A SIMULATION MODEL TO EVALUATE IMPACT OF VEHICLE SIZE AND DISPATCH HEADWAY VARIABILITY ON PASSENGER LOADING AND RELIABILITY OF PUBLIC TRANSIT

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Abstract — Transit service reliability is one of the highly valued attributes for users and operators. This paper examines the impact on headway regularity and passenger loads in a simulated bus operation due to the bus capacity limits and the variability of departure headways. For the simulation purpose, four operational scenarios are set up. Same timetable and route characteristics are considered for all scenarios. In the first scenario, it is assumed that buses have infinite capacity and can accommodate all passengers waiting at bus stops. In other scenarios, bus capacity is constrained with different carrying capacities in order to analyze the impact of passengers being left behind when buses are full. The degree of dispatch headway also is varied to examine effects of headway regularity along the downstream of the route. Passengers arrival and dispatch headway of bus are assumed to follow Poisson and Gamma distribution respectively. Travel time between stops is assumed as constant in order to isolate the effect of dispatch headway variability. The simulation studies demonstrate the propagation of headway irregularity along the downstream of routes, a correlation between bus headways and passenger loading that caused bus bunching.

Keywords — Bus Capacity, Correlation, Dispatch Headway, Headway Regularity**.**

I. INTRODUCTION

Maintaining regular headway and adhering to schedule in transit operation is vitally important for operators and users. Irregular headways cause inconvenience for passengers through delay and uncertainty in their journeys (Bowman & Turnquist, 1981; Turnquist & Bowman, 1980; Wilson, Nelson, Palmere, Grayson, & Cederquist, 1992). To the operators, headway variability results inefficient utilization of vehicles, equipment, and workforces (Adebisi, 1986). Headway deviation in transit operation creates bus platooning or bunching (J. Strathman, 2002). Empirical studies show that passenger loads on bus fluctuate with the deviation of headway. Larger passenger loads result from positive deviation of headway of bus from schedule while negative deviations cause smaller loads (Strathman, Kimpel, & Callas, 2003). Such variation in passenger loads results some buses arrive at stop being overcrowded and bypass the stop without serving waiting passengers (M. K. Islam & Vandebona, 2010). On the contrary, some buses arrive at stops being empty. Thus, headway unreliability diminishes lever of service of and results underutilization of the transit systems. The objective of this paper is to explore the characteristics of such simultaneity between headways and passenger loads when headway of buses deviates from schedule and buses have limited passenger carrying capacity.

There are a number of different measures proposed in the literature to quantify transit service reliability. Turnquist and Bowman (1980), Tseng (2005) proposed the standard deviation of the travel time of an entire route as a necessary and sufficient condition to the reliability of the route. They (Turnquist and

Bowman (1980)) and Tseng and Verhoef (2008) also proposed the coefficient of variation of travel time and difference between the 90th and 50th percentile of travel time of transit route as measures of transit service reliability in addition to standard deviation of travel time (Yatskiv, Pticina, & Savrasovs, 2012). Ruan (2009) presented probability based headway regularity metric to evaluate bus service reliability at stops. Headway variability in this study quantified using the coefficient of variation of headways as proposed by Turnquist and Bowman (1980). This is the measure computed as the ratio of standard deviation of bus headway to mean headway. At the beginning of the transit route, this measure can be termed as the coefficient of variation of dispatch headway of bus (M. Islam, 2011).

In this paper, a simulation model has been presented that evaluate the impact of passenger carrying capacity of buses on service reliability and variation of passenger loads at transit stops. In addition, the model also evaluates the impact of variation of dispatch headway and explains the tendency of bus bunching.

The rest of the paper organized as follows. The simulation model is described in the next section which includes assumptions regarding model development, model inputs, and outputs. Simulation results are presented in Section III. Section IV concludes the paper.

