Filomat 32:5 (2018), 1777–1782
https://doi.org/10.2298/FIL1805777W

Published by Faculty of Sciences and Mathematics,
University of Niš, Serbia
Available at: http://www.pmf.ni.ac.rs/filomat

A New evaluation model for Uncertain Traffic Pollution Control Planning Under the Risk Attitudes of the Decision Maker

Ming Wei[a,b], Yun Li*[b], Bo Sun[b,c], Jianning Wang[c]

[a]*Jiangsu key laboratory of traffic and transportation security, Huaiyin Institute of Technology, Huaian 223003,Jiangsu, China*
[b]*School of Transportation, Nantong University, Nantong, China*
[c]*School of civil engineering, Hebei University of Technology, Tianjin, China*

Abstract. The purpose of this work is to address a new multi-attribute decision making evaluation model for uncertain traffic pollution control program, by considering the preference of each decision maker to different programs. An interval mapping function was introduced to specify the risk attitudes of the decision maker, which can dissect the original problem to decision problems of traditional values. The proposed model can quantitatively analyze how the risk attitudes of the decision makers affect efficiency ranking for different plans. Case studies performed on the four plans showed that the optimistic ranking of the four plans is the same as that of the neutral situation, but there is a significant difference with the results of pessimistic situation.

1. Introduction

Due to the rapid development of urban economic activity and increase in the population, an increased need for road traffic has been observed in urban areas and the number of automobiles has increased drastically during the past decade. As a result, air pollution has become a major environmental problem in these areas. Issues related to traffic pollution emissions, traffic planning, design, management and methods to control transport emissions have been widely studied. In consequence, many measures to control traffic pollution, such as signal controls, speed controls, one-way traffic systems, bus priority lanes, driver training and parking charge systems, etc., have been taken to reduce traffic emissions resulting from actual road conditions (Huan and Kebin, 2012). However, traffic air pollution has remained an issue of concern. It is essential to assess the effectiveness of different measures on the traffic pollution emissions, traffic flow management and road construction to facilitate the development of a traffic emissions control plan (Wang et al., 2013).

To date, an ever-increasing interests of using new measures to analyse and control traffic pollution have been raising. Existing studies to the problems can be divided into two general groups, namely, impact assessment and control technology of traffic pollution.

The impact assessment technology for the traffic pollution mainly reveals how traffic behavior and environment influences them. Ehsani et al (2016) proposed a new model to reveal the relation between

2010 *Mathematics Subject Classification*. 68U35.
Keywords. Traffic pollution control; The risk attitudes of the decision maker; Interval variables; Multi-attribute decision making model; Evaluation model; Uncertain.
Received: 20 October 2017; Accepted: 7 December 2017
Communicated by Hari M. Srivastava
Email address: lyhyit@163.com (Yun Li*)

vehicle fuel consumption and carbon dioxide emission in road transport. Zhang et al. (2016) observed real-world fuel consumption of hybrid diesel buses particularly sensitive to operating conditions. He et al. (2016) estimates the energy consumption and CO_2 emissions from China's urban passenger transportation sector up to year 2030. Qu et al. (2015) measured emission rates and driving conditions from carburetors and MPI vehicles. Zamboni et al. (2015) discussed fuel consumption and pollutant emission estimation through different methodologies based on necessity of characterizing very local driving conditions.

By review of literatures about control technology for traffic pollution, they focused primarily on the emission-control based strategies of planning, design, and management. Lv et al. (2012) studied traffic pollution emissions and proposed a traffic flow distribution model. The capacity of the urban environment to cope with traffic also was investigated (Hou et al., 2008; Li et al., 2008). Lv et al. (2006) proposed a multi-target planning model for ramping up the urban express road network and control its associated pollution emissions. This model focused on the development of a pollution control plan based on specific road traffic conditions and quantitative analysis of their effects on the traffic emissions. Dijkema et al. (2008) investigated the correlation between highway speeds and traffic emissions. Cui et al. (2009) investigated the impact of one-way road reconfigurations on traffic emissions. Li et al. (2010) investigated simulations of energy consumption in transport circulation. Wu et al. (2010) evaluated a reserved bus lane scheme. Zhao et al. (2017) made a significant effort to improve traffic conditions and air quality by implementing traffic restriction measures.

