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ENVIRONMENTAL CRITERIA AND DECISION-MAKING MODEL RELATED TO URBAN STREET NETWORK INVESTMENTS

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Abstract. This paper presents the partial results of an undergoing research project. The designed system for decision assistance in case of traffic closing/opening/restriction uses the real recorded data on environmental and users' costs. Simultaneously, the traffic flows parameters are counted. The cost functions for environmental and users' cost related to the traffic flow parameters are adjusted, in different cases of congestion level and street network state. Additional, the entrepreneur's cost functions related to street taxonomy and type of necessary works are modeled. The traffic flow assignment on the detailed modeled network and the assessment of total social cost for the entire network are the base to find the optimal solution for traffic closing/opening or restriction.

Keywords: environmental effects; users' cost; traffic closing/restriction.

1. Introduction

The present paper represents the partial results of the researches conducted by the Research Center in Transportation-University POLITEHNICA of Bucharest, funded through national budget for research activity.

The issue of planning the interventions to street infrastructure in large urban areas has stirred the scientists in transportation engineering since the years 60s of the last century. Thus, contribution provided by Ridley [1], Roberts *et al.* [2], Stairs [3] could be outlined. All planning methods revealed the difficulties of evaluating and synthesizing urban networks. The recent literature contains contributions proposed by Manoj *et al.* [4], Chen *et al.* [5], Hegazy *et al.* [6] oriented to identify modern methods and algorithms to solve scheduling infrastructures maintaining activities.

The paper analyses two divergent interests: one of the users and residents (which claim to have the shortest periods of works and the smallest environmental costs) and, on the other side – the entrepreneur interest – to have the largest works field and therefore, to have the smallest unit costs, without time (or with a little) concern.

The large amount of money to invest into the urban network infrastructure (the Bucharest case) causes a lot of pressure to the city Authority who has to choose the most valuable and cheapest works on the streets.

They must have a computer aided decision support to choose without any suspicion the winner for this kind of job, taking into consideration all the involved interests (to spend money and have a lot of streets as a building yards with many external effects, to have a lot of construction employment, to have a clean, quiet and secure urban space etc.).

The paper has the following sections – the second one – to show the peculiarities of transport infrastructure assessments; section three- dedicated to the environmental effects mandatory to be quantified, in any transport infrastructure planning process; section four – some of the working strategies for transport infrastructure staggering in a large urban areas, section five – computer aided decision support structure, for the infrastructure works decision assistance. We present also in a final section the most important conclusions.

2. Peculiarities and hierarchy of investment projects in transport infrastructures

Investments assessment is crucial for transport planning and strategies.

Usually, investments are:

- long run;
- practically reversible;
- expensive;
- causing important effects on quality of life and local/regional communities development.

Investment decisions have to be thoroughly analyzed until the final decision. The most used method is the cost-benefit analysis (CBA). Mainly, the CBA trades-off among the future benefits and the present and future costs.

Thus, a hierarchy of competing projects or sub-projects could be set up or even the decision not to invest.

The investment decisions for developing transport systems are generally assumed by public bodies. Their features of public assets, sometimes difficult to be revealed, often justify this. Besides this, the future uncertainties on transport production and the high fixed costs make the private partnership in transport infrastructure extremely feeble.

Therefore, the main aspect in assessing the transport infrastructure investments regards the project contribution to the social welfare, often named social surplus. This is contrary to the profit reason, used by private owned undertakings.

The evaluation of the transport infrastructure projects is not simple.

Relevant effects of the projects have to be identified and quantified.

Different types of effects must be made comparable, so that a decision to be taken, even if some projects is excellent according to several criteria and no project dominates on all criteria.

The main purpose of the CBA is to take the decision by expressing the effects in the same unit (currency unit), so that a mitigation among different types of effects to be possible.

Transport infrastructure investments are characterized by a great variety of effects, most of them on long term and difficult to be expressed in currency units.

A special class of effects joining the transport infrastructure investments is the environmental effects.

