Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 41 (2019) 67–69

Transportation Research Procedia

www.elsevier.com/locate/procedia

International Scientific Conference on Mobility and Transport
Urban Mobility – Shaping the Future Together
mobil.TUM 2018, 13-14 June 2018, Munich, Germany

Can travel time variability be ignored when solving the transit network design problem?

Inbal Haas[a,*], Bernhard Friedrich[b]

[a]*Leibniz Universität Hannover, Institute of Cartography and Geoinformatics, Appelstr. 9A, 30167 Hannover, Germany*
[b]*Institute of Transportation and Urban Engineering, Technische Universität Braunschweig, Herman-Blenk-Str. 42, 38108 Braunschweig, Germany*

Keywords: Transit Network Design; Genetic Algorithm; Traffic assignment

Extended Abstract

Due to the ever-increasing demand for transportation, and the resulting congestion in urban areas, the efficient design of transit systems nowadays is more relevant than ever before. In order to attract users, transit systems should deliver an added benefit. Improving transit systems can assist in encouraging the public to abandon their private vehicle and make an increasing use of transit. This in turn will support generating more sustainable and less congested transportation systems.

Numerous studies have been dedicated to the Transit Network Design Problem (TNDP) (Mandl, 1980; Spiess and Florian, 1989; Baaj and Mahmasani, 1995; Ngamchai and Lovell, 2003; Ceder, 2003; Lee and Vuchic, 2005). Each of which manifested other aspects of the problem, and suggested different solution approaches. A common division identifies a sequence of 5 decisions, covering different related aspects of the problem (Ceder and Wilson, 1986): the design of the routes, setting frequencies, timetable development, bus scheduling and driver scheduling. This paper discuss the first two stages, namely, designing the routes of the system and setting their frequencies, referred in several

* Corresponding author. Tel.: +49-531-391-66831; fax: +49(0)531 391-66828.
E-mail address: i.haas@tu-braunschweig.de

10.1016/j.trpro.2019.09.014

previous studies as the Transit Network Design and Frequencies Setting Problem (TNDFSP) (Guihaire and Hao, 2008; Wang and Lin, 2010).

Similarly to all other TNDP related sub-problems, the TNDFSP has also been studied before. There have been studies considering each part of the TNDFSP separately, namely the generation of routes (Mandl, 1980; Baaj and Mahmassani, 1995; Zhao and Ubaka, 2004; Mauttone and Urquhar; 2009), and the optimization of frequencies (Furth and Wilson, 1982; Constantin and Florian, 1995). However, over the years a notion has evolved, according to which, the problem of routes design and frequency setting are related, and therefore should be considered using a unified framework (Szeto and Jiang, 2014). As a result, a series of studies have been conducted, combining both these elements together. First, in a sequential manner (Carrese and Gori, 2002; Ceder, 2003), where first the optimal routes are generated and later the optimal frequencies are found, and then also simultaneously (Pattnaik et al., 1998; Fan and Machemehl, 2006; Szeto and Jiang, 2014), where the optimal frequencies are found based on different sets of generated routes.

A close relative of the TNDP is the Network Design Problem (NDP), where the optimal design of the network is sought (LeBlanc, 1975). The NDP is usually studied with respect to the potential improvement of a given road network (e.g. expansion of existing links, or construction of new ones). The NDP is usually constructed as a bi-level optimization problem, optimizing the benefit of the network operators, while taking into account the route choices of the road users.

In spite of their close affinity, one principal difference exists in the viewpoint, distinguishing the NDP from the TNDP. In the NDP, each improvement in the network bears the potential of changing the route choices of the users, which will in turn affect the flows in the different links and consequentially also the travel times. As a result, in order to evaluate the differences between different network configurations, there is a need to solve the user equilibrium of traffic assignment problem. In the TNDP, on the other hand, the travel times on different routes are always considered fixed, neglecting the effect of the general traffic, and the mutual effect of the assigned lines. Considering the fact that in many cases transit vehicles share the same lanes as the general traffic, and that they load the network more than private vehicles, this assumption is questionable. In this study we test the fixed travel time assumption while we solve the TNDFSP.

Reviewing previous TNDFSP formulations, no consensus exists concerning the objectives of the TNDSFP and the general structure of the problem. At times, the focus is put on the operators' side, striving to minimize their total costs (Wan and Lo, 2003). At other times, the users' perspective gets a greater attention, and various variables related to the benefit of the users are optimized, e.g. the total travel time, the number of transfers, the waiting time and the number of direct travels (Baaj and Mahmassani, 1995; Constantin and Florian, 1995; Schöbel, 2012; Szeto and Jiang, 2014).

