

Development of a Crawler Type Vehicle to Travel in Water Paddy Rice Field for Water-Dropwort Harvest

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Abstract

Purpose: This study was conducted to develop a rubber-crawler type vehicle as a traveling device for harvesting water-dropwort cultivated in water contained paddy rice field in winter season. **Methods:** A commercial rubber-crawler type vehicle was used to investigate application of rubber crawler to the paddy rice field as preliminary test. As the result of the preliminary test, a both prototype traveling device with rubber crawlers for a water-dropwort harvest was designed with inclination of 45° at the front-end and rear-end of crawler under the basic water depth of 0.6 m in the paddy rice field. The device was fabricated and attached to the experimental harvesting test devices on the front of the prototype vehicle. The size of the prototype crawler vehicle with a harvesting part is 2,800 x 1,460 x 1,040 (mm) (LxWxH) with weight of 9.21 kN (maximum). Sizes of the crawler of prototype vehicle are ground contact length of 900 mm, width of 180 mm, height of 1,070 mm and distance between center to center of crawlers of 720 mm. The side-overturn angle of the prototype was 26.4°. **Results:** Driving performance of the prototype vehicle in water contained paddy field were good at both forward and reverse (backward) directions as weights were applied. The drawbar pull and the maximum sinking depth of the prototype vehicle were 3.5 kN and 0.13 m respectively at water depth of 0.5 m, when the weight and bearing capacity of the prototype rubber crawler in the paddy field were 8.51 kN and 26.3 kN/m², respectively. **Conclusions:** Results of the driving test performance of the prototype crawler in paddy rice field at the water depth of 0.5 m were satisfactory. The prototype had enough drawbar pull and driving ability in the deep water contained paddy field.

Keywords: Crawler vehicle, Drawbar pull, Driving ability, Paddy field, Sinking depth, Water-dropwort

Introduction

Water-dropwort is cultivated in paddy rice field filled with water at maximum depth of 0.6 m during winter season in Korea. Water-dropwort harvesting is done manually and requires a lot of hard work in root digging using shovels and picking of roots for cleaning. The working environment is also harsh because of the water contained paddy fields.

In a related study by Jun, et al. (2009) and Jun, et al. (2011) on the mechanical harvesting for water-dropwort, it was shown that the sinking of a driving

device should be considered as an important factor in the water-dropwort field such as in a water contained paddy field. As a result, the study recommended that a crawler type vehicle is needed to perform a reliable driving and to exert constant drawbar pull in a water contained paddy field.

Michael (1996) reported that it was possible to apply great wheel masses onto the soil without the danger of compaction with modern wide tires under the presupposition that pressure is evenly distributed in the contact area.

In respect of soil pressure the caterpillar has only a little advantage. High pressure rates are beneath the carrier rolls. At low slippage conditions the caterpillar is superior to the tractor. Assuming the same traction

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force; the caterpillar runs with 10% less slippage and is 10% faster with the same engine power and with all other influences constant, the output per unit area could be 10% bigger.

Park et al. (2003) developed a computer simulation program (TPPMTV98) to investigate the mechanical interrelation between soil characteristics and main design factors of a tracked vehicle, and predict the traction performance of the tracked vehicles. The effectiveness of the developed model was verified by comparing the predicted drawbar pulls using TPPMTV98 with measured ones from traction tests with a tracked vehicle reconstructed for test in loam soil with moisture content of 18.92%, d.b.. The drawbar pulls measured by the TPPMTV98 were well matched to the measured ones.

Nikolic (1993) reported he tested the maximum net traction coefficient for Caterpillar Challenger 65 tractor which has rubber tracks, an articulated four wheel drive tractor with dual wheels and a mechanical front wheel drive tractor under an unplowed and plowed wheat stubble field.

The maximum net traction coefficient was established at the traction efficiency of 0.6 on the unplowed wheat stubble field; for the Challenger 65 tractor 0.855; 4WD; 0.624 and MFWD; 0.534 and on the plowed wheat stubble field with the traction efficiency of 0.4 for Challenger 65 tractor 0.82; 4WD 0.57 and for tractor MFWD 0.48.

Matsuo et al. (1993) reported the equations to calculate the velocities, accelerations and penetration angle of the locus of lug motion for the rubber crawler mechanism.

