Trends in Transport Engineering and Applications

Volume 1, Issue 3
www.stmjournals.com

Evaluation of Impacts of Dispatch Headway Variability in Bus Transit Systems in a Simulated Route

Md. Kamrul Islam*
School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia

Abstract

This paper presents reliability analysis of bus transit systems based on numerical simulation of the range of headway variations in a bus route consists of multiple stops. Variation of performance in bus operation due to the variation of departure headways is determined through number of simulations. Operational performance is measured by the average waiting time of passengers at stops. Simulation results show that average waiting time as well as spread of waiting time distribution increases when bus has limited carrying capacity compared with a system where the bus capacity is unlimited. Moreover, the distribution of passenger waiting times widens as the headway variation increases. Variations in headways at a stop adversely affect the scheduled bus operation which result variation in passenger loads for subsequent buses.

Keywords: *Reliability, Dispatch Headway, Waiting Time*

****Author for Correspondence*** E-mail: kamrul126@yahoo.com

INTRODUCTION

Reliability is considered as an important indicator of level of service in public transport systems. Unreliability causes increase in waiting time, late or early arrivals at destinations and missed connections [1–3]. User surveys reveal that reliability is implicitly valued by passengers in stated preference surveys [4]. Reliability is also seen as a governing factor in selection of transport modes by users [5]. Considerable amount of literature has documented causes of unreliability of bus transit systems [6–10]. In particular, with a scheduled bus services, variability of headway along a fixed route causes negative impacts to both transit operators and transit users [11]. Variation of headway at bus stops results in economic loss to transit operators through under utilization of vehicles, equipment and work force. On the other hand, irregular arrival and departure of buses at stops, contribute to additional waiting time for transit users which lowers the level of service of the transit system. For example, the waiting time distribution has a spread over three times more than the experience under schedule services in a scenario created by variation of dispatch time [12]. This paper explains an analysis tool developed to estimate the operational performance of bus transit systems where the route consists of multiple stops. The main purpose is to analyze the effect of variation of departure headway on operational performance. The model presented in this paper also explores the effect of capacity limitation of buses. Average waiting time is used as the main indicator of performance.

PROBLEM DESCRIPTION

Dispatch time from stops and travel time along the route are two main constituents of overall travel time of passengers using bus transit services. Figure 1 shows bus movement in the form of trajectory diagram. The distance traveled by bus along the route stopping at designated bus stops is shown by the vertical axis. The time elapsed during bus travel is indicated by the horizontal axis. Bus travel from one stop to the next stop is shown by inclined lines between two stops. The time spent at stops including boarding and alighting of passengers is shown by the dotted lines between two inclined lines.

Even all variations in bus travel times are eliminated passengers may arrive at destinations early or late due to variation in dispatch headways of buses. Although the model developed is able to handle variation of bus travel times as well as dispatch headway variability, only variability of bus dispatch is considered in the analysis of this paper. A spreadsheet model is developed to estimate the impact of variation of dispatch headway on performance of bus operation along a bus route. In this analysis, average waiting time of passengers at bus stops is adopted as the indicator of performance. In this sense, low average waiting times at bus stops indicate good performance of bus operation. Variation of dispatch headway at the first stop of the bus route is an input in this model. This variation of dispatch time at the first stop affects arrival and departure times at downstream stops because of the linked nature of travel times and stop times as shown in Figure 1.

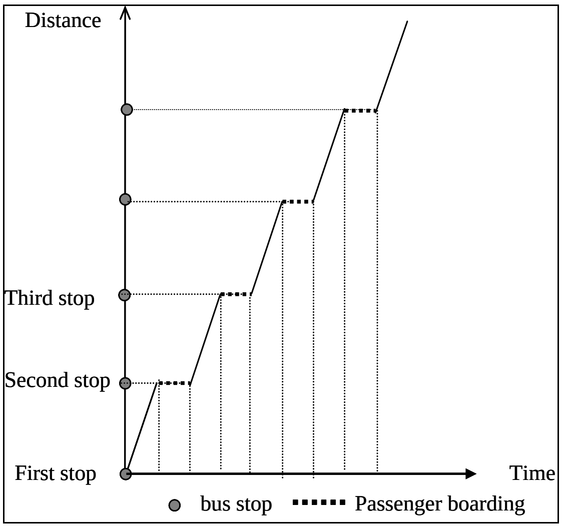

Fig. 1: *Trajectory of Progress of a Bus along the Route.*

SCENARIO ANALYSIS

Three operational scenarios presented in the Table 1 are considered for the purpose of analysis. Same timetable headway and route characteristics are considered for all scenarios. A bus route consists of five stops is analyzed in this paper for the purpose of simplicity whereas the model is able to analyze bus routes more than five stops. In the first scenario, because of infinite vehicle capacity, all waiting passengers at stops are accepted to board on bus. In other scenarios, bus capacity is constrained to analyze the impact of passengers being left behind when buses are full. In Scenario 3, bus capacity is assumed somewhat lower than Scenario 2.

Table 1: *Operational Scenarios.*

	Headway	**Bus Capacity**
Scenario 1	10 min	Unlimited capacity
Scenario 2	10 min	70-passenger bus
Scenario 3	10 min	60-passenger bus

Each scenario represents 200 min of bus operation. 60 passengers per hour are generated using fixed interval times distribution in each scenario. Bus headway variation is generated using normal distribution. The model is also able to handle other conventional distributions. Those applications are not shown here. Five min of travel time between stops are selected arbitrarily. To segregate consequences of departure headway variability, the bus travel time is considered as constant without any chance for variability. There are number of different measures proposed in literature to quantify headway variability. We quantify headway variability in this study using the coefficient of variation of headways as proposed by Turnquist and Bowman (1980). This measure can be presented as follows:

Co-efficient of variation of headway = Standard deviation of headway / mean headway *(1)*

Mean and standard deviation of the input headway variation are recorded. Co-efficient of variation of headways is calculated using Eq. 1. Passenger waiting times at each stop is calculated as the difference of time elapsed between passenger arrival and bus arrival at a stop. Simulations results for above scenarios are discussed in the following section.

SIMULATION RESULTS

This section describes simulation results for the three scenarios shown in Table 1. Distribution of waiting time and excess waiting time of passengers at each stop are shown when bus capacity is unlimited and limited. Limited capacity is selected 60-passenger bus and 70-passenger bus. Average waiting time of passengers at stops for each scenario is shown later.

Distribution of Waiting Time

Scenario 1 (Unlimited Capacity of Bus)

Figure 2 shows the waiting time distribution where there is no variation of headway and the bus headway is 10 min. When dispatch headway is constant, in other words, no headway variation is present; the average waiting time is half of 10 min in all five stops. Passengers arriving at stop at the first minute have to wait 9 min. Similarly, passengers arriving at second minute have to wait 8 min. In this instance, five percent of passengers arrive at the stop at zeroth minute and they have to wait full 10 min for the next bus. Similarly, five percent of passengers arrive at the stops at the 10th minute have no waiting time since they can board the next bus without waiting. Figures 3, 4 and 5 show the waiting time distribution when headway is subject to different degrees of fluctuation and bus capacity is unlimited (Scenario 1). The peak of the waiting time distribution spanned from 1 to 6 min in Figure 3. In Figure 4, this peak waiting time spanned from 1 to 4 min. In Figure 5, this peak waiting time is 2 min. Compared to Figure 2, Figures 3, 4 and 5 show less flatness of the peak and more right skewness of the figure. These long tails of Figures 3, 4 and 5 results in relatively large waiting time which eventually lead to large average waiting times. It can also be seen from Figures 3, 4 and 5 that the waiting time distribution spreads in time scale as variation of dispatch headway increases. For example, in Figure 3, spread of distribution of Stops 1 and 2 ends at 13 min and 16 min respectively when co-efficient of variation of headways is 0.2. For co-efficient of variation of headways = 0.3, the spread of distribution of Stop 1 and 2 end at 16 min and 18 min respectively as shown in Figure 4 . A similar trend can be seen in Figure 5.

