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# Statistical Analysis of Bus Service Failure at Bus Stops with Dedicated Lanes

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# 전용차로가 있는 버스정류장에서의 버스정류장 서비스 실패 상황에 관한 통계분석

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**Abstract** Bus Rapid Transit (BRT) is a system that can enhance the bus operating speed and punctuality on arterial roadways by decreasing or eliminating the many sources of delay that slow the bus operating speed. Because the dedicated lane does not run continuously because of at-grade intersections, buses often experience similar waiting periods at signalized intersections as conventional automobiles. They frequently face queueing formation at bus stops because of low processing capacity. Queuing delays are caused by bus service failure, in which the bus reaches the bus stop only to discover that all loading areas are already occupied. This study examined the rate and the length of bus service failure to gain insights into potential improvement options to reduce delays at bus stops. An exploratory analysis with descriptive statistics was conducted to examine the bus failure rate and duration using CCTV video footage from two bus stops in Goyang, South Korea. A multiple linear regression model was constructed to capture the statistical relationship between the failure rate as a dependent variable and passing lane existence, and time and bus arrival count as the candidate independent variables. The results showed that a bus stop without a passing lane exhibits higher failure rates and longer failure duration. Only the bus arrival count was significant at the 95% confidence level in the regression model. The findings are expected to be preliminary insights for future work aiming at minimizing delays at bus stops.

**요 약** BRT(Bus Rapid Transit)는 버스 운행 속도를 느리게 하는 여러가지 지체 원인을 줄이거나 제거함으로써 간선도로에서 버스 통행 속도와 정시성을 향상시킬 수 있는 시스템이다. 전용차로가 평면 교차로를 통과함으로 인해 버스는 기존 승용차와 유사한 신호교차로 대기시간을 경험하고, 정류장에서 승객 처리능력이 낮은 경우 버스정류장에서 정체가 되는 경우도 빈번하다. 정류장에서의 대기 지체는 버스가 버스 정류장에 도착하여 모든 버스 승차면이 이미 점유되어 있을 때 버스 서비스 실패로 인해 발생한다. 이 연구의 주요 목적은 버스 정류장 지체를 줄이기 위한 잠재적 개선 방안에 대한 통찰력을 얻기 위해 버스 서비스 실패 비율과 서비스 실패 지속시간을 조사하고 분석하는 것 이다. 고양시에 있는 두 개의 버스 정류장들에서의 버스 거동을  CCTV 영상을 이용하여 조사하고 버스 정류장 서비스 실패와 그에 따른 대기시간을 수집하여 통계 분석을 수행하였다. 서비스 실패율을 종속변수로 하고 추월차로 유무, 시간, 버스도착횟수를 독립변수로 하여 통계적 관계를 파악하기 위해 다중선형회귀모형을 구성하였다. 결과는 추월차로가 없는 버스 정류장이 더 높은 서비스 실패율과 더 긴 서비스 실패 지속 시간을 나타냄을 보여주었다. 회귀모형에서는 95% 신뢰수준에서 버스 도착횟수만 유의한 것으로 나타났으며,  이번 연구 결과는 버스 정류장에서의 지체를 최소화하기 위한 향후 연구에 방향성을 제시할 것으로 기대한다.

**Keywords :** BRT, Service Failure, Transit Capacity, Queueing Delay, Bus Operation

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## 1. Introduction

Various factors contribute to bus delays and increasing travel time between stations, thus hindering bus operation efficiency. At a bus stop in particular, delay time arises from several components including, but not limited to, queuing delays, delays due to stopping vehicles, boarding, and alighting delays, re-entry delays, and signal delays [1,2]. These delays are observable in street-side bus stop designs such as curbside stops and bus bays with mixed traffic. Delays caused by vehicle stoppage and re-entry were reduced with the installation of the implementation of exclusive bus lanes, a major component of Bus Rapid Transit (BRT) systems. However, a bus operating along dedicated lanes exhibits similar waiting period at signalized intersections as conventional automobiles, and it frequently faces queueing formation due to low station processing capacity. Queuing delays are caused mainly by bus service failure. According to Transit Capacity and Quality of Service Manual (TCQSM), bus stop failure is defined as the condition where the bus arrives at a bus stop only to discover that all loading areas are already occupied [3]. This is common when numerous buses arrive at the bus stop at the same time, especially during peak hours. The incoming bus must wait until the front bus has finished serving and has left the station. That is why the Korean government intends to construct Super BRT (S-BRT), which will be focused on timeliness and high speeds to address the issue with BRT operation. This entails the development of a cutting-edge BRT system that brings some benefits of urban rail systems to bus transportation. S-BRT is required to maintain punctuality and to increase the average speed to meet the operational objectives. This may be achieved by shortening the time bus spends halted at the bus stops and junctions. The primary purpose of this research is to examine the rate and the length of bus service failure to get insight into potential improvement options to reduce delays at bus stops.

