出國報告（出國類別：出席國際會並發表論文）

出席 **2017 ISBM** 國際學術研討會議及發表論文 心得報告

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摘要

本次出席的 2017 ISBM 國際學術研討會(International Symposium on Business and Management, ISBM 2017)今年是由泰國 Chulalongkorn University 、日本 Hyogo University of Teacher Education、台灣世新大學、及台灣知識學會所共同主辦的年度國際學術研討會，今年在相同的會議場地也同時舉行電子化(商務、控管、社會、教育、技術)研討會、教育與全球化研究研討會，為聯合性質的國際學術研討會。會議主體的研討議程持續兩天半(4/04 下午至 4/06)，今年主辦地點在日本京都市，於國際交流中心內舉行。

參加本次國際會議的目的有二，其一在於了解國際管理領域最新的研究發展趨勢，同時得知不同的專業領域在全球化及電子化之下的因應措施。目的之二在於發表本人的學術研究論文，並藉此與「公共設施規劃」相關領域之專家進行學術交流，藉以獲得後續研究的啓發。

目次

一、 目的

此次本人參加 2017 ISBM 國際學術會議(International Symposium on Business and Management, ISBM 2017)的目的有二：目的之一在於了解國際管理領域最新的研究發展趨勢，同時得知不同的專業領域在全球化及電子化之下的因應措施。目的之二在於發表本人的學術研究論文，並藉此與「公共設施規劃」相關領域之專家進行學術交流，藉以獲得後續研究的啓發。

此外，亦藉此行深入了解各國之管理領域，如何與產業結合、如何進行良好的產學合作計劃，使學術界與產業界能有良性互動、進而相互支援，形成雙贏局面。整體而言，藉由廣泛的心得交流，期望獲得寶貴的經驗。

二、 過程

本次 2017 ISBM 國際學術研討會今年是由泰國 Chulalongkorn University 、日本 Hyogo University of Teacher Education、台灣世新大學、及台灣知識學會所共同主辦的年度國際學術研討會，今年在相同的會議場地也同時舉行電子化(商務、控管、社會、教育、技術)研討會、教育與全球化研究研討會，為聯合性質的國際學術研討會。會議主體的研討議程持續兩天半(4/04 下午至 4/06)，今年主辦地點在日本京都市，於國際交流中心內舉行。本次研討會共計有 530 篇摘要/全文提出，來自於 38 個國家及地區，經嚴格篩選之後共約有 69%的摘要/全文被大會接受，最後共有 270 篇全文論文獲得審查通過並在大會中口頭報告。在兩天半的主體研討議程中，共有 48 個平行場次(Parallel Sessions)進行論文發表及 5 個海報發表場次(Poster

Sessions)，共有來自於 33 個國家的 300 位學者專家出席。

在 2017 ISBM 國際學術研討會的學術論文發表部份：每天的均共有四至五個時段並行發表，每時段約有五個場地同時進行學術論文發表。討論及辯證均十分熱列、交流與激盪的成果豐碩。

此次研討會本人發表的論文為「A Study of Public Renting Bicycle System Considering Location and Number of Bicycle」 (Paper ID: 7005，論文全文詳見附錄)，大會分配於 B4 場次，安排於 4 月 05 日 13:00-14:20 於國際交流中心一樓 Room 2 場地發表。本篇論文以台中市公共自行車租賃系統為研究背景，探討系統中較佳的租賃站設置地點，同時亦估算各租賃站的自行車配置數量，該議題在現今運輸能源費用上漲、環保綠能的環境下更顯重要，與會學者及專家對於本研究的構想與解析均持肯定態度，並對後續的研究方向與研究方法亦提出中肯而建設性的意見。

三、 心得

大會在各不同研究領域的專業激盪之下，與會學者及專家討論極為踴躍，各項研究子題大致以實務導向研究與學術導向研究兩者相輔相成。在實務導向方面，對電子化與全球化管理於產業的實際應用及實務成效，具有相當可貴的經驗分享；在學術導向方面，著重於問題模型的建構與解析的方法為主，同時探討較佳的模型求解方法與求解概念。

此外，本次研討會的特色為第一天(4/4)下午安排 Special Session，由資深企業主管及資深學者發表專題演講，講題分別為: Managing Teaching and Learning Records in Cloud: University Perspective 及 Critical Capabilities for Industrial IoT – From Reference Architectures to Embedded

