Budapest University of Technology and Economics

Faculty of Transportation Engineering

Department of Transport Economics

Conditions of Sustainable Urban Transport and the Toolkit of Development

Ph.D. Theses of

Török Árpád
M.Sc. in Transportation Engineering
M.Sc. in Transport Management

Scientific Supervisor:
Katalin Tánczos D. Sc.
Doctor of the Hungarian Academiy of Sciences

Budapest, 2010

1 Preliminaries

Nearly 80% of the European population live in cities nowadays. This ratio will probably continue growing in the 21th century. The concentration of productive forces results the enlargement of population density of urban areas. Hence the crescendo urban social-economic role will expectedly determine the competitiveness of whole regions.

Due to the spatial concentration resulted environmental, energy efficiency, land use and transport problems, the European Commission called the attention of the European Parliament and European Economic and Social Commission to the importance of the urbanization-caused social-economic losses (*COM(2004)0060*).

The European Parliament agreed with the Commission and supported the preparatory documentation but suggested the application of stricter environmental conditions (*2006/2061(INI)*). Besides, involving citizens, non-government institutes, profit-oriented economic actors and other stakeholders into the preparation of development strategy was strongly recommended.

Since generally there is no possibility to adopt urban policies based on consensual agreement of the different social parties and stakeholder groups, approaches investigating the operation of the complex urban system and most of the actors of urban processes come to the front.

According to the report ("Urban sprawl in Europe" (4/2006)) of the European Environmental Agency, since the tendencies of the population and mobility growth and the enlargement of built-in urban areas are strongly related processes, their interactions should be analysed together in one complex system.

2 Objectives

Instead of the recommendations of the European Union, estimation and planning processes mostly ignore the joint representation of land use and mobility processes in practice.

Hence the aim of the research is to develop a decision support process, which is applicable to assist defining measure toolkits and to ensure sustainable urban development, considering the complexity of the urban environment and the social interests. Therefor defining and modelling urban measure toolkits have to be based on a complex, interdisciplinary approach.

Summing up the objectives, the research has to investigate the urban system and to support working out urban measure toolkits with a complex methodology, integrating the scientific results of the interdisciplinary approaches.

3 Methodology

I applied the methodology of dialectics to evaluate the related literature. This approach made possible to analyse the model development process and the reason of the necessity of methodological evolution.

I used sequence and business diagrams to describe the interactions of the operation processes of cities to be able to define the problems of the complex urban environment,

I analysed the interactions among processes of the urban system with a spatial computable general equilibrium model based on the methodology applied by Anas (*Anas, 2007*).

Consumers use their decisions to maximize their utility subject to their budget constrain. Firms maximize their profit subject to the available resources. Consumers' utility function and firms' production functions were described by Cobb Duglas functions (*Cobb, C. W., Douglas, P. H., 1928.*) **[95]**.

I applied the logit-model to estimate the probability of choices regarding residences and workplaces **[73]**.

Transport supply was described by applying the approach of graph theory **[74]**.

I suggest that the traffic assignment should be done by applying the approach of Larsson and Patriksson (*Larsson, T., Patriksson M., 1995.*) improving their model by considering the effect of externalities and the dynamics of information **[100]**.

I solved the simple optimization problems with defining the first derivatives of the investigated object function **[73]**.

I solved the constrained optimization problems with definig its Lagrangian function (*Lagrange, J. L, 1788*.).

I solved the optimization problems defined by inequalities with apllying the Karus-Kuhn-Tucker (*Kuhn, H. W., Tucker, A. W., 1951.*) conditions.

4 New scientific results

4.1 Development of a new consumer utility function, which involves the effect of trip chains

Traditional spatial computable general equilibrium (SCGE) proccesses do not focus on short term decisions, hence implement the activity approach to extend the basic methodology of SCGE models. With the mentioned approach besides the quantitative properties of consumption it is possible to describe complex mobility demand structures in SCGE models as well

I interconnect attraction places (e.g. shops, offices, schools) with trip chains and the frequency of its realization. The routes to attraction places can be characterized with their travel costs and that makes possible to esstimate the effect of residence and production place choices on mobility structure.

