BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
DEPARTMENT OF TRANSPORT ECONOMICS
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# THEORETICAL FOUNDATION OF USAGE BASED PRICE SETTING ON THE HUNGARIAN ROAD NETWORK

**Ph.D. theses**

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# 1. HISTORY AND RELEVANCY OF THE RESEARCH TOPIC

In the past years the integration process of the European Union has speeded up considerably, which brought up more and more problems to be solved. Among these problems, one of the most relevant areas is transportation. The 10% share of GDP spent to transport expenditures in EU and the more than 10 millions employees highlight relevancy of the sector. Problems and their management in road transport have priorities based on the sector's economic and social relevancy, especially service and production processes, furthermore carrying out and managing social contacts.

The economic and political significance of the European region underline the need of appropriate methodological foundation for managing related problems. The required continuous economic growth infers inseparably the similar in transport needs, especially in road transport. The increasing user needs have to be satisfied by elements of the Trans-European Network and of the national networks. Although EU member countries prefer decoupling of transport needs from economic growth, the road transport remains the dominant sector in transportation.

The top-level decision making bodies of the EU – recognising increased relevancy of problems in road transport – are preparing an optimal transportation system for decades. The process has not been finished yet, the creation of full hierarchical road infrastructure system seems the most relevant problem to be solved. There is a strict correlation between the economic growth and the quality of transportation system. The significant corresponding financial requirements incline the decision makers re-engineering the current financial techniques.

The deteriorating transport conditions caused by stable increasing mobility needs and the growing funding requirements for developing, operating and maintaining transport infrastructure carried out substantive changes in common and national transport policies, where creating an efficient and sustainable road transport system is of primary importance. Nevertheless, this procedure is in need of long-term financial solution. Creation of self-financing and self-supporting road infrastructure system by increasing share of direct user payments in funding has priority. These questions have to be answered more and more critic within toll policy regimes.

# 2. OBJECTIVES

Aim of this Ph.D. dissertation is founding an efficient and usage based road pricing system theoretically, especially in the Central and Eastern European region with specialities. To reach the aim there is need of further view-points in broader aspects. Among these the most important ones from the Common Transport Policy are:

- ensuring sustainable (economic) growth,
- ensuring sustainable transportation system.

Another pole in setting research aspects is infrastructure user charging policy within the transport policy. Considering the conception of European Commission, the following principles are of primary importance:

- "polluter pays" principle (depending on degree of pollution),
- making financial transparency,
- re-structuring the transport modal-split,
- decoupling increasing mobility needs from economic growth.

Keeping all principles above in mind, there is an instant need of creating efficient and equal transport pricing. These efforts – together with rationalising the current systems and increasing their efficiency – provide facilities for a sustainable financial technique in the transportation.

# 3. APPLIED RESEARCH METHODS

The research applied a wide range of classic research methods according to the previously defined aim. From these the most important ones are structured textual analyses and corresponding benchmarking analyses, game-theoretic concepts for strategy optimisation based on theories of normative economics, furthermore other enhanced methods for adaptation and simulation, tests and models adopted to economic regulatories.

Based on international and domestic scientific literature the author revealed and appraised theoretical background, methods and concepts for calculation and setting user prices on road infrastructure. Domestic research papers and EU funded research projects' results ground for researching foreign scientific literature. Among these the most relevant ones are national studies from United Kingdom, Germany and Austria, and publications of Rothengatter and Doll, additionally the UNITE (UNITE (Unification of Accounts and Marginal Costs for Transport Efficiency) and the MC-ICAM (Marginal Cost Pricing in Transport - Integrated Conceptual and Applied Model Analysis) projects. Domestic publications of primary importance have been written by Tánczos and Bokor (based on EU funded projects' results), furthermore Timár, Bakó, Gáspár, Keleti and Orosz.

The part of researching scientific literature was building in EU funded projects' results carried out by the author in the last 3 years, where projects are among others: TIPP (Transport Institutions in the Policy Process), SPECTRUM (Study of Policies regarding Economic instruments Complementing Transport Regulation and the Undertaking of physical Measures), IMPRINT-EUROPE and IMPRINT-NET (Implementing Pricing Reform in Transport Networking) and GRACE (Generalisation of Research on Accounts and Cost Estimation).

Reviewed new approaches in the dissertation, methods applied in the European practice, developed and enhanced adaptation methods are based results of the author as member of the research workshop. All results were supervised by experts of related research networks and EC officers in detail.