Analytics 等。這些主題對雲端、大學教育、及研究發法均具有啟發性，故留下深刻印象亦值得未來效法。

四、 建議事項

關於本次研討會的特色及優勢，提出以下建議事項：

(1) 本次與會學者及專家涵蓋 33 個國家與地區，由於是聯合學術會議亦能涵蓋不同領域的專家學者，在強調知識整合、區域整合的現今國際環境下，由不同專業領域交流與激盪，實較易獲得跨領域合作與成果分享，故台灣辦理各項研討會時議可採用聯合學術會議的概念與做法。

(2) 研討會的成功因素之一，在於參與研討會的專家學者人數。而增加參與者的誘因，其做法之一為：結合主辦國家或主辦城市的特殊文化活動時期或特殊自然景觀時期，同步舉辦研討會。以本次研討會的地點而言，選在日本古都京都實具有極大誘因；以本次研討會的舉辦日期而言，正值本州櫻花盛開季前後，亦具有極大吸引力。

五、 附錄：發表論文全文

「A Study of Public Renting Bicycle System Considering Location and Number of Bicycle」

A Study of Public Renting Bicycle System Considering Location and Number of Bicycle

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ABSTRACT

This study investigates the planning of public bicycle rental system in Taichung City, Taiwan. We use Taichung's MRT stations as the candidates of bike rental station. By combining the data from the Ministry of Transportation and other literatures, the demand of public bicycle can be estimated for each candidate station. The model tries to find the best locations to set up bicycle rental stations and the number of bicycle required for each station.

This study will consider the following costs: bicycle acquisition cost, land cost of bicycle rental station, replacement cost, and bicycle rearrangement cost (*i.e.* a daily operation cost for arranging bicycle back to its initial location). The objective of this study is to minimize total cost by selecting suitable bicycle rental stations and arranging necessary bicycles for each station. In this study, we first develop a mathematical model and then construct a heuristic algorithm to solve the problem by using the simulated annealing logic. In addition, a sensitivity analysis is also conducted by considering different land costs and different distances required between stations.

Keywords: Public Bike Rental System, Site Selection, Setup Costs.

1. Introduction and Background

Due to the green environment considerations in recent years, a public bicycle rental system combined with public transportation systems is believed to be a better way to reduce air pollution and improve transportation efficiency. In designing a public bicycle rental system several factors must be carefully evaluated such as user requirements, bike rental site selection and acquisition cost, bicycle requirement and arrangement for each rental location, system initial investment and operating costs.

In real world bicycle rental system, customer may rent a bike at one location and return it to another location. This situation, sooner or later, may cause some rental location has no space to return a bike or no bike to rent. Therefore, rearrangement of bicycle for each rental station back to its original location is necessary operations which may cause additional cost and should be taken into consideration.

This study tries to propose an effective bicycle rental system in the initial design stage. In this study, a mathematical model is developed to minimize overall cost, including bicycle acquisition cost, land cost for each rental station, replacement cost due to limited service stations can be installed, and bicycle rearrangement cost due to different rental and return point. A heuristic solution algorithm is then developed to solve a real world problem focus on the public bicycle rental system of Taichung city in central of Taiwan.

2. Literature Review

History of public bicycle system evolves in three stages. The first stage was free public bicycle system which was developed in Amsterdam, Netherland (1965). The second stage was coin rental public bicycle system developed in Copenhagen, Denmark (1995). The third stage applies information technology to public bicycle rental system in Plymouth, England (1996). In Taiwan, several cities launch public bicycle rental system since 2009. Most of the systems accept credit card or membership card to activate the bicycle system in renting and returning operations.

2.1 Riding distance of public bicycle system

European Commission (1999) indicates 2 to 8 minutes bicycle riding distance is an efficient equipment for public transportation. In addition, the average riding speed is 15 kilometers per hour (Metropolitan Washington Council of Governments, 2010). Therefore, the average riding distance is 0.5 to 2 kilometers. This study will use 12 kilometers, *i.e*. four times of 2 kilometers, as the maximal distance between two bicycle rental stations.

