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A SLAM II Simulation of Optimal Shuttle Scheduling.

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〈Abstract〉

This paper studies the operating policies of a two-station shuttle system consisting of a fleet of finite size and vehicles of finite capacity which transport passengers between two terminals (each terminal having dispatching control). Passengers arrives at either station according to independent negative exponential processes, and dispatching decisions are made on the basis of fixed-time intervals or queue lengths (greater than zero). The objective is minimization of a total opportunity cost function defined by passenger waiting time, nonutilization of vehicles, and unused passenger seats. The travel time is probabilistic with known distribution and mean. This paper shows by SLAM II discrete event simulation techniques that optimal values for any or all of the three parameters (fleet size, vehicle capacty, dispatching interval) can be empirically determined by sensitivity analysis. This simulation model can be adapted to a wide variety of other problems of the shuttle-system.

왕복교통체계의 최적운영계획을 위한 SLAM II 전산모의 실험

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산 업 공 학 과
(1982. 10. 30 접수)

〈요 약〉

본 논문에서는 두 지역간에 승객을 수송하는 왕복교통체계의 운영계획문제를 다룬다. 왕복교통체계는 두 개의 terminal과 한정된 승객을 수송할 수 있는 유한한 차량들로 이루어진다. 차량의 운행은 각 terminal에서 서로 독립적으로, 일정한 간격 혹은 대기행렬의 길이에 따라 이루어진다.

각 terminal에 도착하는 승객의 도착간격시간이 지수분포를 따르며 두 지역사이의 승객수송시간은 uniform distribution을 한다. 최적운영계획은 승객의 평균대기시간, 차량의 사용도, 각 차량의 좌석이용도를 고려하여 결정한다.

각 운영계획에 대한 분석은 SLAM II 모의실험언어를 이용하였다.

I. Introduction

A dispatching policy consists of detemining the number of, capacity of, and instants in time at which vehicles are dispatched along a route.

The studies about the dispatching policy were made analytically with various assumptions, deterministic passengers arrival rates, infinite vehicle capacity, or single station dispatching. But realistic applications of these analytical solutions to actual transportation system are difficult.

For more realistic solution of dispatching problems, a simulation model will be established which can be used in the determination of optimal shuttle system operating policies for a multiple-vehicle fleet with vehicle of limited capacity and a two-station system. Each station will have the capability of dispatching a vehicle on a one-way trip once the assigned dispatching conditions have been fulfilled.

Busses, trains, subway, and ferries may all be used as cases of shuttle service. Here we shall use an airline shuttle service as an illustration.

Ⅱ. The Model

The model consists of two simulated stations (airports) from which shuttle vehicles (airplanes) will be independently dispatched at fixed time intervals.

Initially we assigned five shuttle vehicles to one station and four to the other (These numbers were later varied during the many simulation runs that were made). An increase in the number of shuttle vehicles at each station could be the result of their remaining day's shuttle service.

During the shuttle service day, vehicles are dispatched from each station independently on a predetermined schedule of fixed time intervals (assuming, of course, that vehicles are available at each station).

Having accounted for the shuttle vehicles in the model, we must now deal with the arrival of passengers to be served. In this model it has been assumed that passengers will arrive for servicing probabilistically according to the negative exponential function. This function seems to typically describe most random queueing cases of this type. The distribution is represented in the follow ingmanner.

$$f(t) = \lambda e^{-\lambda t}$$

where $f(t)$ represents the actual interarrival time and λ (=8 time units in our model) represents the mean time between arrivals.

The next task is to specify the dispatching rules used to send shuttle vehicles to the other station.

Most airlines which operate shuttle service between two terminals do so on a regular time schedule. This schedule is maintained for the convenience of both the passengers, who then know exactly when to expect a shuttle to depart, and the airlines, which are convenient in operating equipment and crews. Regular scheduling is also necessary from a grobal point of view to prevent chaotic traffic-control conditions.

In our model, the shuttle service will be scheduled to depart continuously from either station at five different intervals (300, 450, 600, 750, and 900 time units)

As is true of most shuttle services, this system will also provide backup shuttle vehicles (within constraints of the total supply of vehicles available at each station) at scheduled departure times to handle any overflows of passengers. This prodedure is followed by most airline shuttle services. It specifies that if passengers arrive at the boarding gates by specified departure time, they are guaranteed transportation to the other station immediately if vehicles are available, or if not, as soon as a vehicle becomes available.