The dissertation – processing and structuring theoretical approaches and state-of-the-art application experiences – compares and appraises distinctions of costing and pricing theories and toll policy implementations. These procedures lead to set of dynamic strategy planning tools, which is able to manage properly the social and economic specialities of different regions. Towards the author analysed concluding the applied pricing systems in the international practice and worked out the usage based price setting mechanism on the Hungarian road network. The applied mathematical methods (linear programming, game-theory, dynamic programming, etc.) opened the door to set

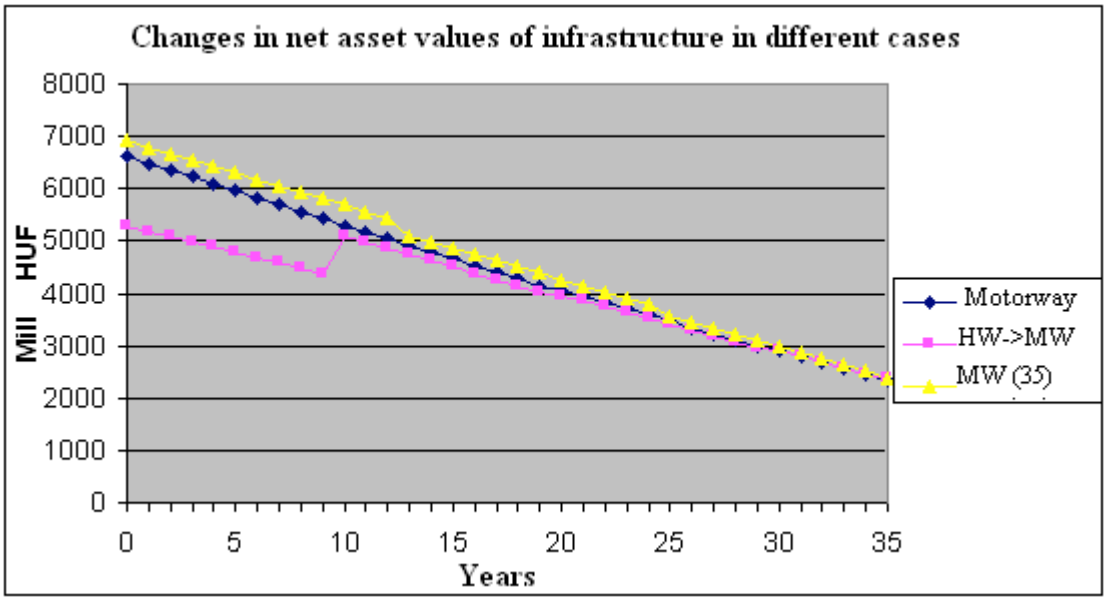
a sustainable financing mechanism satisfying all criteria defined by previous analyses. The resulted price setting technique and the set of strategic regulatory tools can be adopted for countries in same region with similar circumstances.

# 4. NEW SCIENTIFIC RESULTS

## 4.1. Developing a new infrastructure cost calculation model for reducing losses in asset value.

The author analysed hypothetic cases where interests in infrastructure development on domestic and European level are differing. Hypothesis was that gradual extensive capacity expansion of road infrastructure in time (i.e. in the beginning highway functions, than motorway functions in 10 years) and co-relating development of pavement carrying capacity are more efficient solution for using available financial resources.

In the first round of model calculation the author analysed the changes in net asset values in different (regular and hypothetical) cases for 35 years after the investment. The figure below shows that in the hypothetical case for having a same net value compared to the regular case, there are lower investment needs in the beginning. (The case of "Motorway" means demand following development, "Highway to Motorway" case assumes gradual extensive capacity expansion, and "Motorway for 35 years" names infrastructure development planned directly for 35 years demand.




Calculations from the work out and applied model determine that ***gradual extension of road infrastructure in time*** with moderate traffic load ***results favourable solution in using available financial resources***. This way is a win-win deal from investment, operation and maintenance, and user side's view-point without any generated loss in infrastructure service quality.

## 4.2. Developing an algebraic formula for calculating the needed financial contribution of the society aiming optimal share of occurred costs between the users and the whole society. Identifying the functional and causal cost allocation methods using state-of-the-art practices' results and working out these methods' mathematical formulas. Based on these cost calculations and on the value of needed social financial contribution, identifying a complex two-level cost allocation technique. With use of results so far developing a synthetising cost allocation and price setting model which is a possible solution for a usage based pricing system.