2.2 Estimate demand for bicycle rental station

The study on Dublin, Ireland by Commins and Nolan (2011) indicates 3.5% population of 15 years old or older will use bicycle in their daily life. In Taichung city, Taiwan, 2.2% of 15 years old or older will use bicycle in their daily transportation. Lusk *et al*. (2014) indicates 30.9% of male bicycle users will rent public bicycle and the female users is 31.7%. Based on the above information, this study will use 0.6%, *i.e*. 2.2%*(30.9%+31.7%)/2, population of 15 years old or older as the demand for each bicycle rental station.

2.3 Land requirement and candidate location of rental station

Based on the data from the government of Taipei city, every 30 bicycles need 52 square meters, *i.e*. 26 meters long and 2 meters width, therefore, this study will use 2 square meters per bicycle as the land requirement.

In the initial developing stage of Taipei city, most of the bicycle rental stations are located on subway stations which can be easily connected to other public transportation system. This concept will be applied in Taichung city which is the case study in this research.

2.4 Other studies related to public bicycle rental system

Martinez *et al*. (2012) uses mixed-integer programming to solve the public bicycle rental system in Lisbon, Portugal. This study investigates locations of rental station, number of bicycle requirement. The objective of the model is to maximize profit through the revenues generated by the selected stations, setup cost of rental station, and bicycle acquisition cost.

Frade and Ribeiro (2014) estimates demand of bicycle by considering population density, density of job opportunity, density of sale retailers, sightseeing attractions, and type of geology. This study will develops an independent public bicycle system. This bicycle system combines with other transportation systems and it is illustrated by a real city.

Lin and Yang (2011) proposes a mathematical model to minimize system cost by considering setup cost of rental station, construction cost of bike riding paths, and bicycle rearrangement cost under service level constraints.

3. Model Construction and Solution Algorithm

This study assumes that there are *N* candidates locations can be selected as rental stations in a city. Each candidate location should serve local community with known population which will be used to estimate demand of bicycle. For the candidate location do not selected as a rental station, the bicycle rental requirement will be replaced by other rental station which will generate a replacement cost. The replacement cost includes additional land cost and additional bicycle acquisition cost. For those locations selected as bicycle rental stations, distance between two stations must be longer than minimal distance requirement and shorter than maximal distance requirement.

Two types of bicycle return operations considered in this study: (1) rent a bike from A station and return it to B station, (2) rent and return a bike at the same station. These operations will change the number of bicycle availability at the end of each renting period. Therefore, bicycle rearrangement to its initial available number is necessary for each station. In this paper, the cost of rearrangement operation is called the rearrangement cost.

The objective of the model developed in this study is to minimize overall cost of public bicycle rental system. The overall cost includes: (1) setup cost of rental station including land cost and bicycle acquisition cost, (2) replacement cost for the candidate location, (3) cost of bicycle rearrangement.

3.1 Basic assumptions and limitations

This study is developed on the basis of following assumptions and limitations.

1. Candidate locations of public bicycle rental station are given and known. Rental station should be selected from candidate locations. Number of rental station to be selected is given and known. This number should be less than the number of candidate location.
2. Demand of bicycle is calculated by the population around the candidate location and percentage of user. Population of community and percentage of user are given and known.
3. If a candidate location is not selected, its bicycle rental requirement will be replaced by other rental station. This situation will initiate a replacement cost which consists of additional land cost and additional bicycle acquisition cost.
4. All unit costs are given and known. The unit cost includes bicycle acquisition cost per bicycle, unit land cost of each candidate location, replacement cost per bicycle, and rearrangement cost per bicycle per period (day).
5. Distance between any two candidate locations is given and known.
6. For each bicycle rental station, the renter can return bicycle to any station. Probability of returning destination is given and known. These probabilities can be used to calculate rearrangement cost.
7. At the end of each operation period (*i.e.* day), each station should arrange bicycle to its initial number. These operations will generate the rearrangement cost.
8. Each rental station has limitation on space which is represented by number of bicycle can be stored. Each bicycle requires 2 square meters for parking.
9. For any rental station, distance to nearby station should be within 0.5 to 12 kilometer.
10. The public bicycle rental system should satisfy all rental requirements from all candidate locations.

3.2 Notations and variables

In this subsection, several notations and variables are prepared and defined for the following mathematical model.

