Selection of Measurement Strategy for the Assessment of Long-term Environmental Noise Indicators

Darko Mihajlov and Momir Praščević

Abstract - **Since national and European legislation does not prescribe how to determine annual environmental noise indicators by measurement, which is a required piece of data for the calibration of strategic noise maps pursuant to Directive 2002/49/EC on the assessment and management of environmental noise, the primary motivation for this research was to try to find a suitable measurement strategy to determine long-term values of environmental noise indicators. Based on the results of long-term noise monitoring at chosen measurement points for the purpose of selecting the optimal measurement strategy, the research involved an attempt to maximally reduce the measurement time interval for each measurement point. It was necessary to acknowledge the mutually opposed requirements for sufficiently accurate and precise results of semi-permanent monitoring in relation to the experimental results of permanent monitoring on the one hand and the degree of utilization of the measuring equipment on the other hand. The optimal measurement strategy for a multi-criteria-defined problem was then selected using the PROMETHEE method, which was suitable due to the possible choices of how to determine the inter-comparison of alternatives in relation to the nature and values of specific criteria.**

Index Terms - **environmental noise; environmental noise indicators; Directive 2002/49/EC; multi-criteria optimization; PROMETHEE method; measurement strategy; road traffic noise; permanent noise monitoring; semi-permanent noise monitoring**

I. INTRODUCTION

It is necessary to know the annual values of environmental noise indicators in order to: (a) create a variety of local, regional, and national documents for the analysis of the existing state of noise burden on the environment; and (b) plan preventive or corrective measures and activities in order to maintain noise levels within the allowed limits or reduce them in those areas where they seriously interfere with, and even prevent, the regular performance of human activities, thus affecting human health.

Definition of noise level status at any location is a process that involves the identification of dominant noise sources and the monitoring of relevant acoustic and meteorological quantities over a time period at a given location. Indeed, the most effective approach to this problem is the long-term, in this case permanent (continuous), yearly monitoring of noise at a given location, since the creation of a strategic noise map, as the basic document for noise status analysis, requires the knowledge of annual noise burden of a given area. Yet, the complicated and complex nature of such an approach, in terms of the utilization of necessary human and material resources, requires more efficient methods of determining annual noise indicator levels L_{den} and L_{night} at a given location, whose values would sufficiently correspond to the values obtained by long-term measurement. Therefore, the aim of the research is to select the optimal measurement strategy, which would require a single measurement, lasting considerably less than a year, to yield results that would reflect the true annual status of road traffic noise level at a given location with acceptable accuracy and precision.

II. METHODOLOGY

Taking into account economic limitations, the initial assumption is that it is possible to use multiple-criteria decision analysis (MCDA) methods to select the measurement strategy with the optimal duration of measurement interval. This has to be based on the results of long-term permanent noise monitoring and the consideration of every factor that could potentially influence measurement results. The strategy thus selected would meet the initial requirement – to provide sufficiently accurate and precise results for the assessment of annual values of environmental noise indicators at all measurement points with the same characteristics, with a minimal duration of resource utilization.

Since every measurement point is specific in terms of variable quantities of parameters that affect the value of annual noise indicators, already in the first step there is a need for long-term continuous monitoring of noise level status at a given location using a stationary noise monitoring station over the course of one year. Further analysis of measurement results for shorter intervals, which are excluded from the long-term continuous monitoring, allows the application of multi-criteria optimization (MCO) for selecting the measurement interval that yields the mean value of measurement results that most closely corresponds to the value obtained through long-term permanent monitoring. Thus, it is possible to use fewer noise monitoring stations to provide more results across the board, i.e. to obtain sufficiently accurate and precise data on

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annual values of environmental noise indicators from a larger number of measurement points.

The initial assumption of the research is that the planned methodology allows the optimal duration of the measurement interval to be determined, which will then serve as the basis for assessing long-term annual noise indicators at the observed locations, burdened prevalently by road traffic noise. The assessment will be accurate to 1.5 dB with a precision of 1.0 dB.

The required accuracy implies that no value of any noise indicators measured by one of the strategies of semi-permanent monitoring should vary in the absolute amount by more than 1.5 dB from the real (actual) value of the noise indicator obtained through long-term permanent monitoring.