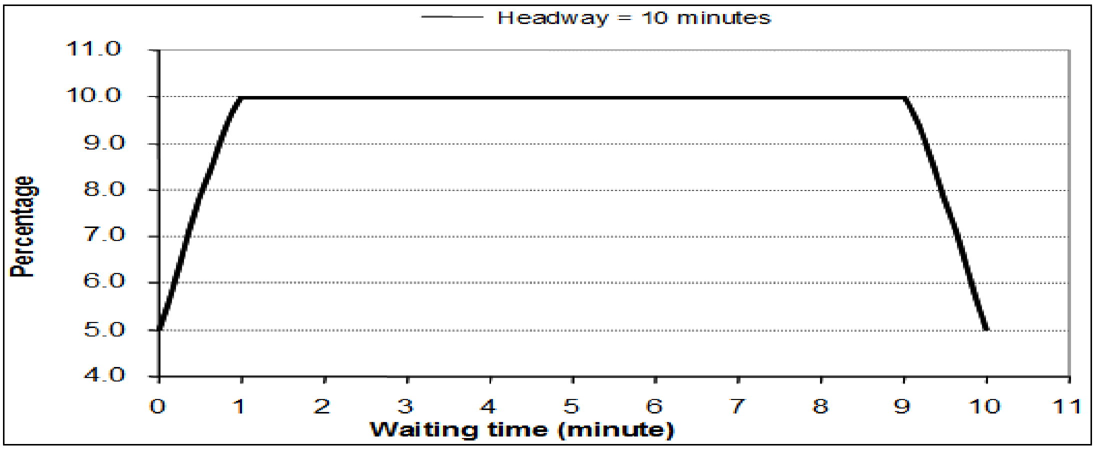

Fig. 2: *Waiting Time Distribution with a Constant Headway of 10 min (Bus Capacity is Unlimited).*

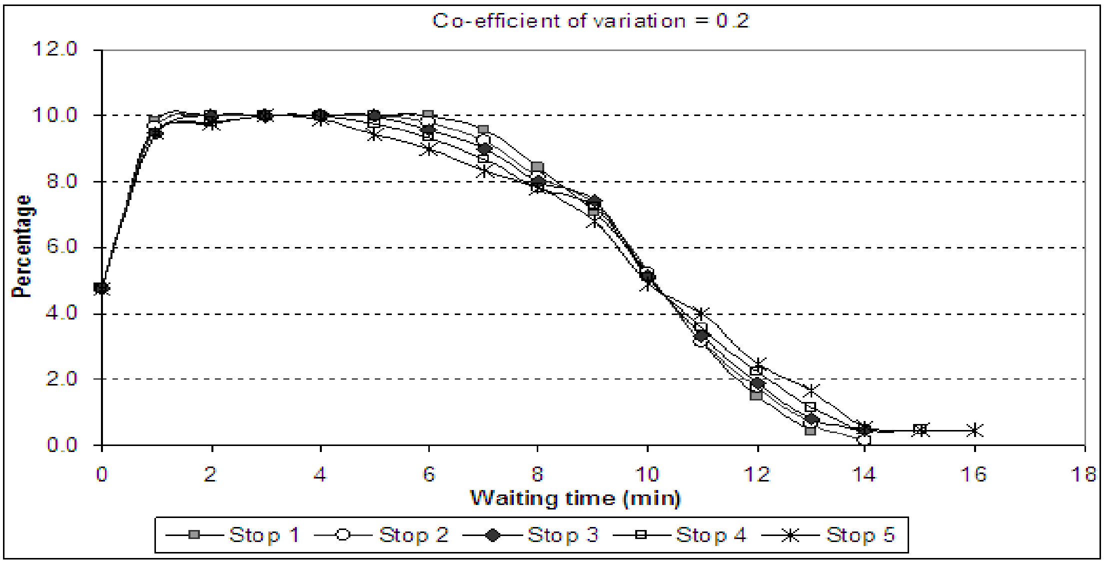

Fig. 3: *Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.2 (Bus Capacity is Unlimited).*

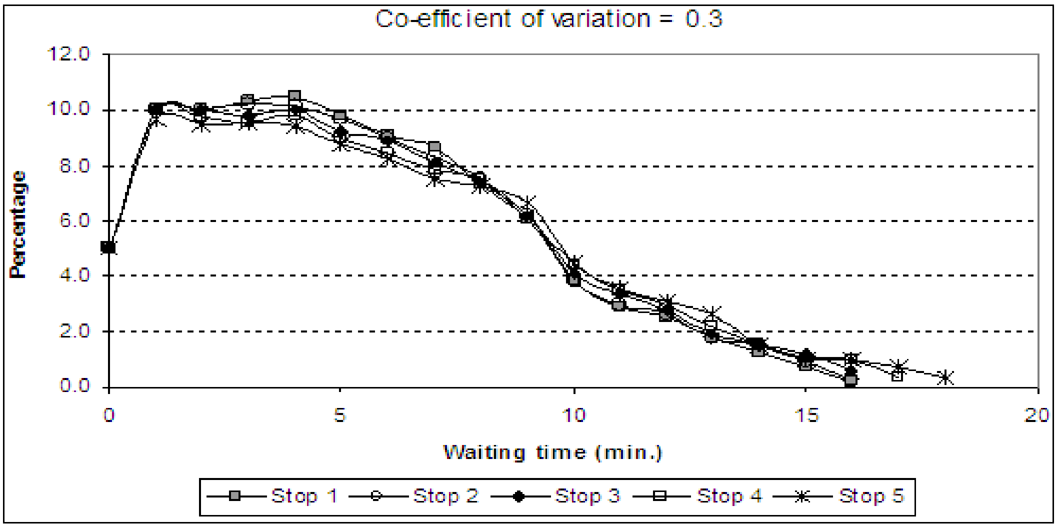

Fig. 4: *Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.3 (Bus Capacity is Unlimited).*

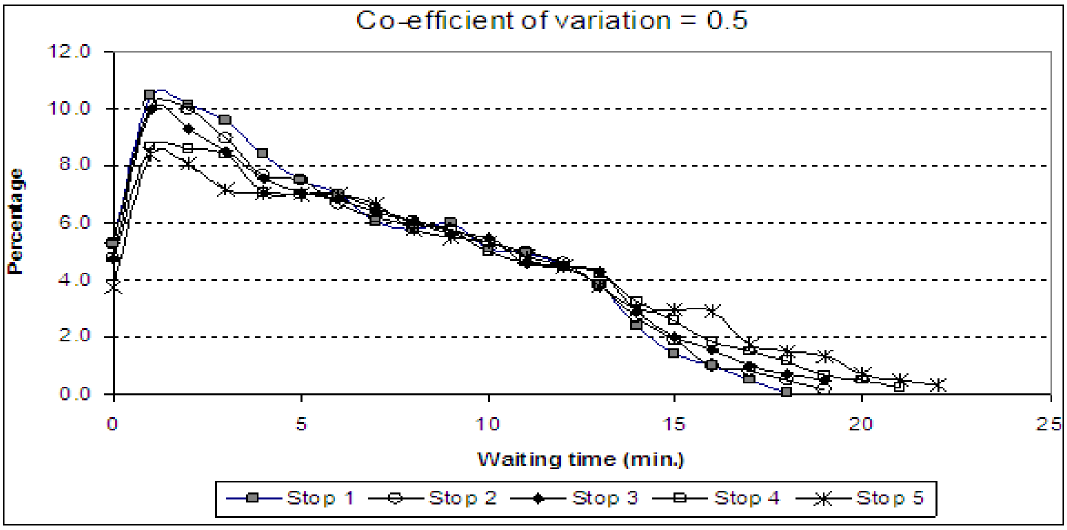

Fig. 5: *Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.5 (Bus Capacity is Unlimited).*

At the next stage of simulation, bus capacity is no longer assumed as unlimited. In these simulations, buses can accommodate only limited number of passengers. If a bus has reached its capacity, it denies service to remaining passengers at the bus stop. Bus size including standing passengers is considered 70 in Scenario 2 and even less in Scenario 3.

