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Intensity Model and Traffic Quality Assessment of the Selected Section of the D1 Highway

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Abstract

This study focuses on analysing the traffic indicators on selected sections of the D1 highway in the direction from Humpolec to Rančířov, with a particular emphasis on the Pávov transportation hub. Data from the nationwide traffic census of 2020 were utilized for calculations, including average daily traffic intensity, average daily load, and transport performance on each section. The capacity of each section was determined and compared to the overall traffic intensity, revealing potential congestion points.
The analysis covers sections 5-8019, 6-8609, 6-1131, 6-1133, 6-1146, 6-1147, and 6-1020, demonstrating a high level of traffic intensity, particularly in terms of heavy motor vehicle traffic volume. The distribution of traffic flow before exit 104 in Větrný Jeníkov into sections 6-1131 and 6-1133 could significantly alleviate temporary traffic congestion. Considering a Mechanized Infantry Brigade comprising 1 320 vehicles, the calculated convoy length would be approximately 70.562 meters, assuming a simple distance of 50 meters between vehicles. This study provides valuable insights for military convoy movement planning and highlights the importance of considering highway traffic conditions for strategic deployments.
The aim of the article is to propose a commercial solution for securing the onward movement of alliance units based on the analysis of traffic intensity in the selected sector of the D1 highway.

KEY WORDS: *D1 Highway, traffic analysis, military convoy movement, transportation hub, traffic congestion, Mechanized Infantry Brigade.*

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1. Introduction

Transport is the intentional movement of means of transport with passengers and goods along transport routes [1], so it is a means of fulfilling mobility needs. It characterizes transport as "the movement of people and goods from a starting point to a designated place" and includes all tools for moving, means of transport, infrastructure, energy and more. [2]. The product of transportation is transportation (relocation), and we therefore understand transportation as relocation through transportation. From the logic of the matter, "it is not possible to store the transport product and cover fluctuations in demand from stocks. These must have transport in the capacity of infrastructure and mobile means" [1].

The transport network is defined by transport routes in the territory, which is composed of transport points. Ending or starting the transport is realized at the transport point, which is a place on the transport routes. From the point of view of passenger transport, a transport point is a point of embarkation, exit or transfer, and for freight transport it is a point of loading, unloading or transhipment of goods.

If an important traffic point is located at the intersection of traffic routes, then it is a traffic node [3]. Transport infrastructure, which is defined by Act No. 183/2006 Coll., on territorial planning and building regulations, defines transport infrastructure "*as transport land, transport structures and related facilities*". At the same time, it is defined that enabling the movement of means of transport along the transport network must be achieved by organizational and technical provision of the transport infrastructure.

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Act No. 111/1994 Coll. on road transport defines road transport as "*a set of activities that ensure the transport of people (line passenger transport, shuttle transport, occasional passenger transport, taxi service), animals and goods (freight transport) by vehicles, as well as the movement of vehicles themselves on highways, roads, local roads and publicly accessible purpose-built roads and open terrain*."

Road transport has an irreplaceable place in the transport of people and cargo, and with increasing demands for the implementation of the „Just in Time" method, the demand for the availability and possibility of basic communication routes grows. The current security situation requires carrying out analyses of traffic especially in the west-east direction, especially when using the backbone road D1. Highlands region, the South Moravian region and the Zlín region were selected for the analysis of the current level of permeability.

Mapping the condition of roads is an important activity, which subsequently influences the creation of maintenance, repair and investment plans, also from the perspective of the host country's support for the armed forces of the Allied units.

