MODELING DYNAMIC SCHEDULING OF PUBLIC TRANSPORT SYSTEM UNDER STOCHASTIC BEHAVIOR

Laurencia EVILYN
Research Fellow
Department of Civil Engineering
University of Indonesia
Kampus Baru UI Depok
16424 Indonesia
E-mail: epoy0194@dnet.net.id

Sutanto SOEHODHO
Transport Research Group
Department of Civil Engineering
University of Indonesia
Kampus Baru UI Depok
16424 Indonesia
Fax: 62-21-7270028
E-mail: tanto@eng.ui.ac.id

Abstract: The well organized scheduling and operational of public transport is something that users need in order to get an efficient trip. In the peak hour condition, there is public transport system with high load factor and also the low value of probability for user to get the bus. Considering this problem, the paper presents an approach of modeling dynamic scheduling of public transport system. The characteristic of passenger arrival and cruising speed of bus are assumed to follow a stochastic distribution pattern, and the results between operation without and with feedback are also compared. The performance of system can be evaluated anytime within the simulation, from the output namely: Bus Load Factor and User Probability of getting on board

1. INTRODUCTION

Providing better service to public transit users or passengers is the challenge to operators. It is, however, hard to provide any better service when resource is limited. This resource in the operational context involves various activities such as route optimization, vehicle scheduling and driver assignment. Vehicle scheduling as one of the activities needs dynamic settlements in which it is supposed to react to the fluctuating demand.

On the other hand, demand could also react actively to the changing supply (e.g., scheduling policy) and so forth. Based on such dynamic behavior it is hard to predict the equilibrium with mathematical programming models even for the elegant one, while decision for sound scheduling strategy is required in any progressing time within the time period of service. This phenomenon is made even worse due to any operational limitation such as fleet size. So it can be viewed that there is a gaming between users and operators to achieve certain level of service.

To achieve such equilibrium a case can be made in which users are spending minimum time to wait the service and operators minimize their resource (e.g., fleet). This is the objective of this study to locate an effective tool to evaluate such equilibrium in achieving better service. The equilibrium can be assumed as balance between tolerable or minimum total wait time of all passengers within a certain capacity (e.g., fleet size) and operational period. Attempt to model such equilibrium is constructed and to comprehend the performance of such model under various conditions a dynamic simulation is elaborated. Furthermore, to represent the real operational aspects stochastic behavior is adopted for characteristics of passenger arrivals as well as for the vehicle movement within the mixed traffic (e.g., bus).

1.1. Problem Identification

The basic things that become core of the problems are:
1. Unbalancing between supply-demand (e.g., fleet size and number of passengers)
2. Inefficiency of the existing operational public transport
3. Improper information system to confirm the real condition of the operational public transport to the user

1.2. Stochastic Behavior

In this paper stochastic behavior means that the attitude of significant components like passengers and fleet of public transport system do not exist in constant assumption, but randomly follow statistical distribution patterns. Passenger arrival is assumed to follow the shape of Poisson Distribution, while the cruising speed of the bus follows the Normal Distribution.

1.3. System Dynamics

System Dynamics is a methodology for understanding a complex problem (Richardson and Pugh, 1983). This method focuses on policy and how the policy decides behavior of problems that is modeled by system dynamic. The main characteristics of the problems are:

1. The problem should have a dynamic characteristic that there is a quantity changing along the progressing time so it can be represented in quantity Vs time interval graphic.
2. Possibility for creating feedback characteristic. The feedback will become input through the system.

2. DYNAMIC APPROACH ON PUBLIC TRANSPORT SCHEDULING

Many significant variables in public transport system change the behavior by time (e.g., time dependent) such as passenger arrival, boarding passenger, alighting passenger, vehicle movement on the street, speed, and others are changed from time to time within an operational period. The basic difference between static and dynamic characteristic is in static characteristic, Talking about quantity in one certain time (t) means checking only the number or condition in (t). But in dynamic characteristic, talking about the quantity in (t) means considering and accounting condition or the number not only in (t) but also in the time before $(t-1)$, $(t-2)$, ...,$(t-N)$. Creating feedback as one of characteristic of dynamic approach is important to give the consideration to the input system within operational period.

3. MODEL DEVELOPMENT

3.1. Modeling Concept

There are many facets to consider the performance of public transport operation. For example by looking at the Load Factor of the bus it can be noticed how full the bus in operation time and by checking User's Probability it is known how difficult for passenger to get the bus.

3.1.1. Probability Condition

Probability Condition for a passenger who is waiting for the bus at the station following:

$$\boxed{Pr\,(X) + Pr\,(Y) = 1} \quad \text{..............................} \quad (3.1)$$

where,

Pr = Probability
X = The event that every passenger can take the first coming bus after his or her arrival at Bus Stop.
Y = The event that not every passenger can take the first coming bus after his or her arrival at Bus Stop.

In practice the event (Y) includes various conditions, such as the condition that the passenger who can never take the bus which results in the infinity of waiting time. That is why the event (Y) is too difficult to be handled. So in order to simplify the optimization problem of the condition defined in equation 3.1, it can be considered to maximize only $Pr\,(X)$ as the objective function of this problem. That is to maximize the probability that every passenger can take the first coming bus after his or her arrival rather than to minimize $Pr\,(Y)$.