Inaba et al. (2000) reported the simulation method to evaluate the travel resistance occurred by the rolling resistance of the track roller. The rolling resistance for each track roller arrangement and effects of the lug phase in the right and left rubber crawler could be estimated quantitatively.

In this study, for good travel performance in water-contained paddy rice field to develop a traveling vehicle for water-dropwort harvest, a commercialized rubber crawler vehicle was preliminarily tested to investigate the travel performance and sinking of the crawler type vehicle and then a prototype crawler vehicle was designed applying results of bearing capacity and shape of crawlers from the preliminary test. This study was conducted to develop a prototype crawler vehicle traveling in water-contained paddy field for water-dropwort.

Materials and Methods

Field test for the commercial rubber crawler-type vehicle (HC-300C)

Field condition

The test field was the water-contained paddy field of newly harvested water dropwort. Texture of soil of the test field was SiL (silt loam) at water depth of 0.2 m. Soft ground layer thickness of the test field was 0.3 m and it has a very hard layer under the soft layer.

Test device: the crawler vehicle (HC-300C)

The test device used in the test was the commercial rubber crawler vehicle (model: HC-300C, Hanseo Precision Industry Co. Ltd.).

The test rubber crawler vehicle is a walking carrier with a maximum load capacity of 2.94 kN. It has a chain that efficiently transmits the engine power to the crawler without power loss. Figure 1 shows the schematic diagram of the test rubber crawler vehicle.

The crawler vehicle has a weight of 2.55 kN and an allowable load of 2.94 kN. The rubber crawler of the vehicle has an average height of 270 mm, width of 180

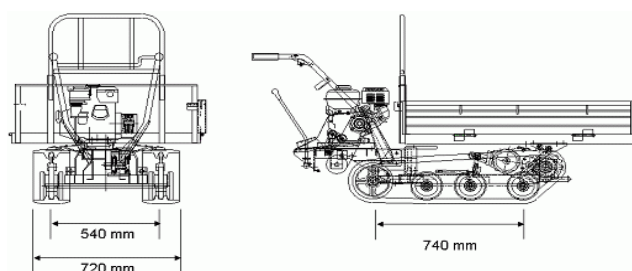
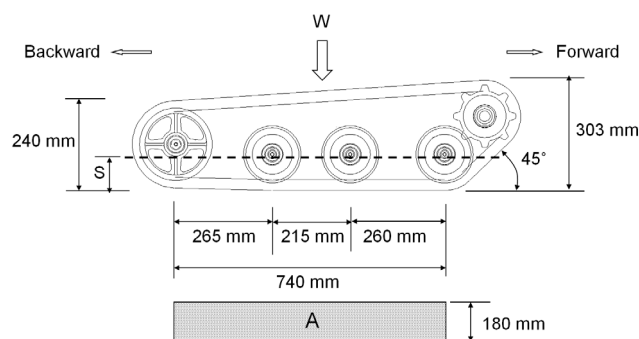


Figure 1. Schematic diagram of the test rubber crawler vehicle (HC-300C).



W : weight of vehicle
S : sinking depth of a crawler from ground surface
A : Ground contact area of a crawler

Figure 2. Structure of a crawler of the test vehicle (HC-300C).

Table 1. Specification of the test rubber crawler vehicle

Parameters	Unit	Value
Weight of the test vehicle	kN	2.55
Power of the test vehicle	kW	5.1
Thickness of crawler	mm	20
Ground contact length of crawler	mm	740
Width of crawler	mm	180
Lug height of crawler	mm	15
Front height of crawler	mm	303
Rear height of crawler	mm	240
Front-end inclination of crawler	°	45
Rear-end radius of crawler	mm	120
Lug pitch of crawler	mm	65
Ground contact area of crawlers	m ²	0.2664

mm and ground contact length 740 mm. The lug of the crawler has a height of 10 mm and pitch 65 mm. The test crawler vehicle has an inclination of 45° at front part and radius of 120 mm in semi circle at rear part. In addition, the fixed-type track rollers were placed in the rear sprocket with spaces of 265 mm, 215 mm and 260 mm.

The structure of a crawler of the test vehicle (HC-300C) is shown in Figure 2 and the detailed specification of the test rubber crawler vehicle is presented in Table 1.

