Operational Evaluation of New Transportation Method for Smart City

Use of Personal Mobility Vehicles under Three Different Scenarios

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***Abstract*—One potential solution to traffic issues is to reduce traffic volumes in urban areas. A number of countries, particularly Japan, will face an unprecedented situation from an increasingly aging society. Thus, new eco-friendly universal mobility vehicles are expected to be developed. We proposed the use of personal mobility vehicles as a new type of transportation device. To evaluate the possibility of our proposed transportation device, it is necessary to conduct operational evaluations under real-world conditions by employing subjects in a pilot study. We used three experimental scenarios for an evaluation. The three scenarios used each different transportation route and subjects. Traveling data and questionnaire relating related to the velocity, stability, safety, and comfort of the proposed device were gathered. The results are valuable for evaluating the social receptivity, safety, and efficiency of a personal mobility device.**

Keywords- Personal Mobility Vehicle; ITS; New Transportation Device; Pilot Study.

I. INTRODUCTION

Many researchers have been seeking ways to solve traffic problems. The increase of urban traffic has led to increases in traffic jams, traffic accidents, and air pollution, all of which have resulted in serious damage [1][2]. One potential solution to these problems is to reduce the traffic volumes in urban areas. Modal shifts from conventional vehicles to public transportation and eco-vehicles, including personal vehicles, should also be considered to reduce urban traffic volumes. In this study, we focus on personal mobility to reduce traffic volumes in urban areas.

The rapid increase in the proportion of elderly people in the population has caused several issues in Japan [3]. Elderly people in Japan account for more road fatalities than any other age group [4]. Automobiles are an optimal means of transportation for the elderly because automobiles allow for door-to-door transportation. However, to address the traffic problems described above, we have to shift at least some movement of people from individual automobiles to public transportation, some aspects of which are less than ideal for the elderly. To resolve this conflict, useful and eco-friendly transportation must be provided for the elderly people. Although public transportation is useful and eco-friendly, the last-mile problem remains, particular for elderly users [5]-[7]. Personal mobility is considered the only option for solving this problem.

To address the aforementioned two challenges described above, we propose the use of personal vehicles as a means of future transportation. The main objective of this study is evaluating the feasibility of a new mobility device, i.e., a Winglet personal mobility vehicle, which is produced by the Toyota Motor Corporation of Japan. To obtain various types of related data, we prepared three different real-world scenarios under which we conducted an experiment using mobile sensors; in addition, we gathered questionnaire results regarding the subjects' overall experience with these scenarios.

Herein, in Section 2, the Tsukuba Designated Zone, where the real-world experiment was conducted, is described. In Section 3, we present the evaluation questionnaires provided. In Section 4, the results of the real-world experiment are all described.

II. TSUKUBA DESIGNATED ZONE FOR EXPERIMENTS

This section describes the Tsukuba Designated Zone, where the experiment was performed. This institution was formed to improve robotics technology (personal mobility is considered to be in the robotics category in Japan). It was officially approved as the Tsukuba Designated Zone by the Cabinet Office in Japan on January 29, 2010. The objective of this institution is described below.

It is impossible to do real-world personal mobility experiments in public areas because personal vehicles (including mobile robots) are prohibited from traveling in public areas under current law. Personal vehicles and robots are expected to contribute to the welfare of future generations through their low carbon emissions and high levels of safety and security. In addition, robotics technology is expected to contribute to the creation and development of new industries.

Since February 2012, Segway Japan, the Hitachi Corporation, and AIST have been engaged in conducting experiments in personal mobility, and more members, including private companies and universities, are planning to join them.

The Designated Zone has two areas for conducting experiments. One is the Tsukuba Center Station area, and the other is the Kenkyugakuen Station area, shown in Figure 1. The Tsukuba Center Station area consists mainly of a pedestrian road from the University of Tsukuba to Akatsuka Park, with a major focus on Tsukuba Central Station, where a large shopping center and a bus terminal are located. The

 ISBN: 978-1-61208-414-5

width of this road is greater than 3 [m] and is sufficient to allow use by bicycles. For these reasons, this public area is appropriate for experimental studies. Even within the Tsukuba Designated Zone, there are some regulations that apply to conducting experiments.