Proceeding from a possible solution for estimating the value-added effects of infrastructure investments, the author developed an algebraic formula for calculating ***the value "τ" of needed social financial contribution*** to wear infrastructure costs. Basis for calculation are the arising social benefits from constructing an infrastructure element. The quantitative value is derived from monetising the benefits. The benefits consider the concept of creating infrastructure service, thus social contribution shall be linked only to cost of capital within the infrastructure costs. The algebraic formula – developed and adopted to reach the defined objective – is the following:

$$\tau = \frac{\sum_{m} n_m * l_m}{\sum_{M} n_M * l_M} * Q * \tilde{\phi} * \tilde{s}_V^* * \frac{\Delta G}{G},$$

where:

$m \in M$ – subset $m$ piece of sections from the set containing all together $M$ sections (length of section is $l_m$ [m], where traffic volume is $n_m$ [veh/day]),

$Q$ – domestic Gross Output (HUF),

$\tilde{\phi}$ – GDP asset value elasticity and GDP fleet elasticity ratio,

$\tilde{s}_V^*$ – GDP vehicle number elasticity,

$\frac{\Delta G}{G}$ – volume change in whole road net asset value.

This formula calculates the value of $\tau$ (HUF), which lowers the ratio of user related cost of capital.

The **specific functional $k_i^f$ costs** allocated to vehicle categories can be calculated as following:

$$k_i^f = \frac{1}{p_{jmű\_km,i}} \left[ K_T \sum_x a_x p'_{x,i} + K_Ü \sum_y b_y p'_{y,i} + K_F \sum_x c_z p'_{z,i} \right],$$

where:

$i = 1..n$ (number of vehicle categories),

$K_T$ – the whole cost of capital (HUF),

$K_Ü$ – the whole cost of operation (HUF),

$K_F$ – the whole cost of maintenance (HUF)

$x, y, z$ – number of factors related to given cost element,

$a_x, b_y, c_z$ – relative weight of given cost element, sum of them equals to 1,

$p_{jműkm,i}$ – traffic performance of the vehicle category $i$ (vkm),

$p'_{x,i}, p'_{y,i}, p'_{z,i}$ – value of factor related to given cost element transformed to vkm (vkm).

The **specific causal $k_i^k$ costs** allocated to vehicle categories can be calculated as following:

$$k_i^k = \frac{p'_i}{p_{jmű\_km,i}} (k_B + k_L + k_Z),$$

where:

$k_B$ – specific external accident cost (HUF/vkm),

$k_L$ – specific cost of air pollution (HUF/vkm),

$k_Z$ – specific cost of noise annoyance (HUF/vkm),

$p'_i$ – traffic performance of vehicle category *i* transformed to vkm (vkm).

The complex two-level cost allocation technique equally considers social and user interests. The meaning of two levels are in the following:

- ***upper level***: model calculation for defining ratio of social and user costs to contribute;
- ***lower level***: model calculation for determining infrastructure user prices of different vehicle categories.