The required precision of 1.0 dB implies that the standard deviation value of the measurement results of any noise indicators measured by a semi-permanent monitoring strategy should not exceed 1.0 dB.

The defined values of 1.5 dB for accuracy and 1.0 dB for precision, as quality parameters for the adopted solutions to the problem considered in the paper, originate from the requirements of the Directive 2002/49/EC [1] that the resolution for strategic noise map design should be 5 dB.

Using a comparative analysis of the results of different strategies, the expected end result is to select and adopt the optimal measurement strategy that would be applicable to all measurement points with similar characteristics. The strategy should also provide sufficiently accurate and precise determination of the annual values of environmental noise indicators.

The solution procedure for the defined problem is based on MCDA, which involves the search for the best solution out of a series of allowable solutions in terms of multiple adopted criteria.

The solution to the problem of selecting the measurement strategy for the assessment of annual values of environmental noise indicators, as the primary task of this research, required, among other things, proper equipment for the measurement of noise parameters. For that purpose, the Environmental Noise Management System (ENMS) by the Danish company *Brüel&Kjær* was used. The ENMS is intended for long-term environmental noise monitoring. Basic ENMS elements comprise software type 7843 and two noise monitoring stations, type 3639-B-203 (Fig. 1). In order to monitor the meteorological conditions during measurement, the system was additionally equipped with a meteorological station by the Finnish manufacturer *Vaisala*, type WXT 520, intended for measurements of temperature and relative air humidity, atmospheric pressure, wind direction and speed, and the amount of precipitation.

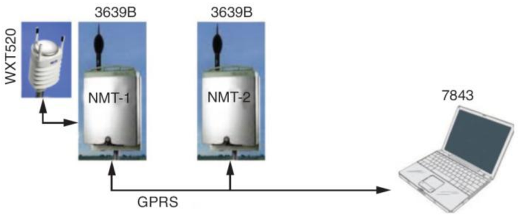

Fig. 1. Environmental Noise Management System – ENMS

Long-term monitoring of road traffic noise in the City of Niš has been conducted since January 1, 2014 at multiple locations [2,3] in keeping with the guidelines provided by standards SRPS ISO 1996-1 [4] and SRPS ISO 1996-2 [5], and by the IMAGINE project [6].

This research is based on the results of measured road traffic noise parameters at three measurement points (M1, M2, and M3) in the City of Niš [7]:

M1 – Generala Milojka Lešjanina and Kneginje Ljubice Street Intersection (GPS: 43^{o}19'13.30"/21^{o}53'28.50");
M2 – 29 Vožda Karađorđa Street, (GPS: 43^{o}19'13.10"/21^{o}54'13.60");
M3 – 81 Dr Zorana Đinđića Boulevard, (GPS: 43^{o}18'57.89"/21^{o}54'56.58").

The shared characteristics of the selected measurement points include nearly equal traffic load of ca. 1,000 vehicles per hour, similar road geometry, and a similar terrain configuration.

III. USE OF MULTI-CRITERIA OPTIMIZATION FOR THE SELECTION OF THE OPTIMAL MEASUREMENT STRATEGY

Solving the problem using MCO involves four basic stages [8]:

1. Problem formulation – creative work characterized by the subjectivity of an individual or a group in establishing the set of alternatives and criteria;
2. Determination of relative importance (weight) of the criteria in two ways – by subjective assessment or by using appropriate techniques aimed at suppressing subjectivity;
3. Selection of an adequate MCO method for the solution of a specified problem;
4. Investigation of the stability of the solution, whether of one best selected alternative, of the selected alternative ranking, or of the subset of good alternatives, in case some of the input data have changed.

In accordance with the defined research aim – finding the minimum measurement interval that will meet the set criteria – the following alternatives have been formulated:

- Alternative a_1 – Measurement strategy with a measurement time interval of one week (from Monday at 00:00 to Sunday at 24:00).
- Alternative a_2 – Measurement strategy with a measurement time interval of one month (from 00:00 on the first day of the month to 24:00 on the last day of the month).
- Alternative a_3 – Measurement strategy with a measurement time interval of six months (for M1 and M2) and nine months (for M3).

- Alternative a_4 – Measurement strategy with a measurement time interval of one year (from January 1 at 00:00 to December 31 at 24:00) for M1.