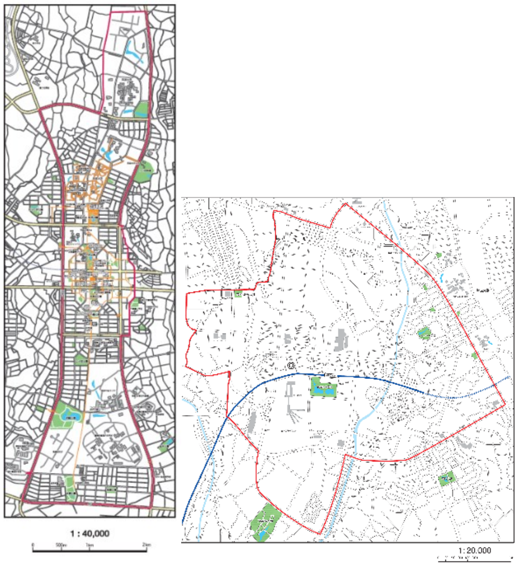

Figure 1. Tsukuba Designated Zone (Left: Tsukuba center area, Right: Kenkyugakuen area)

III. Operational Evaluations in Three Scenarios

We conducted an operational evaluation through real-world experiments. This section describes three scenarios employed in this study, the experimental conditions, the questionnaires provided, and the experimental results, as well as an overall discussion.

A. Personal Mobility Vehicle

The Winglet shown in Figure 2 was employed as the personal mobility vehicle in this study. The Winglet is an assistance-type mobility device that is ridden in a standing position and is designed to contribute to the realization of a world in which everyone can enjoy mobility freely and safely. The Winglet is more compact than a Segway personal mobility device [8]. We equipped each Winglet with several sensors to record data near incident scenes and record travel-related data (velocity, accretion, yaw rate, and location). We chose a Winglet because it is a two-wheeled, self-balancing vehicle, and riding a self-balancing vehicle poses different risks than riding a bicycle or walking.

Figure. 2 Winglets (equipped with mobile sensors)

B. Experimental Scenarios

All routes used in this study are located in the Tsukuba Designated Zone in Japan, which is described in section 2. We chose three scenarios, each of which has different features including a different route and subjects. Before conducting the experiments, we applied a risk assessment of riding a Winglet for every route. Each of the three scenarios is described in the following sub-sections.

1) AIST to Tsukuba St. (Scenario 1)

The route for scenario 1 runs between the AIST and Tsukuba Station in the Tsukuba center area. This route consisted of roads that are open to both pedestrians and cyclists. The route used for the experiment is shown in Figure 3 and Figure 4. The blue line shows the route itself, and the blue dots show the locations of the two stations in Figure 4. The route is mostly flat, but includes some slopes and pedestrian crossings. The surface of the route is asphalt and stone pavement. The distance of this route is about 3.6 km. The subjects participating in the experiment were AIST staff members and licensed drivers. The subjects ranged in age from 31 to 56, with an average age of 46.6. All subjects are engineering researchers. Most of the subjects typically use free AIST buses to or from Tsukuba station. For this scenario, the subjects used a Winglets as substitute for an AIST bus.

Figure 3. Experimental area for Scenario 1 (the blule line indicates the route for this scenario 1)

Figure 4. Photographs of the experimental route for scenario 1

2) Tsukuba City Government Office to Kenkyugakuen Station (Scenario 2)

The route for scenario 2 runs between the Tsukuba City Government Office and Kenkyugakuen St in the Kenkyugakuen area. This route consists of roads that are open to both pedestrians and cyclists. The area used for the experiment is shown in Figure 5 and Figure 6. In Figure 5, the green line shows the specific route used, which is mostly flat with pedestrian crossings. The surface of the route is asphalt and stone-paved. The distance of this route is about 0.7km. The subjects participating in this experiment were Tsukuba City staff members. All subjects were licensed drivers. The average age of the subjects was 36.6, with an overall range in age of 26 to 57. All subjects were office workers. In this scenario, we asked the subjects to use a Winglets as substitute for walking or using their own vehicle, and some of the subjects tried to modal shift from a vehicle to train and Winglet.