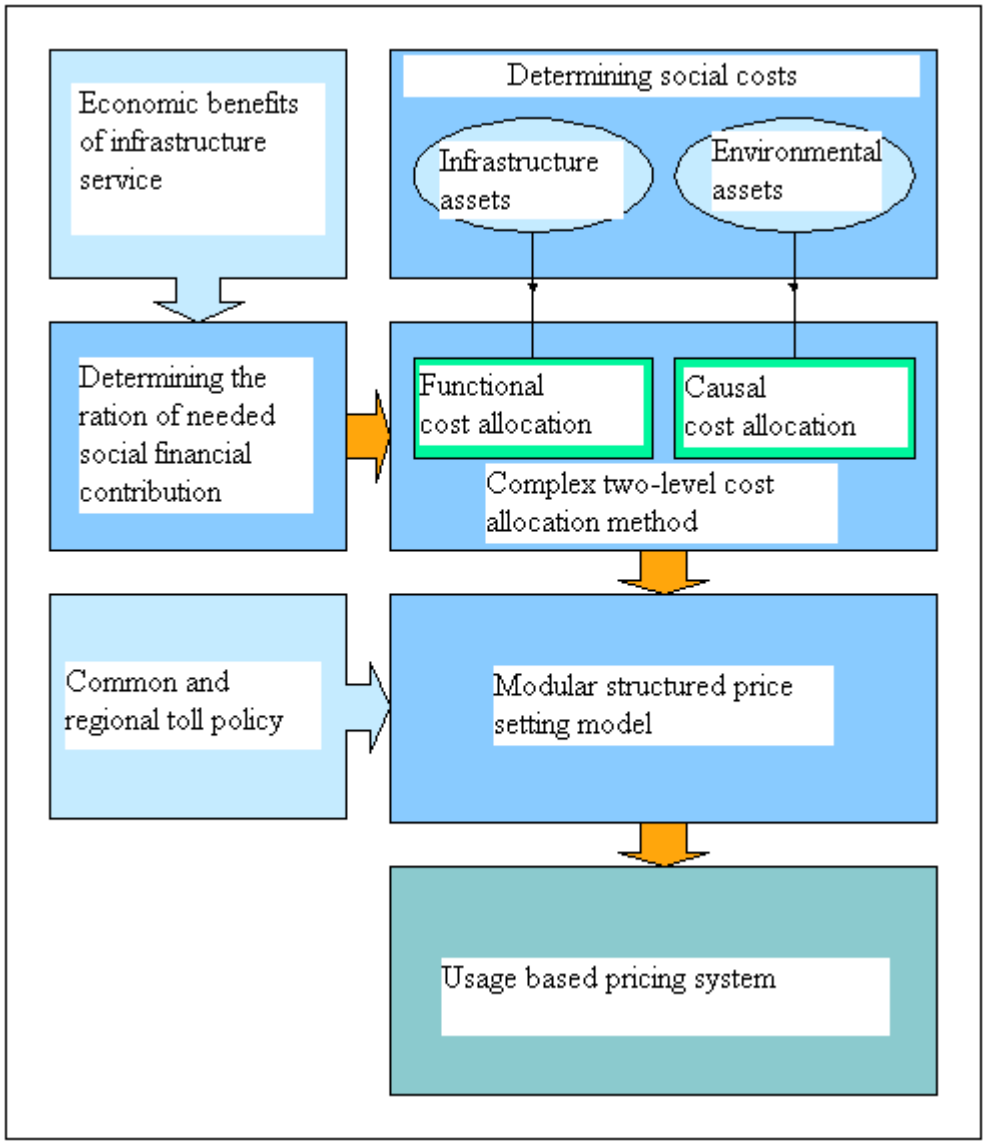
With elaborating the functional and casual cost allocation methods and evaluating the best practices the author developed a synthetising cost allocation and price setting model. The model takes equally into account the structure of infrastructure elements, the level of infrastructure service (meaning carrying capacity), the social value of infrastructure and the social cost based pricing mechanism. The model's modular structure allows for community interest on EU level and regional-specific national toll policy facilities. The joint application of different methods cause synergic effects, which increase the added value of the developed model.

The synthesis of previously defined functional and causal cost allocation techniques leads to determination of specific user prices related to different user (vehicle) categories. The complex two-level cost allocation method integrates the value $\tau$ of social benefits from creating the infrastructure service which defines the needed social contribution to cost of capital. The following formula calculates the specific user prices related to user category *i* considering infrastructure costs:

$$k_i = f(\tau, p_{jmű\_km,i}, k_i^f, k_i^k) =$$

$$= \frac{1}{p_{jmű\_km,i}} \left[ (K_T - \tau) \sum_x a_x p'_{x,i} + K_Ü \sum_y b_y p'_{y,i} + K_F \sum_z c_z p'_{z,j} + p'_i (k_B + k_L + k_Z) \right]$$

The scheme of synthetising model is the following:




## 4.3. Elaborating a macro-level game-theoretic model for verifying the operation of developed cost allocation and price setting mechanism.

The problems is solved by an oligopoly game-theoretic approach. Aim is calculating effective user price levels derived from allocated costs. Optimum criterion is maximising the aggregated value of user benefits ($H$) originated from use of infrastructure service. The algebraic meaning for value of $H$ is in the following:

$$H = f(p_{jmű\_km}, t, m, d)$$

where:

$p_{jműkm}$ – traffic performance related to vehicle category (vkm),

$t$ – time duration of use (hour),

$m$ – monetary saving projected to length of use (time duration, costs of vehicle operation (HUF/km), and

$d$ – determined user price level for specific vehicle category (HUF/km).

