

# Model of the Increasing the Capacity of the Train and Railway Track by Using the New Type of Wagon

Martin Kendra, Jaroslav Mašek, Juraj Čamaj, Martin Búda

**Abstract**—The paper deals with possibilities of increase train capacity by using a new type of railway wagon. In the first part is created a mathematical model to calculate the capacity of the train. The model is based on the main limiting parameters of the train - maximum number of axles per train, maximum gross weight of train, maximum length of train and number of TEUs per one wagon. In the second part is the model applied to four different model trains with different composition of the train set and three different average weights of TEU and a train consisting of a new type of wagons. The result is to identify where the carrying capacity of the original trains is higher, respectively less than a capacity of train consisting of a new type of wagons.

**Keywords**—Loading units, theoretical capacity model, train capacity, wagon for intermodal transport.

## I. INTRODUCTION

THE loading capacity of train is number of wagons, TEUs or the mass of goods that can be transported by one train. This paper works with model of the capacity converted on number of TEUs. The basic assumption is that using VEL Wagon will increase total capacity per train [1]-[5].

TEU – Twenty-feet Equivalent Unit is the basic measure for the description of capacity and performance in intermodal transport. Its dimensions and loading capacity are taken from the dimensions of standard 20 feet ISO container. The capacity of other loading units for intermodal transport as well as capacity of vehicles and intermodal terminals is converted on TEUs.

This paper consists of two parts:

- Theoretical model – general characteristics of relationships and formulas;
- Application of the model on selected model trains with use of common wagons for intermodal transport and with use of VEL wagons.

## II. MAXIMUM NUMBER OF TEUS PER TRAIN CALCULATION

Maximum number of TEUs transported in train depends on the train parameters – length, weight and number of axles normative. The number of TEUs per train is limited [6], [7]:

- maximum number of axles per train;

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- maximum gross weight of train;
- maximum length of train;
- number of TEUs per one wagon.

There is an individual calculation of each of these limitations.

### A. Number of Axles per Train Limitation

Maximum number of TEUs depending on normative of axles per train is calculated according to the following relation:

General relationship:

$$N_{TEU}^{max/train} = \frac{N_{axles}^{max/train} - N_{axles}^{Locomotive}}{N_{axles}^{wagon}} \cdot N_{TEU}^{max/wagon} \quad (1)$$

where;  $N_{axles}^{max/train}$  - maximum number of axles per train (axles);  $N_{axles}^{Locomotive}$  - number of locomotive axles (axles);  $N_{axles}^{wagon}$  - number of axles per wagon (axles);  $N_{TEU}^{max/wagon}$  - maximum number of TEUs on wagon (TEU).

This equation can be edited for common wagon for intermodal transport and for VEL wagon [9].

Common wagon for intermodal transport (wagon type Sgnss) can carry maximum 3 TEUs. VEL wagon can carry at least 4 TEUs.

Formula edited for common 4 – axle wagon (type Sgnss):

$$N_{TEU}^{max/train} = \frac{N_{axle}^{max/train} - N_{axle}^{Locomotive}}{4} \cdot 3 \quad (2)$$

where;  $N_{axle}^{max/train}$  – maximum number of axles per train (axles),  $N_{axles}^{Locomotive}$  – number of locomotive axles (axles).

Formula edited for VEL wagon:

$$N_{TEU}^{max/train} = \frac{N_{axles}^{max/train} - N_{axles}^{Locomotive}}{4} \cdot 4 \quad (3)$$

$$= N_{axles}^{max/train} - N_{axles}^{Locomotive}$$

where;  $N_{axle}^{max/train}$  – maximum number of axles per train (axles),  $N_{axles}^{Locomotive}$  – number of locomotive axles (axles).

