IEOR 4404 Simulation
Final Project

Topic: Subway Station Security Check Simulation
Term: Spring 2021
Team Member: Yingying Deng, Zheyuan Hu, Ruitong Xu, Yao Yi
UIN: yd2547, zh2447, rx2187, yy3097

I. Introduction

In Beijing, during peak hours, there are always long lines (in hundreds of meters) outside of security checks of subway stations. The subway is especially crowded in Fuxingmen Station, the interchange station of Line 1 and 2. Though Beijing now has 19 metro lines, line 1 and 2 still play crucial roles in transporting people in downtown areas. Long time of waiting in lines during peak hours results in huge inefficiency. Thus, we want to understand and simulate the arrival times and screening times during peak hours, in order to bring insights and recommendations to Beijing Metro Center to reduce the crowdedness and amount of waiting time during peak hours.

II. Value Proposition

Based on our simulation of arrival and security check times of Fuxingmen Station, we could recommend the number of security guards needed, size and number of baggage check screening, as well as better security check process, in order to reduce the amount of waiting time during peak hours. As Fuxingmen Station being one of the most crowded subway stations in Beijing, our simulation could be applied to all other subway stations in Beijing.

III. Data Overview

We gathered our data based on our own observation and investigation of Fuxingmen Station during the peak hour of 5:30 pm to 6:30 pm.

Time:

- 5:30 pm - 6:30 pm (T=3600s)

Subway Station:

- 2 entrance (A and B) for Line 1.
- For every 3 minutes, there will be about 200 people exchange line from 2 to 1.
- There is only one security track scanner for bags per entrance.
- There are two security checkpoints for people per entrance, one for people carrying bags, one for people without bags.
- If a person carries bags, they will go through body check during their bag checking.

Arrival per entrance:

- 60 arrivals per minute.
- 40% of people have large bags that needs to go through the track scanner.

Security track:

- 20s for one bag go through the security track.
- 2s for one person to be checked at the security checkpoints.
- Maximumly 5 people can put down and get their bag at the same time on the track .

Subway Platforms:

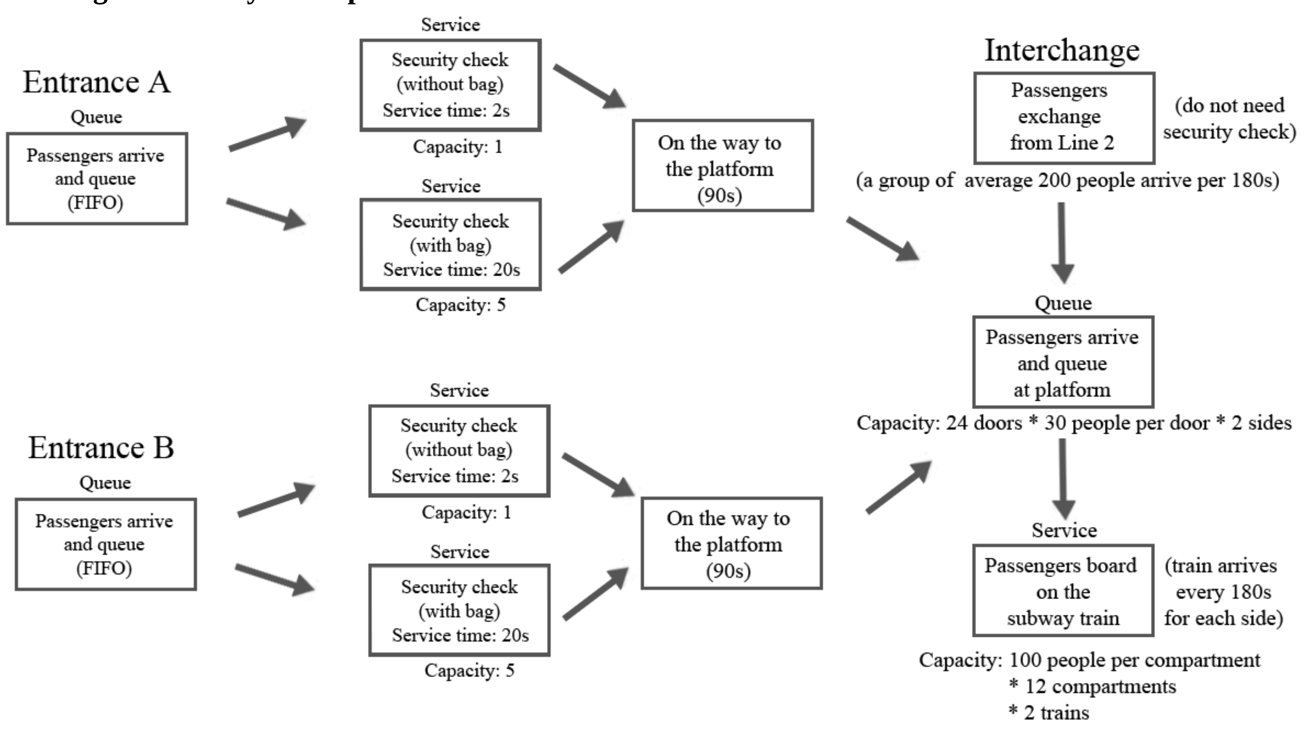
- It takes 90s Security checkpoint to walk to the platform.
- On the platform, there are two subways coming from opposite directions every 3 minutes.
- Each subway train has 24 doors and 12 compartments.
- Each door has a maximum capacity of 30 people waiting in the line.