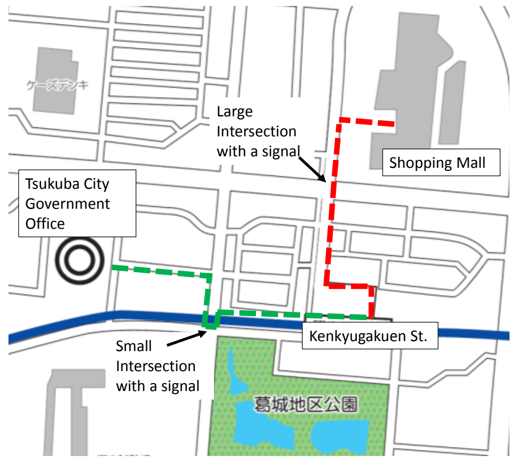

Figure 5. Experimental area for both scenario 2 and scenario 3 (the green lines indicates the route of scenario 2, and the red lines shows the route of scenario 3)

Figure 6. Photographs of the experimental course for scenario 2

3) Shopping Mall to Kenkyugakuen Station (Scenario 3)

The route for scenario 3 runs between the shopping mall and Kenkyugakuen St. tin he Kenkyugakuen area. This route consists of roads that are open to both pedestrians and cyclists. The route used for the experiment is shown in Figure 5 and Figure 7. The red line in Figure 5 shows the route used for scenario 3, which is also mostly flat with pedestrian crossings. The surface of the route is asphalt and stone pavement, and the distance is about 0.6 km. The subjects who participated in the experiment were staff members of the shopping mall. All subjects were licensed drivers. The average age of the subjects

 ISBN: 978-1-61208-414-5

was about 47.5 with a margin of error of plus or minus 5 owing to an issue of privacy. Their ages ranged from 25 to 75, also with a margin of error of plus or minus 5. All subjects were office workers. For this scenario, we asked the subjects to use a Winglet on during their break period.

Figure 7. Photographs of the experimental route for scenario 3

C. *Common Experimental Condition for the three Scenarios*

All of the subjects participated in a seminar regarding the Winglet and received training on how to ride one. In addition, the seminar addressed the control mechanisms of the Winglet and the rules for operating a Winglet in an outdoor environment. The training included both physical skill and written tests, and every subject who participated in the experiment had to pass both tests. All testing was organized by staff members authorized by Toyota Motor Corporation. No testing was conducted under rainy or dark conditions. For safety reasons, one staff member follows behind the personal vehicle during travel.

Each subject drove his or her Winglet from the start point to the end point. There are two pedestrian crossings on each course. The use of public areas was thought to be important in obtaining experimental results that would more closely reflect reality than results that would otherwise be obtained in restricted areas or laboratories.

D. *Questionnaire*

Before participating in the experiment, each subject filled out a questionnaire to provide answers to the following questions.

- ➢ What are your relevant personal characteristics (gender, age)?
- ➢ Which transportation method do you usually use for this route?
- ➢ Have you ever used this type of personal mobility device before?
- ➢ Do you usually do some exercise?

Also, a conjoint analysis of the subjects' responses was conducted.

After the experiment, each subject filled out a questionnaire providing answers to the following questions.

(I) Would you use a Winglet again under the same conditions? (If no, please describe the reason why?)
(II) Do you think the distance of the course was too long? (If so, please state what you think an appropriate length would be.)
(III) Was riding a Winglet more comfortable than walking?
(IV) What was your opinion of the maximum velocity?
(V) What do you consider the advantages and disadvantages of using a Winglet?
(VI) Are there other conditions or locations under which you would like to use a Winglet again?
(VII) If you have any comments regarding this experiments, please let us know.

IV. RESULT AND DISCUSSION

The subjects covered a total distance of approximately 217 km. All of the experiments were conducted without the occurrence of any accidents or near-accident situations that could have led to serious injury. In comparison with the data available for other mobility devices such as bicycles, the amount of experimental data obtained in this study is insufficient to assess the safety of the device. Nevertheless, this mobility device is believed to provide a significant measure of safety. We will continue to conduct experiments to prove its safety statistically in future studies.

The results and an analysis of each question are described in the following.

