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Network design of a transport system based on accelerating moving walkways

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ABSTRACT

Pollution, congestion and urbanistic considerations are leading to a change in the use of private vehicles in dense city centers. More frequently, the *last-mile* is covered with systems such as public transport, car sharing and bike sharing as well as an increase in walking and cycling. Following this trend, we assume a hypothetical scenario where the use of private cars is strongly limited in dense urban areas, and innovative transport modes must be used. This work investigates a futuristic system based on a network of accelerating moving walkways (AMW) to facilitate the movement of pedestrians in city centers where cars have been banned. Unlike constant speed moving walkways, AMWs can reach speeds of up to 15 km/h thanks to an acceleration section. This paper presents a rigorous description of the system characteristics from a transportation point of view, develops a heuristic algorithm for the network design problem, and tests it on a real case study. Given a network of urban roads and an origin-destination demand, the optimization algorithm, which combines traffic assignment and supply modification, explores the trade-off curve between the total travel time and capital cost of the infrastructure. The results give practical insight on the possible dimensioning of the system, show the optimal network designs, and how these vary with a reduction of the available budget. This paper investigates for the first time the use of AMWs at a network scale, and provides results useful for analyzing the system feasibility. The results on travel time, investment budget and payback period indicates that AMWs could be an effective mode of transport in cities.

1. Introduction

Vehicular traffic contributes to pollution, congestion and the risk of accidents for road users, especially in urban areas (Calthrop and Proost, 1998). For these reasons, public authorities adopt various strategies to promote a reduction of private vehicles, such as congestion charges, construction of pedestrian areas and cycling infrastructure, and incentives for public transport (Poudenx, 2008).

Moreover, the current threats to our modern societies caused by global warming, the shortage of energy supply and the population growth justify considering disruptive solutions for the mobility of people. Several municipalities have created new neighborhoods in cities where the entire mobility system strongly limits the use of private motorized vehicles. Successful examples of these areas are the car-free districts of Vauban in the city of Freiburg, Germany, and the district of

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Floridsdorf in Vienna, Austria (Coates, 2013; Ornetzeder et al., 2008). The idea of proposing completely new transportation systems able to replace the role of private cars has been investigated for decades (Urry, 2008; Rigal and Rudler, 2014). For example, referring to private cars, Mumford (1963) states that "the only cure for this disease is to rebuild the whole transportation network on a new model".

In order to explore new modes of transport without restrictions, we assume a scenario where private vehicles are strongly limited in city centers (PCW, 2015). In this scenario, besides traditional systems like buses, metros, trams and taxis, walking and cycling play a much more important role, together with innovative systems like bike-sharing and car-sharing. In addition, futuristic modes of transport can be part of this modal mix. For example, projects of urban cable cars and personal rapid transport systems are increasingly studied as a solution for the future mobility (Brand and Dvila, 2011; Cottrell, 2005).

The focus of this project is a possible futuristic system: an urban network of accelerating moving walkways (AMW). Moving walkways, also referred to as moving sidewalks, are capable of facilitating pedestrian movements, and their use has been imagined since the late 19th century by urban planners, engineers and science-fiction writers (Asimov, 1954). The first real implementations of moving walkways were presented in exhibition events such as the *Exposition Universelle* in Paris, France, in 1900 (Avenel, 1900). Nowadays, they are mostly installed in transportation hubs such as airports and train stations (Scarinci et al., 2017). Among the possible futuristic modes of transport, we investigate AMWs because this technology is fully electric, has a low energy consumption, a high capacity and requires limited space. In many cities, the available space for transportation is scarce, and conflicts are present for the allocation of this space, which is usually primarily devoted to car traffic (Gossling et al., 2016). This makes moving walkways suitable for dense city centers with a high passenger demand. Furthermore, this system could be a catalyst for a more sustainable transport system, having limited greenhouse gas emissions and promoting walking (see Section 2).

Unlike traditional constant speed moving walkways (CMW), AMWs present an acceleration section at the embarking area that accelerates passengers to a speed higher than that of CMWs. Examples of accelerating walkways show that the system can reach 12–15 km/h (Kusumaningtyas, 2009), a speed competitive against urban bus and tram services, as well as private vehicles, which travel at an average speed of 15 km/h during peak hours (Christidis and Rivas, 2012). The use of AMWs is "competitive to that of the discontinuous transport systems [such as busses and light rail] when the walking time, waiting time, and dwell time in stations are taken into account" (Kusumaningtyas and Lodewijks, 2008). Kusumaningtyas and Lodewijks (2008) conclude that AMWs can be competitive thanks to their capacity, speed, energy consumption, safety and possibility to be integrated into the urban environment.

We develop a heuristic algorithm inspired by the ones used to solve transit and road network design problems. The algorithm, presented in Section 5, combines traffic assignment and supply modification. This allows us to design a network, not only individual paths, of AMWs. Each urban road has the possibility to be equipped with an AMW. Besides AMWs on single roads, we envisage AMWs able to span over intersections without requiring disembarking and re-embarking on the next AMW. We refer to these direct links as *expressways*. This allows the study of a complex network of AMWs.

This paper has three main contributions. It is the first time that the AMW system is approached at a network scale. This innovative system is receiving increasing attention as a possible solution to reduce transfer time in transportation hubs, incentivize walking in metropolitan areas and reduce pollution. However, it has never been studied as a possible integrated transportation system at the urban scale. The second contribution is the identification of an appropriate optimization framework specific for the AMW system. Although many mathematical formulations and solution methods have been proposed in the transit and road network design fields, AMWs have particular characteristics not present in any other transport system. Thus, taking inspiration from existing approaches, we propose an adapted framework for optimizing a network of AMWs. The final contribution is given by the results on the real case study. The resulting optimized network designs cannot be considered ready-to-use configurations of the AMW system. However, they provide a valid starting point for discussions with decision makers and town planners to evaluate the potential of AMWs as a possible transport mode in urban areas. We want to underline that the present work is a fundamental research project, and it does not aim to give a practice-ready solution.

The remainder of this paper is structured as follows. Section 2 reviews the transportation characteristics of the accelerating moving walkway system. Optimization frameworks in the fields of transit network design and road network design are reviewed in Section 3. Sections 4 and 5 propose a mathematical model and describe the solution methodology for designing a network of AMWs, respectively. The results of the optimization on a real case study are presented in Section 6. The paper closes with the main conclusions in Section 7.

2. Review of accelerating moving walkways

Since the 1960s, several ideas on how to achieve a speed higher than that of CMWs have been proposed (Kusumaningtyas, 2009). In the 1970s and early 1980s, some of these ideas were made into prototypes of AMWs and tested. Although none of them were commercialized, their working principles were later adapted for subsequent AMW designs. Prototypes of these later designs were built and tested in the late 1990s and early 2000s. For example, in 2000 an AMW was installed in Montparnasse station in Paris, connecting the subway station to the train station (Gautier, 2000). In 2007, an AMW was built in Toronto Airport between Terminals 1 and 2 (Gonzalez Alemany et al., 2007).

The topic of AMWs has received increasing attention in the scientific literature in recent years. Saeki (1996), Shirakihara (1997), Ikizawa et al. (2001) and Gonzalez Alemany and Cuello (2003) present the system from a technological point of view.