Notations and variables:

N: total candidate locations can be selected as public bicycle rental station.

i, j, k: candidate location number which is also the bicycle demand number.

$i, j, k = 1, 2, \ldots, N$

D_i: demand of bicycle for candidate location i. $i = 1, 2, \ldots, N$

d_{ij}: distance from location i to location j. $i, j = 1, 2, \ldots, N$, $i \neq j$ ($d_{ii} = 0$)

K: bicycle acquisition cost.

T_i: land cost per square meter for candidate location i. $i = 1, 2, \ldots, N$

P: replacement cost per bicycle which includes bicycle acquisition cost.

CL_i: number of bicycle can be installed in candidate location i. $i = 1, 2, \ldots, N$

F_i: the shortest distance from rental station i to other rental stations.

$F_i = min\{d_{ij}, j = 1, 2, \ldots, N, i \neq j\}$

SN: number of rental station to be installed. SN is given and known. $SN < N$

MD_k: after replacement consideration, final demand of bicycle in rental station k. $k = 1, 2, \ldots, N$

R_{ik}: if candidate location i is selected as rental station, R_{ik} is bicycle return percentage from rental station k to rental station i. $i, k = 1, 2, \ldots, N$

W_{jk}: if candidate location j is not selected as rental station, W_{jk} is bicycle return percentage from rental station k to candidate location j. $j, k = 1, 2, \ldots, N$, $j \neq k$

RC: rearrangement cost per bicycle per period. (in this study one period is one operation day)

DS: periods in system life. DS is used to calculate overall rearrangement cost, *i.e.* change one period rearrangement cost to life time rearrangement cost.

UG: land requirement per bicycle (square meter)

M: a large positive number

Decision variables:

X_i: if candidate location i is selected as a rental station, then $X_i = 1$, otherwise $X_i = 0$ $i = 1, 2, \ldots, N$

S_{ij}: if the candidate location j is not selected as a rental station and the bicycle demand of candidate location j is replaced by rental station i, then $S_{ij} = 1$, otherwise $S_{ij} = 0$ $i, j = 0, 1, 2, \ldots, N$, $i \neq j$

Y_i: if the candidate location i is selected as a rental station and the bicycle of rental station i need to be rearranged, then $Y_i = 1$, otherwise $Y_i = 0$. $i = 1, 2, \ldots, N$

3.3 Model construction

The objective function and constraints are developed as follows.

$$Min.\ Z = Z1 + Z2 \quad (1)$$

$$Z1 = \sum_{i=1}^{N} X_i[D_i K + UG \times D_i T_i] + \sum_{i=1}^{N}\sum_{j=1}^{N} S_{ij}\left[D_j P + UG \times D_j T_i\right] \quad (2)$$

$$Z2 = RC \times DS \times \sum_{i=1}^{N} Y_i\{\sum_{i=1}^{N} X_i\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N}\left(R_{ik}MD_k + S_{ij}W_{ij}MD_k\right) - (X_i MD_k)\right]\} \quad (3)$$

$$st. \ \sum_{i=1}^{N} X_i = SN \tag{4}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} S_{ij} = N - SN \ , \ i \neq j \tag{5}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} S_{ij} X_j = 0 \ , \ i \neq j \tag{6}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} X_i S_{ij} = N - SN \ , \ i \neq j \tag{7}$$

$$\sum_{i=1}^{N} X_i D_i + \sum_{i=1}^{N} \sum_{j=1}^{N} S_{ij} D_i = \sum_{i=1}^{N} D_i \tag{8}$$

$$M(1 - X_i) + X_i F_i \geq 0.5 \quad , \quad for\ all\ i \tag{9}$$

$$X_i F_i \leq 12 \quad , \quad for\ all\ i \tag{10}$$

$$X_i D_i + \sum_{j=1}^{N} X_i S_{ij} D_j \leq CL_i \ , \quad i = 1, 2, \ldots, N \ , \quad i \neq j \tag{11}$$

$$X_i D_i + \sum_{j=1}^{N} S_{ij} D_j = X_i MD_i, \ \ i, j = 1, 2, \ldots, N \tag{12}$$

$$X_i \in \{0, 1\} \ , \ i \in N \tag{13}$$

$$S_{ij} \in \{0, 1\}, \ \ i, j \in N \ \ , i \neq j \tag{14}$$

$$Y_i \in \{0, 1\}, \ \ i \in N \tag{15}$$

The objective function, equation 1, is to minimize cost of public bicycle rental system which includes two parts as indicate in equation 2 and 3. Equation 2 defines the land cost and bicycle acquisition cost for selected rental station after replacement. Equation 3 defines rearrangement cost by calculating bicycle number to be arranged at the end of each period.

