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Sustainable Electric Personal Mobility: The Design of a Wireless Charging Infrastructure for Urban Tourism

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Abstract: Though new technologies have been applied in all industries, electric mobility technology using eco-friendly energy is drawing a great deal of attention. This research focuses on a personal electric mobility system for urban tourism. Some tourism sites such as Gyeongju, Korea, have broad spaces for tourists to walk around, but the public transportation system has been insufficiently developed due to economic reasons. Therefore, personal mobility technology such as electric scooters can be regarded as efficient alternatives. For the operation of electric scooters, a charging infrastructure is necessary. Generally, scooters can be charged via wires, but this research suggests an advanced electric personal mobility system based on wireless electric charging technology that can accommodate user convenience. A mathematical model-based optimization was adopted to derive an efficient design for a wireless charging infrastructure while minimizing total investment costs. By considering the type of tourists and their tour features, optimal locations and lengths of the static and dynamic wireless charging infrastructure are derived. By referring to this research, urban tourism can handle transportation issues from a sustainable point of view. Moreover, urban tourism will have a better chance of attracting tourists by conserving heritage sites and by facilitating outdoor activities with electric personal mobility.

Keywords: electric vehicle; personal mobility; wireless charging; tourism attraction; infrastructure design

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1. Introduction

Electric vehicles are attracting attention since they are a substitute for fossil fuel vehicles and they reduce greenhouse gas emissions [1]. Electric vehicles have various advantages besides environmental sustainability, such as instant torque and quietness. Generally, stationary charging stations are provided [2]; however, with a wireless charging system, significantly greater convenience could be provided [3]. Although applying the wireless charging system is no easy task, various studies have been performed. According to the authors of [4], wireless charging systems are expected to be applied in various contexts in the near future; especially for vehicles requiring less energy and less time to charge, a wireless charging system can have quite an impact.

Personal mobility technology is becoming popular for various reasons. The authors of [5] speculate that the decreased need for cars and driving licenses as well as shortened travel distance might lead customers to prefer personal mobility compared to cars. Especially when personal mobility vehicles become electric, it is expected to be beneficial and economical [6]. Therefore, personal mobility technology that uses sustainable energy is expected to increase. However, personal mobility technology is infrequently applied in the current urban systems, and therefore, there have been few trials to develop overall urban plans.

The sustainable urban mobility plan (SUMP) was introduced by the European commission to improve mobility friendliness in areas such as roads by planning for personal mobility [7]. SUMP includes various components such as safety, economy, health, and land usage [8]. Though it is clear that SUMP is needed, various considerations should be taken into account when conducting this plan since both personal mobility and general vehicles should also be considered. When considering personal mobility systems in an urban plan, charging and parking stations are very important. However, in the current situation, the number of charging stations and parking lots is insufficient [9]. Therefore, for personal mobility technology to become integrated as part of urban mobility, a charging infrastructure is necessary.

A wireless charging infrastructure can be an important part of the solution to implement an urban personal mobility system, especially when it comes to travel destinations. In the case of Gyeongju, Korea, the shortage of public transportation due to economic issues can decrease tourist satisfaction. Since the time taken for tourists to walk is similar to that of taking public transportation, shared personal mobility could be a great substitute. Likewise, an electric personal mobility charging infrastructure may contribute to increasing tourist satisfaction.

Though there exist various shared personal mobility companies that lease electric scooters, many problems have arisen. A representative problem is the improper return of devices by users, as seen in Figure 1. This can damage the electric scooters, and retrieving such scooters to the charging depots results in greater time and monetary costs for the scooter companies. Therefore, if shared electric scooters from existing companies are used at tourism locations, problems can occur. However, if shared personal mobility only exists at tourism sites, it can be viewed as part of the tourism experience. Since roads at tourism sites are generally narrow or difficult for cars to maneuver, an efficient battery charging system should be devised.

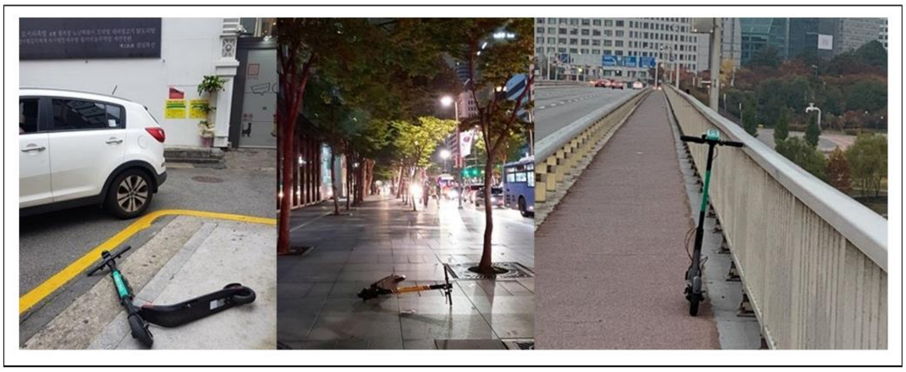

Figure 1. Shared electric scooters neglected on the road.

As can be seen in Figure 2, Gyeongju is not a big city and the distances between the heritage sites are not far. Moreover, most of the tourism sites are located on flatlands, so tourists prefer walking. Currently, businesses allowing tourists to rent electric bicycles are drawing attention. If personal mobility devices can be driven in this area, charging stations are necessary to allow tourists to travel around without worrying about the battery. Moreover, Gyeongsangbuk-do Province, where Gyeongju is located, achieved a government expenditure for "IoT-based infrastructure for wireless charging" in August 2020. Therefore, a practical strategy to install wireless charging stations should be devised here.

