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To cite this article: Marcin Debinski and Janusz Bohatkiewicz 2019 IOP Conf. Ser.: Mater. Sci. Eng. 471 062016

View the article online for updates and enhancements.
The Impact of Road Traffic Fluctuations on the Emission of Road Noise

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Abstract. Significant increase in the road traffic intensity raise the noise emission. The authors of this paper present the results of preliminary studies concerning influence of fluctuations in road traffic on road noise emission. The analyses involved data from measurements taken on voivodeship roads in Lesser Poland. Thanks to the traffic data obtained from the measurements, it has become possible to perform analyses of the road traffic impact on the noise level, using a calculation method developed in Poland in the 1980s, subject to update. The results of the analyses indicate the need to focus on road traffic intensity fluctuation phenomenon, as well as its impact on the noise level. Taking this into consideration provides a complete picture of road traffic impact at roads with highly variable road traffic intensity over short periods of time. The observed phenomena constitute a significant problem in road noise predictions, which will ultimately influence the selection of safety measures, in addition to negative impact on the health and comfort of life in terms of inhabitants in areas adjacent to the roads.

1. Introduction
Over the last years, the road network in Poland has been significantly extended and rebuilt. The number of vehicles and traffic volume have increased significantly along with road infrastructure development. New road sections are also designed while taking note of noise reduction criterion concerning their surroundings. The aim of these actions is to reduce the number of inhabitants at risk of being exposed to road noise. In many cases, it is not always possible to reduce road noise to admissible noise values, merely obtaining the effect of noise emission limitation. It is clear that the increase in road traffic leads to an increase in noise emissions. When designing a road in order to reduce the road noise emission, its geometry and the course of the road are usually modified, along with using noise protection devices. Nevertheless, there are no actions involving taking into account the road traffic conditions present on the road. They have a significant impact on the correctness of noise assessment and noise level forecasting. In many situations, the results of studies on noise indicate significant forecast errors concerning the probable effect of fluctuations in road traffic intensity on noise emissions. Taking note of fluctuations in traffic over a short time period ensures a better picture demonstrating the impact of traffic on road noise.
2. Methods
Measurements of road traffic intensity and road traffic parameters were taken according to the Polish Instruction for General Measurement of Road Traffic of the General Directorate for National Roads and Motorways [1]. The measurement was performed in 15-minute intervals, recording the speed and intensity of road traffic, taking into account the vehicle type structure. Vehicle speed was recorded according to light and heavy vehicles. At the same time, road noise was measured in accordance with Polish regulations [2].

2.1. Measurement methods
The tests were performed on three sections of bidirectional single carriageways. Measurement points were located in the vicinity of each section, measuring the equivalent road noise level, traffic intensity, and vehicle speed. The tests were carried out in accordance with the applicable regulations and guidelines in Poland [2-5]. The measurements were taken on the following roads:

- DW 965 - Młynne
- DW 964 - Wieliczka
- Główna Street - City of Korytów (access section to DK50, outside the city)

2.1.1. Methods of measuring the traffic volume. The traffic volume was measured using the manual and automatic methods. Observers counted the vehicles crossing the cross-section according to [1]. The measurement was performed in 15-minute intervals, taking the type structure into account:

- light vehicles;
  - passenger cars
  - light commercial trucks (light commercial vehicles),
- heavy vehicles,
  - motorcycles;
  - commercial trucks without trailers,
  - commercial trucks with trailers,
  - buses and trolleybuses,
  - agricultural tractors, mobile machinery.

Automatic measurement was also performed with type-related division according to the foregoing categories. Transverse radar was used in the study. Vehicle speed measurements were taken at the same time as road traffic intensity.

2.1.2. Methods of measuring road noise levels. The sound level was measured using the direct method, according to Polish regulations [2] [3][6]. Road noise was measured in the same cross-section as road traffic intensity and vehicle speed. The microphone was located 10 meters from the road edge, and 4 meters above the road surface. The tests were performed using instruments ensuring first class of measurement accuracy. Each of the meters was calibrated before starting the measurement.

