COMPARISON OF THE MILITARY CONVOYS' CROSS-COUNTRY MOBILITY ESTIMATION RESULTS FOR CROATIAN CONDITIONS

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Abstract

The paper investigates the theoretical influence of field conditions and dynamic characteristics of the vehicles on military convoys' cross-country mobility. Convoys' average traveling speed along hypothetical two-way road segments was assessed by the methodologies described in the Transportation Research Boards Highway Capacity Manual 4th and 7th editions. The assumptions on infrastructure and traffic conditions were as follows. The road segment length varied from 0.4 to 6.4 km, its horizontal alignment was linear, and its vertical grade was larger than 6%. As military convoys have a right-of-way, there were no access points, no no-pass zones, and no vehicles in opposing directions along the road segment, and therefore lane and shoulder widths did not influence convoy speed. Average traveling speed on specific upgrades and downgrades was calculated and compared for convoys with 60%, 70%, and 80% of heavy vehicles. The results show there are significant differences in the speed reduction estimated by different methodologies. The results obtained from the Manual 4th edition methodology show that segment length moderately influences speed along specific upgrades and does not influence the speed along downgrades. The Manual 7th edition methodology results were more sensitive to analyzed segment length, grade, base free-flow speed, and convoy composition. The average traveling speed on specific upgrades and downgrades estimated by the Manual 7th edition methodology is on average 10 to 15 km/h lower, respectively. Therefore, it was concluded that this methodology and its results will be further investigated in local conditions through field research for a more comprehensive assessment of its applicability.

Keywords: modeling, road alignment, convoy, speed, Highway Capacity Manual

1 Introduction

When moving armed forces as part of combat operations, it is important to assess the cross-country mobility of military vehicles, which is limited by the achievable average traveling speed (ATS) of a military convoy. Determining this cross-country passability provides insight into the limitations of vehicle mobility and the creation of assumptions on the possible directions of movement of one's own and opposing forces [1]. Factors influencing ATS are the field conditions and the tactical-technological and dynamic characteristics of the vehicles. According to [2] and [3], road grade variation can significantly reduce vehicle speed as grades constrain the vehicle's acceleration and deceleration performance. This is especially true for heavy vehicles (HVs), as the ATS is negatively correlated with the percentage of such vehicles in traffic flow [4]. Due to the high percentage of HVs and the necessity for crossing challenging terrains, military convoys are specific entities for traffic modeling.

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The Croatian Army armed forces carry out convoy transport by different vehicles: defenders, HVs such as 5-tonne and 10-tonne trucks, and special vehicles such as flatbed trailers – defined as military motor and towing vehicles that, alone or together with its cargo, exceed the following dimensions: length greater than 25 m, width greater than 3.6 m, or height greater than 4.5 m. According to the Instructions on transportation in the Croatian Army [5], for security and easier convoy monitoring, the number of vehicles in one convoy cannot exceed twenty. However, there are no official guidelines on assessments of the military convoys' mobility in the Republic of Croatia today. Therefore, this investigation aims to assess the theoretical influence of field conditions and assumed dynamic characteristics of the vehicles forming the standard military convoy on its cross-country mobility. The results of this investigation are planned to be used as inputs for future field investigations and research in the field of convoy traffic flow modeling and routing.
Two-way rural roads comprise more than 94% of the 26.650 km road network in the Republic of Croatia (according to the Decision on the classification of public roads [6]). The convoy ATS was therefore estimated for hypothetical sections of two-way rural roads. According to the Rulebook on the basic conditions that public roads outside settlements and their elements must comply with from the traffic safety point of view [7], estimating the road infrastructure and traffic flow quality should be done by the procedures given in the Transportation Research Boards Highway Capacity Manual (HCM). As HCM 4th edition [8] and 7th edition [9] procedures for ATS calculation differ, both were used for obtaining and comparing the ATS results.

2 Materials and methods

In this section, calculation inputs, assumptions on two-way road infrastructure conditions and convoy volume and composition, as well as HCM 4th edition and HCM 7th edition procedures for ATS calculations are given.