Driving and drawbar pull test of the test rubber crawler vehicle

Driving test for the test crawler vehicle was performed to determine the driving conditions for the test crawler vehicle with maximum weight of 5.49 kN in water contained paddy field when running forward and backward. The water depth conditions of the test field were 0.05 m and 0.2 m. The sinking depth of the rubber crawler was measured loading from the weight of 0.98 kN to to 2.94 kN on the test vehicle. This is taken from the difference of height between the bottom of the crawler and the ground from the water surface. Table 2 is the bearing capacity of the test vehicle for sinking depth measurement.

The drawbar pull testing was done at the paddy field with water depth of 0.05 m according to contact area of the test crawler vehicle. Drawbar pull of the test rubber crawler vehicle was tested by a load cell (allowable load 4.9 kN, CAS Co., Ltd) at the vehicle weight of 5.49 kN. Data were acquired from the load cell by using the equipment DEWE 2010 (DEWETRON GmbH). Figure 3

Table 2. Bearing capacity of the crawlers of the test vehicle

The weight of test vehicle (kN)	Bearing capacity of the crawlers (kN/m ²)
2.55(test vehicle)	9.57
3.53	13.25
4.51	16.93
5.49	20.61

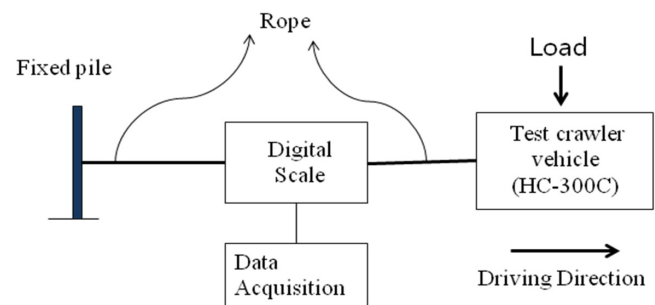


Figure 3. Schematic diagram of drawbar pull test.

is the schematic diagram of drawbar pull test of the test rubber crawler vehicle (HC-300C).

Field testing of prototype rubber crawler-type vehicle

Design of the prototype vehicle

The prototype rubber crawler-type vehicle was designed in triangle shape crawler to travel in water contained paddy field with water depth of 0.6 m. Figure 4 shows the schematic diagram of prototype crawler vehicle. Distance between the crawlers of the prototype was determined into 720 mm with its traveling stability

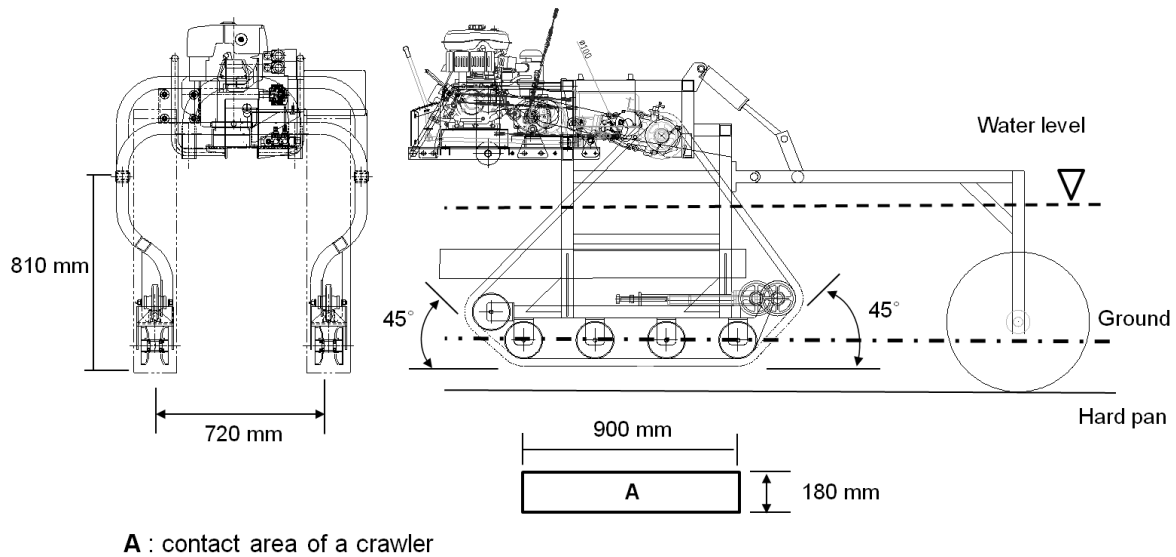


Figure 4. Schematic diagram of prototype crawler vehicle.

