DEJAN PALISKA, Ph.D.
E-mail: dejan.paliska@fpp.uni-lj.si
JURIJ KOLENC, Ph.D.
E-mail: jurij.kolenc@fpp.uni-lj.si
University of Ljubljana,
Faculty of Maritime Studies and Transport
Pot pomorščakov 4, SI-6320 Portorož, Republic of Slovenia

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ANALYSIS OF BUS SERVICE RELIABILITY USING AVL DATA: CASE STUDY OF THE CITY OF KOPER

ABSTRACT

This article uses a statistical approach to examine the bus system reliability in the city of Koper. Four statistical models were developed using OLS to explain the effect of different variables on system reliability. The results indicate that the operator has no serious problems with maintaining system reliability, and that the most important factors affecting reliability are delay variation at previous time point and cumulative distance from route origin. Although the available data were not complete, the results presented appear to be accurate. The results obtained from the developed models could be used to estimate bus delays under various conditions.

KEY WORDS

public transit, reliability measures, statistical models

1. INTRODUCTION

Reliable service is important for both transit passengers and transit providers. Surveys have shown that reliability is strongly related to passenger satisfaction and perceptions of service quality [1], while stated preference experiments have found that passengers implicitly value reliability [2] and consider it in their mode choice decisions [3]. Unreliable service results in additional waiting time for passengers, the unit cost of which has been estimated to exceed the cost of in-vehicle travel time by a factor of three [4].

Unreliable service also has negative economic consequences for transit providers. Effective service capacity diminishes when vehicles become unevenly spaced and "platooning", or "bus bunching" occurs. Bus bunching results in more frequent passenger overloads, which necessitates provision of additional service. Such service expansions would not be required if vehicles were more regularly spaced and passenger loads were more evenly distributed [5]. Capital investments in the vehicle fleet are affected because reliability problems are most acute during peak service periods [6].

There has been considerable research on the underlying causes of unreliable service [7], [8]. Bus routes may exhibit poor performance due to operational problems or simply because schedules are poorly written [9]. Primary causes of unreliability have been attributed to route characteristics (e. g., length, the number of signalized intersections, the extent of on-street parking, stop spacing), operating conditions (e. g., traffic volume, service frequency, passenger activity), and vehicle operators (e. g., departure delays, operator-specific behavioural differences). Considerable attention has also been devoted to identifying operations control actions to improve reliability [10], [11]. Examples of control actions include vehicle holding, stop-skipping, leap-frogging and short turning. However, many of the Level of Service (LOS) factors affecting transit use cannot be easily quantified and there is always a problem of generally not having data available [12].

As can be noticed, the literature generally supports the ability of a transit system with high-quality service to attract more users, as well as for poor service to encourage more automobile use [12]. Public opinion has indicated increases in level of service as an important factor.

While much has been learned about the causes of unreliable service and the corrective actions that can be taken, research on this subject has been hampered by the costs of manual data collection [12]. However, recent deployment of Advanced Public Transit System (APTS) technologies, particularly automatic vehicle location (AVL) and automatic passenger counter (APC) systems, has transformed the data environment for transit providers. Comprehensive data on vehicle operations and passenger activity are now being recorded and archived at very low costs. Data availability varies widely among transit agencies, including type, amount, quality, level of aggregation, and frequency of data collection, and often hampers service planning and scheduling [13], [14], [15], [16]. The new data environment is facilitating more extensive and detailed analysis of transit operations, the benefits of which are reflected in service planning, scheduling, dispatching and operations control improvements [16], [17].

2. MEASURES OF SERVICE RELIABILITY

Transit providers have employed a number of service measures. The indicator that is most widely recognized and the one that probably has the greatest intuitive appeal, measures on-time performance [6]. In practice, on-time performance is probably most relevant in situations of infrequent service, where bus riders tend to time their arrivals in relation to the schedule, or in trips involving transfers. Headways, the time interval between buses, are the second reliability indicator. With short headways and riders arriving randomly in relation to the scheduled service, reliability may be better reflected in the ability to maintain headways rather than adhere to the schedule [5]. The third service reliability indicator examines bus run times. Variations in run times reflect the composite effects of disruptions to service associated with traffic, signal timing, on-street parking, passenger activity, and driver behaviour [7]. Our work focused on measuring on-time performance, which requires precise location positioning of the vehicle.

