Journal of Southeast University (English Edition) Vol. 29, No. 1, pp. 99 - 102 Mar. 2013 ISSN 1003—7985

Factors affecting headway regularity on bus routes

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Abstract: The common phenomenon of uneven headway in bus service is explored based on the automatic vehicle location (AVL) data of Route 2 in Yichun City of Jiangxi province from 6:00 to 9:00 in the morning. The headway regularity of two stages 6:00—7:00 and 7:00—9:00 is comparatively analyzed, and it is found that both the traffic conditions and the passenger demand affect headway regularity. A bus arrival model, which assumes that the dwell time of a bus is linear in headway, is built to probe the effect of scheduled headway, and the model is simulated by Matlab. The simulation results reveal that the departure intervals and fluctuations affect headway regularity. Longer intervals and less fluctuation mean higher regularity of headway. And, the fluctuation has a more obvious influence on headway regularity than the interval. Controlling the fluctuations of scheduled headway can effectively raise the regularity of headway and improve the level of public transport service.

Key words: traffic engineering; bus scheduling; headway regularity; scheduled headway; bus bunching

doi: 10.3969/j.issn.1003-7985.2013.01.020

Until now, the study of headway adherence has been limited, and it has mainly focused on the strategy for improving bus schedule reliability[1-2] or addressing the bus bunching problem[3]. However, identifying the factors affecting the regularity of headway is essential to these researches. This paper analyzes some of these factors based on the automatic vehicle location (AVL) data. A bus arrival model is developed to study the effects of scheduled headway, and Matlab is used to simulate the model.

1 Phenomenon of Uneven Headway Analysis

In Fig. 1, we show the space-time plot of bus positions, which is obtained by the AVL data in Yichun City of Jiangxi Province, and the data provides arrival times of buses at each bus stop on Route 2. There are sixteen bus stops lying along the route, denoted from 1 to 16, and we can obtain every curve in Fig. 1 by connecting each bus's arrival time at each bus stop sequentially and smoothly. The 29 curves in Fig. 1 represent 29 buses which depart from the starting station during the day of September 22nd, 2011 from 6:00 to 9:00 in the morning. The vertical distance between adjacent curves represents the headway.

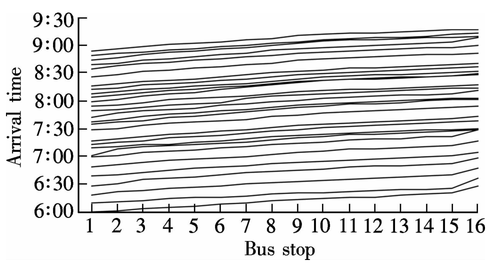

Fig. 1 Space-time of bus position based on AVL data

As can be seen from Fig. 1, there are two distinctive stages of headway, from 6:00 to 7:00 and 7:00 to 9:00. The headway of the former is more regular than the latter, and bus bunching arises in the latter. Obviously, the second stage occurs during the morning peak hour due to the fact that both the traffic conditions and the passenger demand are unusual. Simulation results[4] show that running time fluctuations and uneven passenger arrivals will lead to headway variations.

There are another two differences between these two stages. First, the departure interval is different, which from 6:00 to 7:00 is 10 min, and from 7:00 to 9:00 is 4 min. Secondly, the departure interval from 7:00 to 9:00 is not so uniform as the former. However, we have not known how these two factors affect the regularity of headway.

Although there are some researches[5-7] about adherence of headway, most of those studies assume that the scheduled headway is even and fixed. Hence, it is necessary to study the effect of departure intervals on headway regularity.

2 Bus Arrival Model

We now consider a fixed-route bus service. Each bus is labeled by a number i running from 1 to I. Bus $i+1$ is the one just following behind bus i. Each bus stop is la-

Received 2012-05-06.

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Foundation items: The National Basic Research Program of China (973 Program) (No. 2012CB725402), the National Natural Science Foundation of China (No. 50978057), Program of Scientific Innovation Research of College Graduate in Jiangsu Province (No. CXLX12_0108).