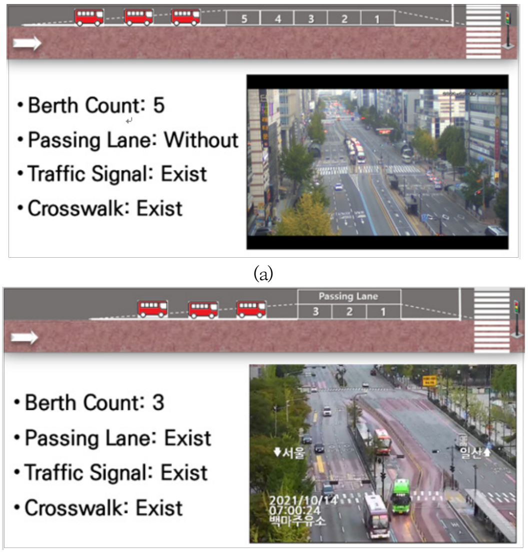
## 2. Literature review

Transportation services will suffer if traffic flow is disturbed [4]. Many transits operating parameters, including dwell time [5,6], headway [7,8], capacity [9,10], queue length [11,12], and bunching characteristics [13,14], are explored in literature to assess the impact of bus stop failures. The proportion of buses that arrive at stops and discover that all berths have been taken, as measured by the failure rate, can be used to calculate how long passengers must wait for a bus. Wang et al. suggested a diffusion approximation strategy after investigating the association between failure rate and four distinct types of transit stay and arrival characteristics [15]. The failure rate, as one of the intended level indices of transit operation, might measure the change in bus berth capacity and LOS [16]. Failure probability and dwell time variability impact bus stop capacity, which can construct a function of bus queue length [16]. According to standard normal distribution fitting, a parameter "Z" is developed to account for the volatility in bus dwell time in bus loading zones, and it is recommended to apply the design failure rates for urban and rural sites when assessing bus berth capacity [1]. At different failure rate levels, a normalized capacity and incremental capacity change (for multi-berth stops) have been proposed [9]. In addition, failure rate analysis is a poor proxy and proposes picking the average waiting time for assessing the bus berth LOS is stated completely [17]. Moreover, bus service failure rate and duration have been examined in a recent study [18]. Other studies reported the importance of considering failure rate to develop bus operating speed calculation methodology [19,20]. One major limitation of the existing literature, most bus failure analysis studies rely on simulation results and do not capture the real situation based on high resolution field data. Also, there is no previous study that examines this phenomena in Korean context.

In this study, we explore bus failure rate and bus failure duration based on data collected from video cameras.

## 3. Data Collection and Methods

Two bus stops were chosen for data collection to evaluate the bus failure rate in Ilsan, South Korea. The first stop, Madu Station, features five loading areas with no passing lane. The second station is Beakmajuyuso, which has three loading areas and a passing lane. CCTV video records were obtained from the Goyang City traffic center during the peak (7 AM to 9 AM) and non-peak (2 PM to 4 PM) hours on October 14th, 2021. A total of eight hours of footage was acquired. Fig. 1 depicts the basic information of investigated bus stops including screen-shots from CCTV footage.




(a)

(b)

Fig. 1. Data collection site illustration (a) Madu Station (b) Beakmajuyuso Station

The obtained videos were analyzed manually by to extract numerical data. When an arriving bus enters the bus stop platform and makes its first complete stop, regardless of whether it is inside the berth or in a bus queue, the time stamp is recorded, and it is called Station Arrival Time (SAT). When the same bus makes a complete stop inside a berth to commence service, another time stamp, Berth Stop Time (BST), is recorded. The failure duration is the period between BST and SAT. One should note that FD might be zero if SAT equals BST, indicating that the approaching bus makes its first complete stop within a berth, which mean that no service failure has occurred. Also, the bus count per 15 minutes is counted for the corresponding time. a sample of the extracted numerical data is shown in Table 1.

