MODELLING AND MULTI-CRITERIA
OPTIMIZATION OF ROAD TRAFFIC FLOWS
CONSIDERING SOCIAL AND ECONOMIC ASPECTS

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1 Introduction

Growing mobility demand, increasingly congested traffic infrastructures, the augmenting environmental burden and the high social sensitivity in this direction make professional decision makers face bigger and bigger challenges. This phenomenon is all the more present in the field of road transport. The most recent transport policies show a clear direction ahead: the aims are to decrease oil dependence, ensure smaller and more efficient energy consumption, increase efficiency without limiting transport demand and enable the more efficient utilization of the whole transport infrastructure capacity by applying up-to-date traffic control and information systems in order to mitigate the most severe transport problems (e.g. congestion, air pollution and noise) [3]. Furthermore, transport planning has also the responsibility of taking into account the negative effects of this industry [4]. Thus, solutions need to be found which make our available tools more efficient but are at the same time capable of fulfilling the professional, political and social expectations [5, 6]. Besides, such “policy” type measures need to be applied which provide relatively cheap solutions and which can easily be introduced in practice [8].

2 Innovative approach to traffic control

These considerations led to the development of the CONTRA research project which aims to model and optimize road traffic flows as based on multi-criteria aspects, taking into account social and economic efficiency [2]. As a result of the project new flow control strategies are to be developed which, apart from the classical traffic parameters, integrate the social and economic effects of transport into the models as well. Thus, the generally applied transport control principles are extended to include costs of environmental pollution, safety and waiting times. The most up-to-date mathematical tools, traffic simulation applications and other innovative solutions were applied in the course of the research. After the development and tests on a prototype to
be realized in a subsequent research phase, the structure of the developed system will make it capable to be implemented in practice as well.

The basis of research is the control loop developed and extended along the principles outlined above and which is shown in Fig. 1.

**Fig. 1 Outline of the extended traffic control loop**

The present article endeavours to introduce in general those branches of the control circuit which take into consideration the social and economic aspects. The basic formulas of the envisaged calculations are identified, furthermore, it is analyzed how the input data needed for the control process can be produced. The authors would like to give an insight into the general methodological framework or background of the complex traffic control system integrating the principles of control theory and the main factors of social-economic considerations.

### 3 Modelling traffic parameters and their effects

The classical approach is based on traffic parameters only, here, as a new element, the increased travel times of road users caused by congestion have also been considered. This can be calculated the following way [7]:

Source: [2]
\[ MEC_{\text{congestion}} = -\frac{F}{v^2} \cdot \frac{\partial v}{\partial F} \cdot TV \]  

(1)

where

\( MEC_{\text{congestion}} \) - social marginal external costs of congestion \( \frac{\text{€}}{\text{vehicle} \cdot \text{km}} \)

\( F \) - traffic volume \( \frac{\text{vehicle}}{\text{h}} \)

\( v \) - velocity of traffic flow \( \frac{\text{km}}{\text{h}} \)

\( TV \) - value of time \( \frac{\text{€}}{\text{h}} \)

4 Modelling emissions and their effects

The environmental effect of the vehicles can primarily be accorded to the polluted exhaust gases they emit. The effects can be calculated as based on the following relationship [7]:

\[ MEC_{\text{air}} = EF \cdot \delta_{\text{air}} + FC \cdot \delta_{\text{production}} \]  

(2)

where

\( MEC_{\text{air}} \) - social marginal external costs of road traffic air pollution \( \frac{\text{€}}{\text{vehicle} \cdot \text{km}} \)

\( EF \) - emission factor \( \frac{\text{g}}{\text{vehicle} \cdot \text{km}} \)

\( \delta_{\text{air}} \) - damage factor of direct emission \( \frac{\text{€}}{\text{g}} \)

\( FC \) - fuel consumption factor \( \frac{\text{g}}{\text{vehicle} \cdot \text{km}} \)

\( \delta_{\text{production}} \) - damage factor of fuel production \( \frac{\text{€}}{\text{g}} \)

In order to incorporate the aspects outlined above into the traffic control system, the recorded data regarding the environmental categories of the Hungarian road...
vehicle fleet have to be statistically analyzed. Since there was no public database available where these data could have been extracted from, the horizontal data of the vehicle fleet of each year and the age of the vehicles was used to determine the environmental categories applicable at the time of registration. The starting point of the analysis was the state of the Hungarian vehicle fleet in 2008 (see Fig. 2).