II.THE SIMULATION MODEL

A single bus route with multiple stops is considered for purpose of simulation. The overall travel time of passengers is comprised of departure time of buses at stops and the travel time of bus between stops. The simulation model considered several events to be occurred in sequences such as passengers arrive at stops, wait for a bus, board the arriving bus if there is any space available after alighting of previously onboard passengers. In case there is no space available in the arriving bus at a stop, the bus skips the stop without serving waiting passengers. The denied passengers remain to wait at the stop for buses until they are served. Then, the bus departs the stop with onboard passengers for the next stop. A similar process continues to stop after stop until the bus reaches the final stop. For the purpose of analysis, four operational scenarios were set following the work M. K. Islam and Vandebona (2010) and M. K. Islam, Vandebona, Dixit, and Sharma (2015) as shown in the Table I. A bus route with six stops equally spaced in five minutes travel time is considered. Passengers and buses arrive at stops in a random fashion. As empty buses start from the first stop, there are no passengers to alight at the first stop. Passengers alight at intermediated stops if they reach their destination stops. All passengers alight at the stop six as this is the last stop. Same timetable and route characteristics are assumed for all scenarios. Ten buses are assumed to run per hour in one-way direction resulting six-minute headway. In the first scenario, it is assumed that bus capacity is large enough to accommodate all waiting passengers at stops while capacity limitations are imposed in other scenarios in order to examine the variation of passenger loading along the route. These capacity restrictions of passenger carrying on a bus are imposed in a stepwise manner such as 60-passenger bus, 48-passenger bus and 36-passenger bus for the second, third and fourth scenario respectively. Each scenario is again sub-divided into five sub-scenarios depending on dispatch headway variability at the first stop. The coefficient of dispatch headway variation is varied from 0.0 to 1.0 with an increment of 0.25. The first and last five buses are not included in the calculation of simulation outputs as an account of "warm up" of the simulation. The simulation is accounted for 180 minutes of bus operation.

A. Simulation model inputs

Following conditions are assumed for model inputs:

1. *Dispatch headway of bus*
   Gamma distribution has been adopted to generate dispatch headway of bus. The reason for adopting the gamma distribution is Ruan (2009) has found by statistical analysis using real data of a bus route operated by the Chicago Transit Authority (CTA) that dispatch headway followed a gamma distribution.

2. *Passenger arrival at stops*

   Passenger arrivals at stops are assumed as random and follow a Poisson distribution. Thus, the interarrival time of successive passengers at stops are generated by an exponential distribution. The passenger arrival rate at a stop is adopted from M. K. Islam and Vandebona (2010) shown in Table II. Moreover, it is assumed that passenger demand remains unchanged during the period of simulation.

3. *Number of alighting passenger*

   A portion of boarded passengers alights upon arrival at their destination stops. The number of passengers to be alighted at stops is determined using binomial distribution as suggested by Andersson and Scalia-Tomba (1981). The proportions of alighting passengers at stops are adopted from M. K. Islam and Vandebona (2010) and listed in Table II.

4. *Boarding time*

   The boarding of passengers on the bus begins as soon as alighting of passengers completed. Since in most bus operation, alighting time per passenger is low, it has been assumed that the boarding move dominates the dwell time at the stop. The boarding time is assumed as constant three seconds for each passenger.

5. *Travel time*

   The travel time is assumed as constant five minutes between two consecutive stops. The travel time is assumed as constant in order to separate the effect of headway variability on the transit operation.

TABLE I
Simulation scenarios (M. K. Islam & Vandebona, 2010)

Scenario		Coefficient of Variation of Dispatch Headway of Bus	Bus Capacity	Bus Dispatch Headway
1	1 (a)	0.0	Unlimited	6 minutes
	1 (b)	0.25		
	1 (c)	0.5		
	1 (d)	0.75		
	1 (e)	1.0		
2	2 (a)	0.0	60-Passengers	
	2 (b)	0.25		
	2 (c)	0.5		
	2 (d)	0.75		
	2 (e)	1.0		
3	3 (a)	0.0	48-Passengers	
	3 (b)	0.25		
	3 (c)	0.5		
	3 (d)	0.75		
	3 (e)	1.0		
4	4 (a)	0.0	36-Passengers	
	4 (b)	0.25		
	4 (c)	0.5		
	4 (d)	0.75		
	4 (e)	1.0		

TABLE II
Passenger arrival and alighting probability at stops (M. K. Islam & Vandebona, 2010)

Stops	Passenger arrival rate at stops (passenger/minute)	Proportion of alighting passengers
1	5.0	0.0
2	4.0	0.2
3	3.0	0.4
4	3.0	0.5
5	2.5	0.6
6	0.0	1.0

B. Simulation model outputs

The following outputs measures are produced from the simulation:

1. *Coefficient of variation of bus headway at stops*
   Bus headway calculated in this simulation as the time difference between two consecutive buses at the same stop. Mean headway and standard deviation of bus headway are recorded in each simulation. The coefficient of variation of bus headway calculated as mentioned in section I.
2. *Shape parameters of headway distribution*
   Shape parameters of headway along the route under the gamma distribution assumption are computed as the ratio of the square of mean headways to the square of a standard deviation of headways at stops (Marguier, 1985).
3. *Mean and standard deviation of passenger load at stop*
   Passengers load at stops is calculated as the total of remaining passengers who was carried by the bus from a previous stop after alighting at the stop under consideration and boarded passengers from the same stop. The coefficient of variation of passenger loading is computed as the ratio of standard deviation of passenger loading to mean passenger loading calculated at each stop.
4. *Correlation coefficient of bus headway and passenger load*
   It is obtained by dividing the covariance of bus headway and passengers load at stops by the product of their standard deviations (Marguier, 1985).

III. SIMULATION RESULTS

Variation of bus headway along the route is shown Table III for a different capacity of a bus for corresponding dispatch variation of a bus at the stop 1. Shape parameter of headway distribution along the bus route is shown in Fig. 1 for selected values of coefficient of variation of bus dispatch headway in the simulation. The coefficient of variation of passenger loading along the route for the corresponding variation of bus dispatch headways and under different bus capacities selected in simulation scenarios are shown in Fig. 2(a) – 2(d). Correlation between bus headway and passenger load is depicted in Fig. 3 for the coefficient of variation of bus dispatch headway of 0.5.

A. Variation of bus headway along the route

The effect of dispatch headway variation on headway regularity along the bus route is presented in Table III. This table also presents the effect of bus sizes on the headway variation along the route as well. The table shows that the irregularity of bus headway increases and propagates along the route as the dispatch uncertainty increases at the beginning of the route. This is because once the dispatch headway becomes irregular at the beginning of a route, it creates knock-on effects and causes to increase the headway variation as buses move towards downstream stops. However, it can be seen from the table that passenger carrying capacity of buses has no significant effect on headway variation of buses, although, there is a very slight increase in headway variation with the increases in passenger carrying capacity. As an example, for the 36-passenger bus, the headway variation reached to 0.532 at stop 5 while the dispatch headway variation at the beginning of the route was 0.25. For the same dispatch headway variation, furthermore, it has been seen that headway variations are 0.533, 0.534 and 0.535 at the stop 5 for the 48-passenger, 60-passenger, and unlimited capacity of bus respectively. However, the numerical difference of these values does not show a significant statistical difference. These results are in line with analysis put forward by M. K. Islam and Vandebona (2010) and Marguier (1985). Moreover, variation of bus headway along the route corresponding to the dispatch headway variation of 0.5 presented in Table III are numerically very closer to those results shown in M. K. Islam and Vandebona (2010) which verify the accuracy of simulation results presented in this paper.

TABLE III
Variation of bus headway along the route

	Bus Capacity	**Stop 1**	**Stop 2**	**Stop 3**	**Stop 4**	**Stop 5**
Coefficient of variation of dispatch headway of bus = 0.0	Unlimited	0.0	0.068	0.103	0.137	0.165
	60-Passengers	0.0	0.067	0.102	0.138	0.166
	48-Passengers	0.0	0.066	0.101	0.134	0.161
	36-Passengers	0.0	0.065	0.099	0.133	0.161
Coefficient of variation of dispatch headway of bus = 0.25	Unlimited	0.25	0.322	0.400	0.478	0.535
	60-Passengers	0.25	0.321	0.399	0.476	0.534
	48-Passengers	0.25	0.320	0.398	0.475	0.533
	36-Passengers	0.25	0.319	0.397	0.475	0.532
Coefficient of variation of dispatch headway of bus = 0.5	Unlimited	0.5	0.505	0.640	0.766	0.870
	60-Passengers	0.5	0.504	0.639	0.765	0.868
	48-Passengers	0.5	0.503	0.638	0.764	0.867
	36-Passengers	0.5	0.502	0.635	0.763	0.865
Coefficient of variation of dispatch headway of bus = 0.75	Unlimited	0.75	0.885	1.049	1.190	1.296
	60-Passengers	0.75	0.883	1.045	1.187	1.287
	48-Passengers	0.75	0.882	1.044	1.183	1.286
	36-Passengers	0.75	0.881	1.042	1.182	1.283
Coefficient of variation of dispatch headway of bus = 1.0	Unlimited	1.0	1.265	1.466	1.616	1.721
	60-Passengers	1.0	1.264	1.465	1.614	1.719
	48-Passengers	1.0	1.263	1.464	1.613	1.716
	36-Passengers	1.0	1.258	1.457	1.608	1.712