Table 3. Specification of the prototype crawler vehicle

Parameters	Unit	Value
Sizes of the prototype (LxWxH)	mm	2800 x 1040 x 1460
Weight of the prototype(depending on weight)	kN	5.59 ~ 9.21
Power of the prototype	kW	5.1
Thickness of rubber crawler	mm	20
Ground contact length of rubber crawler	mm	900
Width of rubber crawler	mm	180
Lug height of rubber crawler	mm	15
Front height of rubber crawler	mm	303
Rear height of rubber crawler	mm	240
Front-end inclination of rubber crawler	°	45
Rear-end inclination of rubber crawler	°	45
Lug pitch of rubber crawler	mm	65
Ground contact area of rubber crawlers	m ²	0.324
Track roller space	mm	300

and allowable working width of 1 m as basis for developing a water-dropwort harvester. Moreover the prototype crawler vehicle was designed to be able to attach the experimental harvesting test devices on the front of the prototype vehicle.

The ground contact length of the rubber crawler of the prototype vehicle was determined in consideration of drawbar pull, traveling stability and sinking depth from the test results for the test rubber crawler vehicle in the water contained paddy field.

The size of the prototype vehicle was 2,800 x 1,040 x 1,460 (LxWxH, mm) and the balance of the prototype

vehicle was controlled by supplement of weights when a harvesting device is placed on the front of the prototype. The rubber crawler of the prototype vehicle has a ground contact length of 900 mm, a width of 180 mm, crawler height of 1,070 mm and an inner distance of 540 mm, center distance of 720 mm and outer distance of 900 mm between the crawlers.

The shape of the rubber crawler was designed easy to travel in paddy field with inclination of 45° both at front-end and rear-end of crawler to prevent the sinking of the crawler while driving back and forth in water-contained paddy field. The power and speeds of the

prototype vehicle were 5.1 kW (gasoline engine) and 0.1~0.3 m/s. The detailed specification of the prototype crawler vehicle is shown in Table 3.

Field testing for the prototype vehicle

Side-overturn testing of prototype vehicle

A side-overturn test of the prototype vehicle was performed to find out a side-overturn angle of the prototype vehicle due to the differential sinking while driving in paddy field. A side-overturn angle of prototype vehicle was measured with one side rubber crawler of prototype fixed on the test plate and the other side rubber crawler free when the prototype vehicle is deviated by inclining the test plate of the side-overturn measuring device. Figure 5 shows measurement of the side-overturn angle of the prototype crawler vehicle.

Driving and drawbar pull test

The driving test of prototype vehicle was carried with the load acting on the rubber crawler according to the weight of harvest device attached on the front of the prototype vehicle.

As shown at the Table 4, the driving test of prototype vehicle was tested at 3 levels according to the weights of prototype (5.59, 7.64, 9.21 kN) while the sinking of

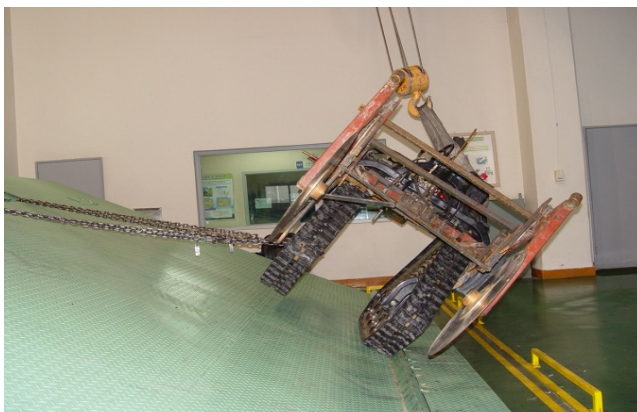


Figure 5. View of side-overturn test of the prototype vehicle.

