Using a fuzzy group TOPSIS model for prioritising and selecting traffic calming measures in residential streets

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Abstract

Selecting appropriate Traffic Calming Measures (TCMs) in residential areas is an essential task which must be carried out through an accurate multi-criteria decision making process. Application of the Technique for Order of Preference by Similarity to Ideal Soloution (TOPSIS) is proposed in this study to solve the problem. The principle of TOPSIS is based on the theory that the selected alternative must have the farthest distance from the negative ideal solution and the shortest distance from ideal positive solution. However the classical model of TOPSIS for dealing with vague-nature problems and linguistic assessment is not suitable. Therefore, in this study fuzzy TOPSIS model is used to prioritise traffic calming measures. Traffic impacts, safety impacts, secondary impacts and cost are the main criteria and the alternatives are TCMs such as speed hump, traffic circle, choker and half closure. Four senior traffic safety experts are selected to participate in this study. Finally the ranking of alternatives or TCMs are carried out and it has been revealed that speed hump/table has the highest priority.

Keywords: TOPSIS, MCDM, Fuzzy, Traffic calming measures

1. Introduction

Nowadays, traffic crashes are threatening the lives of people living in different part of the world, therefore traffic safety strategists apply safety measures to alleviate these problems. Traffic calming is a branch of traffic safety which focuses more on residential areas than highways and arterials (Elvik, 2001). TCMs are physical installations and engineered measures that are developed to reduce traffic speed and control traffic flow. It has been proven that TCMs have great positive impact on the safety of pedestrians, cyclists and residents of local neighbourhood (Ewing, 2000). According to the researches, employing TCM can reduce the number of crashes in urban areas effectively. For example based on ITE (Institute of Transportation Engineers) researches, employing vertical TCMs can reduce traffic speed and traffic volume in residential areas up to 22 percent. In other words, TCMs can reduce the attractiveness of residential streets and discourage non-local drivers from entering local streets (Corkle et al., 2002).

Conventional manuals for traffic calming measure demonstrate the function of traffic calming measures, cost of implementation, advantages and disadvantages of them but there are few studies for helping engineers to select appropriate traffic calming measures. Generally traffic engineers and urban planners rely on their individual engineering judgment to select traffic calming measures, while considering the effectiveness of these selected measures and their impact on road users, local residents and environment issues is essential. The aim of this study is to provide a framework to prioritise TCMs based on a group fuzzy TOPSIS model. In the second section, summary of traffic calming practices and the concept of the fuzzy group TOPSIS method with the relevant studies are represented. In the third section, group fuzzy TOPSIS development is explained. In the fourth section, the structure of prioritisation of TCMs is explained. In the fifth section, by participating four traffic safety experts, a real model is created and the results are discussed. Finally, the research findings is summarised in the conclusion section.

2. Literature review

Traffic calming studies began in Europe in the 1960s. Complaints about the cut-through traffic in residential streets and problems related to excessive speed forced authorities and decision makers to think about ways to improve the safety of residents in residential neighbourhoods. European countries including Netherland, Germany and UK are well known in designing and implementation of traffic calming measures (Pharaah & Russell, 1989). After Europe, the USA, Canada and Australia began to use traffic calming measures as proper solutions for calming and improving safety in their neighbourhoods. Traffics calming measures can be classified into different classifications (Mormilo, 2016; PennDOT, 2012; Ewing, 2000) which have been summarised in Table 1.

Table 1. Different classifications of traffic calming measures

Classifications	Description	Measures
Vertical deflections	Measures that cause vertical deflection on the roads	speed hump, speed tables and raised crosswalks
Horizontal deflections	Measures that transform the centreline of roads from a straight line into a curved line	chicane, traffic circle and centre island chicane
Narrowing measures	Measures that reduce the effective with of roadways	road diet, lane reduction, choker, neckdown and pedestrian refuge islands
pavement treatment	Measures that change the surface of streets in order to attract drivers' attention	brick paving and stone paving
Traffic volume control	Measures that close the road partially or fully to through traffic	full closure, half closure and turning prohibition
Speed limit adjustment	Changing the speed limits in accordance with the traffic condition and environment	speed limit reduction, speed zones and school zones
signing and marking	Raising the awareness about the changes in traffic condition and environment	vertical signs and pavement markings

