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ANALYSIS AND EVALUATION OF APPLICATION OF CAR MODULAR SYSTEMS IN POLISH ROAD TRANSPORT

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Abstract

This study presents an analysis and evaluation of application of European Car Modular Systems in the Polish road transport. Those systems and respective terminology have been analysed and classified. Application of such systems in other countries of the European Union has been described. SWAT analysis has also been carried out in order to enable the most optimal choice of modular system in freight transport to match the condition and characteristics of the Polish road infrastructure. The systems have also been analysed in terms of efficiency and the analysis was performed on the basis of a selected research object – a transport company. An analysis of costs and estimated profits from transport services to be provided by those systems has been carried out on the basis of the research object in comparison with costs borne by the considered company with currently used transport means. This study shows that taking into consideration the results of analyses, safety aspect, road infrastructure and energy efficiency of the vehicles it was found that the proposed oversized vehicles could be implemented to be used on the Polish roads. The analyses and tests performed for a transport logistic company discussed in this article have demonstrated that the proposed modular systems will undoubtedly allow reducing significantly the costs of transport services by increasing load capacity of vehicles.

Keywords: *transport system, car modular system, SWOT analysis, efficiency*

1. Introduction

European Modular System (EMS) is based mainly on transport vehicles presently used in Europe. In German literature, one can find such terms as EuroCombi, Megaliner or Gigaliner. It is made up of a truck tractor or a truck, 13.7 m long articulated saddle trailer and a 7.82 m. long trailer.

Apart from standard vehicles, an EMS vehicle is built from additional non-standard elements [2]:

a) 2-axle trolley (called dolly),
b) special, 3-axle, 7.82 m. long articulated trailer with a removable container/body at the front, equipped with a saddle for another articulated trailer to be hooked.

Basing on the above-mentioned transport vehicles it is possible to create as many as five configurations of modular systems with total maximum authorized weight equal to 60 tones and length 25.25 m (Fig. 1.):

a) configuration A – 2/3-axle saddle truck tractor coupled with 3-axle articulated trailer 13.6 m. hooked with a central axle trailer with length up to 7.82 m,

b) configuration B – 2/3-axle saddle tractor connected with a special articulated trailer to be hooked with a standard articulated trailer, 13.6 m,
c) configuration C – 4-axle chassis 8x2/8x4 hooked with a 3-axle trailer,
d) configuration D – 3-axle chassis 6x2/6x4 hooked with a dolly truck and a 3-axial articulated trailer 13.6 m,
e) configuration E − 2-axle chassis hooked with two central-axle tandem trailer, 7.82 m long.

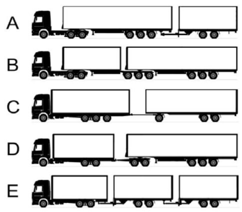

Fig. 1. Possible configurations of modular systems

The speed of modular trucks is limited to 40 km/h; however, if they are equipped with some systems and devices (i.e. braking system in each component vehicle consistent with EC requirements and a saddle equipped with bearings on a dolly truck) the maximum speed increases up to 80 km/h. It is also important to fulfil the condition that there are not more than two 'articulation' points of the system thus the modular truck consisting of a tractor truck, articulated trailer and trailer with a fifth wheel will still be subject to speed limit. There was also a necessity to decrease the minimal radius of turning diameter as accepted in the EU from 5.3 meters up to 2 meters [1].

The maximum axial thrusts depend on the above-mentioned classification of the road and the axial base. The distance between the last axle of the car/truck and the first axle of the trailer/articulated, trailer for full dimensional sixty tone configurations of trailers and articulated trailers has to be minimal, respectively 5 and 4 meters [1].