2.2. Calculation methods
The results of traffic parameter measurements and other information allowed to analyze traffic capacity and conditions at the measurement sections. The analysis used the American HCM method which started in 1983 when it was first published. Further analyses used HCM released in 2016 (HCM 6 edition) [4]. Performing the analyses was possible based on geometrical road data, information on road traffic intensity, type and directional structure, information on road markings and the number of side road accessibility points for the analyzed roads. The HCM method assumes a six-level Level of Service (LOS) rating scale - Table 1.
Table 1. Values characterizing the level of service [1]

| LoS | 1st road group | 2nd road group | 3rd road group |
|-----|----------------|----------------|----------------|
|     | Average travel speed [km/h] | Percentage of time driving in a column [%] | Percentage of time driving in a column [%] | Percentage of journeys in free traffic [%] |
| A   | 88             | ≤35            | ≤40            | 91.7           |
| B   | >80-88         | >35-50         | >40-55         | >83.3-91.7     |
| C   | >72-80         | >50-65         | >55-70         | >75.0-83.3     |
| D   | >64-72         | >65-80         | >70-85         | >66.7-75.0     |
| E   | ≤64            | >80            | >85            | ≤66.7          |

Level A is characterized by the best traffic conditions, while level F is the state when capacity is exceeded and the transition to forced traffic condition occurs. Level F occurs when bandwidth is exceeded, switching to forced traffic condition. This method divides roads into three groups:

- Group 1 – transit routes, high manoeuvrability is expected, high travel speed
- Group 2 – access roads to group 1 roads, high manoeuvrability is expected
- Group 3 – roads passing through towns and cities, drivers are significantly influenced by local traffic

Analyses were performed for group 2 roads due to the nature of the analyzed sections’ environment. The three analyzed sections are fragments of voivodeship roads connecting larger towns with the roads of the first group, which affect the level of service. Characteristic values of LOS include the average travel speed, the percentage of driving time in the column and the percentage of travel in free traffic.

3. Results and discussions

The measurements were taken for three measurement sections. All polygons had the same geometric parameters, making it possible to compare their results.

3.1. Determination of the level of service using the HCM method and the Polish method

In case of measuring traffic volumes, the speeds were calculated using the Highway Capacity Manual method and the Polish method [5], determining the levels of service as well. The first section where the study was carried out was the Voivodeship Road No. 964 near Wieliczka. Four hours of results were obtained from the measurements for further analysis. The road was classified in the second group according to the HCM method. Calculations based on this method demonstrate that road section there had C level of service. However, when using the Polish method, the traffic conditions were classified as F, meaning the state of forced movement. During the measurements, the traffic situation was monitored and no traffic jams (congestions) or significant difficulties for the drivers were noted. The results of measurements and calculations are presented in Table 2.

The second study area was located at Główna Street in Korytów. Due to its location, it was also qualified in the second group according to the HCM method. Traffic in this section demonstrates intercity nature. Surrounding the forest and few single-family buildings makes it possible to classify it in the second group. The traffic volume in this section was very low. No traffic disruptions, drivers could freely manoeuvre and choose their speed.

The LOS was determined by two methods. According to the HCM method, level of service was obtained for all three measurement hours. In case of the Polish method, level E was received for the first hour, with level D presented for two consecutive hours. The results are shown in Table 3.
**Table 2.** Results of measurements and calculations for the section of the Voivodeship Road No. 964