Multiple Criteria Decision Making (MCDM) techniques are generally useful for the problems that different conflicting criteria such as safety and cost must be considered. In recent years TOPSIS has been employed widely for solving MCDM problems. This issue can be explained by two reasons. First, the concept of TOPSIS is not complicate and therefore it could be understand easily by decision makers and secondly, comparing with other methods for example AHP, it require less computations and consequently could be applied in easy way (Huang et al., 2011). In TOPSIS model the appropriate alternative should be in the closest distance from the positive desired solution and as contrary it should be in the farthest distance from the negative ideal solution (Awasthi et al., 2011; Şengül et al., 2015). According to advantages of TOSIS method, in this paper fuzzy group TOPSIS approach has been employed for the process of prioritizing and selecting appropriate traffic calming measures. It must be mentioned that in real life and in most cases decision makers could not select an idea with certainty so their decision will be associated with indefinite characters. Fuzzy theory provides a mechanism for dealing with vagueness and imprecision (Zadeh, 1997). Fuzzy group TOPSIS could be developed based on trapezoidal fuzzy numbers which represent linguistic variables for weight of criteria and rating measures of alternatives (Boran et al., 2009). Different application of fuzzy group TOPSIS methods were used in previous researches. For example, Karimi et al. (2011) applied fuzzy group TOPSIS for selection of wastewater treatment process. Environmental, technical and economic issues were considered as the criteria in this research. Chu (2002) employed fuzzy TOPSIS model for providing solutions to problems related to plant location selection. Availability of skilled workers, expansion possibility, availability of material and investment cost were defined as the criteria.

3. Fuzzy variables and TOPSIS method

In this section the process of developing a Fuzzy TOPSIS model is described. The concept behind this method is that, at the end the chosen alternative should have the longest distance from a negative ideal solution and the shortest distance from the positive ideal solution. In this regard, a positive ideal solution is considered as a solution that maximizes the benefit criteria such as safety and minimizes cost criteria such as maintenance cost. On the contrary, a negative ideal solution minimizes the benefit criteria and maximizes the cost criteria. In a typical TOPSIS method, the weights of each criteria and the ranking of alternatives are carried out precisely as crisp values are employed in the evaluation process. However, under different conditions crisp data are incapable to model real-life decision making problems. Hence, the fuzzy TOPSIS method can be proposed, in which the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. This paper applied the method proposed by Chen et al. (2006) and Chen (2000).

The linguistic variables for importance weight of each criterion and rating of each alternative can be obtained from positive trapezoidal fuzzy numbers shown in Figure 1 and Figure 2.

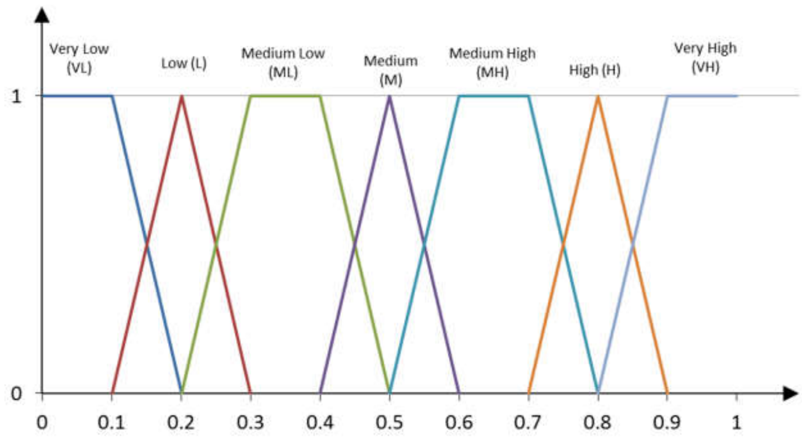

Figure 1: Linguistic variable for importance weights assigned to each criterion (Chen et al. 2006)

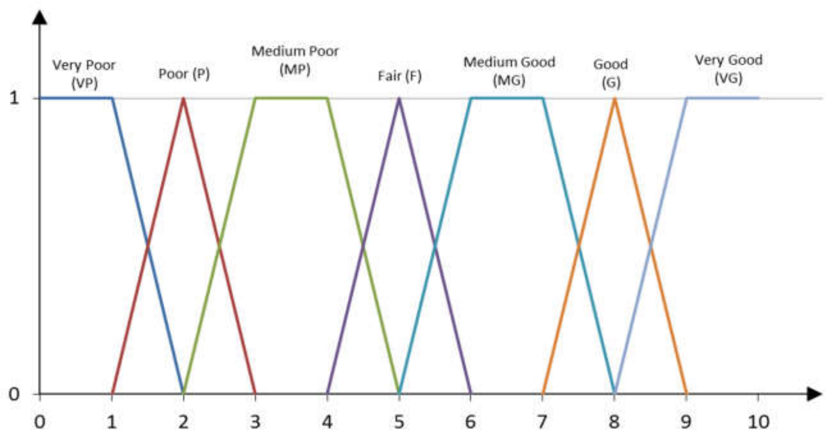

Figure 2: Linguistic variable for rating of each alternative (Chen et al. 2006)

This methods consists of eight consecutive steps which have been represented as follows:

