

# Seoul Metropolitan Intercity Bus System Design

: Using queueing analysis.

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## Problem Statement

### Seoul and satellite cities

Seoul is more than the capital city of South Korea. It is the mecca of everything people expect from urban life. It was the country's strategic choice to concentrate investment in its capital city when financial resources were limited. Now, the city's expansion and sprawl seem unstoppable, and South Korea struggles to develop self-sufficient cities in the metropolitan area. While satellite cities around Seoul were developed in multiple phases, the majority of their residents still need to commute to Seoul for their daily needs.

As the population in these satellite cities grows, the need for efficient transportation to Seoul becomes apparent. Intercity express bus routes have emerged as a vital link, offering residents in the region the convenience of long-distance travel without requiring massive infrastructure investment. However, a challenge arises as the routes of Intercity buses use the same segments as already popular routes through downtown. This leads to congestion on the bus lanes, particularly during rush hours, resulting in a phenomenon known as the 'Bus Train'—a long line of buses on the bus lane waiting for their turn to dock at the stop.

While the fundamental solution to this problem lies in decentralizing efforts, such as relocating jobs away from Seoul, an interim measure is necessary to improve the day-to-day commutes of many citizens.



Fig 1. Buses on the bus lane during rush hour in Gangnam, Seoul (Channel A News (Korea), 2023, 1:57)

## Congested area

The central lane of Gangnam Boulevard, having already accommodated numerous bus routes, has evolved into a hub for various types of buses, including intercity rapid buses. Typically, intercity buses utilize the stop as their turnaround points. The western section of Gangnam Boulevard, spanning from Sinnonhyeon Station to Yangjae Station, experiences significant congestion as various types of buses maneuver to cater to passengers from the southern part of the Seoul metropolitan area.

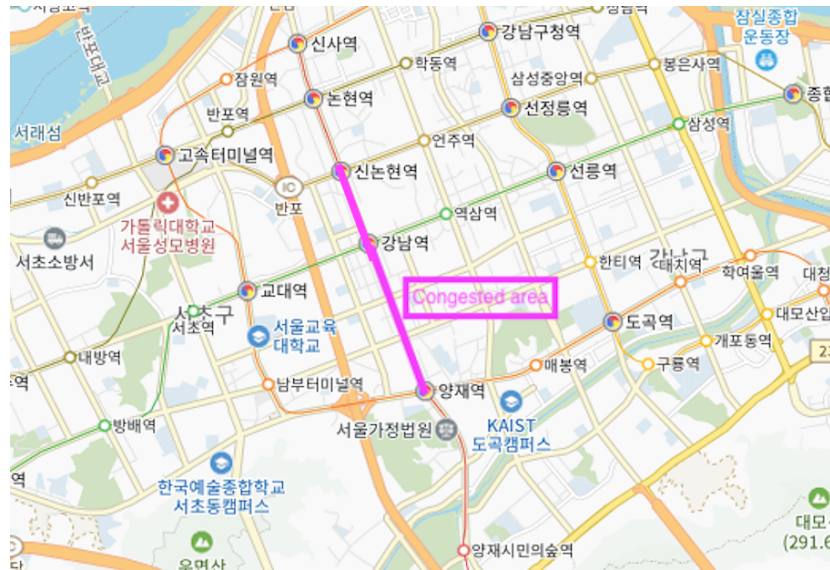


Fig 2. Severely congested parts on Gangnam Boulevard. The base image from Kakao Map (<https://map.kakao.com/>)

## System Design Suggestion

As congestion in the bus lane intensifies, there has been a discussion about relocating the turnaround points for intercity buses. Some potential locations on the outskirts of downtown, yet still connected to it via the subway, are under consideration. One of the candidates is Chungyesan Station, linked to Gangnam station through metro Line 9.

This paper will primarily concentrate on examining the impact of separating the intercity routes from the current bus stop, rather than evaluating the effectiveness of the proposed new location.