The first constraint, equation 4, confirms the required rental stations should be selected. Equation 5 ensures there are *N-SN* candidate locations to be replaced by rental stations. Equation 6 makes sure a selected location, *i.e.* a rental station, cannot be replaced. Equation 7 ensures total unselected location should be *N-SN*. Equation 8 confirmed that all demands of candidate location should be satisfied. Equation 9 and equation 10 make sure distance between rental stations within limitations. Equation 11 ensures number of bicycle do not exceed a predefined maximal number in each rental station. Equation 12 confirms bicycle demand of any rental station comes from the location itself and the replaced location. Equation 13 to equation 15 ensures all decision variables are 1 or 0 integers.

3.4 Solution algorithm

An initial solution is generated randomly and satisfied all constraints as indicated in subsection 3.3. Since the real case study (Taichung city) presented in this study has 40 candidate locations and 35 rental stations to be selected from those candidates, the solution space will reaches 658,008, *i.e.* C(40, 35). In addition, if the possibility of replacement (or substitution) for five unselected locations is considered, the solution space will up to 658,000*$(35)^5$. It becomes a NP hard problem in this case. Therefore, the solution algorithm is developed on the basis of simulated annealing (SA) logic. In each iteration of the improvement procedure, one of the selected rental stations will be replaced by one unselected candidate location. If the cost down, it becomes a better solution. If, on the other hand, the cost raised, this solution still can be accepted with a probability which is defined in SA procedure.

4. Case Study and Discussion

The basic data of this case study collects from Taichung city where is located in central of Taiwan. The public bicycle rental system of Taichung city will install 35 bicycle rental stations from 40 candidate locations, as indicated in Figure 1, which are scattered over eight zones in the city.

