

## FEASIBILITY STUDY ON THE APPLICATION OF MODULAR COMBINATION VEHICLES IN CHINA ROAD TRANSPORT



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### Abstract

China's road transportation system has undergone rapid development with continuous upgrading of its road network, transport equipment and of its regulations. As a consequence the transport efficiency has been significantly improved, but there is still much left to do, especially in the field of more efficient road transport solutions. This is made even more urgent with the recent dual carbon targets<sup>1</sup>, which bring new demands for a green and efficient transport industry.

Based on research pilot projects of intelligent transportation technology and equipment, ROIH (Research Institute of Highway of the Ministry of Transportation) has made detailed plans for the development of modular multi-trailer road-trains to be used on China's road network.

This paper is an analysis of the feasibility to introduce modular multi trailer road-train (CMS, China Modular System) for highway transportation, based on some of the findings from ongoing pilot projects. This paper describes two of the pilots and preliminary results from them, including some data on the operational economy of road trains.

As a conclusion, this paper clarifies the importance and necessity of multi-trailer road trains to quickly realize safe, low-carbon and efficient road transportation and that conditions are ripe in China to take that step.

**Keywords:** Road Train, Feasibility Study, China Modular System, total operation economy, CO2 reduction

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<sup>1</sup> China has set the goal to reach carbon peak by 2030 and carbon neutrality by 2060.

## 1. Introduction

### 1.1. Background

China's current road transport system matches the rapid growth of China's GDP. In 2020 the transport volume amounted to 34 billion tons and turnover of road freight reached 6017 billion ton-kilometers, accounting for 74% and 31% respectively of the total freight volume and turnover. At the end of 2020, China had 11.7 million Heavy Duty Truck (HDT) in operation with a total freight capacity of 157.8 million tons. From 2020 to 2014 the number of tractor units doubled from 1.5 million to 3.1 million, and the number of semi-trailers increased from 1.6 million to 3.3 million. The proportion of tractor semi-trailer combinations of the total population of trucks also increased to 58%. The proportion of tractor to trailer thus continues to increase, replacing single cargo trucks for long-haulage operations due to the need to haul more goods per run. However, the average annual mileage of the trucks is still only 77 600 kilometers based on the average load of 25 tons.

The masses and dimensions standard for road vehicles GB1589 has been continuously updated from the original version of 1979 to the versions of 1989, 2004 and the latest version of 2016. After 44 years of revisions, there is still no significant changes on the gross masses and dimensions. According to the current updated standard, the maximum length of a rigid+center-axle combination is 20 meters, and the maximum length of a car carrier rigid with a center-axle trailer is 22 meters. Due to road safety related laws and regulations, further expansion of masses and dimensions is still restricted.

### 1.2. Challenges

The Chinese road authorities have since the GB1589-2016 revision, been successful in reining in over-weight transport. However, for volume based goods, the real-life situation is that the market actors have found loopholes to exceed the present volume standard. The current container box semi-trailer is legally limited to 95 cubic meters.

The loophole to reach higher transport volume capacity is to fit oversized container boxes on compliant standard semi-trailers rigids. In that way loading volumes of 130-150 cubic meters<sup>2</sup> can be achieved. As a consequence, the external dimensions of the oversized container boxes vastly exceed the limits set in the national standard GB1589-2016. Boundaries are constantly being pushed and as a result, container boxes are getting bigger and bigger.

There is also another way to “almost” legally achieve high volume transport capacity. In the GB1589-2004 standard, so called gooseneck low-bed flat floor semitrailers (“goosenecks”) were exempted for the transport of non-divisible heavy and low frequency goods.<sup>3</sup> The gooseneck is wider (3 meters), lower and longer than an ordinary semitrailer and thus potentially can carry a huge volume. Therefore it has become common practice to use goosenecks for transport of high volume cargo, mostly bare or with a tarpaulin cover, with poor protection or the goods, and with a high risk of goods falling off the trailer. Although the

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<sup>2</sup> Since the container itself does not fall under the GB1589 or other relevant regulations the market has found a loophole to maximize transport volumes, albeit clearly exceeding the dimensions set by GB1589.

<sup>3</sup> The legal life length of vehicles in China is 15 years and the last year goosenecks were allowed to be produced was 2007. Therefore they should be completely banned from 2023, and an accelerated scrapping is now to be expected.

“efficiency” of a gooseneck single transport unit is very high, overall transport compliance management is made difficult and unfair competition in the transport industry is vicious, which leads to large transport safety problem and unlevel playing field competition.



