An exploration of moving walkways as a transport system in urban centers

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Abstract

Moving walkways (MW) have been imagined as a possible means of transport since the late 19^{th} century, and this system has fascinated urban planners and engineers ever since. Contrary to what has been imagined, moving walkways are only used in transportation hub corridors, and not as a main transport mode in city centers. Today however, MWs are receiving increasing attention as a possible solution to congestion and pollution, as well as a catalyst for soft mobility. This paper explores the role of moving walkways as a transport system. We review historical MWs, current installations and future possibilities, using different perspectives, from geography to urban planning to transport engineering. We discuss the way in which MWs influence how people inhabit the urban space, and we review this system in the context of history of urban planning. Then, we describe a technological development called accelerating moving walkways (AMW), i.e. MWs able to reach a higher speed than traditional ones. We develop an optimization framework to design a network of AMWs, and we apply it to a real case study. The results of the network design are a reference useful to discuss the feasibility of the system starting from an engineering perspective. We conclude that the use of MWs can facilitate the flexibility and spontaneity typical of pedestrian movements, and this system could be integrated in the mix of urban transport modes in city centers.

1 Introduction

Moving walkways (MW), also known as moving sidewalks, have been imagined as a system capable of facilitating pedestrian movements on specific routes, or even as the primary transport mode in city centers. This concept is present in the history of transportation since the late 19^{th} century, and it has fascinated science-fiction writers, urban planners and engineers ever since. The use of impossibly fast (more than 100 km/h) and massive moving walkways as the main transport system of future megalopolis was described in several science-fiction novels such as *A Story of the Days To Come* (Wells, 1897), *The Roads Must Roll* (Heinlein, 1940) and *The Caves of Steel* (Asimov, 1954). In the same period, real implementations of moving walkways were presented in exhibition events such as the *World's Columbian Exposition*, Chicago, USA, 1893 (Badger, 1979), *Exposition Universelle*, Paris, France, 1900 (Avenel, 1900) and *42nd street*, New York, USA, 1923 (NYPL, 1923). These MWs were composed of parallel lanes, each of them moving at a higher speed, reaching the maximum speed of 9 km/h. The users could access them laterally everywhere and reach the high-speed lane jumping from one belt to the adjacent one, see Figure 1(a).

Nowadays, MWs consist of one lane only, and the lateral access is not allowed for safety reasons, see Figure 1(b). In addition, the maximum speed is limited to 3 km/h to avoid discomfort. They are used on individual routes with high demand, usually in large transportation hubs such as airports and metro stations. In a few cases, MWs are installed in cities, for example, the *Central-Mid-Levels escalator and walkway system* in Hong Kong (Cullinane, 2002), the *Mechanical Ramps* in Vitoria-Gasteiz (Helzel and Taylor, 2011), or in hilly urban environments to facilitate the access to elevated areas, for instance, Medellin, Colombia (Nakamichi and Nakamura, 2014) and Perugia, Italy

(a) (b)

Figure 1: Moving walkways. (a) historical MW at the Exposition Universelle in Paris, 1900, composed of two parallel lanes with increasing speed. (b) modern MW installed in a transportation hub. Adapted from Avenel (1900) and Otis (2015).

(Ciuffini, 1983).

Contrary to what was presumed in the past, MWs are not used as a means of transport in city centers. The presence of private and public vehicular traffic is still predominant, and pedestrian mobility plays a minor role. Due to congestion, pollution and urbanistic considerations, soft mobility is now being promoted in particular in dense urban environments (EC, 2011). MWs could facilitate walking, and incentivize the modal shift toward more sustainable means of transport. Moreover, the system is fully electric, and it has a low energy consumption and noise level.

This paper explores the use of MWs as a transport mode, the limitations, opportunities, technological developments and cultural paradigm shifts necessary for the success of this system. To do so, we adopt a multi-disciplinary approach. At first, we follow the geographic and urbanistic perspectives. We describe how MWs can influence the way in which individuals experience and move in the urban environment, and we empathize the opportunities offered by this means of transport. Then, we discuss the role of MWs in the broader context of the history of urban planning. After this analysis, we shift the perspective completely, and we investigate the system from a transport engineering point of view. The idea is to design a network of MWs starting from transportation and practical considerations such as speed, cost and passenger demand. This allows us to analyze the characteristics of the system, and to examine its feasibility based on an engineering approach.