The construction and the use of the infrastructure cause important externalities (noise, pollution, emissions etc.) that have to be integrated in a social extended evaluation.

In the modern urban areas, the long run intervention to the transport infrastructure could affect the health of the inhabitants, having remnant effects along many generations. How could the environmental externalities costs be integrated in the decision process for obtaining the social optimum? In fact, everybody needs accurate street infrastructure, but we cannot afford to pay with health and, no matter how much.

In the absence of budgetary restraints, an undertaking acting according to the maximization of the profit must adopt the investments generating positive net present value.

For public investments, the main difference consists in replacing the profit maximization by social welfare maximization as the reason in taking decision.

Transport infrastructures are covering large areas and the long run (structural) effects of the investments involve the use of sophisticated evaluation methods and reliable techniques for the decision makers.

For instance, the effects to be taken into consideration for highways investments are depicted in Table 1.

With such a great number of effects, a decision maker has many difficulties in choosing a project or in setting up their hierarchy.

Table 1. Effects of road infrastructure investments

Effects on traffic and street maintaining	Effects on the environment and land use	Regional development
- Traffic safety - Transport time - Comfort - Vehicle use costs - Maintaining - Benefits for the users	- Noise - Air pollution - Barrier effects (land fragmentation) - Water pollution - Vibrations - Visual intrusion - Environment preservation - Territorial development	- Regional economic growth - Increasing labor force accessibility - Commercial trade-off - Effects on trade, tourism and industry

CBA is the common base of the most evaluation techniques. Two weak points are often mentioned:

- the impossibility to asses shadow prices of different effects,
- the hypothesis that some effects are additive substitutes (the effects can be computed adding cent by cent).

As a result of these two weak points, some additional aspects have been developed, such traffic and costs analysis. An alternative approach is the maximization according to social objectives and not to the market values. This type of approach is quite representative.

3. Environmental effects of transport infrastructure

The externalities costs due to the infrastructure works are quite recently presented in the literature. They are mainly studied in correlation with the traffic effects in congested urban areas. Table 2 presents methods for evaluating externalities costs.

The externalities costs analyzed in project are:

- Externalities costs for the residents:
  - Land or buildings value loss due to the transport infrastructure development;
  - Turnover loss due to infrastructure works on middle term (1-2 years).

The assessment of such costs is realized by surveys at the firms' headquarters or home surveys and by comparing discounted financial data from successive census. We shall add these long terms effects to the short terms environmental costs.

The main issue raised is to associate costs of the long-term effects to the costs of the short/medium term effects.

The solution is to evaluate the time variability of the second category of effects, and to discount them in a continuum way [13].

- Environmental externalities costs:
  - air pollution costs;
  - noise pollution costs.

Table 2. Methods and techniques for evaluating externalities costs due to works on street infrastructure [7]

Monetary assessment			Approximation (estimation) techniques	
Behavior models		Non-behavior models		
Similar markets study	Dummy (imaginary) market study			
Hedonic techniques	Contingent evaluation method	Damages costs (property value loss – land, buildings…)	Prevention costs: potential defensive, to reduce potential effects, potential damages recovery	Similar costs for: protection against effects, effects reduction, damages recovery
Transport costs methods				
Household production function methods		Sickness (health) costs		

Air pollution costs are assessed through emissions sampling, using special labs and high fidelity chemical agents. The most important pollutants of the combustion engines are: carbon monoxide (CO), nitrogen oxides (NO_x) and volatile organic compounds (VOC) which are the subject of further researches that will allow the calibration of an air pollution cost function according to traffic flow.

Using the vehicles emissions level for different speeds and the unit cost for each pollutant, one can obtain the monetary cost function of the pollution for each length unit of a specific road.

The vehicles emissions function depends on fuel consumption according to the speed, and has a quadratic form[8]:

$$C_C = a - bV + eV^2 .$$

where C_c represents the fuel consumption (l/100 km) and V the vehicle speed (km/h).

The emissions level for each type of pollutant is directly dependent of fuel spending, and multiplying with traffic flow on a route, allows to estimate the cost function for each pollutant and traffic level in a given time unit.