In this case, both stationary wireless charging infrastructures and dynamic wireless stationary infrastructures for tourists should be considered. In the case of stationary wireless charging infrastructures, they can be located at some tourism sites so tourists can leave their vehicles while sightseeing. For certain routes that many tourists pass, dynamic wireless charging infrastructure can be applied. In this case, the personal mobility scooters can be charged while tourists are moving. A personal mobility vehicle with a wireless charging infrastructure can help provide a safe and cost-friendly system for tourism [10].

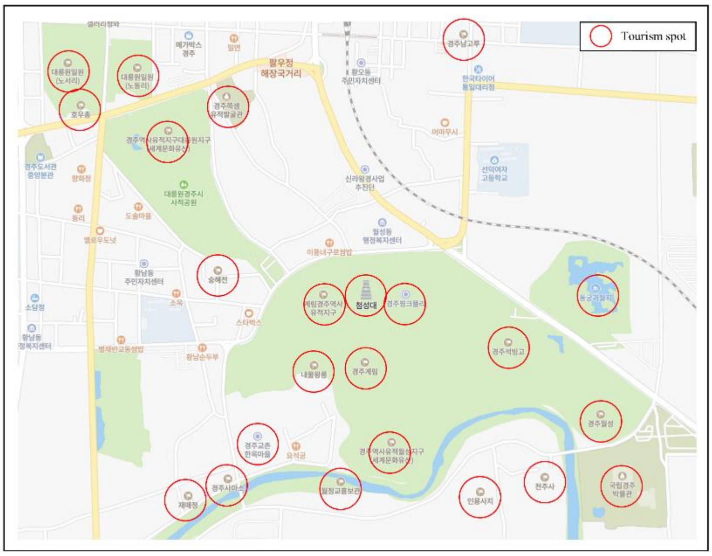

Figure 2. Tourism sites of Gyeongju, Korea.

A literature review is conducted in Section 2. Then, the overall procedures to apply the personal mobility system is described in Section 3. The devised mathematical model is explained in Section 4, and the results of the numerical experiment are demonstrated in Section 5. Lastly, concluding remarks are offered in Section 6.

2. Literature Review

The development of wireless charging technology has been ongoing, and it has been applied in various industries. Wireless charging technology can be commonly found in mobile phone charging. The representative research of wireless phone charging technology was introduced by Qualcomm [11] and Kyoto University [12]. Moreover, wireless charging technology is starting to be applied to electric vehicles as well. In 2006, the Massachusetts Institute of Technology introduced a wireless power transmitting technology that can work at mid-range distances with low frequency [13]. By applying the technology developed by the Massachusetts Institute of Technology, WiTricity devised wireless charging stations for cars [14].

As mentioned above, wireless charging can be done through charging stations or roads that have power transmitters. Thus, electric vehicles can be charged while moving, which is called the Online Electric Vehicle (OLEV) system. The authors of [15] developed an overall power supply system for OLEVs such as a transmitter and wireless transfer mechanism. Moreover, the authors of [16] introduced wireless power transfer by applying a magnetic field. Throughout the system devised in this research, an electric bus could travel with the minimum capacity of the battery. The authors of [17] introduced a mass transportation system by using OLEVs to allocate power transmitters and the battery capacity.

Personal mobility technology introduced these days generally use electric energy. Moreover, the interest in personal mobility is gaining attention. According to the authors of [9], it is discovered that people aged 28 to 65 can use personal mobility vehicles conveniently. Furthermore, personal mobility technology can limit contact with others during the COVID-19 pandemic, and it is expected to be recognized as a sustainable transportation. Additionally, personal mobility vehicles can allow riders to move further distances than walking. Therefore, it might help some people in choosing a personal mobility vehicle as a substitute to cars [18].

Though personal mobility is very convenient since it can pass through narrow roads and park in small areas, its disadvantage is the small battery capacity. Though there are comparatively sufficient charging stations for electric cars, charging stations for personal mobility is insufficient. Therefore, the authors of [10] suggested a wireless charging system for personal mobility. Throughout the experiments, the authors developed a system with 90% of efficiency. Furthermore, the authors of [19] investigated a wireless charging system with a multi-level perspective, so that various types of vehicles can be charged. The authors of [20] conducted an experiment installing an electric scooter charging dock. While observing how people use charging docks, the authors discussed how the charging dock should be operated. The authors of [21] performed research on the energy storage system for electric scooters considering wireless charging. Suggesting a newly developed hybrid energy storage system and wireless power transfer design, the authors conducted an experiment. The result of the experiment showed that the new design could achieve 86.4% efficiency in charging the battery.

Personal mobility can be recognized as a travel mode, but it can also be recognized as recreation. The author of [22] researched how mobility can affect people when they travel around a local area. It was discovered that mobility can bring positive effects such as recreation during tourism. The authors of [23] compared how tourists react when there is a car compared to a sustainable private transportation. The results of this research showed that young people are increasingly interested in sustainable personal transportation and that such an interest is expected to grow in the future. The authors of [24] proposed an electric scooter operated on a small island. According to this research, electric scooters can be suitable for recreational purposes.