3.2. Model Formulation

3.2.1. Route of Public Transport

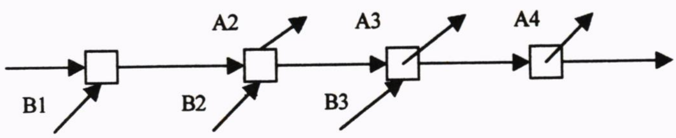

Figure 3. One Way Lane Service

Where: A = Alighting Passenger
B = Boarding Passenger

☐ = stations

The route above consists of several stations. At the first station bus only takes passengers ($B1$) and at the last stations it only drops the passengers ($A4$), while at other stations between first and the last ones, the bus takes and drops the passengers and is constrained by its practical capacity.

Because of the dynamic characteristic, counting the quantity of any entity now means counting the quantity in the context of elapsed time too. The elapsed time mechanism to the scheduling program works as illustrated in Figure 4.

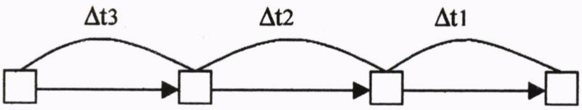

Figure 4. Elapsed time

Notes: n = number of station
Δt = elapsed time which is equals to bus travel from one stop to the other

Dwell Time

$$D(t)=max\{B(t)*Boarding\ Time\ ;\ A(t)*Alighting\ Time\} \quad \text{...................... (3.2)}$$

Dwell Time is defined as time spent by a bus to let passenger get on and off when bus arrives at every bus stop. Equation (3.2) is determined when the maximum one between total boarding time or total alighting time exist or both when they are equal.

Boarding Passenger:

$$Bn(t) = B1(t-\Delta t1-\Delta t2...-\Delta t_n) + B2(t-\Delta t1-\Delta t2...-\Delta t_{n-1}) + ... + Bn(t) \quad \text{...................... (3.3)}$$

Total amount of (only) boarding passengers at any point (for example at the station n) is equal to the addition of boarding passengers at station *1* when time = $t-\Delta t1-\Delta t2...-\Delta t_n$. Where $\Delta t1$ denotes travel time between station $n-1$ to station n + *dwell time* at station ($n-1$),..., and Δt_n denotes travel time between first and second station + dwell time at the first station.

O/D Transition Probability:

O/D transition probability is defined as ration of passenger transition moving on public transport from one origin to many destinations. This ratio, furthermore, has the following characteristic;

$$\sum_{j=1}^{n} R_{ij} = 1 \forall i;r \quad \text{.................................. (3.4)}$$

Alighting Passenger:

$$An(t) = B1(t-\Delta t1-\Delta t2...-\Delta t_n).R12 + ... + B(n-1)\ (t-\Delta t_{n-1}).\ R(n-1)(n) \quad \text{............... (3.5)}$$

Counting (only) total alighting passengers at any point (for example at the station n) is equal to the addition of alighting passengers at station *1* when time = $t-\Delta t1-\Delta t2...-\Delta t_n$.

Where $\Delta t1$ denotes travel time between station $(n-1)$ to station (n) + dwell time at station $(n-1)$,..., $.\Delta t_n$ denotes travel time between first and second station + dwell time at the first station multiplied by O/D probability (R) with index $1n$ (the multiplier for the number of passengers who get on at station 1 and want to drop at station n) and boarding passengers at stations between station 1 and station n multiply by their O/D probabilities.

Total Passenger:

Total number of passengers in the bus when time = t is actually counted by total number of boarding passengers minus total number of alighting passengers up to the evaluated time (time = t). The formula of such number of passengers on board is formulated as follows;

$$
\begin{aligned}
E1(t) &= A1(t) \\
E2(t) &= A1(t-\Delta t1) + A2(t) - B2(t) \\
&= A1(t-\Delta t1) + A2(t) - (B1(t-\Delta t1).R12) \\
&= A1(t-\Delta t1).\ (1-R12) + A2\ (t)
\end{aligned}
$$

$$
\mathrm{En}(t) = \sum_{i=1}^{n-1} A_i(t - \sum_{j=0}^{i-1} \Delta t_j)(1 - \sum_{m=i}^{n} R_{m,m+1}) + A_n(t) \qquad \text{.................. (3.6)}
$$

Load Factor:

$$
LF = \frac{Psg}{C} \qquad \text{.............................. (3.7)}
$$

where,

LF = Load Factor
Psg = Number of Passengers on Board
C = Bus Capacity

Bus Capacity is always constant and as many as the number of seats in the bus or to be multiplied by certain value of load factor, but the number of passengers changes by time. By checking the Load Factor value, how full the bus could be observed along the route.

Cruising Time:

$$
T = \frac{S}{V} \qquad \text{.. (3.8)}
$$

where,

T = Cruising Time
S = Stop Spacing
V = Bus Speed

Cruising time is time taken as time to pass the space from one station to another (Stop Spacing) with certain bus speed. The length of stop spacing is practically constant but not same from one to another. Furthermore, the bus speed is assumed to follow the Normal Distribution.

Back Haul Time

$$Tb = \frac{Sb}{Vb} \quad \text{...} (3.9)$$

where,

Tb = Cruising Time Back
Sb = Distance to return
Vb = Bus Speed to return

Back haul time is determined as time spent to return from the last terminal to the previous one. Sb is equal to total distance between two terminals because in the back trip bus does not stop and take the passengers at any stations while Vb is equal to the average of bus speed when the bus passes the spacing between stops. So, Sb would be constant and Vb is assumed to follow the Normal Distribution.