| No. | Qp Lane No. 1 | Qp Lane No. 2 | Vehicle Share - Lane No. 1 | Vehicle Share - Lane No. 2 | k15 coefficient | Q₀ Lane No. 1 | Q₀ Lane No. 2 | Level of service acc. to HCM |
|-----|----------------|----------------|---------------------------|---------------------------|-----------------|----------------|----------------|----------------------------|
|     | [V/hr]         | [V/hr]         | [%]                       | [%]                       | [-]             | [V/hr]         | [V/hr]         | [-]                       |
| 1   | 295            | 271            | 6.0                       | 8.0                       | 0.956           | 400            | 385            | C                         |
| 2   | 279            | 264            | 6.0                       | 8.0                       | 0.917           | 397            | 378            | C                         |
| 3   | 252            | 255            | 8.0                       | 9.0                       | 0.856           | 366            | 373            | C                         |
| 4   | 239            | 267            | 9.0                       | 9.0                       | 0.861           | 356            | 385            | C                         |

**Table 3a.** Results of calculation measurements for the section of Główna Street in Korytów

| No. | Qp Lane No. 1 | Qp Lane No. 2 | Vehicle Share - Lane No. 1 | Vehicle Share - Lane No. 2 | k15 coefficient | Q₀ Lane No. 1 | Q₀ Lane No. 2 | Level of service acc. to HCM |
|-----|----------------|----------------|---------------------------|---------------------------|-----------------|----------------|----------------|----------------------------|
|     | [V/hr]         | [V/hr]         | [%]                       | [%]                       | [-]             | [V/hr]         | [V/hr]         | [-]                       |
| 5   | 94             | 103            | 13.0                      | 10.0                      | 0.895           | 180            | 188            | A                         |
| 6   | 101            | 99             | 9.0                       | 4.0                       | 0.909           | 182            | 166            | A                         |
| 7   | 105            | 99             | 4.0                       | 0.0                       | 0.927           | 175            | 155            | A                         |

The third study polygon was located on the voivodeship road 965. The traffic in the section was higher than in case of the previous polygon. There were no traffic obstacles. The drivers moved smoothly. The C level of service was maintained for all analyzed measurement hours according to HCM method. F level was given in case of the Polish method.

**Table 3b.** Results of calculations and analyses for the section of the Voivodeship Road No. 965

| No. | Qp Lane No. 1 | Qp Lane No. 2 | Vehicle Share - Lane No. 1 | Vehicle Share - Lane No. 2 | k15 coefficient | Q₀ Lane No. 1 | Q₀ Lane No. 2 | Level of service acc. to HCM |
|-----|----------------|----------------|---------------------------|---------------------------|-----------------|----------------|----------------|----------------------------|
|     | [V/hr]         | [V/hr]         | [%]                       | [%]                       | [-]             | [V/hr]         | [V/hr]         | [-]                       |
| 8   | 205            | 279            | 23.0                      | 13.0                      | 0.840           | 370            | 413            | C                         |
| 9   | 205            | 273            | 11.0                      | 15.0                      | 0.866           | 326            | 416            | C                         |
| 10  | 183            | 290            | 19.0                      | 11.0                      | 0.857           | 329            | 416            | C                         |
| 11  | 187            | 297            | 6.0                       | 15.0                      | 0.877           | 480            | 439            | C                         |

3.2. Determination of the impact of traffic conditions on road noise levels

Based on calculations of the level of service and the results of the noise level measurements, it was possible to determine the impact of the traffic conditions on the noise level. In the following table 4, the combined results of the LOS analysis and the measured equivalent road noise level for one-hour intervals are presented.
Table 4. Results of noise measurements and PSR analyses for the measurement sections