In the literature, some critical issues deserve further investigations: 1) There are many pollution control schemes, which have their own advantages and disadvantages, for different traffic behaviors and environments, leading to choose an optimal scheme is very important (Huan and Kebin, 2012). However, comparative evaluations of the traffic emission control plan have not been included in previous studies. 2) Although several studies have proposed conventional methods (e.g. general reference level analysis, principal component analysis and expert investigations), few of them are ineffective in evaluating the impacts on pollution emission processes of the attitude preferences of policy makers and other uncertainties, which are essential for real applications (Zamboni et al., 2015). Hence, our main objective of this research is to develop a multi-attribute decision making model for evaluating the uncertainties of plans for traffic pollution control. The main contribution is to reveal how the risk attitudes of the decision makers affect efficiency ranking for each traffic pollution control plan. The paper will focus on the following critical research tasks:

1) Build a comprehensive evaluation index system for traffic pollution control planning. The concept of interval variables was introduced to to characterize the uncertainty of the comprehensive evaluation values and their index values for traffic pollution control plan. Based on the risk attitudes of the decision makers, a new approach is proposed to unify the uncertain evaluation value of traffic pollution control plan.

2) By involving the attitude preferences of policy makers on uncertainties, the model, serves as an effective tool for selecting a best traffic pollution control plan, can dissect the features of ineffective evaluation methods to obtain decisions based on traditional values this function.

2. A comprehensive evaluation index system for traffic pollution control planning

The use of appropriate evaluation criteria determines the effectiveness of comparative assessments of traffic pollution control plans. Based on previous studies (Zamboni et al., 2015; Hou et al., 2008; Li et al., 2008), an integrated evaluation set of bus pollution emission control plans, based on factors such as the implementation process, the effect of traffic flow conditions and the amount of carbon emissions was developed, as shown in Table 1. More specifically, the integrated set of indices consists of three subsets. The subset of the implementation process includes the indices of input costs, construction cycles and construction difficulty levels. The subset of traffic flow conditions includes the indices of vehicle speed, traffic volume, travel delays, travel difficulty levels and the frequency rate of traffic accidents. The subset of traffic carbon emissions includes the indices of the amount of nitrogen and oxygen compounds, organic compounds and oxides emissions.

Table 1: Evaluation index system for traffic pollution control plans

Index	Sub-index	Index type	
		Cost	Benefit
Plan implementation	Input costs (W_1)	√	
	Construction cycles (W_2)	√	
	Construction difficulty levels (W_3)	√	
Effect of traffic flow conditions	Speed (W_4)		√
	Traffic volume (W_5)		√
	Travel delays (W_6)	√	
	Travel difficulty levels (W_7)	√	
	Frequency rate of traffic accidents (W_8)	√	
Carbon emissions	Nitrogen and oxygen compounds (W_9)	√	
	Organic compounds (W_{10})	√	
	Oxides (W_{11})	√	

3. A multi-attribute decision making model for traffic pollution control

3.1. Basic concept

The concept of interval variables was introduced to describe the uncertainty of the comprehensive evaluation values and their index values for traffic pollution control planning. For a total $m \geq 2$ of traffic pollution control plan samples $S = \{S_1, S_2, \ldots, S_m\}$, there are $n \geq 2$ independent index sets $Q = \{Q_1, Q_2, \ldots, Q_n\}$. The index weighting vector is defined as $\overline{w} = (\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n)^T$, in which $\overline{w}_j = [\overline{w}_j^L, \overline{w}_j^U]$, and $(\overline{w}_j^L \geq 0, \overline{w}_j^U \geq 0)$. Also, $A = [a_{ij}]_{mn}$ represents the decision-making matrix of the targeted problem, where $\tilde{a}_{ij} = [\tilde{a}_{ij}^L, \tilde{a}_{ij}^U]$ represents a solution of index Q_j in plan sample S_i. This section aims to determine and rank $M\,(\leq m)$ 'satisfied' plans from S samples based on interval data information from traffic pollution measurements obtained from differing types of previous studies.