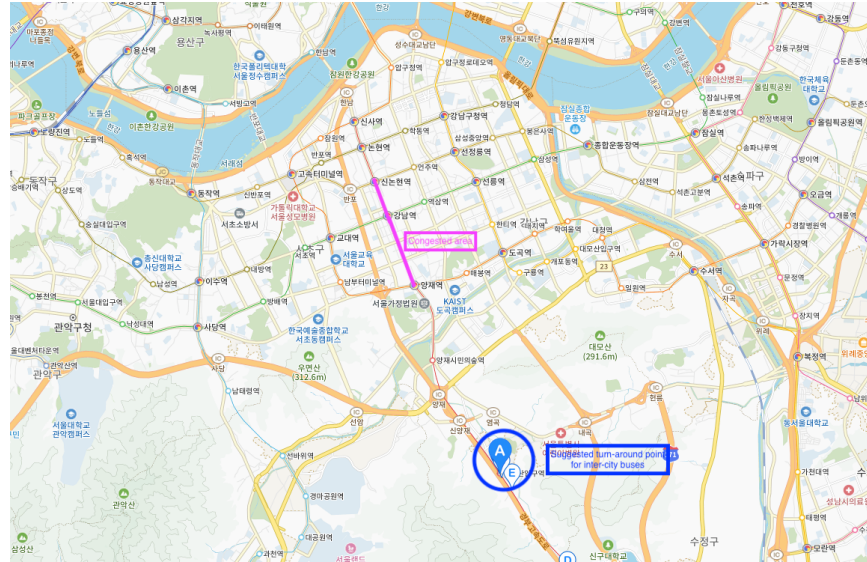


Fig 3. The area identified by the blue circle is being considered as one of the potential turnaround points for intercity buses. The base image from Kakao Map (<https://map.kakao.com/>)

## Benchmarking of the current system

### Data Collection

Bus routes, schedules, and rider data were collected from the South Korea public data portal (<https://www.data.go.kr/>) and Transportation Information Center (<https://stcis.go.kr/>).

### Exploring Data & Research Target

For benchmarking, we will utilize the outbound Gangnam Station (Shinbundang metro line) bus stop. Positioned in the middle of the congested area, this station serves as a bay along the central bus lane. In terms of timing, this study relies on data from 6 pm, marking the onset of rush hour and capturing the highest number of passengers throughout the day.

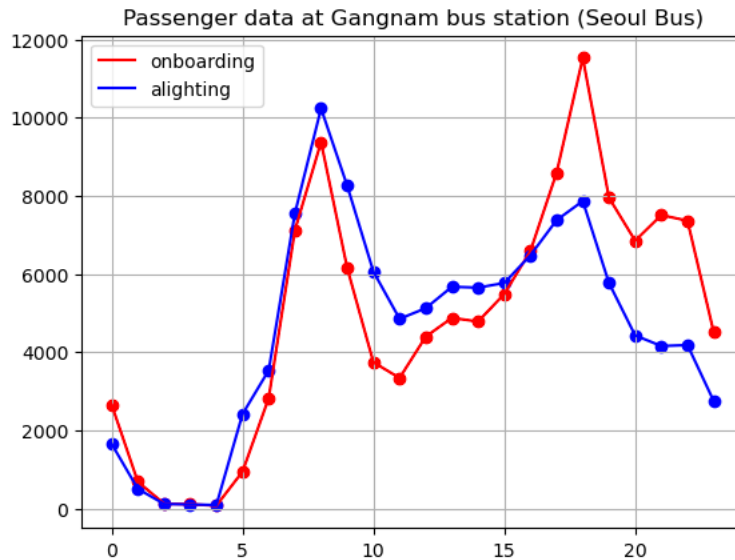


Fig 4. Hourly ridership data of Seoul inner-city bus

At 6 pm, a total of 54 routes make stops at the station. Despite over 40 of these routes being intercity buses, inner-city buses exhibit higher frequencies and attract a greater number of riders.

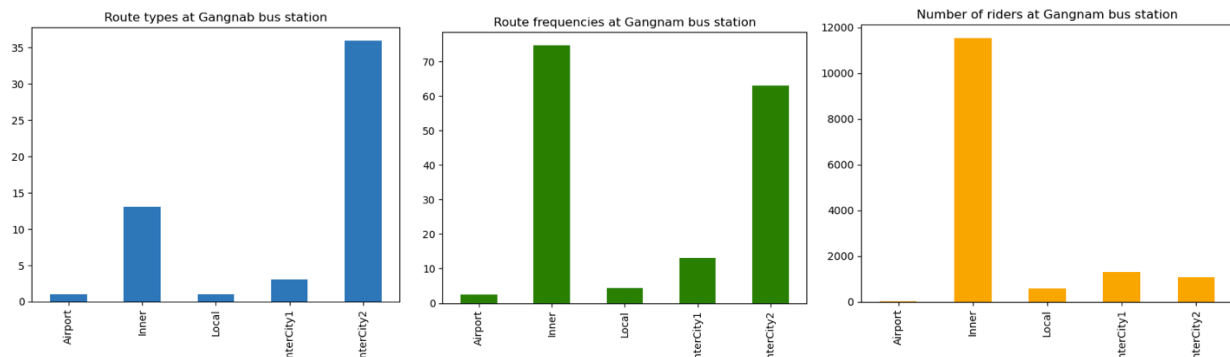


Fig 5. The count of routes per each route type (left), route frequencies per route type (center), number of riders per route type (right)

## Queuing Theory

At the bus bays serving some lines, buses enter the berth sequentially, then load and unload passengers, and finally exit the stop. So the buses and the stop constitute a queuing system (Gu et al., 2013). We will apply queuing theory to benchmark the expected wait time in the queue.