Scenario 2 (Limited Capacity of Bus: 70-Passengers)

Figures 6, 7 and 8 show the waiting time distribution when departure headway is irregular and bus capacity is limited to 70-passengers. In Figure 6, peak probability of waiting times is observed from 2 to 7 min when co-efficient of variation of headways is 0.2. When co-efficient of variation of headways is 0.3, the peak probability of waiting times can be seen from 5 to 7 min in Figure 7. Figure 8 shows the peak probability is 11 min for co-efficient of variation of headways = 0.5. Thus, it can be stated that as variation of headway increases, waiting time distribution becomes peaky and moves to the right of the diagram. This means larger headway variations cause higher percentage of passengers will face longer waiting times. It can be seen from Figures 6, 7 and 8 that the tail of the distribution moves further to right in time scale as variation of dispatch headway increases. The observation is similar to Scenario 1 as observed in previous simulations. For example, in Figure 6, the spread of distribution ends at 13 min for Stop 1 and 16 min for Stop 5 when co-efficient of variation of headways is 0.2. Similarly, for co-efficient of variation of headways = 0.3, the spread of distribution of Stop 1 and Stop 5 end at 20 min and 23 min, respectively as shown in Figure 7. The spread of distribution corresponding to the co-efficient of variation of headways = 0.5 also shows a similar trend in Figure 8. In Scenario 2 where bus capacity is limited to 70 passengers, spread of waiting time increases and the probability of a long wait for passengers becomes higher compared to scenario 1 that have unlimited capacity of bus. When bus becomes full, it bypasses waiting passengers and consequently, the remaining passengers have to wait for next bus which increases their waiting time.

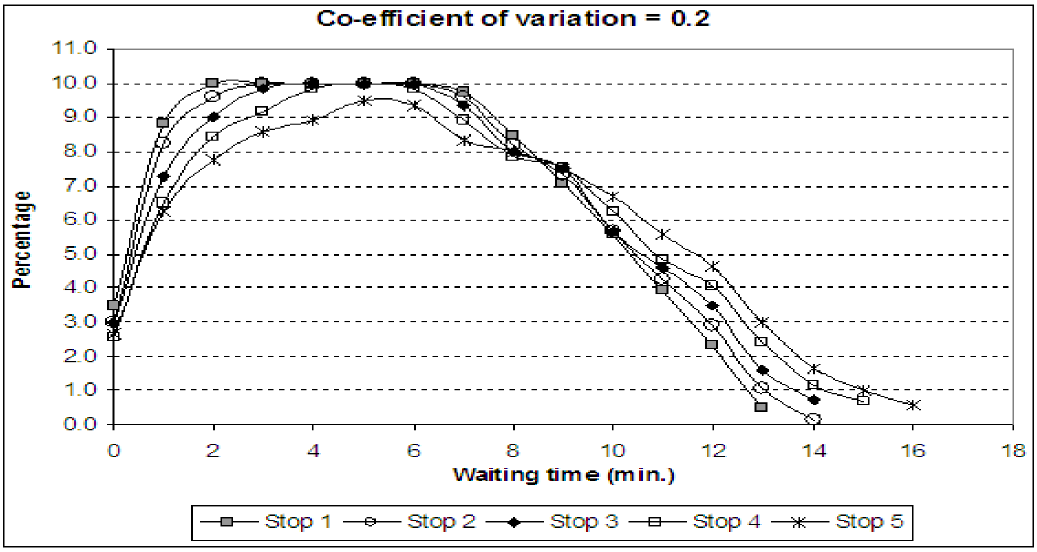

Fig. 6: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.2 (Bus capacity = 70-passengers).*

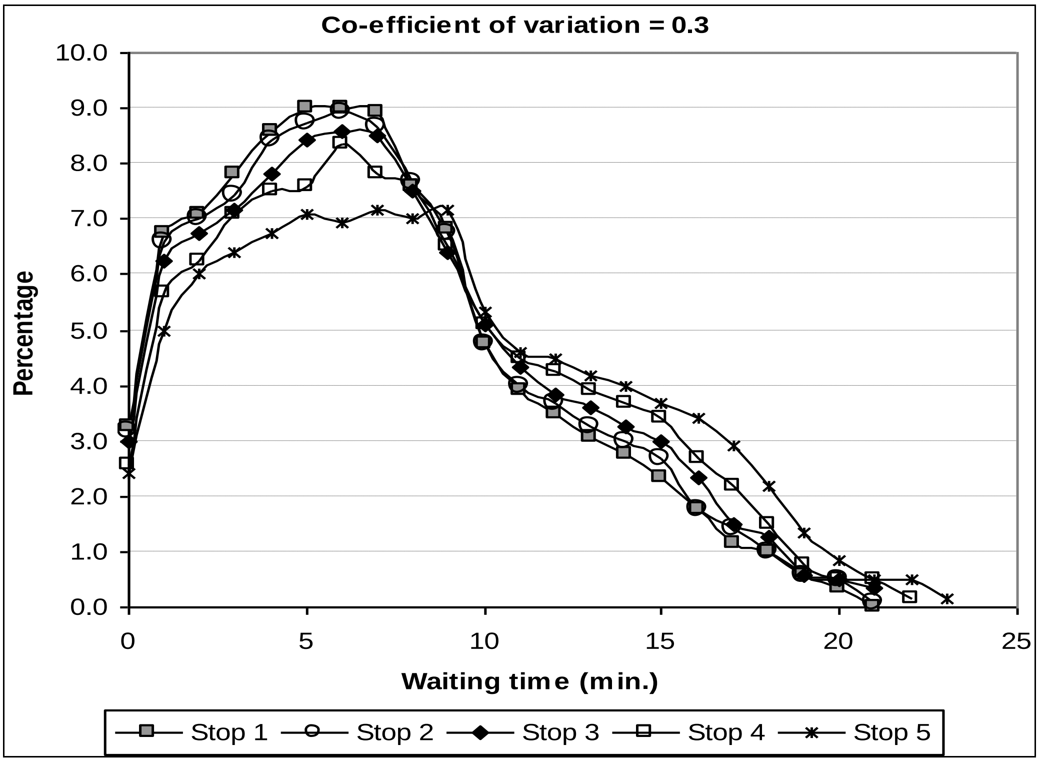

Fig. 7: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.3 (Bus capacity = 70-passengers).*