3.3. Causal Relation of Model

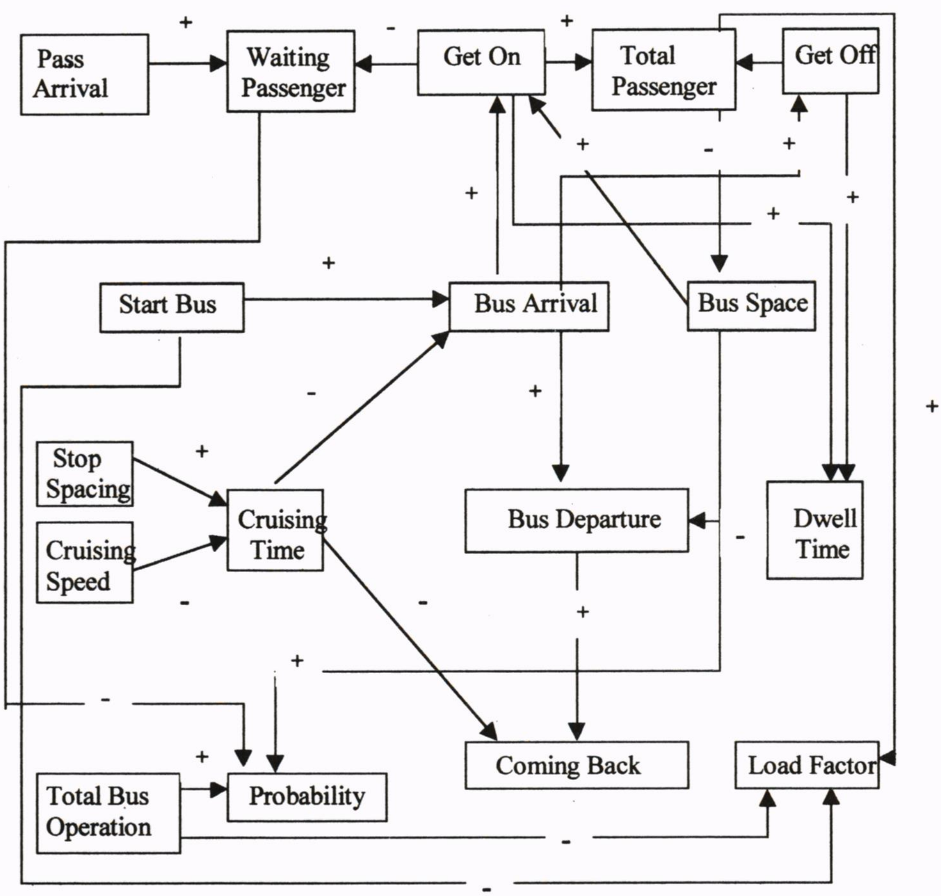

Figure 5. Causal Relation

- Passenger Arrival gives positive effect to Waiting Passenger, means if Passenger Arrival increases then Waiting Passenger also increases, and if Passenger Arrival decreases, then Waiting Passenger also decreases.
- Get On gives negative effect to Waiting Passenger, means the higher the number of Get On Passengers then the lower number of Waiting Passengers and also the lower number of Get On Passengers, the higher number of Waiting Passengers.

3.4. Simulation Tool (*Powersim*)

After building a model the characteristic of system is simulated by using software called; *Powersim* functions in building a model to perform real or unreal attitude from the system, and it provides an editor diagram for building a model. Building a model is almost the same with making a program. And this software also allows graphic, table, etc placed anywhere to perform the model behaviors when it is simulated.

3.5. The Model

This Dynamic Scheduling of public transport system under stochastic behavior comprises of several sub models: Bus Control, Bus Number, Passenger Control, Real Probability, Back Trip, and Feedback as can be explained as follows.