To design a network of MWs, first, we review the technological advances and modern implementations of this system. An interesting development is the so-called accelerating moving walkway (AMW), which provides a higher top speed than traditional MWs. In a related work, we have developed an *ad hoc* optimization framework to design the network of AMWs that minimizes the travel time of passengers (Scarinci *et al.*, 2016). We have tested this framework on a real case study for different budget constraints analyzing travel time and costs. In the current paper, we report the main findings of this study and we focus on urbanistic oriented considerations. In the case study, we envision a Post-Car World scenario, where the use of private cars is limited in city centers (PCW, 2015), and the entire passenger demand is satisfied by AMWs or walking.

The paper is structured as follows. Section 2 discusses the signification of MWs for the individuals moving through the space and the existential implications on the inhabiting space. In Section 3, we look at the re-consideration of MWs in the 20^{th} century, following the critiques of the car and the attempts to seek futuristic mobility alternatives. Section 4 reviews the technical characteristics of accelerating moving walkways, as well as current installations. Section 5 investigates the possibility to use AMWs as an urban transport mode by designing a network of AMWs on a real case study. The main conclusions are reported in Section 6

2 The moving walkway as a new way of inhabiting the urban space

The private car is often regarded as a means of transport offering a great freedom of movement, seen as a major quality of this mode of transport. In fact, the use of the car implies accepting inhabiting the space in a tunnel perspective. The car limits the possible spatial behavior of its driver to a movement forward, and its interaction with the immediate environment to occasional honking or headlight flashing (Ourednik, 2008). Especially in the urban context, it is by no means easy to park a car and to leave it in order to engage into more complex ways of inhabiting the space (Heidegger, 1954; Bollnow, 1967).

As opposed to the coerced freedom of the car, pedestrian movements are characterized by flexibility and spontaneity, providing opportunities for interactions. However, this flexibility is only efficient in the context of dense and diverse urban centers, where such opportunities, whether they consist of people or places, are close to each other. The experience of density itself, however, is also closely related to the speed of movements through a given environment (Ourednik, 2010). Even in an urban setting, the number of reachable elements remains limited by the speed of pedestrian movements. As the average topographic distances between objects of interest grow, only speed of movements can restore an experience of density. Conversely, this also means that urban density, understood as an interaction potential, can be augmented by accelerating the pedestrian movements. Being capable to reach more things, people and places, signifies having more choice of action. It opens up individual's existential perspectives: which is the very purpose of any city. The collateral effect of this acceleration, however, is cutting the individual off the immediate environment of his/her movements. A compromise thus has to be found between speed and the potential of local interactions.

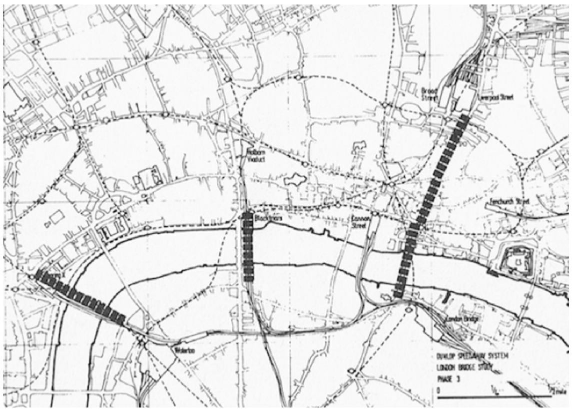
Open vehicles, such as bikes or segways, constitute an answer to this problem. Another original answer is given by MWs, especially when these are organized into a network where the individuals can choose the direction at each crossroads. The technical implications of the construction of such a network are by no means trivial and are discussed in the following of the present paper.

3 The moving walkway in the broader context of the history of urban planning

The ecological consciousness, oil crisis and the spatial consequences of decades of car urbanism generated, during the 1960s and 1970s, an urge to seek alternatives systems to car mobility. With the conviction that "people will use automobiles as long as nothing better is available" (Gruen, 1964) a series of explorations started proposing new innovative possibilities for the future that will give even more delight and convenience to the user. Given the considerable amount of studies and experiments on mechanical means of moving people prior to the mass motorization era, up to 1920s, urban projects in this period reemployed many of the historical schemes and examples to develop the future with the objective of reducing the role of the private car. Among many transport systems imagined, such as mini-rails, self-driven mini taxis, automatic people movers, and other non-stop moving systems, MWs were a promising recurrent scheme. Applied mostly within transportation hubs and shopping malls, it was also imagined to be a viable transport means for intra-city movements, especially within the new developments.