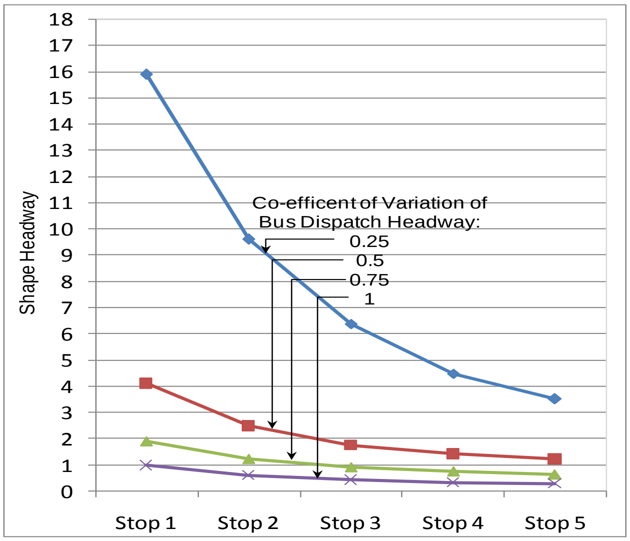

Figure 1. Shape parameters of bus headway distribution

B. Shape parameters of headway distribution

It is important to look at the variation of shape parameters of bus headway along the route. As it is found in Table III that headway variation of a bus is less sensitive to bus size, the shape parameters also show less sensitivity with bus sizes. This means shape parameters of bus headway do not affect by bus sizes. Fig. 3 shows the shape parameters decreases along the route. The decrease of shape parameters causes the mode of the bus headway distribution to move nearer to the origin. This results in the higher probability of small values of bus headway, which indicates the tendency of bunching of buses.

C. Coefficient of variation of passenger loading

Fig. 2(a)-2(d) show a variation of passenger loading along the route due to a variation of headway. In these figures, the effect of bus capacity constraint on the variation of passengers loading is also shown.

In Fig. 2 (a), the effect of headway variation is depicted in a bus system where bus capacity is unlimited. In this case, the coefficient variation of passengers loading increases along the downstream of bus route as headway variation increased. Since the bus system, in this case, has infinite capacity, the effect of bus capacity constraint cannot be seen here.

The expected maximum load is equal to 48-passenger capacity bus in second stop. The capacity of 36-passenger bus will not be adequate to hold the passenger demand due to unavailability of spaces. Passengers will be rejected to board 36-passenger bus and will be accumulated in bus stops over time. This inability of passenger handling due to limited capacity decreases the variation of passenger loading. Passengers load of bus move towards capacity. Fig. 2 (b) to Fig. 2 (d) show that variation of passenger loading become smaller at maximum load stops and restored its original level along the down of the route. In these figures, the effects of bus capacity constraint along with headway variation can be seen. The values of passenger load variation are found to be higher for higher values of bus dispatch headway variation which indicates the balance of passenger load between buses deteriorates due to increasing in variation of bus headway.

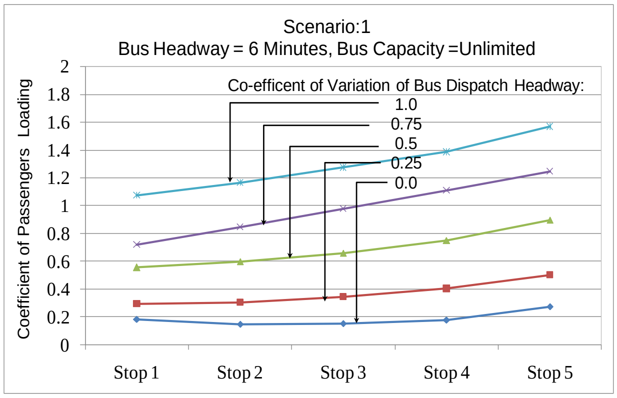

Figure 2(a). Coefficient of variation of passenger loading for unlimited capacity of bus