Definition 1. *For some interval data $\tilde{a} = [a^L, a^U]$, define $\Phi_\varepsilon(\tilde{a}) = n(\tilde{a}) + \varepsilon e(\tilde{a})$ as the mapping function of the risk attitudes of the decision maker, in which ε, $(|\varepsilon| \leq 0.5)$, represents the pessimistic, neutral and optimistic attitudes. The corresponding value range of ε is $-0.5 \leq \varepsilon < 0, \varepsilon = 0$ or $0 < \varepsilon \leq 0.5$. $n(\tilde{a})$ is the middle value of $\tilde{a}$, where $n(\tilde{a}) = \frac{a^L + a^U}{2}$, and $e(\tilde{a})$ is the width of $\tilde{a}$, where $e(\tilde{a}) = a^U - a^L$.*

Targeting and considering the evaluation uncertainties during the decision-making process for traffic pollution control planning, as well as accommodating the risk attitudes of the decision maker, respectively, Definition 1 provides the interval mapping function for the risk attitudes of the decision maker. The function is able successfully to resolve the problem of ineffective evaluation methods of traffic pollution emissions to obtain a decision based on traditional values. The following section illustrates the major calculation steps for solving the multi-attribute decision making problem based on TOPSIS theory.

3.2. Major calculation steps

Based on the uncertainties in the evaluation systems of different traffic pollution emission control plans, this section describes in greater detail the major calculation steps used to break down the problem of ineffective evaluation methods of traffic pollution emissions to obtain a decision problem based on traditional values. This is achievable by using the interval data to represent the uncertainties in the decision-making process, also taking into consideration the different preferences of the decision maker.

Step 1: The risk attitude ε of the decision maker and its mapping function $\varphi_\varepsilon(a) = n(a) + \varepsilon e(a)$ are used and the decision-making matrix of the traffic pollution emissions control plan is converted using $A = [a_{ij}]_{m\times n}$ and the weighted vector $\overline{w} = (\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n)^T$ to $A^\varepsilon = [a_{ij}^\varepsilon]_{m\times n}$ and $w'^\varepsilon_j = (w'^\varepsilon_1, w'^\varepsilon_2, \ldots, w'^\varepsilon_n)^T$ respectively, based on the value of ε.

Step 2: The decision-making matrix $A^{\varepsilon} = [a^{\varepsilon}_{ij}]_{m\times n}$ of the traffic pollution emissions control plan based on ε is normalized to $B^{\varepsilon} = [b^{\varepsilon}_{ij}]_{m\times n}$, and is standardized to formulate the weighted normalization matrix $X^{\varepsilon} = [x^{\varepsilon}_{ij}]_{m\times n}$, in which $b^{\varepsilon}_{ij} = \frac{a^{\varepsilon}_{ij}}{\sqrt{\Sigma^{m}_{i=1}(a^{\varepsilon}_{ij})^2}}$, and $x^{\varepsilon}_{ij} = b^{\varepsilon}_{ij} w^{\varepsilon}_{ij}$.

Step 3: The positive ideal points $x^{\varepsilon+}$ and negative ideal points $x^{\varepsilon-}$ are determined. Based on the weighted normalization decision-making matrix $X^{\varepsilon} = [x^{\varepsilon}_{ij}]_{m\times n}$ of the traffic pollution emissions control plan:

$$x^{\varepsilon+} = \left(x^{\varepsilon+}_1, x^{\varepsilon+}_2, \ldots, x^{\varepsilon+}_i\right) = \left\{\left(\max_i x^{\varepsilon}_{ij} \mid j \in J\right), \left(\min_i x^{\varepsilon}_{ij} \mid j \in J'\right) \mid i = 1, 2, \ldots, m\right\} \text{ and}$$

$$x^{\varepsilon-} = \left(x^{\varepsilon-}_1, x^{\varepsilon-}_2, \ldots, x^{\varepsilon-}_i\right) = \left\{\left(\max_i x^{\varepsilon}_{ij} \mid j \in J\right), \left(\min_i x^{\varepsilon}_{ij} \mid j \in J'\right) \mid i = 1, 2, \ldots, m\right\},$$

where J is the set of benefit index, and J' is the set of revenue index.