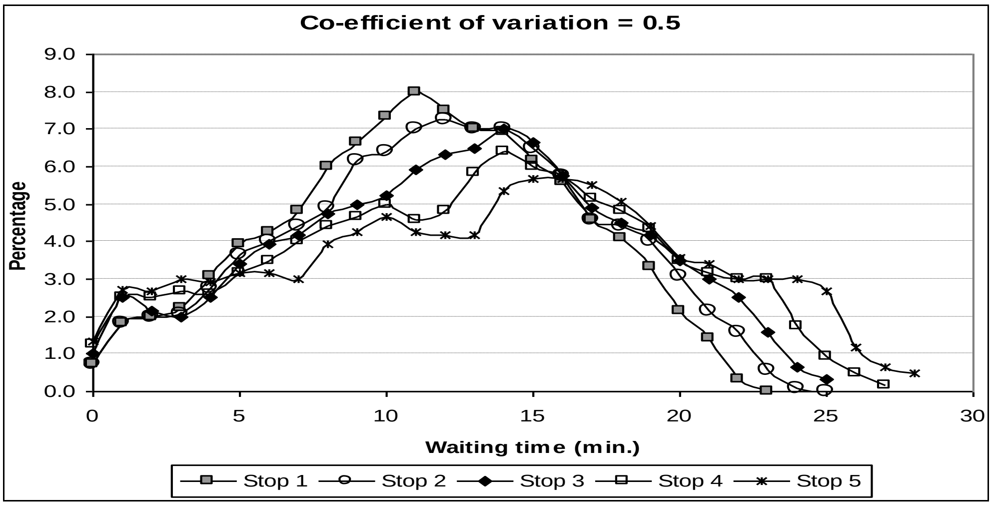

Fig. 8: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.5 (Bus capacity = 70-passengers).*

Scenario 2 (Limited Capacity of Bus: 60-Passengers)

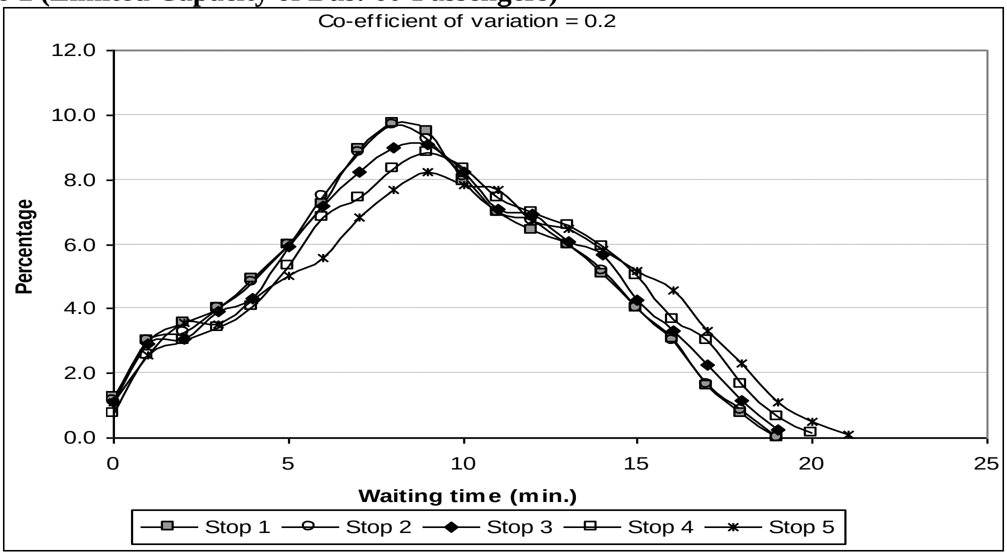

Fig. 9: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.2 (Bus capacity = 60-passengers).*

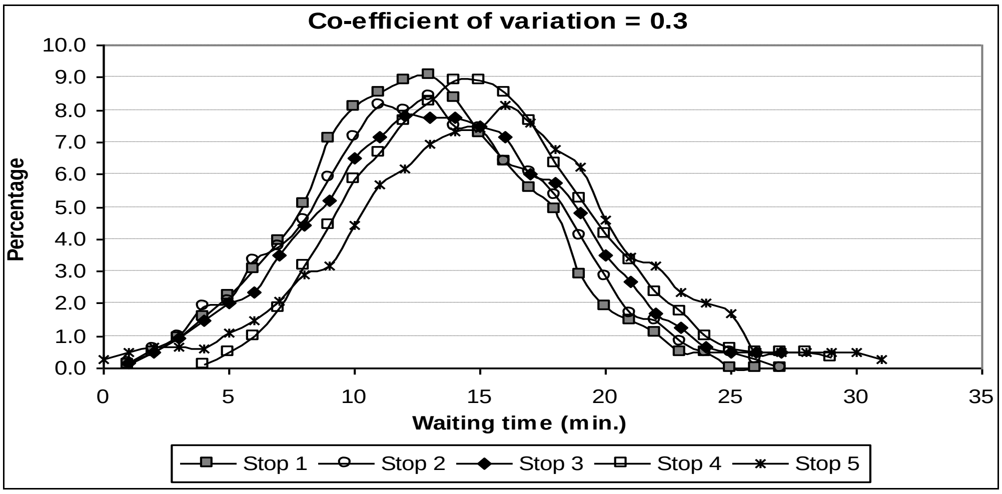

Fig. 10: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.3 (Bus capacity = 60-passengers).*

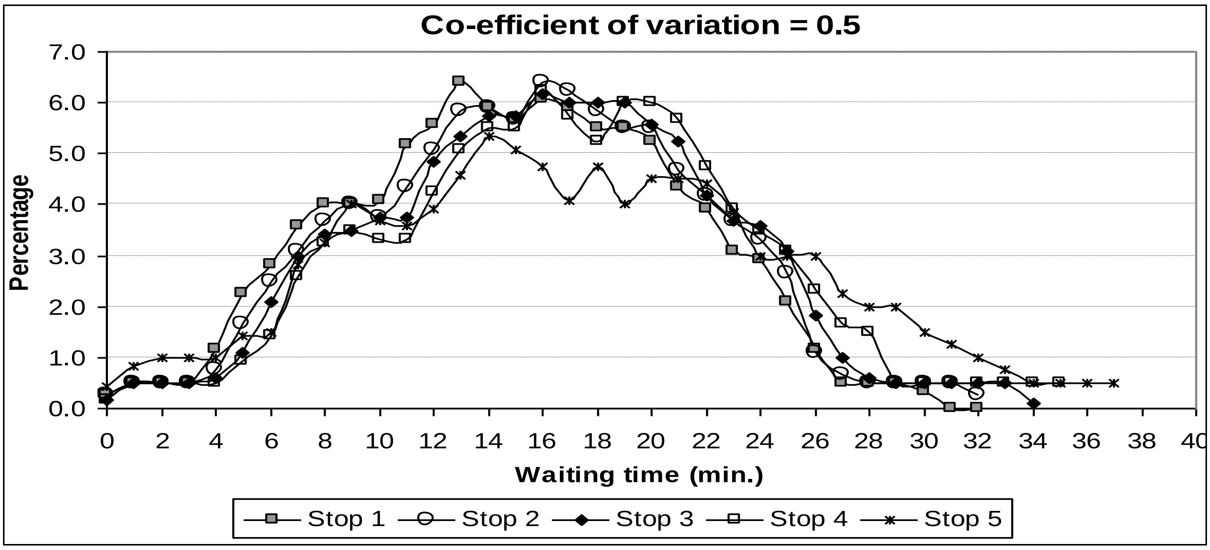

Fig. 11: *Waiting time distribution with headway = 10 min and co-efficient of Variation = 0.5 (Bus capacity = 60-passengers).*

In Scenario 3, 60-passenger capacity buses are selected. The results are shown in Figures 9, 10 and 11. Compared to Scenario 2, in this scenario, the waiting time distribution shows more peakyness and moves towards to the centre of diagrams.