During our investigation, we noticed that the number of people waiting on the platform is far less than the maximum capacity of the platform. Besides, there is space left on each of the compartments of the subway train either. Thus, we believe that the current security check process is lacking efficiency and a lot of people stuck at the security checkpoint. We intended to model on the current security check process and find improvement of the model.

IV. Simulation Model

In order to identify the average waiting time for each passenger, we created a simulation model for Fuxingmen Station. We split the process into five main steps: Train arrival, Passenger exchange, Passenger arrival, Security Check and Waiting for Subway. The total runtime is 1 hour from 5:30 pm - 6:30 pm.

The original security check process we observed:



1. **Train arrival:**
   - The train arrives every 180s, and there are two trains going in opposite directions arriving at the same time. Every train has 12 compartments with a maximum capacity of 100 people per compartment.

- We simulate the number of leftover number of passengers on the train at Fuxingmen station, we assume it allows a normal distribution with $x_1 \sim N(50{,}36)$.

2. **Passengers Exchange from Line 2 to Line 1:**
    - There are passengers exchanging from Line 2 to Line 1 between each of the two arrivals of the trains. These passengers will go directly to the platform without being security checked.
    - We assume the arrival of these passengers follows a normal distribution $x_2 \sim N(200{,}900)$.
    - Passengers exchange from line 2 to line 1 are not the audience we are investigating in our simulation model. Therefore, we assume:
$$the\ capacity\ of\ each\ compartment\ =\ 100 - x_1 - x_2/12$$

3. **Passenger arrival:**
    - We assume the arrival follows a homogeneous poisson distribution with $\lambda = 100/60$.
    - We assume the probability of an arrived passenger carrying bags is P = 0.4.

4. **Security Check:**
    - Passenger with or without bags all line up in the same line waiting for being checked.
    - Passengers with bags would need to go through both bag check and body check. There is a security body checkpoint that is only for people with bags, they check the passenger after the passenger puts down their bag on the bag checking machine. It takes one person 10s for itself and the bag to be checked. The capacity of the bag checking machine could allow 5 people's bags on the track at the same time.
    - Passengers without bags would only need to go through bodycheck for 2s. There is only 1 security guide that checks everyone without bags one at a time.

5. **Wait for the subway:**
    - It takes each passenger 90s to walk from security point to the subway station.
    - The platform has its capacity, and we assume the maximum possible capacity to be:
*capacity = 30 people / door * 24 doors * 2 trains = 1440 people*
    - The number of passengers go through security checkpoint that can be boarded on the train would be:
number of boarded people per compartment = compartment capacity **-** *(number of people in the compartment + (number of exchange passengers /number of compartments))*
    - If there is not enough space for all passengers on the platform to get on the train, those customers will wait for the next train and be on the first in the line.