2.1 Calculation inputs and assumptions

The following assumptions on two-way road infrastructure conditions and convoy volume and composition were made.

- The road segment length varies from 0.4 to 6.4 km, its' horizontal alignment is linear, and its' vertical grade is larger than 6%.
- As military convoys have a right-of-way, there are no access points, no no-pass zones, and no vehicles in opposing directions along the road segment, and therefore lane and shoulder widths do not influence convoy speed.
- According to transportation instructions by the Croatian Army, the convoy consists of a maximum of twenty vehicles (defenders, 5 and 10-tone trucks, and flatbed trailers). In the analysis, defenders were regarded as personal vehicles (PCs) and other vehicles as HVs, i.e., trucks (Ts).
- The calculation and comparison of ATS on specific upgrades and downgrades were performed for an estimated base free flow speed (BFFS) of 40, 50, and 60 km/h (following the speed limits on 3rd, 4^{th,} and 5th category roads defined in [7]).
- Convoys comprised of 60%, 70%, and 80% of Ts were assumed for the 4th edition calculation on specific upgrades and HCM 7th edition calculation (Fig.1). For the 4th edition calculation on specific downgrades, it was assumed that 20%, 40%, and 60% of HVs are using crawl speeds (Fig. 2).

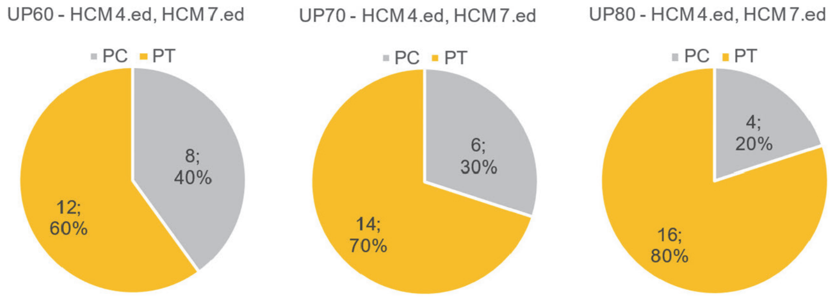

Figure 1 Convoy composition for HCM 4th edition calculation on specific upgrades and HCM 7th edition calculation (PCs = defenders, Ts = 5-tonne and 10-tonne trucks, and flatbed trailers on upgrades)

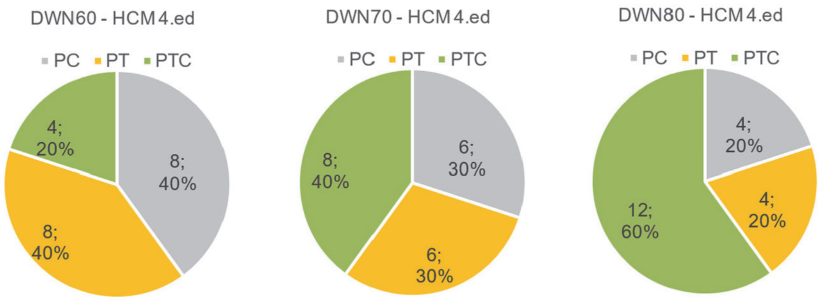

Figure 2 Convoy composition for HCM 4th edition calculation on specific downgrades (PCs = defenders, Ts = 5-tonnes and 10-tonnes trucks, and flatbed trailers on upgrades, TCs = 10-tones trucks, and flatbed trailers on downgrades)

2.2 HCM 4th edition methodology

Procedures given in HCM 4th edition for estimating free flow speed (FFS), determining demand flow rate (v_p), and ATS are the same for specific downgrades and specific upgrades (defined as any upgrade or downgrade of 3 % or more and a length of 1.0 km). However, the procedures for determining the grade adjustment factor (f_G) and HV adjustment factor (f_{HV}) differ.