The probability of waiting time peaks at 9, 15 and 18 min in Figure 9, 10 and 11 respectively. This indicates probability for longer wait time is higher compared to Scenario 2. Thus, the results of Scenario 2 and 3 reveal that the waiting time becomes longer when capacity of bus is reduced.

Excess Waiting Time Distribution

Now, it is possible to compute excess waiting time for individual passenger under the different scenarios. Excess waiting time is the amount of additional time that passengers wait because buses are not on time. Figures 12 to 20 show excess waiting time distributions. These figures show the effects of bus capacity constraint and degree of departure headway variation on excess waiting time of passengers. Waiting time distribution for constant bus headway 10 min with unlimited bus capacity show in Figure 2 can be considered as the base case. Such a case ensures that passenger waiting time for a bus is a result of on time of departure of buses. Thus, this base case is the “zero excess waiting time” state for working out of excess calculating time of other scenarios.

Scenario 1 (Unlimited Capacity of Bus)

Figures 12, 13 and 14 show excess waiting time distributions for Scenario 1 where bus unlimited size bus is subject to different degrees of fluctuation of dispatch time. There is a chance that some passengers can board early buses than what is possible with on time departure of bus service. Probability of excess waiting time is peaked at zero minute in each of these three figures. However, right side tails become longer as variation of dispatch time increase. Evaluation of Impacts of Dispatch Headway Variability in Bus Transit Systems in a Simulated Route

Scenario 2 (Limited Capacity of Bus: 70-Passengers Bus)

Figures 15 and 16, similar to Figures 12 to14, show probability of excess waiting time peaked at zero minute and right side tails extend towards right when bus capacity limit is imposed along with dispatch headway variation (Scenario 2). However, in Figure 17, when co-efficient of variation of headway is increased to 0.5, the peak of excess waiting time distribution shifted towards right which lead to further increase in average waiting time for passengers. Compared to excess waiting time distribution of Scenario 1 (Figures 12 to 14), Scenario 2 (Figures 15 to 17) show longer extensions of right side tails. Peak of distribution also shifted to right in Figure 17. This reveals the effect of capacity constraint of bus on excess waiting time of passengers.

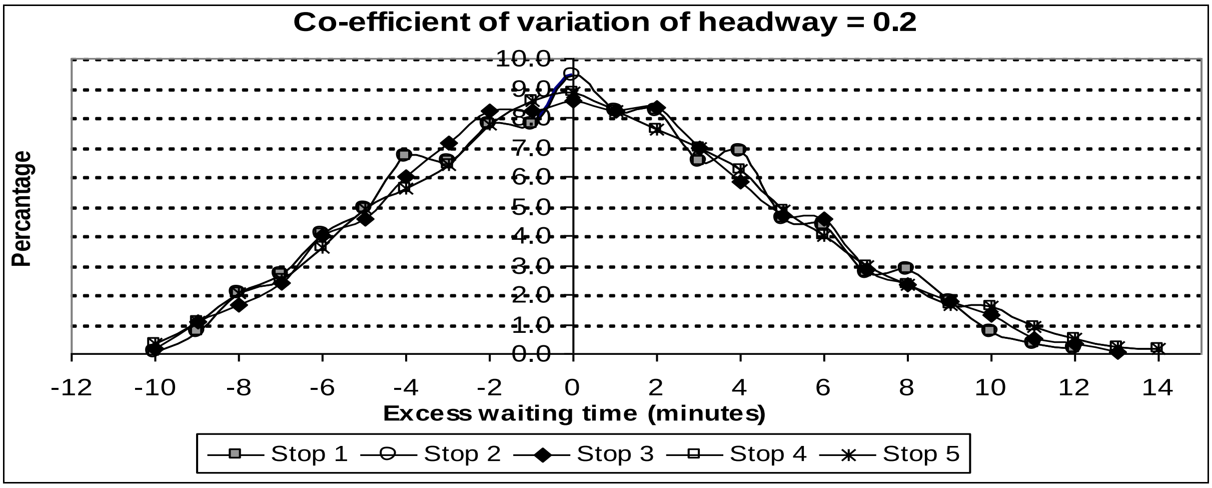

Fig. 12: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.2 (Bus Capacity is Unlimited).*

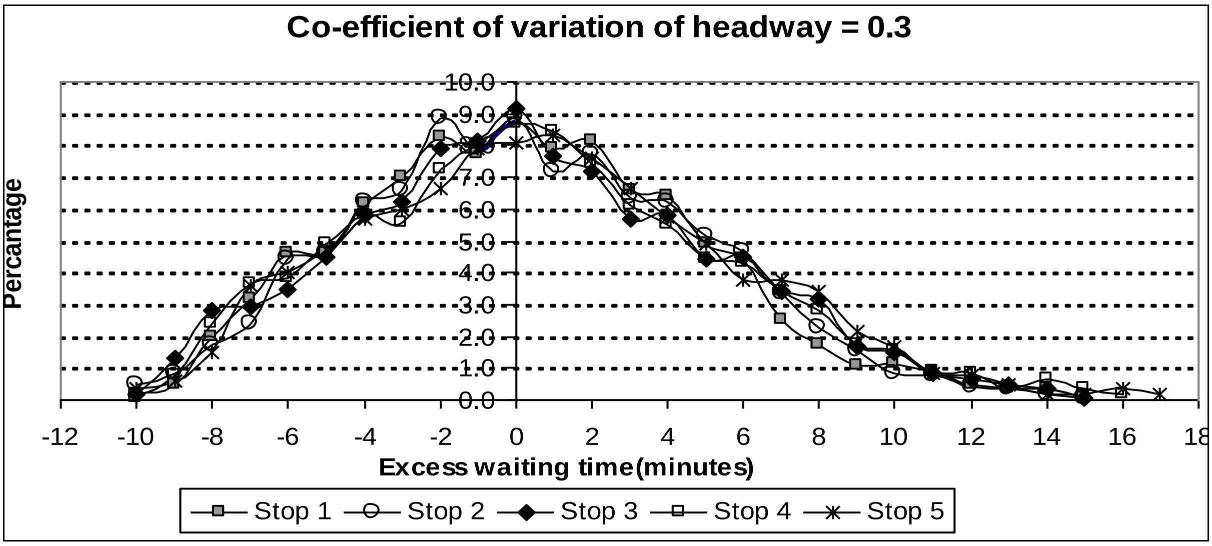

Fig. 13: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.3 (Bus Capacity is Unlimited).*

