Bus Bunching Modelling and Control:  
A Passenger-oriented Approach

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Abstract
Introduction
Bus reliability is one of the crucial elements that describe the performance of the bus system operation. Due to the unreliable transit environment as well as the flexible internal operation, bus irregularity increasingly becomes an issue, especially in big cities with a massive demand.

The uncertain bus operation lead to an imbalance of demand and supplement which influences the efficiency and effectiveness of this transit. This kind of unreliability enables our bus becomes less attractive comparing with other public transportation such as metro and train. Those well-timetable-based mode have the operational advantage of being separable from the other traffic and have a less likelihood of being interrupted by external influence factors such as traffic lights or road constructions, which seems to be more reliable for the passenger. Also, due to the reliable operation, the real-time information provided for passengers is more trustworthy and the passenger arriving pattern are more similar to the uniform pattern, which is proved can increase the level of service reliability. On the other hand, the part of the travel demand that should be satisfied by bus obliged to be reallocated to other transit mode. The decreases of the efficiency and comfortability because of this extra demand would even compel those affordable people to travel by private vehicles which may increase the road pressure. Therefore, it is essential to improve the reliability of the bus service.

One of the measurement of the bus unreliability is the level and extent of bus bunching. If a bus arrives at a stop irregular or unsuccessfully follows its scheduled timetable, the expected demand cannot be satisfied in time and the headway fail to be stable. If the headway is more considerable than the planned result from a delay,
more passenger would be waiting at the stop and this extra number of passenger would increase the boarding time which magnify the delay. Similarly, less number of passenger would further decrease the headway between two buses because of the less dwell time. The change of the headway would yet lead to a phenomenon named bus bunching --several buses arrive at the same station at the same time, which is a kind of extreme less headway situation.

Literature review
Since the improvement of the urbanisation, traffic problem increasingly impacts our daily life. Welding has been start the study about public transport reliability very early since 1957 and he pointed out that the reliability should be definite based on the difference between real operational time and the posted scheduled time. In his research, bus speed control as well as the utilization of layover time could increase the operational reliability. Followed by Polus (1978) who suggested to focus on bus travel time because majority of the time spent on the trip of a passenger was on-road time instead of waiting time or transfer time. He found that the bus reliability might depend on several factors regarding road, traffic, bus, bus driver and passenger themselves such as passenger behaviour and passenger demand. And all above influence factors could be summarised into bus travel time. Thus, Polus suggested that the bus reliability should be the dependability of bus travel time and the bus speed. With the improvement of the study on transportation, attention was transferred to people and there was more concentration on passenger’s feeling.

The research undertook by Silcock in 1981 tended to include the passenger experience as one of the metric of bus reliability. Silcock considered the waiting time and proposed the punctuality ratio based on waiting time and the scheduled bus arrival time to describe the reliability of bus service. Waiting time was never neglected, additionally, more methods were appeared aiming to reduce the passenger waiting time which was proved to have the ability to increase the operational reliability as a result (Guenthner and Sinha, 1983; Turner and White, 1990).

Numbers of the studies were generally focus on the big picture of the whole bus route’s performance, while Nakanishi (1997) started to study based on specific stations by comparing the consistency of scheduled arriving time as well as the real bus arriving time for each stations and suggested that if the planned headway is larger than 10 minutes, there would be a less possibility of bus bunching occur.

In the 21 century, the data about bus operation performance collected with the help of GPS and the sensors was more accuracy and timely which improved the study of bus reliability. Bullock (2005) measured the different between scheduled time and the real travel uploaded from GPS which could determine the performance of this bus system in a more trustable way. According to the actual time information, more efficient study on reliability improvement are proposed, such as the research
provided by Liu and Sinha in 2007. Liu and Sinha found that the traffic congestion influenced the bus reliability very much which would lead to a severe traveling delay. They also illustrated that the bus operation behaviour should be detected by the following three main parts: travel time, headway and passenger waiting time.

Among the above three elements, travel time takes the most significant percentage and influences the total travel time most. In the 21 century, majority of studies were try to balance the travel time and dwell or delay time. Reducing the distance between two stations seem can reduce the travel time and satisfy the demand timely (Daganzo and Pilachowsi, 2011). Frequently service could also decrease the impact of unexpected extra passenger and balanced the relationship between demand and supply.

Due to the boom of traffic, the interruption of other vehicles was considered as a significant factor, especially in the area with limited space. The public traffic priority concept was suggested and one of the strategy named BRT (bus rapid transit) was introduced to form an uninterrupted travel environment for bus only. Similar to the train or metro, the bus is separated from other road vehicles with the isolated lane and priority signal system. Deng and Nelson (2013) then examined the performance of this bus service system and demonstrated that the timetable maintenance turned to be the most determined dimension. Thus, regardless of the interruption of the external factors, the bus travel speed seems more crucial.

More latest study involved new technologies and techniques such as AFC (Automatic Fare Collection). Yu (2016) study the bus reliability based on individual passenger travel behaviour based on the information recorded by smart card and A Least Squares Support Vector Machine regression is established aiming to detect the bus bunching. In addition, they also try to predict bus bunching by inputting the expected road information in their Least Squares Support Vector Machine regression model.

Methodology and Result
In order to propose the solutions to this unstable service problem, a computational simulation based on a mathematical model is built with MATLAB aiming to figure out the internal influence factors. The MATLAB based modelling is built to illustrate the discrete choice model which describes the bus service accessing accurately.

The proposed model describes the bus operational system according to the real-world bus route lines in Sydney, Australia. There are 10 number of bus numbers are covered in this research because they all meet the following three selected criteria: all pass the CBD area of inner Sydney where there is a tremendous demand generated within a limited space; all have large number of bus bunching according
to a pre-analysis of the real field data; all share a same planned timetable with day
time of the weekday yet different from their timeline for night and weekend.

In this research, passenger demand is created by random number based on
exponential distribution, which tend to be used in expressing the specific time
interval event in the Poisson process. While the passenger boarding and alighting
pattern is built based on triangular distribution with a boundary time depending on
the previous studies. The stochastic choice making is proposed to select which
station is the passenger’s destination based on different attraction.

In terms of the output of the model, total travel time and standard deviation of
waiting time can be computed in order to describe the passenger feeling about the
system since passenger value time very much and twice more concentrate the
waiting time than their travel time (Quarmby, 1997).

According to the outcome of the modelling simulation, bus reliability is more
sensitive to the travel speed. If the standard deviation of the bus travel speed is more
substantial, the possibility of bus bunching occur is relatively larger and more
waiting time should be experienced by passenger which will lead to a higher total
travel time in the end.

With the experience of the previous research, the control strategies are proposed
related to the capacity of the bus as well as the departure timetable. By change the
capacity of the bus, the number of bus bunching decreased dramatically, especially
during peak hour when there is larger demand that need to be satisfied. The
reduction of the accumulated passenger in time help balance the supply and demand.

Concerning the timetable, some extra supplementary buses for serving specific
stations only could help reduce the total travel time of the passenger for the whole
system. In the model, the bus routes share same stations in CBD area, which support
satisfy the demand timely. While in the outside area, there are only one bus passing
the specific stations and large accumulated demand cannot be satisfied if the
headway of the bus is fail to determined well. Therefore, a shorter headway time
result from more bus service supply for those station would effectively solve the
problem and avoid increase the road pressure in squeezed CBD area.

**Keywords:** Public transport reliability · Bus bunching · Bus timetable and capacity
control · Headway control · Discrete event modelling and simulation