### B. Maximum Train Weight Limitation

Maximum gross weight of train is depending on the type of locomotive, on the line parameters and the vehicle resistances. It is set in the prescriptions for each line, type of locomotive and used wagons [13]. Maximum number of TEUs per train limited by maximum gross weight of train is calculated by:

$$N_{TEU}^{max/train} = \frac{M_{train}^{max} - M_{Locomotive}}{M_{wagon}^{tarra} + N_{wagon}^{0,TEU} \cdot M_{TEU}^0} \cdot N_{wagon}^{0,TEU} \quad (4)$$

where;  $N_{TEU}^{max/train}$  – maximum number of TEUs in train (TEU);  $M_{train}^{max}$  – maximum gross weight of train (tons);  $M_{Locomotive}$  – locomotive weight (tons);  $M_{wagon}^{tarr}$  – net weight of wagons (tons);  $N_{wagon}^{\phi,TEU}$  – average number of TEUs on wagon (TEU);  $M_{TEU}^{\phi}$  – average TEU weight in train (tons), while following requirement is valid:

$$M_{TEU}^{\phi} \leq M_{TEU}^{max} \quad (5)$$

#### C. Maximum Weight of TEU Limited by the Type of Wagon

Maximum weight of TEU is limited by the axle load. It is calculated by:

$$M_{TEU}^{max} = \frac{N_{axles}^{wagon} \cdot M_{axles}^{max} - M_{wagon}^{tarr}}{N_{TEU}^{wagon}} \quad (6)$$

where;  $M_{TEU}^{max}$  – maximum gross weight of TEU (tons);  $N_{axles}^{wagon}$  – number of wagon axles (axles);  $M_{axle}^{max}$  – maximum axle load (tons); A – 16,0 tons/axle, B – 18,0 tons/axle, C – 20,0 tons/axle, D – 22,5 tons/axle,  $M_{wagon}^{tarr}$  – net wagon weight (tons);  $N_{TEU}^{wagon}$  – number of TEU on the wagon (TEU).

#### D. Maximum Train Length Limitation

The limitation of overall length of train depends on the length of the shortest station track intended for transport (not shunting tracks). This maximum length of train is set in the prescriptions for each line [12], [14]. Maximum number of TEUs per train limited by maximum train length is calculated by ation:

$$N_{TEU}^{max/train} = \frac{(L_{train}^{max} - L_{Locomotive})}{L_{wagon}} \cdot N_{TEU}^{max/wagon} \quad (7)$$

where;  $N_{TEU}^{max/train}$  – maximum number of TEU on the train (TEU);  $L_{train}^{max}$  – maximum train length (m);  $L_{locomotive}$  – locomotive length (m);  $L_{wagon}$  – total wagon length (m);  $N_{TEU}^{max/wagon}$  – maximum number of TEUs on the wagon (TEU).

#### E. Limitation by the Number of TEUs per 1 Wagon

Number of TEUs that can be loaded on one wagon is given by loading length and the construction of the wagon.

Conversion TEU units: 1 ISO 1C container = 1 TEU (20)

$$N_{TEU} = \frac{L_{cont}}{20} \quad (8)$$

where;  $N_{TEU}$  – container length recomputed on number of TEUs;  $L_{cont}$  – container length (feet).

#### F. Conclusion of the Model

The final maximum number of TEUs in the train is the lowest number from these:

- number of TEUs per train depending on maximum number of axles per train;
- number of TEUs per train depending on maximum gross weight of train;
- number of TEUs per train depending on maximum length of train; and given by the minimum value of the maximum number of TEUs resulting from:

- maximum number of axles in train;
- maximum train weight;
- maximum train length.

Capacity - number of TEUs per train:

$$N_{F-TEU}^{max/train} = \min\{N_{i,TEU}^{max/train}\} \quad (9)$$

where;  $N_{F-TEU}^{max/train}$  – final maximum number of TEUs in the train (TEU);  $N_{i,TEU}^{max/train}$  – maximum number of TEUs in the train computed through max. number of axles per train, max. train weight and max. train length (TEU).

### III. CALCULATION OF MAXIMUM TRANSPORTED GOODS MASS AND TRANSPORT PERFORMANCE OF ONE TRAIN

In this calculation, we assume from the estimated number of TEUs per train. Input for the calculation is the average load of one TEU ( $M_{good}^{\phi/TEU}$ ).

Calculation of maximum transported goods mass and transport performance of one train:

$$M_{good}^{max/train} = N_{F-TEU}^{max/train} \times M_{good}^{\phi/TEU} \quad (10)$$

where;  $M_{goods}^{max/train}$  – maximum quantity of goods transported by one train (tons);  $N_{F-TEU}^{max/train}$  – maximum number of TEUs transported by train (TEU);  $M_{good}^{\phi/TEU}$  – average load of one TEU (tons).