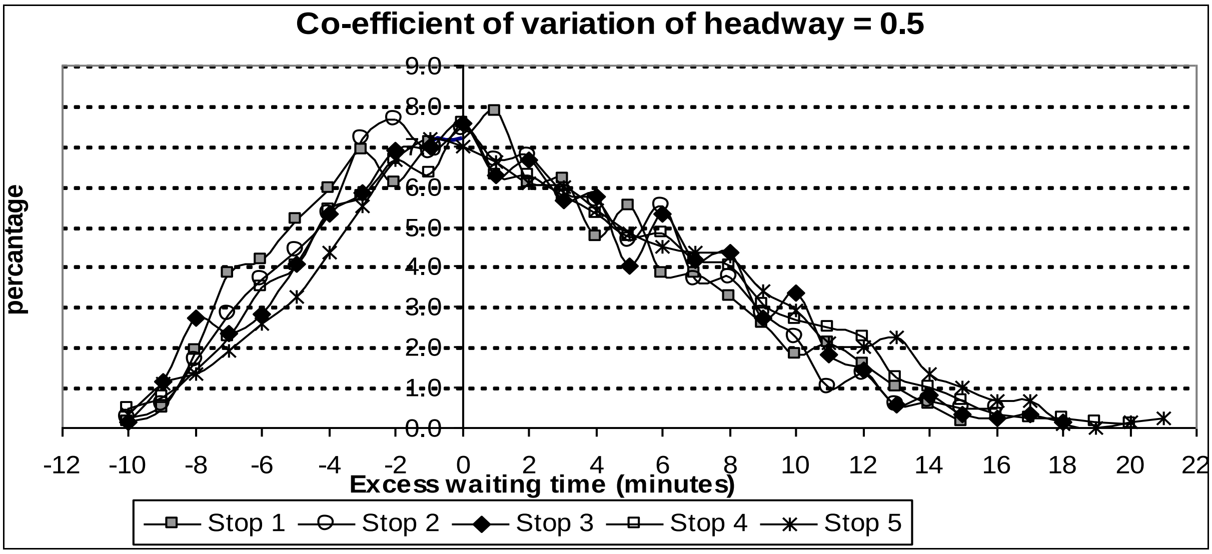

Fig. 14: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.5 (Bus Capacity is Unlimited).*

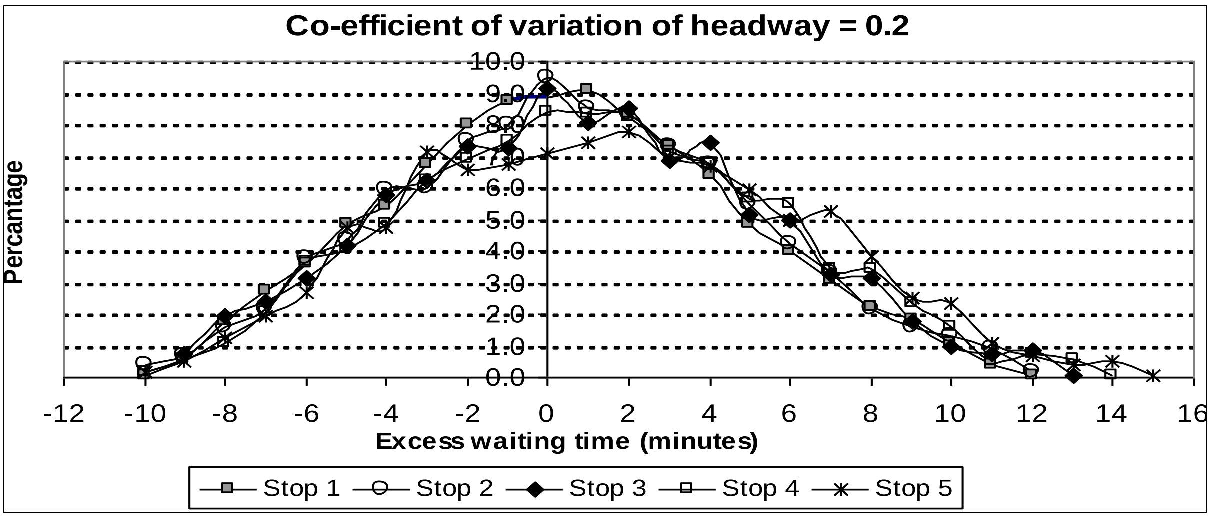

Fig. 15: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.2 (Bus Capacity = 70 Passengers).*

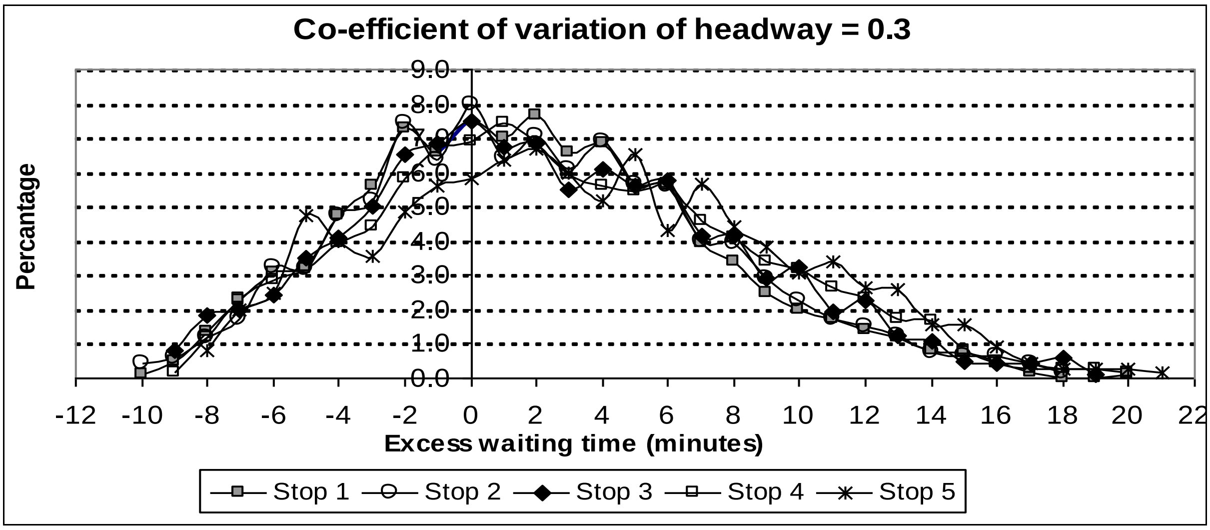

Fig. 16: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.3 (Bus Capacity = 70 Passengers).*

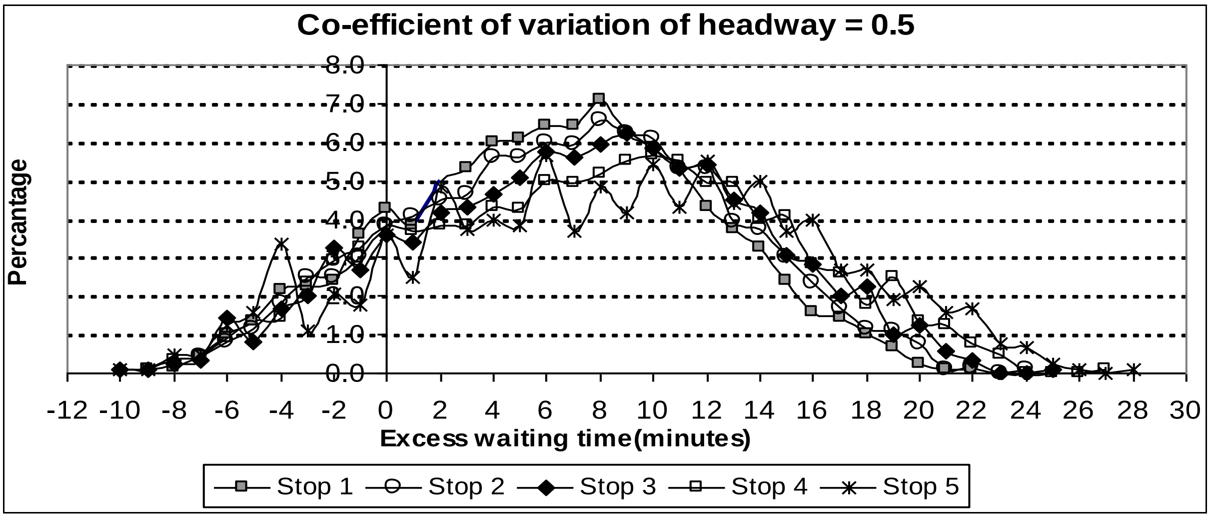

Fig. 17: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.5 (Bus Capacity = 70 Passengers).*

Scenario 2 (Limited Capacity of Bus: 60-Passengers)

The excess waiting time distributions of Scenario 3 where bus capacity is further reduced than in Scenario 2, are show in Figures 18, 19 and 20. The peaks of distributions are moved rightward and spread of distribution extended as degree of headway fluctuations increases. Distributions shown in these Figures for Scenario 3 have peaks moved to right and spread more compared to Scenarios 1 and 2.