We assume both entrances would have the same amount of passenger arrivals. Thus, we could use half of the platform and trains to simulate for passengers arriving from one entrance.

V. Improving Efficiency of the Subway Station Security Check

After simulating the system 1000 times (with distribution histograms in appendix), we calculated the average of the waiting time for the security check and the average of the total waiting time. On average, one person carrying bags would wait for 642.7s, 10.7 minutes outside of the security checkpoint and in total 796.4s, 13.3 minutes to get on the train, and one person not carrying bags would wait for 633.4s, 10.6 minutes and 784.9s, 13.1 minutes respectively. Note that we only consider those who get on the train at 6:30 pm, since we are investigating only during the peak hours. After 6:30 pm, the average waiting time would be less than the peak hour's waiting time. Thus, we want to improve the efficiency of the security check and eliminate the average waiting time for passengers. However, there are also some constraints we must consider. We don't want to speed up the system as soon as possible since the platform has a maximum capacity of 30 people waiting outside of each door. Thus, if there are more than 1440 people in total on the platform, the system fails, meaning that the speed of security check is too fast.

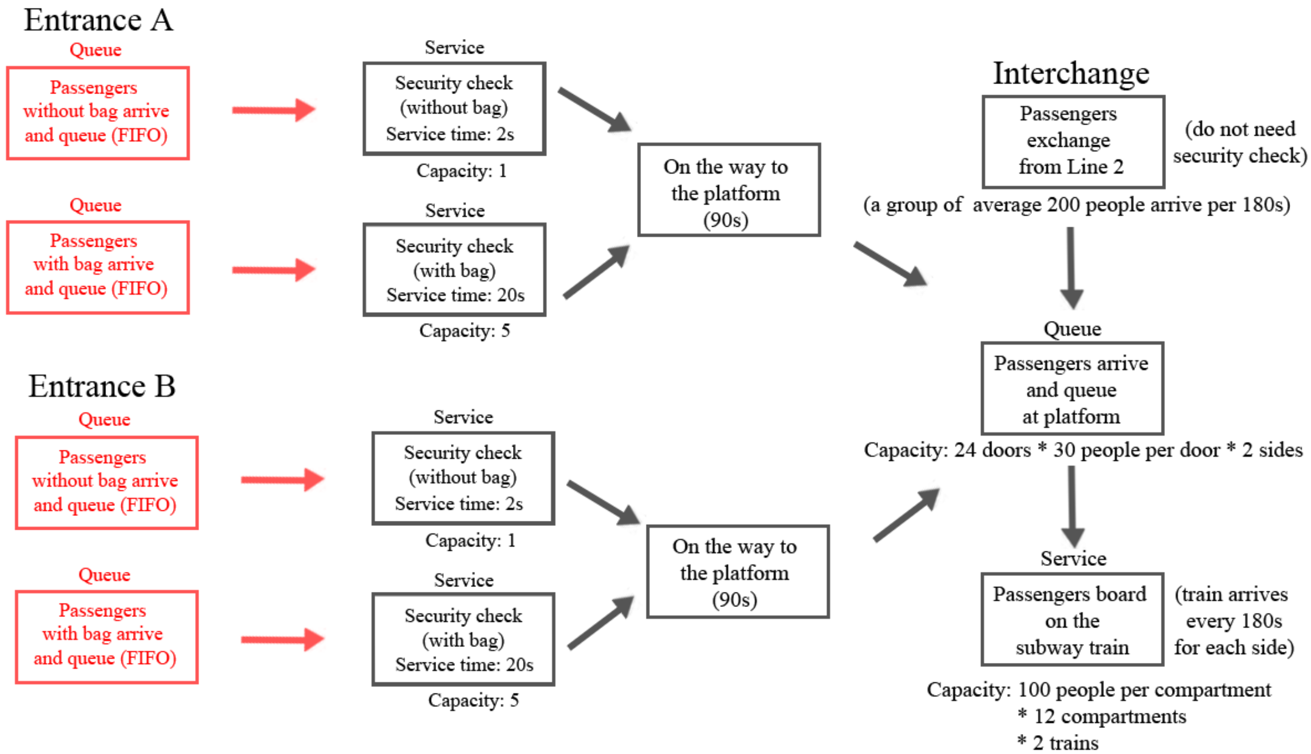
VI. Exploring Policies for Improving the Efficiency

We came up with two ideas of improving the security check efficiency.