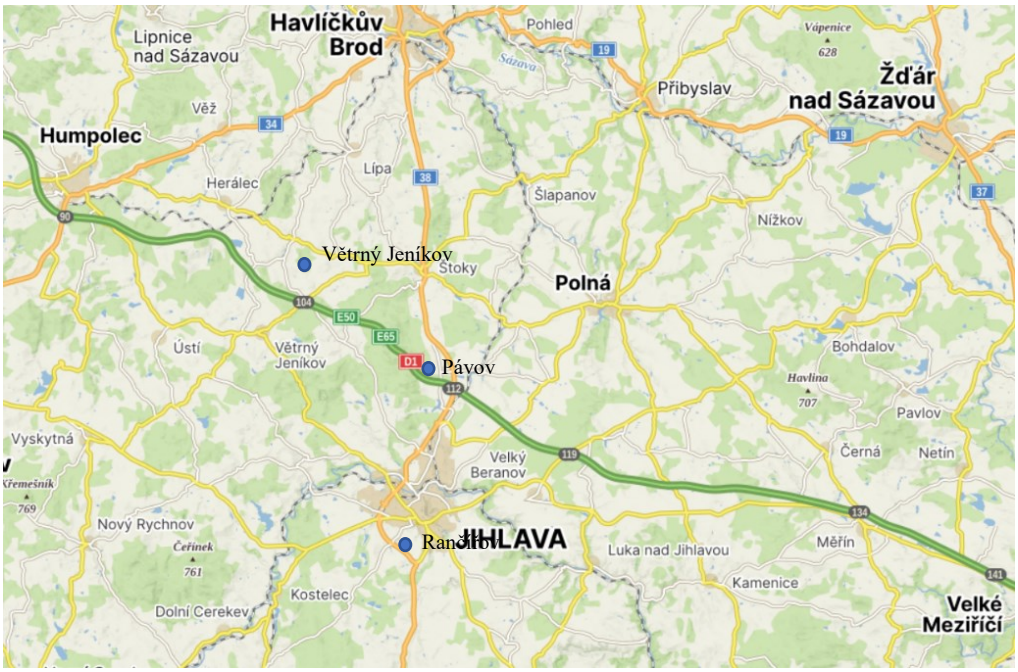

Fig. 1. Highway section D1 Humpolec – Jihlava

In the article, the movement of vehicles in the selected section was modelled, where Pávov represents the traffic point where the highway is left and transport begins in the direction of Rančířov. The authors presented the results of basic statistical data collected during vehicle runs in selected regions of the Czech Republic and the Větrný Jeníkov – Pávov - Měřín (see Fig. 1) section in the period from September to December 2023. The focus of the work is limited to road transport in terms of transport mode and transport infrastructure in terms of transport components. The selected profile of the analysed section is in the range of 691 – 427 meters above sea level.

2. Structure of road transport and indicators of road transport and infrastructure

The road network in the Czech Republic covers the territory of thirteen regions and the capital city of Prague. The total length of road infrastructure in the Czech Republic is 55,761.3 km.

As of 1 January 2022, there are 4.976.5 km of roads in the territory of the Highlands region. The D1 highway crosses the Vysočina region for a length of less than 92.5 km (1.8 %), the I. class road measures 425 km (8.4 %), the II. class almost 1.629 km (32 %) and road III. class of less than 2.937 km (57.8 %). Highlands region therefore owns almost 90 % (4.566 km) of the road network in the region.

As of 1 January, 2022, there are 6.149 km of highways and roads in the territory of the South Moravian Region. Motorways cross the region for a length of less than 74 km (1.2%), class I roads (excluding expressways) measure 646 km, class II roads. class 1.627 km and road III. class of almost 3.800 km. [4].

Condition of road surface II. and III. classes in individual regions rated in the interval of excellent, good, satisfactory, unsatisfactory and emergency.

2.1. Indicators of road transport and infrastructure

Traffic indicators, transport performance, weight of transported cargo, traffic intensity and traffic performance, describe the load on the road network and the impact of traffic on the road transport infrastructure.

Transport capacity in freight transport is calculated by the cost of transporting one ton of cargo over a distance of one kilometer and is calculated according to the formula:

$$P = \sum_{i=1}^{m} q_i lz_i \quad (1)$$

where: P is the transport capacity in freight transport in units of tonne-kilometre (tkm), and q_i is the weigh of i-th cargo transport in tons, lz_i is the transport distance of the *i-th* weight of the cargo in kilometres [4]. The symbol m denotes the number of vehicles [4].

The volume of transported goods is calculated according to the formula:

$$Q = \sum_{i=1}^{m} q_i lz_i \quad (2)$$

where Q is the volume of transported goods - in our case, and q_i is the volume of i-th transpot in a single trip [4].

Traffic intensity is an indicator that tracks the number of vehicles that pass a certain section in a 24-hour time limit. Data collection is carried out through traffic surveys or using automatic traffic counters.

Transport performance evaluates the movement of means of transport (i.e. how many kilometres they travel) regardless of the result of the transport (i.e. the number of people transported or the amount of goods). It is mainly used to determine the capacity of roads and public transport.