MWs, also called pedestrian conveyors in the literature, were thought not only as an aid to pedestrian movements but also capable to provide a new experience, with a view over the city at a different speed, not necessarily faster than that of pedestrians. In an inventory of transport systems proposed by Richards (1966, 1976) the average speed of pedestrians (4.8 km/h) was interestingly higher than that of pedestrian conveyor (3km/h). However, given the fact that they could be walked on, the speed as an advantage was not excluded. Such effortless, immobile walk of the pedestrian conveyors offered another vision of the city without regrets for the car. As described by Rouillard (2013), the city is like a permanent Exposition Universelle. Richards (1976), in his exploratory surveys into the future, also introduces the idea of high-speed conveyors, called Speedaway, with the average speed of 12-16 km/h. The Speedaway was intended to run above London Bridge, one of the densest corridors of movement in London, see Figure 2. The proposal used twin high-speed conveyors, operating within an air-conditioned enclosure and connected at either end with elevated pedestrian decks linked with the underground stations close by. The system was above all considered as a complement to both existing and future modes of transport. The critical challenge however, was the spatial arrangement, the insertion of the system within the existing width of streets. Therefore in many cases it was imagined as an elevated level, following examples like the London Pedways project (Hebbert, 1993). This project planned and partly implemented a network of elevated walkways throughout the city, re-proposing the traditional idea of separating pedestrians from motorized or wheeled traffic.

It is not irrelevant, proposes Rouillard (2013), to link the very concrete and persistent ideas and sketches of moving walkways and other innovative moving systems, with the more utopian imaginaries of the time, which were focused on the idea of augmented pedestrian and ecstatic mobility. For example, Cook (1999) proposes a combination of cushion and vehicle called the Cushicle. It was a sort of mobile structure in two parts: a chassis with appliances and personalized apparatuses and an inflatable envelope. Like a car, the Cushicle was envisioned as eventually becoming part of an urban system of personalized enclosures, though it was conceived as usable in any environment. From the



(a)

(b)

(c)

Figure 2: Speedaway system. (a) Plan showing the Speedaway system crossing the Thames connecting existing underground stations on the north bank with new developments on the south bank. (b) Interior view along the system. (c) Speedaway running above a car-free shopping street. Adapted from Richards (1976).

Cushicle to ideas of individual air travel, they were all struggles to achieve new paradigms in transport in cities, hoping that, as Buchanan (1963) put it, “we are not at the end of our ingenuity for that matter”. Contrary to many of its contemporary ideas, moving walkways were actually applied in real contexts, and nowadays are installed in several environments.

4 Review of accelerating moving walkway

The main limitation of MWs is the low speed, and since the 1960s, technical solutions able to achieve higher speeds have been investigated (Kusumaningtyas, 2009). Some of these solutions were developed between the 1970s and early 1980s, and the first prototypes of accelerating moving walkways (AMW) were made. The successful prototypes were built and tested in the late 1990s and early 2000s.

Since then, AMWs have received increasing attention from researchers. Gonzalez Alemany and Cuello (2003), Ikizawa *et al.* (2001), Saeki (1996) and Shirakihara (1997) study the technological aspects of the system. Abe *et al.* (2001) propose a different design able to cover inclined and even curved paths. The integration of this innovative system with the urban infrastructure is studied by Rockwood and Garmire (2015). Kusumaningtyas *et al.*, in several research papers focused on AMWs, make a comprehensive investigation of the system from a technical and transportation perspective (Kusumaningtyas and Lodewijks, 2008; Kusumaningtyas, 2009; Kusumaningtyas and Lodewijks, 2013).

In the following, we present the AMW characteristics, the different AMW types and two installation examples.

4.1 Technical characteristics

AMWs are divided into three sections: acceleration, constant speed, and deceleration. The acceleration section, as the name suggests, has an acceleration between 0.14 m/s^2 and 0.43 m/s^2, depending on the installations (Dembart, 2003; Gonzalez Alemany *et al.*, 2007; Kusumaningtyas and Lodewijks, 2008, 2013). In this section, the speed increases from the entry speed between 2.1 km/h and 2.7 km/h (Donoghue, 1981; Fruin, 1992) to the top speed. Real implementations of AMWs show that the top speed can be up to 12 km/h (Kusumaningtyas, 2009). The constant speed section has zero acceleration, and passengers can walk. Thus, the walking speed is added to the top speed of the AMW. The walking speed depends on factors such as the age, gender and trip purpose of the individuals. However, as a reference, Young (1999) shows that the walking speed on MWs is on average 3.7 km/h. The final section is the deceleration section. Here, the speed decreases to an exit speed equal to the entry speed for a safe disembarking.