It is crucial to determine the distribution of arrivals and service rates to derive accurate values from the queuing system. Some empirical studies suggest that bus arrivals at multi-line stops during rush hour follow a Poisson process (Danas, 1980; Ge, 2006; Kohler, 1991) similar to an m/m/s queue. However, others propose a more general distribution of service time (Wang et al., 2018; Sun et al., 2015).

This paper adopts the assumption of a general distribution of time. It employs Allen and Cunneen's approximation of G/G/s (based on the basic formula M/M/s) to better reflect the complex nature of bus services during rush hour.

## Elements of the Queue

These are the terms used for queue analysis.

$\mu$  Arrival rates

$\lambda$  Service rates

$s$  Number of servers (Number of bus berths)

$L_q$  Average queue length

$W_q$  Average wait time for the queue

We will use an hour as a unit for both rates. The service time was calculated using the boarding time model developed by Seong et al., 2014. The details of the model were attached in appendix.

Since G/G/s approximation is derived from M/M/s, we can get  $L_q$  of the queue using M/M/s formula.

$$P_0 = \left[ \sum_{n=0}^{s-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{\left(\frac{\lambda}{\mu}\right)^s}{s!} \left( \frac{1}{1 - \frac{\lambda}{s\mu}} \right) \right]^{-1}$$

$$L_q = \frac{P_0 \left(\frac{\lambda}{\mu}\right)^s \rho}{s! (1 - \rho)^2}$$

From the values from M/M/s formula, we can derive the approximated queue length for G/G/s using Allen and Cunneen's approximation like below. The wait time can be calculated by dividing wait time by the service rate.

$$L_q = L_q(\text{M/M/s}) \cdot (c_a^2 + c_s^2)/2$$

$$W_q = \frac{L_q}{\lambda}$$

## Benchmark values

When we applied the formula to our data, the arrival rate was calculated as 157.439. While the time for onboarding passengers could be derived from the model, additional time for the entire service process—such as opening and closing doors, vehicle acceleration and deceleration—remains unknown. Therefore, the service rate was calculated as a range, varying from 69.07 to 50.61 depending on the inclusion of extra time. While it is reasonable to assume extra service

time up to 30 seconds, any time exceeding 8 seconds would lead to an unbounded wait time in the queue. Hence, the extra time is capped at 8 seconds.

The central bus lane stop typically accommodates up to 5 buses, but most buses utilize only the first 2 or 3 berths. Assuming 2 berths results in an unbounded wait time in the queue, even with the highest possible service rate, as the utilization ratio exceeds 1. Therefore, we will consider 3 as the number of servers in our analysis.