As can be seen in the previous research, the need for sustainable electric mobility will increase. There are some countries such as the US, Singapore, Malaysia, and Korea that use shared electric scooters. Though it can be recognized as a transportation for locals, it can also work as an attraction for tourists too. However, it is difficult to find research that deals with personal mobility at tourism sites or as an attraction. Therefore, this research contributes to other research by evaluating how shared electric mobility will affect tourism and where the electric personal mobility can be applied additionally.

3. Application Procedure for Electric Personal Mobility in Urban Tourism

For reasons such as individualization and the recent COVID-19 pandemic, the number of tourists who travel together as a single group is decreasing. That is, it is becoming more common to travel in small groups, such as individually or in twos. In this situation, the operation of mass transportation such as buses or trains can be a waste of resources. As an efficient alternative, electric personal mobility is in the limelight. Tourists can move without waiting for buses or trains by using electric personal mobility vehicles to travel between tourism sites in urban areas. Therefore, mobile scooters are expected to stimulate urban tourism.

However, because an expensive charging infrastructure is necessary for operation, the application of an electric personal mobility system while minimizing the total investment cost is important. In addition, wireless charging technology is adopted in this study, and the installation of a wireless charging infrastructure will be considered. With that, the overall application procedure for electric personal mobility in urban tourism is suggested as in Figure 3.

Figure 3. Overall application procedure.

3.1. Customer Data Collection

There is a great deal of customer-related data which can reveal tourism preferences [25]. In the past, those data were generally collected using questionnaires. The researchers prepared several questions related to tourism preferences and collected the answers by asking those questions. This method is easy to apply, but there are some potential errors since people can either lie or not actually know themselves. Therefore, customer tourism preferences are indirectly estimated with transaction data, which is what the customer actually paid for, or with customer behavior data from a specific situation [26]. Using the method of indirect estimation, such data often leads to more accurate results. Moreover, those data are commonly used in data-based recommendation systems, which have recently been in the spotlight [27].

3.2. Customer Segmentation

Personalization is one of the keywords in the tourism industry in recent years [28]. In fact, in order to develop a truly personalized service, a vast amount of accurate data must be collected, analysis must be performed using an algorithm in a short time, and a service suitable for the result must be found and provided. However, it is often nearly impossible to put these works into practice. Therefore, it is more reasonable to provide a service according to customer segmentation, which is an intermediate level between popularized service and personalized service [29]. In this study, it is proposed to perform customer segmentation that considers the limitations of data collection and the accuracy of the collected data from actual application situations; the size of the problem, that becomes complicated; and the degree of utility that can be obtained by solving the problem.

3.3. Segment Identification

In this study, for optimal installation of a wireless charging infrastructure, it is necessary to derive data for each customer segment such as preferred tourist sites to visit, stay time for each tourist site, and the probability of using personal mobility. In order to identify each customer segment, it is necessary to first define the characteristic elements of each customer segment and to then select the customers considered as representatives of each customer segment [30]. After that, it will be possible to derive necessary data by conducting a questionnaire or focus group interview with the selected customers representing each customer segment.

3.4. Algorithm Development

It is necessary to derive an optimal design for the installation of a wireless charging infrastructure by integrating data such as preferred tourist sites to visit, stay time for each tourist site, and the probability of utilizing personal mobility for each customer segment. In this study, a mathematical model-based optimization technique is applied to develop an algorithm. It is known that this method can derive an optimal solution mathematically when developed as linear programming [31]. A detailed explanation of the developed mathematical model is given in Section 4.

3.5. Charging Infrastructure Installation

When the developed algorithm is applied, an optimal design for the wireless charging infrastructure is derived. In this case, the wireless charging infrastructure can be largely divided into a static charging infrastructure and a dynamic charging infrastructure. The electric personal mobility vehicle with wireless charging technology can be charged through a dynamic charging infrastructure while driving and through a static charging infrastructure while parked [4]. In general, static charging infrastructures can be installed in parking lots at depots and tourist sites. When considering installation, a sufficient number of charging locations should be installed taking into consideration the preferred tourist sites to visit, stay time for each tourist site, and the probability of utilizing personal mobility for each customer segment to prevent cases where charging is not possible due to insufficient charging stations. The dynamic charging infrastructure is buried under the road. Therefore, electric personal mobility can be powered wirelessly when driving on roads with a dynamic charging infrastructure.

4. Model Development

4.1. Problem Description

There are depots at which tourists can rent a personal mobility vehicle. Each tourism site work as both the parking lot and the static wireless charging center. The battery capacity of each personal mobility is fixed, and it is assumed that the tourist rents a fully charged personal mobility. When the tourist moves from one tourism site or depot to another, one optimal route between each node is suggested, and the tourist may only move through the optimal route. Energy is consumed in proportion to the distance traveled by the tourist, and no energy is needed to park the personal mobility. When the tourist passes through the roads installed with a dynamic wireless charging infrastructure, the battery is charged in proportion to the distance that the tourist travels. The personal mobility vehicle should maintain a minimum level of battery until the tourist finishes traveling.

There are different types of tourists considering tour features. The tourism sites each tourist visits, stay time, and visiting order are known based on the type of tourist. There is a maximum stay time at each tourism site. A dynamic wireless charging infrastructure can be installed between each tourism site and depot. To install a dynamic wireless charging infrastructure, cost is charged based on its length. A static wireless charging infrastructure can also be installed, and the cost is charged based on the number of stations. It is assumed that, when the static wireless charging infrastructure is decided to be installed at certain tourism sites, a sufficient number is installed to charge personal mobility. In other words, the tourism site and stay time of the tourist are decided based on the type of tourist. The designated number of static wireless charging infrastructures is installed when the tourists stay there for the maximum stay time. In other cases, the number of static wireless charging infrastructures decreases in proportion to the ratio of visiting tourists and their stay time.