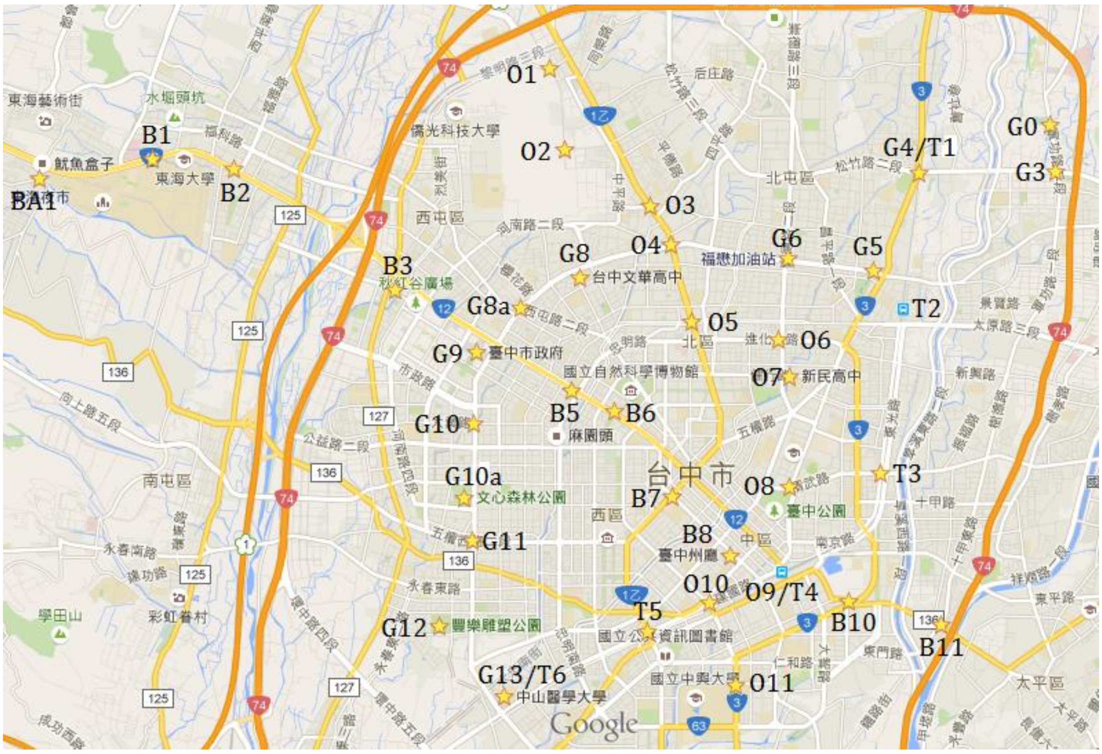

Figure 1 Candidate locations of rental station in Taichung city

4.1 Basic data

The population of each zone and demand of bicycle of each rental station are indicated in Table 1. Based on the literature reviewed in subsection 2.2, the demand of bicycle is estimated by 0.6% of the population (age between 15-59). In Table 1, the bicycle demand of each station in central zone is adjusted, *i.e.* increased, due to several public transportation systems connection in this zone, such as train station, bus terminals, and subway station (in the future). The bicycle return ratios are estimated in Table 2. Most of the cases, the renter will return the bicycle to the rental station where it is rented. These ratios will be used to calculate how many bicycles should be rearranged. The cost of rearrangement is then estimated. If the real-time data can be collected, these estimations will more close to real situation.

Table 1 Population of each zone and demand of bicycle in each candidate location

Zone ID	Population	Bicycle Demand	Rental Station Required	Demand per Station	
				Original	Final
1. Central	11,480	69	4	17	80*
2. Central East	51,167	307	3	102	102
3. Central South	85,333	512	5	102	102
4. Central West	77,002	462	3	154	154
5. Central North	100,500	603	4	151	151
6. West	154,390	926	10	93	93
7. South	74,683	448	3	149	149
8. North	183,691	1102	8	138	138

Table 2 Bicycle return ratios between zones

Zone ID \ Zone ID	8	6	7	4	5	3	1	2	Total
8	0.78	0.1	0.02	0.02	0.02	0.02	0.02	0.02	1.0
6	0.1	0.7	0.1	0.02	0.02	0.02	0.02	0.02	1.0
7	0.02	0.1	0.7	0.1	0.02	0.02	0.02	0.02	1.0
4	0.02	0.02	0.1	0.7	0.1	0.02	0.02	0.02	1.0
5	0.02	0.02	0.02	0.1	0.7	0.1	0.02	0.02	1.0
3	0.02	0.02	0.02	0.02	0.1	0.7	0.1	0.02	1.0
1	0.02	0.02	0.02	0.02	0.02	0.1	0.7	0.1	1.0
2	0.02	0.02	0.02	0.02	0.02	0.02	0.1	0.78	1.0
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

All cost data are summarized as follows. The bicycle acquisition cost is NT$10,000 per bicycle and the replacement cost is NT$15,000 per bicycle. The land cost is collected from websites provided by city government. Table 3 summarizes land cost per square meter for each candidate location. The rearrangement cost is NT$500 per bicycle per period (day). The rearranging bicycle is a daily operation, however, the cost of objective function is count on the basis of life time. Therefore, this study should assume a reasonable life time, which is 10 years (3650 days). The rearrangement cost will be changed from daily basis to life time basis. Distance data between any two locations is collected from the Google map using walking mode.

Table 3 Land cost for each candidate location

Zone ID	Candidate Location ID	Land Cost (NT$/square meter)	Zone ID	Candidate Location ID	Land Cost (NT$/square meter)
6. West	BA1	112,000	8. North	O3	831,250
	B1	162,750		G0	126,875
	B2	195,125		G3	140,000
	B3	169,750		G4	306,250
	O1	271,250		G5	262,500
	O2	87,000		G6	198,625
	G8	214,375		T1	306,250
	G8a	214,375		T2	297,500
	G9	696,500	5. Central North	O4	168,875
	G10	530,250		O5	250,250
4. Central West	B5	514,500		O6	144,375
	B6	315,875		O7	227,500
	B7	133,000	3. Central South	O10	236,250
1. Central	B8	183,750		O11	288,750
	O8	262,500		T5	302,750
	O9	336,000		T6	161,875
	T4	336,000		G13	161,875
2. Central East	B10	231,000	7. South	G10a	831,250
	B11	121,624		G11	507,500
	T3	107,625		G12	787,500

4.2 Solution and discussion

Based on the basic data collected in subsection 4.1 and the solution procedure discussed in subsection 3.4, a computer program is then developed to solve the problem. Table 4 summaries the cost data of initial solution and final solutions.