Table 4. Test conditions of driving test of the prototype vehicle

Parameter	Unit	
weight of prototype (bearing capacity of the crawlers)	kN (kN/m ²)	5.59 (17.25)
		7.64 (23.58)
		9.21 (28.42)
		11.27 (34.78)
Level of shift gear		3 Level (I, II, III)
Engine speed	rpm	1,100

the rubber crawlers was measured while performing each driving test. The driving speed of the prototype vehicle in the paddy field with water depth of 0.5 m was tested at 3 levels (I, II, III) by running the prototype vehicle with three different speeds of gear-shift at an engine speed of 1,100 rpm and weight of 11.27 kN.

Drawbar pull of the prototype vehicle was tested at weight of 8.53 kN of the prototype as shown at Figure 3.

Results and Discussion

Field testing for the commercial rubber crawler vehicle (HC-300C)

Sinking depth of the test rubber crawler vehicle

Figure 6 shows that sinking depth of the crawler of the vehicle was 0.05 m at the bearing capacity of 9.57 kN/m² of the crawlers (at weight of 2.55 kN of the test vehicle) and 0.1 m at the bearing capacity of 20.61 kN/m² of the crawlers (at the weight of 5.49 kN-2.55 kN of the test crawler vehicle + load of 2.94 kN).

Driving condition of the test rubber crawler vehicle

Results of the driving test for the test rubber crawler vehicle showed that driving in the forward direction was possible under water depths of 0.05 m and 0.2 m at the bearing capacity of 9.57 kN of the crawlers (vehicle weight of 2.55 kN) and at the bearing capacity of 20.61 kN/m² of the crawlers (vehicle weight of 5.49 kN) respectively.

However, at the bearing capacity of 20.61 kN/m² of the crawlers (vehicle weight of 5.49 kN), driving in the reverse (backward) direction was difficult under water depths of 0.05 m and 0.2 m in the water paddy field. This

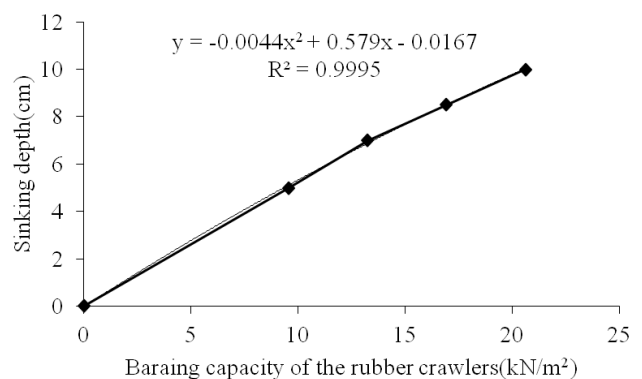


Figure 6. Sinking depth of the test rubber crawler vehicle.



Figure 7. View of the driving test for the test crawler vehicle.

was due to the sinking of the crawler resulting in the test rubber crawler slipping continuously out of place. This condition was caused by the rolling resistance of the rear-end part rubber crawler with the semi-circular shape and radius of 120 mm.

As shown at Figure 6, the sinking depth of the test vehicle was 100 mm deep under the bearing capacity of 20.61 kN/m² of the crawlers (vehicle weight of 5.49 kN) and it was equivalent to 83% of the radius of 120 mm of the rear-end rubber crawler. This is similar like tire slip which occurs in soil surface when the rolling resistance of the tire is larger.

Specifically in the paddy field, the sinking of the rubber crawler occurs when the rolling resistance of the test rubber crawler is very high. Therefore, the shape of the rear-end rubber crawler has to be considered in the design of the inclined-like shape of the front-end rubber crawler for a reliable driving on the water contained paddy field. Drawbar pull of the test crawler vehicle was 1.47 kN at the bearing capacity of 20.61 kN/m². Figure 7 shows a view of the driving test for the test crawler vehicle.

Field testing for the prototype crawler vehicle

Side-overturn angle of the prototype vehicle

The side-overturn angle of the prototype was tested using the side-overturn angle measuring device. Result of the side-overturn angle of the prototype vehicle was 26.4°.