This means that the excess waiting time of passengers increases as bus capacity is reduced along with increasing fluctuation of departure headway. Average of waiting of passengers is increased and the performance of the bus service is weakened.

Average Passenger Waiting Time

The effect of departure headway variation on average waiting time of passengers at different stops is shown in Figure 21. Figure 21 shows average waiting time increases for passengers joining the service further along the route.

This figure also indicates that average waiting time increases as co-efficient of variation of headway increases. Figure 21 also reveals that the average waiting time increases as capacity of bus is reduced. For example, when co-efficient of variation of headway is 0.2, with 60-passenger bus capacity, average waiting time at the first stop is 8.73 min which increases to 9.71 min at Stop 5. In comparison, with capacity of 70-passengers bus capacity, average waiting time at the first stop is 5.42 min which increases to 6.47 at Stop 5.

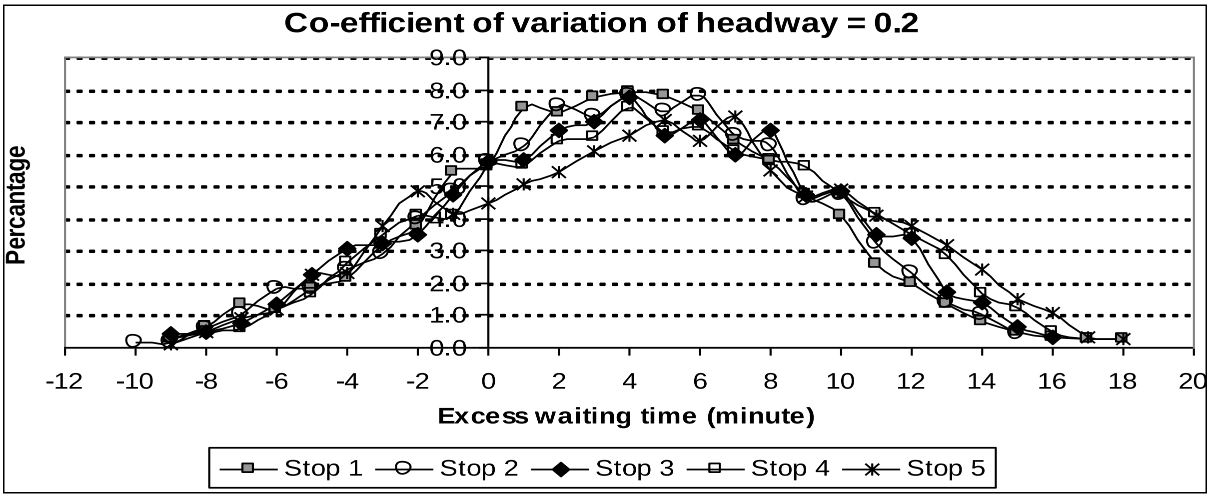

Fig. 18: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.2 (Bus Capacity = 60 Passengers).*

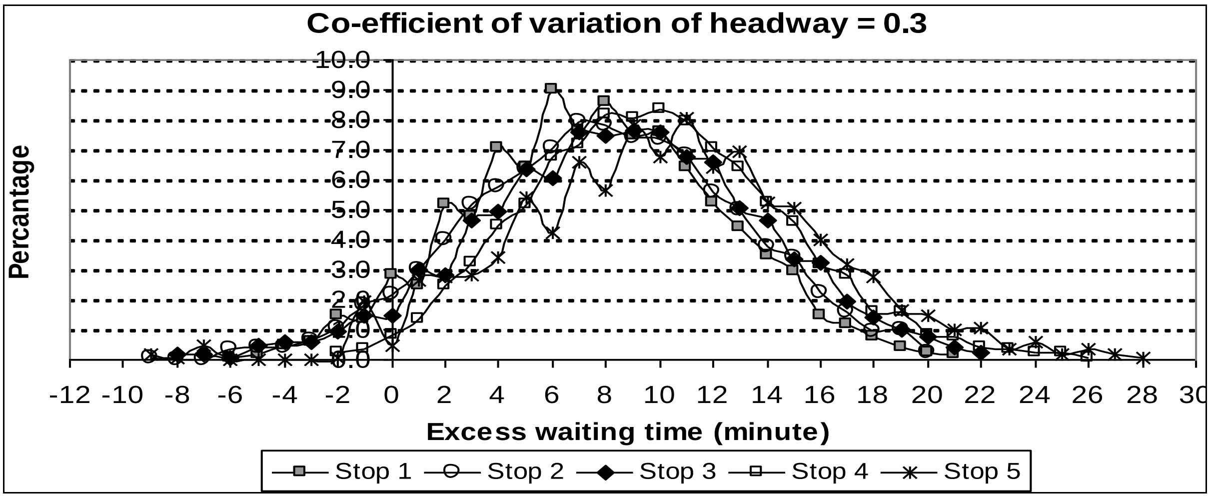

Fig. 19: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.3 (Bus Capacity = 60 Passengers).*

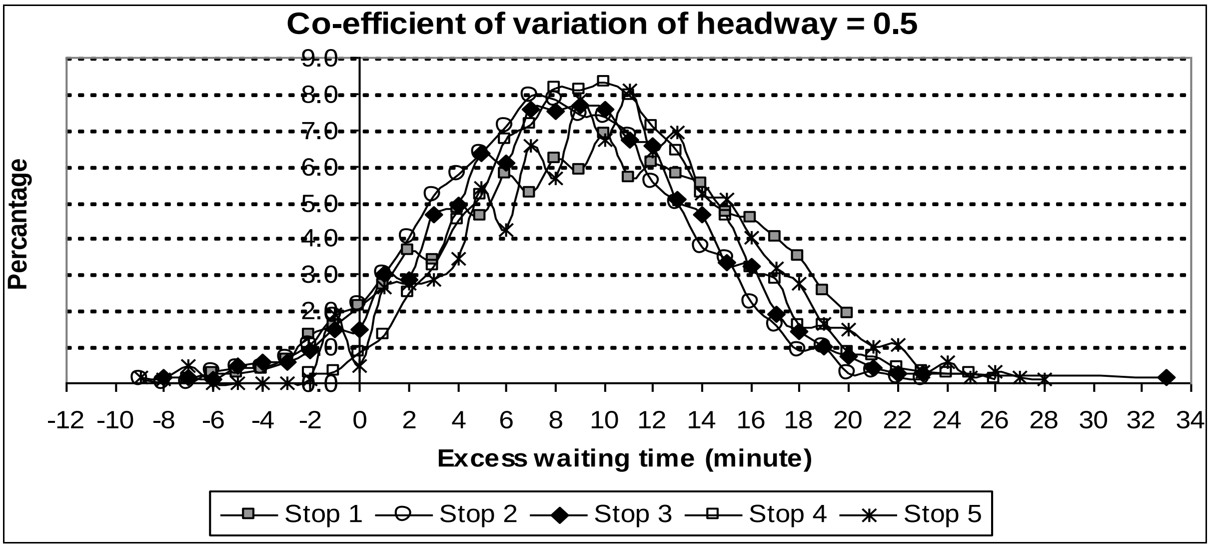

Fig. 20: *Excess Waiting Time Distribution with Headway = 10 min and Co-efficient of Variation = 0.5 (Bus Capacity = 60 Passengers).*

