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A new transportation system for efficient and sustainable cities: Development of a next generation variable speed moving walkway

David Rockwood[a,*], David Garmire[b]

[a] University of Hawaii at Manoa, 2410 Campus Road, Honolulu, HI 96822, USA
[b] University of Hawaii at Manoa, 2540 Dole Street, Honolulu, HI 96822, USA

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ABSTRACT

Urban areas require safe, fast, energy-efficient public transportation in order to provide sustainable living conditions. Unfortunately, many cities do not have the space or resources to provide robust public transport systems, such as subways. We investigate moving walkways as another mode of transportation. To date, moving walkways have served a minor role in transportation and are typically located only within airports. The key challenge that we overcome is how to design and integrate variable speed moving walkways so that they become a fast mode of transport that can integrate with urban infrastructure to provide an alternative or supplement to systems such as busses and subways. We address how to safely control and operate such walkways. In comparison with existing forms of public transportation, this mode of transportation allows lower latencies with higher throughput by operating continuously and allowing acceleration and deceleration of passengers.

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1. Introduction

According to recent U.N. statistics, the majority of the world's inhabitants live in cities, many of which are without developed transportation infrastructure (United Nations Human Settlements Programme, 2013). The trend toward urbanization is projected to continue with much of this growth concentrated in megacities (Parrish & Tong, 2009; Taubenböck et al., 2012). Within dense urban conditions proper transportation infrastructure is a key ingredient to economic and social development. Without it, urban dwellers suffer negative effects of congestion, pollution, and the loss of time and productivity.

Most urban commutes are relatively short; however, larger cities have led to longer commute times on average (Sudhakara Reddy & Balachandra, 2012; Zhao, Lü, & de Roo, 2011). In the context of a city with high density, economic prosperity, and amenable below-grade conditions, a subway system may be configured to provide near optimal primary means to transport the highest numbers of people at the quickest possible speed. Unfortunately, such conditions are fairly rare. This situation appears to call for new solution to the problem of providing quick and affordable urban public transportation. Essentially, transport must be brought closer to both the departure door and the arrival door, and be able to operate in a more continuous manner and at a constant rate of speed. In doing so, even a slower speed system could win out over a faster speed system in many urban door-to-door commutes.

A first step in looking for a new solution is to find a transportation mode that is a continuous system. The transportation mode would not require a rider to wait for a vehicle to arrive, people to enter the vehicle, and for people to exit the vehicle. The only known such transportation systems are escalators and moving walkways. Unfortunately these systems are quite slow. However, in contrast with subway systems, escalators and moving walkways are quite compact, accommodate varying architectural and urban conditions, and are relatively efficient to operate. It is more feasible to bring an escalator or moving walkway closer to a departure or arrival door than a new subway station. In addition to the significant costs of building subway stations, having such stations close together causes the system to lose efficiency in that the trains make frequent stops, and may never reach full speed between stops due to the need to maintain fairly gentle acceleration and deceleration rates.

In answer to these constraints, we detail the implementation and operation of a variable-speed moving walkway which can accelerate and decelerate to accomplish continuous personalized human transport in an urban environment. We show the fabrication details, design footprint, and operating principles for such

* Corresponding author. Tel.: +1 808 222 2036.
E-mail addresses: rockwood@hawaii.edu (D. Rockwood), garmire@hawaii.edu (D. Garmire).

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a system. We report on an examination of its energy efficiency, impact on commute times, and other considerations.

2. Background

There are many types of urban transportation. For shorter commutes, walking or bicycle riding may be a viable choice for many people. For longer distances, powered vehicles may be used, such as cars, buses, and trains. Unfortunately, in many large cities most transportation systems that operate on the main street level are subject to high levels of traffic, and therefore may be quite inefficient both in transit time and energy expended (Barberillo & Saldaña, 2011). Below grade or elevated systems have an advantage over on-grade systems in being able to operate more independently from competing transportation modes. Such above or below grade systems typically use medium or light gauge "subway" trains running on steel rails. These trains can be powered using clean and quiet electrical power, and are relatively efficient to operate. Subway trains can operate at fairly high speed, hold a number of passengers, and therefore provide the highest "throughput" of any urban transportation type. For cities that can afford to build and maintain such systems, they typically provide the primary means – among all other transportation modes – to offer adequate movement of the urban population.

Subway systems have a number of advantages, but also have some drawbacks. Elevated systems may block out views and sunlight, be difficult to access, and may contribute to noise pollution (Maisonneuve et al., 2009). Below grade systems may be difficult and expensive to construct in dense cities having a significant existing below-grade infrastructure or a high water table.

