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Performance measurement of a transportation network with a downtown space reservation system: A network-DEA approach ☆

Y. Zhao [a], K. Triantis [a,*], P. Murray-Tuite [b], P. Edara [c]

[a] Grado Department of Industrial and Systems Engineering, Virginia Tech, Northern Virginia Center, 7054 Haycock Road, Falls Church, VA 22043-2311, USA
[b] Via Department of Civil and Environmental Engineering, Virginia Tech, Northern Virginia Center, 7054 Haycock Road, Falls Church, VA 22043-2311, USA
[c] Department of Civil and Environmental Engineering, University of Missouri-Columbia, E3502 Lafferre Hall, Columbia, MO 65211, USA

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A B S T R A C T

We propose an evaluation approach for a novel travel demand management strategy known as the downtown space reservation system (DSRS). This approach takes into account three perspectives, i.e., transportation service provider's, the user's, and the community's and is based on network-Data Envelopment Analysis (DEA) where the perspectives are inter-related through intermediate inputs/outputs. Two types of network-DEA models (radial and slacks-based models) are considered. An example is provided using data propagated from a microscopic traffic simulation model of the DSRS. The results show that individual node performance can drive network DEA performance and that this information can inform future designs of the DSRS.

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1. Introduction

Transportation systems impact stakeholders in different ways. For example, travelers are concerned with their travel time, transportation service providers strive to meet their financial constraints, and communities focus on safety and environmental issues. Conflicting interests make the traditional economic evaluation methods such as benefit–cost analysis, inadequate to concurrently capture multiple perspectives (e.g., the provider's, the community's, and the user's perspectives) that are important for the performance assessment of transportation systems. Furthermore, the consideration of multiple concurrent perspectives is important for many transportation agencies that have begun to support travel demand management (TDM) strategies, which facilitate traffic congestion mitigation, environmental protection, and energy conservation.

In order to address this need, the objective of this research is the development of a transportation performance measurement approach with an application of a relatively new efficiency measurement methodology, namely network DEA. Our proposed approach expands on Färe and Grosskopf's network DEA approach (2000) and captures the perspectives of transportation system providers, the users and the community, as well as the interrelationships among these perspectives. It also provides an overall performance (efficiency) measure for the transportation network. For validation and completeness purposes, the current research compares two different types of network DEA models, the original network DEA model proposed by Färe and Grosskopf (2000) and the slacks based network DEA model proposed by Tone and Tsutsui (2009).

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* Corresponding author. Tel.: +1 703 538 8446; fax: +1 703 538 8450.
E-mail address: triantis@vt.edu (K. Triantis).

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The essence of our approach is to compare and contrast various instances (scenarios) that occur in the transportation network under the execution of a TDM strategy, namely the downtown space reservation system (DSRS). The scenarios constitute the production possibility set for our analysis. Traffic flow of a downtown area, where the DSRS is implemented, is simulated with a microscopic approach. The data that support the performance measurement analytical approach is obtained from the execution of the micro simulation (Zhao et al., 2010a).

The remainder of this paper is organized as follows. Section 2 presents a brief background of the DSRS and the microscopic traffic simulation. Overview of transportation performance measures and the three-perspective conceptual performance measurement approaches are provided in Section 3. Section 4 introduces the DEA and Network DEA approaches, followed by mathematical descriptions of the original network DEA and the slacks based network DEA with inclusion of undesirable outputs in both models. In Section 5, an illustrative example is presented together with the comparison between the two different network models. Finally, conclusions and future system design and research directions are addressed in Section 6.

2. Background

The transportation network evaluated in this research is characterized by the implementation of the TDM strategy, namely the downtown space reservation system (DSRS). It should be noted that this system has not been implemented. The DSRS has been developed for the purpose of congestion mitigation, for the center of a city or Central Business District (CBD). With the DSRS, travelers who want to drive in a designated downtown area have to book their time slots before making their trips. The transportation authority, who administers and supervises the DSRS, allocates time slots to travelers based on the availability of resources (i.e., road network capacity). Only those who get permission from the transportation authority can drive in the downtown area during the requested time period. The system alleviates traffic congestion by reducing excessive vehicles on the road. Details of the DSRS including implementation issues are addressed by Zhao and Triantis (2009) and Zhao et al. (2010a,b).

The core of the DSRS is an optimization module that maximizes two objectives, i.e., people throughput and revenue obtained from the reservation system where both objectives are subject to the transportation network capacity. In the optimization module, the decision maker assigns weights to the two objectives reflecting their relative importance. In the DSRS, different vehicle types have different vehicle occupancy rates. The people throughput is the total number of travelers that the transportation system services.

In work that followed this initial research work, a microscopic traffic simulation model was built to obtain a better understanding of the transportation system behavior, to evaluate performance of the DSRS, and to evaluate the impact of various changes (e.g., changes in travel demand, etc.). The simulation model allows one to test the DSRS before it is implemented by providing a range of effectiveness measures (such as travel time and average speed). The simulation was based on a transportation network shown in Fig. 1, and it was run under different scenarios characterized by varying travel demand levels and by changing the relative importance of the people throughput and revenue objectives in the reservation system (Zhao et al., 2010b). The simulation provides the data for the network DEA model and this will be illustrated in Section 5.

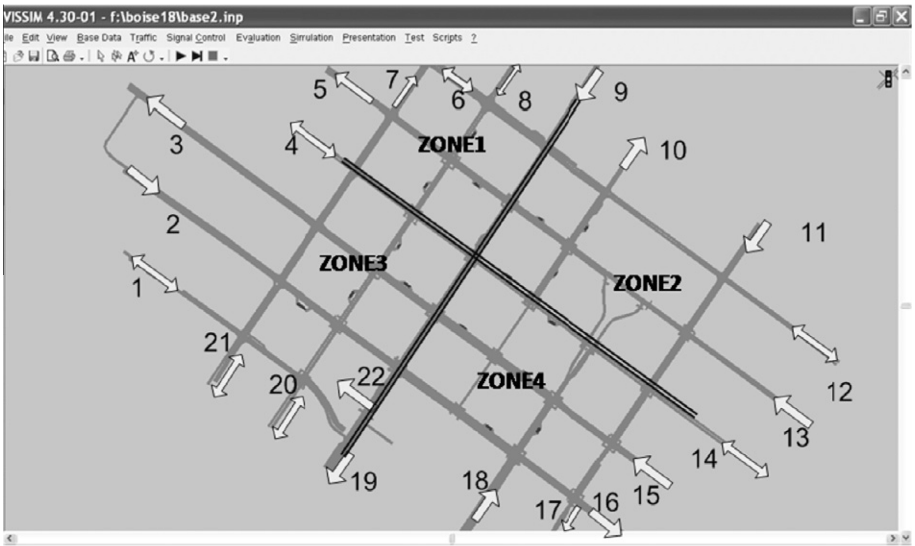

Fig. 1. Transportation network for traffic simulation.