Table 1. A sample of the extracted data

| Station Arrival time | Berth Stop time | Failure Occurrence | Bus count per 15 min | Failure duration (in seconds) |
|---|---|---|---|---|
| 7:13:33 | 7:13:33 | no | 46 | 0 |
| 7:13:40 | 7:13:40 | no | 46 | 0 |
| 7:13:44 | 7:13:44 | no | 46 | 0 |
| 7:13:50 | 7:13:50 | no | 46 | 0 |
| 7:13:54 | 7:14:20 | yes | 46 | 26 |
| 7:13:56 | 7:14:23 | yes | 46 | 27 |
| 7:13:59 | 7:14:28 | yes | 46 | 29 |
| 7:14:02 | 7:14:49 | yes | 46 | 47 |
| 7:14:07 | 7:14:53 | yes | 46 | 46 |

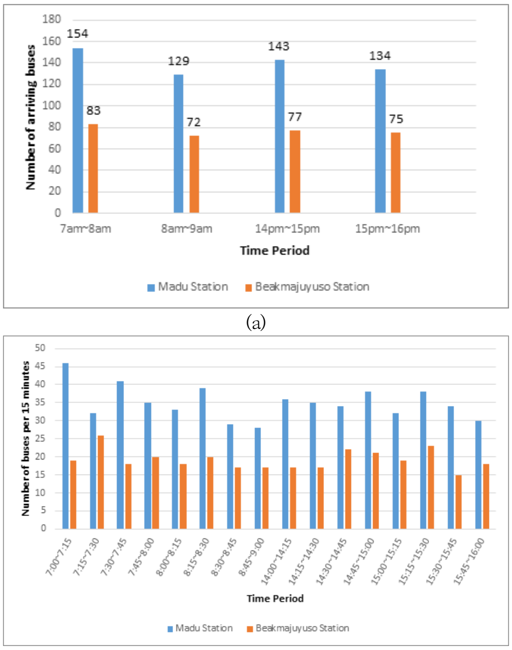
Analysis of the obtained data will be as follow. First, we conduct an exploratory analysis of variables observed from the collected data. These variables are bus arrival count and failure duration, cumulative failure duration, and average failure duration per bus. These variables will be compared between each station and based on time intervals that include hourly based data and 15 minutes based data. After that, statistical analysis was conducted to study the failure rate variable including distribution fitting and regression analysis. The dataset that will be used in this step includes a set of candidate independent variables including station (with and without passing lane), time period (peak and non-peak), and bus arrival count. A failure rate variable, the dependent variable, represents the failure rate during a 15-minutes interval. The final data set comprises 32 records. Firstly, we consider descriptive measures to describe the underlying variables. Then, univariate distribution fitting is applied to model the failure rate variable. In order to assess and compare the goodness of fit of the underline distribution, we consider the Anderson-Darling (AD) test. The null hypothesis of the AD test is that the underline data comes from a specified distribution. We accept the null hypothesis when the corresponding p-value is greater than 0.05 else wise we reject the null hypothesis. Furthermore, the parameters of the distribution discussed above are estimated by Maximum Likelihood Estimation (MLE) method. Finally, as we are interested to study the failure rate and find the significant predictors of the failure rate, multiple linear regression is used to model the statistical relationship between the dependent variable, namely failure rate, and candidate independent variables, namely, station, time period and bus arrival count. Coefficients with corresponding p-values less than 0.05 are included in the final regression equation. For this purpose, the statistical analysis software Minitab-18 was used.

## 4. Exploratory Analysis

In this section, an exploratory analysis is conducted for the extracted variables such as bus arrival count and failure duration, cumulative failure duration and average failure duration per bus. A separate section will be dedicated for the statistical analysis of failure rate later in this study.

### 4.1 Bus arrival count

Manual video assessment and data extraction yielded 867 data records. During the survey periods, each record represents an individual bus arriving at the relevant bus stop. Fig. 2 depicts the number of bus arrivals. For both periods, Madu station has a greater bus arrival count. The distinction might be explained by the fact that many local buses that stop at Madu station do not carry on to Beakmajuyuso station. Most buses that stop at Beakmajuyuso station, leave Ilsan City and head toward Seoul. The maximum hourly count hits 154 incoming buses in Madu Station between 7AM and 8 AM. The number of buses arriving at Beakmajuyuso station swings between 72 and 83. It is worth mentioning that there is no significant difference between peak time and non-peak time.