Table 4 Cost comparison of initial solution and final solutions

Run No.		Total Cost (OFV)	Setup Cost (Land+Bicycle)	Replacement Cost (Land+Bicycle)	Rearrangement Cost
Initial Solution		4,984,695,325	2,722,164,750	319,652,000	1,942,878,575
2	Final Solution (Improvement %)	3,301,499,675* (33.76%)	1,955,821,250* (15.37%)	285,738,500** (0.68%)	1,059,939,925 (17.71%)
	Cost Improvement	1,683,195,650	766,343,500	33,913,500	882,938,650
6	Final Solution (Improvement %)	3,325,549,375 (33.27%)	2,061,267,250 (13.25%)	255,267,000 (1.29%)	1,009,015,125 (18.73%)
	Cost Improvement	1,659,145,950	660,897,500	64,385,000	933,863,450
5	Final Solution (Improvement %)	3,356,306,700 (32.66%)	2,129,205,250** (11.89%)	221,898,750 (1.96%)	1,005,202,700* (18.81%)
	Cost Improvement	1,628,388,625	592,959,500	97,753,250	937,675,875
4	Final Solution (Improvement %)	3,415,149,450 (31.48%)	2,061,267,250 (13.25%)	183,389,250* (2.73%)	1,170,492,950 (15.50%)
	Cost Improvement	1,569,545,875	660,897,500	136,262,750	772,385,625
3	Final Solution (Improvement %)	3,420,028,425 (31.38%)	2,061,267,250 (13.25%)	226,295,750 (1.87%)	1,132,465,425 (16.26%)
	Cost Improvement	1,564,666,900	660,897,500	93,356,250	810,413,150
1	Final Solution (Improvement %)	3,442,058,475** (30.94%)	2,061,267,250 (13.25%)	194,773,000 (2.51%)	1,186,018,225** (15.18%)
	Cost Improvement	1,542,636,850	660,897,500	124,879,000	756,860,350
Average Cost Improvement (Average Improvement %)		1,607,929,975 (32.25%)	667,098,833.3 (13.38%)	91,758,291.67 (1.84%)	849,022,850 (17.03%)

Remark: 1. *The best one out of 6 runs, **The worst one out of 6 runs,

2. Cost Improvement = Initial Cost - Final Cost, $\text{Improvement \%} = \frac{(\text{Initial Cost} - \text{Final Cost})}{\text{Initial Cost}} \times 100\%$

There are six independent runs based on different random number seeds and the best final solution is found in the run #2. In general, the solution procedure proposed in this study can improve overall cost up to 32% which comes from setup cost 13%, replacement cost 2%, and rearrangement cost 17%.

Form the best solution in run #2, Table 5 indicates all 35 rental stations in details, which are selected from 40 candidate locations.