The unit cost for each pollutant is analyzed in different studies [9,10] and includes the induced mortality and morbidity costs.

Thus, air pollution cost function, P_a for a traffic level Q (a.e./h) is:

$$P_a = Q(f + gF) \text{ [m.u./km×h]}$$

a, b, e, f, g are calibration factors.

Noise pollution cost is assessed by financial evaluation of damages' recovery caused by noise exceeding 50 dB. Beyond this threshold, noise becomes annoying and generates illness. Noise pollution also generates property value loss [11], depending on traffic flow, distance to transport infrastructure, number of affected houses per affected surface, average value of properties in the area.

4. The working strategies for transport infrastructure staggering in a large urban areas – the core model

The modeled users' costs function, and environmental cost function have the following form:

$$c_i^{(u,e)} = c_{0i}^{(u,e)} + \alpha_{(u,e)}\left(f_i / q_i\right)^{\beta_{(u,e)}} , \qquad (1)$$

where $c_i^{(u,e)}$ – the utilization cost, and respectively the environmental cost, per km and hour for a passenger car unit (pcu), for a certain link, i;

f_i – correspondent traffic flow, pcu/h/lane;

q_i – lane capacity, related to the street taxonomy, working type and other conditions, for a certain link, i, pcu/h/lane;

$c_{0i}^{(u,e)}$ – the free flow utilization cost, and respectively free flow environmental cost, related to the link type and capacity, pcu/h/lane;

$\alpha_{(u,e)}, \beta_{(u,e)}$ – coefficient to adjust the users' cost function and respectively environmental cost function according to the experimental values [12].

The current regulations in Romania provide public auctions for infrastructure intervening activities, having as main award criteria the total building cost per length unit. It is possible that such regulation to be presented in other European cities, but no investigation has been done in this way.

To obtain the lowest costs per length unit, it is necessary a larger working length so that the construction site opening costs to be recorded only once and the productivity (length per time unit) to increase. This represents the entrepreneur's main interest. The construction costs C_b are:

$$C_b = C_O + c_b \times l, \qquad (2)$$

where C_O represents the construction site opening costs, related to the infrastructure works type - developing, modernizing or maintenance works [13];

c_b – the unit cost per one km of infrastructure, related to the working type and productivity;

l – the auctioned length for building.

The activities scheduling can be carried out on the following schemes, each one defined by the completion periods, users' costs and building costs.

Strategy I: A route, including several links (a sequence of streets), is built by a sole entrepreneur that records only once costs for opening the construction site; the links are built subsequently till the completion of the whole route and traffic opening. Figure 1 depicts on y-axis the users' additional costs during the total traffic closing (e.g.: all three links are totally closed and simultaneously opened to traffic). In this case, C_u^I is the environmental and users' additional costs per month. We note with the same indices, u, total environmental and users' cost for month, for reasons of simplicity.

The entrepreneur's costs are given by eqn. (2), where $l = l_1 + l_2 + l_3$ represents the length of the three links.

The construction site opening costs are C_O^I. The total completion time is:

$$T^I = 1/\gamma , \qquad (3)$$

where γ represents the building productivity [km/month], considered constant for working activities of the same type.

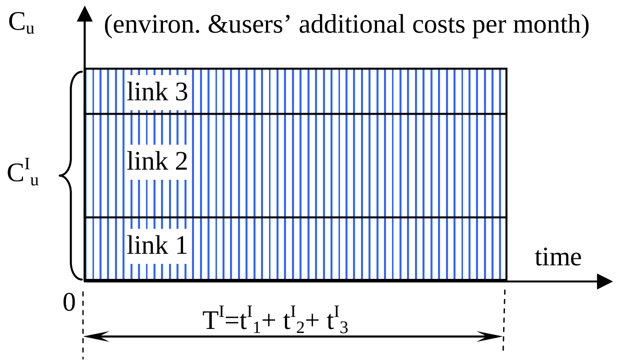

Fig 1. Environ.& users' costs for strategy I – one entrepreneur and a closed route containing a sequence of three consecutive streets

Strategy II: The same route, including three consecutive links, is completed by the same entrepreneur that opens/closes the construction site for each link subsequently. After completing the works on a street (link), this one is opened to traffic. Figure 2 shows the environmental and users' costs for the second strategy and the completion times (C_{ui}^{II} is the environmental and users' additional cost per month in case that link *i* is closed and the others are open).

