Two-lane highway reliability

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1. Introduction

Rural two-lane two-way highways are the most common roads not only in Poland but also in the world. Their overall length is much higher than those of controlled-access highways or expressways. They are used both for short and long distance journeys. Geometric parameters of described roads allow users to travel with higher (first road class) or lower speeds (second road class) according to the American method (HCM-6). The first cited road class consists of roads which usually connects cities or agglomerations while the latter roads act as an access to them and it is not required from them to allow traveling at high speeds. The article will present selected part of research carried out in Poland in 2016 and 2017 on two-lane rural highways during project "*Modern methods of calculating the road capacity and assessment of traffic conditions of roads outside municipal agglomerations, including express roads*" which was performed within national program "*Road Innovations Development*". Evaluation of traffic conditions on these roads is going to take into consideration reliability concept as well as various approaches presented in articles and foreign methods, including German method (HBS -2015). Based on these studies a new polish method is going to be created. Studies were conducted on selected short and long sections of roads located in different surroundings. According to their curvature, longitudinal slopes and cross sections (width of lanes with shoulders) researched highways were collected into homogenous groups. Performed studies of traffic flows, travel times, travel speeds and traffic densities are going to be part of traffic conditions and travel time reliability analysis. Selected roads for research are characterized by good technical parameters and significant traffic fluctuation during day, week and year. Moreover on some of researched sections, one can find congestion which is a situation when traffic volume V on given road is close to or even greater than road capacity C. The purpose of this article is to demonstrate that geometric and movement characteristics have impact on travel speed and time as well as the definition of reliability and its measures for day-to-day data.

2. Novelty and relevance for the conference. Methods and findings

Reliability studies for two-lane highways have not been found in foreign publications. Researchers focus mostly on multilane highways such as controlled-access highways or expressways (Adachi & Others, 2009; Bhouri & Others, 2016; Brilon & Others, 2007; Chen & Others, 2016; Nickolson 2015; Taylor 2013). Conducted research in the article concerns two-lane highways managed by General Directorate for National Roads and Motorways. These roads are of higher standards with speed limit at 90km/h and lane width of typically 3,5m (shoulders normal or hard). These roads constitutes about 86% of all national roads (taking into consideration controlled-access highways, expressways and major roads) in Poland. They belong, according to standards set by American method (HCM-6) to first road class – class from which users demand traveling at speeds close to speed limits. In Germany similar approach applies to roads of comparable function and denotes them as EKLII and EKLIII (HBS-2015). These requirements are very much in line with expectations of managers of these roads in Poland.
Analyzed two-lane highways perform mainly motion functions despite the fact that they have limited capacity (up to 3200 pcu/h according to (HCM-6) and about 2600Veh/h according to (HBS-2015). Travel time reliability of these roads changes during certain periods of day month or year and can

achieve both low and high values. As article focused only on geometric, motion and localization features, research was conducted under favorable weather conditions with very good visibility. Performed analyzes present three possible scenarios of functional reliability:

Scenario 1: The road's reliability is high. Real travel time is similar to travel time with speed limit (85% speed percentile). Traffic volumes in both directions are significantly smaller than road capacity (V/C < 0,5). Overtaking is determined by road geometry i.e. its curvature, longitudinal slopes etc. The traffic conditions level of acceptance (by drivers) is high.

Scenario 2: Traffic volumes in both directions are much higher (V/C in the range from 0,5 to 0,9) than in scenario 1. Overtaking is no longer determined only by road geometry but also by the greater of traffic flow (traffic flow on analyzed or opposite direction). Road reliability value can change according to subjective user's point of view. Moreover the fluctuation of traffic flow has impact on traffic conditions which leads to different level of acceptance by drivers.

Scenario 3: The road's reliability is low. Travel time is long and unaccepted by drivers who travel with speed much slower than the speed limit. Traffic volumes are close or greater than road capacity (V/C > 0,9). Impact of road geometry on overtaking is much smaller as because of high density overtaking is not possible. The level of acceptance of traffic conditions is very low.

When traffic volume is not too high**,** on travel speed and consequently on travel time significant influence have geometric characteristics such as: road curvature, horizontal arc's radius, longitudinal slopes, amount of horizontal arcs on analyzed section, lane width and type of cross section as well as movement factors related to traffic share of heave vehicles. Below on presented diagram selected geometric factors have been shown with their impact on travel speed. The driving speed profile behind the leader has been determined empirically with the aid of GPS device.

