Chapter 11
Pareto Evolutionary Optimization of Joint Network Design and Pricing Strategies Related to Emissions in Urban Networks

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ABSTRACT

In the current social, physical, economical and environmental circumstances of scarcity, the design and management of vital lifelines like transportation systems, especially within the metropolitan context, are subject to the implementation of multiple objectives in a unified framework. Thus, one of the most important issues is the identification of optimal trade-offs among crucial objectives both from the designer's as well as from the users' perspective. In the current study a comprehensive framework for estimating optimal inter-relations and dilemmas among emissions-related carbon footprint and other (social- and economic-related) features of urban road networks design and operation are presented and analyzed, based on techniques of multi-objective and hierarchical mathematical programming with equilibrium constraints, solved by suitable hybridization of evolutionary algorithms. The results of the proposed optimization methodological approach provide the Pareto Frontier of solutions, which corresponds to optimal trade-offs amongst multiple objectives. The computational experience from the application of the proposed methodological approach on a part of a realistic urban network is presented, providing evidence on the applicability as well as on the computational burden of such transportation design paradigms, but most importantly, on the dilemmas emerging in sustainable design and planning of transportation systems.

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INTRODUCTION

In the traditional paradigm of the optimal design or regulation of future transportation infrastructure development plans, investments and/or other interventions are allocated based on criteria expressing the prudence of public and private authorities for the system that is under investigation. The performance criteria used in most such circumstances, endeavor to optimize economic (or economic related) metrics of the investments. Nevertheless, contemporary society's requirements are moving towards a sustainable development pattern, especially since for some time now, environmental conditions have been identified as determining economic attractiveness and thus future development opportunities (European Communities, 2001). Focusing on the transportation sector, this is identified as a major component of the human-activities-based greenhouse gas (GHG) emissions production, especially concerning what is now called the carbon footprint, given that the energy sources are provided -in a very high proportion- by fossil fuels. The negative effects of transportation carbon footprint have been explicitly identified and various initiatives have been put through as an effort to regulate such negative externality. One of those acts concerns the introduction (both in USA and EU) of tradable permit (TP) schemes, a framework that allows the exchange/trade of emissions among a set of countries sharing a geographical area, such as a predefined emissions target to be met with the lowest possible social and economic cost (OECD, 2002). As so, when dealing with designing future development plans, an effort should be made to considering regulating emissions and their possible impact on other social or policy aspects, like mobility opportunities, investment cost, the evolution of urban space etc. (Verhoef, Nijkamp & Rieveld, 1997). Such an analysis and inter-connection has not been thoroughly investigated (in a quantitative manner) within the transportation-related literature.

Since traffic emissions are closely related to congestion, a set of policies and initiatives could be suitably combined to remedy negativities, spanning to infrastructure provision, road pricing and/or other traffic management strategies. The theoretical foundations of optimal traffic networks design and management strategies are mainly depended on classical and neoclassical economic ideas (e.g. Knight, 1924). Nevertheless, the implementation of such ideas have come against the complexity of identifying optimal management plans in realistic networks, as they have been exposed in various paradoxes that emerge in investigating investment or pricing strategies. For example the paradox of the increment of the total social cost (as reflected on total travel time) by the provision of additional transportation infrastructure (Braess, 1968) and the similar case of the increment of congestion-related traffic emissions in special cases of improvement of travel times by capacity improvements (Nagurney, 2000*a*). Also, the paradox of the increment of traffic emissions by reducing total travel time moving from user-optimal towards system-optimal traffic network conditions through network pricing (Yin & Lawphongpanich, 2006), demonstrates the complex and conflicting nature of alternative network development and management strategies.

This study aims to provide a comprehensive framework for identifying optimal network strategies, incorporating carbon footprint considerations in a network development and management procedure. This is done by encompassing joint decisions on both network development (investments) and management policies (pricing) for a realistic case of an urban highway for a multi-objective problem setup. Moreover, instead of determining a unique optimal strategy, a non-linear, non-convex, hierarchical, multi-objective optimization problem is formulated incorporating conflicting (economic, social, and environmental) network objectives, able to provide a Pareto-Optimal set of policies. For doing so, an optimization framework based