### IV. APPLICATIONS OF THE MODEL ON THE SELECTED TYPE TRAINS WITH THE USE OF COMMON WAGONS FOR INTERMODAL TRANSPORT AND WITH THE USE OF VEL WAGON

Application of the model is processed for different variants of model train. We processed separately the analysis of train capacity increase depending on maximum train length, maximum number of axles in the train and maximum train gross weight normative.

Calculations are processed via comparison of train with several possible combinations of the wagon compilation and the block train that consist of VEL wagons [8]. We realized the calculations for these concrete types of trains:

- block train consisting of the Sgnss wagons;
- block train consisting of the Lgs wagons;
- Intermodal transport train set up according to wagon list of actual intermodal transport train which operates on the route Koper (SI) – Zilina (SK).

This wagon compilations are compared with the block train set up from the VEL wagons. In the calculations average gross weight of one TEU is considered 11,7 tons. When considering maximum load capacity usage of VEL wagon (in chosen variants), then gross weight of one TEU is 16,5 tons [10], [11]. When we compare with the train on route Koper – Zilina, we consider the real average weight of one TEU is 5,9 tons.

#### A. Inputs of the Model

Tables I-IV are input data for capacity model.

TABLE I  
WAGON TYPE SGNSS - TECHNICAL DATA

Number of axles		4
Overall length		19,740 m
Tara weight		19,800 t
Loading weight	A	44,20 t
	B	52,20 t
	C	62,20 (60,20) t
	D (120 km/h)	70,20 (60,20) t
Loading length		18,500 m

TABLE II  
WAGON TYPE LGS - TECHNICAL DATA

Number of axles		2
Overall length		14,02 m
Tare weight		10,80 t
Loading weight	A	21,30 t
	B	25,30 t
	C	29,20 t
Loading length		12,78 m

TABLE III  
EXAMPLE OF WAGON LIST OF ACTUAL INTERMODAL TRANSPORT TRAIN WHICH OPERATES ON THE ROUTE KOPER (SI) – ZILINA (SK)

Wagon type	Mount of wagon	Weight (kg)		Overall length (m)	Number of axles (axels)	TEUs on wagon (m)
		Netto	Tara			
1	Kgs	18	181041	232060	13,9	2
2	Sgmrss	1	30249	29000	29,5	6
3	Laags	5	134717	111960	27,8	4
4	Kbkks	3	29151	37000	13,9	2
5	Regs	1	20117	23550	13,9	2
6	Kbgs	1	7058	13000	27,8	4
7	Sgnss	2	53343	38850	13,9	2
Total		31	455676	485420	534,54	82
Locomotive			87000		16,74	4

TABLE IV  
BASIC TECHNICAL DATA OF THE VEL WAGON

Number of axles		4
Overall length		25,94 m
Tare weight		23,9 t

### B. Outputs of the Model

Outputs of model have been calculating by using (1)-(10) and are shown in Tables V and VI and Figs. 1 and 2. Table V shows the saving of wagons per train depending on train gross weight, loaded weight in TEU and type of wagon in train set. In Table VI are the numbers of transported TEUs per train depending on train gross weight, loaded weight in TEU and type of wagon in train set.

### V.CONCLUSION

The normative of train length is limiting factor only for the gross weight of TEU lower than average gross weight – 11,7 t. The normative of number of axles in train affects the capacity of train only in the case when train set is compiled only of two-axle wagons. This model is almost unused in practice due to limited payload of this wagon set.

TABLE V  
DIFFERENCES IN NUMBER OF WAGONS: SET OF VEL WAGON MINUS VARIOUS TYPES OF WAGON SETS IN TERMS OF GROSS WEIGHT OF TRAIN AND GROSS WEIGHT OF TEU

Gross weight of train [t]	38	48	58	68	78	88	98	109	119	129	139	149	159
	3	4	5	6	7	8	9	0	1	2	3	4	5
Sgnss (TEU-1,7t)	1	2	2	3	3	4	5	4	5	5	6	6	7
Various set (TEU-5,9t)	4	5	7	8	9	11	12	13	14	15	16	18	19
Lgs (TEU-1,7t)	6	8	9	11	12	13	15	16	18	19	21	22	24
Sgnss (TEU-6,5t)	1	1	2	2	3	3	3	3	4	4	5	5	6

