MODELLING FOR ENGINEERING & HUMAN BEHAVIOUR 2019

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Instituto Universitario de Matemática Multidisciplinar
Polytechnic City of Innovation

Edited by
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July 10th - 12th 2019

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

50 anys

CIUDAD POLITÉCNICA DE LA INNOVACIÓN

Modelling for Engineering & Human Behaviour 2019

València, 10 – 12 July 2019

This book includes the extended abstracts of papers presented at XXIst Edition of the Mathematical Modelling Conference Series at the Institute for Multidisciplinary Mathematics "Mathematical Modelling in Engineering & Human Behaviour".

I.S.B.N.: 978-84-09-16428-8
Version: 15/11/19
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This book has been supported by the European Union through the Operational Program of the [European Regional Development Fund (ERDF) / European Social Fund (ESF)] of the Valencian Community 2014-2020. [Record: GJIDI/2018/A/010].

GENERALITAT VALENCIANA
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Updating the OSPF routing protocol for communication networks by optimal decision-making over the k-shortest path algorithm

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1 Introduction

Internet routing protocols such as Routing Information Protocol (RIP) pre-compute all the shortest paths by Dijkstra's algorithm (shortest path first, SPF) based on the number of hops between one node and another. Every time any communication is intended, RIP looks-up for the optimal choice in a routing table. This is a high speed method in the decision-making process but not necessary fast for data traffic as it does not take into account any real-time measure of route congestion. Open Shortest Path First (OSPF) presents a dynamic version of this problem by computing the shortest paths taking into account network features such as bandwidth, delay and load. OSPF thereby maintains link-state databases updated at near real-time at every router. Although OSPF protocol is widely used, the Enhanced Interior Gateway Routing Protocol (EIGRP) presents another option for taking the optimal routing. At EIGRP, each node independently runs an algorithm to determine the shortest path (Dijkstra's algorithm) from itself to every other node in the network. In addition to the routing table, EIGRP uses neighbour information (neighbour nodes on node j are those having directly connection node$_j$) and a table of favourite (commonly used) routes.

In this context, a multi-criteria decision-making (MCDM) approach may represent an alternative perspective for the automatic selection of an optimal path among the k-shortest paths.

MCDM methods effectively support a plethora of decision problems, their crucial role being widely acknowledged [8]. With respect to routing protocols in communication networks, a final decision on selecting the optimal path depends on various evaluation criteria. These sometimes are mutually dependent and conflicting with each other. This is the case of criteria such as traffic density, path length, data type, and key performance indicators. Under such criteria,

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the objective is to ultimately select one path among the k-shortest paths. MCDM methods have the ability of going towards the solution that represents a best trade-off for the selected network intends and satisfies their multiple aspects regarding their mutual importance. MCDM are capable of managing both qualitative and quantitative aspects when it is required an evaluation concerning a set of alternatives [10]. Several MCDM methods have been proposed in the existing literature, each one being characterised by specific procedures and objectives. However, common points for MCDM methods are that they can be mainly aimed at: selecting the best option among various alternatives, ranking alternatives to establish their weights and/or to draw up a list of priorities [11], and clustering alternatives into different groups on the basis of their common features [3].

Among MCDM methods, the fuzzy evolution of the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), that is the FTOPSIS [4] method, is herein proposed to get the ranking of the possible k-paths related to a communication network according to the evaluation of suitable criteria and to simultaneously take into account uncertainty affecting input data as it is, for instance, the traffic density.

2 Existing approaches

The literature on routing protocols is commonly focused on protective strategies for communication networks [1]. This is the case of the creation of dedicated or shared backup networks among multiple connections [6] that provide spare capacity to a communication network and that allow to put in practice either reactive and proactive restoration schemes [7]. Using routing protocols based on k-shortest paths [5] instead of the single Dijkstra's algorithm (like in OSPF) is an alternate way to protect the communication network from disruptions [9]. Working with the k-shortest paths also enhances the adaptation capability of the network with respect to variations in the traffic density, not necessary facing disruption but with the objective of higher speed of data packets travelling through the network.

