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SMILE First Project - Verification Tests in Real World for Multi-Purpose Mobility (mPm) - (3rd report)

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Summary

We have conducted verification tests using this mobility vehicle in the real world, have learned about its suitability and necessary improvements, and have studied the road conditions required for its use. We have made improvements to address concerns about the mobility vehicle that have arisen in these tests and in previous exhibitions and test rides. We have achieved the goals of developing a sensor unit that enables the confident, safe movement required for the mobility vehicle to be widely used by the public and incorporating the sensor unit with a control system.

Keywords: demonstration, tricycle, mobility concept, NEV, PAS

1 Intorduction

We must take steps worldwide to decarbonize society and in Japan to prepare for the super-aged society. As one answer, we presented a multi-purpose mobility vehicle (mPm) based on a new concept at EVS29 in 2016[1]. There are three aspects to the new concept: 1) the mPm can be adapted to many uses by changing configuration or mode; 2) the mPm can both move itself and assist movement of another vehicle; and 3) the mPm has the functions to be useful both at ordinary times and in emergencies[2][3].

At the 2nd Light Electric Vehicle Summit (LEVS) in November 2017, we reported on the state of development of a mechanism for attaching the mPm to a standard wheelchair for the purpose of assisting movement of another vehicle as in the second aspect of the concept[4]. We reported that we had created a mechanism with which, provided an attachment is already mounted to the wheelchair, the mPm can be attached or detached in about one minute. However, this operation requires significant bending of the body and is not suitable for elderly people and people with disabilities. Therefore, we are now investigating a mechanism that can be used by anybody.

Evaluating the mPm in realistic usage environments, beyond limited areas such as the laboratory and private spaces, is necessary to identify the development steps required to enable widespread use by the public and to understand the state of the infrastructure in which the mPm will be used. Therefore, verification tests in a range of conditions are necessary. We are currently conducting such tests and we report our results here.

We also touch on how we can make the necessary improvements to the prototypes that we have identified in exhibitions and test rides, and we describe the state of development of an autonomous speed control function that would be desirable to enable safe and confident use of the mPm.

2 Specification of mPm

Table 1 shows specifications of the mPm, which we are developing to be a first-mile and last-mile transport means, a mobility vehicle that can link seamlessly with public transport systems, and a substitute transport means for people unable to drive cars. Fig. 1 shows the modes and uses of the mPm.

Table 1 Specifications of the mPm

		Modes			
		Silver car/ Standing mode	Senior car/ Mobility scooter mode	Kickboard scooter mode	Folded mode
Dimensions (mm)	Width	550			
	Height	950			420
	Length	650	950		1050
Weight (current and targets for production)		22 kg (prototype, no sensors), 10 kg (target without sensors), 15 kg (target with sensors)			
Battery type and capacity		Lithium-ion, 146 Wh (25 V, 6 Ah)			
Distance per charge		15 km @ 4 km/h			
Target price		900 US$ (without sensors), 1400 US$ (with sensors)			

A)Silver car B)Senior car C)Kickboard scooter D)Attached to a standard wheelchair

Fig. 1 Four uses of the mPm

3 Verification tests of the mPm

3.1 Testing at a tourist site

3.1.1 Outline of the test site and testing

As we are developing the mPm to be a transport means adaptable to many purposes, we investigated its use as a means of transport around a tourist site, to learn how compatible its use and movement are with pedestrians.

Hitachi Seaside Park is a famous tourist spot located on the Pacific coast of Japan, not far from Tokyo. The park has a total area of 350 hectares, of which 200 hectares is open to the public[5]. It has flowers in all seasons, such as Nemophila in the spring and Kokia in the autumn, attracting 2.27 million visitors in 2017.

We took the mPm being developed to Hitachi Seaside Park on four weekend days in 2018, January 27 and 28 and February 10 and 11. Table 2 shows weather conditions such as temperature and wind speed on those days. We used an open area about 200 m from the entrance of the park for our testing. Over the four days, 116 park visitors took part in the testing (a breakdown of the participants is shown in Table 3).

Speeds, accelerations, and positions of the mPm were logged. After riding the mPm, the participants answered questionnaires.