2. European Modular Systems in Europe

Presently only a few countries in Europe allow using EMS vehicles, these are [8]: Finland, Belgium, Sweden, Germany, Holland, Denmark, and some parts of Norway. The longest and the heaviest vehicles are allowed to be used in Finland, Holland, Belgium and Sweden. According to the module-based concept, the length of the heavy truck system can be 25.25 m and their gross weight − 60 tons. Tests of longer and heavier trucks are being carried out in some regions of Germany. Scandinavian countries have been experimenting to increase the maximum authorized weight and length of such heavy goods trucks. Tests of European Modular systems with length of 30 m and maximum authorized weight 90 t. have been going on in northern Sweden since 2009. These modular trucks are used to transport wood. In the countries of the European Union EMS, vehicles are to be used on national and international roads with two traffic lanes, though this condition does not have to be met [3].

3. Proposal of introducing car modular systems in Poland

Due to large dimensions and high total weight of modular system vehicles, in Poland they could only travel on the main roads, that is, motorways, highways and national roads. Taking into account an increased number of axles, the permitted axle loads are similar to standard trucks. The load exerted on one EMS vehicle with total mass of 60 tons, consisting of elements with 7 axles, is 8.57 tons on one axle. As compared to a standard truck, it does not make a big difference. For a truck with permitted total mass equal to 40 tons, the average load for 5 axles is 8 tons per one axle. Therefore, from the point of view of loads exerted on axles, EMS trucks could be allowed to move on the main roads in Poland.

As far as the Polish road infrastructure is concerned, there is another obstacle that can prevent introduction of EMS trucks, which are bridges and viaducts. However, infrastructure of these objects would not be exposed to risk of damage due to increased weight of those vehicles. In addition, in this case the main factor is an axle load. With appropriate distribution of load onto particular axles, an oversized truck will not pose a threat to the above-mentioned structures. It is also worth mentioning that although oversized trucks already move on objects of this kind and their total mass is higher than 40 tons they do not threaten the structures.

Crossroads and traffic circles pose the biggest problems for 25.25 m long vehicles.

Currently, standard trucks with length of 16.5 m or 18.75 m happen to have problems with passing through crossroads as the entry radius for sewaged roads of GP, G, Z class and D is 10 meters, whereas for entries of not sewaged roads of G and Z class it is 8 meters.

While passing through a crossroad, which is not sewaged, a truck driver should follow the following traffic rules [6]:

a) a driver must be particularly careful while changing the direction or traffic,
b) a driver is required to approach:
   - the right edge of the road – if they intend to turn right,
   - the middle of the road, or on a one-direction road, the left edge –if they intend to turn left.
c) the rule of art. 2 is not applied if the dimensions of the vehicle make it impossible to turn according to the rule specified in this regulation or it is allowed to move only in one direction.

Following this rule, heavy goods vehicles with lengths: 16.5 m, 18.75 and 25.25 m. equipped with torsion axles with the minimal radius of torsion: 12.5 m. and 14.5 are able to pass each crossroad with islands. The only obstacle for vehicles 25.25 m are sewaged road intersections without islands. These crossroads very rarely occur on national roads but it is recommended to rebuild them. A perfect alternative for oversized vehicles equipped with torsion axles is a ‘dolly’ truck patented by KRONE. This company has developed a truck with an active torsion system in order to provide 25.25 m long truck systems with safety and good riding qualities [7]. Thanks to this device, EMS vehicles are able to make easy turnings as the torsion system provides the vehicle with outer radius of nearly 5.30 m., whereas the articulated trailer follows the traces of the truck (Fig. 2.)

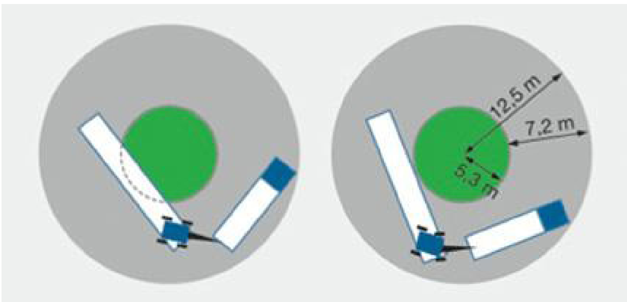

Fig. 2. Path of EMS equipped with KRONE ‘dolly’ truck on a traffic circle [7]

If it comes to passing through traffic circles on national roads, where the radius of the central island is 5 meters, EMS vehicles should be properly equipped with:

a) a system with the proposed ‘dolly’ truck with an active torsion system,
b) articulated trailer with one ‘articulation’ point equipped with a torsion axle,
c) as regards the above-mentioned elements the EMS vehicle configuration needs to have 2 articulation points as in the case of A, B and E configurations.