I developed a spatial computable general equlibrium model, which is compatible with activity-based traffic modelling and considers the effects of trip chains on consumer decisions. (in chapter 4.1.1)

$$U_{ij} = \prod_{hkl} \left((n_h \cdot Z_{ijhkl})^{a_{kl}} \right) \cdot Q^{b}_{ij,FOGY} \cdot L^{g}_{ij}$$

Where:

U_{ij}: utility of consumers living in zone i and working in zone j,

n_h: the probability of the realization of the trip chain h,

Z_{ijhkl}: consumption of inhabitants living in zone i, working in zone j, realizing trip chain h, visiting zone k and choosing product or service type l,

α_{kl}: Cobb-Douglas parameter of product or service type l consumed in zone k,

$Q_{ij,FOGY}$: Size of residence used by inhabitants living in zone i working in zone j,

β: Cobb-Douglas parameter of residence,

L_{ij}: Leisure time of inhabitants living in zone i, working in zone j,

γ: Cobb-Douglas parameter of leisure time.

Related publications: [73], [74], [95].

4.2 The representation of trip chain related mobility processes

To assign mobility demands on the network we need to estimate the result of the consumer's route choice processes. The complex network topology of real networks makes it necessary to involve factors beside traffic dependent travel time in the representation of the network users' decision process, which are more realistically expected to be known by road users [16].

I implemented the route choice processes of the consumers in the methodology of spatial computable general equilibrium models as a constrained optimization problem. (chapter 4.1.2)

$$T_{INT} = \sum_{a \in A} \left(W_t t_{a,INT}(f_{a,INT}) + s_a (W_s + W_{EXT} \bullet EXT(f_{a,INT})) \right)$$

Where:

INT: ordinal number of the intervals generated by deviding up the operative time period of route choice process,

T_{INT}: Summed up cost function of network users,

a: ordinal number of network links,

$f_{a,INT}$: traffic on network link “a” in interval “INT”,

$t_{a,INT}$: time dependent traffic on link „a” in interval “INT“,

EXT: externalitiy parameter,

s_a: length of netwok link “a”,

W_t: weight parameter of time cost,

W_s: weight parameter of distance cost,

W_{EXT}: weight parameter of externalities.

Related publications: [94], [100], [102].

4.3 Defining parameters of spatial computable general equilibrium models

Parameters of spatial computable general equilibrium models are traditionally defined based on the social account matrix, however it is generally not available on regional, metropolitan or urban level. Moreover traditionally parameter definition is getting more and more complex with the growth of the equation number.

Following the method of the representation of the consumer’s decision problem [62], rearranging and deviding with eachother the first derivatives of the Lagrangian function, I defined the consumption of inhabitants living in zone i, working in zone j, realizing trip chain 1, visiting zone 1. With that I rearrange the equation and express the Cobb-Douglas parameter of consumption.

I developed a new method to define the parameters of spatial computable general equilibrium models with the application of spatial approach. (chapter 4.3)

$$a_1 = \frac{n_1 \cdot p_1 \cdot b \cdot Z_{ij11}}{r_i \cdot Q_{ij,FOGY}}$$

Where:

β: Cobb-Douglas parameter of residence,

Z_{ij11}: consumption of inhabitants living in zone i, working in zone j, realizing trip chain no. 1 and visiting zone 1,

$α_1$: Cobb-Douglas parameter of consumption,

$Q_{ij,FOGY}$: Size of residence used by inhabitants living in zone i working in zone j,

n_1: the probability of the realization of the trip chain no. 1,,

r_i: rent in zone i,

p_1: price in zone 1.

Related publication: [107], [110].

4.4 Underlaying methodological framework of definition of urban measure toolkits

Applying the developed urban model, I prepared the methodological framework of defining urban intervention toolkits, which maximize social welfare.