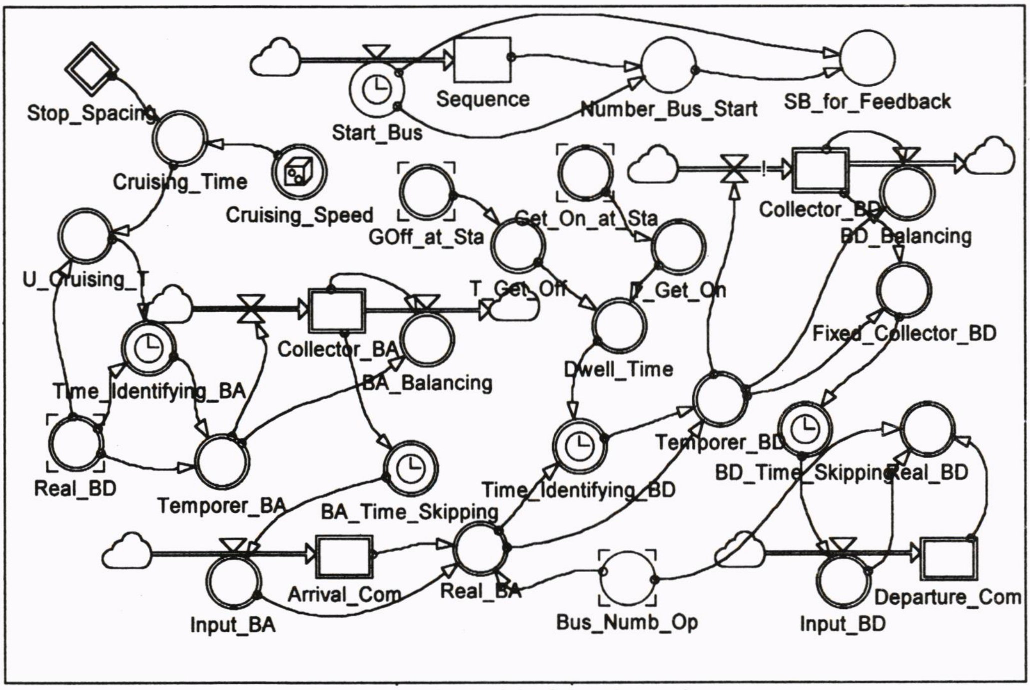

Figure 6. Sub Model of Bus Control

In the sub model of Bus Control creating the rule of operational is provided. In Start Bus departure of bus from the first station is stated. Number Bus Start denotes the number of buses.

Real *BA* actually shows the time when bus arrives and Real *BD* shows the time when bus departs, they also notice the bus number that arrives or departs. Principally time when bus arrives (Real *BA*) = time when bus departs (Real *BD*) from station (*n-1*) + travel time from station (*n-1*) to station n (cruising time) and time when bus departs (Real *BD*) = time when bus arrives at the station + dwell time at the same station.

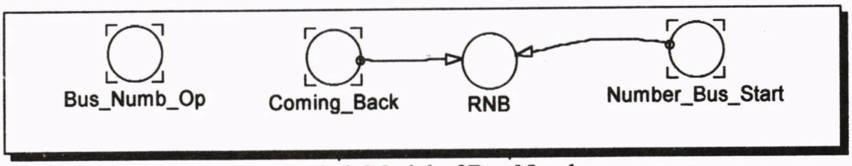

Figure 7. Sub Model of Bus Number

In the sub model of the Bus Number is kept notice. Real Number Bus (*RNB*) shows the bus number and Bus Numb Op shows the sequence operational buses.

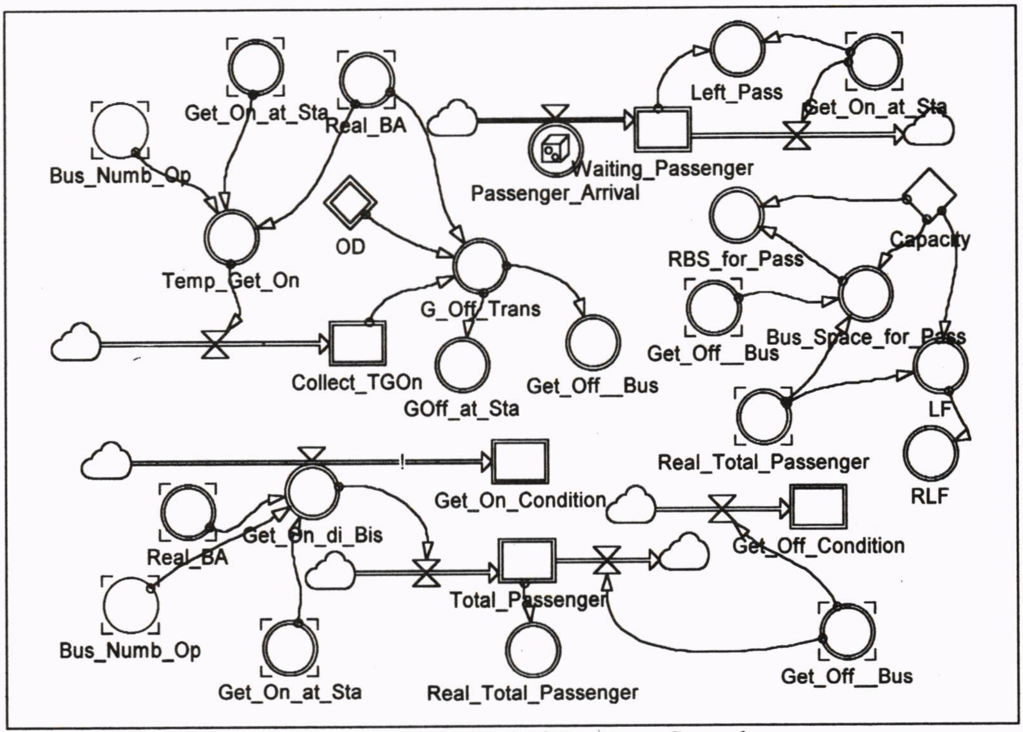

Figure 8. Sub Model of Passenger Control

In Sub Model of Passenger Control the number of Total Passenger and Load Factor at bus are noticed. Get on/off at station shows the number of passenger get on/off at the station. It could be illustrated like a surveyor sitting at station and counting the number of passengers get on/off from buses that arrive. Get on/off Bus shows the number of passengers get on/off the bus