Table 2 Weather conditions during the testing

		9 a.m.–4 p.m. averages			Principal wind direction	General condition
		Temperature	Humidity	Wind speed		
3.1. Testing at a tourist site (Hitachi Seaside Park)	Jan. 27	4.7	30.9	2.8	W -> NW	Sunny
	Jan. 28	3.7	53.6	1.3	N	Cloudy
	Feb. 10	10.5	35.4	2.6	SW	Cloudy
	Feb. 11	10.5	60.4	2.5	SE	Sunny
3.2. Testing on a public road (footpath) (Tsukuba Pedestrian Decks)	Feb. 17	9.8	39.3	4.4	W -> NW	Sunny
	Feb. 18	6.4	25.7	5.7	NW	Sunny

Table 3 Age and sex breakdown of participants

	<20	20–29	30–39	40–49	50–59	60–69	≥70	No answer	Total
Male	20	5	11	15	8	7	4	0	70
Female	16	2	8	6	5	5	3	1	46
Total	36	7	19	21	13	12	7	1	116
Proportion	31%	6%	16%	18%	11%	10%	6%	1%	100%

Regarding modes of the mPm in the testing, snow had fallen shortly before the testing in January and there was still snow and ice at the test site. Therefore, in consideration of safety, only the senior car mode was used (mode B in Fig. 1). In the period before the testing in February, the weather had been clear and the safety concern did not apply. Therefore, both the senior car mode and the kickboard scooter mode (mode C in Fig. 1) were used.

3.1.2 Questionnaire results

After riding, the participants were asked to rate six characteristics of the mPm. Fig. 2 shows the characteristics ranked in order of the proportions of respondents rating them as "good". Throttle operation is similar to a motorbike, brake operation is similar to a bicycle and, when sitting on the saddle, the rider has a low center of gravity and can place their feet on the ground. With these features, not previously seen in mobility vehicles, "ease of operation" was rated "good" by over 60% of respondents and "good" or "fairly good" by around 90%, which is a very high rating. In contrast, "ease of folding" and "sense of safety" received low ratings, the former because the participants did not actually do the folding operation, and the latter because the mPm was not satisfactorily rigid. This was a consequence of using flexible linking portions with the aim of making turning easier and reducing collisions.

Safe and comfortable interaction with pedestrians was judged to be satisfactory. Fig. 3 shows how it was possible to move safely at low speeds while chatting with pedestrians. In the current form of the mPm, the speed cannot be deliberately changed during forward movement; there is no accelerator control. As a result, some participants felt worried about how the mPm moved during acceleration. Improvements in control when accelerating from a stop and when increasing speed will be important to encourage acceptance of the mPm.

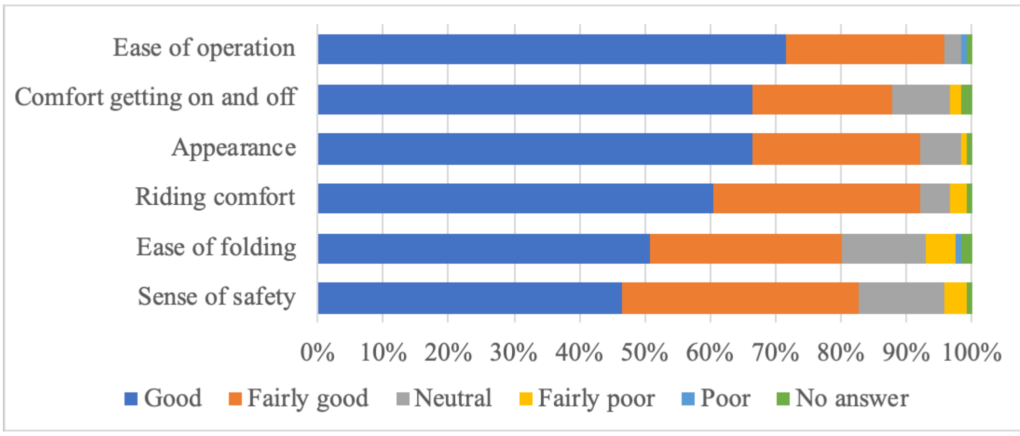

Fig. 2 Participant impressions of the mPm at the tourist site

Fig. 3 People walking with an mPm user (one in front and two alongside)

Participants were asked what driving assistance function the mPm would need for safe interaction with pedestrians. The four options offered were collision prevention, tipping prevention, fall prevention on uneven surfaces and autonomous driving. The function that attracted the most support was collision prevention, which has started to become standard in cars in recent years.

3.1.3 Conclusions from the testing at the tourist site

The tourist site was a limited area and the responses of participants to mPm mobility proposal or demonstration were favorable. It seems likely that favorable responses were received because the three-wheeled mPm felt more stable than a standing type two-wheeled electric vehicle, which is a typical small personal mobility vehicle. In addition, because the mPm has a saddle to sit on, there is less need to focus on driving and it is less tiring.