Step 4: Determine the distances $d^{\varepsilon+}_i$ and $d^{\varepsilon-}_i$ of $x^{\varepsilon+}$ and $x^{\varepsilon-}$ respectively, according to the values of $x^{\varepsilon+}$ and $x^{\varepsilon-}$:

$$d^{\varepsilon+}_i = \sqrt{\Sigma^{n}_{j=1}\left(x^{\varepsilon}_{ij} - x^{\varepsilon+}_{ij}\right)^2}, i = 1, 2, \ldots, m,$$

$$d^{\varepsilon-}_i = \sqrt{\Sigma^{n}_{j=1}\left(x^{\varepsilon}_{ij} - x^{\varepsilon-}_{ij}\right)^2}, i = 1, 2, \ldots, m.$$

Step 5: Calculate the corresponding relative proximity $c^{\varepsilon}_i = \frac{d^{\varepsilon-}_i}{(d^{\varepsilon-}_i + d^{\varepsilon+}_i)}$ from the values of d^{z+}_i and d^{z-}_i for each alternative traffic pollution emission control plan, i.e., using the evaluation value for each control plan.

According to the above steps, under the same value of ε, the $m \geq 2$ samples of alternative traffic pollution emission control plans $S = \{S_1, S_2, \ldots, S_m\}$ can be arranged in a descending order by comparing the value of c^{ε}_i, and the plan option with the highest value of c^{ε}_i has the higher priority. Under different values of ε, the best plan option can be determined based on actual decision-making needs.

4. Case study

Table 2: Plan decision-making matrix

Index \ Plan	w^U_j	w^L_j	S_1		S_2		S_3		S_4	
			a^U_{ij}	a^L_{ij}	a^U_{ij}	a^L_{ij}	a^U_{ij}	a^L_{ij}	a^U_{ij}	a^L_{ij}
W_1	0.3	0.1	150	110	170	160	90	70	180	160
W_2	0.2	0.15	5	3.5	3.8	3.5	4	3.5	6.5	5
W_3	0.4	0.15	0.8	0.6	0.4	0.4	0.85	0.8	0.2	0.2
W_4	0.4	0.25	55	30	45	35	50	35	50	40
W_5	0.4	0.3	750	600	650	650	700	650	700	700
W_6	0.3	0.3	8	5	7	6	7	6	7	6
W_7	0.3	0.3	0.7	0.4	0.6	0.5	0.5	0.5	0.6	0.6
W_8	0.1	0.1	0.15	0.05	0.05	0.03	0.04	0.02	0.05	0.03
W_9	0.2	0.2	1700	1300	1600	1400	1600	1500	1500	1400
W_{10}	0.1	0.1	800	600	750	600	600	550	600	400
W_{11}	0.2	0.2	450	350	500	400	450	350	350	300

To illustrate the applicability of the proposed models in the traffic emissions efficiency assessment, this study has selected four possible plans of a road for a case study, involving speed limitation, one-way traffic, traffic channeling and signaling. The raw data of the decision-making matrix is shown in Table 2. Through

Table 3: Positive and negative ideal distances of each plan

ε \ Plan	S_1		S_2		S_3		S_4	
	$d_1^{\varepsilon+}$	$d_1^{\varepsilon-}$	$d_2^{\varepsilon+}$	$d_2^{\varepsilon-}$	$d_3^{\varepsilon+}$	$d_3^{\varepsilon-}$	$d_4^{\varepsilon+}$	$d_4^{\varepsilon-}$
-0.5	0.0853	0.0696	0.0793	0.0635	0.0645	0.0938	0.0907	0.0852
0	0.0544	0.1375	0.1222	0.0826	0.0982	0.1482	0.1578	0.0842
0.5	0.0560	0.2247	0.1737	0.1121	0.1362	0.2109	0.2229	0.1136

key steps in the evaluating plans, the positive and negative ideal distances of each plan could be obtained in Table 3 under the different risk attitudes of the decision maker.