Most airlines can promise such a service because they maintain standby capacity in their shuttle fleet. This additional capacity handles abnormal deviation from the mean passenger arrival rate, within certain levels of confidence. Additional backup aircrafts are made available at each station as shuttle flights continue to arrive from the other station. Thus the fleet of vehicles is being constantly rotated.

In the model, all members of the queue(people waiting for service at the scheduled departure time), will enter the airplane. If there are any members of the queue remaining who cannot fit into the reqularly scheduled plane, they are immediately transfered to the next waiting plane (if there is one available). If a backup plane is not available, the member of the queue wait until one does become available and then leave immediately. In the mean time, the queue is continuously incremented by passengers arriving for the next flight. When the backup plane(or the regularly scheduled one if it has been delayed) finally becomes available, we shall assume that anyone waiting in line will want to take that plane at that time rather than wait for the next regularly scheduled flight. Passengers arriving later, then queue up for the next regularly scheduled departure. A schematic diagram of the logic describing these dispatching rules is shown in Figure 1.

It becomes obvious from the above discission that queue lengths and passenger waiting times are a fuction of three factors; the capacity of shuttle vehicles, the total number of shuttle vehicles available for use at the terminal, and the dispatching schedule itself. These three factors are all variables in the model we have formulated. By simply changing a few statement in the programs, we can vary all these parameters in a coarse sensitivity analysis to determine optimal values for each of the three parameters in this particular model.

Once the airplane is dispatched to the other terminal, the travel time is represented by random deviate generator. We set travel time to be a following distribution.

$$f(t)=1/200 \quad 500<t<700$$

Once the shuttlevehicle arrives at the other terminal, the passengers disembark immediately and the airplane becomes available for the return trip. In our model, the entire process is carried on continuously and simultaneously at both station as vehicles continually shuttle back and forth between terminals until 3,000 passengers transactions have been handled by the shuttle system.

Having explained the basic structure of the model, we must now establish a criterion which will measure the efficiency of each configuration of system parameters. This criterion is necessary in order to employ sensitivity to determine the optimal set of parameters for implementing the model.

As stated above, the controllable input variables are (1) capacity of the vehicles, (2) number of vehicles in the fleet, and (3) vehicle dispatching intervals. The uncontrollable system variables in this case are passenger arrival rates and vehicle travel times.

From these variables, the optimal system parameters will be determined on the basis of total opportunity cost to the transit company (airline). This hypothetical cost will be calculated from the system output generated in the simulation model. These are (1) opportunity cost incurred in passenger waiting time, (2) opportunity cost incurred in nonutilization of shuttle vehicles, and (3) opportunity cost incurred in dispatching vehicles with empty seats.

The effect on efficiency of each variation of the parameters of the system will be measured in a total opportunity cost figure for the airplane company. The cost are calculated as follows;

(1) The opportunity cost of passenger waiting time is a hypothetical figure representing cost to the transit company in passenger complaints about long waiting lines, loss of future sales, loss of good will due to dissatisfaction caused by excessive time spent waiting for shuttle service. Long waiting times may arise from infrequent dispatching or from the una-