European modular systems moving on the remaining roads such as highways and motorways will have no problems with passing through traffic circles due to a long diameter of central islands and large radii of exit.

Fig. 3. EMS configuration equipped with an articulated trailer with a torsion axle [9]

4. SWOT analysis of modular truck systems

SWOT analysis involves classification of information on a given topic into four categories of strategic factors [4, 8, 10]. It is a supportive tool for selection of an optimal variant of combination of particular factors, which will improve the decision, making process in assessment of the analysed systems, these are:

- S (Strengths) – strong points: everything which is a merit, advantage of the analysed object,
- W (Weaknesses) – weak points: everything which is weakness, drawback, disadvantage of the analysed object,
- O (Opportunities) – chances: everything which provides a given object with an possibility to make a positive change,
- T (Threats) – dangers: everything, which poses a risk of negative change.

The first stage of the analysis involved identification of strong/weak points as well as opportunities and threats for the considered modular vehicles. Next, by means of an expert method, 5 most significant features were chosen for each category. The experts were workers (including drivers) of different departments of the analysed transport company. The selected features are presented in Tab. 1.

Tab. 1. Set of features for the European Modular System

European modular system	
Strong points	Weak points
– Increased load capacity. – Easy and fast transformation into different combinations – Number of used vehicles decreases. – Gross total mass increased. – Lower axle loads than in standard trucks.	– Costs connected with adjustment of infrastructure. – Drivers' problems with adaptation – Costs connected with fleet adjustment. – Low index of mobility . – Reduction of workplaces for truck drivers.
Opportunities	Threats
– Reduced fuel consumption. – Reduction in the number of collisions per one load unit. – Lower road surface damage. – Savings from drivers' salaries and from vehicle amortization. – Emission of a smaller amount of exhaust fumes	– Increased noise. – Negative impact on parking lots and bridges. – Increase in accident risk due to longer vehicles. – Reduction in railway transport demand. – Increased negative effects of accidents.

Further, each category was given values of weights which have been presented in Tab. 2.

Another step was to answer 4 key questions concerning relations between the categories [10]:

- will the identified strong points make it possible to take the opportunities?
- will the identified strong points allow overcoming threats?
- will the identified weak points allow taking the opportunities?
- will the identified weak points increase threats?

Tab. 2. Values of weights assigned to particular categories

Strong points	Weight	Weak points	Weight
Feature 1	0.35	Feature 1	0.4
Feature 2	0.1	Feature 2	0.5
Feature 3	0.1	Feature 3	0.35
Feature 4	0.2	Feature 4	0.15
Feature 5	0.25	Feature 5	0.5
Opportunities	Weight	Threats	Weight
Feature 1	0.15	Feature 1	0.1
Feature 2	0.15	Feature 2	0.25
Feature 3	0.35	Feature 3	0.2
Feature 4	0.25	Feature 4	0.25
Feature 5	0.1	Feature 5	0.2

In order to answer the questions concerning relations between the categories, a cross tables have been made, which were earlier completed with the above listed features [4].

When there is a dependence between the categories, the space of the table was filled with value „1". If there is no dependence like that, the value is „0". In the column and line, 'weight' there is earlier determined weights for each of the features. The product of weights and interactions means multiplication of weight and interaction. The rank was filled with value from „1" to „5", paying attention to dependence of the product of weights and interaction. In the place where the product has the highest, value '1' was entered and where it is the lowest '5'. Rank/significance defines the power of the feature.

Table 3. shows values of the features, categories concerning questions 1.