In this investigation, there were no access points along the road segment, no vehicles in opposing directions, and no influence of lane and shoulder widths on convoy speed. Therefore, the FFS was equal to the BFFS:

$$FFS = BFFS \tag{1}$$

where FFS is the free-flow speed in km/h, and BFFS is the estimated base free-flow speed in km/h (assumed 40, 50, and 60 km/h).

To determine v_p, three adjustments were applied to the assumed convoy volume value (V): the peak hour factor (PHF), f_G, and f_{HV} according to:

$$v_p = \frac{V}{PHF + f_G + f_{HV}} \tag{2}$$

where v_p is the passenger-car equivalent flow rate for a peak 15-min period in pc/h, V is the demand volume for the full peak hour in veh/h (assumed 20 veh/h), PHF is the peak hour factor (assumed 1.00), f_G is the grade adjustment factor, and f_{HV} is the HV adjustment factor.

On specific upgrades, f_G accounts for the effect of the grade on ATS in a traffic stream composed entirely of PCs. In this investigation, it was assumed that the vertical grade is larger than 6%. Therefore, the fG values ranged from 0.59 to 0.38 for segment lengths from 0.4 to 6.4 km, respectively. For specific upgrades, f_{HV} was calculated as:

$$f_{HV} = \frac{1}{1+P_T\left(E_T-1\right)} \tag{3}$$

where P_T is the proportion of trucks in the traffic stream (see Fig. 1), and E_T is the passenger-car equivalents for trucks accounting for the effect of trucks on ATS on the specific upgrade, over and above the effect of the grade on PCs.

For specific downgrades, f_G is 1.0. If specific downgrades are long and steep enough, some HVs must travel at crawl speeds to avoid loss of control. This, of course, impedes other vehicles and decreases ATS. Therefore, the f_{HV} was calculated as:

$$f_{HV} = \frac{1}{1+P_{TC}\cdot P_T\left(E_{TC}-1\right)+\left(1-P_{TC}\right)P_T\left(E_T-1\right)} \tag{4}$$

where PTC is the proportion of all trucks in the traffic stream using crawl speeds on the specific downgrade (the proportion of all trucks that use crawl speeds was estimated as equal to the proportion of all trucks that are tractor-trailer combinations, see Fig. 2), ETC is the passenger-car equivalent for trucks using crawl speeds (based on the directional flow rate and the difference between the FFS and the truck crawl speed), and E_T is the passenger-car equivalent for other trucks on level terrain (set to 1.7).

Finally, the ATS was estimated from the FFS and v_p as:

$$ATS = FFS - 0.0125 v_p \tag{5}$$

where ATS is the average travel speed in km/h, FFS is the free flow speed in km/h, and v_p is the calculated passenger-car equivalent flow rate for a peak 15-min period in pc/h.

2.3 HCM 7th edition methodology

Procedures given in HCM 7th edition require classifying the vertical alignment based on the road segment's length and grade. The vertical alignment classification value is used to identify the appropriate set of coefficient values used to estimate the influence of HVs on BFFS reduction. If the demand flow rate is less than 100 veh/h, the ATS is equal to the FFS, estimated indirectly as:

$$ATS = FFS = BFFS - a\left(HV\%\right) \tag{6}$$

where FFS is the calculated free-flow speed in km/h, BFFS is the estimated base free-flow speed in km/h (assumed 40, 50, and 60 km/h), HV% is the percentage of HVs (for the assumed percentage of trucks of 60%, 70%, and 80%), and a is the coefficient used to estimate the influence of HVs on BFFS reduction calculated as:

$$a = max\left[0.0333,\ a_0 + a_1 \times BFFS + a_2 \times L\right] \tag{7}$$

where L is the segment length in km, and a_0, a_1, and a_2 are coefficients corresponding to the vertical alignment classification value defined according to the analyzed segment length and grade.