**Figure 1 – Left: Oversized container box on a compliant semitrailer chassis  
Right: Gooseneck flat low bed semitrailer**

### 1.3. Development of Environmental and Emissions Requirements

China's carbon emissions in the transportation sector account for about 11% of the total emissions, and road transports accounts for 87% of emissions from all transport modes.

On October 12 2021, Chinas president Xi Jinping called for the acceleration of establishing a low carbon and green transport system, which will promote the further development and use of electrified, intelligent, digital and light-weight equipment.

On October 6, 2021, the Ministry of Transport issued the *Opinions of the Research Institute of Highway Sciences of the Ministry of Transport on the Development and Application of Highway Infrastructure Life Extension and Green Construction and Maintenance Technology and other construction sites of powerful transportation countries (JGH [2021] No. 519)*. The target is to, within two years, make a significant breakthrough in the research and development of technical standards for modular multi-trailer road train.

The Ministry of Transport, Research Institute of Highways (RIOH) has successively signed the *Cooperation Agreement on the Joint Implementation of the Safe, Low-Carbon and Efficient Transport Pilot Project* with Jinzhong City, Shanxi province, Ganzhou City, Jiangxi province, and Hami City in the Xinjiang province, to carry out modular multi-trailer road trains.

## 2. Experience of Using Modular Trailer System

Many countries and regions in the world have successively piloted and implemented modular multi-trailer road train transportation systems. Although vehicle specifications and standards are not globally unified, the efficiency improvement and emission reduction effects are substantial.

### 2.1. USA

In 1991, the United States Congress passed the *Intermodal Surface Transportation Efficiency Act (ISTEA, commonly known as the Iced Tea Act)*. In order to coordinate and handle the relationship between larger trucks and highway safety. The Congress passed the *Federal Size Regulation for Commercial Vehicles, Longer Combination Vehicles (LCV)* which allows extra-long road trains on dedicated state highways or toll roads.

## 2.2. EU

When Sweden joined the European Union in 1995, it had to adopt the same vehicle standards as other EU member countries, the *European Council Directive 85/3 EEC (Masses and Dimensions)*. The maximum total length of a road train was at first reduced from 24 meters to 18 meters, and the maximum total mass was reduced from 60 ton to 40 ton. In order to efficiently meet with forestry transportation needs in Sweden and Finland, the European Union in 1996 launched the European Modular System (EMS, or EuroCombi), which is a modular combination system of trailers and towing vehicle, based on two standardized loading platform units (7.82m or 13.60m) as defined by the EU Directive 96/53/EC. Member countries are, under this directive allowed, to combine and use road train combinations of different lengths and gross train weights.

**Table 1 - Summary statistics of EMS regulations changes.**

Year	Country	Vehicle Spec
2013	Netherland	60t/25.25m
	Finland	76t/25.25m
2014	Denmark	60t/25.25m (Long-term testing)
	Norway	60t/25.25m
2015	Sweden	64t/25.25m
2016	Spain	60t/25.25m (Special permission)
2017	Germany	40t/44t/25.25m
2018	Sweden	74t/25.25m
2019	Finland	76t/35.5m

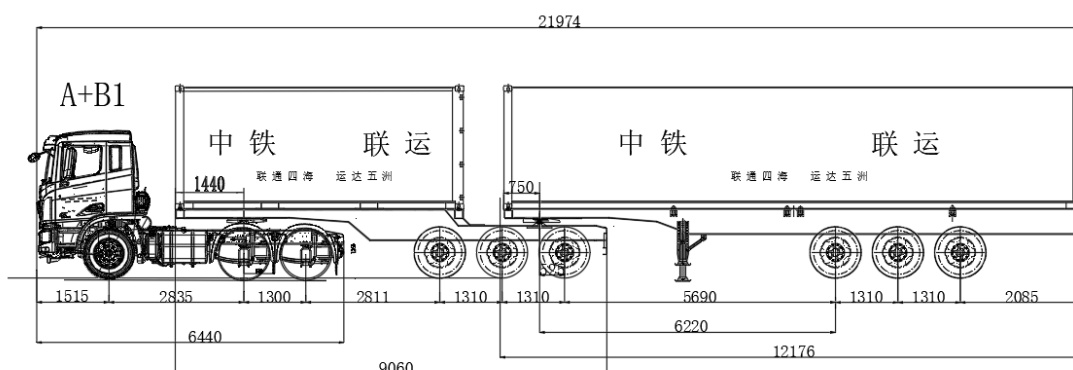
## 3. China Ongoing Pilot Case Studies

Within the current limits, set by the masses and dimensions standard of road vehicles GB1589-2016, domestic enterprises and institutions have had to be creative in setting up pilot projects that adhere to the GB1589-2016 limits, whilst still stretching the boundaries.