Table 5 The rental stations selected in run #2 (the best) and cost data

Station ID	Setup Cost	Replacement Cost (Station ID/Bicycle)	Rearrangement Cost	Sub Total
BA1	21,762,000	35,611,000 (G10a / 149)	0	57,373,000
B1	31,201,500	0	40,648,225	71,849,725
B2	37,223,250	0	40,648,225	77,871,475
B3	32,503,500	0	40,648,225	73,151,725
O1	51,382,500	0	72,134,950	123,517,450
O2	17,205,000	0	72,134,950	89,339,950
G8	40,803,750	0	65,827,750	106,631,500
G8a	40,803,750	0	65,827,750	106,631,500
G10	99,556,500	0	65,827,750	165,384,250
B6	98,829,500	0	0	98,829,500
B7	42,504,000	0	0	42,504,000
B8	30,200,000	0	64,373,225	94,573,225
O8	42,800,000	0	95,859,950	138,659,950
O9	54,560,000	0	95,859,950	150,419,950
T4	54,560,000	105,798,000 (B5 / 154)	0	160,358,000
B10	48,144,000	0	24,223,225	72,367,225
B11	25,831,500	0	24,223,225	50,054,725
T3	22,975,500	36,149,250 (O3 / 157)	0	59,124,750
G0	41,408,750	0	0	41,408,750
G3	45,530,000	0	0	45,530,000
G4	97,732,500	0	0	97,732,500
G5	83,995,000	0	0	83,995,000
G6	63,938,250	0	0	63,938,250
T1	97,732,500	0	65,992,000	163,724,500
T2	94,985,000	0	65,992,000	160,977,000
O4	52,510,250	0	0	52,510,250
O5	77,085,500	0	0	77,085,500
O6	45,111,250	0	0	45,111,250
O7	70,215,000	0	0	70,215,000
O10	49,215,000	0	55,709,950	104,924,950
O11	59,925,000	0	55,709,950	115,634,950
T5	62,781,000	57,706,500 (G9 / 93)	0	120,487,500
T6	34,042,500	50,473,750 (G12 / 149)	0	84,516,250
G13	34,042,500	0	48,298,625	82,341,125
G11	152,725,000	0	0	15,2725,000
Total	1,955,821,250	285,738,500	1,059,939,925	3,301,499,675

There are five rental stations replace five unselected candidate locations, therefore, the replacement costs, *i.e.* land cost and bicycle acquisition cost, should be added in these rental stations. It is believed that if other requirements of replace condition are considered, then the associated constraints should be included in the mathematical model. In this study, the judgment only focuses on a “lower” replacement cost.

4.3 Sensitivity analysis on land cost and distance between stations

Most of the large cities, the land cost is the major cost item in installation of a public bicycle rental system. This study conducts a sensitivity analysis assuming different land cost per square meter, *i.e*. 50%, 80%, 100% (the original case), 120%, and 150%. The results and cost data are presented in Table 6. It is found that the costs of rearrangement will change, however, the cost trend of rearrangement is different from the trend of land cost.

Table 6 Sensitivity analysis on land cost per unit square

Scenario No.	Adjustment of Unit Land Cost (%)	Total Cost (OFV)	Setup Cost (Land+Bicycle)	Replacement Cost (Land+Bicycle)	Rearrangement Cost
(1)	50%	2,323,070,263	1,166,349,875	134,403,750	1,022,316,638
(2)	80%	3,039,207,775	1,657,427,800	208,613,400	1,173,166,575
Original	100%	3,301,499,675	1,955,821,250	285,738,500	1,059,939,925
(3)	120%	3,990,605,888	2,465,106,700	336,936,000	1,188,563,188
(4)	150%	4,618,388,200	2,913,066,875	481,638,750	1,223,682,575

In design stage of public bicycle rental system, distance between rental stations is an important issue in user friendly and convenient. Therefore, the following sensitivity analysis focuses on reduce distance from 0.5-12 kilometer (the original case) to 0.5-2 kilometer. The cost results are indicated on Table 7. Reducing distance between stations will increase overall cost up to 132% in this scenario. It is obviously that increasing the convenience of renter will increase the installation cost. A more detailed investigation is deserved if a more user friendly system is considered.

Table 7 Sensitivity analysis on distance between rental stations

Scenario No.	Distance Limitation (Kilometer)	Total Cost (OFV)	Setup Cost (Land+Bicycle)	Replacement Cost (Land+Bicycle)	Rearrangement Cost
Original	0.5 to 12	3,301,499,675	1,955,821,250	285,738,500	1,059,939,925
(1)	0.5 to 2	4,341,293,788	2,724,489,750	417,696,000	1,199,108,038

5. Conclusions

This study suggests a mathematical model to select suitable rental stations for a public bicycle rental system from candidate locations. The objective function is to minimize costs including land cost and bicycle acquisition cost. The requirements of bicycle from the unselected locations are considered in the objective function as replacement costs. In addition, the daily operational cost of bicycle arrangement is also included in consideration. A heuristic solution algorithm is also suggested to solve a real world NP hard problem.

A case study of Taichung city's public bicycle rental system is conducted to illustrate the model and solution heuristic. The solution results and sensitivity analysis are useful for system designer and management level. The analysis approach suggested in this study is worth of future researches.

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