Based on the situation above, the optimal number of static and dynamic wireless charging infrastructures is derived while minimizing investment cost.

4.2. Notations

4.2.1. Known Parameters

This paper generates a solution for installing static and dynamic wireless charging infrastructure for urban tourism. The following notations are composed of the elements regarding the electric personal mobility and type of tourists.

4.2.2. Decision Variables

The decision variable set for this mathematical model represents the installation of the static and dynamic wireless charging infrastructures at the tourism location.

4.3. Mathematical Model

Equation (1) is the objective function that minimizes total investment costs. It consists of the sum of the static infrastructure installation cost and dynamic infrastructure installation cost.

$$\sum_{i \in I} c_{static} \cdot K \cdot n_i \cdot y_i + \sum_{i \in I^+} \sum_{j \in I^+} c_{dynamic} \cdot x_{ij} \quad (1)$$

Equation (2) explains the calculation of the energy level of battery after the tourist leaves the depot and arrives at a tourism site. Equation (3) denotes the energy level of the battery when the tourist moves from one tourism site to another tourism site. Equation (4) represents the remaining state of charge when the tourist arrives at the depot after finishing the tour.

$$\sum_{i \in I} c_{static} \cdot K \cdot n_i \cdot y_i + \sum_{i \in I^+} \sum_{j \in I^+} c_{dynamic} \cdot x_{ij} \quad (2)$$

$$e_{start}{}^{z} - r^{z}_{0j} \cdot \left(ea_{0j} - x_{0j} \cdot eb\right) \geq e^{z}_{j} - \left(1 - r^{z}_{0j}\right) \cdot M j \in I,\ z \in Z \quad (3)$$

$$e'^{z}_{i} - r^{z}_{ij} \cdot \left(ea_{ij} - x_{ij} \cdot eb\right) \geq e^{z}_{j} - \left(1 - r^{z}_{ij}\right) \cdot M\ i \in I,\ j \in I,\ z \in Z \quad (4)$$

Equation (5) shows the energy level of battery while charging at the static wireless charging infrastructure.

$$e_i^z + t_i^z \cdot ec \cdot y_i \geq e\prime_i^z,\ i \in I,\ z \in Z \quad (5)$$

Equation (6) ensures that the energy level of the battery cannot exceed its maximum capacity when the tourist arrives at a tourism site, and Equation (7) denotes that the energy left when the personal mobility vehicle departs from the depot cannot exceed its maximum capacity when the tourist arrives at the tourism site. Equation (8) shows that the energy level of the battery when the personal mobility vehicle finishes a tour cannot exceed its maximum capacity. Equation (9) ensures that the energy level of the battery when the personal mobility vehicle arrives at a certain tourism site should be greater than the minimum energy level. Equation (10) shows the energy level of the battery when the personal mobility vehicles departs from a tourism site should be greater than the minimum energy level. Equation (11) shows that the energy level of the battery when the personal mobility vehicles finishes a tour should be greater than the minimum energy level. Lastly, Equation (12) ensures that the energy level of the personal mobility vehicle after arriving at the tourism site should be greater than when it departs from it.

$$e_i^z \leq e_{max},\ i \in I,\ z \in Z \quad (6)$$

$$e\prime_i^z \geq e_{min},\ i \in I,\ z \in Z \quad (7)$$

$$e_{end}^z \leq e_{max},\ i \in I,\ z \in Z \quad (8)$$

$$e_i^z \geq e_{min},\ i \in I,\ z \in Z \quad (9)$$

$$e'^z_i \geq e_{min},\ i \in I,\ z \in Z \quad (10)$$

$$e_{end}^z \geq e_{min},\ i \in I,\ z \in Z \quad (11)$$

$$e'^z_i \geq e_i^z,\ i \in I,\ z \in Z \quad (12)$$

Equation (13) makes sure that the length of the dynamic wireless charging infrastructure is not negative. Lastly, Equation (14) denotes that the distance of the routes should be longer than the length of the dynamic wireless charging infrastructure to be installed. Equation (15) prevents the routes from overlapping.

$$x_{ij} \geq 0,\ i,j \in I^+ \quad (13)$$

$$x_{ij} \leq d_{ij},\ i,j \in I^+ \quad (14)$$

$$x_{ij} = x_{ji},\ i,j \in I^+ \quad (15)$$

5. Numerical Experiment

The solution to the numerical experiment is derived by applying IBM CPLEX version 12.9.0. IBM CPLEX is a commercial software that can solve linear programming models, mixed integer programming models, and so on.

5.1. Parameter Settings

A numerical experiment is conducted by considering the circumstances of Gyeongju, Korea. Gyeongju is known as a representative tourism location that has significant historical heritage sites. The tourism sites and the types of tourists that are considered in this research are organized in Table 1.

The mathematical model devised in this research adopts two different categories of parameters. The first category of parameters is related to the wireless charging infrastructure and electric personal mobility, and a part of those are generated in Table 2. The energy charging speed and the minimum and maximum battery capacities can differ with the level of technology applied. Moreover, c_{static} and $c_{dynamic}$ can be different based on the situation.

The parameters suggested in Table 2 are an example, and the optimal result can be derived when the parameters are changed.