Since the mathematical description of the behavior of vehicles on the road is very complicated, we will only focus on the description of one vehicle that drives repeatedly.The formula:

$$^1L = {}^1L_1 + {}^1L_0 = nl_Z + \sum_{i=1}^{m} l_{oi} \quad (3)$$

represents the transport work (total distance travelled) of one vehicle for a given operating time [km], $^1L_1$ is the distance travelled by one vehicle on a regular line according to the timetable, or distance travelled with passengers in irregular traffic [km], ^1L_O is the distance travelled by one vehicle without passengers (parking and stopping the vehicle) [km], n is the number of connections of one vehicle during the time of operation on the line, l_Z is the operational length of the line [km], l_{oi} is the distance of the i-th port, i =1, 2, ..m, or parking trips of one vehicle [km], m is the number of port and parking trips [5].

2.2. Analysis of the density of the transport infrastructure of selected regions of the Czech Republic for the transport of armed forces

The assessment of the density of the transport network is calculated depending on the length of the infrastructure and the size of the region. The calculated values are in the following table 1.

Table 1.

Density of transport infrastructure in km/km^2 [4]

	Highway	The expressway	Class I road	Road II. classes	Road III. classes	Railway	In total
Czech Republic	0.010	0.006	0.073	0.185	0.433	0.121	0.828
Highlands region	0.014	0.000	0.063	0.239	0.432	0.092	0.839
South-Moravian region	0.019	0.004	0.059	0.204	0.196	0.109	0.590

2.3. Analysis of selected sections when deploying alliance units

Sections of the D1 highway were selected, which may affect the movement of allied units, especially with a focus on the Pávov traffic point. Data from the national transport census 2020 were used for the calculations. The indicators that were calculated are the following: average daily intensity of the section, average daily load and transport performance on the given section. Subsequently, the capacity of the section was determined and compared with the overall intensity of the section. This revealed the congestion of the given section. Data from the previous intensity analysis were used for the calculations.

2.3.1. Analysis of section 1: Humpolec – Větrný Jeníkov – Jihlava, exit 112

The calculation of this section consists of two sections 5-8019 and 6-8609 (see Fig. 2). The intensity in the given section of interest is described in Table 2.

Table 2.

Fifty-fold hourly intensity for extravillan fivesatiraze and for peak hourly intensity intravillan [6]

Counting section	**5-8019**	**6-8609**
Fifty-fold traffic intensity (heavy motor vehicles) – vehicles/hour	716	760
Peak hourly traffic intensity (heavy motor vehicles) vehicles/hour	0	0
Fifty-fold traffic intensity (all motor vehicles in total) – vehicles/hour	3134	3306
Peak hourly traffic intensity (all motor vehicles in total) vehicles/hour	0	0
Value for heavy goods vehicles	21 779	220823