Regarding both solo use and walking with family members, the results of the questionnaire showed that the size of the mPm and safety at low speeds are very important, and that the driving assistance function that participants would want for safe interaction with pedestrians is collision prevention.

3.2 Testing on a public road

3.2.1 Outline of the test site and testing

Previous testing had been conducted under restricted conditions on mostly flat surfaces with few bumps. The purpose of this testing was to better understand conditions for which the mPm should be prepared on actual public roads (specifically footpaths) with bumps and slopes, and the requirements for usable road infrastructure.

Two of the mPm, capable of the same transformations, were equipped with different tires (a single pneumatic tire and front double sponge tires) and saddles (thickly padded and firm). The two variants were fixed in senior car mode (Fig. 4). We planned to conduct a similar survey in kickboard scooter mode, but this was not possible because of restrictions under Japanese law.

Fig. 4 The two mPm models used in testing on a public road

(Left, front double sponge tires and soft saddle; right, single pneumatic tire and hard saddle)

As the test site, we selected roads constructed by Tsukuba City that are reserved for pedestrians and bicycles (below referred to as "pedestrian decks"). The pedestrian decks extend over 43 km in an area reaching about 5 km north and south from the area around Tsukuba station and bus terminal. We used a stretch of about 800 m between the city center and a nearby park (Ninomiya Park) as the test road. In recruiting participants, we got help from Tsukuba City, who sponsored this testing, to create a recruitment page on the city's website. We also recruited participants meeting our requirements from people associated with our institute. The requirements were that participants be at least 50 years old, capable of riding a bicycle, and willing to follow instructions from the person explaining the mPm.

The testing was conducted from 10 a.m. to 4 p.m., apart from a one-hour break for lunch. Each participant's test ride took about one hour, including a briefing before the test ride, the test ride itself. and a questionnaire after the test ride. Up to five participants a day rode each mPm. In total, 18 people took part over the two days of testing. Fig. 5 shows the ages and sexes of the participants. Weather conditions during this testing are shown in Table 2 together with the tourist site testing.

At a reception location, precautions were explained and each participant gave signed consent. Then, driving operations of the mPm were explained in an open area. When the participant was familiar with operation of the mPm, they started the test. In order to prevent anticipated accidents, one observer was located in front of the driver and one to the side. Fig. 6 shows how the study was carried out.

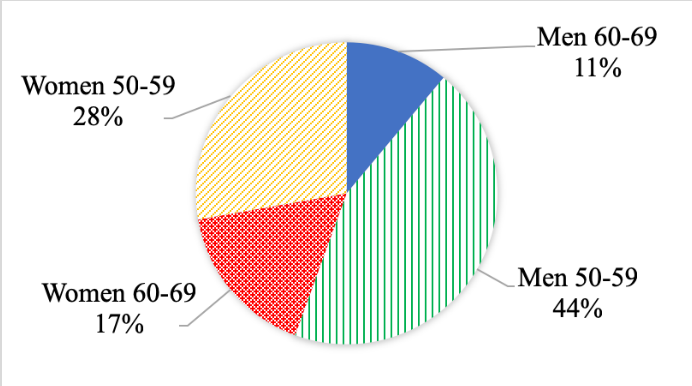

Fig. 5 Ages and sexes of participants

Fig. 6 During the test (photograph taken by a following observer)

3.2.2 Summary of post-ride questionnaire responses

I) Multiple choice answers

The results for questions about the performance and functions of the mPm, similar to the tourist site test, are shown in Fig. 7 ranked in order of which characteristics the greatest proportion of respondents rated "good". "Comfort getting on and off" and "ease of operation" were rated "good" by over 60% of respondents, but "riding comfort", "sense of safety" and "appearance" were rated "good" by fewer respondents.

It seems that the responses about riding comfort and sense of safety related to concern by many participants about bumps in the road surface and the vibrations they caused. Because the pedestrian decks feature connections between asphalt surfaces, paving stones, bridges and so forth, bumps are inevitable. In contrast, Hitachi Seaside Park only has asphalt surfaces, which have no bumps and are smooth and well-maintained. Therefore, it seems that differences in the roads influenced the evaluations of the mPm.