3. STUDY AREA AND DATA COLLECTION

The study area was a part of the bus transit system in the city of Koper. The city is situated in the south-western part of Slovenia, at the northern edge of the Adriatic Sea. With 25,000 inhabitants, the city of Koper is a regional centre of the Slovenian coastal area. The settlement pattern is distinctively longitudinal, stretching along the coast. This makes it difficult to set up an efficient transit service. In addition, rapidly increasing car ownership in the last 10 years has had negative impact on transit use. In the past, there have been different attempts to revitalize the transit public system; one of the latest was the introduction of a small bus transit system. The system runs on fixed routes with a fixed schedule, connecting the old city core with the newer, high-density suburban areas. The data used in this study were collected within four bus routes. The route lengths are between 6.4 and 7.8 km, with 9 to 12 bus stops in each direction. There are two common bus stops with higher passenger demand, and routes cross 4 to 5 signalized intersections. All the routes start near the old city core, passing near by a port, shopping malls, downtown, and enter the high-density suburban area. The scheduled headway differs during the day with a minimum value of 7 minutes during morning and evening peak periods, and increasing to 30 during off-peak periods. The evening headway varies from 30 minutes up to 130 minutes during late evening.

Data were collected between January 1 and February 15, 2005. A GPS based bus positioning system was used coupled with an Automatic Passenger Counter (APC) to record the data at the bus stop level. The GPS receiver recorded the location and the time of arrival each time the bus stopped and opened the doors. When the door opened, the APC unit started to count passengers boarding and alighting; when the doors closed, the data were saved. During the observation period, a sample of 2,996 stops was recorded.

4. RESULTS

Indicators of reliability were observed and recorded at time point level. Usually level of reliability recorded at time point level is noticeably higher than it would be if observed at route destination. This is a result of the tendency for the delay to accumulate over the course of a route [10]. It also reflects the fact that operators are not warned against early arrivals at destinations, while they are admonished for early departures at other time points.

From the data available two indicators were calculated; departure delay (actual departure time minus scheduled departure time) and standardized indicator Headway ratio (100* observed headway/scheduled headway). Summary statistics for on-time performance (Delay at time points) and Headway ratio, for the entire observed period, are reported in Table 1. It can be noticed that the maximum delay did not exceed an absolute value of 7 minutes, with an average value of 1.26 minutes delay.

As Figures 1 and 2 show, there is a regular pattern of on-time performance over the observed period. The distribution of delay is unimodal with the highest peak at a value of 0-minute delay. In practice, the headway ratio value ranging from 70% to 130% can be

Table 1 - Summary statistics

Variable	Mean	StDev	Minimum	Median	Maximum	Skewness	Kurtosis
HR	101.91	3.15	88.33	101.67	123.33	0.67	3.83
Delay	1.26	1.89	-7.00	1.00	7.00	0.02	1.14

