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Finding Viable Pollution Routes in an Urban Network under a Predefined Cost

Dimitra Alexiou, Stefanos Katsavounis, Ria Kalfakakou

Abstract**—**In an urban area the determination of transportation routes should be planned so as to minimize the provoked pollution taking into account the cost of such routes. In the sequel these routes are cited as pollution routes.

The transportation network is expressed by a weighted graph $G=(V,E,D,P)$ where every vertex represents a location to be served and E contains unordered pairs (edges) of elements in V that indicate a simple road. The distances / cost and a weight that depict the provoked air pollution by a vehicle transition at every road are assigned to each road as well. These are the items of set D and P respectively.

Furthermore the investigated pollution routes must not exceed predefined corresponding values concerning the route cost and the route pollution level during the vehicle transition.

In this paper we present an algorithm that generates such routes in order that the decision maker selects the most appropriate one.

Keywords**—**bi-criteria, pollution, shortest paths.

I. Introduction

POPULATION exposure to air pollution [1], [3] is a critical component with negative impact to health issues due to industrial settlement close to inhabited urban area. Therefore the transportation that can deteriorate the pollution of the environment should be planned so as to minimize the provoked pollution and the adverse health consequences on the population located nearby the transition routes.

While determining routes it is evident to take into account certain parameters concerning the transition time or the corresponding cost.

To each road of the network two weights are assigned, representing its vehicle transition cost and its air pollution level exposure (APE), [3] respectively.

Conclusively, we have to solve a bi-criteria problem [4]. Next Section is dedicated to an analytical formulation of the stated problem. Section III is devoted to the presentation of a procedure that applies the speculations referred in Section II. Section IV gives a relevant small numerical example. The conclusions are the content of the last section.

Dimitra Alexiou is with Dept. of Spatial Planning and Development Engineering, School of Engineering, Aristotle University of Thessaloniki, Greece (phone:00306937163380, e-mail:dimitraalexiou@plandevel.auth.gr).

Stefanos Katsavounis is with Dept. of Production & Management Engineering, School of Engineering, Demokritos University of Thrace, Greece.

Ria Kalfakakou is with Dept. of Civil Engineering, School of Engineering, Aristotle University of Thessaloniki, Greece.

II. Problem Formulation

The transportation network is expressed by a weighted graph $G=(V,E,T,P)$ where every vertex represents a location to be served and E contains unordered pairs (edges) of elements in $V=(v_1,v_2,\dots,v_n)$ that indicate a simple road. The distances / cost and a weight that depict the provoked pollution by a vehicle transition at every road are assigned to each road as well. These are the items of set $D=\{d_{i,j},(i,j)\in E\}$ and $P=\{p_{i,j},(i,j)\in E\}$ respectively.

The problem presented here generates all viable routes under a predefined route cost for any given pair of vertices $(S,T)\in V$ of a network that correspond to an urban area, where S is the source and T the destination vertex. We say that a route is viable if the sum of the provoked pollution level of its roads does not surpass a predefined summative pollution value, such a route is a feasible route [2].

Let $SD(x,y)$ and $SP(x,y)$ be the value of the shortest paths from x to y for every pair $(x,y)\in V, x\neq y$ concerning the weights assigned to the edges of E as to the transit cost and to the provoked pollution separately [3]. A route is a set $R=\{r_1,r_2,\dots r_{n_r}\}$ of ordered adjacent vertices of G. The route cost is $sumr=\sum_{i=1}^{n_r-1}D(r_i,r_{i+1})$ and the associated pollution is $sump=\sum_{i=1}^{n_r-1}P(r_i,r_{i+1})$. The predefined maximum allowable route cost of a route R and the corresponding pollution route gravity are the values of $Mroute$ and $Mpol$, obviously the following relation must be verified.

$$Mroute > SD(x,y) \text{ and } Mpol > SP(x,y) \qquad (1)$$

Next section is dedicated to the proposed algorithm we named FVP that applies the above analysis in order to Find Viable Pollution routes in an urban network under predefined cost and pollution level exposure.

