



## EVALUATION OF A SHARED CYCLE APPLYING A QUEUEING NETWORK

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### Abstract

In recent years, the need for bicycles as a means of transportation that does not emit carbon dioxide has increased. In addition, shared bicycles are being introduced all over the world as a means of urban public transportation. However, the concentration of bicycles at certain cycle ports requires a relocation of bicycles. Since this is putting pressure on the operating business, a new method to get unbalanced is needed to replace this method. Therefore, this study aims to smooth ports without relying on trucks and other transportation, and to clarify the relationship between the number of bicycles initially placed and the total waiting time through simulation analysis. Simulation of queues was constructed using data of a social experiment conducted by Nerima Ward, Tokyo, in October 2018. The data includes the usage results of share bike system on five weekdays and two holidays, for a total of seven days. Using the simulation, we calculated how large the total waiting time varied by changing the number of bicycles initially placed at the port and the total number of bicycles, and clarified the relationship. I moved the number of initially placed bicycles from the low-demand port to the high-demand port in front of the station by one unit, but found no decrease in total waiting time. Next, the simulation was conducted by increasing the number of bicycles at the nine high-demand ports one each. At this time, the total waiting time for all ports decreased. Simulation experiments showed that changing the initial number of bicycles in accordance with demand did not lead to a decrease in waiting time for the entire system. One reason for this is that although the waiting time at high-demand ports decreased, the waiting time at low-demand ports exceeded the decrease. It became clear that measures to increase the total number of bicycles must be taken to reduce wait times.

*Keywords: share bike, relocation, simulation*

### 1 Introduction

In recent years, the need for bicycles as a means of transportation that does not emit CO<sub>2</sub> has been increasing. In addition, shared bicycles are being introduced all over the world as a means of public transportation in urban areas. In Japan, the number of municipalities introducing shared bicycles is increasing year by year. However, more than 60% of the businesses are operating at a loss, making it difficult to generate revenue. Particularly in large metropolitan areas, the number of bicycle rentals and returns at cycle ports near railroad stations is concentrated in the morning commuting hours and at night when people are going home. This results in an imbalance of ports. Transportation by trucks and other vehicles is required, which increases transportation costs and puts pressure on the operating business. Therefore, a new alternative method is needed to get unbalanced. Thus, we thought that by changing the number of bicycles, the cycle port could be smoothed.

In this study, Targeting shared bicycles in Nerima Ward, Tokyo, we will clarify the relationship between the total waiting time and the number of bicycles initially placed at each bike port and the total number of bicycles by changing the number of bicycles and the total number of bicycles through simulation.

## 2 Previous studies

### 2.1 Studies in which simulations are conducted

Daniel Chemla et al. [1] note that one of the problems is maintaining an adequate number of bicycles at each port. Not having enough bicycles at a port can ultimately lead to user dissatisfaction; conversely, too many bicycles at a port can prevent users from finding available racks to park their bicycles, a problem referred to as imbalance. The objective of this study is to investigate ways to reduce imbalance during the day. Through simulations, we proposed a pricing strategy that would allow reducing imbalance without having to transport by truck or other means.

### 2.2 Research on relocation

Fábio Cruz et al. [2] used a heuristic to find the least-cost route that meets the demand for all ports using only one vehicle, such as a truck, and does not violate minimum and maximum loading limits during the tour, and also analyzed how the performance of the algorithm varies with the number of ports and vehicle capacity.

Leonardo Caggiani et al. [3] also propose a comprehensive, dynamic, operator-based bicycle redistribution methodology that begins with a prediction of the number and location of bicycles and ends with a decision support system (DSS) for the transfer process. A demand forecasting model is applied to determine the number of bicycles needed. Finally, a dynamic free-floating bicycle reallocation DSS is presented to determine the optimal reallocation flow and distribution pattern.

While there are many examples of research on shared bicycles regarding bicycle guidance methods that do not rely on transportation by trucks, etc. to minimize relocation, which accounts for a significant portion of learning costs, there are no examples of research focusing on the number of bicycles initially placed or the total number of bicycles at each port. In this study, we will clarify the relationship between the total waiting time at all stores and the number of bicycles initially placed and the total number of bicycles by changing the number of initially placed bicycles and the total number of bicycles.

## 3 Overview of the used data

The regional target was Nerima Ward, Tokyo. The district has numerous parks and many residential neighbourhoods lining the streets. A summary is given below, Table 1.

**Table 1** Outline of Nerima Ward

Location	Located northwest of Tokyo
Population	741,375 (as of the end of January 2024)
Population Density	15,667 persons/km <sup>2</sup>

Nerima Ward, Tokyo, conducted a social experiment on shared bicycles for about two years starting in 2017. Currently, the system is in full-scale operation, and the number of users is increasing every year. This study used data on actual use on a total of seven days during the social experiment, five weekdays and two holidays. Figure 1 shows the locations of the cycle ports and the number of bicycles initially placed. It also includes major road and rail lines as well as municipal boundaries.