**Fig. 2 Hungarian vehicle fleet in 2008**

![Hungarian vehicle fleet in 2008](image)

Source: [2]

In 2008 72% of the Hungarian vehicle fleet had a spark-ignition engine while 28% disposed of a compression-ignition engine, which is in line with the tendencies observed in the preceding years. The average age of the spark-ignited fleet was 8.71 years, while this index was 10.35 for their compression ignited counterparts. Otherwise, it can be stated that the car fleet is significantly younger than in the earlier years. This phenomenon can supposedly be attributed to the fact that the age of used cars imported from the member states of the European Union had decreased. The environmental categories of the road vehicle fleet as based on EUR emission norms are shown in Fig. 3-8 for private cars, buses and lorries [11].
In order to be able to estimate how the vehicle flows are distributed on the network, the connection between the recorded data and the traffic flow on the public network has been established.

As based on the first research results, the traffic performance of national and international traffic being realized on the national public network could be represented: especially on the main network elements where the dominant share of traffic flow is being realized and also, considering a city environment, on the main

Source: [11]
routes of Budapest. The EURO environmental categories of the vehicles running on
the characteristic network elements have also been determined.

The vehicle flow on the national public network shows the presumed distribution
of Table 1, grouped along the different vehicle classes, the fuel type and EURO
categories.

**Tab. 1 Annual daily traffic volumes in vehicle categories, fuel types and EURO
emission classes**

<table>
<thead>
<tr>
<th></th>
<th>Passenger car</th>
<th></th>
<th>Bus</th>
<th></th>
<th>Lorry</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 0</td>
<td>7918</td>
<td>3248</td>
<td>11167</td>
<td>14</td>
<td>220</td>
<td>244</td>
</tr>
<tr>
<td>Euro 1</td>
<td>3099</td>
<td>1083</td>
<td>4182</td>
<td>1</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Euro 2</td>
<td>5509</td>
<td>1541</td>
<td>7050</td>
<td>3</td>
<td>110</td>
<td>113</td>
</tr>
<tr>
<td>Euro 3</td>
<td>11017</td>
<td>4486</td>
<td>15503</td>
<td>1</td>
<td>149</td>
<td>150</td>
</tr>
<tr>
<td>Euro 4</td>
<td>6863</td>
<td>4072</td>
<td>10935</td>
<td>0</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Euro 5</td>
<td>1033</td>
<td>928</td>
<td>1961</td>
<td>0</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>34428</td>
<td>15319</td>
<td>49747</td>
<td>26</td>
<td>640</td>
<td>666</td>
</tr>
</tbody>
</table>

Source: [2]

The EURO categories of the different vehicle classes in case of Budapest is
distributed in the following way: it is taken into account that the economic
development of Budapest is 50% higher than the national average as based on the
GDP/capita ratio, thus the average age of the vehicles is also significantly different.
Accordingly, their environmental categories will also show a more favourable picture.
The subsequent diagrams for the different vehicle classes are based on derived data,
thus the real life data may differ from these. (The estimates are to be validated in a
later work package of the research project.) Further, it has to be noted that in case of
bus transport, the traffic of gasoline driven buses has been neglected, as bus transport
is dominated by diesel oil driven buses utilized in the public transport (Fig. 9–13).
Fig. 9-13 Share of EURO emission classes in traffic performances by vehicle categories and by fuel types

Share of EURO emission classes in traffic performances of diesel driven passenger cars

Share of EURO emission classes in traffic performances of gasoline driven passenger cars
Share of EURO emission classes in traffic performances of diesel driven buses

Vehkm/day/1000 buses

Share of EURO emission classes in traffic performances of diesel driven lorries

Vehkm/day/1000 lorries

Share of EURO emission classes in traffic performances of gasoline driven lorries

Vehkm/day/1000 lorries

Source: [2]

-77-

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5 Modelling accidents and their effects

The next branch of the control circuit is transport safety, i.e. taking into account the social and economic effects of road accidents. Accidents are one of the major external effects of transport [1]. The costs of accidents add up from the following elements: financial damage, administrative costs, medical costs, loss in production and value of risks.