### 3.1. China Railway Intermodal Logistics

China Railway Intermodal Logistics Co., Ltd. has developed an efficiency-improving multimodal transport system, the China Railway Modular Transport (CRMT), where standard 20 foot maritime containers constitute the basic loading unit.

The CRMT system aims at greatly improving the efficiency of the transfer of containers between railway and road in the railway container depots. Since 22 meters total length today is allowed for car carriers, a special container road train (B-double) has been designed consisting of a tractor unit, a front semitrailer (A) and a standard semitrailer (B1), where the design of the front semitrailer (A) ensures that the combination total length is within 22 meters. By adding more axles than the GB1589 currently allows for but still keeping with the axle and bogey weight limits, the total gross weight of the road train can add up to 74 tons, with a payload of max 56 tons. This road train can transport 3X20 foot containers or 1X40 foot + 1X20 foot containers. Under the current legislation only 2X20' or 1x40' can be transferred from train to truck at the depot. A 50% efficiency improvement is thus possible using a modular multi-trailer road train.



**Figure 2 – CRMT B-double trailer drawings**

Furthermore the transport economy of a CRMT combination compared with a standard Tractor/Semi-trailer combination is significantly better as demonstrated in table 2, below:

**Table 2: Real transport cost operations based on a typical Chinese transport company**

Annual Mileage 150k km		CRMT		Tractor/ Semi-trailer	
Fixed Cost	Labour	320k RMB(China currency)/y	2.13 RMB/km	320k RMB/y	2.13 RMB/km
	Depreciation	114k RMB/y	0.76 RMB/km	85.7k RMB/y	0.57 RMB/km
	Interests	44.8k RMB/y	0.30 RMB/km	33.6k RMB/y	0.22 RMB/km
	Total	478.8k RMB/y	3.19 RMB/km	439.3 RMB/y	2.93 RMB/km
Variable Cost	Fuel	2.7 RMB/km		2.4 RMB/km	
	Toll	4.1 RMB/km		2.6 RMB/km	
	Total	6.8 RMB/km		5.0 RMB/km	
Total Cost		9.99 RMB/km		7.93 RMB/km	
Unit Freight cost (expressway)		0.178 RMB/km.t		0.227 RMB/km.t	
Unit Freight cost (non-expressway)		0.105 RMB/km.t		0.152 RMB/km.t	

It is preliminarily estimated that the container transport cost based on the CRMT system can be reduced by approx. 30% and that the transportation efficiency can be increased by 50%.

### 3.2. China International Marine Containers Group

CIMC Vehicle (Group) Co., Ltd. (CIMC) is a global leader in the high-end manufacturing of semitrailers and special vehicles. In order to solve the low efficiency of the existing standard vehicles and to reduce the potential safety hazards caused by the widespread use of non-standard over-sized containers and gooseneck trailers, fully compliant vehicles that can increase the loading volume capacity and meet the road transportation standards need to be introduced on China’s roads.

Therefore tests of dual-trailer road trains have been initiated. The combination shown in the figure below consists of a:

- 6X4 tractor unit
- 13.75 m or 13.6 m box type semi-trailer (Trailer 1). Both these semi-trailers conform with the GB1589-2016 standard;

- Center-axle box trailer, with a maximum length of 8 meters, which conforms with the GB1589-2016 standard.



**Figure 3 – CIMC semitrailer/center-axel trailer truck train<sup>4</sup>**

The advantage of this combination is that the semitrailer and center-axle trailer are already approved in the existing gazette<sup>5</sup>. If in the future, regulation would permit 25,25 meter combinations on designated routes, the dual-trailer road train can be used in a flexible way: When operating on a non-designated route, the rear center-axle trailer can be decoupled. The total loading volume of the full vehicle train can reach about 150 cubic meters, which is more than 50% higher than the existing semi-trailer and rigid+center-axle trailer combinations.

#### **4. Traffic Safety Tests of CAERI and CIMC**

In China the iterative work method of test and validation for new regulation, is often used. The key assessment item for the pilot projects is safety. China Automotive Engineering Research Institute (CAERI) and (RIOH) conducted comprehensive road train safety and validation tests for the two pilot projects of CRMT and CIMC, and also compared some economic indicators.

