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 description of capacity and performance in intermodal transport. Wagon will increase total capacity per train [1]-[5].

There is an individual calculation of each of these parameters.

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;
- 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:

\[ N^\text{max/train}_\text{TEU} = \frac{N^\text{max/train}_\text{axles}}{N^\text{max/wagon}_\text{axles}} \cdot N^\text{max/wagon}_\text{TEU} \]  

(1)

where;
- \( N^\text{max/train}_\text{axles} \) - maximum number of axles per train (axles);
- \( N^\text{max/wagon}_\text{axles} \) - number of locomotive axles (axles);
- \( N^\text{max/wagon}_\text{TEU} \) - 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):

\[ N^\text{max/train}_\text{TEU} = \frac{N^\text{axles}}{4} \cdot 3 \]  

(2)

where;
- \( N^\text{axles} \) - maximum number of axles per train (axles), \( N^\text{axles} \) - number of locomotive axles (axles).

Formula edited for VEL wagon:

\[ N^\text{max/train}_\text{TEU} = \frac{N^\text{max/train}_\text{axles}}{N^\text{axles}} \cdot 4 \]  

(3)

where;
- \( N^\text{max/train}_\text{axles} \) - maximum number of axles per train (axles), \( N^\text{axles} \) - 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:

\[ N^\text{max/train}_\text{TEU} = \frac{N^\text{max/wagon}_\text{TEU}}{N^\text{TEU}} \]  

(4)

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

$$M_{\text{max}}^{\text{TEU}} = M_{\text{max/train}}^{\text{TEU}}$$

(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:

$$M_{\text{max}}^{\text{TEU}} = \frac{M_{\text{avg}}^{\text{TEU}} \times M_{\text{max}}^{\text{wagon}}}{N_{\text{TEU}}}$$

(6)

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

$$N_{\text{max/train}}^{\text{TEU}} = \frac{(L_{\text{max}}^{\text{Locomotive}} - L_{\text{wagon}})}{L_{\text{TEU}}^{\text{max/wagon}}} \times N_{\text{TEU}}$$

(7)

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

$$N_{\text{TEU}} = \frac{L_{\text{cont}}}{25}$$

(8)

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

F. Conclusion of the Model

The final maximum number of TEUs in the train is the lowest number from these:
- maximum number of axles in train;
- maximum train weight;
- maximum train length.

Capacity - number of TEUs per train:

$$N_{F-\text{TEU}} = \min\{N_{\text{max/train}}^{\text{TEU}}\}$$

(9)

where; $N_{\text{max/train}}^{\text{TEU}}$ – final maximum number of TEUs in the train (TEU); $N_{\text{max/train}}^{\text{TEU}}$ – 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 ($M_{\text{good}}^{\text{TEU}}$).

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

$$M_{\text{max/train}}^{\text{good}} = N_{\text{max/train}}^{\text{TEU}} \times M_{\text{good}}^{\text{TEU}}$$

(10)

where; $M_{\text{max/train}}^{\text{good}}$ – maximum quantity of goods transported by one train (tons); $N_{\text{max/train}}^{\text{TEU}}$ – maximum number of TEUs transported by train (TEU); $M_{\text{good}}^{\text{TEU}}$ – 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 Sgnw 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 – 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**

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

### TABLE II
**WAGON TYPE LGS - TECHNICAL DATA**

<table>
<thead>
<tr>
<th>Number of axles</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length</td>
<td>14,02 m</td>
</tr>
<tr>
<td>Tara weight</td>
<td>10,80 t</td>
</tr>
<tr>
<td>Loading weight</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>21,30 t</td>
</tr>
<tr>
<td>B</td>
<td>25,30 t</td>
</tr>
<tr>
<td>C</td>
<td>29,20 t</td>
</tr>
<tr>
<td>Loading length</td>
<td>12,78 m</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Wagon type</th>
<th>Mount of wagon</th>
<th>Weight (kg)</th>
<th>Overall length (m)</th>
<th>Number of axles</th>
<th>TEUs on wagon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kgs</td>
<td>18</td>
<td>161041</td>
<td>232060</td>
<td>13,9</td>
<td>2</td>
</tr>
<tr>
<td>Sgmmss</td>
<td>1</td>
<td>30249</td>
<td>29000</td>
<td>29,5</td>
<td>6</td>
</tr>
<tr>
<td>Laags</td>
<td>5</td>
<td>134717</td>
<td>111960</td>
<td>27,8</td>
<td>4</td>
</tr>
<tr>
<td>Khkks</td>
<td>3</td>
<td>29151</td>
<td>37000</td>
<td>13,9</td>
<td>2</td>
</tr>
<tr>
<td>Regs</td>
<td>1</td>
<td>20117</td>
<td>23550</td>
<td>13,9</td>
<td>2</td>
</tr>
<tr>
<td>Kbgs</td>
<td>1</td>
<td>7058</td>
<td>13000</td>
<td>27,8</td>
<td>4</td>
</tr>
<tr>
<td>Sgnss</td>
<td>2</td>
<td>53343</td>
<td>38850</td>
<td>13,9</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>455676</td>
<td>485420</td>
<td>534,54</td>
<td>82</td>
</tr>
<tr>
<td>Locomotive</td>
<td></td>
<td>87000</td>
<td>16,74</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

### TABLE IV
**BASIC TECHNICAL DATA OF THE VEL WAGON**

<table>
<thead>
<tr>
<th>Number of axles</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length</td>
<td>25,94 m</td>
</tr>
<tr>
<td>Tara weight</td>
<td>23,9 t</td>
</tr>
</tbody>
</table>

### 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.

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.
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 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 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 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. 

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