic variable simulation to reduce the variance of the result. A guideline for the optimum number of vehicles has also been presented as a formula for an example of a large-scale AGV system. This guideline also enables a decrease in the number of simulation experiments and moreover provides us with preliminary criteria for determining an appropriate figure for the number without simulation experiments.

7 REFERENCES

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