##### **4.1. CRMT test by CAERI**

CAERI has conducted a comprehensive technical evaluations and safety assessments of the 22 meter B-double road train of CRMT.



**Figure 4 – 22m CRMT dual trailer in testing**

During tests of the CRMT it was verified that it meets with Chinese standards with regards to breaking, swing amplitude, roll over and handling stability. The engine power also met with Chinese calculation standards. However, three issues were found:

- 1) According to GB 1589-2016, the maximum total Gross Train Weight of a six axle combination is 49 000kg. The pilot CRMT vehicle is designed according to the

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<sup>4</sup> The test sample vehicle is jointly produced by SAIC Hongyan Automobile Co., Ltd. and Yangzhou CIMC Tonghua Special Purpose Vehicle Co., Ltd.

<sup>5</sup> For any vehicle to be able to be sold and used on China's public roads it needs to be tested, approved and published in the vehicle Gazette of the Ministry of Industry and Information Technology.

maximum axle loads of single axle, bogey axles and triple bogey axles allowed in the standard: By adding up the permissible axle weights of a 6X4 air tractor with air suspension, one front trailer bogey and a semi-trailer triple bogey, the maximum total gross train weight is 74 000kg. The curb weight of the CRMT is 18 640kg. If one fully loaded 20 foot container and one fully loaded 40 foot container are added,  $30\,480\text{kg} \times 2 = 60\,960\text{kg}$ , the maximum total laden Gross Train Weight is 79 600kg. In order not to exceed the axle weight based GTW of 74 tons the curb weight of the CRMT needs to be further reduced and/or containers need to be weighed before loading.

- 2) During the test of minimum turning diameter, the containers of the front semi-trailer (A) and of the standard semi-trailer (B) will interfere with each other. 22 meters total length may not be enough for safe turning.
- 3) The rear axle wheels on the standard semi-trailer (B) will skid in the Y direction of the vehicle. It is recommended that a steering axle is added to the trailer.

## 4.2. CIMC test by RIOH

On July 23, 2022, RIOH, together with Xiangyang Da'an Automobile Testing Center Co., Ltd. and CIMC, conducted a performance test to verify the compliance of the dual-trailer road train with the current Chinese mandatory automobile standards and regulations, and to verify the feasibility of the dual-trailer road train based on the PBS method. In March 2023, all performance tests and 2500 km of reliability tests were completed. A full-load test of the entire vehicle was carried out for dual-trailer road trains with a maximum allowable total mass of 60t and for semi-trailer train with a maximum allowable total mass of 49t.

### 4.2.1. Static Roll Stability

The road train was subjected to an un-loaded roll stability test in accordance with the requirements of the "Static Roll Stability Bench Test Method for Cars, Trailers, and Car Trains" (GB/T 14172-2021). When the roll reached 35 °, the tires of the towing vehicle and trailer did not detach from the test bench, and the force on the tire support surface is not zero, indicating that the dual-trailer road train has good roll stability.



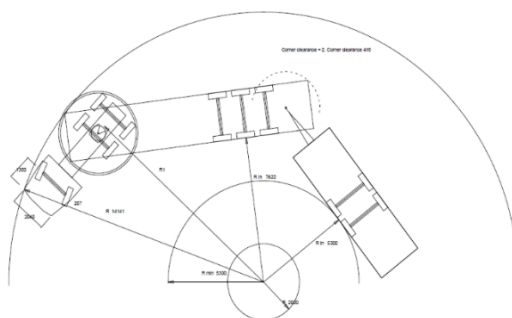
**Figure 5 – roll stability test Picture**

#### 4.2.2. Passing Ability Test

According to GB1589-2016 (Table 3, Figure 6), the inner turning circle radius of the double-trailer train passage should be 10.6 meters. Through simulations it has been calculated that the maximum outer circle radius of the CIMC combination, is 14.14 meters, which is 1.64 meters more than the 12.5 meters specified in the GB1589. According to the current road design, this road train combination can be safely driven on express highways down to second class highways. The GB1589-2016 standard should be revised in this respect.

**Table 3 – CIMC dual trailer train Turning circles radius and road width needed**

PASSING CAPACITY(m)		
Inner circle radius	Outer circle radius	Required road width
5.30	14.14	8.84



**Figure 6 – CIMC dual trailer train Turning clearance circle illustration**

#### 4.2.3. Power Performance Test

The tractor vehicle was equipped with a 560 horsepower engine, and the dual-trailer road train could achieve a maximum slope climbing and starting ability of 16.6%, and could reach a maximum speed of 116.72 km/h under full load. The test was repeated with the same tractor with a standard semitrailer. It reached a maximum speed of 117.11 km/h. It can be seen that the maximum speed of a dual-trailer road train is equivalent to that of one semi-trailer combination.



