Simulation for Balancing Bike-Sharing Systems

Yang-Kuei Lin and Francois Liang

***Abstract*—In this research, we studied the problem of balancing a dynamic bike-sharing system in Taiwan. A simulation model for solving vehicle repositioning problems in bike sharing systems is presented. The objective of this research is to decide the optimal number of vehicles for the repositioning that minimizes customers waiting time.**

***Index Terms*—Simulation, bike-sharing systems, repositioning problem.**

I. INTRODUCTION

In recent years, bike sharing systems have been evolving in cities all over the world. Bike sharing systems allow individuals to rent a bike from an automated rental station, use it for a short period of time, and return it to any other rental station in the city. Due to lots of factors such as demographic characteristics or nearby public transport stops, some stations tend to run out of bikes, whereas others tend to run out of racks to park the bikes. In the case of running out of bikes, customers are not able to rent bikes while in the case of a full station, customers are not able to return their bikes. Therefore, bike-sharing system operators need to redistribute bikes among stations on a regular basis to avoid customer dissatisfaction. Usually, this task is done by a vehicle that picks up bikes from stations with excesses of bikes and delivers bikes to stations with deficits. In this research, we consider the repositioning problem of the bike-sharing systems in Taichung City, Taiwan, [1]. We aim to decide the optimal number of vehicles for the repositioning that minimize customers waiting time. Examples of papers that tackle this problem are [2]-[5]. Contardo *et al.* [2] studied balancing a dynamic bike-sharing system for Montreal city in Canada. Caggiani and Ottomanelli [3] proposed a dynamic simulation based model for optimal fleet repositioning in bike-sharing systems. Their objective is to minimize the vehicle repositioning costs subject to high-level user satisfaction. Kloimüllner *et al.* [4] proposed greedy and PILOT construction heuristics for balancing dynamic bike sharing systems in Vienna. Sörensen and Vergeylen [5] proposed a mixed-integer programming formulation for bike request scheduling problems. They also proposed a new approach for the city bike repositioning problems.

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II. SIMULATION MODEL

In this research, we used ARENA simulation software to build the model. In the initial stage, we only consider 5 major rental stations in Taichung City, Taiwan. The complete simulation model of these 5 major rental stations is shown in Figure 1. We highlight the repositioning part in red rectangle. The repositioning policies are actually quite simple. The simulation model dynamically redistribute bikes across stations in order to avoid them becoming overly full or empty. We are assuming there is a center that controls all the repositioning vehicles. When a station is out of racks for customers returning bikes, the station will send a signal to the center. If the center has a vehicle available, then the center will send the vehicle to the station to carry bikes (assuming 20 bikes per vehicle route) back to the center (refer to Figure 2, A rectangle). Similarly, when a station is out of bikes for customers to rent, the station will send a signal to the center. The center will send a vehicle to bring bikes to the station (refer to Figure 2, B rectangle). We assume that every vehicle will return back to the center after it finishes a single task. If no vehicle is available, the "first come first served" policy will be applied, depending on which event comes earlier.

Eater settings, as shown in Table 1. We assume that initial empty racks are 20% of the total bike amount. We also assume the arrival rate of each station, probability of return station, and rental time distribution of customers. We also assume that when no bikes are available, 80% of customers will be willing to wait and 20% of customers will leave without renting a bike. The vehicle capacity was set to 20 bikes.