II) Written answers

A) The mPm itself

The results for questions about the performance and functions of the mPm, similar to the tourist site test, are shown in Fig. 7 ranked in order of which characteristics the greatest proportion of respondents rated

To summarize the participants' opinions, the concept of the mPm as a lightweight, compact (physically small) three-wheeled vehicle that can move safely at a speed that allows relaxed conversation with a pedestrian was considered good. Improvements mentioned as necessary include the need for precise speed adjustment, to prevent sudden leaps forward and to control speed on downward slopes, and maintenance of safety if the rider panics. Although the mPm is lighter than other mobility vehicles, further reductions in weight are necessary for use by frail people and the elderly. There is little space for placing feet, people unfamiliar with throttle operation will need instruction, and the mode changing (and mechanisms) must be reviewed to prevent injuries. These responses identified improvements we must introduce in further development.

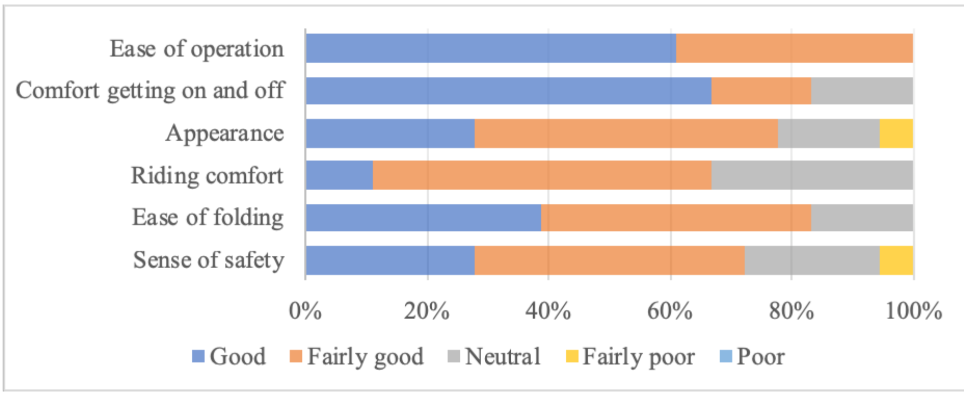

Fig. 7 Participant impressions of the mPm on the public road

B) Infrastructure and road conditions

None of the respondents were satisfied with current road conditions. The pedestrian decks are constructed of asphalt, bridges, paving stones and so forth; there are many bumps at the joints of different surfaces and between paving stones. Vibrations were transmitted through the mPm and some respondents identified dangers such as tipping over. The respondents pointed out that providing dedicated smooth paths with few bumps or simply smoother roads with fewer bumps will be necessary to encourage the use of this kind of mobility vehicle. It is clear that smoother roads with fewer bumps would be helpful not just for the mPm but also for many other people such as pedestrians, wheelchair users, and users of baby buggies and wheeled walking frames. This improvement of road surfaces should be promoted in the future.

3.2.3 Comparison with the tourist site results

We compared the mPm evaluations with the responses at the tourist site from participants in the same age ranges: 13 aged 50–59 (8 male) and 12 aged 60–69 (7 male). The characteristics that had low proportions of "good" responses on the public road—"riding comfort" (10%) and "sense of safety" (30%)—had proportions of around 70% if "fairly good" responses are included. However, these proportions were even higher at the tourist site, around 80–90% (Fig. 8). It seems that the better the maintenance of the road used for testing was, the better the evaluations of the mPm.

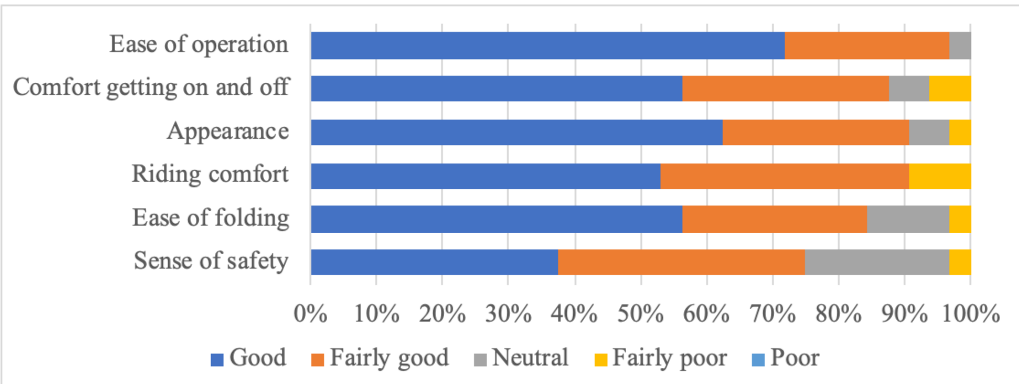

Fig. 8 Responses of participants at Hitachi Seaside Park aged 50–59 (13) and 60–69 (12)