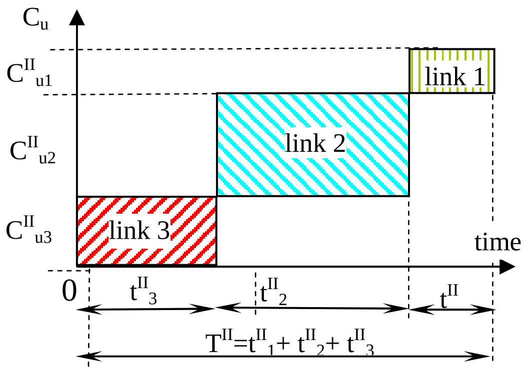

Fig 2. Environ. & users' costs for subsequently schedule of works on the route

The entrepreneur costs are:

$$\begin{aligned} C_b^{II} &= C_O^{II} + c_b l_3 + c_b l_2 + c_b l_1 = \\ &= C_O^{II} + c_b \gamma (t_1^{II} + t_2^{II} + t_3^{II}), \end{aligned} \qquad (4)$$

and $C_O^{II} > C_O^I$.

Strategy III: The works are completed simultaneously; there are three construction sites opened at the starting time (by the same entrepreneur or by three different entrepreneurs) (see Figure 3).

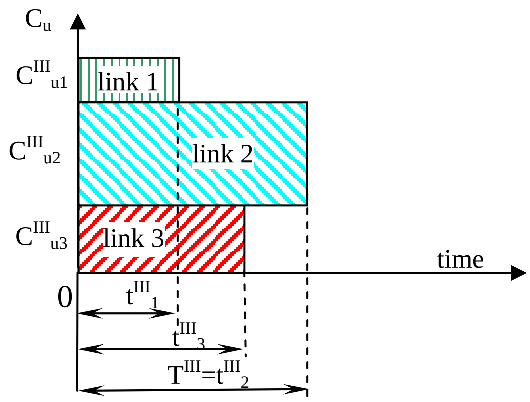

Fig 3. Environmental and users' costs for simultaneous completing of works on the links

Each street (link) is opened to traffic after the completion of works. The total building costs are:

$$\begin{aligned} C_b^{III} &= C_{O3}^{III} + c_b l_3 + C_{O2}^{III} + c_b l_2 + C_{O1}^{III} + c_b l_1 = \\ &= C_{O1}^{III} + C_{O2}^{III} + C_{O3}^{III} + c_b \gamma (t_1^{III} + t_2^{III} + t_3^{III}) \end{aligned} \qquad (5)$$

and $C_{O1}^{III} + C_{O2}^{III} + C_{O3}^{III} > C_{O1}^{II} + C_{O2}^{II} + C_{O3}^{II} > C_{O1}^{I}$.

In this model we consider constant working productivity, but usually, for some working types, a productivity enhancement could be achieved for greater working area. Because the residents, users' and entrepreneur's interests are divergent, the selection of the optimal strategy can be done taking into consideration the total social cost as the sum of the two costs (users and entrepreneur).