An interesting alternative to the Eppstein k-shortest paths algorithm is the loop-less approach which uses $k-1$ deviations of the main Dijkstra's shortest path. This was firstly developed by Yen [12] and has been successfully adapted further to communication networks [2]. The algorithm encompasses two main steps: determining the first of the k-shortest path, and then determining all other k-shortest paths. It is used an auxiliary matrix working as a container for the candidates to k-shortest paths and from which it is selected the minimum length path in an iterative process.

3 The FTOPSIS to rank the possible k-paths

As already expressed in the introduction, final decisions about the shortest path depend on evaluation criteria such as traffic density, path length, data type and key performance indicators. These often are interdependent and sometimes conflicting with each other.

Being the FTOPSIS technique the fuzzy evolution of the TOPSIS method, it allows to better represent practical real-life situations, since eliciting exact crisp numerical values may be difficult. Indeed, the TOPSIS ranks alternatives just on the basis of their crisp ratings on various qualitative and/or qualitative criteria, opportunely weighted.

The steps required to apply the FTOPSIS method are synthesised in Figure 1.

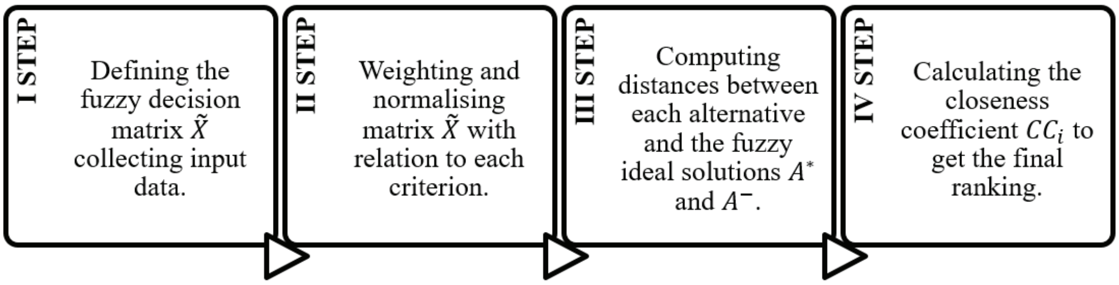

Figure 1: Steps representing the FTOPSIS procedure.

I STEP: defining the fuzzy decision matrix $\tilde{X}$ collecting input data.
It is firstly necessary to collect all the evaluations of the alternatives in the fuzzy decision matrix (Table 1):

$$\tilde{X} = \begin{bmatrix} \tilde{X}_{11} & \dots & \tilde{X}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \dots & \tilde{X}_{mn} \end{bmatrix}, \tag{1}$$

The generic fuzzy number $\tilde{x}_{ij}$ represents the rating of alternative i under criterion j. In the present case, we take into account triangular fuzzy numbers (TFNs), characterized by ordered triples:

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \tag{2}$$

	DECISION MATRIX											
	Traffic Density (min)			**Path Lenght (min)**			**Data Type (max)**			**Network Features (max)**		
	25%			**25%**			**25%**			**25%**		
Path 1	a_{11}	b_{11}	c_{11}	a_{12}	b_{12}	c_{12}	a_{13}	b_{13}	c_{13}	a_{14}	b_{14}	c_{14}
Path 2	a_{21}	b_{21}	c_{21}	a_{22}	b_{22}	c_{22}	a_{23}	b_{23}	c_{23}	a_{24}	b_{24}	c_{24}
Path 3	a_{31}	b_{31}	c_{31}	a_{32}	b_{32}	c_{32}	a_{33}	b_{33}	c_{33}	a_{34}	b_{34}	c_{34}
Path 4	a_{41}	b_{41}	c_{41}	a_{42}	b_{42}	c_{42}	a_{43}	b_{43}	c_{43}	a_{44}	b_{44}	c_{44}
Path 5	a_{51}	b_{51}	c_{51}	a_{52}	b_{52}	c_{52}	a_{53}	b_{53}	c_{53}	a_{54}	b_{54}	c_{54}
Path 6	a_{61}	b_{61}	c_{61}	a_{62}	b_{62}	c_{62}	a_{63}	b_{63}	c_{63}	a_{64}	b_{64}	c_{64}
Path 7	a_{71}	b_{71}	c_{71}	a_{72}	b_{72}	c_{72}	a_{73}	b_{73}	c_{73}	a_{74}	b_{74}	c_{74}
Path 8	a_{81}	b_{81}	c_{81}	a_{82}	b_{82}	c_{82}	a_{83}	b_{83}	c_{83}	a_{84}	b_{84}	c_{84}
Path 9	a_{91}	b_{91}	c_{91}	a_{92}	b_{92}	c_{92}	a_{93}	b_{93}	c_{93}	a_{94}	b_{94}	c_{94}