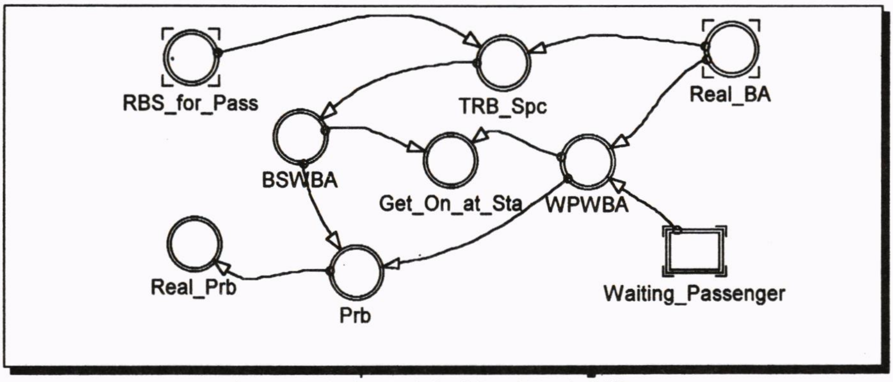

Figure 9. Sub Model of Real Probability

In Sub Model of Real Probability, the Bus Space When Bus Arrive (BSWBA) is divided by Waiting Passenger When Bus Arrive (WPWBA) in order to get the probability of passenger to get on the bus. Real Probability (Real *Prb*) is stated to perform value 1 if BSWBA/WPWBA > 1.

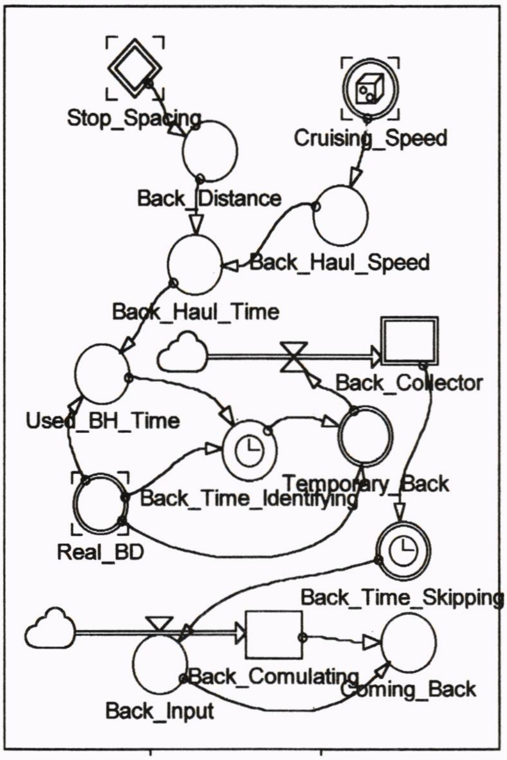

Figure 10. Sub Model of Back Trip

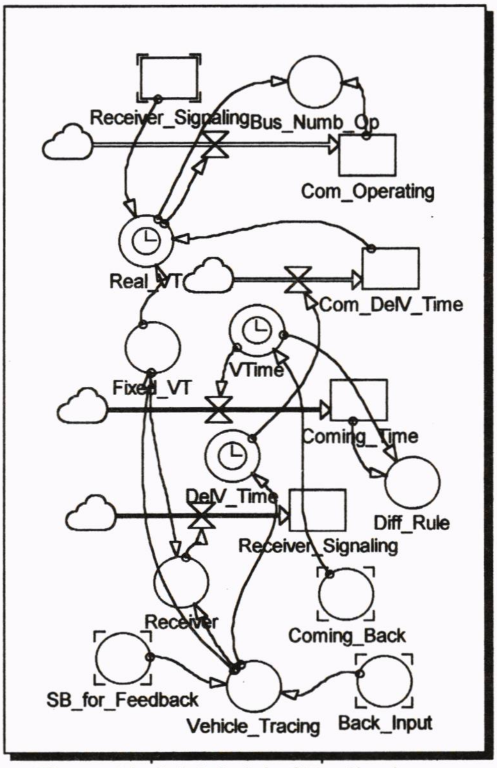

Figure 11. Sub Model of Feedback

In Sub Model of Back Trip, after bus arrives and gets the passengers off at the last station it would be re-dispatched to the previous terminal. Back-haul time is used in this sub model.

Finally, in Sub Model of Feedback the new rule of departure time at first station or terminal would be stated. The bus that returns is an incentive to the system (feedback) and would be re-dispatched again (i.e., Variable Real *VT*). The bunching effect at the first station (e.g., due to layover time) is also anticipated with 1-minute delay for the incoming bus. This bus is received at Receiver, and would be operated 1-minute after the bunching time.

4. SIMULATION EXPERIENCE

To make some policy a simulation can be done and some results can be analyzed and compared further with some alternative policies to reach the best policy. The outputs of simulation would be; Arriving Time, Departure Time, Total Passenger and after that the results, namely Load Factor and Probability.

4.1. Assumptions

The simulation considers some assumptions as follows;

- First bus is dispatched at time = 0'. And total simulation time = 60 minutes (1 hour)
- Total number of bus are 10, time headway = 6 minutes before there are buses from the opposite come back as the feedback of system to supply the fleet
- Bus capacity = 100 passengers/bus
- Number of stations = 4
- Stop spacing = 2.5 ; 2.7 ; 3.0 km
- Bus speed is around 40 km/ hour, and following a Normal Distribution.
- Dwell Time depends on max passengers (Get on/off). Except at the last station it takes 6 minute for lay-over time.
- In case there is a 'Bunching Effect' at the first station, the feedback bus would be delayed for1 minute before it is re-dispatched

There are two cases to be analyzed:

Case 1: -Passenger Arrival at Station has expected rates (15,12,9) passenger/minute and it follows the Poisson Distribution
- Bus Speed between Station has expected rates (750,700,670) m/minute and It follows the Normal Distribution