The completion period extends over several months or years, therefore the discount of costs is mandatory. The social costs of the presented strategies, S^I, S^{II} and respectively S^{III}, are:

$$\begin{aligned} S^I &= \sum_{t=1}^{t_1^I + t_2^I + t_3^I} \frac{C_{u1}^I + C_{u2}^I + C_{u3}^I}{(1+\Delta)^t} + \\ &+ \frac{C_O^I + c_b \gamma \left(t_1^I + t_2^I + t_3^I\right)}{(1+\Delta)^{t_1^I + t_2^I + t_3^I}} \end{aligned} \qquad (6)$$

$$\begin{aligned} S^{II} &= \sum_{t=1}^{t_3^{II}} \frac{C_{u3}^{II}}{(1+\Delta)^t} + \sum_{t=t_3^{II}}^{t_3^{II}+t_2^{II}} \frac{C_{u2}^{II}}{(1+\Delta)^t} + \\ &+ \sum_{t=t_3^{II}+t_2^{II}}^{t_3^{II}+t_2^{II}+t_1^{II}} \frac{C_{u1}^{II}}{(1+\Delta)^t} + \frac{C_O^{II} + c_b \gamma t_3^{II}}{(1+\Delta)^{t_3^{II}}} + \\ &+ \frac{c_b \gamma t_2^{II}}{(1+\Delta)^{t_3^{II}+t_2^{II}}} + \frac{c_b \gamma t_1^{II}}{(1+\Delta)^{t_3^{II}+t_2^{II}+t_1^{II}}} \end{aligned} \qquad (7)$$

$$S^{III} = \sum_{t=1}^{t_1^{III}} \frac{C_{u3}^{III} + C_{u2}^{III} + C_{u1}^{III}}{(1+\Delta)^t} + \\ + \sum_{t=t_1^{III}}^{t_3^{III}} \frac{C_{u3}^{III} + C_{u2}^{III}}{(1+\Delta)^t} + \\ \sum_{t=t_3^{III}}^{t_2^{III}} \frac{C_{u2}^{III}}{(1+\Delta)^t} + \frac{C_{O3}^{III} + c_b \varkappa t_3^{III}}{(1+\Delta)^{t_3^{III}}} + \\ + \frac{C_{O2}^{III} + c_b \varkappa t_2^{III}}{(1+\Delta)^{t_2^{III}}} + \frac{C_{O1}^{III} + c_b \varkappa t_1^{III}}{(1+\Delta)^{t_1^{III}}} \qquad (8)$$

where Δ is the discount rate.

Other strategies are also available, taking into consideration some simultaneous parts of the stages, so called mixed strategies.

We can identify how much simultaneity is appropriate, for different category of works, and different types of streets.

The total social cost (sum of users, entrepreneur and environmental cost) can be express also as a function of this simultaneity of stages. The solution will be that strategy which minimizes the total social cost.

5. Structure of the computer aided decision support to find optimal staggering of transport infrastructure works

Figure 4 depicts the scheme of the main modules of the computer aided decision support system for closing/restriction traffic, during the infrastructure works.