Restrictive conditions were analysed on two levels:

1. on level of users: user price ($d_i$)determined for vehicle category $i$ should not exceed the monetary savings ($m_i$), because it is restricting the use of the investigated road infrastructure, namely:

$$\frac{m_i}{d_i} \geq 1;$$

2. on level of infrastructure operator: revenues from different vehicle categories should minimally cover the relating costs from infrastructure use, namely:

$$p_{jmű\_km,i} d_i \geq K_{Ti} + K_{Üi} + K_{Fi}, \text{ for } \forall i .$$

The developed model can be written in the following formula:

$$H = \max \sum_i p_{jmű\_km,i} (m_i - d_i) .$$

## 4.4. Determining the technique for revising the regional toll strategic approaches, identifying the target groups' preferences of toll policy in the Central and Eastern European region, and developing an optimal strategic package for toll policy based on specialities of regions.

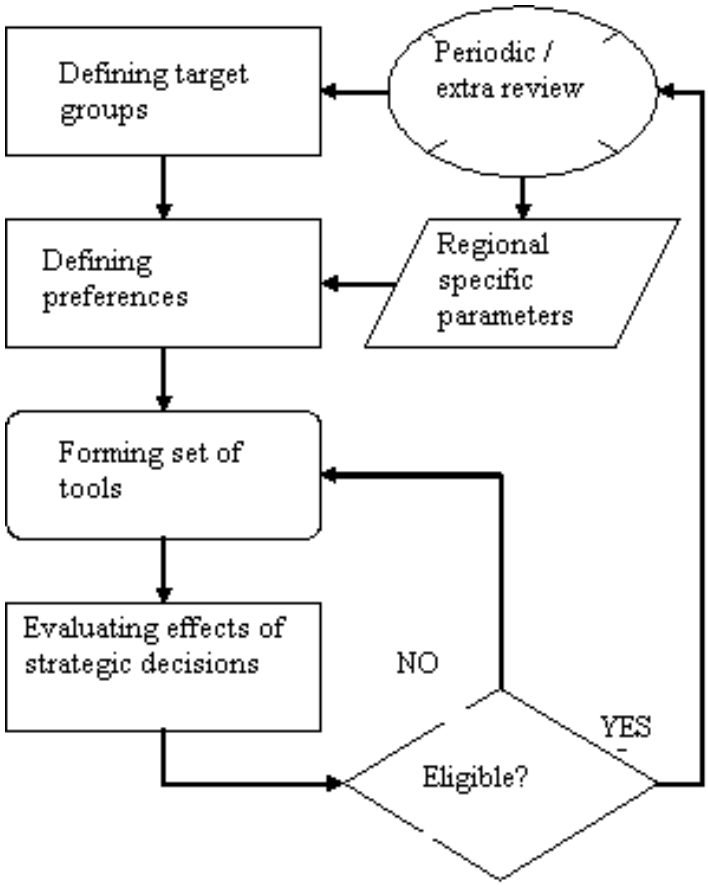
For verifying the compliance of strategic decisions on toll policy there is need for a strategic decision supporting tool. This helps the review of Hungarian and regional strategies on toll policy. The continuous changes in economy and politics and priorities in transport policy in the Central and Eastern European region enforce a periodic review of strategic concepts depending on the economic capacity. Optimum criterion is that the balance of revenues and costs in current toll system shall reach the cost recovery point,

and the possible social effects of derived needed changes to be implemented shall be minimised.

The author defined the preferences of goals in toll policies for interurban road transport in the EU-15 and the Central and Eastern European member countries.

The author assigned qualitative parameters for Bak's groups of effects with forming clusters. This step allowed of evaluating the different factors of strategic packages of toll policy. **Based on the evaluated factors the optimal toll strategy can be definitely formed** taking into account the different goals of toll policies.

The flow chart of the determined technique of revision is as follows:



# 5. UTILISATION OF NEW SCIENTIFIC RESULTS

The results and reports of the thesis are suitable for consulting decision making, for education and for international applications.

The utilisation of results so far concerned several international and Hungarian research projects related to the hosting Department of Transport Economics at BUTE, furthermore the gradual and post-gradual education related to the Department, not only on theoretic but as on practical level (in form of case studies) as well.

In form of scientific collaborations the results and reports are presented in other (domestic and foreign) research and higher education institutes and performing domestic R&D orders. The thesis can be of use for further supporting toll in Hungarian strategic toll policy decisions.

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