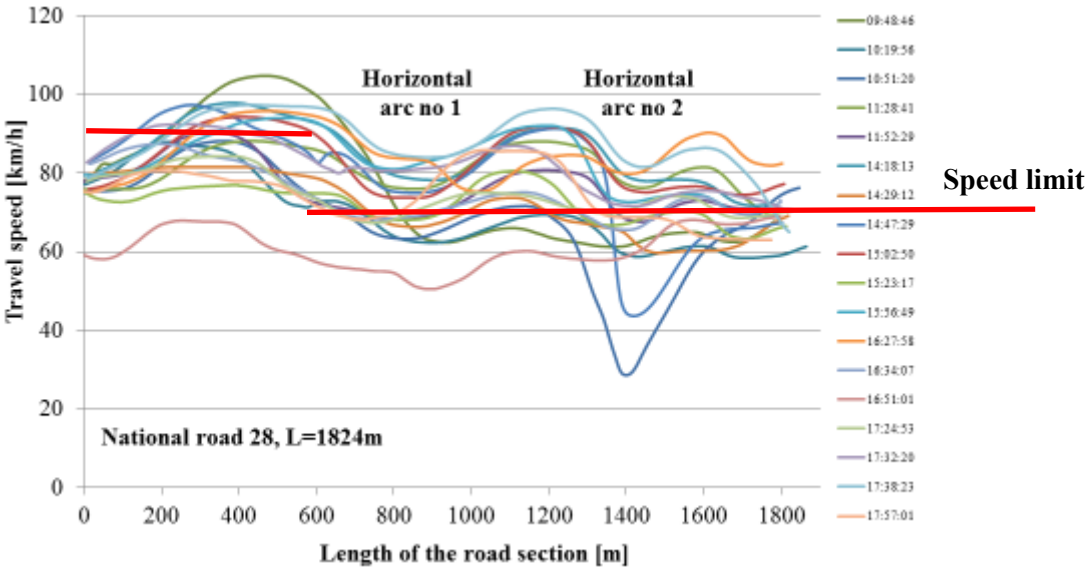

Figure. 1. Selected speed profiles behind the leader, presenting impact of presence of horizontal arcs located close to each other on variability of vehicle speed.

The graph indicates that not only presence of horizontal arcs has meaningful impact on speed but also lengths of straight segments preceding the arc affect it. It is assumed that when such length is greater than 400m, it no longer has impact on free flow speed.
Based on empirically collected data on the traffic volumes, speeds and densities (determined by the laboratory) on highway divisions of length from 1km to 5km (from 36 road sections), diagrams were created for 4 curvature classes and 4 longitudinal slopes classes. Presented below, they show influence of traffic volume and density on travel speed.

