University of Sopron, Faculty of Forestry

Measurement and analysis of recreational traffic on highly visited forest roads

Theses of doctoral (PhD) dissertation

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Introduction and aims

Forests are one of the most important natural resources of Hungary. Social function is gaining importance, or at some areas it is the most important one next to the ecological and economical roles. Forests can be accessed and thus its benefits can be enjoyed through the forest road network. According to the Hungarian Forest Law it is allowed to use the forest roads by the forestry company's vehicles and by anyone on foot, by bicycle, on horseback or by horse-pulled vehicle for recreation or sporting purposes. As a consequence, mixed aim and mixed means traffic is expected on forest roads.

The more the social services of a forest, the higher the non-forestry traffic on the forest roads. This can clearly be seen at frequented touristic sites. The road management of these areas requires the knowledge of traffic information such as number of passes, composition of traffic and road user preferences and expectations. Based on this information, optimal visitor management techniques can be applied and thus, high visitor satisfaction can be achieved.

The presented research aims to prove that accurate and detailed long term traffic counting is feasible in a forest environment, and that counting can provide sufficient data for road management. Five goals were defined:

- Develop a method to automatically count traffic on forest roads
- Long term application of the method on a selected road, deriving traffic data
- Determining daily, weekly and yearly traffic patterns
- Develop a method to model the yearly visitor number
- Assessing inter-visitor group conflict potential

Developing a method to automatically count traffic on forest roads

The dissertation presents the development of a traffic counter that provides visitor class, direction of movement and activity information on road users passing a given section of a forest road.

According to the literature, the expected output can be achieved by cameras, laser scanners or microwave sensors. Digital camera systems were chosen due to accurate and detailed data that can be archived or processed by human interpreters. No such turnkey product was available in Hungary for outdoor conditions therefore an experimental instrument was developed. It stored digital still images of road users. The system included a digital surveillance camera placed on a pole 4 meters high, two consecutive reflective optical sensors that controlled image shooting and provided direction, and a central unit that connected the sensors with the camera and provided download and maintenance interface. The tool was installed on a forest road called "Apátkúti út" near Visegrád, in the management area of the Pilisi Parkerdő forestry company. After several improvements from 2012 to 2015, the counter worked continuously for 10 months in 2016. Therefore the initial concept was proofed.

The 1 MP digital images were analyzed by human interpreters. It was a labor-intensive task that provided not only the basic traffic data but the input data for automatized image recognition as well. The convolutional neural network called YOLO (You Only Look Once) was adapted to automatically detect and recognize visitors on the images. Pedestrians, cyclists and cars were recognized with 95, 95 and 85% accuracy respectively. This result could be achieved by applying the network weights from the 11000. epoch, by using 288×288 pixel size input images and by applying a 0,35 threshold for the final output. The error of the automatic recognition should be compensated by a multiplication of 0,95 for pedestrians, 1,01 for cyclists and 1,14 for cars.

Analysis of the counter data

The traffic database of the evaluated road was completed by interpreters. It contains date and time of the passes, the class, the activity and the direction of movement of the road users. Traffic patterns on different time scales and by visitor classes and activities could be derived from the database.

The four dominant road user class were pedestrians, cyclists, cars and trucks by 58.2, 25.6, 13.6 and 1.5% respectively. On an average working day pedestrians and cars were responsible for the majority of the 180 passes. On an average holiday 600 visitor passed the counter

and the 3/4 of this was pedestrian. The typical activities of pedestrians and cyclists were hiking and sporting, while a major proportion of cars and trucks used the road in connection with forest operations.

The daily pattern of pedestrians showed one peak around noon on every day, the peak of cyclist traffic was around noon on weekends and around 14h on working days. The hourly numbers of cars were almost even during working hours on working days.

The most detailed view of the traffic could be get by the monthly analysis of the data on working days and on weekends. The daily number of pedestrians and cyclists on working days was the highest in the summer, while in the spring and autumn on weekends. The daily numbers decreased spectacularly on summer weekends. The daily numbers of cars duplicated from winter to summer, and there was a slight decrease in the summer. Trucks showed increased activity only in winter.

A similar pattern to the monthly traffic of pedestrians and cyclists were found in two supplementary counting in lookout towers and in the literature about a research conducted near Vienna. Therefore – in the author's opinion – the presented non-forestry traffic pattern can be characteristic to forest roads near big cities.