Figure 8 shows the results for question I. We found that the subjects expressed favorable opinions regarding the Winglet, and many expressed a desire to use it again in the future. For those who answered "no" regarding their future use of a Winglet, their reasons are as follows:

- ➢ It took too long because of the low maximum velocity (6km/h).
- ➢ I want to use the Winglet without an accompanying staff member.
- ➢ The Winglet needs to be improved when traveling on uneven roads.
- ➢ I want to avoid muscle fatigue in my foot.

These comments indicate that we need to improve the riding capability of the Winglet. In addition, privacy was found to be an important factor on using this type of mobility device.

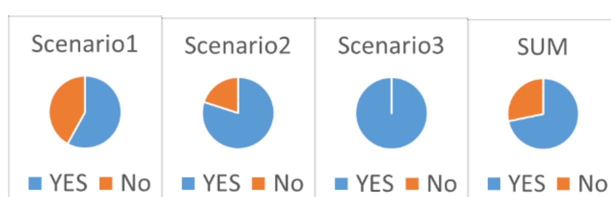

Figure 8. Results of wuestionnare I : Would you use a Winglet again under the same conditions

Figure 9 shows the results for question II. We found that the route distances of both scenarios 2 and 3 were appropriate.

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Based on those subjects who answered "yes" to whether the distances were appropriate, it is assumed that the average appropriate distance for a Winglet is about 2.6 km.

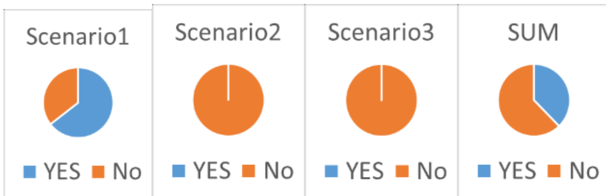

Figure 9. Results of questionnaire II:Do you think the distance of the course was too long?

Figure 10 shows the results for question III. Most subjects answered that the Winglet is more comfortable than walking. It is assumed that a Winglet can contribute to a reduction in fatigue when traveling.

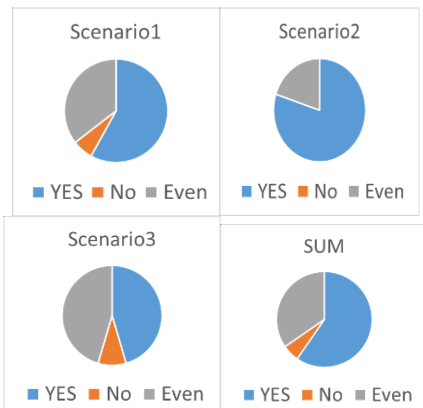

Figure 10. Results of questionnaire III ("Even" indicates no difference between riding a Winglet and walking)

Figure 11 shows the results for question IV. None of the subjects answered that the maximum velocity (6km/h) was too fast. About 80% of the subjects who answered that it was too slow hoped for a maximum velocity of over 10 km/h, and the average maximum velocity desired was about 12 km/h. Depending on the user preference, it may be better for users to be able to change the maximum velocity.

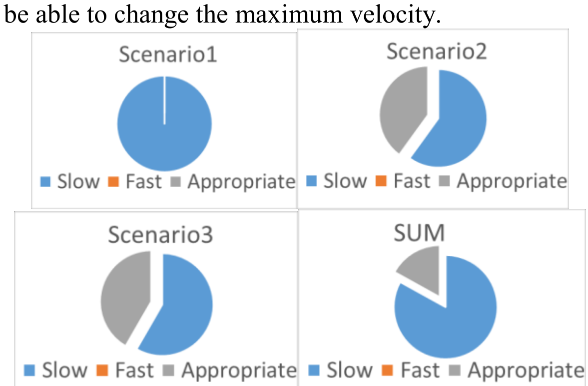

Figure 11. Results of questionnaire IV: What was your opinion of the maximum velocity?

Positive comments in the result of question V are as follows:

- I was able to enjoy great view because of the higher vantage point when riding the Winglet than when walking.
- I could communicate well because I felt comfortable during the experiment.
- I can commute to my office without using my vehicle
- I can travel without sweating.
- I was comfortable without pitch movement compared to walking.
- I can avoid getting my shoes dirty.