Table II shows the queue waiting time of different repositioning settings. During the peak time, if no repositioning is applied, at Stations S3, S4, and S5 the waiting time for renting a bike is quite long due to lack of bikes. The average waiting time for Stations S3, S4, and S5 are 70.48, 61, and 87 minutes. When repositioning is applied, the average waiting time for renting a bike is reduced significantly. The average waiting time for renting a bike decreases as the number of repositioning vehicles increases. For example, in station S4, the average waiting time for renting a bike is 23 minutes if one vehicle is using for repositioning. The average waiting time for renting a bike will be reduced to 18 minutes if two vehicles are used for repositioning, and 7.5 minutes if three vehicles are used for repositioning. Similarly, if no repositioning is applied, at Stations S1 and S2 the average waiting time for returning a bike is quite long due to lack of empty racks. The average waiting time for Stations S1 and S2 are 76.7 and 26.3 minutes. When vehicle repositioning is applied, the average waiting time for returning a bike is reduced significantly. The average waiting time for returning a bike decreases as the number of

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repositioning vehicle increases. For example, in station S1, the average waiting time for returning a bike is 60.1 minutes if one vehicle is using for repositioning. The average waiting time for renting a bike will reduce to 28.9 minutes if two vehicle is using for repositioning and 25.1 minutes if three vehicle is using for repositioning. The results also showed that using two vehicles for repositioning reduced the average waiting time more significantly than using three vehicles.

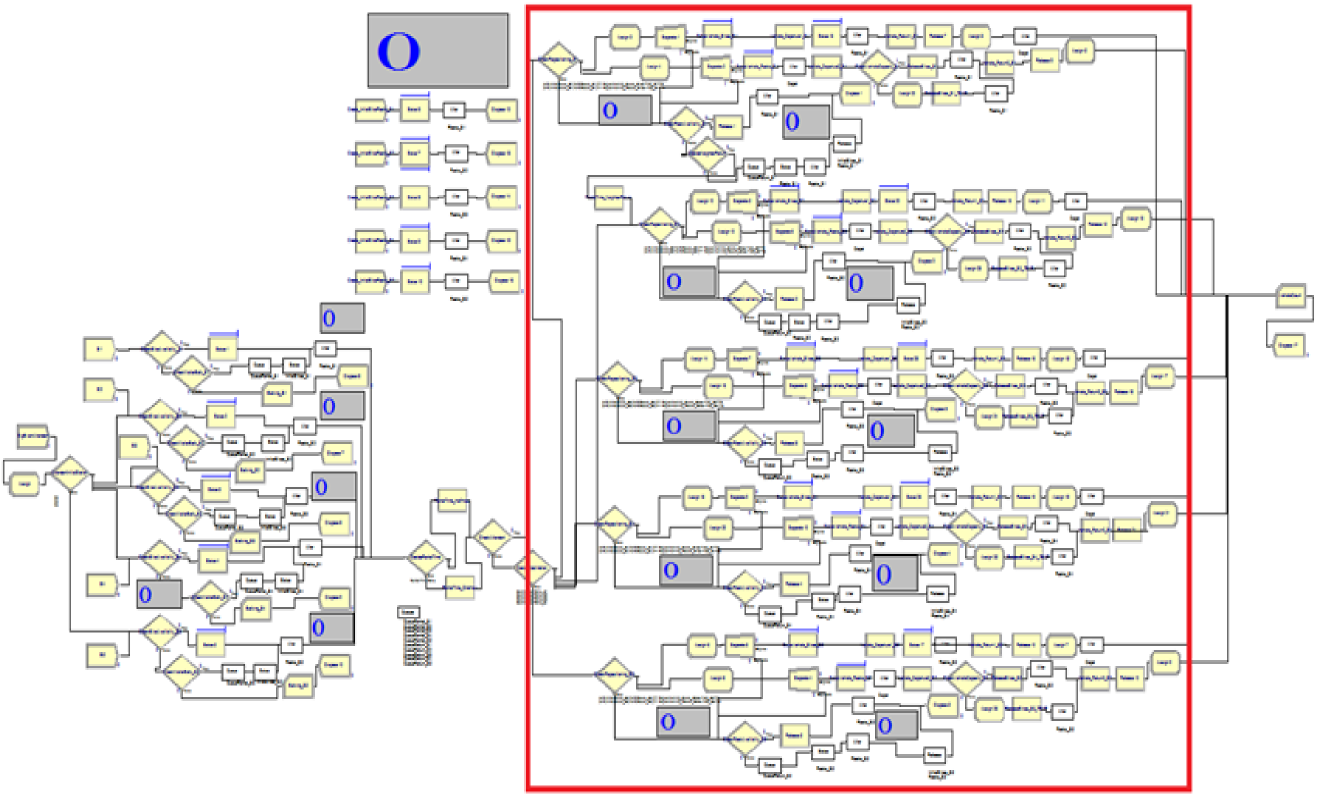

Fig. 1. Simulation model.