Model development for yearly visitor number

One of the most basic information for the road manager is the total yearly visitor number. The presented database was suitable for the development of a daily visitor number based yearly model. According to literature, daily visitor numbers are determined by the day of the week, the time of the year and the weather. As a result of statistical tests, day of the week can be taken into account as a binary variable (working day - weekend) and time of the year can be represented by the seasons. Weather data cannot be forecast for a year, seasonal changes include weather changes, therefore the weather variable was excluded from the model to maintain robustness. Yearly visitor number is determined by uncertain variables therefore it can only be predicted with high uncertainty as well. Monte-Carlo style simulations are able to handle this kind of uncertainty. With the help of this type of simulation the possible outputs of a system can be generated based on the distribution or the probability density function and the connection of the variables.

Weibull and gamma distributions could be fitted on the distribution of the daily visitor numbers on working days and on weekends. distribution fitting was carried out by exploratory data analysis tools in the R statistical software. 65 working days and 26 weekends were generated based on the fitted distributions. The sum of the visitor numbers generated for the four seasons produce the total yearly visitor number. By running the simulation 10 000 times, the possible yearly numbers and their probabilities can be evaluated. Normal distribution could be fitted onto the resulting yearly numbers. This model provided the expected value of the total yearly visitor number on the investigated road (107 526), the expected extremes (90 000 and 125 000) and the probability that the actual number exceeds any given number.

Conflict analysis

Forest roads are used by different means. It is to the forest road manager's interest to ensure the conditions of mixed use or to put restraint on it. In order to do this one should know what road user types disturb each other and how often do these road users meet on a given road section. The number of the road user encounters could be estimated from the experimental traffic counter's data. In this case an encounter was when two road users were present on the same photo. On the examined road, from 1000 passing pedestrians and cyclists encounter 24 times, pedestrians met cars 9 times and cyclists met cars once. An online questionnaire survey was conducted to assess how problematic an encounter can be. According to the non representative answers, non motorized road users were disturbed by motorized ones. Inversely, motorized road users tend to like to meet with non motorized road users. According to these findings, pedestrian - car or cyclist - car encounters have conflict potential on the examined road. Due to the relatively low number of these two types of encounters there is no high risk of inter-user group conflicts according to the author.

Significance for the practice

The presented results showed that the traffic of a forest road section can be counted accurately, in detail and automatically. Based on the counter data valuable traffic properties and indicators could be calculated to assist road management. The developed experimental counter

is capable of measuring the traffic on a single point therefore it can be used by not only the forestry companies, but by legislation, by road designers, by land development professionals or by the judges of tenders. In addition to its primary purpose the counter can be used in security applications.

Based on the proven concept the monitoring method of the traffic of forest road networks can be developed. Knowing the network-wise non-forestry traffic, forest managers can plan social activities and visitor management. Traffic data can help to choose the timing and location of road maintenance, forest operations and public events. Conflict assessment is needed to apply the proper management tool. The road properties, required to serve mixed traffic safely, could be determined by comparing the properties of the road sections and the passing traffic.

Theses

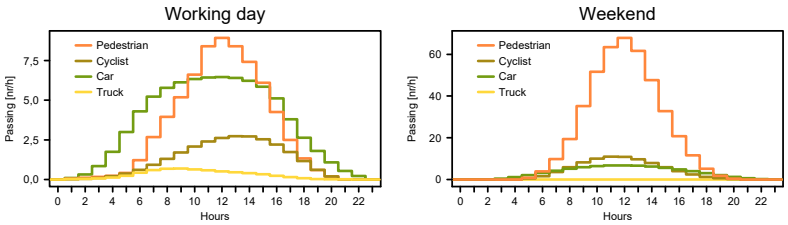
1. An experimental traffic counter was developed to monitor the non-forestry traffic on forest roads. The counter takes digital still images of road users passing the instrument. The direction of movement of the road users is registered by two consequent optical sensors. Compared to the turnkey models, the experimental instrument is capable of providing accurate and detailed traffic data under forest conditions.

