Sustainable Interurban Road Network Planning Through a Multi-objective Approach

Bruno F. Santos *, António P. Antunes, Mark Santos
Department of Civil Engineering,
University of Coimbra, Coimbra, Portugal
* Email: bsantos@dec.uc.pt

Road transportation, due to its high flexibility and the unique capability to provide door-to-door transportation, play a vital role in the sustainable development of societies. In the last decades, countries like Portugal, Spain, and Poland have made large investments in the transformation of their interurban roads networks. These investments were decided through trial-and-error approaches, using simulation models based on the classic (or four-step) transportation model [1]. Trial-and-error approaches do not allow full exploration of possible planning solutions. Developing countries, such as Brazil, India or China, will certainly need to invest in their networks in the future, in order to keep their high economic growth rates. These countries should plan their networks according to sustainable development principles. In this paper, we present a multi-objective approach to long-term interurban road network planning that could help road authorities in their strategic analysis of this planning problem.

Over the last 30 years, significant research efforts have been devoted to optimization-based road network planning (or design) models. Most of these efforts were oriented toward two models: the discrete road network design (DRND) model, especially, the continuous road network design (CRND) model. The former focuses on the addition of new links to a road network, whereas the latter concentrates on the (continuous) expansion of capacity of existing links. For a relatively recent review of this literature see [2] and for an interesting early study of this kind of models with an application to a national road network see [3]. The objectives considered in these models vary widely. The most frequent are efficiency objectives, such as user cost minimization or user benefit maximization (as measured by the consumers' surplus). Other important objectives that have been dealt with in previous studies include robustness [4] and equity [5]. A number of articles address multi-objective road network design models. The first one reported in the literature is due to Friesz and Harker [6]. More recently, Santos et al. [7] considered a robustness objective in addition to an efficiency objective (accessibility maximization), Feng and Wu [8] considered horizontal and vertical equity objectives, and Cantarella and Vitetta [9] considered environmental objectives (minimization of carbon monoxide emissions).

Despite being appealing from a theoretical standpoint, the models referred to above apparently were never used in practice. The approach proposed aims to tackle some of the issues that make the current theoretical approaches not so applicable in practice. In particular, it is consistent with the planning framework of the Highway Capacity Manual (a manual widely used in practice in most countries in the world), where the concept of level of service is used to assess traffic flow conditions. Road segments are classified according to a hierarchy and, in the search of solutions, two types of action are considered: the construction of a new link of a given hierarchic level; and the upgrading of an existing link to a higher level. Demand is assumed to be elastic with respect to investment decisions. More than one objective is combined in the objective function - e.g., objectives of efficiency, equity, robustness, and energy consumption. In addition, accessibility to natural parks (or to other points of interest) and environmental constraints in protected areas, can also be considered.

The main road network of the State of Paraná, Brazil, is used to show the applicability of the approach and to illustrate the differences between efficiency-oriented solutions and more sustainable solutions, where equity, energy consumption objectives, accessibility to natural parks and environmental concerns are also taken into account. Preliminary results, only considering efficiency, equity and energy consumption objectives, show that the solutions can vary widely with the inclusion of sustainable objectives (Figure 1). More important, they show that reducing the efficiency of the network by just 0.4% can allow a reduction of energy consumption by 9.5%. This clearly indicates that the proposed approach can be a valuable tool for sustainable interurban sustainable planning.

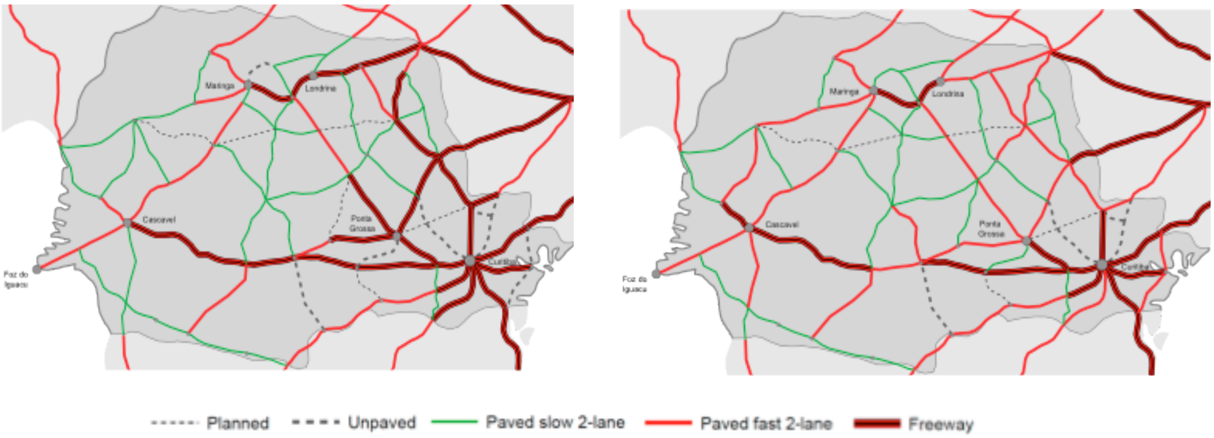

Figure 1 - (left) Solution for efficiency maximization; (right) Solution for efficiency maximization and energy consumption minimization

References

[1] Daly, A., "National Models" Handbook of Transport Modelling, D. A. Hensher and K. J. Button, eds., Elsevier Science, Oxford, UK, 2000.

[2] Yang, H., and M. G. H. Bell, "Models and algorithms for road network design: A review and some new developments." Transport Reviews,18 (3), 257–278, 1998.

[3] Boyce, D. E., and B. N. Janson, "A discrete transportation net- work design problem with combined trip distribution and assignment" Transportation Research Part B: Methodological 14 (1–2), 147–154, 1980

[4] Lo, H. K., and Y. K.Tung, "Network with degradable links: Capacity analysis and design" Transportation Research Part B: Methodological 37 (4), 345–363, 2003.

[5] Meng, Q., and H. Yang, "Benefit distribution and equity in road network design" Transportation Research Part B: Methodological 36 (1), 19–35, 2002.

[6] Friesz, T. L., and P. T. Harker,, "Multi-objective design of transportation networks—The case of spatial price equilibrium" Essays and Surveys on Multiple Criteria Decision Making: Proceedings of the 5th International Conference on Multiple Criteria Decision Making, P. Hansen, ed., Springer, Berlin, 86–93, 1983.

[7] Santos, B. F., Antunes, A. P., and E. J. Miller, "Interurban road network planning model with accessibility and robustness objectives" Transportation Planning and Technology 33 (3), 86–93, 2010.

[8] Feng, C. M., and J. Y. J. Wu, "Highway investment planning model for equity issues" Journal of Urban Planning and Development 129 (3), 161–176, 2003.

[9] Cantarella, G. E., and Vitetta, A., "The multi-criteria road network design problem in an urban area" Transportation 33 (6), 567–588, 2006.