3.2.4 Conclusions from testing on the public road

Previous participants had ridden the mPm and given their opinions on its characteristics at sites with few bumps and slopes. In this testing, the usage distance was less than 1 km each way but the participants were doing the test in ordinary road conditions. The opinions the participants gave after the test rides were not the same as the opinions after rides in a smooth area as in previous tests but their feelings about usage in real-world road conditions. These opinions will be very valuable in finding a way toward use of the mPm by the general public.

Ordinary roads that are used by many people tend to have more road damage and loose surfaces than restricted areas such as private land. In addition, because of slopes and the like, it is necessary to be aware of weight effects that might not normally be noticed. It is clear that we have to take account of these factors to enable safe riding; the mPm needs a structure or design that improves the sense of safety.

3.3 Movement on roads with vehicle lanes and footpaths

3.3.1 Field survey in Bangkok, Thailand

Because the goal of the mPm is that anyone—young or old, male or female—can use it, test sites cannot be limited to Japanese conditions. We surveyed the potential for use of the mPm in Thailand, where there is great concern about the challenges of an ageing society. The survey method was to take the mPm to Bangkok and use it in real-world situations such as riding in the vicinity of a hotel, riding between the hotel and a BTS (elevated railroad) station, and taking the mPm onto trains and traveling around the city. We studied ease of use of the mPm, infrastructure conditions and so forth.

3.3.2 Usability on footpaths

Because of the problems of flooding, there are large steps between roads and footpaths in Bangkok, with steep gradients (Fig. 9). At intersections, because vehicle lanes are considered more important than footpaths, the vehicle lanes meet at the same height but the footpaths are interrupted. Moreover, because the concrete-paved surfaces of footpaths crack and breakup, there are many bumps and flatness is poor (Fig. 10).

We tried to use the mPm in these conditions. The results of our survey showed that, given the goal that anyone can use the mPm, it was difficult to move along the footpaths safely and confidently with the current model of the mPm. Control and hardware to make the vehicle more stable will be necessary. The paths we used are crossed by vehicle lanes and so forth, interrupting the footpaths; we found the situation to be very bad. Driving the mPm along vehicle lanes would be unrealistic because it would increase the danger of accidents for both cars and the mPm. In other words, it will be necessary to provide footpaths that can be used safely and confidently by the elderly and people with mobility problems.

Fig. 9 Step between a footpath and vehicle lane

Fig. 10 State of a footpath surface

Fig. 11 Stairs up to a BTS station above a major road

3.3.3 Taking the mPm onto the public transport system

We surveyed whether the mPm can be used not just for short distances in the vicinity of a user's home but also for using a public transport system to travel further. Bangkok has the Skytrain (BTS), which is an elevated railroad, and a subway system (MRT). We investigated whether it was possible to use the BTS to travel to other stations easily with the mPm. The survey site was the BTS between Nana station, Asok station and Phrom Phong station. This BTS line runs above Sukhumvit Road, which is a major road with three vehicle lanes in each direction. The stations are accessed by stairs, escalators and elevators from the footpaths on both sides of the road (Fig. 11). However, there are not always elevators from the footpaths on both sides. Wheelchair users, people carrying large cases and the like who are accessing a station from a side at which there is no elevator must carry these things up themselves. These arrangements are not pleasant for users.

It is expected that as the society ages in the near future, the numbers of elderly people and people who have difficulty walking will increase. Thai society should now be considering how to create buildings, facilities and equipment that everyone can use. The mPm itself is currently heavy, over 22 kg, and it has to be carried up and down for travel using an elevated railway such as the BTS. We reaffirmed that reducing the weight of the mPm is an important aspect of its development.

3.4 Necessary improvements according to the verification tests and measures to achieve them

Through many tests, it has become clear that modifications are required for safe use of the prototype and confidence in changing modes. Table 4 shows aspects of the prototype requiring improvement together with modifications to achieve these improvements.