In the first step a group of decision makers which in real world are the experts in the desired field are gathered:

D=$\{D_1, D_2, \dots, D_T\}$ (1)

Where D is a decision maker and T is the number of decision makers;

In the second step the alternatives, criteria and sub-criteria are determined:

A=$\{A_1, A_2, \dots, A_m\}$ (2)

Where A is an alternative and m is the number of alternatives;

C=$\{C_1, C_2, \dots, C_n\}$ (3)

Where C is a criterion and n is the number of criteria;

$S_{j=}\left\{S_1, S_2, \ldots, S_{l_j}\right\}$ (4)

Where S is a sub-criteria of criterion j and $\sum_{j=1}^{n} l_j = l$;

$\tilde{x}_{ijk}$, i=1,…,m, j=1,…,n, k=1,…, l_j with respect to an alternative A_i (i=1,…,m), criterion C_j (j=1,…,n) and sub-criterion S_{jk} (j=1,…,n; k=1,…, l_j) by decision maker D_t (t=1,…,T).

In the third step aggregated fuzzy weight of criteria ($\widetilde{w}_j$), fuzzy weight of sub-criteria ($\tilde{u}_{jk}$) and fuzzy rating of alternatives ($\tilde{x}_{ijk}$) are defined as follows:

$\widetilde{w}_j$=(w_{j1}, w_{j2}, w_{j3}, w_{j4}) (5)

Where:

$w_{j1}=\min_t\{w^t{}_{j1}\}$, $w_{j2}=\sum_{t=1}^{T} w^t{}_{j2}/T$, $w_{j3}=\sum_{t=1}^{T} w^t{}_{j3}/T$, $w_{j4}=\max_t\{w^t{}_{j4}\}$ (6)

$\tilde{u}_{jk}$=(u_{jk1}, u_{jk2}, u_{jk3}, u_{jk4}) (7)

Where:

$u_{jk1}=\min_t\{u^t{}_{jk1}\}$, $u_{jk2}=\sum_{t=1}^{T} u^t{}_{jk2}/T$, $u_{jk3}=\sum_{t=1}^{T} u^t{}_{jk3}/T$, $u_{jk4}=\max_t\{u^t{}_{jk4}\}$ (8)

$\tilde{x}_{ijk}$=(a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk}) (9)

Where:

$a_{ijk}=\min_t\{a^t{}_{ijk}\}$, $b_{ijk}=\sum_{t=1}^{T} b^t{}_{ijk}/T$, $c_{ijk}=\sum_{t=1}^{T} c^t{}_{ijk}/T$, $d_{ijk}=\max_t\{d^t{}_{ijk}\}$ (10)

In the fourth step, after calculating the arrays of fuzzy rating of each alternative, the fuzzy matrix should be normalized as follows:

$\tilde{R}=\left[\tilde{r}_{ijk}\right]_{m\ \ l}$ (11)

Where:

$\tilde{r}_{ijk}=\left(\frac{a_{ijk}}{\max_i\{d_{ijk}\}}, \frac{b_{ijk}}{\max_i\{d_{ijk}\}}, \frac{c_{ijk}}{\max_i\{d_{ijk}\}}, \frac{d_{ijk}}{\max_i\{d_{ijk}\}}\right)$, i=1,…,m, j=1,…,n, k=1,…, l_j (12)

In the fifth step by multiplication operation on calculated trapezoidal fuzzy numbers, the weighted normalized matrix can be achieved as follows:

$V=\left[v_{ijk}\right]_{m\ \ l}$ (13)

Where:

$v_{ijk}=P(\tilde{r}_{ijk}\quad \tilde{u}_{jk}\quad \widetilde{w}_j)=\frac{1}{6}(a_{ijk}+2b_{ijk}+2c_{ijk}+d_{ijk})\times\frac{1}{6}(u_{jk1}+2u_{jk2}+2u_{jk3}+u_{jk4})\times\frac{1}{6}$
$(w_{j1}+2w_{j2}+2w_{j3}+w_{j4})$

i=1,…,m, j=1,…,n, k=1,…, l_j (14)

Considering farthest distance from the negative ideal solution and closeness to the positive ideal solution is useful characteristic of the TOPSIS method so it is possible to define both benefit-type criteria and cost-type criteria. For example if an alternative is cost-type criteria, the linguistic variable assigned to them for rating will be poor, in contrast if an alternative is benefit-type criteria the linguistic variable assigned to them regarded as high.