Based on Table 2, the relative proximity also was determined to rank the traffic emissions efficiency. The results are shown in Table 3 respectively. Taking $\varepsilon = -0.5$ as an instance, the ranking order was $S_3 \to S_4 \to S_1 \to S_2$, so that S_3 has a higher priority than S_4 and S_1, while S_2 has the lowest priority. Obviously, ranking of four plans is affected by risk attitude ε of the decisionmaker fluctuating from -0.5 to 0.5, resulting from the evaluation value $\Phi_{i\varepsilon}(\tilde{a}) = n_i(\tilde{a}) + \varepsilon_i e(\tilde{a})$ of each plan S_i containing determination information $n_i\,(a) = \Sigma_{j=1}^{n}(\frac{a_{ij}^U - a_{ij}^L}{2})$ and uncertainty information $e_i(a) = \Sigma_{j=1}^{n}(a_{ij}^U - a_{ij}^L)$ of all indicators at the same time, from which we can see:

(1) When $n_i(\tilde{a}) > n_k(\tilde{a})$ and $e_i\,(a) > e_k\,(a)$ $(n_i(\tilde{a}) < n_k(\tilde{a})$ and $e_i\,(a) < e_k\,(a))$, $\Phi_{i\varepsilon}(\tilde{a}) > \Phi_{k\varepsilon}(\tilde{a})$ $(\Phi_{i\varepsilon}(\tilde{a}) < \Phi_{k\varepsilon}(\tilde{a}))$ for any risk attitude ε is always satisfied. For example, the plan S_3 is always better than the plan S_4.

(2) If a threshold contact degree of evaluation values of two plans S_i and S_k exists, changes of system efficiency ranking with threshold contact degree are satisfying $\varepsilon = \frac{n_i(\tilde{a}) - n_k(\tilde{a})}{e_k(\tilde{a}) - e_i(\tilde{a})} \in [-0.5, 0.5]$. For example, bus ranking of the plan S_3 and S_1 changes as $\varepsilon = -0.1$.

Table 4: Rankings for different risk attitude factors

ε	c_1^{ε}	c_2^{ε}	c_3^{ε}	c_4^{ε}	**Rankings Results**
-0.5	0.4494	0.4444	0.5927	0.4845	$S_3 \to S_4 \to S_1 \to S_2$
0	0.7164	0.4033	0.6016	0.3479	$S_1 \to S_3 \to S_2 \to S_4$
0.5	0.8006	0.3922	0.6076	0.3377	$S_1 \to S_3 \to S_2 \to S_4$

5. Conclusion

As traffic emissions are a key environmental problem in urban areas, it is of great significance to select an best control plan, based on effective evaluations and assessments of different traffic management and control measures. In order to deal with the uncertainty of different type of attribute indicators in traffic pollution control, this paper proposes a multi-attribute decision making model consdering risk attitude of the decision maker.The contribution of our research is to reveal the relationship between the uncertainty of these evaluation indicators, risk attitude of the decision maker, and the threshold changes of traffic control plan efficiency ranking, and through an example to verify the validity of the model. The result shows:

(1) The evaluation value of traffic control plan is an uncertain value, and its ranking is related to risk attitude of the decision maker, which reflects the influence of the uncertainty of contact degree on traffic control plan efficiency ranking.

(2) Both of the certain information $n_i(a) = \Sigma_{j=1}^{n}(\frac{a_{ij}^U - a_{ij}^L}{2})$ and uncertainty information $e_i(a) = \Sigma_{j=1}^{n}(a_{ij}^U - a_{ij}^L)$ of all attribute indicators play an more important role in traffic control plan assessment process.If efficiency ranking of two traffic control plans changes, their threshold contact degrees $\varepsilon = \frac{n_i(\tilde{a}) - n_k(\tilde{a})}{e_k(\tilde{a}) - e_i(\tilde{a})} \in [-0.5, 0.5]$ would be found.

Nonetheless, this paper focused on the evaluation of traffic emissions control plans from one decision maker and the results may be biased. In consequence, therefore, future studies should include more comprehensive assessments by evaluating the opinions and experiences from different decision makers. Moreover, the decision method can be explored relating risk attitudes to the multi-attribute group for resolving pollution emission issues in urban traffic planning.