(a)

(b)

Fig. 2. Bus arrival count for each Station
(a) by hour (b) by 15-minutes

### 4.2 Failure duration

Similarly, failure duration data was analyzed.

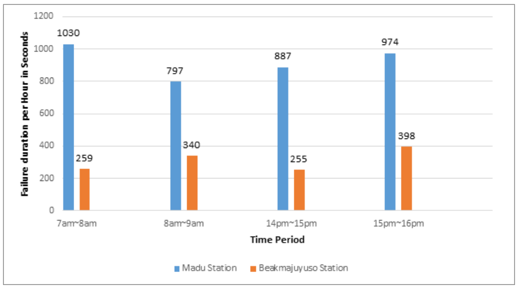
In this study, failure duration is defined as the time duration that an arriving bus has to spend waiting to enter berth. Failure duration represents by the time duration between first bus stopping time and berth stopping time. Failure duration is equal to zero, meaning that the arriving bus makes its first complete stop. Descriptive statistics of failure duration for both stations is shown in Table 2. It should be noted that only data considered in this analysis is from buses with occurring failure. The average failure duration values at Madu Station are 28.55 seconds during Peak time and 26.21 seconds for non peak time. Beakmajuyuso station had lower average failure duration at 27.23 seconds during peak time and 22.52 during non peak time.

## 4.3 Cumulative bus failure duration

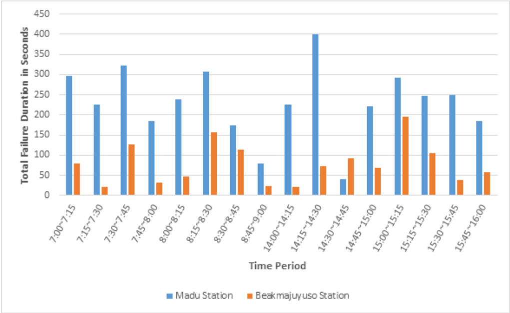
Cumulative bus failure duration is the total waiting time for all buses arriving within a certain period. This metric may be used to assess the performance of a bus stop (see Fig. 3 for results). Madu Station has a greater average total failure duration, with 17 minutes per hour lost while waiting for berth clearance and commencing service during morning peak time. Beakmajuyuso Station, on the other hand, has a lower total failure length for both periods, ranging between 4.25 and 6.63 minutes per hour.

Table 2. Descriptive statistics of failure duration (failed bus only)

| | Madu Station | | Beakmajuyuso Station | |
|---|---|---|---|---|
| | AM Peak | PM Non-Peak | AM Peak | PM Non-Peak |
| Mean | 28.55 | 26.21 | 27.23 | 22.52 |
| Median | 26 | 28 | 27 | 23 |
| Standard Deviation | 8.82 | 10.78 | 10.29 | 7.47 |
| Minimum | 11 | 3 | 2 | 10 |
| Maximum | 59 | 45 | 42 | 35 |
| Sum | 1827 | 1861 | 599 | 653 |

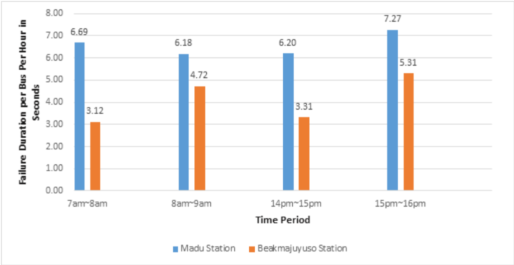



(a)

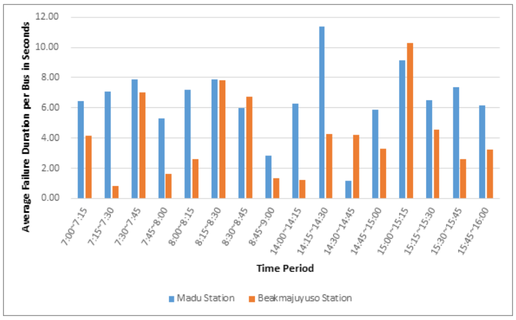



(b)