The preference towards certain alaternatives according to the presented order ($a_1 \rightarrow a_2 \rightarrow a_3 \rightarrow a_4$) stems from the research aim: to use the shortest possible measurement time interval via a monitoring station to obtain satisfactory results for annual noise indicator value at a given measurement point, whose accurate value can be obtained only by measurement over a period of one year. The core of the problem is the fact that in the case of long-term permanent monitoring of noise over one year (alternative a_4) the monitoring station is located in the same place for the entire period, which significantly reduces its usability.

Since measurements of noise parameters at measurement points M2 and M3 were conducted over time intervals shorter than a year, the alternative a_4 was disregarded for them when the optimal measurement strategy was selected.

A. Defining the Set of Criteria

In order to select the optimal measurement strategy using MCDA, a set of nine criteria is considered (Table I). The listed criteria are regarded as general criteria for the selection of the optimal measurement strategy in every considered case.

TABLE I
CRITERIA FOR THE SELECTION OF THE OPTIMAL MEASUREMENT STRATEGY

Criterion	Criterion name / definition
f_1	Standard deviation of value L_{day}
f_2	Standard deviation of value $L_{evening}$
f_3	Standard deviation of value L_{night}
f_4	Standard deviation of value L_{den}
f_5	Maximum deviation of value L_{day}
f_6	Maximum deviation of value $L_{evening}$
f_7	Maximum deviation of value L_{night}
f_8	Maximum deviation of value L_{den}
f_9	Degree of measu. equipment utilization

After the alternatives and criteria have been defined, the mathematical formulation of the given problem of MCO can be represented as follows:

$$Max / Min \begin{Bmatrix} f_1(x), f_2(x), \dots, f_j(x), \dots, f_9(x) \\ \forall x \in A = \left[a_1, a_2, a_3, a_4\right] \end{Bmatrix}. \quad (1)$$

The selected criteria are divided into three categories, whereby criteria $f_1 \div f_4$ pertain to standard deviation of noise indicator measurement results, as the measure of average deviation of all data from the mean value within individual variant solutions, represented by different measurement time intervals. It is in the interest of the set task that the value of standard deviation of measurement results for specific noise indicators should be less than 1 dB during different measurement intervals. This value ultimately meets the result precision requirement, which is why a minimization requirement is set for the given criteria. Small standard deviation values of measurement results suggest small deviations from the average value of a noise indicator for a given measurement time interval. This means that the factors influencing the generation of value of specific noise indicators at a given location vary with time only slightly.

The second category of criteria comprises criteria $f_5 \div f_8$, which represent the maximum deviation of noise indicator values for specific measurement time intervals from their annual value (for M1), nine-month value (M3), and six-month value (for M2). The less the difference deviates from the 1.5 dB accuracy limit set in the research hypothesis, the more justified the selection of a shorter measurement time interval becomes. Thus, the criteria need to be minimized in this case as well in order to accomplish the goal.

The analysis of measurement results indicates that the result accuracy and precision increase as the measurement time interval increases. In contrast, the degree of measuring equipment utilization decreases with longer time intervals (Fig. 2).

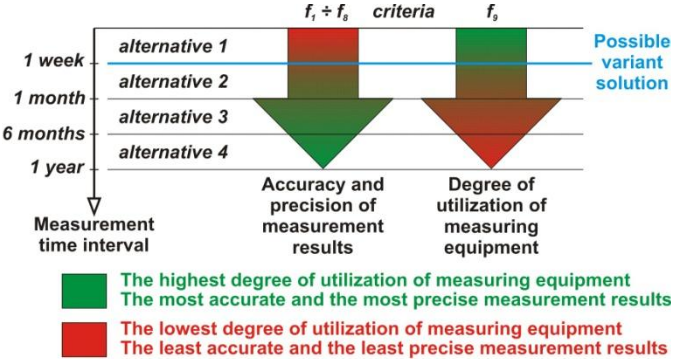

Fig. 2. Trend of criteria value changes with the increase of measurement time interval

The basic task of the research is to determine the interdependency of the given criteria and their influence on the selection of the optimal measurement strategy (blue line in Fig. 2).

The goals of the defined criteria and the requirement of their extremization (maximization or minimization), as well as the manner of their evaluation (evaluation type), are given in Table II.