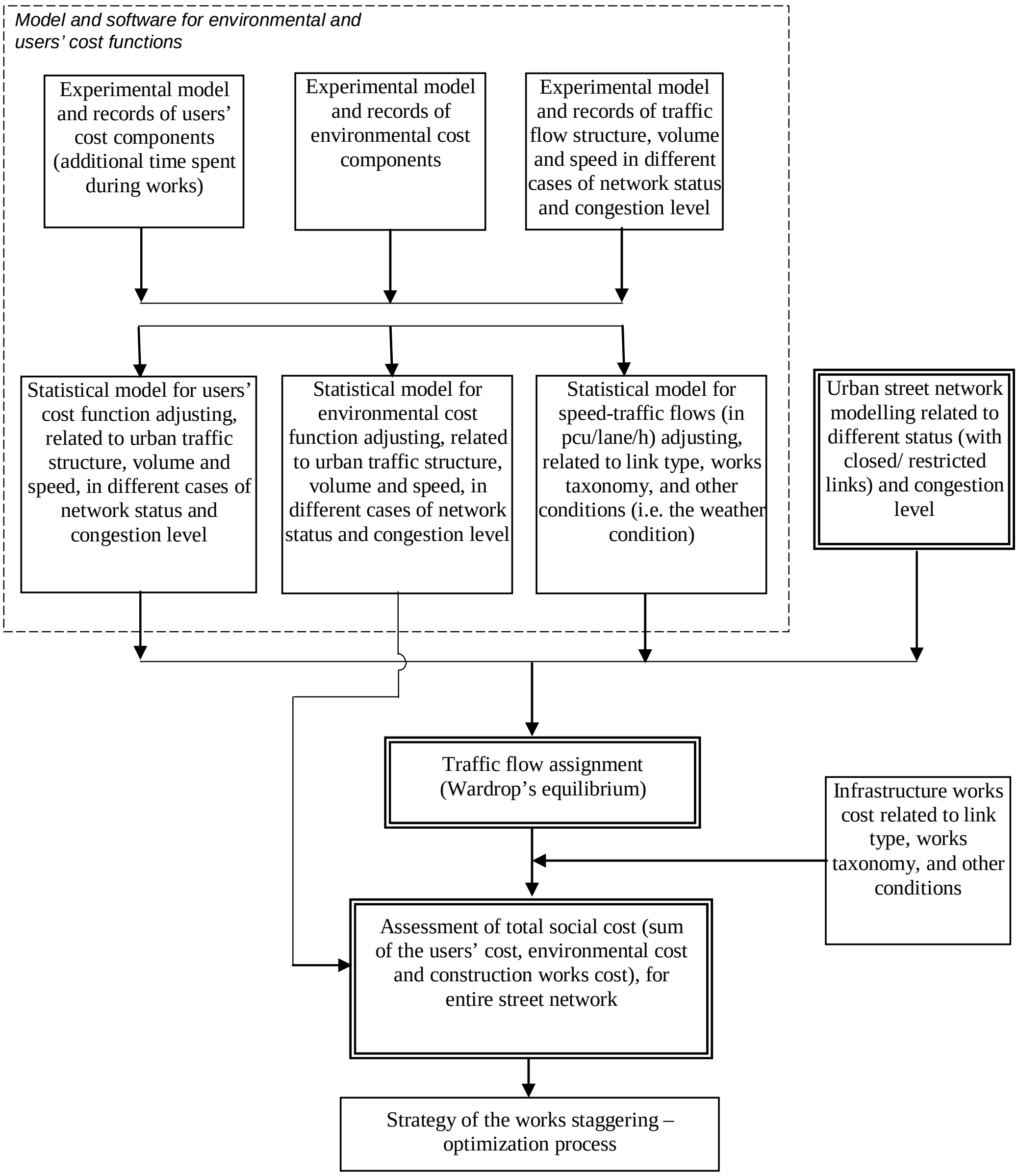

Fig 4. Computer aided decision system for traffic closing/restriction – main modules schema

We used double lines for multiple used modules. The system can be used to assist decision makers in case that there are no street infrastructure works and an entire area network must be isolated (for large social events or in case of risk area).

The main modules of the system development are:

- Experimental model design for environmental and users' effects recording, and registrations in different conditions of congestion level and network state;
- Traffic flow counting methods and equipments design, and registrations (simultaneously with the first stage);
- Statistical model for environmental and users' cost functions development, related to the traffic flows parameters, and adjusting according to registrations elements;
- Detailed street network modeling;
- Entrepreneur' cost functions related to the streets taxonomy and type of works, in a specific economic conditions;
- Traffic flow assignments, related to the different congestion levels and network state [14];
- Assessment of total social costs, to find the optimal solution for the traffic closing/opening/restriction decision.

6. Conclusions

The computer aided decision support for closing/ opening/ restraining traffic on routes in a dense urban area provides:

–Thoroughly design of the street network and socio-economic activities originating in the modeled urban area;

–Traffic flows assignment on the street infrastructure in different network state hypothesis (with works causing traffic closing/ restraining or one-way routes etc.), with Wardrop's equilibrium condition;

–Assessing of the utilization and environmental total costs for the whole urban transport network, in different hypothesis of state and utilization (traffic flows dimension);

– Optimal traffic assignment providing the minimum total cost (utilization and environmental) for all those involved (drivers, entrepreneurs, residents, public authorities) in specific street network states, and optimal planning alternatives for network infrastructure works, taking into consideration streets category from a route under construction, type of works etc., bringing the lowest utilization and environmental costs.

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