My new approach represents the public decisions as a constrained optimization problem, where the object function is the social welfare function, which contains the aggregated utilities of the inhabitants and the constrain of the objective function is the financial frame of the communitiy. (chapter 4.4)

$$U = \prod_i \left(U_i^{j_i} \right)$$

$$FC = \sum_i (Dev_{i1} - 1) \bullet Inv_{i1kl}$$

Where:

U social welfare function,

U_i utility of consumers living in zone i and working in zone j,

φ_i ratio of utility of consumer group i and the total utility of the community,

FC: financial constrain of the community,

Dev_{i1}: rate of development on network element connecting zone i and zone 1 (e.g. in case of a transport infrastructure investment, $1<Dev_{i1}<n$, where n is the ratio of the maximum travel time savings related to the investment),

Inv_{i1}: unity price of investment on network element connecting zone i and zone 1.

Related publication: [108], [112].

5 Further development orientations

The deeper integration of trip-chains methodology in spatial computable general equilibrium models results the extension of the aspects of the investigation of the urban system. Implementing trip-chains in the model as independent variable should make the evaluation process more complex but can generate new examining approaches and the new approaches would be able to describe consumer behavior more realistically.

The enhancement of the models complexitiy, the complicated optimization problems and the extended data needs of the models makes it necessary to apply new methodlogical approaches. Non-classical, biological models show good applicability in solving other transport problems, hence they are expected to be well applicable in the field of spatial computable general equilibrium models as well.

Neural networks could be applied to analyse relationship between different types functional social-economical and transport datasets. Besides they can be used to explain the different effects of system interactions in time. Genetic algorithms could solve the problem of complexity in reference to the optimization problems, since the increasing number of model variables could cause extremely high solving time for traditional equation system solving approaches.

6 References of the author associated with the theses

[73] Török, Á.: A komplex urbánus környezet modellezésének korszerű módszerei. Városi Közlekedés (ISSN 0133 0314), XLVII. évfolyam, 5. sz.: 291 – 297 2007.

[74] Tánczos, K., Török, Á.: Linear optimization model of urban areas' operating efficiency. Research Journal of Vilnius Gediminas Technical University and Lithuanian Academy of Sciences. Vol. 22, No. 3. 225-228. 2007.

[94] Bokor, Z., Török, Á.: Általános egyensúlyi modellek alkalmazása a közlekedéstervezésben. Innováció és Fenntartható Felszíni Közlekedés Konferencia, Budapest, BMF, 2009.

[95] Török, Á.: The possible role of mathematical optimization in urban planning. Kuhmo Nectar Conference, University of Urbino, 2007.

[100] Tánczos, K., Török, Á.: Proposal for reduction the calibration process in reference of the trip distribution method. PROMET - Traffic&Transportation, Scientific Journal on Traffic and Transportation (ISSN 0353-5320), University of Zagreb, Faculty of Transport and Traffic Sciences, No. 1 , p. 15-21. 2009,

[102] Török Árpád, Dr. Florian Heinitz: Estimation Model of Observed Road Transport Volumes Based on Thuringian Regional Structural Data. Transbaltica Litvánia, Vilnius, 2009 április. 22-23. pp 232-236. Proceedings of the 6th International Scientific Conference TRANSBALTICA 2009.

[107] Török, Á.: Városi rendszerek optimálása komplex egyensúlyi modelleken keresztül. Tavaszi Szél Konferencia – Műszaki tudományok, Élő és élettelen természettudományok (ISBN 978-963-87569-1-6), Zrínyi Miklós Nemzetvédelmi Egyetem, Budapest, 2007.

[108] Török, Á.: A fenntartható városi közlekedési és hatékony tervezési feltételeinek megfelelő modellezés. Városi közlekedés, XLVII. évfolyam, 5. sz, 2007.

[110] Török, Á, Bokor, Z.: Introduction of a capacity sensitive OD matrix estimation process applying genetic algorithm based calibration of SCGE model. Megjelenés alatt: WCTR, Lisszabon 2010.

[112] Tánczos, K., Török Á.: Dynamic model of urban controlling based on artifical intelligent methods. Peridoica Polytechnika 37. 2009.

