The Speed – Flow Relationship on Urban Roads in A Romanian Town

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Abstract. The paper is presenting a study regarding the Speed – Flow relationship on a major artery in the urban area. The study corridor is a two-lane road from the town of Seini, Romania, where the posted speed is 50 km/h. The route was divided in five segments according to the urban space characteristics and the traffic zones. The speed data base includes the speeds collected by radar – using the TrueCAM equipment, as well as by analysing second-by-second in-vehicle global positioning system (GPS) – using the Racelogic equipment. The traffic characteristics, including the volumes, traffic composition, and peak intervals were provided from the traffic census. The statistical analysis of the significant variables (operating speed and running speed) against the model speed have highlighted the impact of the traffic characteristics in the shaping of the urban system. Therefore, the speed – flow relationship analysis is a basic component in the integrated planning process, connecting the important parameters of the urban model.

1. Introduction

Speed represents an important aspect of the functionality of the road transportation system. Speed has several meanings, such as: Design Speed, Running Speed, Operating Speed, Posted Speed, and Free Flow Speed. Each type of Speed has a different applicability, but they are all interconnected. In time, the definitions of the above-mentioned concepts have undergone various changes. A summary of the major changes is presented next.

Design Speed was defined at first, by Barnett [1] in 1936: ‘Assumed Design Speed is the maximum reasonably uniform speed which would be adopted by the faster driving group of vehicle operations, once clear of urban areas’. Several changes in the definition of the Design Speed followed. One of the main revision that was kept for forty years was made in 1954 [2]: ‘Design Speed is a speed determined for design and correlation of the physical features of a highway that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favourable that the design features of the highway govern’. An important aspect of this definition is that for the first time, the connection between Design Speed, Operating Speed (or Observed Speed) and Posted Speed (or Speed Limit) is highlighted. Furthermore, using the concept of ‘maximum safe speed’ in the definition, stands as an acknowledgement that Posted Speed can be
higher than the Design Speed in operating conditions with no implications on the road safety. Many studies have considered that as a value, Design Speed should be the correspondent of a high percentile, such as 85th percentile speed. Nowadays, the currently used definition is given by AASHTO Green Book 2011, [3] ‘A selected speed used to determine the various geometric design features of the highway’.

The terms for the speed in operational conditions may vary such as: Operating Speed, 85th Percentile Speed or Pace Speed. Operating Speed refers to the observed speed of a driving group of vehicles on a road section. Most frequently, the measurement of the Operating Speed is given by the 85th percentile of the distribution of the observed speeds dataset. This analysis can also be used as a tool for determining the level of service, the delays and congestion in traffic. The speed profile of a road section is done with the help of individual speeds observed in a spot speed study.

Running Speed refers to ‘the highest safe speed at which a vehicle is normally operated on a given roadway under prevailing traffic and environmental condition’ [4].

This paper is focused on the comparison of the Operational Speed and Running Speed against the model speed in a small town of Romania, similar to [5]. The town of Seini is under 10000 inhabitants and it is located in the county of Maramureș. The specific characteristic of the town is its location, equally distanced from two main urban centres of the neighbouring counties Maramureș and Satu Mare. Recently, a traffic model was created and analysed for Seini [6].

According to the Romanian Standards [7, 8], Design Speed in Seini is 60 km/h and Posted Speed is 50 km/h on each of the five studied sections.

2. Data collection methodology

For this study, the data were collected using traditional methods: point/section method and corridor method. Point method employee’s manual collection (traffic census) and automatic collection (radar gun). Corridor method is a spatial method in which data were collected second-by-second using a probe vehicle in motion. The test vehicle was equipped with mobile sensor (GPS).

The data collection methodology of the study employees three different methods for determining

- Model speed (km/h).
- Operating Speed (km/h).
- Running Speed (km/h).

The arterial streets were divided into five different segments based on the model intersections. The European Road (E78) is also running on the selected streets. All streets have one lane in each direction.

Table 1 presents the general traffic composition on each sector as number of vehicles and percentages of total traffic. It can be observed that the non-motorized traffic has a small share while heavy traffic has an important share, higher than 10%. The highest share of heavy traffic is found outside downtown, in the low-density built area. The highest number of heavy vehicles was registered around the stone quarry (1395 vehicles). Data collection follows the traffic model of the town as well as the specific traffic characteristics.

| Speed Section | Traffic (veh. both directions, 12h) | Heavy traffic, (veh.) | Heavy traffic (% of total veh.) | Bicycles, (veh.) | Bicycles (% of total veh.) |
|---------------|-----------------------------------|----------------------|-------------------------------|----------------|--------------------------|
| 1             | 7310                              | 1395                 | 19                            | 79             | 1                        |
| 2             | 7975                              | 1176                 | 15                            | 73             | 1                        |
| 3             | 8708                              | 1394                 | 16                            | 159            | 2                        |
| 4             | 9441                              | 1211                 | 13                            | 398            | 4                        |
| 5             | 5973                              | 1279                 | 21                            | 173            | 3                        |
2.1. Model Speed