In the sixth step, after completing the weighted normalized fuzzy decision matrix, the positive ideal solution (A) and negative ideal solution (A^-) can be calculated as below:

A =(v_{11}, v_{12},…, v_{nl_n}) (15)

A^-=(v_{11}^-, v_{12}^-,…, $v_{nl_n}^-$) (16)

Where:

$v_{jk}=\max_i\{v_{ijk}\}$ $v_{jk}^-=\min_i\{v_{ijk}\}$ (17)

i=1,…,m, j=1,…,n, k=1,…, l_j

In the seventh step, the distance of each alternative from A and A^- can be defined as follows:

$D_i=\sqrt{\sum_{j=1}^{n}\sum_{k=1}^{l_j}(v_{ijk} \quad v_{jk})^2}$ (18)

$D_i^-=\sqrt{\sum_{j=1}^{n}\sum_{k=1}^{l_j}(v_{ijk} \quad v_{jk}^-)^2}$ (19)

In the final step, the closeness coefficient ($\bar{C}_i$) of each alternative to the ideal solution can be defined as below:

$\bar{C}_i=\frac{D_i}{D_i \; +D_i}$ where: $\bar{C}_i \in [0,1]$ (20)

According to the closeness coefficient ($\bar{C}_i$), the alternatives which have the greater $\bar{C}_i$ will be closer to the ideal solution and farther from the negative ideal solution.

4. Structure of prioritisation of TCMs

In this section, the proposed structure of TCMs prioritisation which can be categorised into criteria, sub-criteria and alternatives has been discussed. Prioritizing and selecting TCMs need a multi criteria decision making model which should involve all factors that are related to traffic calming procedure. Each of these factor or criterion have relevant sub-criterion which accounting them could improve the decision making process. For selecting the criteria and sub-criteria, traffic calming manuals, previous researches and related papers in traffic calming subject (Ewing, 2000; Elvik, 2001; Biddulph, 2010; Koorey & Mao, 2010; Lee et al., 2013; Nadesan-Reddy & Knight, 2013; Sobngwi-Tambekou et al., 2010) have been studied also the traffic safety experts (with more than 10 years of the relevant experience) working at Tehran Traffic and Transportation

Organization (TTTO) have been questioned for expressing their comments about the criteria and sub-criteria suitable for prioritising traffic calming measures. The criteria for prioritizing TCMs have been categorized into four groups including traffic impacts, safety impacts, secondary impacts and cost. In the category of traffic impacts three main sub-criteria have been accounted including the speed reduction (the impact of TCMs on reducing the 85^{th} percentile speed of vehicles), the volume reduction (the impact of the measures on cut through driving and reducing the amount of non-local traffic in residential streets) and enforcement (the level of enforcement that the measures can impose on vehicles to force them to obey traffic rules). Safety impacts divided into two sub-criteria including the pedestrian movement and the accident reduction. The pedestrian movement criterion represents the level of safety improvement provided to pedestrians crossing the streets or walking along them when a TCM is installed. Another sub-criteria is the accident reduction. In this regard, the number of accidents before and after the implementation of each traffic calming measure should be considered. The secondary impacts indicate the indirect influences of TCMs after their implementation. This criterion is divided into three sub-criteria including the impact of implementation on the air quality and environmental issues, the impact on emergency vehicles (for example how ambulances or fire truck pass streets which are equipped with traffic calming measures) and the level of public acceptance after traffic calming measure are installed. The last criterion is the cost which is divided into initial cost and maintenance cost. Initial cost represents the amount of budget needed for constructing TCMs and maintenance cost represents the cost needed for repairing and renovating the measures after their installation. Alternatives are traffic calming measures which have been selected from the literature review section. In Figure 3 the hierarchical structure of the prioritizing TCMs is depicted. As shown in this figure, the first level represents the criteria considered in the prioritising. The second level represents the sub-criteria and the last one represents alternatives or traffic calming measures.