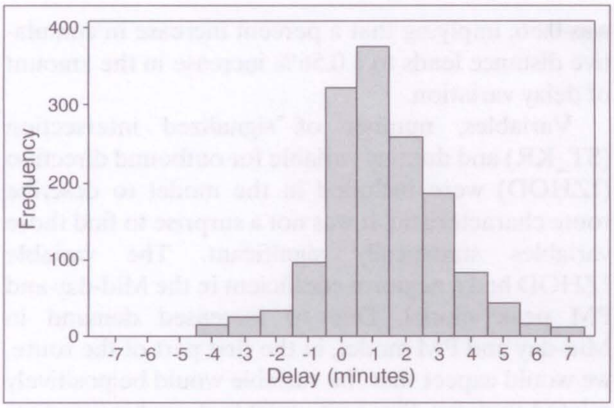

Figure 1 - Distribution of Delay

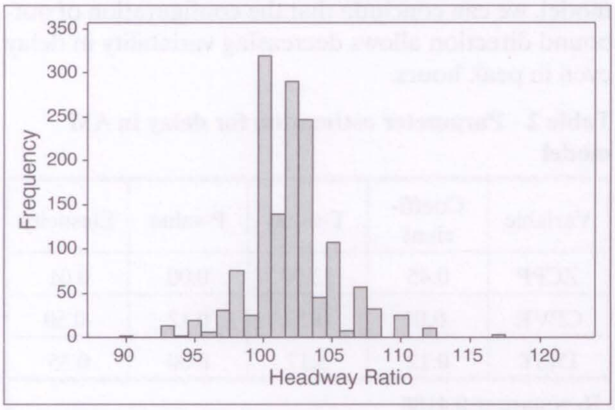

Figure 2 - Distribution of Headway ratio (HR %)

attributed to regular service. Bus bunching, which is represented by headway ratio below 70%, was not present during the observed period.

Additional insight can be gained from delay per hours frequency distributions, which are shown in Figure 3.

It is evident that the shapes of distribution change over time. Overall, it is apparent that the distributions are shifted to the right during the off-peak hours and more symmetric during peak hours. This fact benefits the passengers since they do not perceive early arrival equally to late arrival.

4.1 Statistical analysis of factor affecting on-time performance

An attempt was made to include as many variables as possible in the analysis. Unfortunately, the information on driver's behaviour, number of unscheduled stops with door closed, and on street parking were not collected during the observation period, and consequently were not included in the models. The departure delay at time point was selected as a dependent variable in the models. The independent variables selected to develop the models were the variable that describes passenger activity (A_POT), scheduled headway (CPVR), dummy variables for outbound directions (IZHOD), scheduled distance (DIST), number