The average travel speed of the model (ATS\textsubscript{model}) is estimated from the FFS, the peak hour traffic volume, and an adjustment factor for the percentage of no-passing zones, according to [9,10]. The peak hour traffic volume for estimating model average travel speed is presented in Table 2 column 3. The values are compiled from the census data. The data collection method for the traffic model was the traffic census. This was undertaken manually during characteristic periods of time, namely weekdays.

\[
    ATS_{\text{model}} = FFS - 0.0125 \cdot PHT - f_{np} \tag{1}
\]

Where:

- \(ATS_{\text{model}}\) = Model average travel speed for both directions of travel combined (km/h)
- \(FFS\) = Free flow speed for both directions of travel combined (km/h).
- \(PHT\) = Peak hour traffic volume, passenger-car equivalent (pce/h).
- \(f_{np}\) = Adjustment for percentage of no-passing zones.

### Table 2. Traffic characteristics of the five sections

| Speed Section | Peak hour traffic volume (vehicles) | Peak hour traffic volume (pce/h) | Peak hour | Model Link Length (m) | Capacity | Ratio V/C Volume/Capacity |
|---------------|------------------------------------|----------------------------------|-----------|------------------------|----------|--------------------------|
| 1             | 689                                | 1210                             | 9:00 - 10:00 | 1100                   | 1450     | 83                       |
| 2             | 725                                | 1121                             | 12:00 - 13:00 | 1720                   | 1450     | 77                       |
| 3             | 758                                | 1193                             | 12:00 - 13:00 | 1000                   | 1450     | 82                       |
| 4             | 887                                | 1299                             | 12:00 - 13:00 | 480                    | 1060     | 123                      |
| 5             | 586                                | 1050                             | 9:00 - 10:00 | 750                    | 1325     | 79                       |

The influence of the road environment and traffic volumes in the traffic capacity is highlighted in speed section 4 where the Ratio V/C is above 100 because the link length is short and impacts on the stopping conditions.

The model links at the extremities of the study corridor have an earlier peak hour, while the links located inside the built area have the peak hour during the middle of the day.

2.2. Operating Speed

Operating Speed was measured on the five road segments, by means of Radar Gun, at least 100 values on each section (figure 1).

![Figure 1. Data collection sections for the speed study (Google Earth)](image-url)
The data collection method was the spot speed study with the aim to define the speed profiles for the five segments. In each location, the speed profiles are graphically represented in order to determine the space mean speed for the study and evaluations of the traffic characteristics. The observed speeds were classified into detailed intervals of 2 km/h to determine the frequency of distribution and cumulative percentage.

2.3. Running Speed
Running speed data was collected by means of Track GPS along the study corridor in both directions of travel for three times. The GPS data collecting method was employee to generate the speed profiles against the distance.

Figure 2 and figure 3 represent the typical speed profiles for the both directions from the three overlaid data sets. The influence of the road environment and traffic volumes on speed are graphically represented in the above figures as leaps on the vertical axis.

3. Analysis and Study Results
The corridor study is relevant for the Speed-Flow relationship on an urban road because it surpasses five of the total of eight traffic zones.

According to Table 3 the model speed is similar on the five segments between 49÷52 km/h due to the traffic volume impact. There is a high percentage of vehicles that may determine the slow traffic 16%÷24% on each link (Table 1).
Table 3. Characteristics of the Speed Sections

| Speed Section | Street   | Road | Model Traffic zone | Model Intersection | Model Section | Model Link Length (m) | Model speed (km/h) | Model travel time (s) |
|---------------|----------|------|--------------------|---------------------|---------------|-----------------------|-------------------|----------------------|
| 1             | Principala | DN1C | 6                  | 1                   | 3             | 1100                  | 50                | 121                  |
| 2             | Principala | DN1C | 7                  | 2                   | 3             | 1720                  | 51                | 182                  |
| 3             | Baii      | DN1C | 3                  | 10                  | 3             | 1000                  | 50                | 109                  |
| 4             | Piata Unirii | DN1C | 1                  | 9                   | 3             | 480                   | 49                | 55                   |
| 5             | Eroilor   | DN1C | 2                  | 7                   | 3             | 750                   | 52                | 77                   |

3.1. Statistical Analysis
The model validation is conducted with the data set collected in the spot speed study. Spot speed study results are statistical analysed and presented in Table 4.

