Optimising investments on urban bus networks: an elastic demand model[1]

Mariano Gallo(*), Luca D'Acierno(+), Bruno Montella(+)

gallo@unisannio.it, dacierno@unina.it, montella@unina.it

(*) Dipartimento di Ingegneria, Università degli Studi del Sannio, Italy
(+) Dipartimento di Ingegneria dei Trasporti, Università degli Studi di Napoli "Federico II", Italy

Keywords: transit network design, bus frequencies, elastic demand, optimisation models.

Extended Abstract

In this paper we study the problem of optimising investments on urban bus networks. We assume that the planner has some monetary resources to invest in an urban bus network and that those resources can be used to increase the current frequencies of bus lines (no new lines are designed and current frequencies cannot be reduced). Since such interventions on line frequencies will improve the level of service of the bus network, they will produce changes in modal split. Hence an elastic demand model has to be adopted to simulate the system.

This problem is a particular case of the more general Transit Network Design Problem, where we assume that line routes are known and only service frequencies have to be designed. The Transit Network Design Problem has been extensively studied in the literature, some recent reviews are available in Guihaire and Hao (2008) and Desaulniers and Hickman (2007). Several papers have focused on the specific problem of optimising transit frequencies, including Constantin and Florian (1995), Gao et al. (2004), Goossens et al. (2004), Borndorfer et al. (2007), and Yu et al. (2010). All the above adopt the assumption of rigid demand. This hypothesis is acceptable in practical applications where an existing network has to be (re)designed without allowing for new investments in the transit system. In this case, improvements in network performance are usually unable to significantly affect user mode choices. However, the assumption of rigid demand is inappropriate if transit services can be significantly improved with new investments. In such cases, one of the main design aims is precisely to shift users from road systems to transit systems and therefore the simulation of demand elasticity is indispensable. Recent contributions on transit network design problems with elastic demand have been proposed by Lee and Vuchic (2005), Cipriani et al. (2006), Fan and Machemehl (2006, 2008), Marín and García-Ródenas (2009), and Gallo et al. (2011).

In this paper, in order to simulate the elastic demand and evaluate the optimal investments on the bus network, we consider three transportation systems (bus, private car and pedestrian systems) and evaluate the effects of the interventions on the whole multimodal transportation system.

In the proposed model we assume that the topological configuration of the bus network and the road network are known and invariable. The decision variables are bus line frequencies; they could be assumed as continuous variables but in our problem we prefer to consider them as discrete variables, with constraints on the minimum (current frequency) and maximum value (for instance 15 buses/h). Other constraints concern the budget (maximum number of buses available and maximum bus-kms operable), capacity (maximum number of users per bus link) and assignment. In particular, a multimodal assignment constraint is used for estimating jointly the equilibrium user flows on all transportation systems (D'Acierno et al., 2002).

In the objective function we have to consider effects of investments on all transportation systems and on society. Therefore we propose an objective function that is a weighted sum of operator costs, transit user costs, car user costs, pedestrian user costs and external costs.

---

[1] Partially supported by the Italian MIUR under PRIN2009 grant no. 2009EP3S42_002.

The proposed model is a non-linear constrained discrete optimisation model where the objective function is neither linear nor convex (except in particular cases). In particular, an elastic demand assignment must be performed to evaluate each solution, some constraints are non-linear and the assignment constraint is not expressible in a closed form. Moreover, the problem is NP-Hard. For solving the optimisation problem, we propose to use and compare two meta-heuristic algorithms: a scatter search (Martì et al., 2006) and a genetic algorithm (Holland, 1975). The proposed model and algorithms were tested on a real-scale network representing the transportation network of Naples, a city in the south of Italy with about 1,000,000 inhabitants, with over 120 transit lines, over 1,600 road links and over 690 nodes. Initial results show the applicability of the model on real networks in terms of acceptable computing times for strategic planning.

References

Borndorfer, R., Grotschel, M., Pfetsch, M.E. (2007) A column-generation approach to line planning in public transport. *Transportation Science*, 41, pp. 123–132.

Cipriani, E., Petrelli, M., Fusco, G. (2006) A multimodal transit network design procedure for urban areas. *Advances in Transportation Studies*, A10, pp. 5–20.

Constantin, I., Florian, M. (1995) Optimizing frequencies in a transit network: a nonlinear bi-level programming approach. *International Transactions in Operational Research*, 2, pp. 149–164.

D'Acierno, L., Montella, B., Gallo, M. (2002) Multimodal assignment to congested networks: fixed-point models and algorithms. *Proceedings of 'European Transport Conference 2002'*, Cambridge, UK.

Desaulniers, G., Hickman, M. (2007) Public transit. *Handbooks in Operation Research and Management Science*: *Transportation*, 14, pp. 69–120.

Fan, W., Machemehl, R.B. (2006) Optimal transit route network design problem with variable transit demand: genetic algorithm approach. *Journal of Transportation Engineering*, 132, pp. 40–51.

Fan, W., Machemehl, R.B. (2008) Tabu search strategies for the public transportation network optimisations with variable transit demand. *Computer-Aided Civil and Infrastructure Engineering*, 23, pp. 502–520.

Gallo, M., Montella, B., D'Acierno, L. (2011) The transit network design problem with elastic demand and internalisation of external costs: an application to rail frequency optimisation. *Transportation Research C*, 19, pp. 1276-1305.

Gao, Z., Sun, H., Shan, L. (2004) A continuous equilibrium network design model and algorithm for transit systems. *Transportation Research B*, 38, pp. 235–250.

Goossens, J.-W., van Hoesel, S., Kroon, L. (2004) A Branch-and-Cut approach for solving railway line-planning problems. *Transportation Science*, 38, pp. 379–393.

Guihaire, V., Hao, J.-K. (2008) Transit network design and scheduling: A global review. *Transportation Research A*, 42, pp. 1251–1273.

Holland, J.H. (1975) Adaptation in natural and artificial systems. *The University of Michigan Press*, Ann Arbor (MI), USA.

Lee, Y.J., Vuchic, V.R. (2005) Transit network design with variable demand. *Journal of Transportation Engineering*, 131, pp. 1–10.

Marín, A., García-Ródenas, R. (2009) Location of infrastructure in urban railway networks. *Computers & Operations Research*, 36, pp. 1461–1477.

Martí, R., Laguna, M., Glover, F. (2006). Principles of scatter search. *European Journal of Operational Research*, 169, pp. 359-372.

Yu, B., Yang, Z., Yao, J. (2010) Genetic algorithm for bus frequency optimization. *Journal of Transportation Engineering*, 136, pp. 576–583.