Fig. 3. Cumulative failure duration for each station (a) by hour (b) by 15-minutes




(a)




(b)

Fig. 4. Average failure duration per bus for each station (a) by hour (b) by 15-minutes

### 4.4 Average failure duration per bus

The average failure duration per bus was utilized in the analysis to further investigate bus failure duration. To calculate this value, divide the total failure length reported over a particular period by the total number of buses arriving during that period, regardless of whether a failure occurred. This value represents the total amount of time buses must wait in line before entering an available berth and beginning to serve passengers. Fig. 4 displays the average failure time per bus at each stop. Madu Station has an average bus waiting time of 6.43 seconds per bus during morning peak time and 6.73 seconds per bus during afternoon non-peak time. On the other hand, Beakmajuyuso Station has an average waiting time of 3.92 seconds per bus during afternoon/non-peak time. The low average waiting time per bus compared to total failure duration time is due to the high number of zeros related to buses not experiencing failure.

## 5. Statistical Analysis of failure rate

The failure rate was computed using the data extracted from video footage. In this study, the failure rate is defined as the proportion of buses that must make a complete stop outside loading areas, forcing them to wait in line when they arrive at the bus stop because berths are already taken by other vehicles. The failure rate is calculated by dividing the number of buses that fail to start service upon arrival during a given time interval by the total number of buses arriving during that period. Fig. 5 depicts the failure rate values for each station across various periods. Madu Station has an average hourly failure rate of 30%, with values ranging between 26% and 32%. The average hourly failure rate for Beakmajuyuso station is 16%, with values ranging from 13% to 21%. In terms of the 15-minute failure rate, it was discovered that both stations had identical failures between 15:00 and 15:15. Furthermore, the only time that the failure rate at Beakmajuyuso station exceeded that of Madu station was between 14:30 and 14:45. Similar to bus arrival count results, there is no significant difference observed between peak time and non-peak periods for both stations.

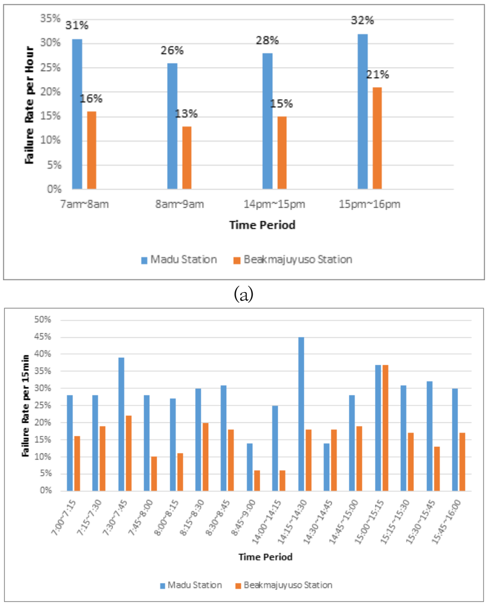
We further report the results of the empirical analysis of bus failure rate. Based on visual assessment of the failure rate histogram shown in Fig. 6, two candidate theoretical distributions were tested for the best fit, namely Normal and Weibull distributions. Table 3 shows the results of goodness of fit as well as the parameter estimation for underline distributions using MLE. The p-value of Anderson Darling test for the Normal and Weibull distributions are 0.40, and 0.25, hence both of the distribution can be used to model the underline data. Therefore, on the basis of the AD test we claim that Normal and Weibull distribution are equally suitable to model the bus failure rate data with Normal distribution being slightly superior based on the higher p-value. The results of the regression analysis are shown in Table 4. Two categorical variables and one continuous variable are included in the regression model building process. The Minitab results show only one variable is significant with p-value less than 0.05 which is “Arrival Count”. Variables “Station” and “Time” have p-values of 0.47 and 0.29 respectively. In the final model, the estimated intercept is 0.0305 and the estimated coefficient is 0.00734 indicating that when the arrival count is increased by one unit, the failure rate may increase by 0.00734. The R-square value is 0.44 and the adjusted R-square value is 0.42 indicating that 42% variation in the failure rate is explained by the underline model containing bus arrival count as a predictor. Therefore, the final regression model is given by Eq. (1):

$$FR = 0.0305 + 0.00734\,Arrival\_Count \qquad (1)$$

Where, FR denotes the bus failure rate per 15-minutes time period and Arrival_Count indicates the number of buses arriving during the same time period. The results of regression analysis suggest that bus arrival count has a great influence on the failure rate. These findings are expected previous studies have shown that arrival rate is among the actors that directly affect queue formation and increase service delays at bus stops [15]. Time period was found to have no significant influence on the failure rate. This finding contradicts a previous study where researchers concluded that peak times and non-peak times have a large difference in the observed failure rates [18]. This may be explained by the fact that no significant difference was observed in bus arrival count between peak and non-peak time.