TABLE II
CRITERIA GOAL FUNCTIONS AND EVALUATION TYPES

Criterion	**Goal /Requirement**	**Evaluation type**
f_1	min	Quantitative
f_2	min	Quantitative
f_3	min	Quantitative
f_4	min	Quantitative
f_5	min	Quantitative
f_6	min	Quantitative
f_7	min	Quantitative
f_8	min	Quantitative
f_9	max	*Qualitative*

Only criterion f_9 is represented by qualitative attributes, which need to be converted into numerical values for the purpose of MCDA. The quantification of qualitative attributes, using the Saaty scale to quantify the relationships between criterion pairs, is given in Table III.

TABLE III
QUANTIFICATION OF QUALITATIVE ATTRIBUTES ACCORDING TO CRITERION GOAL FOR THE DEFINED ALTERNATIVES

	Criterion f_9	
	Criterion goal: *max*	
	Qualitative eval.	Quantitative eval.
a_1	Very high	9
a_2	Medium	4
a_3	Low	2
a_4	Poor	1

Since the defined criteria are not of equal importance, it is necessary to define the importance factors of specific criteria by using the appropriate weight coefficients or weights.

Relative criterion weights were determined through consideration of the criterion weights proposed by ten selected experts in this field (excluding the person who processed the data) [7].

Alternatives and criteria are presented together in Table IV, based on the decision matrix shape and the determination of criterion weight coefficients w_j.

TABLE IV
ALTERNATIVES, EVALUATIONS, GOALS, AND WEIGHT COEFFICIENTS OF CRITERIA FOR THE SELECTION OF THE OPTIMAL MEASUREMENT STRATEGY

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9
a_1	$f_1(a_1)$	$f_2(a_1)$	$f_3(a_1)$	$f_4(a_1)$	$f_5(a_1)$	$f_6(a_1)$	$f_7(a_1)$	$f_8(a_1)$	$f_9(a_1)$
a_2	$f_1(a_2)$	$f_2(a_2)$	$f_3(a_2)$	$f_4(a_2)$	$f_5(a_2)$	$f_6(a_2)$	$f_7(a_2)$	$f_8(a_2)$	$f_9(a_2)$
a_3	$f_1(a_3)$	$f_2(a_3)$	$f_3(a_3)$	$f_4(a_3)$	$f_5(a_3)$	$f_6(a_3)$	$f_7(a_3)$	$f_8(a_3)$	$f_9(a_3)$
a_4	$f_1(a_4)$	$f_2(a_4)$	$f_3(a_4)$	$f_4(a_4)$	$f_5(a_4)$	$f_6(a_4)$	$f_7(a_4)$	$f_8(a_4)$	$f_9(a_4)$
Goal	*min*	*min*	*min*	*min*	*min*	*min*	*min*	*min*	*max*
w_j	0.05	0.05	0.05	0.10	0.05	0.05	0.05	0.10	0.50

The form of the decision matrix (Table IV) is used for the MCO of measurement strategy selection for all measurement points.

IV. SELECTION OF THE OPTIMAL MEASUREMENT STRATEGY USING THE PROMETHEE METHOD

In this research, MCO of measurement strategy selection was performed using the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) [9] for the three selected measurement points, in five steps:

1. Definition of the type of general criterion and preference and indifference parameters for each individual criterion [7]:

Criterion	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9
Type of general criterion	III	III	III	III	V	V	V	V	III
Preference parameter p	2	2	2	2	3	3	3	3	10
Indifference parameter q	-	-	-	-	0.5	0.5	0.5	0.5	-

The adopted types of general criteria and the defined values of preference and indifference parameters were used for calculations for all measurement points.

2. Determination of preference for each pair of alternatives according to each criterion seriatim;
The value of the preference function $P_j(a_1,a_2)$ indicates a preference for the alternative a_1 over a_2 by the j^{th} criterion:

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9
$P_j(a_1,a_2)$	$P_1(a_1,a_2)$	$P_2(a_1,a_2)$	$P_3(a_1,a_2)$	$P_4(a_1,a_2)$	$P_5(a_1,a_2)$	$P_6(a_1,a_2)$	$P_7(a_1,a_2)$	$P_8(a_1,a_2)$	$P_9(a_1,a_2)$
$P_j(a_1,a_3)$	$P_1(a_1,a_3)$	$P_2(a_1,a_3)$	$P_3(a_1,a_3)$	$P_4(a_1,a_3)$	$P_5(a_1,a_3)$	$P_6(a_1,a_3)$	$P_7(a_1,a_3)$	$P_8(a_1,a_3)$	$P_9(a_1,a_3)$
$P_j(a_1,a_4)$	$P_1(a_1,a_4)$	$P_2(a_1,a_4)$	$P_3(a_1,a_4)$	$P_4(a_1,a_4)$	$P_5(a_1,a_4)$	$P_6(a_1,a_4)$	$P_7(a_1,a_4)$	$P_8(a_1,a_4)$	$P_9(a_1,a_4)$
$P_j(a_2,a_1)$	$P_1(a_2,a_1)$	$P_2(a_2,a_1)$	$P_3(a_2,a_1)$	$P_4(a_2,a_1)$	$P_5(a_2,a_1)$	$P_6(a_2,a_1)$	$P_7(a_2,a_1)$	$P_8(a_2,a_1)$	$P_9(a_2,a_1)$
$P_j(a_2,a_3)$	$P_1(a_2,a_3)$	$P_2(a_2,a_3)$	$P_3(a_2,a_3)$	$P_4(a_2,a_3)$	$P_5(a_2,a_3)$	$P_6(a_2,a_3)$	$P_7(a_2,a_3)$	$P_8(a_2,a_3)$	$P_9(a_2,a_3)$
$P_j(a_2,a_4)$	$P_1(a_2,a_4)$	$P_2(a_2,a_4)$	$P_3(a_2,a_4)$	$P_4(a_2,a_4)$	$P_5(a_2,a_4)$	$P_6(a_2,a_4)$	$P_7(a_2,a_4)$	$P_8(a_2,a_4)$	$P_9(a_2,a_4)$
$P_j(a_3,a_1)$	$P_1(a_3,a_1)$	$P_2(a_3,a_1)$	$P_3(a_3,a_1)$	$P_4(a_3,a_1)$	$P_5(a_3,a_1)$	$P_6(a_3,a_1)$	$P_7(a_3,a_1)$	$P_8(a_3,a_1)$	$P_9(a_3,a_1)$
$P_j(a_3,a_2)$	$P_1(a_3,a_2)$	$P_2(a_3,a_2)$	$P_3(a_3,a_2)$	$P_4(a_3,a_2)$	$P_5(a_3,a_2)$	$P_6(a_3,a_2)$	$P_7(a_3,a_2)$	$P_8(a_3,a_2)$	$P_9(a_3,a_2)$
$P_j(a_3,a_4)$	$P_1(a_3,a_4)$	$P_2(a_3,a_4)$	$P_3(a_3,a_4)$	$P_4(a_3,a_4)$	$P_5(a_3,a_4)$	$P_6(a_3,a_4)$	$P_7(a_3,a_4)$	$P_8(a_3,a_4)$	$P_9(a_3,a_4)$
$P_j(a_4,a_1)$	$P_1(a_4,a_1)$	$P_2(a_4,a_1)$	$P_3(a_4,a_1)$	$P_4(a_4,a_1)$	$P_5(a_4,a_1)$	$P_6(a_4,a_1)$	$P_7(a_4,a_1)$	$P_8(a_4,a_1)$	$P_9(a_4,a_1)$
$P_j(a_4,a_2)$	$P_1(a_4,a_2)$	$P_2(a_4,a_2)$	$P_3(a_4,a_2)$	$P_4(a_4,a_2)$	$P_5(a_4,a_2)$	$P_6(a_4,a_2)$	$P_7(a_4,a_2)$	$P_8(a_4,a_2)$	$P_9(a_4,a_2)$
$P_j(a_4,a_3)$	$P_1(a_4,a_3)$	$P_2(a_4,a_3)$	$P_3(a_4,a_3)$	$P_4(a_4,a_3)$	$P_5(a_4,a_3)$	$P_6(a_4,a_3)$	$P_7(a_4,a_3)$	$P_8(a_4,a_3)$	$P_9(a_4,a_3)$
w_j	0.05	0.05	0.05	0.10	0.05	0.05	0.05	0.10	0.50

3. Determination of preference indices for each pair of alternatives according to (2) and creation of a preference index table:

$$\pi(a_1,a_2)=\frac{\sum_{j=1}^{m}\left[w_j\cdot P_j(a_1,a_2)\right]}{\sum_{j=1}^{m}w_j}, \tag{2}$$

where:
- w_j is the relative importance (weight) of a criterion;
- $P_j(a_1,a_2)$ is the preference of the alternative a_1 rather than a_2 by the j^{th} criterion.