3 Results

The results of ATS estimations for military convoys performed by two different methodologies (presented in HCM 4th and 7th editions) for an estimated BFFS of 40, 50, and 60 km/h and convoys with 60%, 70%, and 80% of HVs, on specific road upgrades and downgrades of more than 6% and a length ranging from 0.4 to 6.4 km are presented in Fig. 3, 4, and 5.
Results based on HCM 4th edition methodology show that on upgrades the speed reduction depends on the BFFS, the length of the segment, and the percentage of HVs. For assumed BFFS of 40 km/h the speed reduction ranges from 4% to 20%, for BFFS of 50 km/h the speed reduction ranges from 3% to 16%, while for BFFS of 60 km/h, the speed reduction ranges from 2% to 14%, depending on traffic flow composition (reduction gets higher as the percentage of Ts and the length of the grade increases). The rate of speed reduction is higher on shorter, up to 1.2 km long, segments.

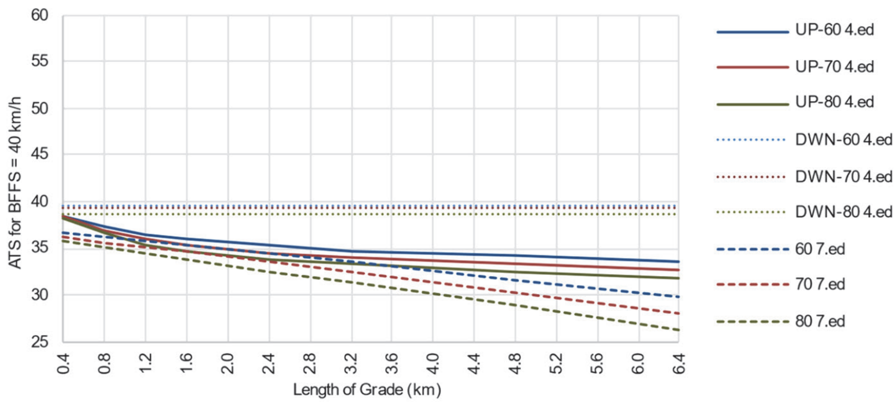

Figure 3 ATS for BFFS = 40 km/h

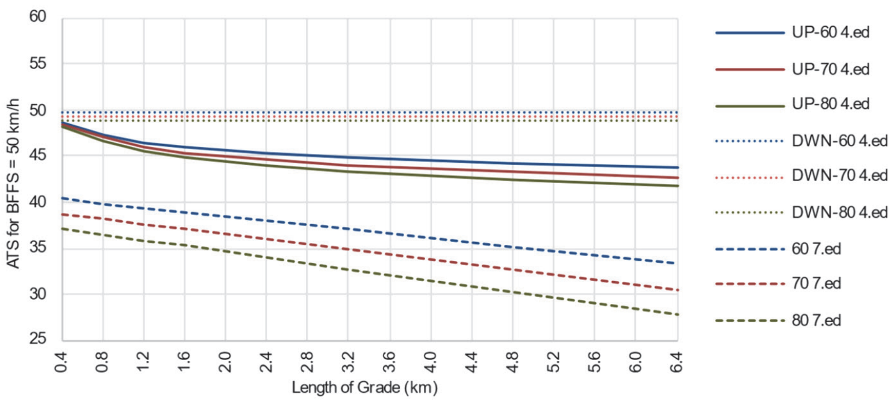

Figure 4 ATS for BFFS = 50 km/h

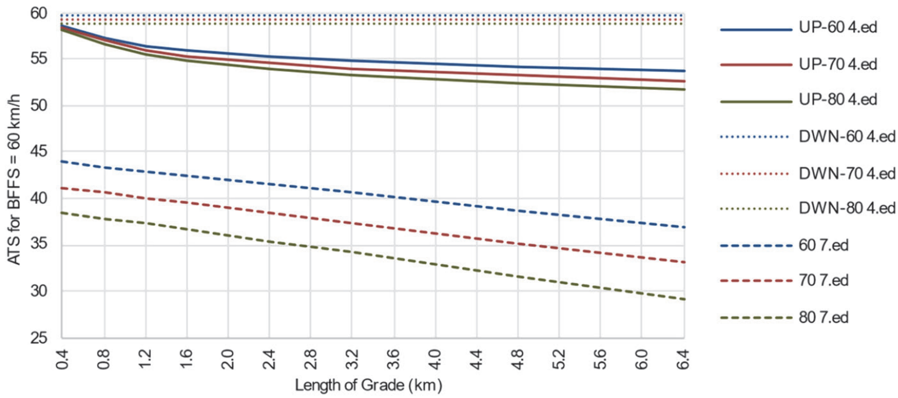

Figure 5 TS for BFFS = 60 km/h

Results based on HCM 4th edition methodology show that on downgrades the speed reduction depends on the BFFS and the percentage of HVs, but it does not at all depend on the length of the segment. For assumed BFFS the speed reduction ranges from 1% to 3%, depending on traffic flow composition (reduction gets higher as the percentage of TCs increases). On downgrades, the speed reduction is more pronounced for smaller BFFS. When compared to results obtained on upgrades, the speed reduction is generally considerably lower and is notably less dependent on BFFS and the HVs percentage.

Results based on the HCM 7th edition methodology show the speed reduction depends on the BFFS, the length of the segment, and the percentage of HVs. For assumed BFFS of 40 km/h the speed reduction ranges from 8% to 34%, for BFFS of 50 km/h the speed reduction ranges from 19% to 44%, while for BFFS of 60 km/h, the speed reduction ranges from 27% to 51%, depending on traffic flow composition (reduction gets higher as the percentage of Ts and the length of the grade increases).