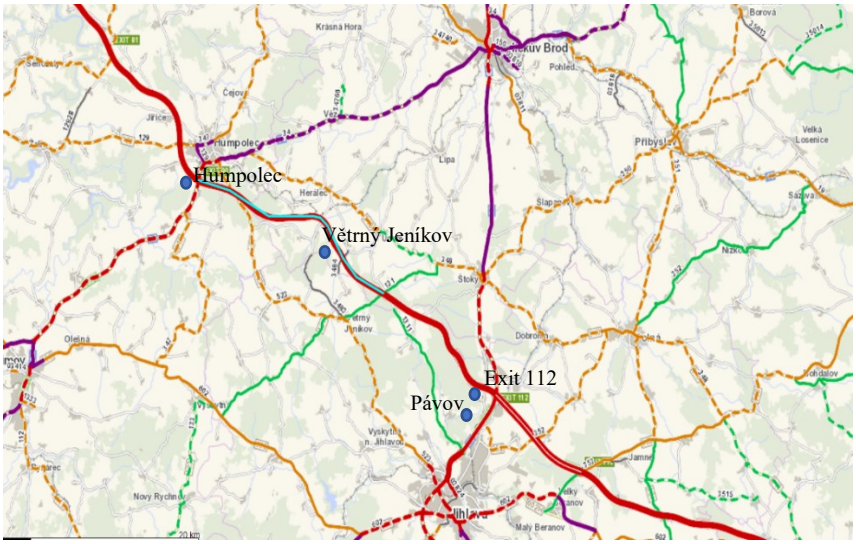

Fig. 2. Highway section D1 Humpolec – Větrný Jeníkov

Counting traffic in the section is implemented for different types of vehicles - light trucks (useful weight up to 3.5 t / total weight up to 7.5 t) without trailers and with trailers (LN), medium trucks (useful weight 3.5 – 10t / gross weight 7.5 – 20t) without trailers (SN), medium trucks (useful weight 3.5 – 10t / gross weight 7.5 – 20t) with trailers (SNP), heavy trucks (useful weight over 10t / total weight over 20t) without trailers (TN), heavy trucks (useful weight over 10t / total weight up to 20t) with trailers (TNP), trailer sets of trucks (NSN), bus (A), articulated buses (AK), tractors without trailers (TR), tractors with trailers (TRP), total heavy motor vehicles (TV), passenger and delivery vehicles without trailers and with trailers (O), single wheel motor vehicles (M), all motor vehicles total (SV) and heavy trucks (TNV).

The following table 3 calculates the annual average of daily traffic intensities (RPDI) for all days, working days and holidays, excluding holidays.

Table 3.

Counting traffic in the section 5-8019 [6]

Annual average traffic intensity		LN	SN	SNP	TN	TNP	NSN	A	AK	TR	TRP	TV	O	M	SV
RPDI – all days	VHC/day	3 773	974	383	248	517	8 018	74	0	0	0	13 967	21 457	27	35 471
RPDI – Mo - Fr	VHC/day	4 121	1 143	447	291	603	9 352	78	0	0	0	16 035	20 767	24	36 826
RPDI - days off, no holidays	VHC/day	2 821	463	191	118	258	4 005	66	0	0	0	7 922	24 966	40	32 928

Hourly traffic intensity is also related to the previous table, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 716 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 3.134. In the category of heavy trucks, it is a value of 21.779 for Value TNV, based on the number of vehicles per day.

Reducing the load on roads, especially in exits 112 and 104, variants of reducing the intensity of freight traffic were proposed, since freight traffic makes up the majority of the mass load on the roads.

Another area of interest is Větrný Jeníkov, which represents an important traffic point.

The most critical part of the movement is Exit 112 – Jihlava, when the convoy leaves the D1 highway and continues along road 38 (see Fig. 3).

Fig.3. Map of the movement from Exit 112- Jihlava – Rančířov.

If we evaluate the basic traffic indicators, we proceed along the route from the D1 highway to the village of Rančířov, when we analyzed sections 6-1131, 6-1133, 6-1146, 6-1147 and section number 6 -1020, table 4.

In the given case, the main factor is the fifty-fourth and peak hourly intensity, which is based on the intensities measured for the whole year for individual days and in a 60-minute interval.

Table 4.

50-hour intensity for extravillan 50-hour intensity and for intravillan peak hourly intensity [6]

Counting section	**6-1131**	**6-1133**	**6-1135**	**6-1146**	**6-1147**	**6 -1020**
Fifty-fold traffic intensity (heavy motor vehicles) – vehicles/hour	524	524	521	352	290	231
Peak hourly traffic intensity (heavy motor vehicles) vehicles/hour	437	437	435	294	243	193
Fifty-fold traffic intensity (all motor vehicles in total) – vehicles/hour	2434	2434	2825	1383	1134	920
Peak hourly traffic intensity (all motor vehicles in total) vehicles/hour	2032	2032	2359	1154	947	768
Value for heavy goods vehicles	5964	5964	5734	4377	3809	3361

Directorate of Roads and Highways statistical data is an important part of military movement planning, but immediate situational awareness can be enhanced by the use of Movement Control Teams, or a corresponding UAV. Modern UAVs have tracking functions and can contribute to surveillance activities in the implementation of convoy movements. The use of noiseless means enables monitoring of areas of interest – intersections, bridges and tunnels with very low costs.

Testing of unmanned aerial vehicles (UAV) for traffic tracking and analysis is conducted worldwide [7]. Khan et al. [8] systematically reviewed the research studies conducted in UAV traffic monitoring and analysis up to 2016. The development of 5G technologies made it possible to abandon traffic monitoring for fixed-trajectory UAVs. [7]

Table 5.