Table 4. Descriptive statistics on the five sections of the study corridor

|                      | Section 1 | Section 2 | Section 3 | Section 4 | Section 5 |
|----------------------|-----------|-----------|-----------|-----------|-----------|
| Mean                 | 61        | 55        | 53        | 42        | 55        |
| Standard Error       | 1.043800  | 0.996650  | 0.786360  | 1.082459  | 1.016174  |
| Median               | 60        | 54        | 52        | 45        | 55        |
| Mode                 | 55        | 51        | 49        | 47        | 54        |
| Standard Deviation   | 10.438004 | 9.966505  | 7.863604  | 10.824589 | 10.161742 |
| Sample Variance      | 108.95    | 99.33     | 61.84     | 117.17    | 103.26    |
| Kurtosis             | 2.83      | 1.05      | 0.63      | 1.45      | 7.36      |
| Skewness             | 0.22      | -0.11     | 0.53      | -0.82     | -1.28     |
| Range                | 74        | 62        | 41        | 66        | 72        |
| Minimum              | 19        | 18        | 33        | 6         | 10        |
| Maximum              | 93        | 80        | 74        | 72        | 82        |
| Sum                  | 6076      | 5461      | 5311      | 4180      | 5546      |
| Count                | 100       | 100       | 100       | 100       | 100       |
| Confidence Level(95.0%) | 2.071126 | 1.977571  | 1.560310  | 2.147833  | 2.016310  |
Median value represents the 50th percentile speed (v50) of the traffic flow. The values of the median on each section is comparable with the model speed. The difference is justified by the road environment and data collection conditions.

Figure 5. Median, minimum and maximum speed on the five sections of the study corridor

Section 4 presents the smallest maximum value as well as the higher minimum value because it is situated in the traffic zone number 1, which is located in the downtown area (figure 5).

GPS collected data are also statistically analysed for the three round-trip data sets (Table 5).

| Table 5. Descriptive statistics on the GPS data of the study corridor |
|---------------------------------------------------------------|
|                  | Tour 1 | Retour 1 | Tour 2 | Retour 2 | Tour 3 | Retour 3 |
| Mean            | 56     | 70       | 52     | 55       | 53     | 46       |
| Standard Error  | 0.221095 | 0.228325 | 0.234674 | 0.125220 | 0.171348 | 0.107817 |
| Median          | 61     | 72       | 53     | 56       | 54     | 47       |
| Mode            | 66     | 74       | 68     | 58       | 64     | 48       |
| Standard Deviation | 15.205787 | 14.244289 | 16.834451 | 8.768955 | 12.273808 | 8.179916 |
| Sample Variance | 231.22 | 202.90   | 283.40 | 76.89    | 150.65 | 66.91    |
| Kurtosis        | 2.42   | 0.71     | -0.43  | 1.99     | 0.81   | 5.08     |
| Skewness        | -1.60  | -0.82    | -0.51  | -0.29    | -0.94  | -1.11    |
| Range           | 77     | 66       | 70     | 57       | 60     | 61       |
| Minimum         | 0      | 26       | 9      | 24       | 16     | 8        |
| Maximum         | 77     | 92       | 79     | 82       | 75     | 69       |
| Sum             | 266394 | 270591   | 269496 | 268913   | 270137 | 267532   |
| Count           | 4730   | 3892     | 5146   | 4904     | 5131   | 5756     |

The results presented in Table 5 are not relevant for the comparison of the speed in each traffic zone, but it stands as an overview of the speed evolution on the corridor although the minimum and the maximum speeds are comparable to the spot speed study in the sections.
Figure 6. Median, minimum and maximum speed for the three round-trip routes on the study corridor

GPS collected data are relevant to analyse the speed profile against the distance (figure 2 and figure 3) and the speed profiles against time (figure 7 and figure 8).

Figure 7. GPS data collection, speed profile against time – Tour (section 5 ->section 1)

Figure 8. GPS data collection, speed profile against time – Retour (section 1 ->section 5)

Considering the similarities between the model travel time (544 seconds) and the GPS travel time registered on tour trips (472÷515 seconds) a future analysis should be conducted on the subject.

3.2. Graphical Analysis
The graphic analysis highlights the Operating Speed values. Furthermore, the analysis of the 85th percentile Speed is conducted in this study. In each of the five sections the 85th percentile Speed (71 km/h, 64 km/h, 60 km/h, 50 km/h, and 62 km/h) is above the Posted speed, excepts for the downtown
area. The downtown area has the highest traffic for both periods of the 12 h census and peak hour and there the 85th percentile Speed, Posted Speed and Design Speed is similar, 60 km/h.

Figure 9. Graphic analysis of the speed on the five sections of the study corridor

Urban road environment has a major impact on the flow-speed variation, as illustrated by the histogram and descriptive statistics analysis of the collected GPS data.
4. Observations and conclusions

Speed analysis is an important aspect of the road transportation field, including road design, road safety, traffic flow and road environment characteristics, road traffic emissions, and travel time estimation.

The methodology used in the study is based on several data collection methods according to the specific concept of the speed. The theoretical speed-flow relationship used to determine the model speed was validated by the results of the speed spot study as well as the GPS running speed. However, there are some differences. Operating speed is higher than the model speed, explaining the necessity of adjusting Equation (1) for the urban environment. Moreover, the site variation of the Operating Speed is directly influenced by the traffic zone and urban built area. When designing urban streets, Design Speed should be chosen according to the safe values of the Operating Speed due to the complexity of the urban area.

Considering the value of the 85th percentile Speed above the Posted speed in four of the five sections of the urban area, imposing the speed limit is necessary for safety conditions.

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