III. Procedure FVP

F : Set that contains the vertices included at a current stage in a partial route.

$\Gamma(v)$: Set containing the adjacent vertices of v.

$Q(v)$: Set that contains the adjacent vertices of v not contained in a partial route at a current stage.

n_r : Number of vertices included in a partial route R at a current stage.

The items of $D=\left\{d_{i,j},(i,j)\in E\right\}$, $P=\left\{p_{i,j},(i,j)\in E\right\}$ and $R=\left\{r_1,r_2,\ldots r_{n_r}\right\}$ are placed and handled in the linear arrays D,P and R, respectively.

The routes are yielded in the order they are produced.

Insert $G=(V,E,D,P)$, Read S,T

{ Compute the square arrays SD and SP using Floyd algorithm }

$v\leftarrow S,\quad n_r\leftarrow 1,\quad Q(v)\leftarrow\Gamma(v),\quad F\leftarrow v$

$sumr\leftarrow 0,\quad sump\leftarrow 0$

DO

If $Q(v)=\varnothing$ then CALL *BACK*

Select $y\in Q(v)$

If $F=\varnothing$ then

$n_r\leftarrow n_r+1,\quad R(n_r)\leftarrow y,\quad v\leftarrow y,\quad \{y=n_r\}$

$F\leftarrow F+\{v\},\quad Q(v)\leftarrow Q(v)-\{v\}$

$sumr\leftarrow sumr+D(R(n_{r-1}),R(n_r))$

$sump\leftarrow sump+P(R(n_{r-1}),R(n_r))$

Endif

If $sumr>Mroute$ OR $sump>Mpol$

Then

CALL BACK

Else

If $v=T$ then

Write $R(i),i=1,2,\ldots,n_r,\quad SC,SG$

End if

End if

CALL *BACK*

End DO

BACK:

$n_r\leftarrow n_r-1$

If $n_r<0$ Then End

$F\leftarrow F-\{v\},\quad Q(v)\leftarrow\Gamma(v),\quad v\leftarrow R(n_r)$

$sumr\leftarrow sumr-D(R(n_{r-1}),R(n_r))$

$sump\leftarrow sump-P(R(n_{r-1}),R(n_r))$

Return

IV. Numerical Example

Procedure FVP was applied in the network shown in Fig. 1. The distances $d_{i,j}$ are denoted in italic nearby the edges (*i,j*) and next the provoked pollution $p_{i,j}$ in bold and in parenthesis. We selected routes connecting the verticew 1 and 15, s=1, T=15 for which SD(1,15) = 18 and SP(1,15) = 11. We selected the predefined allowable values Mroute and Mpol to be 25% more than the corresponding shortest paths, that is Mroute = SD(1,15)*1.25=23 and Mpol=SP(1,15)*1.25 = 14.

The viable feasible routes are shown in Table I and the relation between them are expressed with two perpendicular axes accordingly.

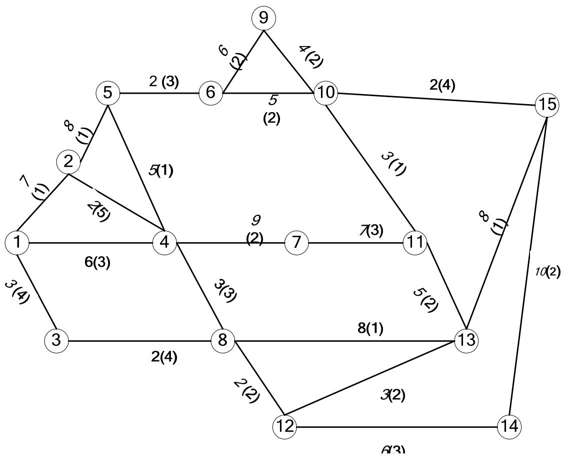

Fig. 1 Network example

Source s=1, Destination T=15

$$SD(s,T),\ Mroute,\ SP(s,T),\ \text{Mpol}$$
$$SD(s,T)=18,\ Mroute=23,\ SP(s,T)=11,$$
$$Mpol=14$$