Most of the subjects provided comments related to the better vantage point while riding the device, which was unexpected, but may be a significant motivation for people to utilize a personal vehicle such as a Winglet. There were no negative comments in the results for question V.

Other possible uses for a Winglet found from the result of question VI include the followings:

- On sloping roads
- In a shopping mall
- For sightseeing
- For poor physical condition
- To go to a restaurant during lunch break
- On patrol

The results of question VII indicate that the subjects found it easy to avoid pedestrians when riding the Winglet because the footprint of the Winglet is close to that of a pedestrian and the device is easy to turn. Although the maximum speed of a Winglet is 6 km/h, which is close to walking speed, the rider of a Winglet tends to maneuver to avoid pedestrians before the pedestrians maneuver to avoid the rider.

Based on the results of all of the question, we determined the following evaluations regarding the use of a Winglet.

- The device should be utilized for short transportation distances owing to its size and velocity.
- It is useful for multiple purposes including commuting and sightseeing.
- It can be a great private transportation device.
- It assists the rider, especially when traveling on sloping roads.

The results of this technological evaluation are similar to reports on experiments conducted using Segway [8]-[13]. In analyzing the questionnaire results, we found that those people who used this personal device expressed favorable opinions for all three different scenarios.

The results obtained show that a Winglet personal mobility vehicle offers good social receptivity and safety on pedestrian roads, regardless of the age or gender of the rider. Therefore, riding a Winglet is presumed to be a feasible activity for all types of people, regardless of their age, gender, exercise habits or other factors.

To examine the various factors that can affect the experience of a Winglet, the relationships among the various factors identified from both the questionnaire and data analysis results will be analyzed in a future study.

 ISBN: 978-1-61208-414-5

In Japan, traffic regulations prohibit the use of standing-type vehicles, such as Winglets and Segways, on public roads, and hence, it is difficult to conduct experiments with these devices frequently, as mentioned previously in the section on the Tsukuba Designated Zone. Thus, the relaxation of these regulations is key to encouraging the use of the Winglet. If this issue is resolved, this system can be more widely used and would be particularly useful in a country such as Japan, given its traffic jams, expensive parking fees, and limited availability of parking lots. The findings obtained concerning efficiency, protection of the ecosystem and traveling data are not presented in this paper.

V. CONCLUSION

In this paper, we described an operational evaluation of a personal mobility vehicle as new type of transportation device. To evaluate the feasibility of the proposed transportation device, it was necessary to conduct an operational evaluation under real-world conditions by employing actual subjects in a pilot study. We used three experimental scenarios for our evaluation, each of which applied a different route and subjects. Travel data and questionnaire results related to the velocity, stability, safety, and comfort of the device were gathered. These results are valuable for evaluating the social receptivity, safety, and efficiency of a personal mobility device. In analyzing the questionnaire results, we found that the people who used this personal mobility expressed favorable opinions of the Winglet in three different scenarios. No accidents associated with the Winglet occurred during our experiments. Thus, the results of three experiment and questionnaire described in this paper show that Winglet personal mobility vehicle offers good social receptivity and safety on pedestrian roads for the multiple purposes. The Winglet riding assistance system for personal mobility are being developed [14][15]. A personal smartphone is used to determine percentage of closure of eyelid, eye blink time, eye-blinking rate, eye gaze, pupil movement, eyelid movement, postures, head pose using the front camera as well as Winglet speed and acceleration, vehicle headway (measurement of the distance or time between vehicles), lane position and road signs, Winglet turns using the back camera and other smartphone sensors. Rider Assistance Systems are the systems that assist the rider during the driving process. They are designed with a safe human-machine interface aiming to increase vehicle and road safety. It is common practice that such kind of systems are designed for car riders by the third party manufacturers that are specialized on them and can develop similar applications for the smartphones and tablets.

For future work, we will perform the experiments with the riding assistance system in the real world.

ACKNOWLEDGMENT

This work was supported by New Energy and Industrial Technology Development Organization in Japan, Japan Society for the Promotion of Science fellowship program and Government of Russian Federation, Grant 074-U01.

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