A comparison of the results on specific upgrades showed that ATS estimated by the HCM 4th edition methodology is on average 2, 10, and 17 km/h higher than one estimated by the 7th edition methodology, for BFFS of 40, 50, and 60 km/h, respectively. A comparison of the results on specific downgrades showed that ATS estimated by the HCM 4th edition methodology is on average 6, 14, and 22 km/h higher than one estimated by the 7th edition methodology, for BFFS of 40, 50, and 60 km/h, respectively. The differences are more pronounced as the percentage of HVs rises.

Further analysis of the HCM 7th edition methodology results showed that the ATS decreases linearly as the length of the segment increases, and could be determined by the following equation:

$$ATS = a \cdot L + b \tag{8}$$

where ATS is the average travel speed in km/h, L is the length of the analyzed linear road section in grade larger than 6%, a is the coefficient dependent on BFFS, and b is the coefficient dependent both on BFFS and percentage of HVs in convoy (Table 1).

Table 1 he coefficient a and b values for equation (8)

BFFS	a	$b_{60\%}$	$b_{70\%}$	$b_{80\%}$
40 km/h	-1.17	37.24	36.78	36.32
50 km/h	-1.36	40.80	39.26	37.73
60 km/h	-1.56	44.35	41.74	39.14

4 Conclusions

Assessing mobility and optimizing routing for military convoys (transporting combat equipment and material resources from the area of deployment to the area of combat operations or military exercises) is a challenging task due to the high percentage of HVs and the necessity for crossing difficult terrains. This investigation aimed to assess the theoretical influence of field conditions and assumed dynamic characteristics of the vehicles forming the standard military convoy on its cross-country mobility. Convoys' average traveling speed along hypothetical two-way road segments was assessed by the methodologies described in HCM 4th and 7th editions.

The results show there are significant differences in the speed reduction (from BFFS to ATS) estimated by different methodologies. The methodology given in the HCM 7th edition provided ATS results that are 10 to 15 km/h lower, and more sensitive to road segment length, grade, BFFS, and convoy composition. Additionally, the investigation resulted in the formulation of ATS as a function of BFFS and a length of linear road section in grade larger than 6%, for the convoy containing 60%, 70%, and 80% HVs. Therefore, this methodology and its results will be further investigated in local conditions through field research for a more comprehensive assessment of its applicability.

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