Table 1. Information about tourism sites and tourist type.

Index of i	Node	Index of i	Node	Index of z	Type
1	Chenmachong	9	Dongbu historic site	1	Family
2	Hwangridan-gil	10	Gyerim	2	Friend
3	Daereungwon stonewall	11	Woljeonggyo Bridge	3	Couple
4	Daereungwon	12	Lotus subdivision	4	Field trip
5	Gyeongju station	13	Wolseong	5	Single
6	Daereungwon gate	14	Donggung and Wolji		
7	Kyochon village	15	Gyeongju National Museum		
8	Cheomseongdae	16	Bunhwangsa		

Table 2. Known parameters related to electric personal mobility.

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
e_{max}	10 kWh	${e_{start}}^z$	10 kWh (z = 1)	n_i	0.14 (i = 3)	n_i	0.16 (i = 10)
e_{min}	2 kWh		10 kWh (z = 2)		0.18 (i = 4)		0.13 (i = 11)
eb	0.0022 kWh		10 kWh (z = 3)		0.02 (i = 5)		0.19 (i = 12)
ec	2 kWh		10 kWh (z = 4)		0.08 (i = 6)		0.03 (i = 13)
c_{static}	$ 900		10 kWh (z = 5)		0.17 (i = 7)		0.22 (i = 14)
$c_{dynamic}$	$ 10	n_i	0.17 (i = 1)		0.18 (i = 8)		0.23 (i = 15)
K	100		0.15 (i = 2)		0.14 (i = 9)		0.1 (i = 16)

Energy consumption is dependent on the distance of each tourist's move, and this is demonstrated in Table 3.

Table 3. Value of ea_{ij}

i \ j	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0.00	1.54	1.96	1.01	1.09	0.95	1.09	3.20	1.87	1.75	1.87	3.20	2.60	2.40	2.80	3.40	3.40
1	1.54	0.00	0.50	1.46	0.45	2.20	0.45	2.20	1.58	1.78	1.58	2.80	3.80	3.20	3.60	4.40	4.60
2	1.96	0.50	0.00	1.88	0.87	2.60	0.87	2.40	1.52	1.72	1.52	2.60	3.40	3.20	3.60	4.20	5.00
3	1.01	1.46	1.88	0.00	1.01	1.80	1.01	2.40	0.92	1.03	0.92	2.60	2.80	2.60	3.00	3.60	4.20
4	1.09	0.45	0.87	1.01	0.00	1.79	0.10	2.60	1.94	2.00	1.94	3.20	3.40	3.40	3.60	4.40	4.20
5	0.95	2.20	2.60	1.80	1.79	0.00	1.79	3.80	2.60	2.40	2.60	3.80	3.00	3.00	3.20	4.00	3.20
6	1.09	0.45	0.87	1.01	0.10	1.79	0.00	2.60	1.94	2.00	1.94	3.20	3.40	3.40	3.60	4.40	4.20
7	3.20	2.20	2.40	2.40	2.60	3.80	2.60	0.00	1.40	1.60	1.40	0.59	2.60	2.60	2.80	3.00	5.40
8	1.87	1.58	1.52	0.92	1.94	2.60	1.94	1.40	0.00	0.25	0.10	1.74	1.80	1.68	2.00	2.80	4.00
9	1.75	1.78	1.72	1.03	2.00	2.40	2.00	1.60	0.25	0.00	0.25	1.86	1.74	1.59	1.94	2.60	3.80
10	1.87	1.58	1.52	0.92	1.94	2.60	1.94	1.40	0.10	0.25	0.00	1.74	1.80	1.68	2.00	2.80	4.00
11	3.20	2.80	2.60	2.60	3.20	3.80	3.20	0.59	1.74	1.86	1.74	0.00	2.40	2.20	2.60	2.60	5.20
12	2.60	3.80	3.40	2.80	3.40	3.00	3.40	2.60	1.80	1.74	1.80	2.40	0.00	0.37	0.60	1.18	2.00
13	2.40	3.20	3.20	2.60	3.40	3.00	3.40	2.60	1.68	1.59	1.68	2.20	0.37	0.00	0.37	1.07	3.00
14	2.80	3.60	3.60	3.00	3.60	3.20	3.60	2.80	2.00	1.94	2.00	2.60	0.60	0.37	0.00	0.38	2.20
15	3.40	4.40	4.20	3.60	4.40	4.00	4.40	3.00	2.80	2.60	2.80	2.60	1.18	1.07	0.38	0.00	2.80
16	3.40	4.60	5.00	4.20	4.20	3.20	4.20	5.40	4.00	3.80	4.00	5.20	2.00	3.00	2.20	2.80	0.00

The distance between nodes is set based on the actual road distance, and this is organized in Table 4.