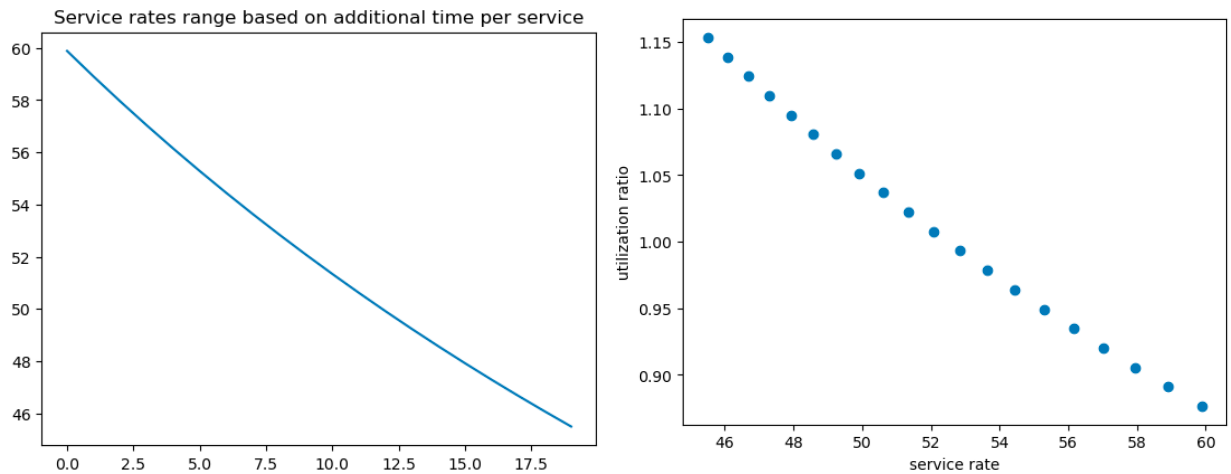
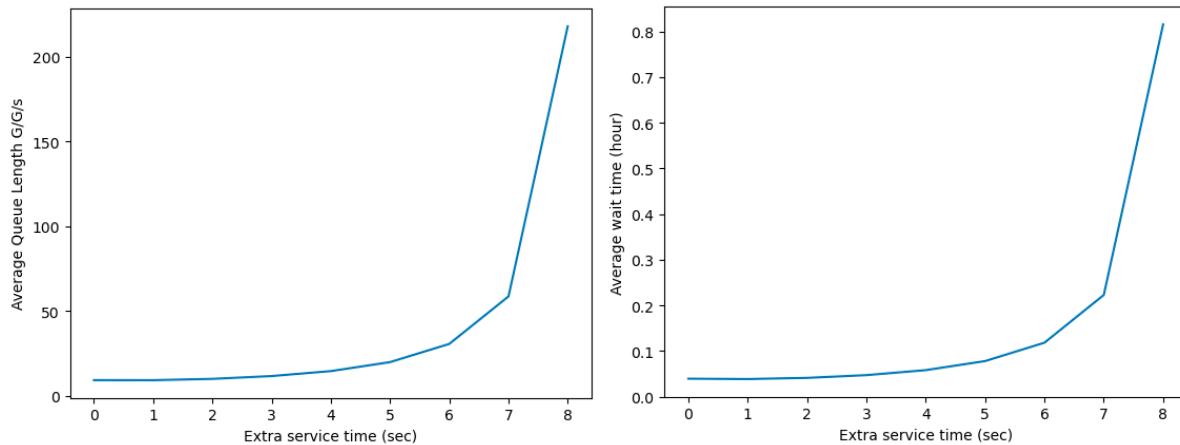


Fig 6. Service rate changes based on the additional service time (left) utilization ratio change based on the service rate (right). The number of berths is assumed as 3.

Below is the average wait time and average wait time with G/G/s approximation.



Extra service time (sec)	Average queue length	Average Wait time (hour)
0	9.338	0.059
1	9.306	0.059
2	10.083	0.064
3	11.729	0.074
4	14.660	0.0931
5	19.964	0.127
6	30.702	0.195
7	58.708	0.373
8	212.949	1.384

Fig 7. Average queue length variations based on extra service time (Top Left), Average wait time based on extra service time (Top Right), with detailed values presented in the table format (Bottom).

### Findings from the benchmark

From the benchmarking, we deduced that the wait time for the queue can increase up to 1.3 hours, depending on the additional service time needed. The queue becomes unbounded first when fewer than 3 berths are utilized at the stop, and secondly, when the service time requires more than additional 8 seconds to complete their services. Considering 8 seconds is just enough time to cover opening and closing the door, the benchmark effectively reflects the current ‘bus train’ phenomenon.

### The measure of the suggested design

The new design proposes a dedicated queue exclusively for intercity buses. Calculating the queue elements using only intercity bus data yields an arrival rate of 62.94. The service rate varies from 1348.15 to 337.39, depending on the additional service time.

As the service rate increases, there is notable improvement in both average queue length and average wait time. With the range of service rates, the average queue length is nearly zero, resulting in an equally minimal average wait time for the queue. This marks a significant improvement compared to the current system, which exhibits a range of wait times from 0.059 to 1.384 hours.

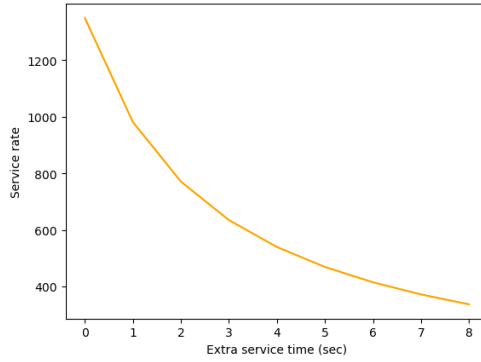
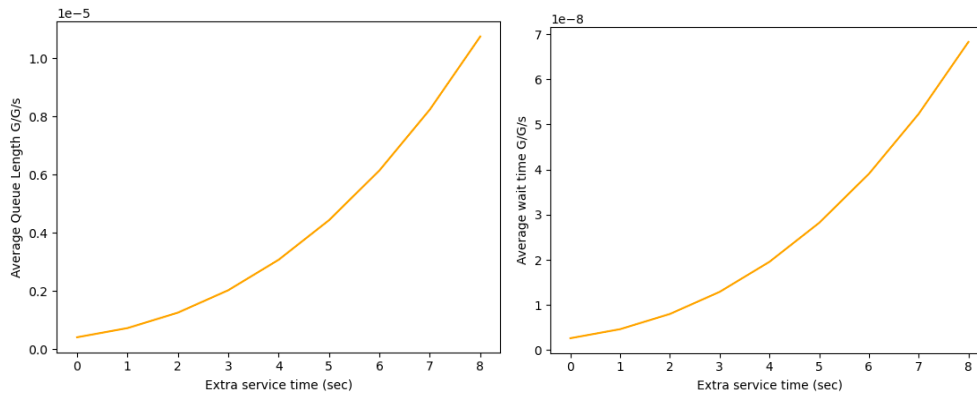