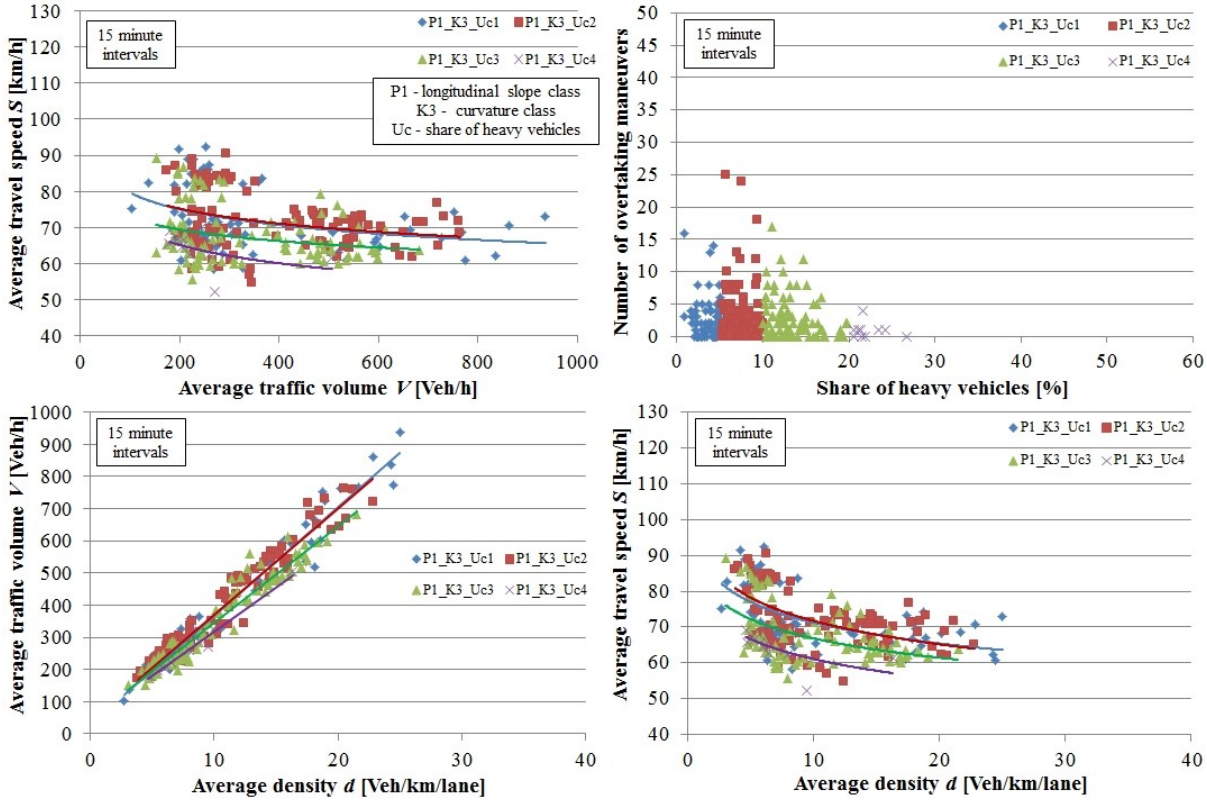

Figure 2. Dependence of speed, traffic volume and traffic density, and number of overtakes from traffic share of heavy vehicle in traffic for 3rd curvature class and 1st longitudinal slope with different shares [%] i.e. Uc1: 0÷5, Uc2: 5÷10, Uc3:10÷20, Uc4: 20÷30. Diagrams were created based on data from 10 statistically similar road sections.

On diagrams one can easily notice the impact of traffic volume and density on travel speed (and consequently travel time) as well as of traffic share of heavy vehicles on number of overtakes. The number of overtakes increases (travel speed rises) when road curvature is small with simultaneously small values of longitudinal slopes. In every curvature class and longitudinal slopes classes the influences are statistically significant but the effect size varies (multiple regression method).
Based on analyzed variations of geometric characteristics among given sections it can be concluded that their effect on drivers' behavior differs. When analyzing variation of speed travel, (and therefore travel time) on longer road (above 5km), such road shall be divided into homogeneous sections with respect to the described geometrical and location features. After checking the range of variability and structure of traffic flow, it is usually assumed that it does not chance significantly on the analyzed section in the analyzed period of time.

In order to analyze the variability of travel times on particular days on selected longer divisions of roads (above 5km), mobile application "Timewave" has been developed. App has been written for devices with Android system (for minimum API 16). Several APIs have been used: Google Maps Directions API, Google Maps Android API, Here Routing API, Here Geocoder API, Bing Routes API, Weather Underground API. Data used in this program come from devices with localization services and other sources such as floating car data.
The application allows to analyze the travel time variability (three scenarios: best guess, pessimistic, optimistic) at a specified time (with every 5min increments) in the chosen time horizon (ex. for the next *n* working days) on the analyzed episode with the possibility of dividing it into shorter sections. Such division might be derived from accepted classes of roads curvature or longitudinal slopes.
The drawback of „Timewave" is lack of data on all vehicles and the share of traffic of heavy vehicles. Only those vehicles with enabled localization services are included in the analysis. Therefore results are only suitable for selected vehicles whose behavior reflects the behavior of other users on the road

(similar to driving behind the leader). For collected data (travel times at given period in consecutive days) histograms were created with proper fit of mathematical theoretical distributions (mainly gamma and lognormal) (Andrews & Others, 2002).
For travel time reliability analysis purposes, an indicator resulted from speed limits (which can change along the road) was introduced. The permissible speed on the road is in practice identified with 85% quantile (Gaca & Others, 2008). Generally it was assumed that if travel time is no greater that travel time with travelling at speed limits, such road service can be called reliable. Other cases have been divided and lower reliability levels were assigned to them. Additional reliability measures such as buffer time, misery time, planning time, PTI, TTI, standard deviation etc. have been calculated for the purposes of comparisons and finding proper border values for reliability levels.

3. Results and conclusions

Empirical studies (traffic volume and transit times) were conducted on rural road sections with lengths ranging from 1km to 5km without the impact of larger intersections which presence would have significant impact on drivers' behaviours. Additionally during the research the rides behind the leader (every 15 minutes) were performed and number of overtakes was noted (video technique). Based on gathered data the influence of geometrical characteristics (curvature, longitudinal slopes) as well as movement features (traffic volume and its structure) on travel speed and time, statistical significance was determined.
In order to analyze the variability of travel times on particular days on longer divisions of roads, mobile application "Timewave" has been developed. The *app* uses data collected from vehicles with special devices with localization services. The application allows to gather travel times data (scenarios: best guess, pessimistic, optimistic) on analyzed section in designated period on consecutive days. This data allowed to conduct travel time reliability analyses for selected road section. An attempt was made to determine the border values of reliability levels with respect to the speed limit (quantile 85%) and average speed. For comparisons purposes, other reliability measures known in literature have been analyzed.
By compiling data from the geometric road inventory i.e. road sections curvature, longitudinal slopes with data achieved from application "Timewave" for selected divisions, it is possible to indicate a section which geometric features have the biggest impact on increasing the travel time. The approach can also be useful to road managers in planning for the redevelopment of sensitive sites (road repairs, horizontal arc rebuilding or upgrading certain road segment's standard) to improve road functional reliability.

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