Table 4. Value of d_{ij}

i \ j	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0	770	978	506	545	476	545	1600	937	873	937	1600	1300	1200	1400	1700	1700
1	770	0	248	731	224	1100	224	1100	792	892	792	1400	1900	1600	1800	2200	2300
2	978	248	0	940	433	1300	433	1200	758	858	758	1300	1700	1600	1800	2100	2500
3	506	731	940	0	507	901	507	1200	462	513	462	1300	1400	1300	1500	1800	2100
4	545	224	433	507	0	895	50	1300	969	1000	969	1600	1700	1700	1800	2200	2100
5	476	1100	1300	901	895	0	895	1900	1300	1200	1300	1900	1500	1500	1600	2000	1600
6	545	224	433	507	50	895	0	1300	969	1000	969	1600	1700	1700	1800	2200	2100
7	1600	1100	1200	1200	1300	1900	1300	0	701	799	701	295	1300	1300	1400	1500	2700
8	937	792	758	462	969	1300	969	701	0	126	50	868	900	840	1000	1400	2000
9	873	892	858	513	1000	1200	1000	799	126	0	126	931	870	794	970	1300	1900
10	937	792	758	462	969	1300	969	701	50	126	0	868	900	840	1000	1400	2000
11	1600	1400	1300	1300	1600	1900	1600	295	868	931	868	0	1200	1100	1300	1300	2600
12	1300	1900	1700	1400	1700	1500	1700	1300	900	870	900	1200	0	186	300	592	1000
13	1200	1600	1600	1300	1700	1500	1700	1300	840	794	840	1100	186	0	186	533	1500
14	1400	1800	1800	1500	1800	1600	1800	1400	1000	970	1000	1300	300	186	0	192	1100
15	1700	2200	2100	1800	2200	2000	2200	1500	1400	1300	1400	1300	592	533	192	0	1400
16	1700	2300	2500	2100	2100	1600	2100	2700	2000	1900	2000	2600	1000	1500	1100	1400	0

The stay time of customers (t_i^z) and whether a certain type of tourist visits the tourism site (s_i^z) is depicted in Table 5.

Table 5. Stay time and visiting travel sites of tourists.

	t_i^z					s_i^z				
i \ z	1	2	3	4	5	1	2	3	4	5
0	30	20	0	40	10	1	1	0	1	1
1	0	30	30	0	30	0	1	1	0	1
2	0	30	30	0	20	0	1	1	0	1
3	30	10	10	40	20	1	1	1	1	1
4	20	0	0	0	0	1	0	0	0	0
5	10	10	10	10	5	1	1	1	1	1
6	0	30	40	0	20	0	1	1	0	1
7	30	20	0	40	20	1	1	0	1	1
8	30	0	0	40	20	1	0	0	1	1
9	45	0	10	40	0	1	0	1	1	0
10	0	20	30	0	20	0	1	1	0	1
11	50	30	40	0	0	1	1	1	0	0
12	0	0	0	0	30	0	0	0	0	1
13	0	40	50	0	30	0	1	1	0	1
14	50	0	0	60	50	1	0	0	1	1
15	30	0	0	30	0	1	0	0	1	0
16	30	20	0	40	10	1	1	0	1	1

Lastly, the routes of certain types of tourists (r_{ij}^{z}) are decided by considering the tourism sites that each type of tourists might prefer. The order of routes visited by tourists is decided based on the entrance and exit while considering Gyeongju city's tour route recommendations. Moreover, tourist type (z) is hypothetically set as family ($z = 1$), friend ($z = 2$), couple ($z = 3$), field trip ($z = 4$), and single ($z = 5$). Furthermore, the number of each tourist type (z) is decided as 100 ($z = 1$), 200 ($z = 2$), 300 ($z = 3$), 300 ($z = 4$), and 100 ($z = 5$). The route for each type of tourist is depicted in Figure 4.

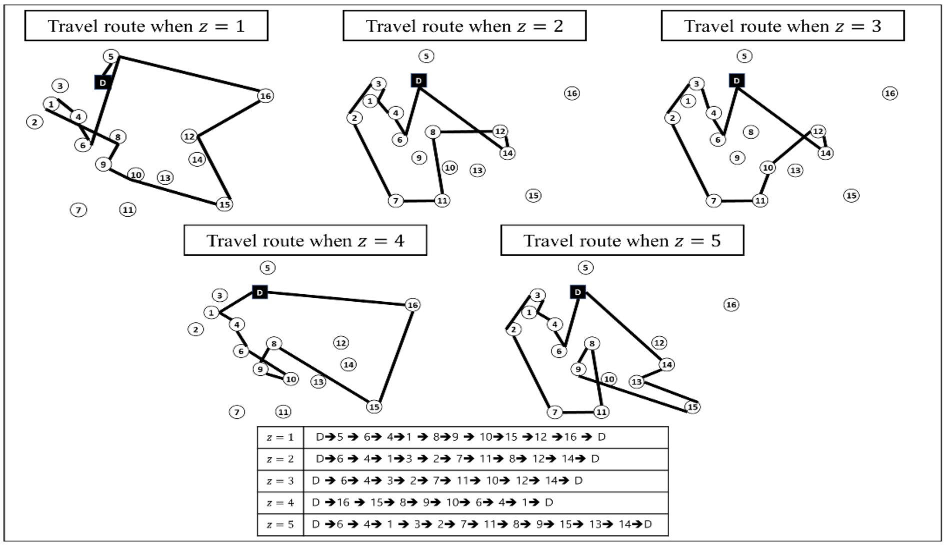

Figure 4. Travel route of each tourist type.

5.2. Result

Based on the parameters set in Section 5.2, the results of the numerical example are derived. The total investment cost is $119,920 to install 3 static wireless charging infrastructures and a 4211 m long dynamic wireless charging infrastructure. The location of the result is expressed in Figure 5. As can be seen in Figure 5, the static wireless charging infrastructure is built in the suburbs of the tourism sites. However, the dynamic wireless charging infrastructure is installed relatively central to all the sites.