Citation: Zhang Man, Li Wenquan. Factors affecting headway regularity on bus routes[J]. Journal of Southeast University (English Edition), 2013, 29(1): 99 - 102. [doi: 10.3969/j.issn.1003-7985.2013.01.020]

beled by a number j running from 1 to J, and the starting one is labeled as 1. Each bus stops at all the bus stops. The arrival time of bus i at bus stop j is defined as $t_i(j)$. We define the headway of bus i at bus stop j as follows:

$$\Delta t_i(j) = t_i(j) - t_{i-1}(j) \tag{1}$$

We define the dwell time of bus i at bus stop j as $h_i(j)$, and we assume that $h_i(j)$ is linear in $\Delta t_i(j)$. The dwell time can be influenced by the time required for crippled or old passengers loading as these activities will result in a longer-than-average dwell time, which can be treated as random disturbances and we use $\beta(j)$ to denote this variability. We can obtain the equation of the dwell time for bus i at bus stop j in terms of headway as follows:

$$h_i(j) = \lambda_j \Delta t_i(j) + \beta_i(j) = \lambda_j [t_i(j) - t_{i-1}(j)] + \beta_i(j) \tag{2}$$

where λ_j is the dimensionless parameter expressing the marginal increase in bus dwell time arising from unit headway. The random term $\beta(j)$ is normally distributed, $\beta(j) \sim N(0, \sigma_j^2)$, and it is independent of $\Delta t_i(j)$.

We define the travel time of bus i between bus stop j and $j-1$ as $\alpha_i(j)$. We assume that $\alpha_i(j)$ is random and normally distributed, $\alpha_i(j) \sim N(\mu_j, \delta_j^2)$. μ_j is the average travel time between bus stop j and $j-1$, and δ_j^2 is the random noise. The arrival time $t_i(j)$ of bus i at bus stop j is given by

$$t_i(j) = t_i(j-1) + h_i(j-1) + \alpha_i(j) \tag{3}$$

Combining Eqs. (2) and (3), we obtain the law of bus arrival time as follows:

$$t_i(j) = t_i(j-1) + \lambda_{j-1}[t_i(j-1) - t_{i-1}(j-1)] + \beta_i(j-1) + \alpha_i(j) \tag{4}$$

where $\alpha_i(j) \sim N(\mu_j, \delta_j^2)$, $\beta(j) \sim N(0, \sigma_j^2)$, $j \in [2, J]$, $i \in [2, I]$.

$$t_i(1) = t_1(1) + \sum_{i=2}^{i} \Delta t_i(1) \qquad j = 1 \tag{5}$$

$$t_1(j) = t_i(j-1) + \lambda_{j-1}\Delta t_i(1) + \beta_i(j-1) + \alpha_i(j) \, i = 1 \tag{6}$$

Note that the motion described by Eq. (4) is unstable, because the headway increasingly deviates from the scheduled headway as time passes, until buses bunch up, i. e., $t_i(j) = t_{i-1}(j)$. To solve this instability, we assume that the bus behind cannot pass over the delayed bus, i. e., $t_i(j) - t_{i-1}(j) \geqslant 0$. If $t_i(j) - t_{i-1}(j) < 0$, then $t_i(j) = t_{i-1}(j)$.

3 Simulation and Discussion

We carry out two simulations by Matlab for the bus arrival model described by Eq. (4), $J = 18$. The simulations are all performed with the parameters in Tab. 1. The first simulation is executed under the fixed scheduled headway, with no fluctuation, and three departure intervals are simulated. The second simulation is carried out with different fluctuations of scheduled headway within a given range. All the simulations are implemented from 7:30 to 9:30 in the morning.