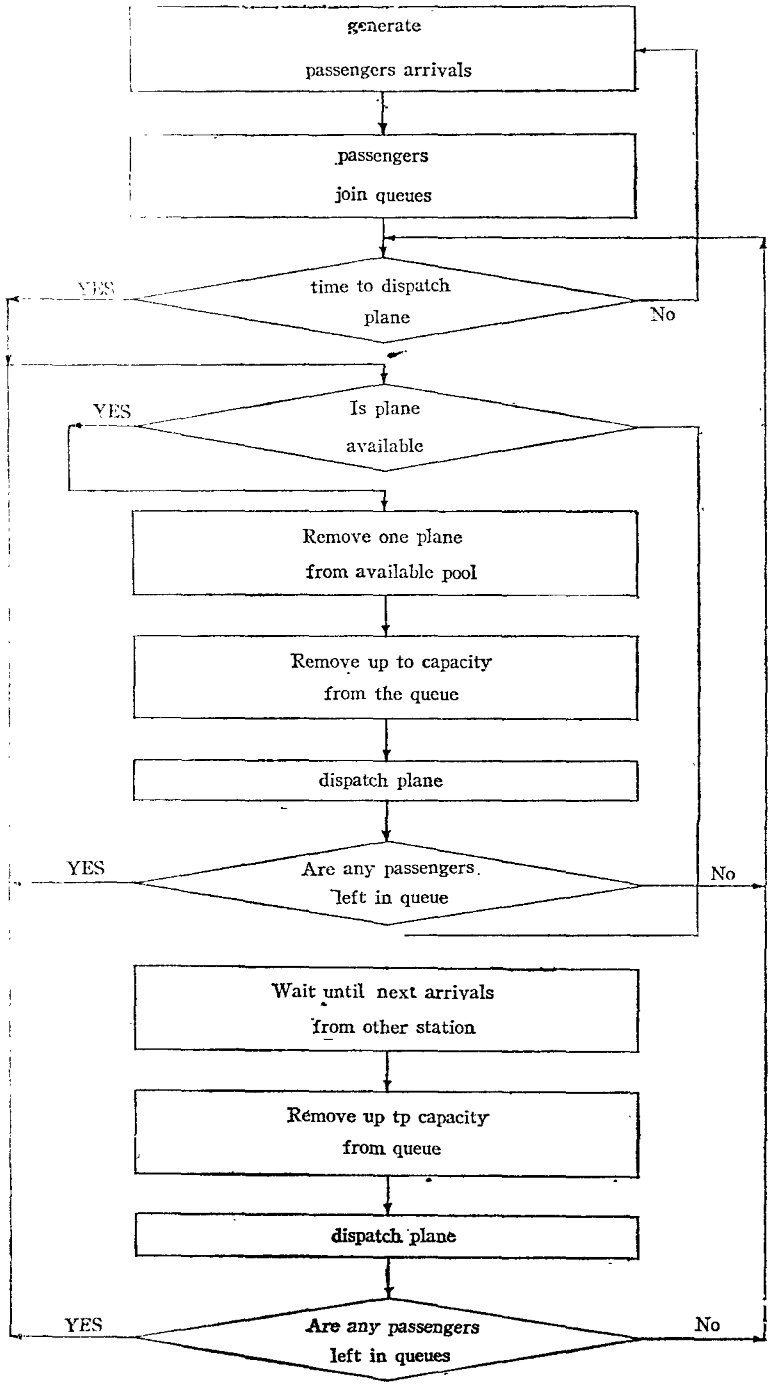


Fig. 1 Diagram of logic describing dispatching rule

vailability of shuttle vehicles at the scheduled departure times. The total cost of passenger waiting time is computed by multiplying the average waiting time per passengers in the shuttle queue by the total number of passengers served. This figure is then multilied by an arbitrary cost factor of 0.01 per unit of passenger waiting time to give an opportunity cost.

(2) The opportunity cost incurred from nonutilioation of shuttle vehicles is meant to represent the potential sales lost on other flights by tying up airplanes in the shuttle fleet which are not actually in use. An airplane can only make a profit for the airline company if it is carrying passengers on a flight; if it sits idly on the ground, it is incurring an opportunity cost. This hypothetical cost will be computed first by multiplying the average overall percentage of idle time per vehicles by the number of vehicles in the fleet. This figure is then multiplied by an appropriate opportunity cost factor to the passenger carrying capacity of the vehicles in the fleet.

The opportunity cost in idle time for tying up a fleet of 200-passenger vehicle must obviously be greater than the cost for a fleet of 50-passenger vehicles. In the simulation, the cost coefficient is arbitrarily determined by multiplying the vehicle capacity by 10. Thus, the 200-passenger vehicles would have a cost coefficient of 2000 per vehicle and the 50-passenger vehicle would have a cost coefficient of 500 per vehicle. The nonutilization percentage is computed by summing the average vehicle-utilination values, U_i, for each of the N vehicles in the fleet ($i=1, 2, \cdots, N$) and substracting the sum from the total number of vehicles in the fleet, N.

Analytically, this is represented as

$$\text{Nonutilization} = N - \sum_{i=1}^{N} U_i \text{ where } 0 < U_i < 1.$$

(3) The opportunity cost incurred in dispatching vehicles with empty seats represent the unrealized profit that would have been made had all the seats been sold. In this case, an arbitrary cost coefficient of 10 was used as profit contribution of each passengers.