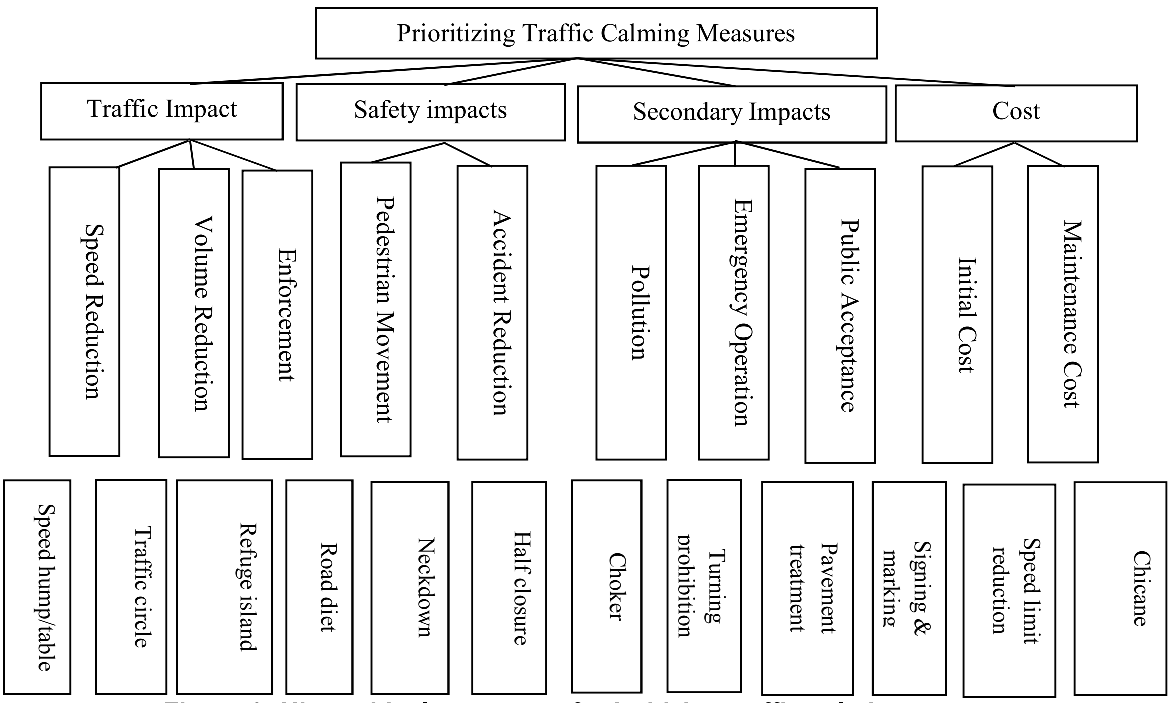

Figure 3: Hierarchical structure of prioritizing traffic calming measures

5. Numerical example and results

For prioritizing TCMs in residential areas four decision makers (D1, D2, D3 and D4) have been selected. These decision makers are traffic experts from Tehran Traffic and Transportation Organization (TTTO) with huge experience in the field of traffic safety. Dealing with traffic safety issues such as excessive speed in residential areas, pedestrian-vehicle accidents and excessive non-local traffic are among their practical experiences. All four decision makers made their judgments about the prioritization of TCMs separately so their opinions did not have effects on other ones. In Table 2, the result of judgments of decision makers for importance weights of criteria and sub-criteria are shown also the aggregated fuzzy weight of criteria and sub-criteria are shown in Table 3.

Table 2: linguistic value of importance weights for criteria and sub-criteria

Criteria and sub-criteria	Decision-maker			
	D1	D2	D3	D4
traffic impact (c1)	VH	H	H	VH
speed reduction(s11)	VH	VH	VH	H
volume reduction (cut-through) (s12)	H	H	VH	H
enforcement (S13)	H	VH	H	H
Safety (c2)	H	VH	H	VH
pedestrian movement (S21)	VH	H	MH	VH
accidents reduction(s22)	H	H	VH	H
secondary effects (c3)	H	M	H	H
Pollution controlling (s31)	H	MH	MH	H
emergency impact (s32)	M	M	MH	M
public acceptance (s33)	H	MH	M	MH
cost (c4)	H	H	VH	M
initial cost (s41)	H	MH	M	M
meintenance cost (s42)	MH	M	M	M

Table 3: the aggregated fuzzy weight of criteria and sub-criteria

Criteria and sub-criteria	Fuzzy			
c1	(0.70	0.85	0.90	1)
s11	(0.70	0.87	0.95	1)
s12	(0.70	0.82	0.85	1)
s13	(0.70	0.82	0.85	1)
c2	(0.70	0.85	0.90	1)
s21	(0.50	0.80	0.87	1)
s22	(0.70	0.82	0.85	1)
c3	(0.40	0.72	0.72	0.9)
s31	(0.50	0.70	0.75	0.9)
s32	(0.40	0.52	0.55	0.8)
s33	(0.40	0.62	0.67	0.9)
c4	(0.40	0.75	0.77	1)
s41	(0.40	0.60	0.62	0.9)
s42	(0.40	0.52	0.55	0.8)

Linguistic values for alternatives with respect to the sub-criteria by decision makers are shown in Table 4 and in Table 5 decision matrix for alternatives with respect to criteria and sub-criteria after calculating trapezoidal fuzzy numbers are shown.