**Figure 7– Power Performance Test Picture**



#### 4.2.4. Lateral stability

Referring to the test method of "Road vehicles - Heavy commercial vehicle combinations and articulated buses - Lateral stability test methods" (ISO 14791:2000), a lateral stability test on a dual-trailer road train was conducted. Fully loaded (60t) at a speed of 80km/h, a single sine-wave steering input test was performed. The lateral acceleration rear amplification coefficient obtained was 1.05, and the yaw rearward application coefficient obtained was 1.07. The test, thus demonstrates that the dual trailer train has good lateral stability.



Figure 8 – Lateral stability Picture

#### 4.2.5. Economic comparison

Fuel consumption tests of semitrailer combinations and dual-trailers road trains were conducted under constant speed conditions of 40km/h, 50km/h, 60km/h, 70km/h, and 80km/h, and driven for 500 km. The test shows that the fuel consumption of a standard semitrailer combination was per 30.73 liters/100km and the fuel consumption of a dual-trailer road train was 35.92 liters/100 km.

#### 4.2.6. Conclusion of the tests

- The pass-ability of a road train is not as good as that of a semitrailer combination. Fitting a rear-end steering axle on the trailer is one possible solution to improve the pass-ability of the road train.
- The outer diameter of the GB1589-2016 should be revised
- Compared with semitrailer combinations, the total mass of a CIMC dual-trailer road train has been increased by 22.5%, and the total freight volume has been increased by 64.8%.
- When selecting a reasonable engine, there is no significant difference in the maximum speed between a dual-trailer road train and a semitrailer combination at full load.
- Under constant speed conditions, the fuel consumption per 100 kilometers of a dual-trailer road train is 16.89% higher than that of a semitrailer combination.
- Considering the added value of mass and volume, the advantages of a dual-trailer road train are obvious.

### 5. Comparative analysis of domestic and foreign highways

As the representative of the formulation and supervision of China's highway network

standards, RIOH of the Ministry of Transport needs to evaluate the operating conditions and feasibility of dual-trailer road trains with regard to China's existing road infrastructure.

### 5.1. Expressway lane width

The width of the highway lane directly decides the safe use of dual-trailer road trains for normal operation and turning. The China highway route design standard (JTG D20-2017) stipulates a highway lane width of 3.75m, which is the same as that of European highways.

### 5.2. Turning radius of highway lane

The turning radius of the highway lane directly affects the turning dual-trailer road trains. Because a highway permits high speeds, the road turning radius has to be larger compared with ordinary highways. According to a review of relevant foreign literature, the turning radius limit conditions for European highways are shown in Table 4. The limit values for the turning radius of JTG D20 expressway are shown in Table 5.

**Table 4; Turning radius limits for European highways**

Design Speed (km/h)		120	100	80
Minimum radius of circular curve (m)	General value	998	638	360
	Limit Value	665	425	240

**Table 5: Turning radius limits for highways in China**

Design Speed (km/h)		120	100	80
Minimum radius of circular curve (m)	General value	1000	700	400
	Limit Value	650	400	250

Note: The maximum superelevation value is 8%.

From Tables 4 and 5, it can be seen that the minimum turning radius of Chinese highways is generally greater than that of European highways, with a deviation of about 4% at high speeds and medium to low speeds.

### 5.3 Highway ramp

A highway ramp is a road on the right side of the entrance (or exit) of a highway, usually an acceleration lane for entering the highway or a deceleration lane for exiting the highway. The design speed and turning radius of China's highway ramps are shown in Table 6, and the minimum requirements for ramp radius are higher than the specific requirements of European standards.

**Table 6: General Principles and Technical Standards for Expressway Ramp Design**

Design speed of highways (km/h)		80	90	100	110	120
Ramp design speed (km/h)	Recommended value	70	75	85	90	95
	Lowest value	40	45	50	50	55
Ramp radius (m)	Recommended value	165	195	245	310	310
	Lowest value	45	65	70	70	90

In summary, by comparing and analysing the design standards of domestic and foreign highways, it is confirmed that the road requirements in China are basically the same as those in Europe, confirming that dual-trailer road trains can be safely used on Chinese highways.