TABLE I
VIABLE FEASIBLE ROUTES

#	Routes	Sumr	Sump
1	1 2 5 6 10 15	20	11
2	1 3 8 12 14 15	19	14
3	1 3 8 13 15	21	14
4	1 4 5 6 10 15	18	13
5	1 4 8 12 13 15	22	14
6	1 4 8 12 14 15	23	13

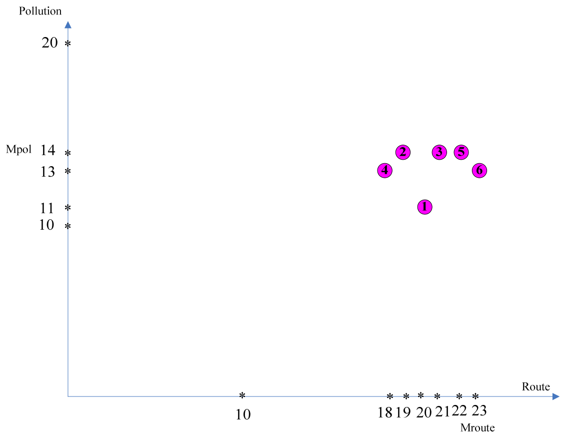

Fig. 2 Route cost vs route pollution

V. Conclusions

A brief look at Fig. 2 indicates that the decision maker will select route 1 or 4 depending on his personal preference or on the gravity he gives to the route cost opposed to the route pollution.

The bi-criteria problem presented here is an NP-hard problem [2], although in various cases the method presented here can face successively real-world practical problems if the predefined cost and pollution values are not far away from the corresponding shortest paths, for example the network of Fig. 1 gives 18 feasible routes when the related predefined values exceeds 50% the shortest path values, since greater predefined values increase significantly the number of feasible routes.

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Alexiou Dimitra, Permanent residence: 3, Argonafton St., Thessaloniki, Tel.(Mobile) 6937 163380, E-mail: alexd@tee.gr

1) STUDIES

1985:Graduate of the Model Lyceum of Zosimaia School in Ioannina.

1985-1986:Student of the Department of Civil Engineers, Polytechnic School, Aristotle University of Thessaloniki.

1998:Doctor of the Department of Civil Engineers, Polytechnic School, Aristotle University of Thessaloniki, Specialized in Mathematics.

2) EXPERIENCE

3) TEACHING

2003 up to this day:Scientific collaborator at the Department of Civil Works Infrastructure at the Higher Technological
Educational Institute of Thessaloniki in the subject of "Applied Mathematics" as an Associate Professor.

2010: Elected Lecturer at the University of Thessaloniki, School of Urban-Planning Regional and Development Engineering

4) *PUBLICATIONS (Pertaining to the of subject of Mathematics)*

"A non-linear problem for heat extraction in a technological process" (2004).
"Numerical solution of ordinary differential equations" (2005).
"Rectilinear Congruence with a priori known spherical representation" (2005).
"A multi-Criteria Mathematical programming model for Farm Regional Planning in Greece" (2006).
"Blowing-ups along exceptional curves" (2006).
"Divisors of the canonical resolutions of some singularities" (2007).
"A linear programming model for Farm Regional Planning under risk" (2007).

RESEARCH PROGRAMMES

1. "Numerical analysis of Mathematical Data", Polytechnic School of the Aristotle University of Thessaloniki
2. "Definition and solution of differential equations systems using Mathematica", Polytechnic School of the Aristotle University of Thessaloniki
3. "Mathematical problems of optimization", Polytechnic School of the Aristotle University of Thessaloniki
4. "Elaboration and solution of Mathematical problems», Polytechnic School of the Aristotle University of Thessaloniki
5. "Numerical analysis of Mathematical Data", Polytechnic School of the Aristotle University of Thessaloniki.
6. "Mathematical Data process and Mathematical models development», Polytechnic School of the Aristotle University of Thessaloniki
7. "*Development of Mathematical models",* Polytechnic School of the Aristotle University of Thessaloniki