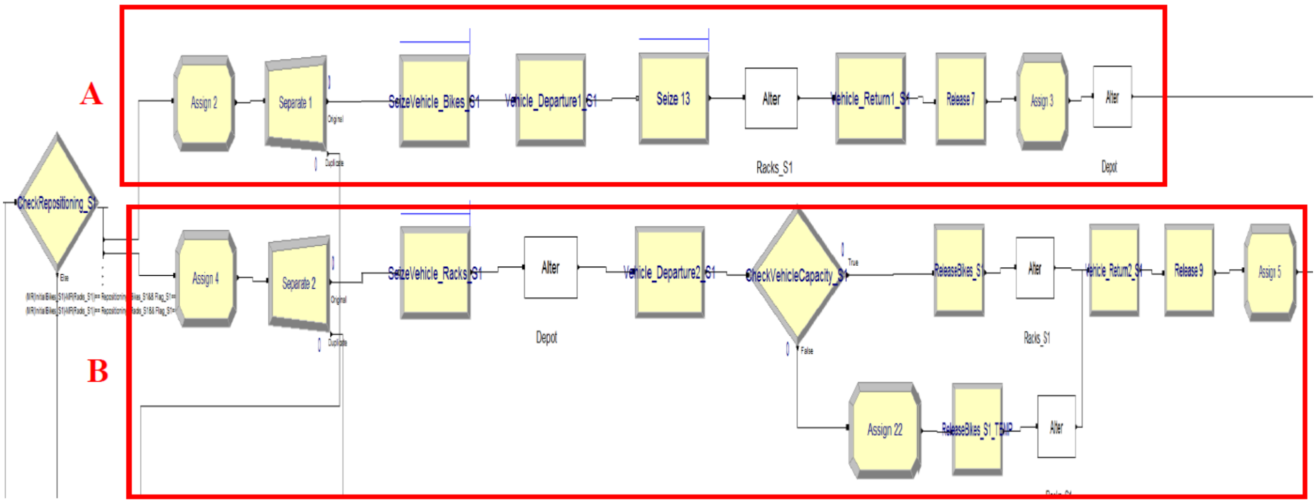

Fig. 2. Repositioning parts.

III. Computational Results

In this section, we present some computational results on the performance of the proposed simulation model. The simulation model is built in ARENA simulation software and executed on a computer with a 3 GHz CPU and 4GB of memory. Simulation time was set to 1 day, 8 hours per day. The warm up period was set to 1 hours with one replication. Table I shows the parameter settings for the bike sharing systems. The ibike systems in Taichung started in July, 2014,and the ibike systems are still expending by adding more rental stations. The official historical data for user demands are not available yet. We focus our research on 5 major stations of ibike systems. The total bike amount of each station is given by the ibike official website [1]. Based on some initial experimental models, we make assumptions for other param

TABLE I: BIKE SHARING SYSTEMS PARAMETER SETTINGS

Station	Total bike amount	Initial empty racks/bikes	Arrivial rate	Return station (probability,%)					Retal time distribution		Rental prob.(%)	
				S1	S2	S3	S4	S5	30 minutes	60 minutes	waiting	balking
S1	100	20/80	Expo(2)	25	15	15	25	20	Expo(80)	Expo(20)	80	20
S2	40	8/32	Expo(4)	25	15	15	25	20	Expo(80)	Expo(20)	80	20
S3	58	12/46	Expo(4)	25	15	15	25	20	Expo(80)	Expo(20)	80	20
S4	96	19/77	Expo(2)	25	15	15	25	20	Expo(80)	Expo(20)	80	20
S5	52	10/42	Expo(3)	25	15	15	25	20	Expo(80)	Expo(20)	80	20