1. Add one more machine and one more security body check point on each entrance, so there are 10 people with bags that can be checked at the same time (capacity for machines is now 10). After simulating the model for 1000 times, we get that the average waiting time for a security check of one person carrying bags is 22.1s (0.4 minutes), and for a security check of one person not carrying bags is 288.3s (4.8 minutes). The total waiting time from arrival till getting on the train is 173.8s (2.9 minutes) for a person with bags and 440.1s (7.3 minutes) for a person without bags. We eliminate 96.6% of with-bags waiting for security and 78.2% of the with-bags total waiting time. These percentages would be 54.5% and 43.9% if without bags, respectively. The distribution histogram of this model is listed in the appendix.

2. Separate one line into two lines. Instead of only one line we originally have, we now add one human resource to split the people up front, have one line for people with bags and one line for people without bags. After simulating the model for 1000 times, we get that the average waiting time for security check of people with bags is 643.2s (10.7 minutes), and for security check of people without bags is 284.8s (4.7 minutes). The total waiting time from arrival till getting on the train is 796.8s (13.3 minutes) for a person with bags and 436.4s (7.3 minutes) for a person without bags. There is no improvement of with-bags waiting for security and with-bags total waiting time. These percentages of drop in waiting time are 55.0% and 44.4% if without bags, respectively. The distribution histogram of this model is listed in the appendix.

Improved security check process :



VII. Results

The main outputs for each of the models in our project are average waiting times for bag/no-bag passengers in security check lines and total average waiting times in the system as well. To compare the results from all three models here, we also include the concept of machine purchase cost, operational/maintenance cost, and staffing cost (2 staffs needed for machine check, 1 staff needed for body check) in order to be more comparable with real life context.

For improvement model 1, we greatly decreased the waiting time for people with bags by a huge amount while also cutting the waiting time for people without bags to around half of before, at the cost of purchasing a new machine and hiring two more employees. The average cost of a brand-new security check machine is around 30k CNY (~4.7k USD). The average wage for a security check staff is around 5k CNY per month (~770 USD).

For improvement model 2, we can decrease the waiting time of people without bags to the same level as improvement model 1 but indicating nearly no impact on waiting time of people with bags . However, this model does not require additional costs.

Therefore, the choice of these two models really depends on the specific needs of the station. If more passengers with bags are anticipated in the near future, the suggestion will be deploying improvement model 1. Otherwise, if the station will be expecting more people without bags or the station is on budget, improvement model 2 might be a good choice.

VIII. Conclusion

System simulation helps us have a clearer idea about how sophisticated systems work such as the Beijing subway security check system here in this project. By making a few assumptions and determining several parameters, we successfully simulated the security check system in Fuxingmen Station under various scenarios. Comparing and contrasting the real-life model and our proposed potential alternative models, we could provide actionable insights and detailed solutions to Beijing Subway authority to assist improving security check efficiency and decreasing the average time passengers have to wait in the line. With given data from other similar stations, this project could always be utilized to perform the same simulation after minor modification to the code.

However, there are still limitations and drawbacks with our model. To begin with, most of the assumed rates and distributions are not perfect enough. For example, passenger arrival follows a homogeneous Poisson, but it could be a non-homogeneous Poisson as time varies. In addition, we did not consider any exceptions or incidents with small probabilities, such as train delays and disabled passengers (separate security check queue, longer walk time to platform). All these can possibly be improved by more detailed dataset so that we can implement models with more precise parameters instead of just on-site observation to gather data.