Table 1: Fuzzy Decision Matrix $\tilde{X}$.

II STEP: weighting and normalising the previously defined matrix with relation to each criterion. The second step of the procedure consists in obtaining a matrix $\tilde{U}$ by weighting and normalising matrix $\tilde{X}$. In particular, elements of matrix $\tilde{U}$ are defined as follows:

$$\tilde{u}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \cdot w_j, \;\; j \in I', \tag{3}$$

$$\tilde{u}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \cdot w_j, \;\; j \in I'', \tag{4}$$

where I' is the subset of criteria to be maximized, I'' is subset of criteria to be minimized, w_j represents the relative importance weight of criterion j, c_j^* and a_j^- are calculated as:

$$c_j^* = \max_i c_{ij} \;\; if \;\; j \in I', \tag{5}$$

$$a_j^- = \min_i a_{ij} \;\; if \;\; j \in I''. \tag{6}$$

III STEP: computing distances between each alternative and the fuzzy ideal solutions A^* and A^-. At the present stage, each fuzzy alternative has to be compared with both a fuzzy positive ideal solution A^* and a fuzzy negative ideal solution A^-, namely:

$$A^* = (\tilde{u}_1^*, \tilde{u}_2^*, \ldots, \tilde{u}_n^*), \tag{7}$$

$$A^- = (\tilde{u}_1^-, \tilde{u}_2^-, \ldots, \tilde{u}_n^-), \tag{8}$$

where $\tilde{u}_j^* = (1,1,1)$ and $\tilde{u}_j^- = (0,0,0)$, $j = 1 \ldots n$. In detail, distances between each alternative and these points are computed through the vertex method [4], for which the distance $d(\tilde{m}, \tilde{n})$ between two TFNs $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ is the crisp value:

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}. \tag{9}$$

Then, aggregating with respect to the whole set of criteria, the related distances of each alternative i from A^* and A^- are:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{u}_{ij}, \tilde{u}_j^*), \;\; i = 1 \ldots n, \tag{10}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{u}_{ij}, \tilde{u}_j^-), \;\; i = 1 \ldots n. \tag{11}$$

IV STEP: calculating the closeness coefficient CC_i to get the final ranking. The mentioned closeness coefficient CC_i is calculated as:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \tag{12}$$

To get the final ranking it is necessary to sort the values of the closeness coefficient related to each alternatives in a decreasing way. That means the path with a higher value of CC_i will be selected.

4 Conclusions

The research deals with the topic of internet communication networks and it is focused on the problem of selecting the shortest path among the possible k-paths. Various existing protocols are capable to compute this kind of selection by taking into account networks features and a multi-criteria decision making approach has been herein proposed as alternative way to sort such problem out. The FTOPSIS technique appears to be suitable because of its capability to rank even a huge number of options. The FTOPSIS makes use of fuzzy numbers instead of crisp ones, so that uncertainty affecting input data can effectively be managed, and the final decision circa the shortest paths is taken by assigning different degrees of importance to those criteria of interest for the problem under analysis. The immediate benefits of the FTOPSIS over the k-shortest paths are the improvement on network protection strategies for abnormal scenarios as well as the speed up of network data-traffic under regular conditions.

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