Tab. 1 Values of parameters min

Item	Bus stop j																
	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16	17	18
λ_j	0.22	0.20	0.23	0.20	0.12	0.15	0.17	0.19	0.20	0.23	0.17	0.16	0.15	0.15	0.12	0.12	0.00
μ_j		2.8	3.0	3.3	3.5	2.8	3.4	3.5	3.1	3.0	3.4	3.5	3.5	3.5	3.0	2.5	2.8
δ_j		0.4	0.4	0.5	0.6	0.7	0.6	0.4	0.6	0.5	0.7	0.6	0.5	0.6	0.7	0.8	0.8
σ_j	0.04	0.08	0.09	0.10	0.08	0.07	0.08	0.11	0.10	0.06	0.04	0.08	0.05	0.04	0.07	0.08	0.04

3.1 Simulation with even scheduled headway

When the scheduled headway is even with $\Delta t_i(1) = H$, we can rewrite Eq. (5) as

$$t_i(1) = t_1(1) + \sum_{i=2}^{I} \Delta t_i(1) = t_1(1) + (i-1)H \qquad i = 2, 3, \dots, I \tag{7}$$

Figs. 2(a) to (c) are obtained, respectively, with even scheduled headways, i. e., $H = 6$, 5, 4 min. In Fig. 2 (a), $H = 6$ min, and the headways between successive buses are relatively regular with only a small fluctuation and no bus bunching. However, in Fig. 2 (b), $H = 5$ min, and most of the headways are still regular but bus bunching arises. In Fig. 2(c), bus bunching arises more often than the situation in Fig. 2(b), but the fluctuation of the headways is still acceptable. By comparison, under the even scheduled headway, it can be concluded that the regularity of headway is affected by the intervals, and longer intervals result in more regular headway. But the effect is not obvious.

According to TCRP Report 100[8], headway adherence is measured based on the variation coefficient of the headway of transit vehicles serving a particular route arriving at a stop, and it is calculated as follows:

$$c_{\mathrm{vh}} = \frac{\sigma_{\mathrm{dh}}}{\overline{H}} \tag{8}$$

where c_{vh} is the variation coefficient of headway; σ_{dh} is the standard deviation of headway deviations; and $\overline{H}$ is the mean scheduled headway.

In this simulation, with the even scheduled headway, the mean scheduled headway equals the departure interval H. Based on Eq. (8), longer intervals result in smaller values of c_{vh}, which means more regular headway, and this conclusion is in good agreement with the simulation results.

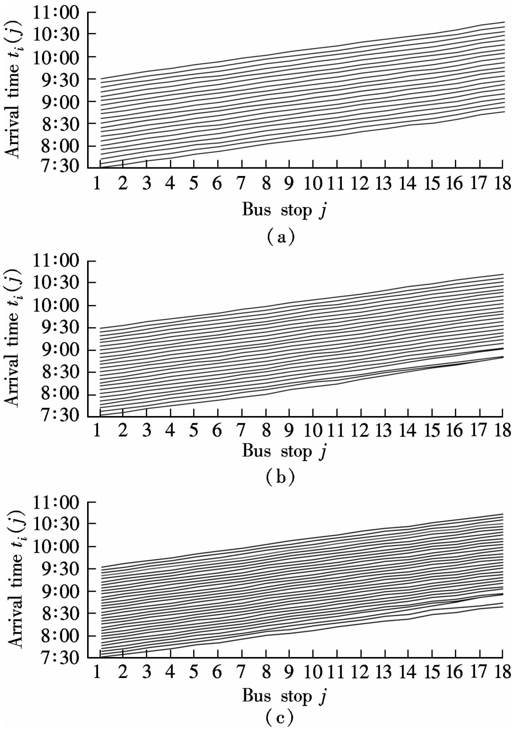

Fig. 2 The space-time of bus position with even scheduled headway. (a) $H=6$ min; (b) $H=5$ min; (c) $H=4$ min

3.2 Simulation with uneven scheduled headway

We carry out the simulations under the following initial condition:

$$\Delta t_i(1) = H + 0.5(R(1) - 0.5) \tag{9}$$

$$\Delta t_i(1) = H + (R(1) - 0.5) \tag{10}$$

$$\Delta t_i(1) = H + (R(2) - 1) \tag{11}$$

where $R(i)$ is the random number ranging from 0 to N, and the second term represents the fluctuation of scheduled headway at starting bus stop, $H=6$ min.