Table 4 A new prototype with minor changes from the current prototype (version 2)

Item	Prototype #2	New prototype #2
1 2	Lack of stiffness Low load capacity	Use steel components and review structure for stiffness: increase load capacity to over 100 kg
3	Possibility of injury during mode changes	Review mode changing mechanism to reduce risk of injury to fingers

Our original idea was to make linking portions of the mPm non-rigid so that flexing could be utilized to make turning easier. However, in some circumstances this feels unstable and insufficiently rigid. We are trying to improve stiffness along with increasing the load capacity. This results in a large increase in weight, over 10 kg, and will negatively affect ease of carrying and compactness. We have tested durability in accordance with the JIST9208 standard (the standard for steerable electric wheelchairs).

Mode changing to adapt to different uses are a feature of the mPm. The current prototype was created with the assumption that transformation operations are conducted by a person who knows the vehicle well. However, there is a high risk of injury due to trapped fingers and the like during these operations. To introduce the mPm to the public and ultimately have it widely used, we must devise transformation operations and mechanisms that enable confident, safe transformations by people who know very little about the mPm. We are currently redesigning the mechanism.

3.5 Examining and developing measure to improve safety

3.5.1 Background and objectives

Under the current laws of Japan, we understand that the mPm will fall into the same category as pedestrians. What is important is that mPm users and pedestrians can use the same spaces safely, without accidents and without causing alarm. For this category, the mPm would be used in senior car mode. In this mode, the space taken up by the mPm is not as long as the length of a bicycle, not as wide as the width of a standing-type two-wheeled electric vehicle such as a Segway, and not as large as the space taken up by a wheelchair.

The greatest difference between mPm users and healthy people, walking stick users and wheelchair users is that an mPm uses artificial power to move. Even if an mPm user is paying attention to their surroundings and moving with care, there is a danger that another person may approach the mPm user and possibly collide with the mPm user and be injured. When a person is moving under their own power, as soon as that person stops moving they stop applying force to someone they are colliding with. However, when a person is moving under artificial power, the possibility that they cannot come to a controlled stop but will continue moving cannot be ignored.

3.5.2 Details of development

We have worked on developing a unit with the goal of providing functions to automatically control speed of the mPm in accordance with the distances and speeds of other people. To be specific, the maximum speed of the mPm in senior car mode is 6 km/h, which is 1.67 m/s. For this speed, the sensors that are installed in ordinary cars and measure distances between cars would be over-powerful and expensive. Given that we are aiming for a price level of 100,000–200,000 yen (approx. 900–1800 US$) when the mPm becomes widely used, we must build a control system with inexpensive sensors and circuits. We investigated a large number of sensors and managed to find a sensor that is close to our requirements. With this sensor, we have developed the unit that controls speed in accordance with distances between the mPm and other people and obstacles.

3.5.3 Speed control by the speed control unit

The unit we developed has three sections: the sensors, a power supply, and a control unit. We mounted the unit to the mPm and verified its performance. We designed the unit such that when the user twists the throttle to raise the speed, safety control takes precedence and prevents the speed from changing; we verified this operation in the real world. The completion of this unit brings safe interaction with pedestrians in the same areas a step closer to reality.

3.5.4 Development conclusions

The mPm could contribute to the creation of new mobility vehicles that are suitable replacements for cars for the elderly and others in the super-aged society. If the speed control unit can be employed for the control of other electric mobility vehicles beyond the mPm, it may be possible to create a society that uses safe and reliable low-speed mobility vehicles, including mobility vehicles in categories that cannot be addressed by the mPm. The elderly being active in society is likely to contribute to maintaining and improving health, and reducing social spending such as medical expenses. The mPm may also contribute as an aid for maintaining and encouraging social activity by people who have difficulty walking due to injuries and disabilities. We have high hopes for the mPm to become a part of social infrastructure and be a tool that will help many people to overcome mobility problems, enjoy travel, enjoy life, and fulfill their potential as members of society.

4 Conclusions

We are developing a new mobility vehicle that can be adapted to many uses by transformations of its shape. We have conducted verification tests using this mobility vehicle in the real world, have learned about its suitability and necessary improvements, and have studied the road conditions required for its use. We have made improvements to address concerns about the mobility vehicle that have arisen in these tests and in previous exhibitions and test rides. We have achieved the goals of developing a sensor unit that enables the confident, safe movement required for the mobility vehicle to be widely used by the public and incorporating the sensor unit with a control system. We expect to estimate the cost of the mobility vehicle equipped with this safety control unit when we have established the details of mass production. Subsequently, we hope to advance research and development to promote widespread use of the mobility vehicle and establish a mode changing mechanism that offers no risk of injury during transformations.

Acknowledgments

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