## 6. Revision of Standards

In July 2022, the Office of the Security Committee of the State Council issued a notice on the issuance of the *National Road Traffic Safety Plan for the "Fourteenth Five-Year Plan"* (Security Committee Office [2022] No. 8), in which it proposed to "strengthen the research on the operation safety of new types of vehicle road trains such as center-axle trailer road trains and dual-trailer road trains". This ambition was further emphasized in section six of the above mentioned notice. "VI. Strengthen the research into intrinsic safety and operation safety of vehicles", which was clearly proposed by China during the "Fourteenth Five-Year Plan".

The National Technical Committee for Automobile Standardization and the Whole Vehicle Standardization Committee plan to carry out the development plan of the dual-trailer road train during the "Fourteenth Five-Year Plan" period.

Furthermore, the Trailer Sub-committee of the National Technical Committee for Automobile Standardization has issued the: *"Strength Requirements for Connecting Devices between Road Vehicles and Trains"* (ISO 18868: 2013 Commercial road vehicles - Coupling equipment between vehicles in multiple vehicle combinations - Strength requirements) *Road vehicles drawbar couplings and eyes for rigid drawbars - Strength tests* (ISO 12357-1: 2007 Commercial road vehicles - Drawbar couplings and eyes for rigid drawbars - Strength tests) (ISO 12357-2:) which is a key safety aspect of road trains.

## 7. Market Demand

In March 2022, Mr Liu Hanru, representative of the National People's Congress (NPC) and Chief Technology Officer (CTO) of Geely New Energy Commercial Vehicle Group, proposed to promote modular transport systems as a means to speed up the quick realization of China's goal to develop into a strong transportation nation. Relevant ministries and commissions of the State Council have issued policies to support qualified provinces and cities to actively carry out pilot demonstration projects of highway modular transport systems, and to accumulate experience for the comprehensive implementation of modular transport systems in the country. This is the first time that Chinese commercial vehicle enterprises, represented at the National Peoples' Congress (NPC) have appealed to society to carry out the research on dual-trailer road trains.

After the GB1589-2016 revision, goods center-axle trailers are allowed on road with a limit of 20 meters total length. Unfortunately, when compared with the large volume of oversized container box semitrailers, the inherent advantages and high flexibility of center-axle combinations are not convincing. The malpractice of allowing oversized box containers and gooseneck trailers has to be discontinued. The market instead needs modular truck and trailer combination applications to improve safety, logistics efficiency and to reduce operating costs. SF Express, JD Logistic and other companies have also clearly expressed a wish to rapidly upgrade trailer equipment and to move towards a standardized multi-trailer road train system.

## 8. Conclusions

In summary, equipment manufacturers and logistics companies have made a variety of attempts under the backdrop of current restrictive standards and laws, to design high capacity road trains. RIOH has carried out practical pilot projects together with transportation enterprises in several geographies. Various results show that the prospects of a road transport modular system and its transportation applications are feasible in China.

With China's stated dual carbon goals, the road transport modular system is an excellent way to simultaneously achieve carbon reduction and efficiency improvements for enterprises, society and government. It can furthermore help reduce the number of fatal road accidents. What is lacking are amendments of the existing GB1589 standard and of the Road Traffic Safety Law to allow for dual-trailer road trains on designated Chinese roads. The next revisions are expected to be completed around 2025.

## 9. Acknowledgements

This work is supported by special fund project for scientific and technological innovation of RIOH No. 2021-C-316 (QG2021-2-6-2) and the central public welfare research institutes for basic research funds No. 2020-9036c.

## 10. References

- Cider L, Larsson L, HCT DUO2-project Gothenburg-Malmö in Sweden, page 10-11, 2019
- CN Statistic Bureau, Page 2, 8, 9 and 20 of Volume 16, China Statistic Yearbook 2014-2022, 2023
- Fengfeng, EU EMS update, Page 15 and 21, ACEA 2022.06
- High Capacity Transport, Page 2, ACEA 2019.05
- Ni Zhengtao, Draft proposal of CN modular trailer train system, Page 7,8, 18, 19 and 26, HYVA 2021.09
- TFK & KTH, European Modular System for road freight transport – experiences and possibilities, Page 7 and 8, 2007
- Wu Shifeng, Dual trailers train technical development, Page 17 and 29, CIMC Tonghua, 2021.11
- Xiao Wei, Performance Assessment of Dual Trailer Truck Train system, Page 11, 13, 21,23 and 26, CAERI, 2021.11