The opportunity cost for empty seats is computed by first calculating the total number of shuttle runs made for each set parameters. When it is multiplied by the passenger capacity, the product is the total number of seats available. The simulation was designed to run for 3,000 paying passengers. The total of 3,000 is subtracted from the number of seats available, leaving the total number of unoccupied seats. When this is multiplied by the opportunity cost factor of 10 per empty seat, the product is the opportunity cost incurred in dispatching vehicles with less than full loads.

The sum of these three opportunity cost becomes the total opportunity cost to each combination of system parameters.

Ⅲ. Simulation Model

SLAM Ⅱ is an advanced FORTRAN based simulation languages that allows simulation models to be built on three different ways, networks, discrete event, and continuous model. Combining capabilities are also available.

To simulate a discrete event model like our model, SLAM provides a set of FORTRAN subprograms for performing all commonly encountered fuctions such as event scheduling, statistics collections, and random sample generation. The advancing of simulated time and the order in which the event routines are processed are controlled by the executive program. Thus, SLAM relieves the simulation programmer of the task of sequencing events in their proper chronological order.

The wide variety and capabilities in SLAM allows several different approaches to the simulation of our systems. Our approach is described in Figure 2.

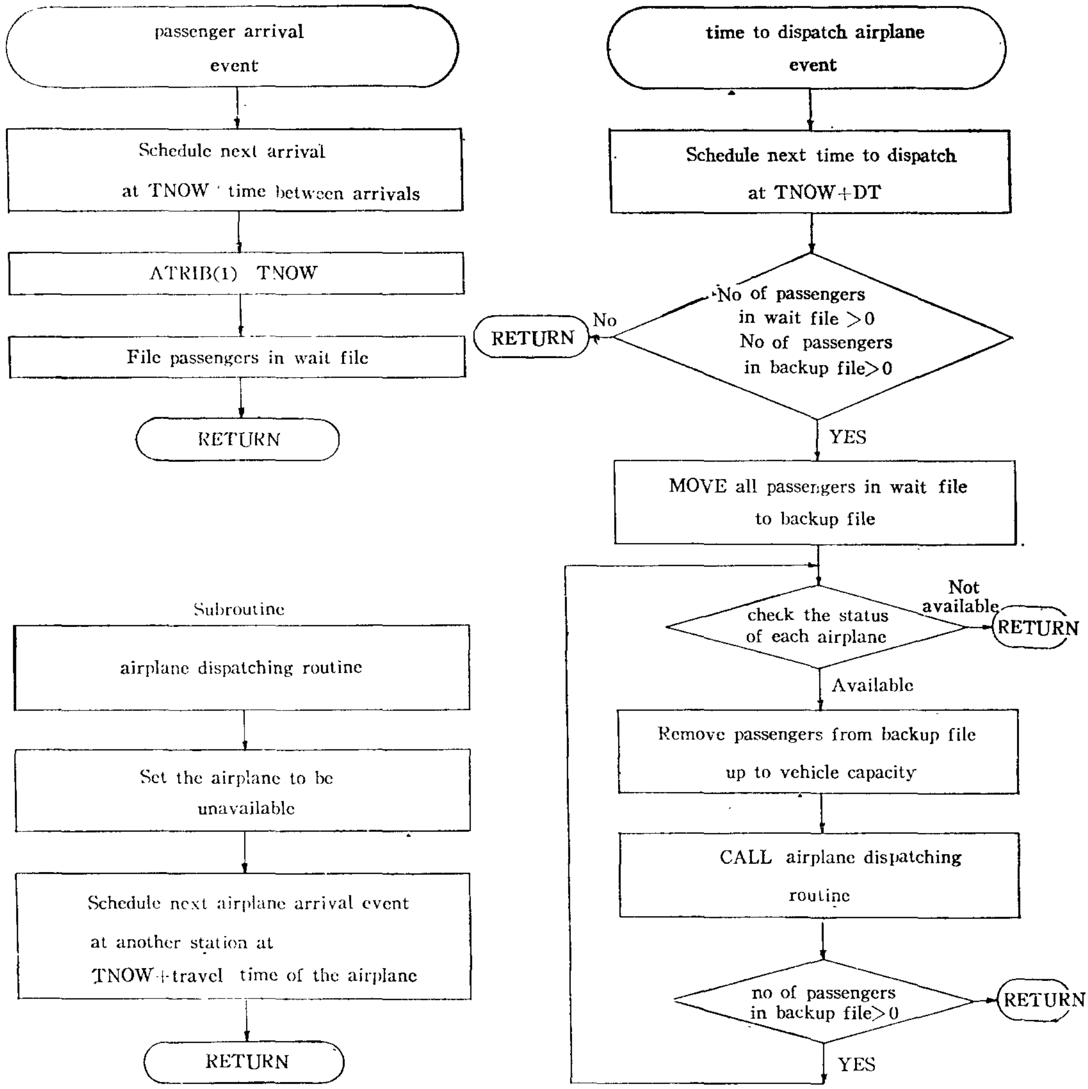


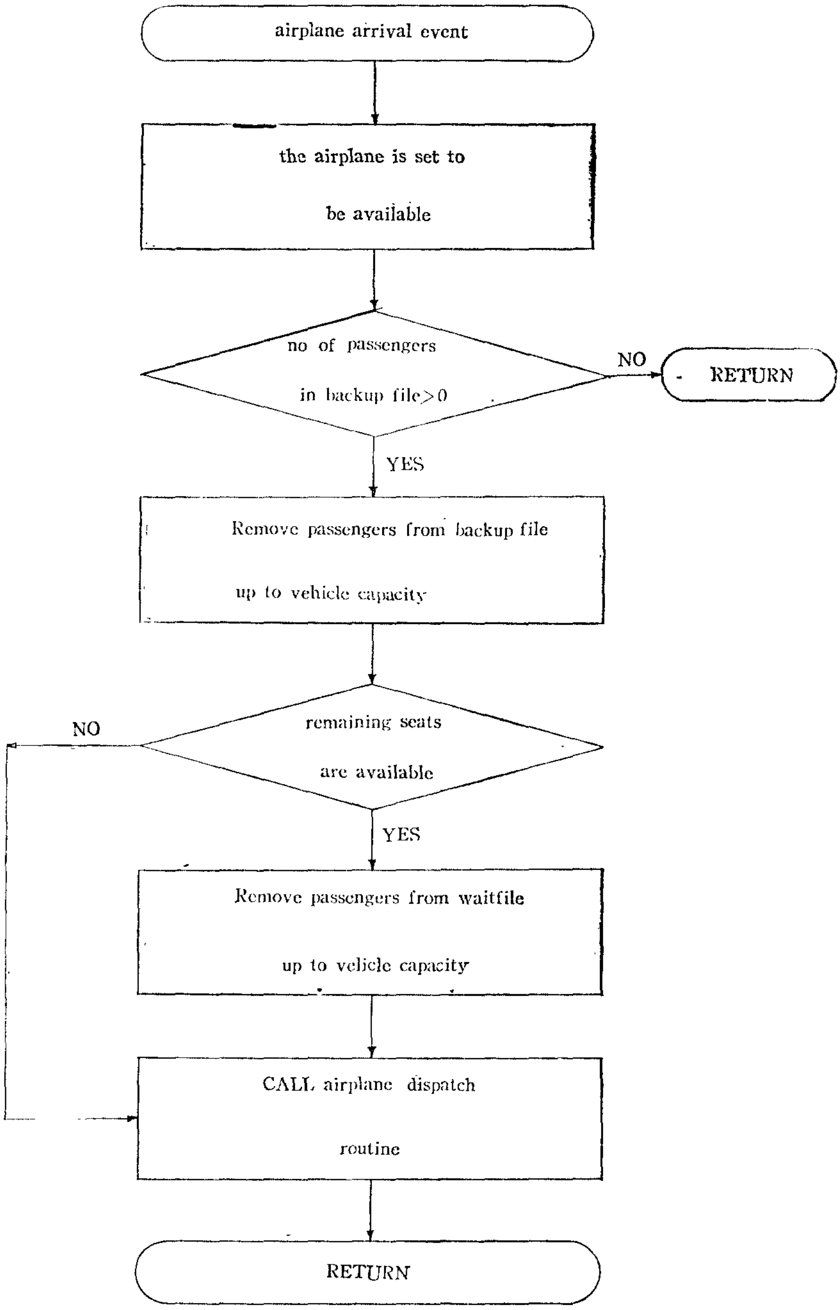
Fig. 2-a. Event Control logic for a station (—Continued—)

Ⅳ. Results and Discussion

Having simulated the model in SLAM Ⅱ language, runs were made varying (1) the dispatching interval from 300 to 900 time units in increment of 150, (2) the capacity(of the shuttle vehicles from 50 to 200 passengers in increment of 25, and (3) the size of the shuttle fleet from 5 to 9 vehicles.