Case 2: -Passenger Arrival at Station has expected rates (13,12,11) passenger/minute Is following the Poisson Distribution
- Bus Speed between Station has expected rates (750,695,690) m/minute and It follows the Normal Distribution

IV.2. Results

Case 1

a. With feedback: - Load Factor: 0.474

- Probability : 0.66

b. Without Feedback:- Load factor: 0.654
- Probability : 0.619

There are improvements when feedback is allowed, and the load factor decreases up to 27.5 % and the probability increases up to 6.62 %

Case 2

a. With feedback:
- Load Factor: 0.441
- Probability : 0.633

b. Without Feedback:- Load factor: 0.614
- Probability : 0.609

Results of simulation are summarized in the ensuing tables and figures. Table 1 and 2 summarize the load factor of buses for cases with and without feedback respectively. Similar occasions are shown in Table 3 and 4 for case 2. It can be seen clearly that a policy of re-dispatching the buses increases the performance by reducing the average load factor. This policy can be made possible if a good scheduling system is developed and a certain objective to users is also set up.

Table 1. Load Factor for Case 1 with Feedback

	LF(1)	LF(2)	LF(3)	LF(4)	LF(5)	LF(6)	LF(7)	LF(8)	LF(9)	LF(10)	LF(11)	LF(13)	LF(14)	LF(15)	1 hour
LF with FeedBack															
															Avg LF
R_BA1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
R_BA2	0	1	0.92	1	0.89	1	1	0.29	0.32	0.31	0.54	0.61	0.38		
R_BA3	0.42	1	1	1	1	1	1	0.23	1	1	1				
R_BA4	1	1	1	1	1	1	1	1	1						
Average	0.355	0.750	0.538	0.750	0.723	0.750	0.750	0.380	0.580	0.437	0.513	0.305	0.190	0.000	0.501

Table 2. Load Factor for Case 1 without Feedback

LF Without FeedBack											
											Avg LF
	LF(1)	LF(2)	LF(3)	LF(4)	LF(5)	LF(6)	LF(7)	LF(8)	LF(9)	LF(10)	1 hour
R_BA1	0	0	0	0	0	0	0	0	0	0	
R_BA2	0	1	0.92	1	0.89	1	1	0.92	0.73	0.99	
R_BA3	0.42	1	1	1	1	1	1	0.74	1		
R_BA4	1	1	1	1	1	1	1	1			
Average	0.355	0.750	0.730	0.750	0.723	0.750	0.750	0.665	0.577	0.495	0.654

In different matter cases can also be made to comprehend the users' satisfaction by representing their chance to get on the bus with a chance to get on the bus with comfort and expectation that is their probability. Table 5 and 6 provide information on such probability for case 1 with and without feedback. As for case 2 similar situation is illustrated in Table 7 and 8. In average it is obvious that their chance or probability is improved by introducing the re-dispatching policy in scheduling. So control to re-dispatching policy is apparent to increase the bus utilization provided good scheduling is made.

It is, however, interesting in the scheduling of public transport that effect of bunching of buses is avoided. Such situation may be analyzed further by knowing all simulation results and represented with time-space diagram of bus movement along the route. Figure 12 and 13 provide the illustration of bus movement for case 1 without and with feedback, and in similar way Figure 14 and 15 provide such information for case 2. It is apparent from the figures that for these contrived and relatively small size samples a bunching effect of buses can hardly be found. However, extra attention should be paid for the cases of larger scale

Table 3. Load Factor for Case 2 with Feedback

LF with Feedback																Avg LF
	LF (1)	LF (2)	LF (3)	LF (4)	LF (5)	LF (6)	LF (7)	LF (8)	LF (9)	LF (10)	LF (11)	LF (12)	LF (13)	LF (14)	LF (15)	1 hour
R_BA1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
R_BA2	0	0.65	0.87	0.82	0.83	0.82	0.97	0.38	0.31	0.14	0.57	0.12	0.62	0.08		
R_BA3	0.54	1	1	1	1	1	1	0.3	1	1	1					
R_BA4	1	1	1	1	1	1	1	1								
Average	0.39	0.66	0.54	0.71	0.71	0.71	0.74	0.42	0.44	0.380	0.523	0.060	0.310	0.040	0.000	0.47

Table 4. Load Factor for Case 2 without Feedback

LF without Feedback											Avg LF
	LF(1)	LF(2)	LF(3)	LF(4)	LF(5)	LF(6)	LF(7)	LF(8)	LF(9)	LF(10)	1 hour
R_BA1	0	0	0	0	0	0	0	0	0	0	
R_BA2	0	0.65	0.87	0.82	0.83	0.82	0.97	0.69	0.71	0.82	
R_BA3	0.42	1	1	1	1	1	1	0.55	1		
R_BA4	1	1	1	1	1	1	1	1			
Average	0.355	0.663	0.718	0.705	0.708	0.705	0.743	0.560	0.570	0.410	0.614

operations since there are high possibilities of having bunching effects especially when there are overlapping routes in which it is not uncommon in practice.

Quantitatively there are improvements when using the feedback in which the load factor decreases up to 28.18 % and the probability increases up to 4.0 %. In the second test there is bunching effect at first station at time = 48'. When bus 9 would be ready to operate bus 1 arrives from the opposite station. We treat the oncoming bus with 1-minute delay. So bus 1 is operated at time = 49'.