Table 4: Linguistic values for alternatives with respect to the sub-criteria by decision makers

Decision maker 1	C1			C2		C3			C4	
	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
Speed Hump/Table	VG	MG	VG	MG	VG	MP	MP	MG	F	F
Traffic Circle	G	F	G	F	G	G	F	G	MP	F
Refuge island	G	F	MG	VG	G	F	F	G	P	F
Road Diet	G	MG	MG	G	G	F	F	G	P	F
Neckdown	MG	MG	F	VG	G	F	P	VG	P	F
Half Closure	F	VG	F	F	MG	F	P	G	MG	G
Choker	MG	MG	G	VG	F	F	F	G	MP	F
Prohibiting Right/Left Turn	F	VG	F	F	MG	MG	P	MG	G	G
Pavement Treatment	MG	F	MG	F	MG	F	VG	VG	P	P
Signing and Marking	F	F	MP	F	F	VG	VG	MG	G	G
Changing Speed Limit	MG	F	P	F	MG	VG	VG	F	G	G
Chicane	MG	F	G	G	F	F	MP	G	F	G
Decision maker 2	C1			C2		C3			C4	
	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
Speed Hump/Table	VG	G	VG	F	VG	P	P	G	MP	MP
Traffic Circle	MG	MG	MG	F	MG	MG	MG	VG	P	MP
Refuge Island	MG	F	F	VG	F	F	F	VG	MP	P
Road Diet	MG	G	F	G	G	F	F	G	P	F
Neckdown	MG	F	F	G	G	F	F	G	P	P
Half Closure	F	VG	G	F	MG	F	P	G	MG	G
Choker	MG	MG	G	G	MG	F	P	MG	MP	F
Prohibiting Right/Left Turn	F	MG	MP	MG	F	F	P	F	G	G
Pavement Treatment	MG	P	F	MG	F	G	VG	VG	MP	P
Signing and Marking	P	P	MP	F	F	VG	VG	F	G	VG
Changing Speed Limit	MG	MG	VP	F	MG	VG	VG	MG	G	G
Chicane	G	MG	G	F	P	MP	P	F	MP	F
Decision maker 3	C1			C2		C3			C4	
	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
Speed Hump/Table	VG	MG	VG	MG	G	VP	VP	MG	MP	MP
Traffic Circle	G	MG	VG	F	MG	MG	F	G	MP	F
Refuge island	MG	MG	F	VG	P	F	F	G	P	F
Road Diet	MG	MG	G	MG	F	F	P	G	MP	MP
Neckdown	MG	MG	G	G	F	F	P	MG	MP	F
Half Closure	F	MG	G	P	F	F	VP	MG	MG	G
Choker	G	MG	G	VG	MG	P	VP	G	MP	MP
Prohibiting Right/Left Turn	F	G	G	F	P	F	P	F	VG	VG
Pavement Treatment	G	P	G	F	F	MG	VG	VG	MP	MP
Signing and Marking	F	P	P	F	F	VG	VG	F	VG	VG
Changing Speed Limit	G	F	P	F	F	VG	VG	G	F	F
Chicane	F	F	G	G	MP	F	P	G	MP	G
Decision maker 4	C1			C2		C3			C4	
	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
Speed Hump/Table	VG	VG	VG	MG	MG	F	MP	MP	F	MP
Traffic Circle	G	MG	G	MG	MG	F	F	G	F	F
Refuge island	G	MG	F	VG	MG	F	F	F	P	P
Road Diet	G	MG	G	G	F	F	F	VG	P	MP
Neckdown	G	MG	G	VG	F	F	MP	G	P	MP
Half Closure	MG	VG	G	MG	MG	F	VP	G	F	G
Choker	G	G	G	VG	G	F	P	F	MP	MP
Prohibiting Right/Left Turn	MP	VG	F	G	MG	F	F	F	VG	VG
Pavement Treatment	MG	F	F	F	F	F	F	G	P	P
Signing and Marking	P	MP	MP	MP	F	VG	VG	G	G	VG
Changing Speed Limit	F	F	P	F	MG	VG	VG	VG	VG	VG
Chicane	G	F	G	G	MP	F	P	G	MP	G

Table 5: calculated decision matrix for alternatives with respect to criteria and sub-criteria

Criteria	C1			C2		C3			C4	
	0.87			0.87		0.70			0.74	
Sub-criteria	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
weight	0.89	0.84	0.84	0.81	0.84	0.72	0.56	0.65	0.63	0.56
Speed Hump/Table	0.73	0.56	0.70	0.43	0.59	0.14	0.10	0.27	0.19	0.16
Traffic Circle	0.58	0.45	0.59	0.39	0.56	0.26	0.16	0.37	0.16	0.18
Refuge island	0.56	0.43	0.42	0.66	0.39	0.25	0.20	0.34	0.12	0.16
Road Diet	0.56	0.51	0.51	0.52	0.48	0.25	0.16	0.39	0.12	0.17
Neckdown	0.53	0.45	0.49	0.59	0.48	0.25	0.13	0.36	0.12	0.17
Half Closure	0.43	0.61	0.53	0.32	0.45	0.25	0.05	0.34	0.28	0.33
Choker	0.56	0.51	0.60	0.63	0.48	0.20	0.10	0.31	0.16	0.17
Prohibiting Right/Left Turn	0.34	0.59	0.41	0.44	0.35	0.28	0.12	0.26	0.40	0.36
Pavement Treatment	0.54	0.26	0.47	0.39	0.41	0.32	0.31	0.41	0.13	0.11
Signing and Marking	0.27	0.24	0.23	0.31	0.37	0.47	0.37	0.29	0.39	0.37
Changing Speed Limit	0.51	0.41	0.12	0.35	0.45	0.47	0.37	0.33	0.35	0.31
Chicane	0.52	0.41	0.60	0.49	0.26	0.22	0.10	0.32	0.18	0.29