References

[1] Európai Parlament: A városi környezetre vonatkozó tematikus stratégia. Brussel, 2006. (2006/2061(INI)).

[2] European Environment Agency: Urban sprawl in Europe - The ignored challenge. Brussel, 2006. (EEA Report No 10/2006, ISSN: 1725-9177).

[3] Hagerstrand, T.: What about people in regional science? Regional Science Association Papers 24, 7–21. 1970.

[4] Hunyady, Gy., Székely, M.: A közgazdaságtan pszichológiai vonatkozásai. Osiris Kiadó, Budapest, 2003. (ISBN: 963-389-310-0).

[5] Gubbins, E. J.: Managing Transport Operation. London, Kogan Page Ltd., 2002. (ISBN: 978-0749439286).

[6] Juhász, J.: Magyar értelmező kéziszótár. Budapest, Akadémia Kiadó, 2003. (ISBN: 9789630578745).

[7] A bizottság zöldkönyve a Tanácsnak, az Európai Parlamentnek, az Európai Gazdasági és Szociális Bizottságnak és a Régiók Bizottságának: Alkalmazkodás az éghajlatváltozáshoz Európában – Az uniós fellépés lehetőségei. Brussel, 2007. (COM(2007) 354, 2007.06.29.).

[8] A bizottság közleménye az Európai Parlamentnek, a Tanácsnak, az Európai Gazdasági és Szociális Bizottságnak és a Régiók Bizottságának: A városi mobilitás cselekvési terve. Brussel, 2009. (COM(2009) 490, 2009.09.30.).

[9] Fehér könyv: Európai közlekedéspolitika 2010-ig: itt az idő dönteni. (COM(2001)370)

[10] Tartsuk mozgásban Európát: Fenntartható mobilitás kontinensünk számára (COM(2006)314)

[11] Fehér könyv: Az éghajlatváltozáshoz való alkalmazkodás: egy európai fellépési keret felé. (COM(2009)147)

[12] Maslow, A.: A Theory of Human Motivation. Psychological Review 50(4), 370-96. 1943.

[13] Carey, H. C.: Priciples of Social Sciences. Philadelphia, J.B. Lippincott & Co., 1877.

[14] Weiner, E.: Urban Transportation Planning in the United States. Washington, US Department of Transportation, 1987. (ISBN: 978-0-387-77151-9).

[15] Chicago Area Transportation Study. Chicago, Illinois, Harrison Lithographing, 1959-1962. (Study Findings (Volume I) December 1959., Data Projections (Volume II) July 1960., Transportation Plan (Volume III) April 1962.)

[16] Hensher, D. A., Button, K. J.: Handbook of transport modelling. Oxford, Eslevier Ltd., 2000. (ISBN: 0 08 043594 7).

[17] Bureau of Public Roads: Highway Capacity Manual, 1950.

[18] Schuchmann, G., Kisgyörgy, L.: Közlekedéstervezés – Utak. Budapest, Műegyetemi Kiadó, 2001.

[19] Balassa, M., Doboly, T., Kovács Gy.: Mélyépítő gyakorlati számítások. Budapest, Műszaki Könyvkiadó, 1958.

[20] Berczik, A., Bényei, A., Borsos, J., Czére, B., Szabó, D., Turányi, I., Vásárhelyi, B.: Városi közlekedési kézikönyv. Budapest, Műszaki könyvkiadó, 1965.

[21] Bureau of Public Roads: Traffic Assignment Manual. Washington D.C., U.S. Dept. of Commerce, Urban Planning Division, 1964.

[22] Monigl, Vásárhelyi.: Analitikus forgalomelőrebecslési módszerek vizsgálata. KÖTUKI kiadvány, 20. sz., 1976.

[23] ABAG Regional Data Center, Association of Bay Area Governments: Final 1990 census and historical population data of the San Francisco Bay Area cities and counties. San Francisco, Association of Bay Area Governments, 1991.

[24] Berki, Zs.: A személyközlekedési adatfelvételeken alapuló modellek fejlesztése, Doktori Értekezés. Budapest, 2008.