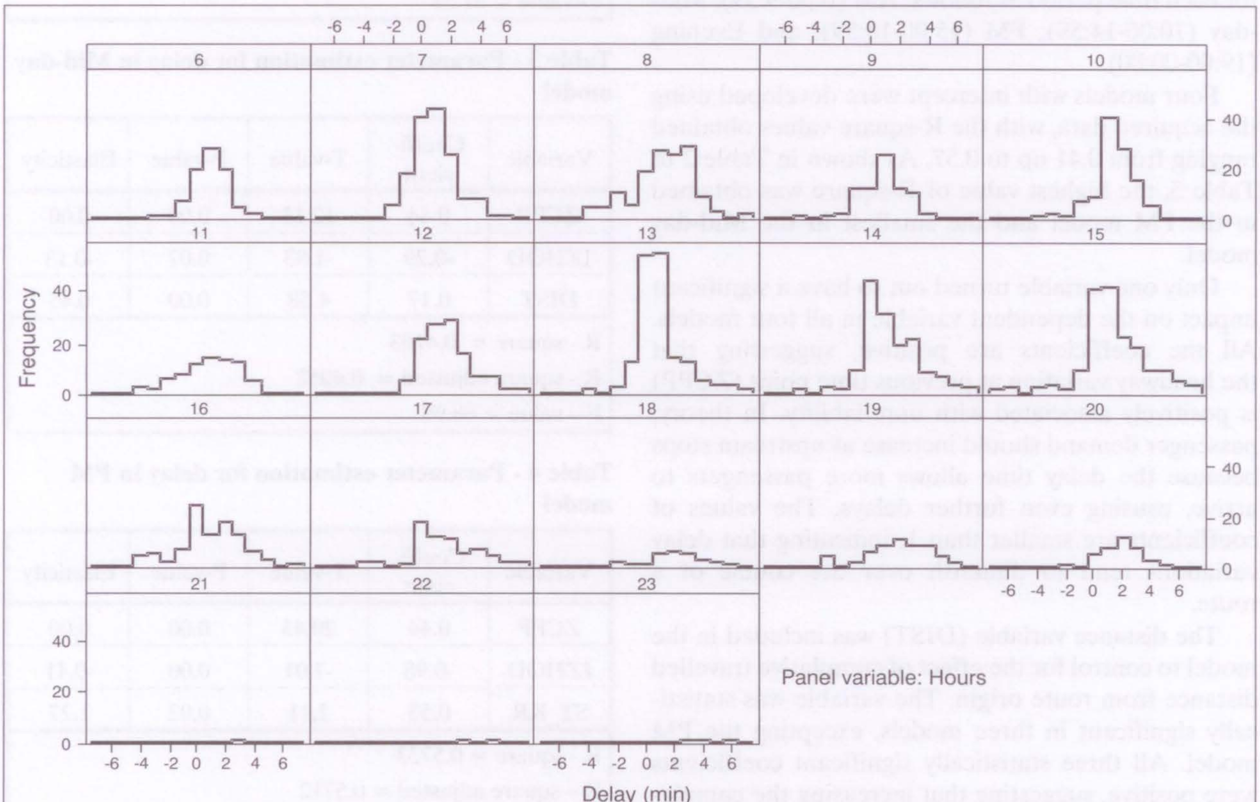

Figure 3 - Distribution of Delay per hours

of signalized intersections (ST_KR), and headway variation at previous time point (ZCPP).

4.1.1 Model estimation

Multiple regression analysis was performed to determine the most significant factors that affect transit service reliability. In MINITAB 14 the best subset and the stepwise (backward and forward) procedure were employed to select independent variables. The statistical correlation matrix between different independent variables indicated a strong multicolinearity between certain variables. Thus, some independent variables causing most multicolinearity problems were removed from further analysis. Variables having significance level values higher than 0.1 were considered insignificant and were not included in the models. A decision as to whether the model was effective was based on the signs (+, -) of the coefficients, R-square value, and analysis of the residuals. The presence of autocorrelation was controlled with Durbin-Watson statistics and multicolinearity was detected by examining the variance inflation (VIF) score. If the VIF factor exceeded the value of 10, the correlation factors between independent variables were examined, and the model was corrected either by eliminating or by joining the variables.

The analysis of numerous regression model results indicated that it was best to develop a separate model for each time period as follows: AM (6:00-9:59); Mid-day (10:00-14:59); PM (15:00-18:59); and Evening (19:00-00:00).

Four models with intercept were developed using the acquired data, with the R-square values obtained ranging from 0.41 up to 0.57. As shown in Table 2 to Table 5, the highest value of R-square was obtained in the PM model and the smallest in the Mid-day model.

Only one variable turned out to have a significant impact on the dependent variable in all four models. All the coefficients are positive, suggesting that the headway variation at previous time point (ZCPP) is positively associated with unreliability. In theory, passenger demand should increase at upstream stops because the delay time allows more passengers to arrive, causing even further delays. The values of coefficients are smaller than 1, indicating that delay variations tend to diminish over the course of a route.

The distance variable (DIST) was included in the model to control for the effect of cumulative travelled distance from route origin. The variable was statistically significant in three models, excepting the PM model. All three statistically significant coefficients were positive, suggesting that increasing the cumulative distance increases the variability in delay. The elasticity for cumulative distance in the evening model was 0.56, implying that a percent increase in cumulative distance leads to a 0.56% increase in the amount of delay variation.

Variables, number of signalized intersection (ST_KR) and dummy variable for outbound direction (IZHOD) were included in the model to describe route characteristic. It was not a surprise to find those variables statistically significant. The variable IZHOD had a negative coefficient in the Mid-day and PM peak model. Due to increased demand in Mid-day and PM model, in the first part of the route, we would expect that the variable would be positively related to delay. Since no variable describing passenger activities were statistically significant in any model, we can conclude that the configuration of outbound direction allows decreasing variability in delay even in peak hours.