IX. Links and Contribution

1. **Code:**
   Model of Original Security Check Process:
   https://colab.research.google.com/drive/1GrMJt6Grfytr6f5i6qqiXSko0GColKGJ?usp=sharing
   Model version 1 of Improved Security Check Process (machine capacity changed to 10):
   https://colab.research.google.com/drive/1iiCM38lekR4DIN3TpUSP3PZaBAy0Supn?usp=sharing
   Model version 2 of Improved Security Check Process (divided into two queues):
   https://colab.research.google.com/drive/10coZWFXmuAjARwPsglnXIl-5fZcYs5PJ?usp=sharing

2. **Data:** No dataset. All required data collected by us and listed in Part III.

3. **Contribution:**
   - Project Ideation: Yingying Deng
   - Project Proposal: Yingying Deng, Zheyuan Hu, Ruitong Xu, Yao Yi
   - Data Gathering and Investigation: Yingying Deng, Yao Yi
   - Original Security Check Process Model - Draft/Debug: Yingying Deng, Yao Yi
   - Original Security Check Process Model - Implementation: Yingying Deng, Yao Yi
   - Improved-efficiency Model - Draft/Debug: Zheyuan Hu, Ruitong Xu
   - Improved-efficiency Model - Implementation: Zheyuan Hu, Ruitong Xu
   - Final Report: Yingying Deng, Zheyuan Hu, Ruitong Xu, Yao Yi