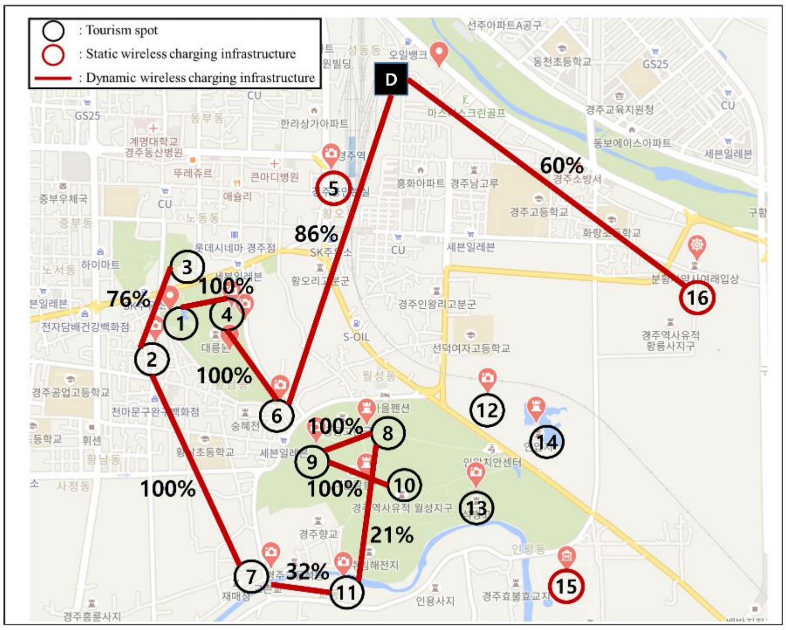

Figure 5. Installation result of the dynamic and static wireless charging stations.

To check if the derived result is correct, the proportion of each tourist type passing through certain routes and sites is provided simultaneously with the installation status of the dynamic wireless charging infrastructure in Table 6. The installation status of the static wireless charging infrastructure is provided in Table 7. The visiting probability of each route is calculated based on the sum of tourists that visit the route or node. For example, as seen in Table 6, if all the tourist types travel through route 4 to 6, then the probability of visiting that route is 1.0, which is 100%.

Table 6. Installation status of the dynamic wireless charging infrastructure.

Route		Visiting Probability	Dynamic Wireless Charging Infrastructure Installation
Departure	Arrival		
4	6	1.0	O
1	4	0.7	O
Depot	6	0.6	O
2	3	0.6	O
2	7	0.6	O
7	11	0.6	O
Depot	14	0.6	X
8	9	0.5	O
12	14	0.5	X
9	10	0.4	O
Depot	16	0.4	O
1	3	0.3	X
8	11	0.3	O
3	4	0.3	X
10	11	0.3	X
10	12	0.3	X
15	16	0.3	X
8	15	0.3	X
6	10	0.3	X
Depot	1	0.3	X
8	12	0.2	X
Depot	5	0.1	X
5	6	0.1	X
1	8	0.1	X
10	15	0.1	X
12	15	0.1	X
12	16	0.1	X
9	15	0.1	X
13	15	0.1	X
13	14	0.1	X

Table 7. Installation status of the static wireless charging infrastructure.

Tourism Site	Visiting Probability	Static Wireless Charging Infrastructure Installation
15	0.23	O
14	0.22	X
12	0.19	X
4	0.18	X
8	0.18	X
1	0.17	X
7	0.17	X
10	0.16	X
2	0.15	X
3	0.14	X
9	0.14	X
11	0.13	X
16	0.10	O
6	0.08	X
13	0.03	X
5	0.02	O

According to Tables 6 and 7, interesting insights are derived. First, the dynamic wireless charging infrastructure is not installed proportionally with the probability of tourists visiting. In the case of the route between tourism site 14 and the depot, a dynamic wireless charging infrastructure is not installed because tourist types 2, 3, and 4 pass many routes with the dynamic wireless charging infrastructure. For example, tourist type 2 passes the route between tourism site 6-4-1 and tourism site 3-2-7-11-8 with the dynamic wireless charging infrastructure. Tourist type 3 passes the through the route between tourism site 6-4 and tourism site 3-2-7-11 with the dynamic wireless charging infrastructure. Lastly, tourist type 4 passes the route between the depot, tourism site 16, tourism site 8-9-10, and tourism site 6-4-1 with the dynamic wireless charging infrastructure. Likewise, the reason that the routes between tourism sites 12-14 and 1-3 do not have a dynamic wireless charging infrastructure is the same.

Second, the reason that a static wireless charging infrastructure is not installed at tourism sites 14 and 12 is because they are located near the end of each travel route for tourists. If enough energy remains in the battery, they do not need to be charged. The static wireless charging infrastructure is not installed at tourism sites 1,2,3,4,7,8,9 and 10 because the dynamic wireless charging infrastructure is installed between these nodes. Moreover, since they are generally located in the middle of their travel routes, they can charge their personal mobility vehicles along the other routes. Therefore, a static wireless charging infrastructure is not needed.

Lastly, the reason that the static wireless charging infrastructure is installed at tourism sites 16 and 5 is as follows. Tourism site 16 is visited by tourist type 4 first. However, it is far from the depot. Therefore, both dynamic and static wireless charging infrastructures are installed. To minimize the investment cost, the dynamic wireless charging infrastructure is installed only along 60% of the routes since the static wireless charging infrastructure is installed simultaneously. In the case of tourism site 5, only one type of tourist can visit. However, the tourist should travel between tourism sites 5 and 6, in which case the travel distance is long. Therefore, a static wireless charging infrastructure is installed.