Tab. 3. Will the identified strong points allow taking the opportunities? [4]

Strong points/ Opportunities	Strong point 1	Strong point 2	Strong point 3	Strong point 4	Strong point 5	Weight	Number of interactions	Product of weight and interaction	Rank
Opportunity 1	0	0	0	1	1	0.15	2	0.3	3
Opportunity 2	0	0	1	0	0	0.15	1	0.15	4
Opportunity 3	0	1	1	0	1	0.35	3	1.05	1
Opportunity 4	1	0	0	1	0	0.25	2	0.5	2
Opportunity 5	0	1	1	1	0	0.1	1	0.1	5
Weight	0.35	0.1	0.1	0.2	0.25				
Number of interactions	1	2	3	3	2				
Product of weights and interaction	0.35	0.2	0.3	0.6	0.5				
Rank	3	5	4	1	2				
Sum of interactions							20/2		
Sum of products								4.05	

Tables 4 show values of the features, categories concerning questions 2.

Tab. 4. Will strong points allow overcoming threats? [4]

Strong points/ Opportunities	Strong point 1	Strong point 2	Strong point 3	Strong point 4	Strong point 5	Weight	Number of interactions	Product of weight and interaction	Rank
Threat 1	0	0	1	0	0	0.1	1	0.1	5
Threat 2	0	1	1	0	1	0.25	3	0.75	1
Threat 3	0	1	1	0	0	0.2	2	0.4	3
Threat 4	0	1	1	0	0	0.25	2	0.5	2
Threat 5	0	1	0	0	0	0.2	1	0.2	4
Weight	0.35	0.1	0.1	0.2	0.25				
Number of interactions	0	4	4	0	1				
Product of weights and interaction	0	0.4	0.4	0	0.25				
Rank	4/5	1/2	1/2	4/5	3				
Sum of interactions							18/2		
Sum of products								3.0	

Table 5 shows values of the features, categories concerning questions 3.

Tab. 5. Will the identified weak points not allow taking the opportunities? [4]

Strong points/ Opportunities	Weak points 1	Weak points 2	Weak points 3	Weak points 4	Weak points 5	Weight	Number of interactions	Product of weight and interaction	Rank
Opportunity 1	1	1	0	1	1	0.15	4	0.6	2/3
Opportunity 2	1	1	1	0	1	0.15	4	0.6	2/3
Opportunity 3	0	1	1	0	1	0.35	3	1.05	1
Opportunity 4	0	1	0	1	0	0.25	2	0.5	4
Opportunity 5	1	1	0	0	0	0.1	2	0.2	5
Weight	0.4	0.5	0.35	0.15	0.5				
Number of interactions	3	5	2	2	3				
Product of weights and interaction	1.2	2.5	0.7	0.3	1.5				
Rank	3	1	4	5	2				
Sum of interactions							30/2		
Sum of products								9.15	

Table 6 shows values of the features, categories concerning questions 4.

Tab. 6. Will the identified weak points increase threats? [4]

Strong points/ Opportunities	Weak points 1	Weak points 2	Weak points 3	Weak points 4	Weak points 5	Weight	Number of interactions	Product of weight and interaction	Rank
Threat 1	0	0	0	0	0	0.1	0	0	4/5
Threat 2	0	0	0	1	0	0.25	1	0.25	3
Threat 3	0	1	0	1	0	0.2	2	0.4	½
Threat 4	0	0	0	0	0	0.25	0	0	4/5
Threat 5	1	1	0	0	0	0.2	2	0.4	½
Weight	0.4	0.5	0.35	0.15	0.5				
Number of interactions	1	2	0	2	0				
Product of weights and interaction	0.4	1	0	0.3	0				
Rank	2	1	4/5	3	4/5				
Sum of interactions							10/2		
Sum of products								2.75	

The analysis results are shown in Tab. 7.

Tab. 7. SWOT analysis results

Combianation	Swat analysis results	
	Sum of interactions	Sum of products
Strong points/opportunities	20/2	4.05
Strong points/opportunitie	18/2	3.10
Weak points/opportunities	30/2	9.15
Weak points/opportunities	10/2	2.75

Analysing the final results (contained in Tab. 7), it can be said that with a defined configuration of internal and external factors and a fixed system of weights, the most desirable variant for choice of the considered modular systems will be using the combination of weak points and opportunities. The other combination to be taken into consideration for assessment of such systems will be the combination strong points/ opportunities.