Table 2 - Parameter estimation for delay in AM model

Variable	Coefficient	T-value	P-value	Elasticity
ZCPP	0.45	13.90	0.00	0.01
CPVR	-0.01	-1.57	0.12	-0.50
DIST	0.12	3.17	0.00	0.35
R- square = 0.4186 R- square adjusted = 0.4138 F- value = 87.38				

Table 3 - Parameter estimation for delay in Mid-day model

Variable	Coefficient	T-value	P-value	Elasticity
ZCPP	0.44	12.13	0.00	0.00
IZHOD	-0.29	-1.83	0.07	-0.13
DIST	0.17	4.58	0.00	0.45
R - square = 0.4103 R - square adjusted = 0.4052 F – value = 68.99				

Table 4 - Parameter estimation for delay in PM model

Variable	Coefficient	T-value	P-value	Elasticity
ZCPP	0.44	20.43	0.00	0.00
IZHOD	-0.98	-7.01	0.00	-0.41
ST_KR	0.53	2.41	0.02	1.27
R - square = 0.5733 R – square adjusted = 0.5712 F – value = 227.2				

Table 5 - Parameter estimation for delay in Evening model

Variable	Coefficient	T-value	P-value	Elasticity
ZCPP	0.3493	6.153	0	0.0229
DIST	0.3317	5.322	0	0.5602
A_POT	0.1441	2.455	0.016	0.1164
R-square = 0.4610				
R-square adjusted = 0.4463				
F - value = 31.36				

Another interesting observation that can be made from the results is that variables describing passenger activities were significant only in one model. The reason passenger activities did not prove significant in the model is largely due to the fact that the major activity occurs at route origin. Because transit centres often represent layover points prior to the start of trips, passengers typically board buses a few minutes prior to departure. The fact that passengers are already on board buses at the time of departure has no bearing on the bus performance.

The significance of bus performance variables is different between models. Scheduled headway (CPVR) is statistically significant only in the AM model. The sign of coefficient shows that scheduled headway has a negative impact on the amount of delay variation. The size of coefficient indicates that a one-minute increase in scheduled headway leads to a 0.01-minute decrease in delay variation. Since the value of the coefficient is very small, we can conclude that the variable CPVR has no notable effect on service reliability.

5. CONCLUSION

This article has sought to investigate the level of service reliability and how specific factors influence service reliability. The collected data showed that the service is fairly regular, with no evident problems in reliability. The analysis also developed a statistical model for estimating the effect of different variables on service reliability. Estimation results indicated that delay variation at previous time point and cumulative distance are primary causes of service unreliability. In contradiction to other studies, the results recognized that the relationship between passenger activities and service reliability is subject to simultaneity, with passenger loads positively affected by delay and delay positively affected by passenger activity [17]; our study did not find passenger demand to be a cause of service unreliability.

The consistency of the results and the models would certainly improve if more data were available allowing more variables to be included in the models. There were no data available on bus drivers; hence, no information on driver behaviour was included in the models. Also, other important information such as roadside parking, unscheduled stops with door closed, link speed, and non-recurring event were not collected. Although the available data were not complete, the results presented here appear to be reasonably accurate.

Dr. **DEJAN PALISKA**
E-mail: dejan.paliska@fpp.uni-lj.si
Dr. **JURIJ KOLENC**
E-mail: jurij.kolenc@fpp.uni-lj.si
Univerza v Ljubljani, Fakulteta za pomorstvo in promet
Pot pomorščakov 4, 6320 Portorož, Republika Slovenija

POVZETEK

ANALIZA ZANESLJIVOTI STORITVE Z UPORABO PODATKOV PRIDOBLJENIH Z AVL SISTEMOM: PRIMER AVTOBUSNEGA PREVOZNIKA V MESTU KOPER

V članku so predstavljeni rezultati raziskave o zanesljivosti avtobusnega sistema na primeru mesta Koper. Zajeti vzorčni podatki so obdelani z uveljavljenimi statističnimi metodami in uvrščeni v štiri različne modele. Za analizo statistično značilnih spremenljivk v modelih zanesljivosti in njihovih koeficientov, je bila uporabljena metoda OLS. Rezultati kažejo, da prevoznik nima posebnih težav pri zagotavljanju zanesljive storitve in da sta pomembni predvsem dve spremenljivki; kumulativna prevožena pot od začetne avtobusne postaje in zamuda na predhodnem avtobusnem postajališču. Spoznanja o delovanju sistema je moč uporabiti pri napovedovanju zamud oz. nezanesljivosti sistema v različnih scenarijih.

KLJUČNE BESEDE

javni potniški avtobusni prevoz, AVL, zanesljivost storitve, statistični modeli

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