Fig. 3 gives the simulation results. Figs. 3(a) to (c) are obtained by Eqs. (9) to (11), respectively, with uneven scheduled headways. In these plots, there are apparent headway fluctuations between successive buses. Even in Fig. 3(a), where the fluctuation of scheduled headway is only 0.25 min, some bus bunchings arise, and obviously, the headways are not regular as those shown in Fig. 2(a). In Fig. 3(c), the fluctuation is 1 min, bus bunching happens very frequently, and the headways between buses fluctuate widely. The bus service under this condition is unstable. We can say that uneven scheduled headway will result in irregular headway, and the effect should not be overlooked.

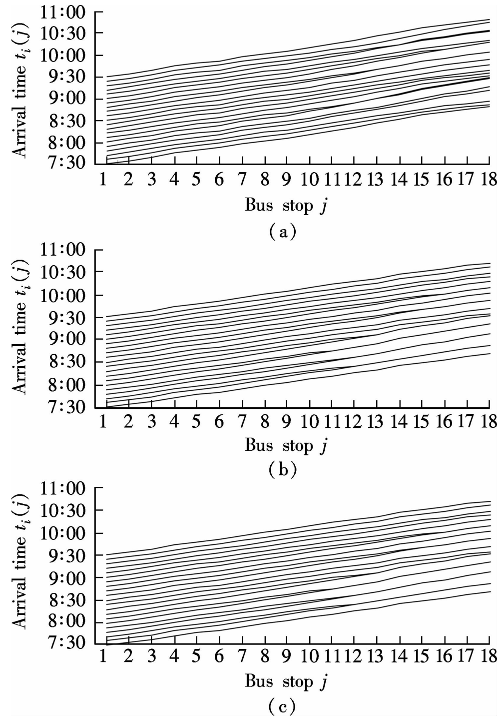

Fig. 3 The space-time of bus position with uneven scheduled headway. (a) $\Delta t_i(1) = H + 0.5(R(1) - 0.5)$; (b) $\Delta t_i(1) = H + (R(1) - 0.5)$; (c) $\Delta t_i(1) = H + (R(2) - 1)$

4 Conclusion

Traffic condition, passenger demand and scheduled headway are the key factors affecting headway regularity. It is found that longer intervals and less fluctuation of scheduled headway lead to more regular headway. What's more, the fluctuation affects headway regularity more obviously than the interval. As the scheduled headway is a controllable parameter compared to the traffic condition and passenger demand, controlling the scheduled headway, especially its fluctuation, is an effective strategy to improve the reliability of bus service.

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影响公交线路车头时距稳定性的因素

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摘要:采用江西省宜春市2路公交车早上6:00—9:00的车辆自动定位数据,分析了公交运营中常见的车头时距不稳定现象.对比讨论了6:00—7:00和7:00—9:00两个时段的车头时距稳定性,结果表明:交通状况和客流需求均会影响车头时距的稳定性.为了分析发车间隔对车头时距稳定性的影响,建立了车辆到站时间模型,该模型假设车辆的停靠站延误与车头时距线性相关.采用Matlab对该到站时间模型进行了仿真,仿真结果表明:发车间隔的大小和波动均对车头时距稳定性有影响,发车间隔越大,波动性越小,车头时距越稳定;发车间隔的波动对车头时距稳定性的影响比发车间隔的大小对其的影响更为显著.控制发车间隔的波动可以有效改善车头时距的稳定性,提高公交服务水平.

关键词:交通工程;公交调度;车头时距的稳定性;发车间隔;串车

中图分类号:U491