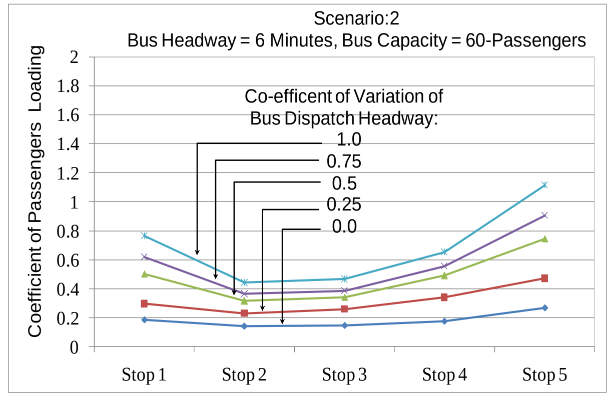

Figure 2(b). Coefficient of variation of passenger loading for 60-Passenger bus

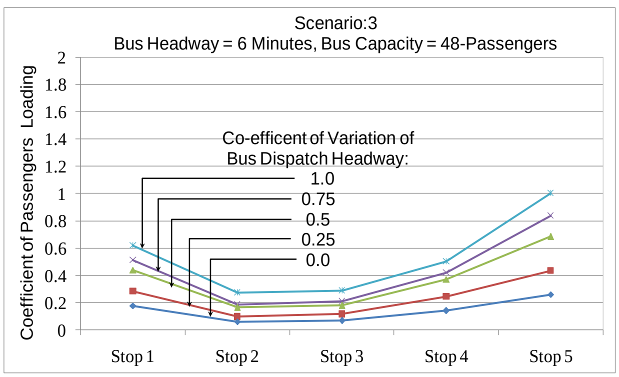

Figure 2(c). Coefficient of variation of passenger loading for 48-Passenger bus

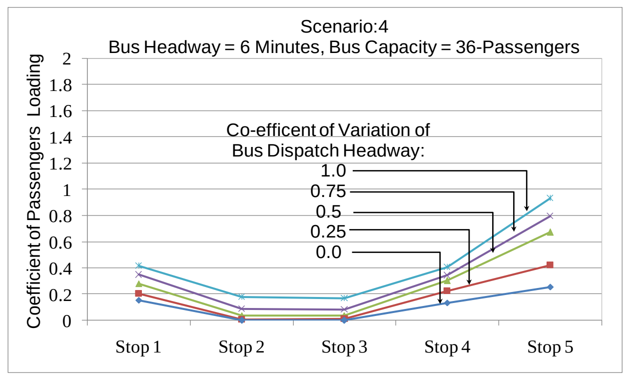

Figure 2(d). Coefficient of variation of passenger loading for 36-Passenger bus

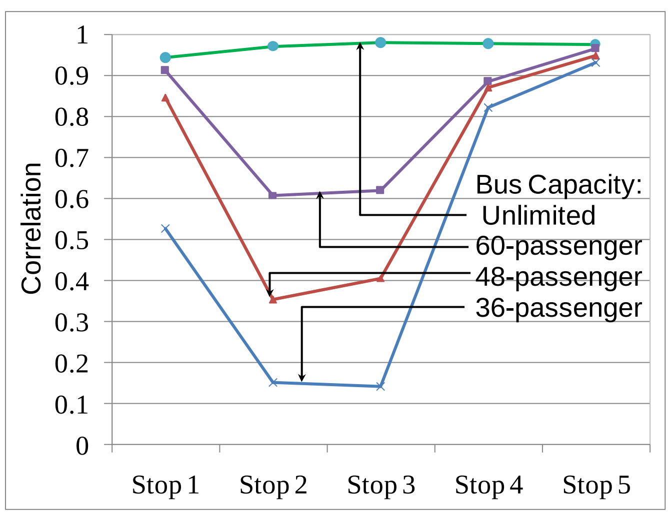

Figure 3.Correlation between headways and passengers loads when coefficient of bus dispatch headway is 0.5

IV. CONCLUSIONS

A simulation model on a bus route with multiple stops is presented in this paper. The purpose of the model is to demonstrate the effect of dispatch headway variability and passenger carrying capacity of buses on the variation of bus headway and variation of passenger loading along the route. Scenarios with four different bus sizes are analyzed where dispatch headways are varied from 0 to 1.0 with the increment of 0.25. Thus, total twenty scenarios are analyzed. The simulation results show that dispatch headway variability creates knock-on effects on headway variability on downstream stops. However, such headway variability does not influence by the passenger carrying capacity of buses. Moreover, shape parameters of headway distribution of bus show less sensitivity to the change in bus capacity and decrease down to the route indicating the higher probability of small headways of a bus which increase the tendency of a pairing of buses. The coefficient of variation of load decreases at stops where expected passengers load is higher. The positive correlation is found between bus headway and passenger load.

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