For each of the 175(5×7×5) different possible combinations of the system parameters, we computed the total opportunity cost in accordance with the method previously described. All the cost figures are tabulated in Table 1.

The data can also be plotted graphically using the cost figures as dependent variables and each of controllable input variables as independent variable. For example, a plot of total opportunity cost versus the capacity of



wait file: waiting customer queue
backup file: backup customer queue
DT: dispatch interval

Fig. 2-b. Event Control logic for a station.

Table 1. Total Opportunity Costs for Various Combinations of System Parameters

Fleet Size	Vehicle Capacity	Dispatching Intervals				
		DT=300	DT=450	DT=600	DT=750	DT=900
9	50	16542	24058	17870	20900	23284
	75	34733	21449	31990	32309	25915
	100	54785	35295	22325	31324	38434
	125	74825	49916	33122	29425	33907
	150	94873	64541	43915	39041	32731
	175	114919	79165	54707	48658	40922
	200	134965	93789	65501	58275	49112
8	50	16047	11055	18941	19049	22783
	75	33986	20702	30494	29388	25161
	100	53782	34291	21332	30324	37430
	125	73577	48665	31870	28174	32657
	150	93373	63039	42421	37541	31229
	175	113169	77413	52957	46908	39170
	200	132965	91787	63501	56285	47110
7	50	15152	21318	16782	20460	22331
	75	33235	19948	28481	28663	24411
	100	52781	33291	20326	29155	36428
	125	72326	47415	30619	26924	32907
	150	96872	61539	40916	36041	29729
	175	111417	75663	51206	45167	37420
	200	132235	89787	61499	54275	45110
6	50	15737	20321	17503	17816	20630
	75	32484	31198	30414	28673	23661
	100	51780	32290	19325	28054	35428
	125	71075	46163	29368	25673	31657
	150	90370	60038	39411	34541	28229
	175	109665	73912	49454	43408	35670
	200	128961	87785	59497	52275	43110
5	50	14283	16612	16216	17703	18073
	75	32480	17668	26614	26991	22911
	100	51768	31276	20095	30209	33037
	125	71056	44883	29873	23255	29959
	150	90343	58491	40653	31642	26728
	175	109630	72098	50932	39031	32918
	200	128918	85706	61211	48421	41108

the vehicles and the dispatching interval is given in Figure 3.

The numerical results in this particular simulation are meaningful only in sofar as they reflect the ability of simulation to employ quantitative methods for comparing the relative efficiencies of a transit system with certain variable parameters.

Because thecosts were all arbitrary, the computed values are meaningless. However,

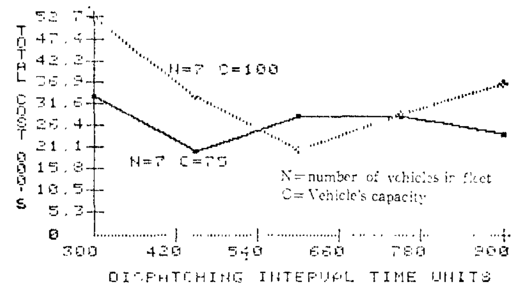


Fig. 3. Cost Vs. Dispatch

the relative magnitudes of the cost in the tabulated results indicate that a set of optimum policies for each combination of system parameters can be drawn from the model.

Ⅴ. Conclusion

The significance of this paper lies in the fact that the model developed is directly applicable to the solution of almost any kind of the two-station, finite-capacity, finite-fleet size, shuttle-service problem which is found today in many transportation systems. The paper has shown that by constructing a simulation model of a complex, discrete, stochastic system with a finite time horizon, a quantitative sensitivity analysis can be carried out to determine optimal parameters in the shuttle system.

Simulation is the only practical solution to this kind of problem since neither analytical nor numerical solutions can be reached.

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