Counting traffic in the section 6- 8609 [6]

Annual average traffic intensity		**LN**	**SN**	**SNP**	**TN**	**TNP**	**NSN**	**A**	**AK**	**TR**	**TRP**	**TV**	**O**	**M**	**SV**
RPDI – all days	VHC/day	4 084	1 099	453	295	423	8 408	85	0	0	0	14 847	22 497	68	37 412
RPDI – Mo - Fr	VHC/day	4 487	1 298	532	348	496	9 866	89	0	0	0	17 116	21 902	60	39 078
RPDI - days off, no holidays	VHC/day	3 004	514	223	138	208	4 131	74	0	0	0	8 292	25 749	97	34 138

Hourly traffic intensity is also related to the previous table 5, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 760 vehicles in total heavy motor vehicles and in the category all motor

vehicles total it is a number of 3,306. In the category of heavy trucks, it is a value of 22,832 for Value TNV, based on the number of vehicles per day.

The analyzed section assumes an exit from the backbone road D1, exit 112 Jihlava, where there is an intersection on section 6-8609, which should not create cross and interweave collision points.

The offered option is to use road 1311 and leave D1 at exit 104 Větrný Jeníkov. If we evaluate the basic traffic indicators, we proceed along the route from the D1 highway to the village of Rančířov, when we analysed sections 6-1131, 6-1133, 6-1146, 6-1147 and section number 6 -1020. In the given case, the main factor is the fifty-fourth and peak hourly intensity, which is based on the intensities measured for the whole year for individual days and in a 60-minute interval.
If we take into account the busyness of the D1 highway, it appears as a possibility to use the exit 104, Větrný Jeníkov.

Table 6.

Counting traffic section 6-6830 [6]

Annual average traffic intensity		**LN**	**SN**	**SNP**	**TN**	**TNP**	**NSN**	**A**	**AK**	**TR**	**TRP**	**TV**	**O**	**M**	**SV**
RPDI – all days	VHC/day	48	12	2	15	2	12	5	0	0	9	105	564	8	677
RPDI – Mo - Fr	VHC/day	56	15	3	19	3	15	6	0	0	11	128	591	8	727
RPDI - days off, no holidays	VHC/day	27	4	1	5	1	4	2	0	0	3	47	496	8	551

Hourly traffic intensity is also related to the previous table 6, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 12 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 81. In the category of heavy trucks, it is a value of 71 for Value TNV, based on the number of vehicles per day.

3. Creation of traffic flow

A traffic stream is the movement of vehicles behind one another or in lanes next to each other in one direction, so it can consist of several traffic streams. The basic characteristics of the traffic flow are the intensity of the traffic flow, the density of the traffic flow, the time interval between the vehicles and the distance between the vehicles.

The intensity of the traffic flow is the number of traffic units that will pass through a certain transverse profile of the road in 1 direction during the selected time period: *I* - [car. /h], the traffic flow density represents the number of vehicles that are present in 1 direction on the selected length of road at a given moment: *H* [vehicles/km]. Another factor is the time gap between the vehicles, which is the time that elapses between the passages of the fronts of two consecutive transport units (vehicles) determined by the traffic profile, and the length gap of the vehicles is the distance between the fronts of the following vehicles at a certain moment.

Hourly traffic intensity is also related to the previous table, where fifty-fold traffic intensity (heavy motor vehicles) is calculated - vehicles/hour, where in our case it is 12 vehicles in total heavy motor vehicles and in the category all motor vehicles total it is a number of 81.

In the category of heavy trucks, it is a value of 21.779 for Value TNV, based on the number of vehicles per day.

4. Traffic flow models

Traffic flow models are used to investigate the behavior of vehicles driving behind each other, i.e. forming a traffic flow. The macroscopic approach is symbolized above all by the so-called fundamental relationships between the speed, density and intensity of the traffic flow. The calculation is made according to the formula:

$$I = V * H \tag{5}$$

where: *V*- speed [km/hour], *H*- density [vehicles/km], *I*- volume [vehicles/hour].

In the calculations of traffic flow models, the Greenshields relationships from 1935 are used, where the relationship between speed and volume and the relationship between speed and density are taken into account.

The trailing vehicle model is defined as the interrelationship between the driving of the vehicle and the driving of the vehicle in front of it. To determine the driving parameters of the vehicle, we use the position *x* [m], the speed of the vehicle [m/s], the acceleration *a* [m/s^2] and ryvem *j* [m/s^3].
We use the position x which depends on the time x=x(t). The speed *v* and acceleration *a* can be calculated by means of derivation.

$$v = \frac{dx}{dt} \; ; \; a = \frac{d^2x}{dt^2} = \frac{dv}{\mathrm{d}t} \; ; j = \frac{d^3x}{dt^3} = \frac{d^2v}{dt^2} = \frac{da}{dt} \tag{6}$$

The leading vehicle sets the rhythm of the movement, which is transmitted to the following vehicle. This process has a domino effect on subsequent vehicles. If we evaluate the level of traffic quality according to the technical conditions in the selected section of the road infrastructure, we evaluate the edges and nodes, we start from the document Technical conditions189 – the determination of traffic intensity, which is determined in six levels according to the capacity of a larger number of vehicles than the expected load. Considering the fact that the specified section is satisfactory, we continued with the evaluation of two indicators: the delay time [s] and the number of vehicles.