Fig 8. Service rate variations in the suggested design



Extra service time (sec)	Average queue length	Average Wait time (hour)
0	4.114e-07	2.513e-09
1	7.269e-07	4.613e-09
2	1.258e-06	7.988e-09
3	2.029e-06	1.289e-08
4	3.077e-06	1.954e-08
5	4.437e-06	2.819e-08
6	6.148e-06	3.905e-08
7	8.241e-06	5.234e-08
8	1.075e-05	6.829e-08

Fig 9. Variations in Average Queue Length based on Extra Service Time (Top Left), Average Wait Time based on Extra Service Time (Top Right), and detailed values of Average Wait Time and Service Time presented in a table format (Bottom) for the new design.

## Conclusion

The queue analysis of the suggested design reveals a significant potential improvement in the average wait time for intercity buses. Introducing changes in established transportation planning can be challenging, especially when it involves direct commutes to workplaces of many people. However, the analysis demonstrates a substantial improvement that is both notable and achievable. The immediate improvement and long-term benefits, including shorter travel times, reduced overcrowding, and increased reliability, are substantial and outweigh the initial inconvenience. Embracing this shift in transportation dynamics is a pivotal step towards creating a more robust and scalable bus network.

## Appendix

Boarding time model (Seong et al., 2014)

$$Y_{max} = \max(Y_B, Y_A)$$

$Y_A$ : Time spent for alighting passengers

$Y_B$ : Time spent for boarding passengers

$$Y_B = -1.704 + 2.445X_1 + 0.115X_2 + 0.020X_3$$

Onboarding time

$X_1$ : number of the boarding passengers

$X_2$ : number of the standing riders in the bus (Ignored in this paper since unknown)

$X_3$ : the distance between the street and the bus stairways

$$Y_A = -3.655 + 1.376X_1 + 0.049X_2$$

Alighting time

$X_1$ : number of the alighting passengers

$X_2$ : the distance between the street and the bus stairways

Any negative value was rounded up to zero in this paper.

## References

Channel A News (Korea). (2023, May 23). [자막뉴스] 강남역 막히는 이유 있었다 ... 퇴근길 광역버스들이... / 채널 A. Youtube. <https://youtu.be/XQWvC1VJlk0?feature=shared&t=117>

Danas, A. (1980). Arrivals of passengers and buses at two London bus stops. *Traffic Engineering and Control*, 21:10, 472–475.

Ge, H. (2006). “Traffic impacts of bus stops in urban area and related optimization techniques (translated from Chinese).” PhD Thesis, Southeast University, China.

Kohler, U. (1991). "Capacity of transit lanes." Proceedings of the International Symposium on Highway Capacity, Karlsruhe, Germany.

Seong, M, Choi, K, Shin, K, Chung, W, Lee, K. (2014). An Empirical Model for Estimating Bus Boarding and Alighting Time. Journal of Korean Society of Transportation.  
<http://dx.doi.org/10.7470/jkst.2014.32.2.152> (Translated from Korean)

Sun F, Sun L, Sun SW, Wang DH (2015). Study on the calculation models of bus delay at bays using queueing theory and Markov chain. Comput Intell Neurosci.  
<https://doi.org/10.1155/2015/750304>

Teknomo, Kardi. (2014) Queuing Theory Tutorial.  
<http://people.revoledu.com/kardi/tutorial/Queuing/>

Wang, C., Ye, Z., Fricker, J. D., Zhang, Y., & Ukkusuri, S. V. (2018). Bus Capacity Estimation using Stochastic Queuing Models for Isolated Bus Stops in China. Transportation Research Record, 2672(8), 108-120. <https://doi.org/10.1177/0361198118777358>