In this study, and similarly to several previous studies (Constantin and Florian, 1995; Szeto and Jiang, 2014), we choose to model the TNDFSP as a bi-level optimization problem. In the upper level the objective is to minimize the total travel time of the users, and in the lower level we solve the user equilibrium, which considers both the general traffic and the routes and frequencies of transit lines. Network operators' related aspects are integrated in the problem as constraints. Using this formulation, we strive to obtain a more reliable representation of the problem, which also captures traffic-related aspects, often neglected in other TNDFSP related studies.

It should be noted that the integration of the user equilibrium in the TNDFSP is not as straightforward as it might seem. When solving the NDP, one usually assumes that each travel means an additional vehicle that should be loaded on the network. When solving the TNDFSP this assumption is no longer valid, since multiple travelers may use the same transit vehicle. Therefore when integrating the user equilibrium in the TNDFSP this should be considered, and an adequate conversion of the demand to transit vehicles should take place. Nevertheless, since the objective function of the upper level of the problem minimizes the total travel time of the travelers, the relation to the total number of individual travels should be maintained. This issue is taken into account both in the problem formulation and in the developed solution algorithm.

The TNDFSP is classified as a NP-hard problem, and therefore for large instances it is usually solved using metaheuristics (Fan and Machemehl, 2004), as is also the case in this study. The proposed model is solved using the genetic algorithm, where all necessary modifications are performed for adapting the algorithm to the conditions of the current problem. Comparison to the case where fixed travel times are used is also performed, in order to establish the need in considering travel time variability in TNDFSP models. Furthermore, sensitivity analyses are performed to determine to which extent considering the variability of travel times affects the obtained results, and in which cases, if at all, it can be neglected.

The main contribution of this study lies in proposing a new formulation for the TNDFSP, a formulation which is based on the solution of the user equilibrium, and therefore increases the reliability of the model by capturing travel time variability. Moreover, this study provides means for assessing the correctness of the assumption underlying previous models, suggesting that travel time variability can be neglected while solving the TNDFSP.

References

Baaj, M.H., Mahmassani, H.S., 1995. Hybrid route generation heuristic algorithm for the design of transit networks. Transportation Research Part C, 3, 31–50.

Carrese, S., Gori, S., 2002. An urban bus network design procedure. Applied Optimization, 64, 177–196.

Ceder, A., Wilson, N.H., 1986. Bus network design. Transportation Research Part B: Methodological, 20(4), 331-344.

Ceder, A., 2003. Designing Public Transport Network and Routes. Pergamon Imprint/Elsevier Science Ltd. pp. 59–91.

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

Fan, W., Machemehl, R.B., 2004. Optimal transit route network design problem: Algorithms, implementations, and numerical results (Report No. SWUTC/04/167244-1). Retrieved from Texas Transportation Institute, URL:https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/167244-1.pdf

Fan, W., Machemehl, R.B., 2006. Optimal transit route network design problem with variable transit demand: genetic algorithm approach. Journal of transportation engineering, 132(1), 40-51.

Furth, P.G., Wilson, N.H.M., 1982. Setting frequencies on bus routes: theory and practice. Transportation Research Record, 818, 1–7.

Guihaire, V., Hao, J.K., 2008. Transit network design and scheduling: A global review. Transportation Research Part A: Policy and Practice, 42(10), 1251-1273.

Leblanc, L.J., 1975. An algorithm for the discrete network design problem. Transportation Science, 9(3), 183-199.

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

Mandl, C.E., 1980. Evaluation and optimization of urban public transportation networks. European Journal of Operational Research, 5(6), 41–47.

Mauttone, A. and Urquhart M.E., 2009. A route set construction algorithm for the transit network design problem. Computers and operations research, 36, 2440-2449.

Ngamchai, S., Lovell, D.J., 2003. Optimal time transfer in bus transit route network design using a genetic algorithm. Journal of Transportation Engineering, 129(5), 510-521.

Pattnaik, S.B., Mohan, S., Tom, V.M., 1998. Urban bus transit route network design using genetic algorithm. Journal of Transportation Engineering, 124(4), 368–375.

Schöbel, A., 2012. Line planning in public transportation: models and methods. OR Spectrum, 34(3), 491–510.

Szeto, W. Y., Jiang, Y., 2014. Transit route and frequency design: Bi-level modeling and hybrid artificial bee colony algorithm approach. Transportation Research Part B: Methodological, 67, 235-263.

Spiess, H., Florian, M., 1989. Optimal strategies: A new assignment model for transit networks. Transportation Research Part B, 23(2), 83–102.

Wang, J. Y., Lin, C.M., 2010. Mass transit route network design using genetic algorithm. Journal of the Chinese Institute of Engineers, 33(2), 301-315.

Wan, Q. K., Lo, H.K., 2003. A mixed integer formulation for multiple-route transit network design. Journal of Mathematical Modelling and Algorithms, 2(4), 299-308.

Zhao, F., Ubaka, I., 2004. Transit network optimization – minimizing transfers and optimizing route directness. Journal of Public Transportation, 7(1), 67–82.