[25] Ruiter, E. R., Ben-Akiva, M. E.: Disaggregate Travel Demand Models for the San Francisco Bay Area. Transportation Research Record 673, 121-128. 1978.

[26] Bowman, J. L., and Ben-Akiva, M. E.: Activity based travel forecasting. Activity-Based Travel Forecasting Conference. June 2-5, 1996: Summary, Recommendations and Compendium of Papers, New Orleans, Louisiana. USDOT report. T-97-17, 32 pages. 1996.

[27] Hensher, D.,Greene W. H.: Using stated response choice data to enrich revealed preference discrete choice models, Marketing Letters, Volume 4, Number 2 139-151, 1993.

[28] McFadden, D., Gan, L., Hurd, M.: Individual Subjective Survival Curves. NBER Working Paper No. 9480, 2003.

[29] Khan, M. A., Willumsen, L. G.: Modelling car ownership and use in developing countries. Traffic Engineering and Control, vol. 27, issue 11, 1986.

[30] Nagy, E. (szerk.), Szabó, D. (szerk.) :Városi közlekedési kézikönyv. Budapest, Műszaki Könyvkiadó, 1984.

[31] Berki, Zs., Monigl, J., Nagy, E., Dobrocs, T., Dávid, G., Perjés, T., Badalay E., Fejes, B.: A Budapestre bejárók közlekedési preferenciáinak vizsgálata. Városi közlekedés, XLVII. évfolyam 6., 2007.

[32] Kövesné Gilicze, É., Debreczeni, G., Füzy, F.: Az utazási időtényező értékelése a személyközlekedésben a háztartástatisztika alapján. Közlekedéstudományi szemle XXXVIII 11, pp. 500-505, 1987.

[33] Pálfalvi, J.: Egyéni közlekedési szokások Magyarországon és az Európai Unióban, Közlekedéstudományi Szemle, 53. évf., 5.sz., 2003.

[34] Koren, Cs.: Minőség az egyéni közlekedésben és a közúti forgalomban, Közúti és mélyépítési szemle, 49. évf., 3. sz., 1999.

[35] Jászberényi, M.: Fenntartható mobilitás Budapest agglomerációjában, PhD értekezés, 2008.

[36] MOTOS Transport Modelling: Towards Operational Standard sin Europe. Contract no.: TREN/06/FP6SSP/S07.56151/022670, D2.1 State-of-the-art report 2007.

[37] Silverman, D. P.: Ancient Egypt. Oxford, University Press US, 2003. (ISBN 9780195219524).

[38] Smith, A.: An Inquiry into the Nature and Causes of the Wealth of Nations. London, Methuen & Co., Ltd. 1776.

[39] Kopányi, M., Berde, É., Martin, H. Gy., Vági, M., Bara, Z. Tóth, F., Lehoczki, Zs.: Mikroökonómia. Budapest, Economix Kiadó, 1989. (ISBN: 963 02 7212 1).

[40] Ricardo, D.: On The Principles of Political Economy and Taxation. London, John Murray, 1817.

[41] Von Thunen, J.: Die isolierte Staat in Beziehung auf Landwirtschaft und Nationalokonomie. Perhtes. Hamburg, 1826.

[42] Arnott, R., McMillen, D.: A companion to Urban Economist. Malden, Blackwell Publishing Ltd., 2006.

[43] Walras, L.: Éléments d'économie politique pure. 1876.

[44] Cunningham, W., McLure, M.: Vilfredo Pareto: critical assessments of leading economists. New York, Routledge, 1999.

[45] Pareto, V.: The New Theories of Economics. Journal of Political Economy 5, 485-502. 1897.

[46] Arrow, K. J., Debreu G.: Existence of an equilibrium for a competitive economy. Econometrica 22, 265-290. 1954.

[47] Wald, A.: Über die eideutige positiveLösbarkeit der neuen Produktiongleischungen. Ergebnisse eines matematischen Kolloquiums, 6, 12–20. 1933.