Preference index $\pi(a_1,a_2)$ indicates a preference for the alternative a_1 over a_2, taking into account all the criteria simultaneously; it varies within the range from 0 to 1.

	a_1	a_2	a_3	a_4
a_1	0	$\pi(a_1,a_2)$	$\pi(a_1,a_3)$	$\pi(a_1,a_4)$
a_2	$\pi(a_2,a_1)$	0	$\pi(a_2,a_3)$	$\pi(a_2,a_4)$
a_3	$\pi(a_3,a_1)$	$\pi(a_3,a_2)$	0	$\pi(a_3,a_4)$
a_4	$\pi(a_4,a_1)$	$\pi(a_4,a_2)$	$\pi(a_4,a_3)$	0

4. Calculation of the values of input and output flow for each alternative according to (3) and (4) and partial ranking of compared alternatives (PROMETHEE 1):

$$\Phi^{+}(a_i)=\frac{1}{n-1}\sum_{j=1}^{n}\pi(a_i,f_j), \tag{3}$$

$$\Phi^{-}(a_j)=\frac{1}{n-1}\sum_{i=1}^{n}\pi(f_j,a_i). \tag{4}$$

The output flow value $\Phi^{+}(a_1)$ indicates how much the alternative a_1 is better than all the other alternatives from the set of alternatives A by all criteria from the set of criteria C. By analogy, the input flow value $\Phi^{-}(a_1)$ indicates the opposite, i.e. how much all the other alternatives are better than the alternative a_1. The higher the value of the output flow $\Phi^{+}(a_1)$, the more the a_1 dominates other alternatives in the set of alternatives A. The higher the value of the input flow $\Phi^{-}(a_1)$, the more the other alternatives dominate the alternative a_1 in the set of alternatives A.

	a_1	a_2	a_3	a_4	Φ^{+}
a_1	0	$\pi(a_1,a_2)$	$\pi(a_1,a_3)$	$\pi(a_1,a_4)$	✓
a_2	$\pi(a_2,a_1)$	0	$\pi(a_2,a_3)$	$\pi(a_2,a_4)$	✓
a_3	$\pi(a_3,a_1)$	$\pi(a_3,a_2)$	0	$\pi(a_3,a_4)$	✓
a_4	$\pi(a_4,a_1)$	$\pi(a_4,a_2)$	$\pi(a_4,a_3)$	0	✓
Φ^{-}	✓	✓	✓	✓	

5. Calculation of the values of clean flows for all alternatives according to (5) and complete ranking of alternatives (PROMETHEE 2):

$$\Phi(a_i)=\Phi^{+}(a_i)-\Phi^{-}(a_i)\,. \tag{5}$$

	Φ	*Ranking*
a_1		
a_2		
a_3		
a_4		

A. *Results of the Selection of the Optimal Measurement Strategy Using the PROMETHEE Method*

1. The procedure for selecting the optimal measurement strategy at the selected measurement points highlights the alternative a_1 (one-week measurement interval) as the most acceptable in terms of the set criteria.
2. Complete ranking of measurement strategy alternatives for each measurement point has the following form:

$$\boldsymbol{a}_1 \rightarrow \boldsymbol{a}_2 \rightarrow \boldsymbol{a}_3.$$

3. The obtained solution fully corresponds to the research aim – minimizing the measurement time interval while achieving sufficiently accurate and precise results, thus producing the maximum degree of utilization of the measuring equipment.

B. *Selection of the Optimal Measurement Strategy Using Visual PROMETHEE Software*

With the aid of Visual PROMETHEE software [10], the first step was to verify the calculated results for the selection of the optimal measurement strategy for each selected measurement point (scenario 1). Subsequently, in order to valorize the obtained solution, the types of preference functions and the parameter values for the same criteria values were changed (scenario 2) [7].

Stricter conditions for the ranking of alternatives are imposed for scenario 2, as its selected preference function has a linear preference and has the indifference area for all the criteria; likewise, a lower value of the preference parameter was adopted for scenario 2 [7].

