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Overview Paper

A survey on planning semi-flexible transit systems: Methodological issues and a unifying framework

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ABSTRACT

When demand for transportation is low or sparse, traditional transit cannot provide efficient and good-quality service, due to its fixed structure. New transportation alternatives are therefore increasingly proposed, combining on-demand service adjustment capabilities to the regular route and schedule characteristics of traditional transit. Such so-called *semi-flexible* systems require careful planning, but no formalization of the corresponding decisions problems, nor any comprehensive methodology has been proposed yet. This paper aims at contributing to fill this gap by presenting a comprehensive literature review, and a general and unifying modeling framework for representing and planning semi-flexible systems. The latter takes the form of the Demand Adaptive Systems, which generalizes the semi-flexible systems described in the literature, and also offers a number of advanced features, the scheduling mechanism, in particular. The paper then provides a classification of planning decisions, which is used to structure a comprehensive and comparative literature review of the field of semi-flexible systems, including methodological contributions as well as a number of particularly significant practical experiences.

1. Introduction

When the demand for transportation is consistently high during a given time period, traditional transit operates well and efficiently as it naturally allows for a high degree of resource sharing and good level of service. In contrast, when the demand for transportation is low or sparse, the potential for resource sharing drops drastically, particularly because of the rigid structure of traditional transit in terms of route and schedule. For this reason, mass transit evolved towards some degree of flexibility.

The well-known Dial-A-Ride systems (*DAR*), originally designed to serve people with reduced mobility (Wilson et al., 1971; Cordeau and Laporte, 2003) and later extended to general customer service, constitute a first attempt in this direction. With respect to traditional transit, DAR provides *personalized* service by modifying itineraries, schedules and stop locations according to the transportation needs of users at given times. At the same time, it still guarantees a certain degree of resource sharing by serving requests *collectively*. The extension of DAR to general users displays a number of drawbacks, however, some of which follow from the extreme flexibility inherent within the system definition. Thus, for example, since the supply of transportation services changes according to the needs expressed for particular time periods, neither the transit operator nor the users may predict the vehicle itineraries, stop locations, and schedules. As a consequence, users are obliged to book

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the service well in advance of the actual desired time of utilization and the actual pick up time is very much left to the discretion of the operator.

Consequently, practitioners started to experiment with new transportation paradigms with the scope of combining regular (traditional) transit systems with pure on-demand services such as DAR. Some of these efforts aimed at efficiently coordinating traditional transit and DAR, e.g., Hickman and Blume (2000); Hickman and Blume (2001); Häll (2006); Häll et al. (2009). Such systems, sometimes called *Integrated*-DAR (IDAR), allow the user to transfer from a DAR vehicle to traditional transit and, possibly, again to a DAR vehicle. The main drawback of IDAR systems is that the DAR component is managed at operation time (including transfers), thus maintaining many of the inconveniences of DAR systems.

To address some of these issues, researchers and practitioners explored during the last decades new transportation paradigms. Koffman (2004) and, more recently, Potts et al. (2010) report several attempts aimed at combining the different characteristics of traditional transit and DAR in the *same* transit system. The systems that were proposed and implemented vary considerably in terms of organization, fleet management, service policies, and so on. They all present some basic common features, however. On the one hand, they have a set of stops with a fixed, predetermined timetable, similarly to traditional transit. On the other hand, part of the service is flexible and, as in a DAR context, users can ask for service at optional locations. The fundamental idea behind such systems is that the regularity of the service is by itself a valuable property of public transportation because it helps users to plan their trips, facilitates integration with other transportation modes, makes it possible to access the service without booking, etc. At the same time, such systems try to inject flexibility by considering "additional" time for the route of the vehicle, which can be used to possibly deviate from a basic path to operate services in a demand-responsive framework. These systems, that we call *semi-flexible* to underline the fact that they are a compromise between the flexibility of DAR and the fixed structure of traditional transit, are the main focus of this paper.

Transportation systems dedicated to service several demands with the same vehicle require complex planning activities, the resulting plan significantly determining the overall behavior and performance of the system. Semi-flexible services, combining characteristics of traditional and on-demand systems, require both a service-design phase and user request-dependent adjustments of vehicle routes and schedules at operational-level. Such a high level of planning complexity requires a formalization of the decision process and the utilization of comprehensive and general modeling frameworks. This has been done for traditional transit (see, for example, Desaulniers and Hickman, 2007). No such effort can be found in the literature for semi-flexible systems, however. As a result, even though the number of contributions to various planning aspects of semi-flexible transit system is relevant, there is a general lack of comprehensive view of the problem. Most contributions focus on specific aspects only, with particular assumptions, sometimes application specific, sometimes very simplified. This makes it hard to relate and compare the efforts of different lines of research within a comprehensive view of the field.

This paper aims at contributing to fill this gap by presenting a comprehensive literature review and a unifying modeling framework for representing and planning semi-flexible systems. We proceed through three main steps. We first propose a general and unifying modeling framework for the class of semi-flexible transit systems taking the form of the Demand Adaptive System (DAS) introduced in Malucelli et al. (1999). In particular, we show that the DAS framework generalizes all the semi-flexible systems described in Koffman (2004) and Potts et al. (2010). Moreover, it also offers more advanced features, the scheduling mechanism, in particular. We then provide a classification of planning decisions for DAS, inspired by what has been done for the planning of traditional transit. It is noteworthy, however, that the more complex configuration and operation of semi-flexible systems require richer planning processes in comparison with traditional transit, and this is reflected in the proposed classification. Finally, we take advantage of the common framework offered by the classification to report a comprehensive and comparative literature review of the field of semi-flexible systems, including methodological contributions as well as a number of particularly significant practical experiences.

The paper is organized as follows. Section 2 is dedicated to, first, describing the main classes of semi-flexible systems as found in actual operations, second, recalling the DAS organization and characteristics and, third, showing how DAS generalizes semi-flexible systems and thus offers an appropriate general representation. We discuss planning issues for semi-flexible systems in Section 3, proposing a classification of the associated decisions used to contrast the traditional transit, DAR and DAS cases. This classification is further used in Section 4 to review the literature on semi-flexible systems. We conclude in Section 5.

2. Semi-flexible systems and DAS

The scope of this section is first to illustrate a variety of semi-flexible systems, which have been actually implemented as reported in Koffman (2004) and Potts et al. (2010), and, then, to introduce the details of DAS and use it as unifying model for the entire class of semi-flexible systems.

2.1. Semi-flexible systems

Koffman (2004) reported an inquiry on the state-of-the-practice of semi-flexible systems in North America. Following the same lines, Potts et al. (2010) performed a more extended inquiry, obtaining a considerable amount of new information. These two works form the most comprehensive and up-to-date review of practical experiences we are aware of. The authors also report a number of very interesting, statistically based, considerations about relations among type of service, region to