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Inter-city bus scheduling under variable market share and uncertain market demands☆

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Abstract

Bus scheduling is essential to a carrier's profitability, its level of service and its competitiveness in the market. In past research most inter-city bus scheduling models have used only the projected (or average) market share and market demand, meaning that the variations in daily passenger demand that occur in actual operations are neglected. In this research, however, we do not utilize a fixed market share and market demand. Instead, passenger choice behaviors and uncertain market demands are considered. Stochastic and robust optimizations and a passenger choice model are used to develop the models. These models are formulated as a nonlinear integer program that is characterized as NP-hard. We also develop a solution algorithm to efficiently solve the models. They are tested using data from a major Taiwan inter-city bus operation. The results show the good performance of the models and the solution algorithm.

Keywords: Scheduling; Inter-city bus; Variable market share; Uncertain market demands; Stochastic programming; Robust optimization

1. Introduction

Bus scheduling is a critical activity in inter-city bus operations and is essential to a carrier's profitability, its level of service and its competitiveness in the market. There has already been some research devoted to inter-city bus scheduling problems; for example, see [1–4]. However, in these researches fixed parameters, such as the projected market share and market demand, have usually been used for bus scheduling. The resultant bus schedules are produced neglecting variations in daily passenger demand that occur in actual operations.

Actually, market share may vary with passenger choice behaviors, especially in competitive markets. The actual market share may also decrease with respect to the projected market share if a bus schedule is inferior, and vice versa. Moreover, market demand usually varies on a daily basis due to disturbances that may occur in actual operations. Passenger fluctuations arising from variable market share and uncertain market demands can affect the "actual" performance of the planned schedules. These planned schedules are the basis for real operations, while, on the other hand, real operations must fulfill the planning objectives by implementing the planned schedules. This interrelationship between the planned schedules and real operations cannot be neglected in the bus scheduling process. However, the traditional models, based on the projected (or average) market share or market demand, do

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not consider passenger fluctuations, so produce overly optimistic optimal schedules where resources may be used too tightly. Unfortunately, this may produce large variations in "actual" performance when applied in real operations, where passenger numbers often fluctuate. Therefore, to set a good schedule, not only does related bus supply have to be considered, but also variations in the market share and uncertain market demands also have to be taken into account.

Yan and Chen [3] developed an inter-city bus scheduling model, based on fixed projected market share and market demand. Their model would be a useful tool for inter-city bus scheduling provided that the market share projection was accurate. However, in inter-city bus scheduling problems, the estimation of the target carrier's market share, for each OD pair from the origin–destination table (known as the OD table), and for each time interval, is complicated. The market share for all OD pairs, and for all time intervals, will vary simultaneously with changes in the supply (for example, the bus schedule). In practice, market share is correlated with passenger choice behaviors. It is not easy for a carrier to make an accurate projection of the competitive market share without taking into consideration of passenger choice behaviors.

To improve Yan and Chen [3]'s model, Yan et al. [4] employed a time–space network technique and a passenger choice model so as to incorporate variable market share into a bus scheduling model. It was expected that with Yan et al.'s [4] model, bus scheduling and passenger choice behaviors in a competitive market could be more efficiently integrated. However, as was the case in Yan and Chen [3]'s model, market demand was also assumed to be fixed. In other words, daily variations of the market demand in actual operations were neglected. In practice, the market demand for each OD pair, for each time interval, usually follows a specific distribution. If the uncertainties of market demand do not conform to the bus schedule, then, to solve Yan et al.'s [4] model, the carrier needs to make repeated adjustments to the market demand in relation to the distribution, until a satisfactory bus schedule is acquired. Such a trial-and-error process is less systematic and less efficient. As a result, it is very difficult for a carrier to incorporate both variations in the market share and market demand, to perform a sensitivity analysis, using this model. Nevertheless, Yan et al.'s [4] model could serve as a basis for the development of an inter-city bus scheduling model under variable market share and uncertain market demands.

Therefore, to improve on Yan et al.'s work [4], both variable market share and uncertain market demands, such as that occur in actual operations, are considered here. Our research differs from Yan et al.'s [4] on several other points:

1. Yan et al. [4] utilized a fixed market demand in their model; we not only consider variable market share but also take uncertain market demands into account. Such an approach should more accurately reflect variations in market share and market demand, and thus be more practical in actual operations.
2. To consider uncertain market demands, two stochastic and robust optimization concepts (which will be introduced later) are employed in our modeling. These were not considered in Yan et al.'s [4] research.
3. Yan et al. [4] considered the scheduling of non-stop and one-stop bus trip operations. However in Taiwan, inter-city bus trips are typically short-haul so that in actuality, Taiwan inter-city bus carriers mainly provide non-stop bus trips. For example, Yan et al. [4] found that about 93% of all passengers were transported on non-stop bus trips (the remainder were served by one-stop bus trips). We consider both variations in the market share and market demand in the modeling, a more complicated procedure (details will be discussed in Section 2), to reduce the problem complexity, so we only consider non-stop bus trips.
4. In Yan et al.'s [4] model, a draft timetable was not utilized. In theory, their model had the capability of directly and systematically managing the interrelation between supply and demand. However, such an approach, without the prior consideration of service frequency and other supply constraints in the draft timetable, would be inclined to result in an impractical bus schedule that needs to be adjusted by a post-optimization process. In our research, the draft timetable is used as a medium for the scheduling process, meaning the obtained bus schedule will be more practical and suitable for Taiwan carrier operations.

Since we consider passenger choice behaviors and uncertain market demands during the bus scheduling process, we draw on past research in both these fields for reference purposes. For the former, there has been research applying multinomial or nested logit models to formulate passenger choice behaviors in competitive market situations. For examples, see [5–9]. For the latter, there has been research considering uncertain disturbances in other fields. For examples, see [10–34]. In general, stochastic and robust optimization concepts have recently been employed to deal with these types