To determine the traffic intensity, we used the results of the national traffic census for roads of the second and higher classes. The layout of the grade crossing is a key factor for capacity assessment, which is assessed at the points of disconnection, connection and interweaving of vehicles. In this regard, we can also mention the resistance of the network, which can be expressed by the capacity, which represents the simple number of vehicles able to pass through an edge or a node. Here we evaluate the increase in travel time compared to an empty road. The capacity of the road or intersection can be set for one lane as a flat rate in the range of 1.800 to 2.000 vehicles per hour.

The traffic flow models will of course also take into account the commander's requirements, which means that the movement will be carried out unit by unit. The next calculation is based on the division on the main phase, which calculates the relationship between entrances to the intersection and the use of shifting lanes, which have a major impact on the non -collision passage through the intersection.

We have chosen one direction (1) which uses entrances AB (a) and CD (b), the other entrance (2) includes entrances EF (c) (see Fig. 4). A draft signal plan is prepared for each intersection and load levels. Due to the nature of the traffic load used, which does not change over time, it is not possible and necessary to design dynamic control (6).

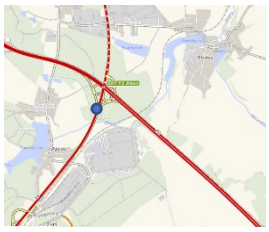

Fig. 4 (a) Section 6-1131 intersection AB

Fig. 4(b) Section 6-1135 – intersection CD

Fig. 4(c) Section 6-7481 – EF (9)

The basic parameters for intersections are Selected cycle time of 80 seconds and Split time-vehicle-vehicle of 4 second. The traffic load of the entire network 4.540 vehicles/h, network extent of 2 intersections and speed between intersections 50 km/h. An optimization algorithm was performed, where we evaluated the optimal time to leave the intersection with a vehicle length of 10 meters for a selected section of the track when commercial traffic stops. If we include the values of normal traffic on the section 6-1135 - intersection CD, the values will be significantly different and with normal commercial traffic and 20 vehicles in the convoy. The numbers and types of vehicles are shown in figure 5.

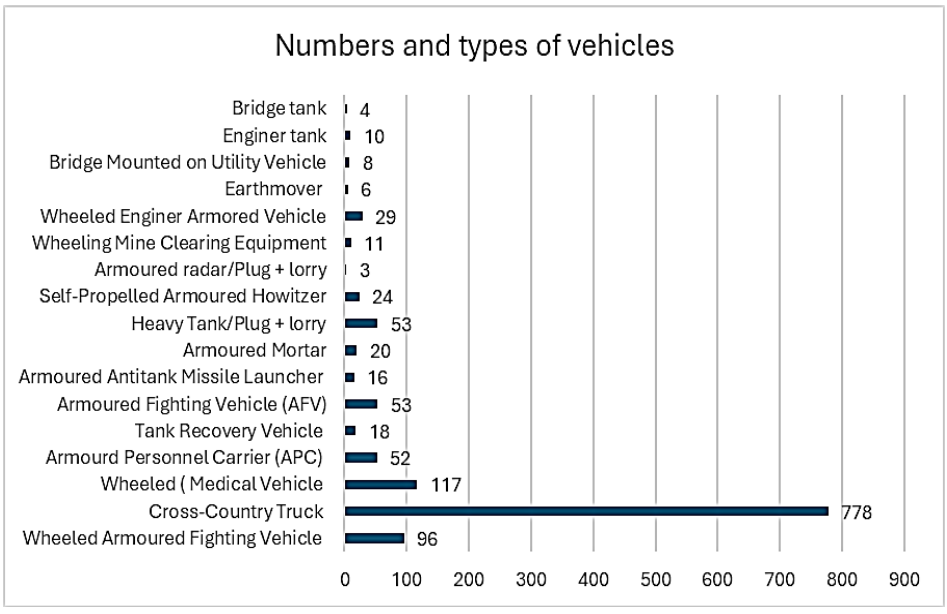

Fig. 5. Overview of transported equipment

5. Conclusions

The analysis of traffic indicators of selected sections of the highway in the direction D1 – Humpolec- Větrný Jeníkov – Jihlava – Rančířov consists of sections 5-8019, 6-8609, 6-1131, 6-1133, 6-1146, 6-1147 and 6-1020 and shows a high level of