the weighted normalized decision matrix for alternatives are shown In Table 6.

Table 6: weighted normalized decision matrix for alternatives

Criteria	C1			C2		C3			C4	
Sub-criteria	S11	S12	S13	S21	S22	S31	S32	S33	S41	S42
Speed Hump/Table	0.73	0.56	0.70	0.43	0.59	0.14	0.10	0.27	0.19	0.16
Traffic Circle	0.58	0.45	0.59	0.39	0.56	0.26	0.16	0.37	0.16	0.18
Refuge island	0.56	0.43	0.42	0.66	0.39	0.25	0.20	0.34	0.12	0.16
Road Diet	0.56	0.51	0.51	0.52	0.48	0.25	0.16	0.39	0.12	0.17
Neckdown	0.53	0.45	0.49	0.59	0.48	0.25	0.13	0.36	0.12	0.17
Half Closure	0.43	0.61	0.53	0.32	0.45	0.25	0.05	0.34	0.28	0.33
Choker	0.56	0.51	0.60	0.63	0.48	0.20	0.10	0.31	0.16	0.17
Prohibiting Right/Left Turn	0.34	0.59	0.41	0.44	0.35	0.28	0.12	0.26	0.40	0.36
Pavement Treatment	0.54	0.26	0.47	0.39	0.41	0.32	0.31	0.41	0.13	0.11
Signing and Marking	0.27	0.24	0.23	0.31	0.37	0.47	0.37	0.29	0.39	0.37
Changing Speed Limit	0.51	0.41	0.12	0.35	0.45	0.47	0.37	0.33	0.35	0.31
Chicane	0.52	0.41	0.60	0.49	0.26	0.22	0.10	0.32	0.18	0.29

The positive ideal solution (A) and negative ideal solution (A^-) are given below:

A = (0.73, 0.61, 0.70, 0.66, 0.59, 0.47, 0.37, 0.41, 0.40, 0.37)

A^-= (0.27, 0.24, 0.1. 0.31, 0.26, 0.14, 0.05, 0.26, 0.12, 0.11)

In Table 7, the calculated values for distance of each alternative from A and A^- and closeness coefficient ($\bar{C}_i$) are shown. In this Table, ranking the alternatives is carried out based on closeness coefficient.

Table 7: Results for ranking the alternatives

Measures	D_i	D_i^-	$\bar{C}_i$	Ranking
Speed Hump/Table	0.59	0.89	0.60	1
Choker	0.56	0.74	0.57	2
Traffic Circle	0.56	0.71	0.56	3
Road Diet	0.57	0.67	0.54	4
Neckdown	0.60	0.64	0.52	5
Half Closure	0.65	0.68	0.51	6
Refuge island	0.63	0.62	0.50	7
Chicane	0.65	0.64	0.50	7
Prohibiting Right/Left Turn	0.68	0.64	0.49	8
Changing Speed Limit	0.75	0.65	0.47	9
Pavement Treatment	0.70	0.59	0.46	10
Signing and Marking	0.87	0.61	0.41	11

Based on the result of this study (Table 7) speed hump/table as a powerful measure is chosen with the highest priority ($\bar{C}_i$=0.60) for the purpose of traffic calming. According to Table 4, In terms of traffic impacts and safety impacts, the decision makers are satisfied with the performance of vertical measures while their impacts on environmental and emergency vehicles are not satisfactory. Similar to vertical deflections, narrowing measures and horizontal deflections measures such as choker, traffic circle and road diet are among the top-ranked measures. On the contrary, signing/marking as a measure which cannot force drivers effectively to slow down their speed in residential areas has the lowest priority ($\bar{C}_i$=0.41). Based on the comments of decision makers, it can be expressed that, the more TCMs physically force drivers to follow and obey traffic rules, the more they will be able to improve the safety and reduce vehicles' speed. It can be predicted that if these type of measures are accompanied by traffic enforcement camera or police presence, their effectiveness will increase.