Table 5. Probability for Case 1 with Feedback

Probability with Feedback					
Bus Arrival	R PR(1)	R PR(2)	R PR(3)	R PR(4)	
1	0	1	0.765	1	
2	1	0.253	0.559	1	
3	1	0.193	0.376	1	
4	0.971	0.106	0.349	1	
5	1	0.119	0.284	1	
6	1	0.067	0.279	1	
7	0.98	0.058	0.25	1	
8	1	0	0.652	1	
9	1	0.195	0.438		
10	1	0.232	0.549		
11	1	0.192	0.661		
12	1	0.339			
13	1	0.234			
14	1	0.366			
15	1				
Average	0.930	0.240	0.469	1.000	
Tot Avg					0.660

Table 6. Probability for Case 1 without Feedback

Probability without Feedback					
Bus Arrival	R PR(1)	R PR(2)	R PR(3)	R PR(4)	
1	0	1	0.765	1	
2	1	0.253	0.559	1	
3	1	0.28	0.376	1	
4	0.971	0.106	0.349	1	
5	1	0.119	0.284	1	
6	1	0.067	0.279	1	
7	0.98	0.058	0.25	1	
8	1	0	0.325	1	
9	1	0.092	0.218		
10	1	0.043			
Average	0.895	0.202	0.378	1.000	
Total Avg					0.619

Table 7. Probability for Case 2 with Feedback

Probability for Case2 with Feedback					
Bus Arrival	R PR(1)	R PR(2)	R PR(3)	R PR(4)	
1	0	1	0.466	1	
2	1	0.593	0.258	1	
3	1	0.275	0.232	1	
4	1	0.236	0.21	1	
5	1	0.183	0.187	1	
6	1	0.144	0.164	1	
7	1	0.082	0.144	1	
8	1	0	0.318	1	
9	1	0.236	0.17		
10	1	0.349	0.176		
11	1	0.252	0.181		
12	1	0.479			
13	1	0.362			
14	1	0.979			
15	1				
Average	0.933	0.369	0.228	1.000	
Tot Avg					0.633

Table 8. Probability for Case 2 without Feedback

Probability for Case2 without Feedback					
Bus Arrival	R PR(1)	R PR(2)	R PR(3)	R PR(4)	
1	0	1	0.625	1	
2	1	0.608	0.322	1	
3	1	0.28	0.279	1	
4	1	0.218	0.226	1	
5	1	0.172	0.21	1	
6	1	0.137	0.177	1	
7	1	0.078	0.155	1	
8	1	0	0.26	1	
9	1	0.11	0.138		
10	1	0.080			
Average	0.900	0.268	0.266	1.000	
Total Avg					0.61