TABLE VI  
DIFFERENCES IN NUMBER OF TEUs: SET OF VEL WAGON MINUS VARIOUS TYPES OF WAGON SETS IN TERMS OF GROSS WEIGHT OF TRAIN AND GROSS WEIGHT OF TEU

Gross weight of train [t]	38	48	58	68	78	88	98	109	119	129	139	149	159
	3	4	5	6	7	8	9	0	1	2	3	4	5
Sgnss (TEU-1,7t)	2	0	2	0	2	0	-2	3	1	3	1	3	1
Various set (TEU-5,9t)	3	3	1	2	2	1	1	2	4	4	5	3	4
Lgs (TEU-1,7t)	-2	-4	-2	-4	-2	-2	-4	-2	-4	-2	-4	-2	-4
Sgnss (TEU-6,5t)	1	2	0	1	-1	0	2	3	1	2	0	1	-1

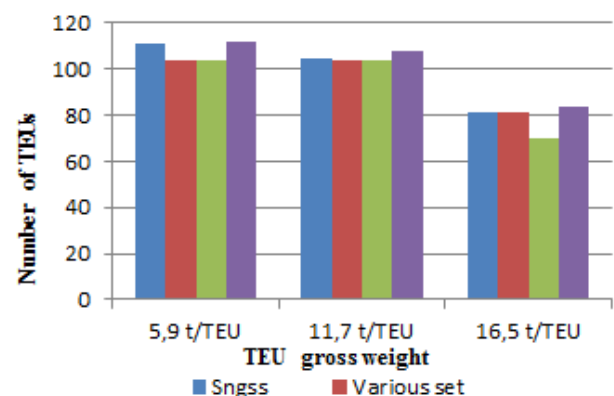


Fig. 1 Graphical representation of difference train capacity (number of TEUs) of various types of trains and different types of TEU gross weight according to criteria of maximum gross weight of train (1600 t) and maximum length of train (750 m)

The most limiting parameter of the train capacity increase is the gross weight of train and gross weight of TEU. Table V shows that train consisting of VEL wagons only has always lower number of wagons, in some cases the number is more than 50 % lower. The use of lower number of wagons, together with the same or higher capacity of transported TEUs (in selected examples, Table VI), can be considered as the biggest advantage of new VEL wagon.

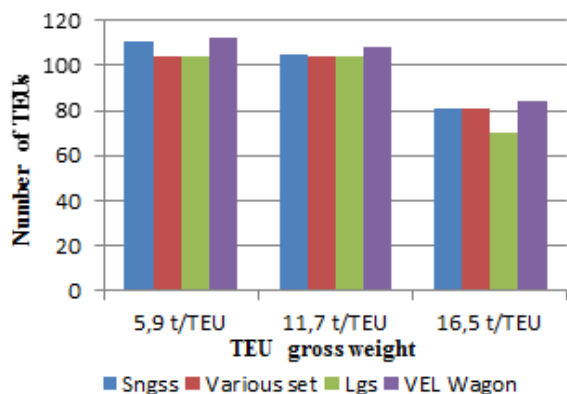


Fig. 2 Graphical representation of difference train capacity (number of TEUs) of various types of trains and different types of TEU gross weight according to criteria of maximum gross weight of train (2000 t) and maximum length of train (750 m)

Taking into account another advantages resulting from the construction of VEL wagon (which are not part of this model), this wagon can be usable innovative railway car for future and development of intermodal transport. Mentioned another advantages of the VEL wagon are:

- possibility to carry high cube containers without exceeding the loading gauge;
- possibility to carry 45' containers;
- reduction of rolling resistance, aerodynamics (fewer bogies, underneath air resistance);
- less energy consumption (tare of the wagon);
- less maintenance (les axles);
- less noise.

#### ACKNOWLEDGMENT

This paper is prepared with the support of the projects:

- The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265610,
- VEGA 1/0701/14 Impact of liberalization of the rail freight market on the social costs of transport,
- This paper is prepared with the support of the project "Transfer of innovative knowledge and technology in logistics and transport processes", ITMS project code 26220220006, University of Žilina.



ERDF – European Regional Development Fund  
The project is financed by funds from the EC.

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