6. Conclusion

Converting car-dominated residential streets into a safer, liveable and pleasant place for residents, pedestrians and cyclist is the main objective of traffic calming strategies. In this context, selecting and installing appropriate TCMs are essential tasks. In this study, based on reviewing the previous studies and consulting with the domain experts, criteria and sub-criteria suitable for prioritising TCMs are identified and selected. Four criteria and ten sub-criteria were employed to prioritise traffic calming measures. The main criteria are traffic impacts, safety impacts, secondary impacts and cost related issues. Alternatives are speed hump/table, traffic circle, centre island, pavement treatment, neck-down, half closure, choker, turning prohibition, road diet, signing/marking and speed limit reduction. Using Fuzzy TOPSIS is a good solution for decision making problem due to considering uncertainty of the real world conditions. Four senior experts in traffic safety from TTTO have participated in the decision making process. Finally speed hump/table was selected as a powerful measure for making residential areas calm and safe because of its significant impact on speed reduction and high level of enforcement by the evaluation of the decision makers. For developing future studies, involving more decision makers and considering more alternatives can be suggested. Furthermore, conducting fuzzy AHP method along with the current method and comparing the results of the both methods can improve the prioritisation process.

References

Awasthi, A., Chauhan, S.S. & Omrani, H., 2011. Application of fuzzy TOPSIS in evaluating sustainable transportation systems. *Expert Systems with Applications*, 38(10), pp.12270–12280. Available at: http://dx.doi.org/10.1016/j.eswa.2011.04.005.

Boran, F.E. et al., 2009. A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications*, 36(8), pp.11363–11368. Available at: http://dx.doi.org/10.1016/j.eswa.2009.03.039.

Chen, C.-T., 2000. Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems*, 114(1), pp.1–9. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0165011497003771.

Chen, C.T., Lin, C.T. & Huang, S.F., 2006. A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics*, 102(2), pp.289–301.

Chu, T.C., 2002. Selecting plant location via a fuzzy TOPSIS approach. *International Journal of Advanced Manufacturing Technology*, 20(11), pp.859–864.

Corkle, J., Giese, J.L. & Marti, M.M., 2002. *Investigating the Effectiveness of Traffic Calming Strategies on Driver Behavior, Traffic Flow and Speed*, Minnesota.

Elvik, R., 2001. Area-wide urban traffic calming schemes: A meta-analysis of safety effects. *Accident Analysis and Prevention*, 33(3), pp.327–336.

Ewing, R., 2000. Traffic calming liability issues. In *ITE Annual Meeting and Exhibit*. Washington: Institute of Transportation Engineers.

Huang, I.B., Keisler, J. & Linkov, I., 2011. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment*, 409(19), pp.3578–3594. Available at: http://dx.doi.org/10.1016/j.scitotenv.2011.06.022.

Karimi, a R. et al., 2011. Using of the Fuzzy Topsis and Fuzzy Ahp Methods for Wastewater Treatment Process Selection. , 3(1), pp.737–745.

Mormilo, S., 2016. *Alaska traffic calming manual*, Anchorage.

Şengül, Ü. et al., 2015. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renewable Energy VO - 75*, (C), p.617. Available at: http://www.sciencedirect.com/science/article/pii/S0960148114006727 [Accessed September 17, 2017].

Zadeh, L.A., 1997. Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. *Fuzzy Sets and Systems*, 90(2), pp.111–127. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0165011497000778.

Biddulph, M. (2010). Evaluating the English Home Zone Initiatives. Journal of the American Planning Association, 76(2), 199–218. http://doi.org/10.1080/01944361003622688

Koorey, G., & Mao, J. (2010). Investigating and Modeling the Effects of Traffic Calming Devices. IPENZ Transportation Group Conference, 15.

Lee, G., Joo, S., Oh, C., & Choi, K. (2013). An evaluation framework for traffic calming

measures in residential areas. Transportation Research Part D: Transport and Environment, 25, 68–76. http://doi.org/10.1016/j.trd.2013.08.002
Nadesan-Reddy, N., & Knight, S. (2013). The effect of traffic calming on pedestrian injuries and motor vehicle collisions in two areas of the eThekwini Municipality: A before-and-after study. South African Medical Journal, 103(9), 621–625. http://doi.org/10.7196/SAMJ.7024
PennDOT. (2012). Pennsylvania Traffic Calming Manual. Pennsylvania.
Sobngwi-Tambekou, J., Bhatti, J., Kounga, G., Salmi, L. R., & Lagarde, E. (2010). Road traffic crashes on the Yaounde-Douala road section, Cameroon. Accident Analysis and Prevention, 42(2), 422–426. http://doi.org/10.1016/j.aap.2009.09.003
Pharaoh, T., & Russell, J. (1989). Traffic calming: Policy and evaluations in three European countries. London, UK: Department of Planning, Housing and Development, Faculty of the Built Environment, South Bank Polytechnic.