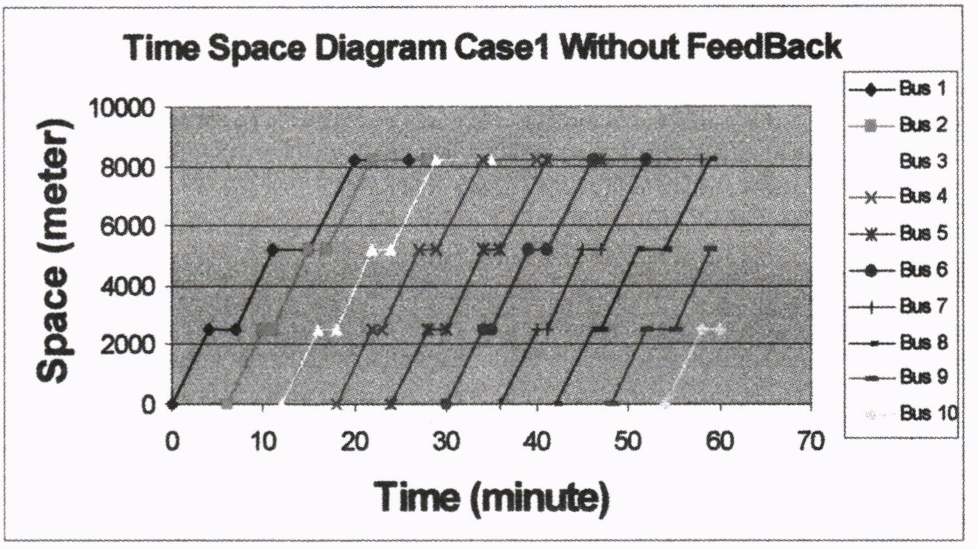

Figure 12. Time Space Diagram Case 1 Without Feedback

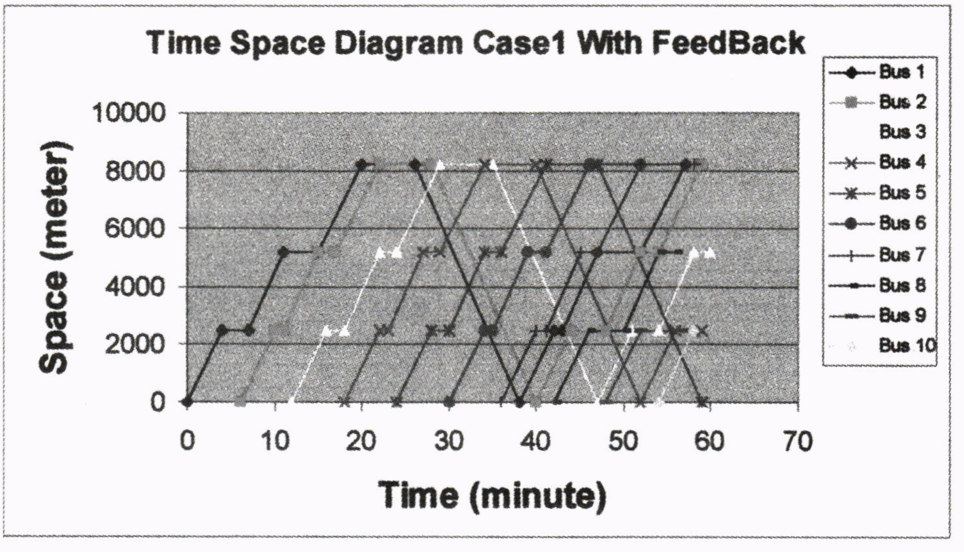

Figure 13. Time Space Diagram Case 1 With Feedback

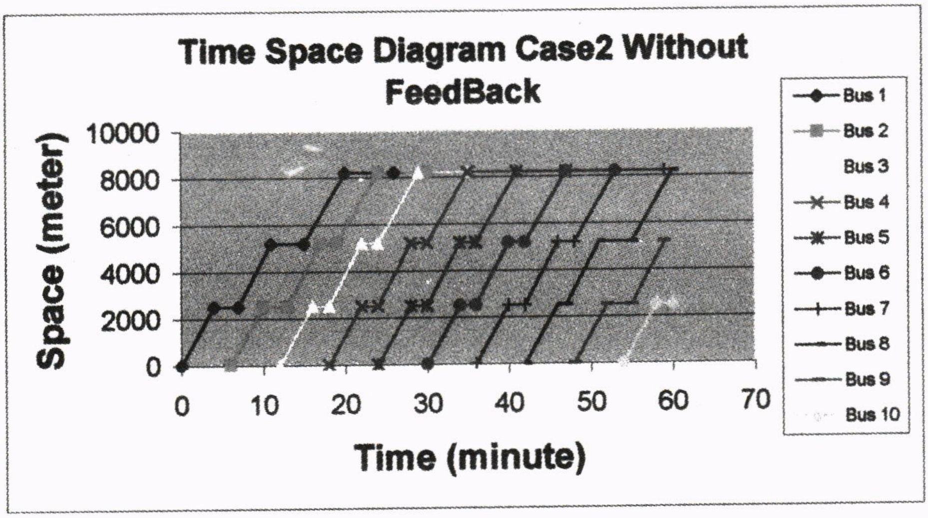

Figure 14. Time Space Diagram Case 2 Without Feedback

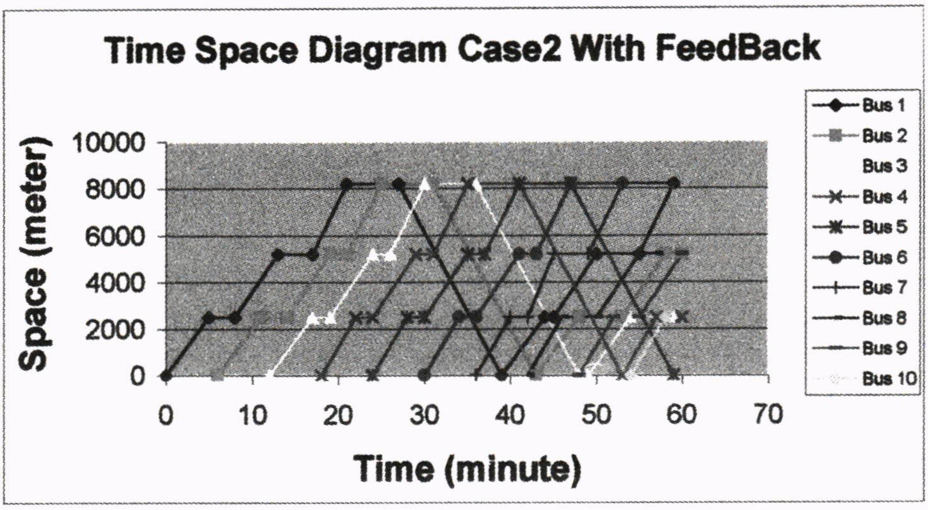

Figure 15. Time Space Diagram Case 2 With Feedback

5. CONCLUSIONS

Based on simulation results there are some conclusions to be drawn;

1. Bus arrival time at any station can be predicted at earlier station where the bus leaves.
2. The simulation model may be used to evaluate the load factor or total number of passengers in a bus at any point.
3. The less time headway causes lowers load factor and consequently higher probability.
4. According to conclusion number 3 by using feedback in public transport operating system would increase performance system by decreased load factor up to 27.5% in case 1 and 28.18% in case 2.
5. Also for user's probability to get on the bus, it would increase if feedback is accommodated, and in this particular cases improvements would be about 6.62% in case1 and 4.0% in case 2.

REFERENCES

- Baugsto B, et. al., Powersim ™ , **The Complete Software Tool for Dynamic Simulation**, Modelldata AS, 1993.
- Forrester J, **World Dynamics**, MIT Press, 1971.
- Law A.M. and Kelton W.D., **Simulation Modeling and Analysis**, 2 nd edition. Mc Graw, Hill. New York,1991.
- Robert N et. al., **Introduction to Computer Simulation: A System Dynamics Approach**, Addison-Wesley Publishing Company, 1997.
- Payne J.A., **Introduction to Simulation**, Singapore, Mc.Graw Hill,1988.