5. Evaluation and analysis of introduction of modular trucks into a selected transport – logistic company

The described company has its seat in central Poland and deals with package shipping to its 18 divisions situated throughout Poland. A saddle truck with an articulated trailer for 34-euro pallets is used for transport of those shipments. The rate accepted for one vehicle – kilometre is 2.80 pln.

The company is involved in s hipping packages to different divisions. Due to the amount of cargo shipped with the use of pallets, it is crucial for the company to have a sufficient number of transport means. The proposed changes aim at replacing the currently used saddle trucks by vehicles of the European Modular System. Currently there 18 destination points and more than 34 pallets of goods are sent to 4 of them. This increases the demand for the number of transport means.

In Tab. 8 there are average numbers of pallets sent to the above mentioned company divisions.

Tab. 8. List of the number of pallets sent to the company divisions

Division	number of pallets sent to the company divisions
Division 1	54
Division 2	64
Division 3	52
Division 4	48

Introduction of D configuration of the European Modular System with total maximum authorized weight 40 tons is a good alternative for the company. It consists of a rigid truck for 19 pallets and a standard articulated trailer fixed on a dolly truck for 33 pallets. The vehicle, which is made up of such elements, is capable to carry 52 pallets in one ride. D configuration of EMS provides the possibility to articulate the vehicle in two points. Some traffic circles in Poland, situated on national roads between the divisions, require this kind of configuration. However, there are not many of them. On the routes to given divisions the vehicles will travel mostly on the main roads.

The rate of one vehicle kilometre has been accepted to be 3.90 pln. This sum was consulted with the workers of the company division and other carriers and the logistic department having taken into consideration the costs of amortization, driver's average salary and costs to be borne for adjustment of the fleet.

Theoretically, the introduced EMS truck does not give the possibility to carry more than 52 pallets. However, the experience of the warehouse workers and their routine handling of the same type of cargo make it easy to stack it in a vehicle. For example, the division in division 2 is reported to be accepting 64 pallets sent. With such a number of pallets, the warehouse workers are able to load additional 12 pallets stacking them evenly on both parts of the EMS vehicle.

Therefore, such a number of pallets do not make it impossible for the EMS configuration to transport them. It should also be mentioned that a larger number of pallets does not in any way because exceeding the maximum authorized weight of the vehicle because the existing transport means use only 75% of their load capacity due to high weight of the cargo. In order to estimate the transport costs for both the current vehicle and the proposed EMS one it is necessary to account for the number of kilometres from the company seat to its divisions. The distances are presented in Tab. 9.

These are assumed kilometres costs paid by the logistic operator. The numbers are presented in Tab. 9.

Tab. 9. Distances between the divisions according to the type of vehicle

Division	distance to cover for a standard vehicle	distance to cover for EMS truck
Division 1	140	165
Division 2	190	210
Division 3	210	210
Division 4	280	280

Apart from the rate for one kilometre, it is necessary to add to each route payments for toll roads and via-tool.

Table 10 contains the total cost for transport of a given number of pallets for standard vehicles at the rate 2.80 pln/km, taking into consideration the number of vehicle kilometres and additional costs. Due to the number of pallets that are carried to given divisions, 2 truck systems are used so the cost is doubled.

Tab. 10. Overall cost of goods transport for a standard truck system

Standard truck	
Route	transport cost [PLN]
Division 1	818.00
Division 2	1327.16
Division 3	1269.30
Division 4	1735.86

Table 11 demonstrates the cost for transport of a given number of pallets for EMS trucks for the rate 3.90 pln/km, including the number of kilometres and additional costs.

Tab. 11. Overall cost of goods transport for EMS trucks

EMS	
Route	transport cost [PLN]
Division 1	644.00
Division 2	965.58
Division 3	865.65
Division 4	1175.93

The above presented proposal of changes shows that replacement of standard trucks with EMS trucks in the company on routes to the selected divisions would have a positive influence on transport costs. An analysis of the difference in costs after introduction of EMS trucks as compared to standard trucks was made on the basis of the data shown in Tab. 10 and 11. The results of this analysis are shown in Tab. 12.