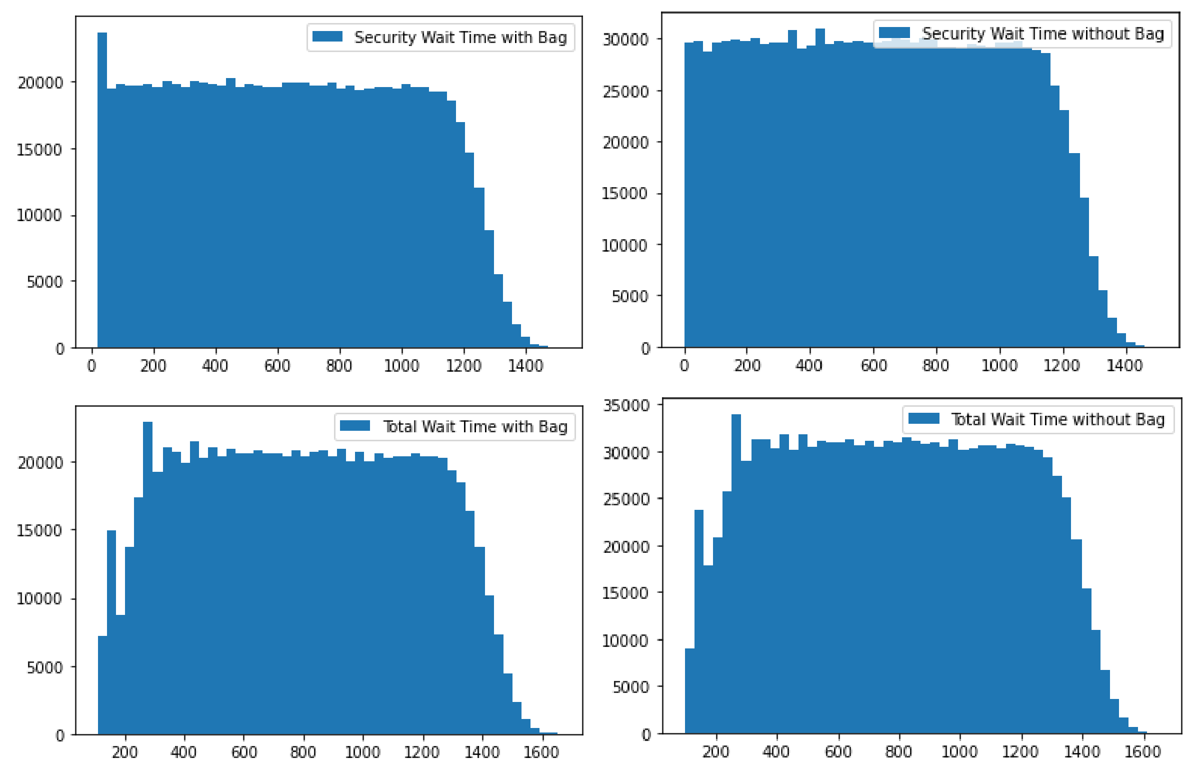
   All in Alphabetical Order

X. References

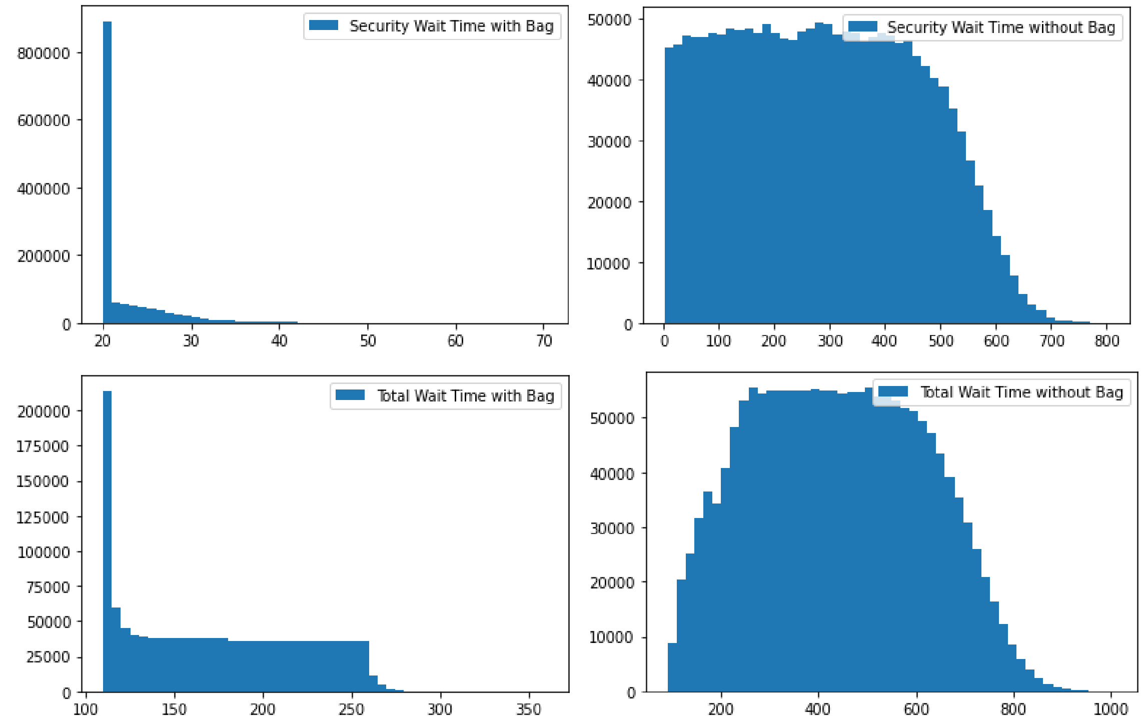
1. Beijing Subway Official. “Passenger Flow Information” Beijing Subway, 16 July 2018, https://www.bjsubway.com/support/cxyd/klxx/. Accessed 25 March 2021.
2. Wang, Kai. “Analysis of Beijing Subway Passenger Flow Characteristics” Hans, March 2014, https://image.hanspub.org/Html/13395.html. Accessed 25 March 2021.
3. Beijing Metro Network Control Center. “Beijing Subway Official Passenger Flow Statistics” Baidu Wenku, 12 April 2020, https://wenku.baidu.com/view/3accbc2ab107e87101f69e3143323968001cf40d.html. Accessed 25 March 2021.
4. Liu, Qigang and Zhang, Lan. “The Study of Interchanging Ability of Beijing Fuxingmen Subway Station” Railway Transport and Economy, April 2011, https://wenku.baidu.com/view/e63d2159ad02de80d4d84084.html. Accessed 25 March 2021.

XI. Appendix

Appendix 1. Distribution of 1000 simulations of original model:



Appendix 2. Distribution of 1000 simulations of improved model version 1 (machine capacity changed to 10):



Appendix 3. Distribution of 1000 simulations of original model (divided into two queues):