Sinking depth, slip rate and drawbar pull of the prototype vehicle

Driving conditions of the prototype vehicle in water contained paddy field were good at both forward and backward driving test conditions at the prototype vehicle weights (5.59 kN, 7.64 kN, 9.21 kN) are applied on the prototype. The sinking depth of the prototype rubber crawler was 0.13 m at the bearing capacity of 28.42 kN/m² and it agreed well with results calculated from the

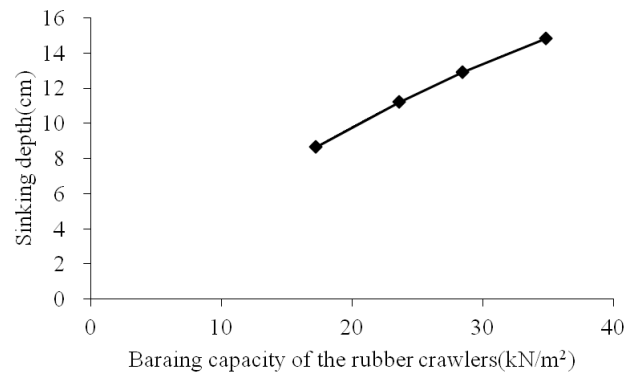


Figure 8. Sinking depth of the crawler of prototype vehicle.

Table 5. The slip ratio of crawler of the prototype vehicle in water-contained paddy field

Level of shift gear ¹	Driving speed (m/s)		Slip ratio of crawler (%) [(a-b)/b]*100
	Water paddy field (a)	Concrete pavement (b)	
I	0.070	0.072	2.7
II	0.142	0.143	0.4
III	0.204	0.217	6.0

Foot Note: I (low speed), II (middle speed), III (high speed)

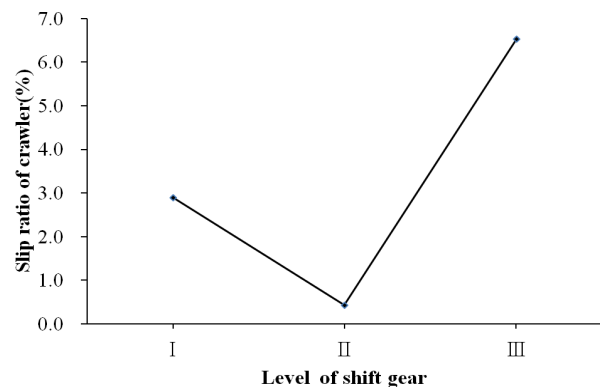


Figure 9. The relationship of slip ratio between crawlers of the prototype and water-contained paddy field.

functional formula of figure 6. At the sinking depth at the bearing capacity of 34.78 kN/m², driving performance of the prototype rubber crawler was good. Figure 8 is sinking depth of the crawler of prototype vehicle.

Also, the slip ratio of the prototype under driving speeds in the water contained paddy field is shown in Table 5. Figure 9 is the relationship of slip ratio between crawlers of the prototype and water-contained paddy field.

The slip ratio of the crawler of the prototype at the shift gear level III was 6.0% higher than the slip ratio of 0.4%



Figure 10. View of driving test of the prototype crawler vehicle.



Figure 11. View of drawbar pull test of the prototype crawler vehicle.

of crawler at shift gear level II. Accordingly, the slip ratio of the prototype in water contained paddy field was higher when the driving speed of the prototype was faster. Figure 10 shows a view of driving test of the prototype crawler vehicle.

The drawbar pull of the prototype vehicle was 3.5 kN in the paddy field at a weight of 8.51 kN and rubber crawler bearing capacity of 26.3 kN/m². Figure 11 shows a view of drawbar pull test of the prototype crawler vehicle.

Conclusions

The side-overturn angle of the prototype was tested using the side-overturn angle measuring device. Result of the side-overturn angle of the prototype vehicle was 26.4°.

Driving performance of the prototype vehicle in water contained paddy field were good at both forward and reverse (backward) directions as weights were applied.

The sinking depth of the prototype rubber crawler was 0.13 m and it was proportional to the weight of the prototype vehicle.

However, at sinking depth of 0.13 m of the prototype rubber crawler, there was not much effect on driving of the prototype.

The ratio of crawler slip of the prototype at the shift gear level III was 6.0% higher than the ratio of 0.4% of crawler slip at shift gear level II. Accordingly, the ratio of the slip of the prototype in water contained paddy field was higher when the driving speed of the prototype was faster.

The drawbar pull of the prototype vehicle was 3.5 kN in the water-contained paddy field at the rubber crawler bearing capacity of 26.3 kN/m² (prototype vehicle weight of 8.51 kN).

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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