Output results provided by Visual PROMETHEE software, expressed through the ranking of alternatives for both scenarios in different ways, confirm that the alternative a_1 (one-week measurement interval) is indeed the most acceptable in terms of the set criteria for all three measurement points [7].

V. DISCUSSION OF RESULTS

The values of weight coefficients of set criteria, as the dominant factors for the given case of decision making, are the result of a detailed analysis of the problem, analysis of each criterion’s importance, and their comparison by a team of experts, which significantly reduced the researcher’s subjectivity in the decision-making process.

The research results greatly depend on the selection of the type/form of preference function, since it indicates smaller, greater, or equal importance of one alternative over another according to a given criterion. The selected preference functions are the result of detailed analysis of criteria quantities, their values, and potential sensitivity of the function itself to slightest changes in the criteria values. In accordance with the given requirements, the procedures for selecting the optimal measurement strategy for each measurement point were conducted through two scenarios, combining two types of criterion functions.

The third factor significantly influencing the outcome of the optimization is the definition of the values of indifference parameters q and preference parameters p. When attempting to generalize their values for all measurement points with same or similar noise characteristics, this is perhaps the most demanding portion of the multi-criteria analysis performed in this research.

The only factors of measurement uncertainty for the experimental results are the uncertainty due to the measurement chain and the uncertainty due to non-stationary traffic load, represented by a standard deviation of the weekly values of noise indicators at specific measurement points.

The accuracy and precision of noise indicator values at the observed measurement points, obtained through one-week measurement interval, correspond to the initial hypothesis: the mean values of specific noise indicators obtained during semi-permanent monitoring deviate up to 1.5 dB from the actual values of those noise indicators obtained during permanent monitoring, and the measured levels of specific noise indicators obtained during semi-permanent monitoring have a standard deviation of up to 1 dB.

The methodology was developed for selecting the measurement time interval for semi-permanent monitoring of noise for the purpose of establishing annual noise indicator values. It was analyzed and confirmed for three measurement points with a very similar traffic load of ca. 1,000 vehicles per hour. As a result, the one-week noise measurement interval was found to be the optimal solution according to the set criteria.

Since meteorological conditions had no influence on the results of long-term noise measurements at the observed locations [11,12], when using the one-week interval for noise monitoring at locations with a traffic load of 1,000+ vehicles per hour and with other shared characteristics, it is important to make sure that no public events that could taint the measurement results will be held at the selected locations during the week planned for noise monitoring.

VI. CONCLUSION

Based on the results obtained in the research, the following conclusions can be made:

1. The use of MCO is a qualitative step forward in the decision making regarding the duration of the time interval of noise indicator measurement based on the set criteria and the limitations for the purpose of ensuring maximum utilization of the available measuring equipment.
2. The following factors influence the selection of the optimal solution:
   - Selection of the method for the MCO procedure in terms of the method's sensitivity to the set criteria and expected outcomes;
     Use of the PROMETHEE method for multi-criteria analysis of the available base of experimental data, with the option of defining conditions and parameters that additionally influence the selection of the optimal measurement strategy, is an acceptable solution in terms of the defined research aim and expected results.
   - The subjectivity of the researcher, inevitable in MCDA, expressed through personal opinion and preference towards specific variant solutions;
     An objective approach to the selection of the optimal measurement strategy was provided by experts in this field, each of whom approached the problem independently and defined the importance of specific criteria.
3. The selection of the measurement strategy with a one-week measurement interval is in keeping with the initial hypothesis that a measurement interval shorter than a year is able to provide information on noise indicator values, which do not significantly deviate from their actual values and do not exceed the pre-defined limits of 1.5 dB for accuracy and 1 dB for precision.
4. The measurement strategy with a one-week measurement interval, selected as the optimal solution in this research, was used at "noisy" urban locations with a traffic load of 1,000+ vehicles per hour, with road traffic as the dominant source of environmental noise that exceeds the limit values of noise indicators.
5. With relatively minor weather changes, the climatic conditions at the locations of long-term noise monitoring did not affect noise indicator levels; therefore, any week during the year can be chosen to perform measurements.
6. The only limitations regarding the choice of any particular week were national holidays and planned public events at the measurement location, in which case increased acoustic activity was expected.

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