[48] Wald, A.: Über die produktionsgleichungen der ökonomischen Wertlehre (II. Mitteilung). Ergebnisse eines matematischen Kolloquiums, 7, 1–6. 1934.

[49] Neumann, J.: Über ein ökonomisches Gleichungssystem und eine Verallgemeinerung des Brouwerschen Fixpunktsatzes. Ergebnisse eines mathematischen Kolloquiums, 8, 73–83. 1937.

[50] Kornai, J.: Anti-equilibrium. Közgazdasági és Jogi Könyvkiadó. Budapest, 1971.

[51] Moczár, J.: Arrow–Debreu-modell és a Kornai-kritika harminc év után. Közgazdasági Szemle, LIII. évf., 175–194. 2006.

[52] Leontief, W. W.: Input-output economics. Oxford University Press, 1966.

[53] Augusztinovics, M.: Mirõl szól az input-output modell? Közgazdasági Szemle, XLIII. évf., 315-320. 1996.

[54] Samuelson, P.: The Stability of Equilibrium: Comparative statics and dynamics. Vol. 9., Nr.2. 1941.

[55] Dixit, A. K., Stiglitz, J. E.: Monopolistic Competition and Optimum Product Diversity. The American Economic Rewiew. 297-308. 1977.

[56] Járosi, P.: A közösségi döntések elmélete és a térbeli általános egyensúlyi modell egy lehetséges adaptációja Magyarországra. EU Working Papers 2006/4, BGF KVIF folyóirat. 2006.

[59] Krugman, P.: Increasing returns and economic geography. Journal of Political Economy 99, 483–499. 1991.

[58] Samuelson, P.: Spatial price equilibrium and linear programming. American Economic Review. 42, 283-303. 1952.

[59] Samuelson, P., Keating M. O.: Economics from the heart: a Samuelson sampler. Harcourt Brace Jovanovich, 1983. (ISBN: 9780156275514).

[60] Committee On Facilitating Interdisciplinary Research, National Academy Of Sciences, National Academy Of Engineering, Institute Of Medicine: Facilitating Interdisciplinary Research Report. National Academy Press. 2005.

[61] Braun, T., Schubert, A.: Interdiszciplinaritás. Elfogadjuk-e Magyarországon? Magyar Tudomány, 2008/01 78. 2008.

[62] Samuelson, P.: Foundation of Economic Analysis. Harvard University Press, 1947. (ISBN: 0674313003).

[63] Bagwell, P. S.:The Transportation Revolution from 1770. New York, Barnes & Noble, 1974. (ISBN: 0649028899).

[64] Nábrádi, A.: A vidékfejlesztés társadalomtudományi megalapozása. Az agrár innovációtól a társadalmi aszimmetriáig, Debreceni Egyetem Agrártudományi Centrum, Debrecen. 32- 39. 2006.

[65] Wegner, M., Fürst, F.: Land-Use Transport Ineraction: State of the Art. TRANSLAND project. Universitat Dortmund – Fakultat Raumplanung, 1999.

[66] Russo, F., Musolino, G.: Multiple equilibria in spatial economic transport interaction models. Association for European Transport and contributors, 2009.

[67] Anas, A.: Discrete Choice Theory and the General Equilibrium of Employment, Housing and Travel Network sin a Lowry Type Model of the Urban Economics. Environment and Planning A, 16, 11, 1489-1502, 1984.

[68] de la Barra, T.: Integrated Land Use and Transport Modelling. Cambridge: Cambridge University Press, 1989.

[69] Schade, W., Rothengatter, W.: Improving the Assessment of Transport Polices by Dinamic Cost-Benefit-Analysis: Interim Results of the IASON project for the European Commission. Washington D. C., 82nd Annual Meeting of the Transportation Research Board (TRB), 2003.

[70] Oosterhaven, J.,Knaap, T., Ruijgrok, Tavassz, L.: On the development of RAEM: the Dutch spatial general equilibrium model and its first application to a new railway link. 41th Congress of the European Regional Sciences Association, Zagreb, 2001.