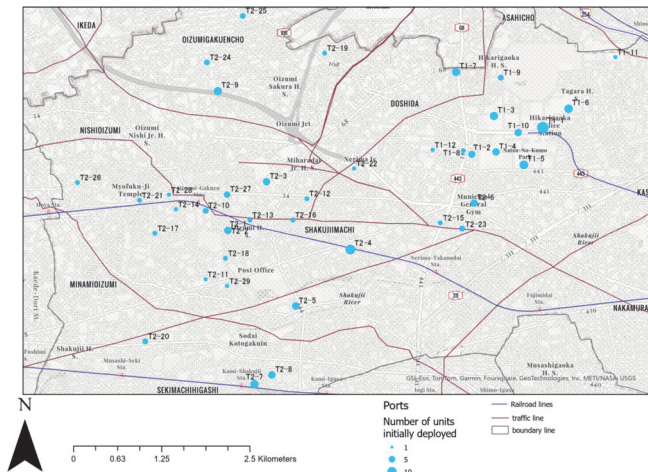


Figure 1 The locations of the cycle ports and the number of bicycles initially placed

## 4 Parameter estimation

### 4.1 Identification of probability distribution of arrival rates

Parameters were estimated assuming that the number of arrivals per unit time for the entire system follows a Poisson distribution. The figure 2 shows the probability distribution of arrival rates on weekdays and holidays. It can be seen that there is no significant difference between weekdays and holidays. The average arrival rate was 12.9 (persons/hour).

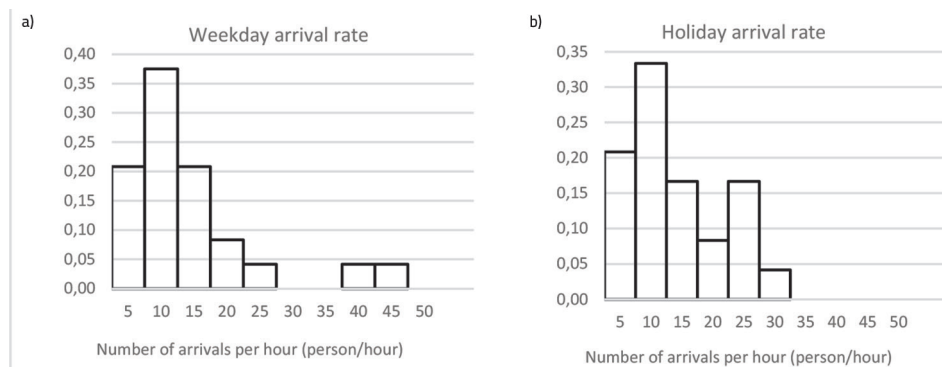


Figure 2 a) weekday arrival rate, b) holiday arrival rate

## 4.2 Identification of probability distribution of service hours

Regarding the time of bicycle use, the distribution of time of use is divided into two groups: those who borrowed and returned bicycles at the same port and those who borrowed and returned bicycles at different ports. As for the former trend, it can be read that the majority of the respondents used the bicycles for relatively long periods of time. We assume that this is due to the one-day pass users. The following figure 3 shows the distribution of usage time for each category. The left figure shows the distribution of usage time for those who checked out and returned at different ports, and the right figure shows the distribution for those who checked out and returned at the same port.

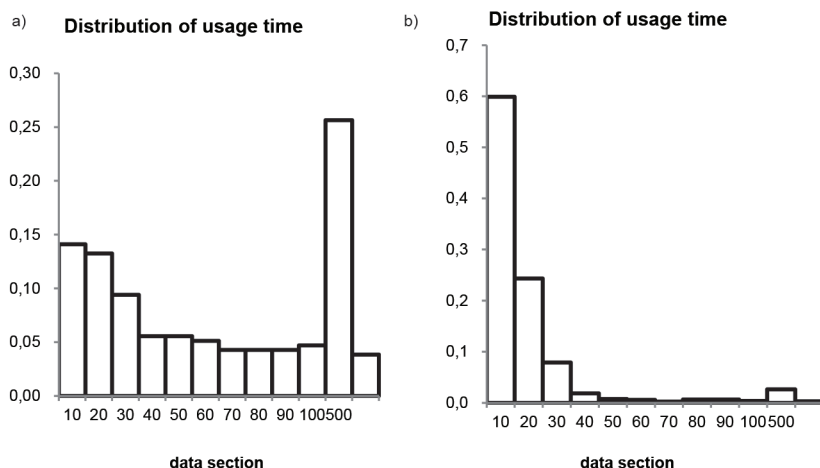


Figure 3 Lending and returning at the same port

In this study, the parameters were estimated assuming that lending times follow an exponential distribution. The parameter  $\lambda$  was calculated from real data by maximum likelihood estimation. Let  $\lambda_1$  denote the parameter for users who lent and returned at the same port, and let  $\lambda_2$  denote the parameter for users who lent and returned at different ports. The values were  $\lambda_1 = 0.01$  and  $\lambda_2 = 0.05$ . A goodness-of-fit test of the distributions verified that both followed an exponential distribution.