traffic intensity in selected indicators fifty-four times traffic intensity (heavy motor vehicles) – vehicles/hour and peak hourly traffic intensity (heavy motor vehicles) vehicles/hour. The main recommendation is to use two exits, which means that also using exit 104 Větrný Jeníkov for sections 6-1131 and 6-1133 would significantly reduce the temporary pressure on traffic intensity. If we assume that the Mechanized Infantry Brigade has 1.320 vehicles in its structure, when calculating the length of individual types of vehicles, the length of the column would be 9.975 meters, while keeping a simple distance between vehicles of 50 meters, the length of the column of vehicles would be 60.835 meters, i.e. the calculated total length of the brigade would be 70.562.2 meters.

The Brigade Road March has its own specifics, which are determined by the dimensions of the vehicles and their weight. Limiting factors include speed. Speed limits are described in Table 8.

Table 8.

Estimated speeds of convoys on roads

Features of the road	**Mechanized units**	**Motorized units**
Motor ways	50	60
Rapid roads	40	50
Small roads	30	40
Slow roads	20	30

The Intervals are the timings fixed between the Elements within a Unit Column usually 05 minutes and the gaps are the timings fixed between the Columns (Packages, Battalions or Separate Convos): usually 15 to 30 minutes.

Fig.6. The structure of the Střechov rest area [6]

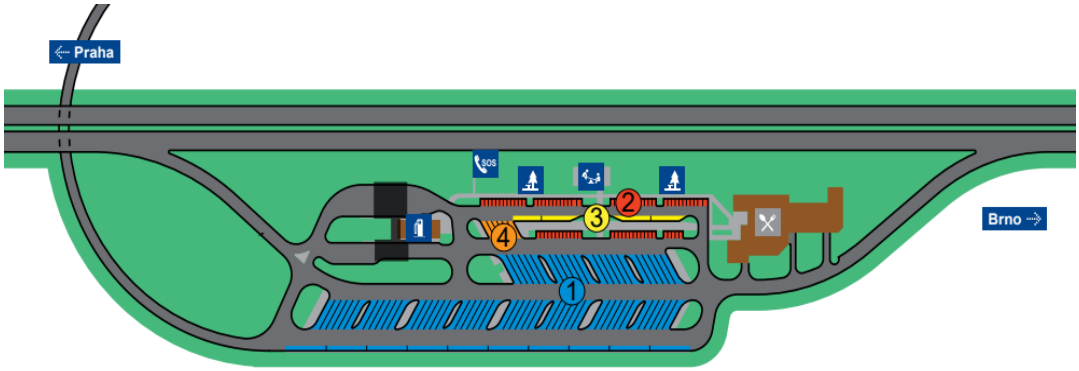

Fig.7. The structure of the Střechov rest area [11]

One of the solutions within the framework of support activities by the host state is the use of the Střechov rest area, which has parking spaces for 98 trucks, 76 passenger vehicles, 4 buses and 6 parking spaces for vehicles with trailers, caravans, and motorhomes.

The rest stop is 52 kilometres in the direction of Prague and is also equipped with a gas station and a restaurant (see Fig. 6). The use of rest periods that are managed by the Roads and Highways Directorate requires an understanding of the fact that support by the host state is not only the responsibility of the Ministry of Defense of the Czech Republic, but of the state, which as an active member of NATO should use all capacities for the safe practice of onward movement in the conditions of the Czech Republic.

The rest area is equipped with catering facilities and a gas station. It can be assessed that the use of the rest area, which is 230 kilometres from the Rozvadov border crossing and 180 kilometres from the Breitenau border crossing, could meet the requirements for a Convoy Support Centre according to the Bi-SC Capability Codes and Capability Statements, which require providing real life support and services (accommodation, catering, sanitary facilities, medical) for up to 750 personnel and sufficient refuelling capacity and parking spaces for 350 vehicles per day (see Fig. 7). These advantages collectively contribute to a more effective and successful operation [9,10].

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