[71] Monigl, J.: Szempontok a közúthálózati fejlesztések területfejlesztési hatásainak értékeléséhez. Budapest, TRANSMAN, 2005.

[72] Erdélyi, Zs, Monigl, J.:Nagy bevásárlóközpontok telepítésének közlekedési és városrendezési kérdései. Városi közlekedés 1999/1, 1999.

[75] Jávor, B.: Az élő város és a városgép. Ökotrend, 2005, 2, 20-21. 2005.

[76] Oosterhaven, J., Sturm, J.E., Zwaneveld , P.: Naar een theoretische onderbouwde aanpak van voorwaartse economische effecten: Modelmatige definitie. Rijksuniversiteit Groningen / TNO Inro, Delft, 1998.

[77] Bernoull, D.: Specimen theoriae novae de mensura sortis. Commentarii Academic Scientiarium Imperialis Petropolitanae. Vol. 5. 1738.

[78] Berde, É., Petró, K.: A különféle hasznosságfogalmak szerepe a közgazdaságtanban. Közgazdasági Szemle, XLII. évf., 5.: 511-529. 1995.

[79] GOSSEN, H.: Entwicklung der Gesetze des menschlichen Verkehr. 1854.

[80] Pareto, V.: Manual of Political Economy. 1906.

[81] Samuelson, P.: Consumption theory in terms of revealed preference. Econometrica 15.: 243-253. 1948.

[82] Le Chatelier, H. L.: Loi de stabilité de l'equilibre chimique. 1888.

[83] Fujita, M., Krugman, P., Venables, A. J.: The Spatial Economy. Cities, Regions and International Trade. Massachusetts Institute of Technology. 1999. (ISBN:0-26206204-6).

[84] Cobb, C. W., Douglas, P. H.: A Theory of Production. American Economic Review Supplement 18 .: 139–165. 1928.

[85] Arrow, K. J.; Chenery, H. B.; Minhas, B. S.; Solow, R. M.: Capital-labor substitution and economic efficiency. Review of Economics and Statistics 43.: 225–250. 1961.

[86] Varga, A.: Térszerkezet és gazdasági növekedés. Budapest, Akadémiai Kiadó Zrt. 2008. (ISBN: 9789630586764.)

[87] McKitrick, R.R.: The Econometric Critique of Computable General Equilibrium Modeling: The Role of Parameter Estimation. Department of Economics in its series UBC Departmental Archives with number 95-27. 1995.

[88] Arndt, C., Robinson, S., Tarp, F.: Parameter estimation for a computable general equilibrium model: a maximum entropy approach. Economic Modelling 19. 3: 375-398. 2002.

[89] Ortúzar, J, de D., Willumsen, L. G.: Modelling Transport. John Willey and Sons, 2001.

[90] Anas, A., Kim, I.: General Equilibrium Models of Polycentric Urban Land Use with Endogenous Congestion and Job Agglomeration. JOURNAL OF URBAN ECONOMICS 40, 232-256. 1996.

[91] Anas, A., Liu, Y.: A regional economy, land use, and transportation model (RELU-TRAN): formulation, algorithm design and testing. 2007.

[92] Daganzo, C. F., Sheffi Y.: On Stochastic Models of Traffic Assignment. Transport Sciences, Vol. 11. No. 3.: 253-274. 1977.

[93] Anas, A.: A unified theory of consumption, travel and trip chaining. Journal of Urban Economics 62.: 162-186. 2007.

[96] Dial, R. B.: A Probabilistic Multipath Traffic Assignmet Model Which Obviates Path Enumeration. Trans. Res. 5. 83-111. 1971.

[97] Burrel, J. E.: Multipath route Assignment and Its Application to Capacity Restraint. Fourth International Symposium on the Theory of Traffic Flow, Karlsruhe, Germany. 1968.

[98] Larsson, T., Patriksson M., An Augmented Lagrangean Dual Algorithm For Link Capacity Side Constrained Traffic Assignment Problem. Transport Res. -B. Vol. 29, No 6, pp. 433-455. 1995.