Acknowledgements

This paper is funded by Jiangsu provincial government scholarship program; the National Natural Science Foundation of China (61503201); Natural Science Foundation of the Jiangsu Province in China (BK20161280); the Humanities and Social Sciences Foundation of the Ministry of Education in China (16YJCZH086); Natural Science Foundation of the Jiangsu High Education (15KJB580011, 17KJB520029); Nantong Science and Technology Innovation Program (GY12016020, GY12016019); the Science and Technology Key Research and Development Project of Huai'an City (HAS2015015); the open fund for the Key Laboratory for traffic and transportation security of Jiangsu Province (TTS2016-01) Project of excellent graduate innovation in Hebei province (2016348).

References

[1] Cui Z., The impact of one-way roads reconstruction on traffic emissions, Jilin University, Master Degree Thesis (2009).

[2] Dijkema A., Zee S., Brunekreef B., Air quality effects of an urban highway speed limit reduction, Atmospheric Environment 42 (2008) 9098–9015.

[3] Ehsani M., Ahmadi A., Fadai D., Modeling of vehicle fuel consumption and carbon dioxide emission in road transport, Renewable & Sustainable Energy Reviews 53 (2016) 1638–1648.

[4] Hou D., Yan K., Cheng F., The model and algorithm for the analysis of the carrying capacity for urban traffic noises, Computer Science and Application 44(18) (2008) 215–220.

[5] Huan L., Kebin H., Traffic optimization: a new way for air pollution control in China's urban areas, Environmental Science & Technology 46(11) (2012) 5660–5661.

[6] He D., Liu H., He K., et al., Energy use of, and CO 2, emissions from China's urban passenger transportation sector – Carbon mitigation scenarios upon the transportation mode choices, Transportation Research Part A 53 (2013) 53–67.

[7] Li T., The environmental traffic capacity of urban roads, Journal of Southeast University (Natural Science) 38(2) (2008) 309–313.

[8] Li W., Liu J., A quantitative study on transport energy consumption: urban circulation transportation energy consumption simulation, Urban Development Research 17(6) (2010) 32–63.

[9] Lv J., Zhang Y., Zietsman J., A convex approach to traffic assignment problem under air quality constraints for planning purposes, Advances in Transportation Studies (2012) 85–96.

[10] Lv Z., Fan. B., The multi-target planning model of urban express network ramp and pollution control, Control and Decision 21(1) (2006) 64–87.

[11] Qu L., Li M., Chen D., et al., Multivariate analysis between driving condition and vehicle emission for light duty gasoline vehicles during rush hours, Atmospheric Environment 110 (2015)103–110.

[12] Wang Y., Discussion on the development situation and direction of environmental monitoring, Environmental Science and Management 38(3) (2013) 149–151.

[13] Wei M., Yu. S., The evaluation model of multi-attribute decision making based on risk attitudes of decision maker in public transportation network, Operation Research and Management Science 5(11) (2002) 104.

[14] Wu M., Li T., He W., The evaluation of the special bus lane scheme and its environmental impacts, Journal of transportation engineering and information 8(1) (2010) 82–108.

[15] Xu Z., Uncertain multi-attribute decision-making method and its application, Beijing Tsinghua University Press (2004).

[16] You T., Fan Z., A risk attitudes decision-making method in multi-attribute decision making with interval data, Operation research and management science 5(11) (2002) 104.

[17] Zhang S., Wu Y., Liu H., et al., Real-world fuel consumption and CO_2, emissions of urban public buses in Beijing, Applied Energy 113(6) (2014) 1645–1655.

[18] Zamboni G., André M, Roveda A, et al., Experimental evaluation of Heavy Duty Vehicle speed patterns in urban and port areas and estimation of their fuel consumption and exhaust emissions, Transportation Research Part D Transport & Environment 35 (2015) 1–10.

[19] Zhao S., Ye Y., Effect of short-term regional traffic restriction on urban submicron particulate pollution. Journal of Environmental Sciences 55(5) (2017) 123–134.