It can be found that the dynamic wireless charging infrastructure is installed along routes that many people travel. Comparatively, a static wireless charging infrastructure is installed at tourism sites that are far from the others. However, a higher percentage of visitation does not always necessitate the installation of wireless charging. This is the reason why a scientific and quantitative method is needed to decide the infrastructure design. By referring to the results of this research, it is expected that many regions can consider adopting wireless charging stations.

6. Conclusions

This study devises a design for static and dynamic wireless charging infrastructures for urban tourism. Some of the regions that have tourism sites gathered in an area that is too small for tourists to drive a car but big enough for tourists to walk can consider adopting electric personal mobility technology. Electric personal mobility has many advantages such as reducing greenhouse gas emission by using sustainable energy and creating additional recreational attractions at tourism sites for sustainable tourism.

To adopt personal mobility successfully, user friendliness is essential. Too many personal mobility vehicles parked in tourism sites can affect scenic views. However, with an efficient charging infrastructure, usage of personal mobility can be maximized. Current commercial, shared electric scooter companies generally collect the discharged vehicles and charge them through wires. If the vehicles located at tourism sites are charged this way, it would incur much customer dissatisfaction because tourists may have to wait for a long time.

Therefore, with the installment of a wireless charging infrastructure at tourism destinations, many tourists do not have to worry about the battery while they are using the vehicle. This research considered both static and dynamic wireless charging for efficient operation of personal mobility technology at tourism sites.

The derived results from the numerical experiment show some interesting results. It is found that a static wireless charging station can even be located at tourism sites that not many customers visit. The reason is that some tourism sites are located far from others, making it necessary for tourists to charge their personal mobility vehicles. It can be said that the devised model considers all types of tourists so that they can enjoy sightseeing by riding a personal mobility vehicle. Moreover, the dynamic wireless charging infrastructure is generally installed along the routes that many tourists visit.

The value of this research is not the provision of the infrastructure design, but the decision-making algorithm to be applied for various situations. The parameters applied can vary depending on the level of technology and region. However, this research can also derive the optimal result for each situation. Though the current parameter is hypothetical, with actual data, a reasonable result to be applied in actual infrastructure design can be derived.

This study is expected to contribute to the literature on the application of personal mobility in the tourism industry. Though there have been various researches about personal mobility, many of them focus on the negative side of them. However, when people follow safety rules well, personal mobility can be settled as one of the recreational attractions. As young people are increasingly interested in personal mobility vehicles, positive research that can help them to enjoy personal mobility safely should be conducted. Moreover, compared to the research about wireless charging for conventional vehicles such as cars, those that deal with personal mobility have rarely been done. Since the battery capacity of a personal mobility vehicle is very small, an efficient charging strategy should be devised.

In a practical point of view, there can exist some tourism sites struggling with the neglected shared personal mobility at tourism sites. For these vehicles to be charged, companies must visit the tourism sites, find those neglected shared personal mobility vehicles, and collect them for wired charging. Since they are not that light for people to move without electric power, superintendents of tourism sites might be stressed. However, it might be difficult to ignore the increasing attention toward personal mobility. Therefore, the superintendents of tourism sites can refer to this research to decide whether they will adopt their own personal mobility system. By installing a wireless charging infrastructure, tourism destinations may attract more customers, prevent commercial shared personal mobility from being be neglected, and hence obtain a chance to generate additional benefits.

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Abbreviations

i, j	Index for the tourism site and depot
0	Index for the depot
I	Set of tourism sites
I^+	Set of tourism sites and depots, $\mathrm{I} \cup \{0\} = \mathrm{I}^+$
z	Index for the type of tourist, $\mathrm{z} \in \mathrm{Z}$
t_i^z	Stay time of tourist type z at tourism site i
d_{ij}	Distance between node i and node j
ea_{ij}	Energy consumption when a tourist moves from node i to node j
s_i^z	1, when the tourist type z visit tourism site i0, otherwise
r_{ij}^z	1, when the tourist type move from node i to node j0, otherwise
e_{start}^z	Initial energy battery level of personal mobility that tourist type z rides
n_i	Coefficient to calculate the number of the static wireless charging infrastructure to be installed at tourism site i
e_{max}	Maximum battery level that can be charged
e_{min}	Minimum battery level that should be kept
eb	The amount of energy charged as the personal mobility vehicle moves some distance on the dynamic wireless charging infrastructure (kWh/m)
ec	The amount of energy charged as the personal mobility vehicles stays an hour beside the static wireless charging infrastructure (kWh/h)
c_{static}	Cost for static wireless charging infrastructure to be installed
$c_{dynamic}$	Cost for dynamic wireless charging infrastructure to be installed per unit distance (USD/m)
K	Number of static wireless charging infrastructures when the maximum number of tourists stay the maximum stay time at a tourism site
M	Large positive number
x_{ij}	Length of dynamic wireless charging infrastructure installed between node i and node
e_i^z	Energy level in the battery of the personal mobility vehicle driven by tourist type *z* arriving at tourism site
$e_i'^z$	Energy level in the battery of the personal mobility vehicle driven by tourist type z departing from tourism site i
e_{end}^z	Energy level in the battery of the personal mobility vehicle that tourist type z rides when arriving at the depot after finishing a tour
y_i	It becomes 1 if a static wireless charging infrastructure is installed at tourism site i, otherwise 0

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