[99] Wardrop, J. G.: Some Theretical Aspects of Road Traffic Research, Proc. Inst. Civ. Eng. (Part 11) 1, 325-378, 1952.

[101] Török, Ádám.: A közlekedési árképzési / díjképzési rendszerek korszerűsítését megalapozó közúti közlekedési implementációs stratégiák kidolgozása. Doktori értekezés, Budapesti Műszaki és Gazdaságtudományi Egyetem. 2008.

[103] Lagrange, J. L.: Mécanique analitique. Berlin. 1788-ban jóváhagyva a Francia Tudományos Akadémia által. 1788.

[104] Hearn, D. W.: Bounding Flows in Traffic Assignment Models. Research Report No. 80-4. University of Florida, Department of Industria and System Engineering. 1980.

[105] Kuhn, H. W., Tucker, A. W.: Nonlinear Programming. Proceedings of 2nd Berkley Symposium. Berkley: University of California Press, 481-492. 1951.

[106] Eurostat: Europe in Figures, Eurostat Yearbook 2009. ISSN.1681-4789. 2009.

[109] Samuelson, W., Marks, S.: Managerial Economics 4th ed.: 47. 2003.

[111] Doherty, Miller.: A computerized Household Activity Schedulding Elicitor Survey. Transportation 2000/2, 75-97, 2000.

[113] Samuelson, P.: The pure theory of public expenditure. The Review of Economics and Statics, Vol. XXXVI, No. 4, 1954.

[114] Mills, E.S., de Ferranti, D.M.: Market choice and optimum city size. American Economic Review 61, 340–345. 1971.

[115] Mills, E.S., MacKinnon, J.: Notes on the New Urban Economics. Bell Journal of Economics and Management Science. Vol. 4, No. 2. 593-601. 1973.

[116] Magyar Pályázatkészítő Iroda Zrt.: Békéscsaba Megyei Jogú Város – Integrált Városfejlesztési Stratégia. 2009.

[117] HB.c.e. Kft. – T7 Mérnökiroda Kft. Konzorcium.: Békéscsaba Megyei Jogú Város Közlekedésfejlesztési Terve. , 2010.

[118] Monigl, J.: A személyközlekedési igények tér-idő-költség-elvű modellezése. Habilitáció. 2001.

[119] Központi Statisztikai Hivatal: Magyar Statisztikai Évkönyv, 2008. Felelős szerkesztő: Németh Eszter. Nyomdai kivitelezés: Xerox Magyarország Kft. ISSN: 1215-7864. 2009.

[120] Tímár, A.: Közlekedési Létesítmények Gazdaságtana. Egyetemi Jegyzet. Budapest, Műegyetemi Kiadó. 2002.

[121] Tánczos, K., Bokor Z.: A közlekedés társadalmi költségei általános és mód specifikus hazai sajátosságai. Közlekedéstudományi szemle, 2003/08. 281-291. 2003.

[122] Oosterhaven, J.: Ont he development of RAEM: the Dutch spatial general equilibrium model and its first application to a new railway link. Congress of the European Regional Science Association, Zagreb, August 29 – September 1, 2001.

[123] Ivanova, O.: PINGO: a model for prediction of reional and interregional freight transport. Rapport vol. 578/2002, Institute of Transport Economiocs. 2002.

[124] Péter, T.: Nagyméretű nemlineáris közlekedési hálózatok modellezése. Közlekedéstudományi Szemle LVII.:(9) pp. 322-331. 2007.

[125] Tillema, F.: Neural networks outperform gravity models in trip distribution estimation. Presented at the 10th world conference on transportation research, Istanbul, Turkey, 2004.

[126] Hadi, M. A., and C. E. Wallace. Hybrid Genetic Algorithm to Optimize Signal Phasing and Timing. Transportation Research Record 1421, TRB, National Research Council, Washington, D.C. pp. 104–112. 1993,

[127] Cevallos, F., and F. Zhao. Minimizing Transfer Times in a Public Transit Network with a Genetic Algorithm. Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.