Those who lent and returned bicycles at the same port may not be able to track their behaviour along the way and may not have accurate bicycle usage times.

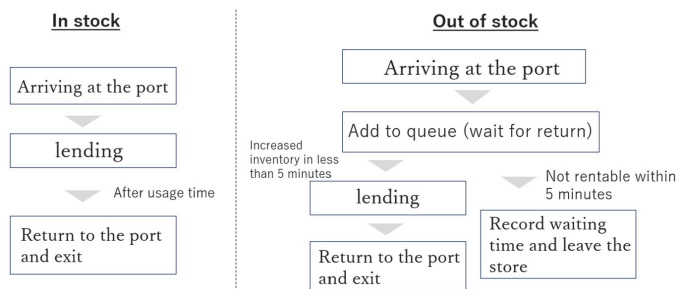
## 5 Simulation overview

Based on the actual data, the simulation is performed after setting parameters. The setting conditions are shown in the table 2. For the above reasons, the distribution of usage times of those who lent and returned bicycles at different cycle ports was adopted during this simulation. The following was done with respect to the handling of OD data. We identified where users arrived by using the ratio of loans per port. Destinations were also identified using the ratio of each destination from that port. The flow during the simulation is shown below. In this section, we have considered two cases: when a user arrives at a certain port and when it is stocked, and when it is not. In the latter case, the maximum allowable waiting time is set to 5 minutes, and if the waiting time exceeds that, the bicycle is not rented, the waiting time is recorded, and the user leaves the store. In addition, the FIFO (First in First out) system will be adopted for the bicycle rental service.

**Table 2** Simulation settings

Simulation time	24 hours
Number of cycle ports	41 ports
arrival interval	Average attendance rate 12.9 (person/time)
usage time	Exponential distribution with mean 19.9

In the Nerima Ward shared cycle system, bicycles can be parked near the port even if the port is full when they are returned, even if the number of racks in the port is exceeded.



**Figure 4** Simulation flow

## 7 Simulation experiment

The simulation will be conducted 100 times for each of the following two patterns to identify the relationship between the number of bicycles initially placed, the total number of bicycles and the total waiting time by changing the following two conditions from the initial condition (sensitivity analysis):

Pattern 1: Varying the number of bicycles initially placed at ports with high demand

Pattern 2: Varying the total number of bicycles

**Table 3** Number of cycle ports placed at each of the initial

	Average of total latency of all ports	Difference from Scenario 1
Scenario 1	205.25	0.00
Scenario 2	214.07	8.82
Scenario 3	249.90	44.66

First, several simulations were performed under initial conditions to identify the current status. In this process, ports with high and low demand were found. This initial state is defined as Scenario 1.

In Pattern 1, we set up Scenario 2 and Scenario 3. In Scenario 2, the number of initially placed units is increased from the four low-demand ports identified in Scenario 1 to the four high-demand station ports. In Scenario 3, the number of units is increased by four from the four ports with similarly low demand to one port in front of the station with particularly high demand.

In Pattern 2, then, the relationship between the total number of bicycles and the total waiting time is clarified. In Scenario 4, the number of bicycles placed at the nine ports is increased by one from the one with the highest demand. In Scenario 5, the simulation was conducted by increasing the number of bicycles placed at the three ports with particularly high demand by three.

## 6 Simulation results

The following table shows the results of simulation experiment pattern (1). When the initial placement of bicycles at a particular port was varied, the total waiting time increased from Scenario 1 (current conditions) by 8.82 (minutes) and 44.66 (minutes), respectively. Thus, there was no relationship between total waiting time and the number of bicycles initially placed.

Table 4 Result of oattern 1

	Average of total latency of all ports	Difference from Scenario 1
Scenario 1	205.25	0.00
Scenario 4	199.84	-5.41
Scenario 5	193.24	-12.01

Next, we show the results when the number of bicycles at high-demand ports was increased, i.e., Pattern 2. When the total number of bicycles was increased, there was a decrease in total waiting time for both patterns, but a particularly large decrease was observed when the number of bicycles was increased at the three high-demand ports in front of the stations.

Table 5 Result of pattern 2

## 7 Conclusion

In this study, a simulation applying a queueing network was conducted based on actual data of shared bicycles in Nerima Ward, Tokyo, in October 2018. The results of the simulation experiment showed that changing the initial number of bicycles in accordance with demand did not lead to a decrease in waiting time for the entire system, and that measures to increase the total number of bicycles must be taken to reduce waiting time.

## References

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