TABLE III: QUEUE WAITING TIME OF DIFFERENT REPOSITIONING SETTINGS

Name	Queue Rental. Waiting Time (minutes)				Queue Return. Waiting Time (minutes)	
	S2	S3	S4	S5	S1	S2
No Repositioning	6.44	70.48	61.00	87.00	76.70	26.30
OneVehicle	4.10	27.85	23.00	25.00	60.10	26.50
TwoVehicles	4.31	8.204	18.00	17.00	28.90	16.30
ThreeVehicles	4.31	12.05	7.50	8.20	25.10	14.90

Table III shows the queue length of different repositioning settings. During the peak time, if no repositioning is applied, the average queue lengths for Stations S3, S4, and S5 are 14.38, 14.46, and 29.86. When repositioning is applied, the average queue length for renting a bike is reduced significantly. The average queue length for renting a bike decreases as the number of repositioning vehicle increases. For example, at Station S4, the average queue length for renting a bike is 5.57 if one vehicle is using for repositioning. The average queue length for renting a bike will be reduced to 3.24 if two vehicles are used for repositioning, and 0.52 if three vehicles are used for repositioning. Similarly, if no repositioning is applied, at Stations S1 and S2 the average queue length for returning a bike is quite long due to lack of empty racks. The average queue lengths for Stations S1 and S2 are 54.63 and 5.86. When vehicle repositioning is applied, the average waiting time for returning a bike is reduced significantly. The average waiting time for returning a bike decreases as the number of repositioning vehicle increases. For example, in station S1, the average queue length for returning a bike is 44.62 if one vehicle is using for repositioning. The average queue length for renting a bike will be reduced to 19.54 if two vehicles are used for repositioning, and 14.04 if three vehicles are used for repositioning.

TABLE III: QUEUE OF DIFFERENT REPOSITIONING SETTINGS

Name	Queue Rental. Number In				Queue Return. Number In	
	S2	S3	S4	S5	S1	S2
No Repositioning	0.18	14.38	14.46	29.86	54.63	5.86
OneVehicle	0.25	2.55	5.57	6.42	44.62	7.10
TwoVehicles	0.24	0.50	3.21	2.81	19.54	4.09
ThreeVehicles	0.24	0.57	0.52	0.89	14.04	3.99

Table IV shows the number of repositionings for different vehicle settings. The number of repositionings increases as the nunber of vehicles increases. When only one vehicle is used, 8 repositionings has been occued. When two vehicles are used, 16 repositionings have occured and when three vechles are used, 21 repositionings has have occured. Also, the utiliations for using one vehicle, two vehicles and three vehicles are 0.959, 0.927, and 0.778. Moreover, the number of customers served for no repositioning, using one vehicle, using two vehicles, and using three vehicles are 644, 777, 884, and 874. The utiliation for using three vehicles is low, and using two vehicles can serve more customers than using three vehicles. Hence, using two vehicles for repositioning is recommended.

TABLE V: VEHICLE UTILIZATION

Name	Vehicle Count	Vehicle. Utilization	System Number Out
OneVehicle	8	0.959	777
TwoVehicles	16	0.927	884
ThreeVehicles	21	0.778	874

IV. CONCLUSION AND FUTURE WORKS

In this research, a simulation model for solving vehicle repositioning problems in bike sharing system in Taiwan is presented. We tested several different scenarios, and the recommended number of vehicles for the repositioning problem that minimized customers waiting time. Future work can extend the model to include all bike-sharing stations in Taichung City in Taiwan and test on instances based on real-world data where the model for user demand is derived from historical data.

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