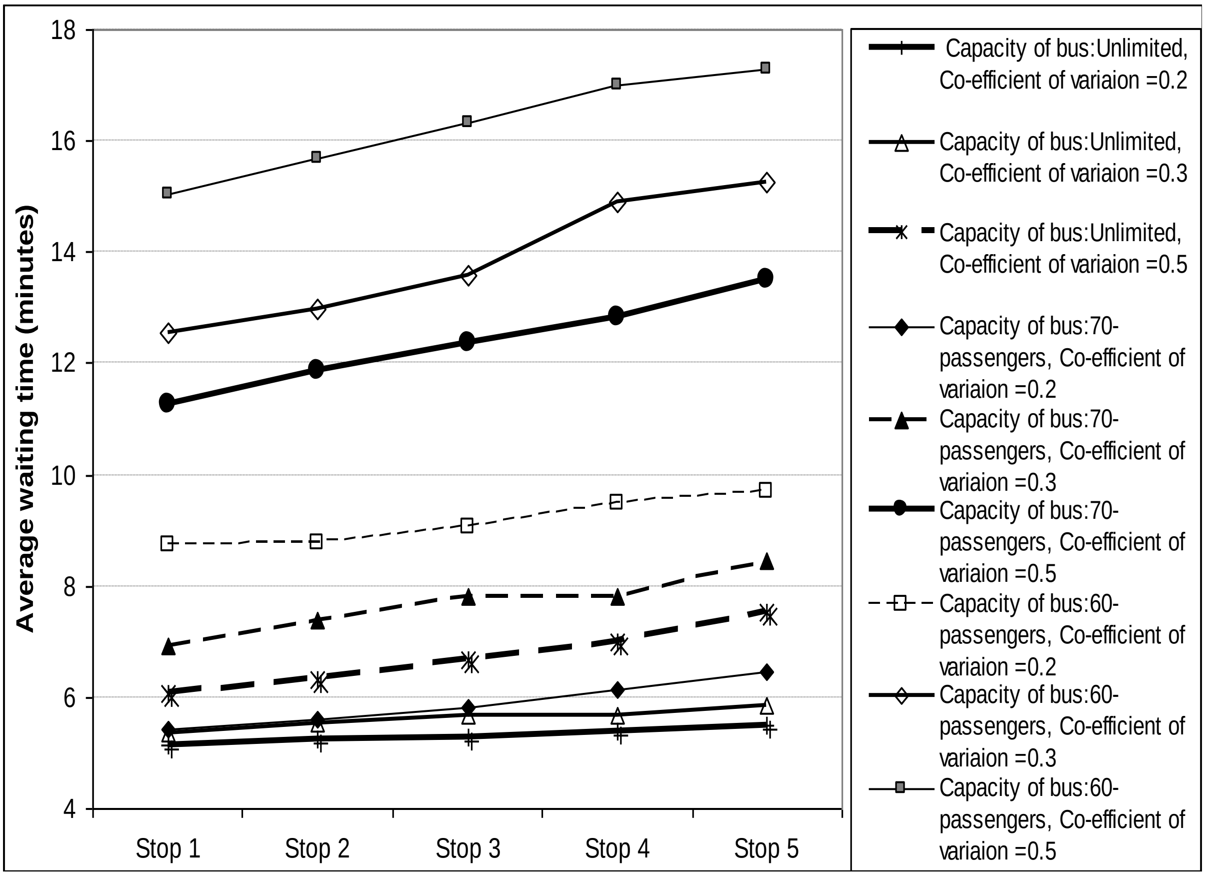

Fig. 21: *Average Waiting Time for Passengers along Bus Route.*

CONCLUSIONS

Reliability analysis presented in this paper is based on a spreadsheet simulation. Three scenarios are presented. These scenarios vary the bus size from 60-passengers to 70-passnegers to infinity. Simulation results show that distributions of passenger waiting times widen as the departure headway variation increases. Spread of waiting time as well as average waiting time of passengers become large when bus capacity is reduced. The proposed model is able to vary departure headway of buses and bus travel time according to various probability distributions which makes this model suitable to analyze bus transit systems. In this paper, the focus has been variability of dispatch headways. At the next stage of analysis, it is worthwhile to explore the effect of reduction of headway along with bus capacity on operational performance of bus services. It is also proposed to extend the analysis to investigate consequences of variability of bus travel time.

REFERENCES

1. Turnquist M. A model for investigating the effects of service frequency and reliability on bus passenger waiting times. *Transportation Res Record*. 1978; 663: 70 –3p. http://trid.trb.org/view.aspx? Id = 74132
2. Bowman L, Turnquist M. Service frequency, schedule reliability and passenger wait times at transit stops. *Transportation Res. Part A.* 1981; 15: 465–71p. http://www.sciencedirect.com/science/article/pii/019126078190114X
3. Wilson N, Nelson D, Palmere A, Grayson T, Cederquist C. Service quality monitoring for high frequency transit lines. Paper presented at the 71st Annual Meeting of the Transportation Research Board, Washington, DC, 1992. http://trid.trb.org/view.aspx?id=370840
4. Bates J, Polak J, Jones P, Cook A. The valuation of reliability for personal travel. *Transportation Res, Part E.* 2001; 37: 191–229p.
5. Prioni P, Hensher D. Measuring service quality in scheduled bus services. J of Public Transportation. 2000; 3: 51–74p.http://www.nctr.usf.edu/2000/07/measuring-service-quality-in-scheduled-bus-services/
6. Sterman B, Schofer J. Factors affecting reliability of urban bus services. *Transportation Eng J.* 1976; 102: 147–59p.http://cedb.asce.org/cgi/WWWdisplay.cgi?6506
7. Abkowitz M. Transit Service Reliability. Cambridge, MA: USDOT Transportation Systems Center and Multisystems, Inc., 1978 (NTIS No. UMTA/MA-06-0049-78-1).
8. Turnquist M, Bowman L. The effects of network structure on reliability of transit service. *Transportation Res. Part B.* 1980; 14:79–86p. http://www.sciencedirect.com/science/article/pii/019126158090034X
9. Strathman J, Hopper J. Empirical analysis of bus transit on-time performance. *Transportation Res. Part A.* 1993; 27: 93–100p. https://www.pdx.edu/sites/www.pdx.edu.cus/files/PR060.pdf
10. Strathman J, Kimpel T, Dueker K, Gerhart R, Callas S. Evaluation of transit operations: data applications of Tri-Met's automated bus dispatching system. *Transportation.* 2002; 29: 321–45p. http://link.springer.com/article/10.1023%2FA%3A1015633408953#page-1
11. Adebisi O. A mathematical Model for headway variance of fixed-route buses. *Transport Research, Part B.* 1986; 20: 59–70p. http://www.sciencedirect.com/science/article/pii/0191261586900366
12. Vandebona U, Ismatulla E. Reliability of Multi-Modal Transport Systems, Paper presented at the 25nd Conference of Australian Institutes of Transport Research (CAITR), University of South Australia, Adelaide, Australia, 2003.