Table 3. Goodness of fit test and Parameter estimation

| Distribution | AD statistic | p-value | Parameter Estimation | | |
|---|---|---|---|---|---|
| | | | Location | Shape | Scale |
| Normal | 0.372 | 0.40 | 0.229 | - | 0.097 |
| Weibull | 0.326 | 〉0.25 | - | 2.590 | 0.259 |



(a)
(b)
Fig. 5. Failure rate for each station (a) by hour (b) by 15-minutes

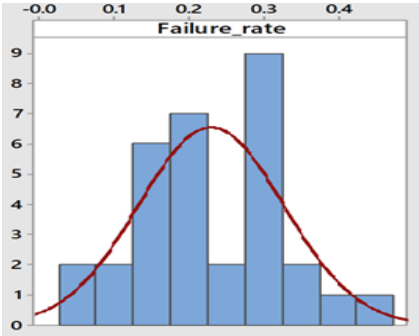


Fig. 6. Failure rate histogram

As for passing lane, a possible explanation for the non-significance of the variable may be attributed the sequential aspect of bus operation within the bus stop. Even though a bus that completes boarding and alighting service is allowed to the passing lane, not all berths are accessible by buses. In other words, only the last berth should be empty to allow the first bus in queue to enter it. For example, in case of Beakmajuyuso station (see Fig. 1(b)), suppose all three berths are occupied by buses at a given time and there is a queue of buses waiting enter loading areas. If the bus in berth number 2 completes service and departs using passing lane, the first bus in queue will not be able to replace it. This is only possible when berth 3 is empty. This issue will be further addressed in future work.

Table 4. Results of multiple linear regression

| | Coefficient | p-value |
|---|---|---|
| Constant | 0.0305 | - |
| Arrival_count | 0.00734 | 0.000 |
| Station (with passing lane=1) | 0.0451 | 0.472 |
| Time (non-peak=1) | -0.0298 | 0.298 |
| R-square | 0.44 | |
| Adjusted R-square | 0.42 | |

## 6. Conclusion

Bus service failure is a primary element that contributes to increasing delays at bus stops, thus reducing the efficiency of the bus networks. In this study we investigated the features of bus failure rate and bus failure duration using CCTV data from two bus stops in Goyang, South Korea. The failure rate was found to be highest at the Madu station bus stop, which had the highest number of bus arrivals. In comparison, the figure at the Beakmajuyuso Station bus stop is only 16 percent. The average bus failure duration did not differ significantly between the two stops. However, during the morning peak hour, buses might spend up to 17 minutes waiting in line at the Madu Station bus stop. As per the findings, bus service failure should be considerably reduced to minimize overall time spent at bus stops. Additionally, a regression analysis was conducted using multiple linear regression to investigate the potential effect of several independent variables such as time period, passing lane existence and bus arrival count on the dependent variable bus service failure rate. Maximum likelihood estimation method was employed to estimate the coefficients and the final model R-square was found to be 0.44 and the adjusted R-square value was 0.42. Only bus arrival count was found to be significant at 95% confidence level.

The main limitations of this study are the sample size and the minimal number of stations considered. During data collection, available CCTV cameras along Ilsan route were examined carefully to select bus stops to be considered for our study. Only two CCTV cameras were identified to have a clear range that allows to capture the data required for this study with a possibility to simultaneously record the exact “station arrival time”, “berth stop time” and “departure time” of all buses. Another limitation is that other variables that could potentially affect the bus failure rate were not considered in this study.

Future work will focus on collecting additional data to corroborate the findings. A further research will be conducted to consider other possible factors associated with high service failure rate and duration, such as the influence of signal timing, crosswalk usage, number of bus stops, and the impact of the presence of an overpassing lane. Moreover, bus service failure phenomenon will be further studied using traffic microscopic simulation tools.

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