Tab. 12. Difference in costs after introduction of EMS

Route	standard truck	EMS	Savings
Division 1	818.00	644.00	174.00
Division 2	1327.16	965.58	361.58
Division 3	1269.30	865.65	403.65
Division 4	1735.86	1175.93	559.93
		TOTAL	1499.16

It can be said that replacement of standard trucks with European Modular System trucks provides a company with savings, as follows:

- **7495.80 pln** for transport of goods during one week,
- **29983 pln** for transport of goods during one month,
- **89949 pln** for transport of goods during three months.

The proposed changes will reduce transport costs by **29%**.

Conclusions

Fast development of infrastructure and increasing customers' demands motivate people to look for new, innovative technical solutions in order to increase load capacity and load space of heavy goods vehicles. This makes entrepreneurs search for new technical systems to be implemented in their companies. The aim of these solutions is to ensure efficient functioning of the company and meet the needs of customers as well as obtain possibly the biggest savings with maintenance of the quality and efficiency of provided services. This also should be done with as little interference with the local infrastructure as possible.

The attempt to replace of supplement the existing truck systems by modular vehicles is a solution, which provides the possibility to meet these requirements. A choice of a proper transport means depends on the specificity of the provided services and benefits expected by a given company.

After having made an analysis and assessment of road modular vehicles, they were found to be an optimal solution for the analysed logistic company. Taking into consideration the results of analyses, safety aspect, road infrastructure and energy efficiency of the vehicles it was found that the proposed oversized vehicles could be implemented to be used on the Polish roads. EMS is a relatively new solution and it has not been applied in Poland yet. However, some European countries have proven, on the basis of numerous tests and analyses, advisability of implementation of these vehicles and the research is still going on. The analyses and tests performed for a transport logistic company discussed in this article have demonstrated that the proposed modular systems will undoubtedly allow reducing significantly the costs of transport services by increasing load capacity of vehicles. This will bring savings of nearly 30%, for 4 divisions of the considered company.

References

[1] Starkowski, Bieńczak, K., D., Zwierzycki, W., *Samochodowy transport krajowy i międzynarodowy, Kompendium wiedzy praktycznej*, Systherm, Poznań 2009.

[2] Brach, J., *Sposoby podniesienia efektywności europejskiego transportu drogowego,* Logistyka, 2007.

[3] *Longer Semi-trailer Feasibility Study and Impact Assessment*, Transport Research Laboratory (TRL), Report commissioned by Department for Transport, United Kingdom 2010.

[4] Przeradzki, P., *Analiza przydatności europejskich systemów modułowych w transporcie samochodowym na przykładzie wybranego zakładu logistycznego,* Praca dyplomowa pod kierunkiem Ł. Muślewskiego, KSW, Włocławek 2015.

[5] *Maximum Weights of Trucks in Europe, Maximum Dimensions of Trucks in Europe*, International Transport Forum, United Kingdom October 2011.

[6] Ustawa z dnia 20 czerwca 1997 r. *Prawo o ruchu drogowym*. (Dziennik Ustaw. z 2005 r. Nr 108, poz. 908 zm. z 2005 r. Nr 108, poz. 909).

[7] Wojcieszak, A., *Europejska koncepcja mega-ciężarówek,* Log24, 2013.

[8] http://pl.wikipedia.org.

[9] http://40ton.net.

[10] Jeżerys, B., *Metoda SWOT.* W: *Analiza strategiczna*. U. Gołaszewska-Kaczan (red). PWE, Warszawa 2014.

[11] *Long-Term Climate Impacts of the Introduction of Mega-Trucks.* Study for the Community of European Railway and Infrastructure Companies (CER). Karlsruhe, 2009.

[12] Muślewski, Ł., *Study and assessment of transport system operation efficiency.* Journal of KONES Powertrain and Transport, Warsaw 2010.

[13] Muślewski Ł., Bojar P., Szubartowski M., *Analysis of intermode connections in terms of transport system development in Poland.* Journal of KONES Powertrain and Transport, Warsaw 2011.