| Road | Q₀ Lane No. 1 [V/hr] | Q₀ Lane No. 2 [V/hr] | LOS | Measured road noise level [dB] | Calculated road-noise level [dB] | Difference between measured and calculated values [dB] | The difference above +/-1.5 dB |
|------|----------------------|----------------------|-----|-------------------------------|-------------------------------|----------------------------------------------------|-----------------------------|
| DW964 | 400                  | 385                  | C   | 68.7                          | 69.2                          | -0.5                                               | -                           |
| DW964 | 397                  | 378                  | C   | 68.9                          | 69.1                          | -0.2                                               | -                           |
| DW964 | 366                  | 373                  | C   | 68.7                          | 68.9                          | -0.2                                               | -                           |
| DW964 | 356                  | 385                  | C   | 68.8                          | 68.9                          | -0.1                                               | -                           |
| Korytów | 180                  | 188                  | A   | 63.5                          | 66.0                          | -2.5                                               | -1.0                        |
| Korytów | 182                  | 166                  | A   | 62.9                          | 65.8                          | -2.9                                               | -1.4                        |
| Korytów | 175                  | 155                  | A   | 63.2                          | 65.5                          | -2.3                                               | -0.8                        |
| DW965 | 370                  | 413                  | C   | 68.0                          | 69.2                          | -1.2                                               | -                           |
| DW965 | 326                  | 416                  | C   | 67.3                          | 69.0                          | -1.7                                               | -0.2                        |
| DW965 | 329                  | 416                  | C   | 67.2                          | 69.0                          | -1.8                                               | -0.3                        |
| DW965 | 480                  | 439                  | C   | 67.0                          | 69.9                          | -2.9                                               | -1.4                        |

The analysis was performed for traffic conditions determined traffic condition levels using the HCM method. Based on HCM analysis, the critical traffic intensities for the analyzed sections are as follows: LOS A 422 V/hr, LOS B 716 V/hr, LOS C 1140 V/hr. The obtained values of noise measurement results broken down into individual LOS are presented in Figure 1.

Figure 1. Results of LOS-specific noise measurements

Despite the small sample size for the traffic, and noise measurement results, one can notice characteristic relationships between the traffic parameters and the noise level. As you can see, the increase in traffic is normally accompanied by an increase in noise levels. In addition, virtually all
measurement results demonstrate higher values than the noise calculation results. This means that the calculation model overestimates the calculation results. There may be several reasons for the absence of a good match between the measurement results and the noise level calculation. One of these may be the impact of traffic conditions on noise levels outside the standard traffic parameters (traffic intensity, heavy vehicle share, speed). The LOS A range is the largest, ranging from -2.3 dB to -2.5 dB. Such a divergence may result in very significant errors concerning the acceptance of road noise reducing devices, and is generally unacceptable. In case of LOS C, the range of divergences between the measurement results and the calculation of the noise level is large and ranges from -0.1 dB to -2.9 dB. Again, more than half of the results are outside the acceptable error range of +/- 1.5 dB.

These results indicate that, in addition to typical road traffic parameters, other traffic-related factors present impact on noise levels, as in case of road junctions.[6][7]. Another important factor influencing the results include the speed, which can take different values within a single LOS. It should also be noted that changes in traffic intensities always entail changes in speed – according to the rules, the higher the traffic intensity and the share of heavy vehicles in the traffic flow, the lower the speed [8][9]. Most models used to forecast road noise do not take this into account, and this can cause many noise forecasting errors.

4. Conclusions

Based on conducted analyses, conclusions were drawn on the influence of road traffic conditions on the road noise level:

- Based on the obtained results and the performed analyses, it was found that road noise levels are influenced by road traffic intensity variability.
- When calculating the road noise level for variable traffic intensity, it was noted that the change in speed due to an increase in the number of vehicles crossing a section, as well as changing heavy vehicle share and their effect on light vehicle speed should be taken into account.
- Ignoring the relationship between traffic intensity and speed, as well as its change with the increase in traffic volume when forecasting road noise levels can result in significant calculation errors.
- In the analyzed example, a difference of over 1.5 dB can be observed between the measured values and the calculated values for road noise. This may indicate the necessity to take further parameters into account, such as road traffic conditions, in addition to the three basic road traffic parameters (traffic intensity, heavy vehicle share, speed) in the calculations. Failure to take these values into consideration may result in overestimation of road noise levels, thus oversizing or using acoustic protection in inappropriate locations.

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