Trains use a vehicle body as a first line of defense to protect riders against contacting stationary objects or objects moving at different rates of speed. The vehicle body can contain a given number of people. People must therefore wait for the vehicle to arrive, and wait for people to enter and exit the vehicle. As such, a train is type of intermittent system. The frequency of subway trains is typically determined by estimated required carrying capacity at different day/time periods. For example longer trains might be scheduled for more frequent periods during peak periods. Some cities however may not be able to afford to provide the necessary capacity during peak periods, leading to crowded stations and longer wait times (Lam et al., 1999).

Transit time is an important concern for many people, as it is typically not highly productive time, and takes away from other activities. It is therefore important to examine the various steps that contribute to total transit time. For example, a typical "door-to-door" commute might consist of a person undertaking the following steps: (1) walking from their apartment to the subway street entrance, (2) taking a stair or escalator to the subway station, (3) walking through the subway station to locate the correct track, (4) waiting for the train to arrive, (5) waiting for passengers to unload, and waiting for passengers to load, (6) stopping at intermediate subway stations, (7) disembarking from the train, (8) walking through the subway station to the desired exit, (9) taking a stair or escalator to the street level, (10) walking to the desired final destination. These steps of course add up, and may be particularly time intensive in certain circumstances. A worst-case scenario might be where the walking distance from the original departure point to the station and from the station to the final destination is quite long, the train distance is relatively short, and the train arrival frequency is low. Such a scenario would obviously equate to a fairly long time used to travel a relatively short distance.

An amusing, though perhaps enlightening event, named the Seventh Annual Great NYC Commuter Race pitted a bicyclist, subway rider, and car driver on a sample commute between Fort Greene in Brooklyn and Union Square in Manhattan (approx. 7 km). The results were that the bicyclist finished in 16.5 min (average 25 km/h), the driver 22 min (average 19 km/h), and subway rider 29 min (average 14.5 km/h) (Parrish & Tong, 2009). According to U.S. Census information, the average U.S. commute time in 2009 was 25.1 min (Mckenzie & Rapino, 2011a). The rates tend to be higher in urban areas, with 34.6 min being the average in the New York-Northern New Jersey-Long Island Metro Area commute time (Mckenzie & Rapino, 2011b). While a subway system promises to speed the door-to-door transit time, this is not always the case.

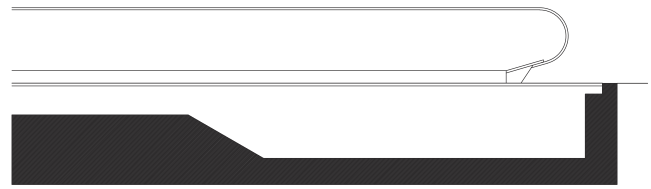

Fig. 1. Longitudinal section of typical moving walkway showing below floor service space.

To be more effective, a system would have to build more stations to decrease the distance between stations, and run trains more frequently. Such measures would entail significant initial and operating costs. Extremely large and dense cities – of which Tokyo is perhaps the best example – can afford to implement such systems, while the majority has to provide more compromised approaches. One study for Calgary, Canada reported average walking times to light rail transit of 326 m (O'Sulivan & Morrall, 1996). Assuming an average walking speed of 4.5 km/h, this would equate to a walking time of 13.8 min. Having stations closer together decreases walking time to the station, and may tend to encourage ridership. However, time saved in walking to the station may be offset in some circumstances by the train needing to make more frequent stops.

2.1. Existing single speed moving walkways

Therefore, if a continuous system, such as an escalator or moving walkway could be made to run at higher speed, it appears a new solution to urban transportation might be available. Moving walkways have become commonplace in recent years as a means for low-speed mass transit in public spaces, such as airports, train stations, and amusement parks. Typically, a moving walkway includes a chain of linked pallets that provides a standing surface, along with a belt handrail. The standing surface and handrail are driven at a speed slightly slower than a normal walking speed (approx. 0.75–1.25 m/s) to help provide an adequate safety margin for persons entering and exiting the moving walkway (Kusumaningtyas & Lodewijks, 2008).

Conventional moving walkways have a number of drawbacks that limit their wider application. The most common type of moving walkway uses a number of interconnected metal pallets set on rollers. The pallets so assembled form a loop chain in which an exposed upper portion provides the standing surface for users. When the loop chain reaches the end of the walkway, the pallets are turned and returned in a service space concealed directly below the exposed upper portion. The concealed service space is typically around 1 m deep at the walkway ends, and 0.3 m deep in-between (Fig. 1). This relatively deep space requirement below the walking surface and floor level imposes particular requirements on the building or supporting structure that may prove difficult or expensive to achieve, as the underfloor space may not be made readily available.

Another drawback found in conventional moving walkways is the degree of mechanical complexity involved in the design. Such complexity may precipitate in mechanical failures, frequent servicing, and mechanical noise. The number of moving parts

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