2. An artificial convolutional neural network was applied to automatically detect and recognize road users on the photos taken by the counter. The basis of the network was presented by Redmon and Farhadi (2016) and is called YOLO9000. The weights of the network were determined by teaching my own classes to the network for 11000 epochs. The resolution of the input image was set to 288×288 pixels and the threshold for the output was set to 0.35. It was proofed that by applying these parameters to the YOLO network, pedestrians cyclists and cars can be detected and recognized by 95, 95 and 85% accuracy respectively on the photos taken by the counter. This result was achieved under forestry conditions in varying light conditions.

3. A highly accurate, detailed and four year long traffic database was developed based on the photos taken by the counter on the inspected forest road section. Such database was not existent in Hungary

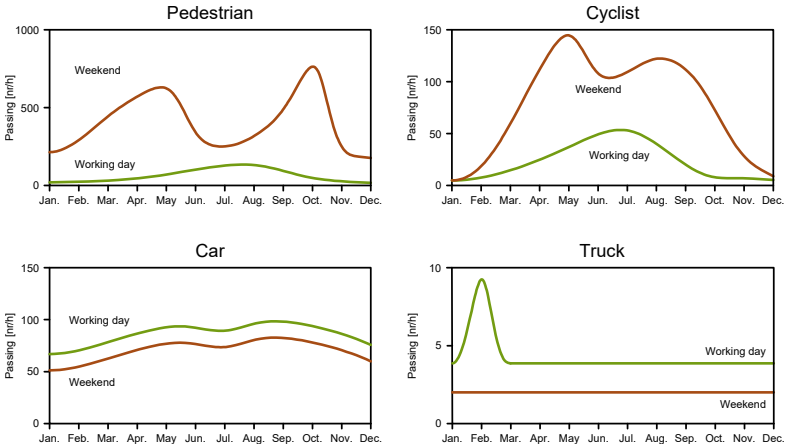
before, therefore it can serve as a basis for further research. The traffic database is suitable to characterize the traffic pattern of forest roads located near a big city. The most important data are: The average traffic on working day was 180 passing per day, and 600 passing per day on weekend. The traffic composition on working days was 44% car, 37% pedestrian, 14% cyclist, 3% truck, while on weekend it was 13% car, 73% pedestrian and 14% cyclist.

4. On an hourly basis it was found that on the examined road on working days the traffic peaks between 11 and 16 hours, on weekend, between 11 and 13 hours. The hourly traffic pattern was different by road user classes that can be seen on characteristic graphs. These graphs can be applied for the coordination of forest operations and public welfare activities, as well as for traffic simulation.



5. It was demonstrated on the example of the examined road that the daily pedestrian traffic of forest roads located near a big city increases from January to August, then decreases until December on working days, while on weekends it increases from January to May, in June it drops near the value of the winter months, reaches a peak in October and decreases until the end of the year. The daily number of cyclists on working days increases from January to August, and decreases until December, while on weekend it increases from January to May, there is a small fallback in June followed by a second, but lower peak in August then it drops until December. The daily visitor numbers of pedestrians and cyclists are usually higher on weekend than on working days. The daily traffic of cars increases in the summer. The daily number of trucks is uniform along the year with the exception of February when it doubles on working days. The daily visitor numbers of cars and trucks are usually higher on working days than on weekend. Characteristic graphs were produced by road user groups based on the median values of the daily visitor numbers by months. These graphs can be applied

for the coordination of forest operations and public welfare activities, as well as for traffic simulation.



6. A Monte-Carlo simulation based model was developed to predict the expected yearly visitor number of a forest road based on known distribution of visitor numbers on working days and weekends by seasons. Weibull and gamma distributions were fit to the distribution of these visitor numbers. By applying the method to the experimented road section, it was determined that the generated yearly visitor numbers of the road followed the normal distribution. the parameters of the distribution: $\mu = 107526$ and $\sigma = 6000$. The expected minimum value is 90000 while the maximum is 125000 passing.

7. An online questionnaire survey was conducted to assist conflict analysis. It was found that forest road users are mostly annoyed by meeting bikers. It was verified for Hungary that non motorized road users are disturbed by motorists while motorists are neutral or slightly positive towards non-motorized visitors. Proper conflict management tools can be applied by knowing the traffic patterns of the forest road network and the attitude of the road user groups towards each other. According to the counting data, the number of negatively evaluated encounters is low on the examined road, therefore the risk of conflict development is also low, management intervention is not needed.

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