\[
MEC_{\text{accident}} = \sum_{j} \sum_{i} \frac{NC_{i,j}}{P_i} \cdot MVA_j \cdot (1 - \tau) \cdot \varepsilon_{\text{risk}}
\]

where

- \( MEC_{\text{accident}} \) - social marginal external costs of accidents \( \left[ \frac{\varepsilon}{\text{vehicle} \cdot \text{km}} \right] \)
- \( NC_{i,j} \) - number of injuries by vehicle type \( i \) and injury type \( j \) \([-]\)
- \( P_i \) - traffic performance by vehicle type \( i \) \( \left[ \text{vehicle} \cdot \text{km} \right] \)
- \( MVA_j \) - monetary value of accident type \( j \) \( \left[ \varepsilon \right] \)
- \( \tau \) - coefficient \([-]\)
- \( \varepsilon_{\text{risk}} \) - risk elasticity \([-]\)

The factors mainly determining the costs are the number and the severity of accidents. Monetary cost data can be attained from the statistics of insurance companies and medical institutions. Loss of production and the value of risks can be deduced from internationally accepted norms knowing the number and the severity of accidents. One part of the transport accident costs is external to the transport sector (it is born by the society) and principally these external cost items are to be considered from the point of view of social pricing.

Regarding the cost elements of accidents, the value of risks is non-monetary while the rest are monetary factors. Naturally, the evaluation of the non-monetary factors poses the bigger problem, where, ideally, different modelling and preference revealing methods are to be applied or, as a substitutive solution, the widely accepted international values are to be adapted to the national circumstances (see Table 2).
Tab. 2 Elements of accident costs and their valuation methods

<table>
<thead>
<tr>
<th>Cost elements</th>
<th>First-best valuation</th>
<th>Substitute (second-best) valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property damage costs</td>
<td>Based on insurance data</td>
<td>Calculated based on average costs and number of accidents</td>
</tr>
<tr>
<td>Administrative costs</td>
<td>Based on police data and other statistics</td>
<td>Calculated based on average costs and number of accidents</td>
</tr>
<tr>
<td>Medical costs</td>
<td>Recorded costs of medical appointment</td>
<td></td>
</tr>
<tr>
<td>Production losses</td>
<td>Monetary value of loss of human resource from production (in function of salary, duration, substitution, etc.)</td>
<td>Derived from Value of Statistical Life in the ratio of GDP</td>
</tr>
<tr>
<td>Risk costs</td>
<td>Based on Stated Preference techniques</td>
<td></td>
</tr>
</tbody>
</table>

Source: [9]

6 Conclusion

The statistical analysis of the road vehicle fleet in Hungary has covered the size, the composition and environmental categories of the national vehicle fleet. As based on these results, it has become possible to provide input data to the traffic model regarding the environmental (EURO) categories of the Hungarian vehicle fleet. Beside the environmental characteristics of the recorded vehicle fleet, it is necessary to know the composition of the national traffic flow and also the spatial and time-based distribution of national and, where it is observable in the performances, international traffic.

In the related analyses the traffic composition was investigated along two dimensions: with regard to the high speed network representing the core of the national public network, and at the main routes of Budapest, representing the road network in a city environment. Thus, it has become possible to integrate the environmental data of the recorded vehicle fleet into a dynamic model.
A much emphasized task of the traffic model is to incorporate the social and economic effects of the traffic flow into the decision making process, thus, as part of the research project, the most characteristic social and economic specific costs (arising due to congestion, accidents and emissions) as related to transport performance have been determined. Essential conclusion of the present phase of research is that the input parameters of the drafted theoretic control circuit can be produced and it is justified to further analyze the concept [10].

This work is connected to the scientific program of the "Development of quality-oriented and harmonized R+D+I strategy and functional model at BME" and “Modelling and multi-objective optimization based control of road traffic flow considering social and economical aspects” projects. These projects are supported by the New Széchenyi Plan (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002) and by program CNK 78168 of OTKA.

References


This article deals with an innovative road traffic control model, considering also social and economic aspects. The approach tends to meet the latest policy, social and environmental requirements, therefore it contributes to cutting back and to making more predictable and reliable travel times, to reducing environmental impacts of road traffic and to enhancing road safety. The authors outline the planned control model. They sketch the theoretical correlations between real processes and their economic impacts, and derive the required input parameters for the advanced control policy.

Key words

Traffic control, travel time, environmental pollution, road safety

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