AMWs have a constant width along the entire length. The typical width of the internal space usable by passengers is between 0.8 and 1.6 meters, and, considering the required lateral installation, the corridor width ranges between 1.2 meters and 2.3 meters (Kusumaningtyas, 2009). The length is limited by the technology, and it ranges between 120 meters and 350 meters (Abe *et al.*, 2001; Lechner, 2011).

The capacity of an AMW, expressed in passengers per hour (pax/h) per direction, depends on the entry speed and the width. Typical installations have capacities ranging from 4,500 pax/h to 7,500 pax/h (Kusumaningtyas and Lodewijks, 2008). The capital cost of AMW, including the surrounding structure, is between 34.8 million EUR/km and 54.4 million EUR/km, and the operational cost ranges from 0.08 EUR/pax-km to 0.42 EUR/pax-km, with a typical value of 0.13 EUR/pax-km (Kusumaningtyas, 2009).

AMWs present a limited energy consumption of approximately 0.11 MJ/pax-km. They are fully electric, thus, reduce local emission of greenhouse gases. In addition, the system has a low noise level close to 54 dB(A) (ThyssenKrupp, 2004).

In comparison with other urban means of transport such as buses and light rail metro services, AMWs have a competitive speed, operational cost and capacity with the advantage of a limited corridor width. However, AMWs present a greater capital cost, especially in comparison with busses (Kusumaningtyas and Lodewijks, 2008). Busses and light rails have higher top speeds than AMWs, however, the discontinuous nature of these systems decreases the average speed. Busses have an average speed between 15 km/h and 20 km/h, while light rail can reach speeds up to 45 km/h (Brand and Preston, 2003; KFH Group, 2013). AMWs can have maximum speeds up to 15-17 km/h thanks to the possibility of pedestrians to walk on the constant speed section. This speed is competitive with private cars during peak hours, which travel at an average speed of 15 km/h (Christidis and Rivas, 2012). AMWs are designed for a high traffic demand, and they have a maximum capacity larger than buses which is between 1,000 pax/h and 4,500 pax/h, but lower than light rail services, which can serve up to 30,000 passengers per hour (Brand and Preston, 2003; KFH Group, 2013). Moreover, AMWs require a limited space for installation in comparison with the other means of transport. This is an advantage for the integration of the system in the urban environment. Busses and light rails have corridors width between 2.5 meters and 4.2 meters per direction, more than double the minimum width of an AMW (KFH Group, 2013). While the operational cost is similar among all means of transport, AMWs present the high capital cost. This cost is comparable with the one of light rails, but much higher than the bus cost, which maximum is around 6.7 million EUR/km (Kusumaningtyas and Lodewijks, 2008). AMWs consume less energy than busses and light rails, which consumption ranges from 0.30 MJ/pax-km to 2.50 MJ/pax-km. Also the noise level is lower than the other means of transport that are between 60 dB(A) and 84 db(A) (Brand and Preston, 2003).

In order to study a network of AMWs and not only AMW on individual paths, we need to make hypotheses on the behavior of the system at junctions. Passengers have two options at intersections. Either the AMW where they are travelling spans over the intersection allowing them to travel at the top speed, or they disembark and re-embark the next one. We refer to AMWs that span over several roads without decelerating at intersections as *expressways*. Given the absence of MW junctions in real installations, we take inspiration from existing embarking/disembarking and intersection systems from other technologies, and we propose hypothetical designs. Inspiration is given by reviewing solutions implemented for conveyor belts used for goods (Alspaugh, 2008), and real life implementations and futuristic ideas of intersections for pedestrian and vehicular traffic such as cross intersection, rotating platform, circular walkway (DfT, 2011). We envisage several designs, from a simple approach where everyone is slowed down, to a complex intersection with multiple expressways at different levels, see Figure 3. The intersection design itself and the necessary technology is not part of the present study. We refer to

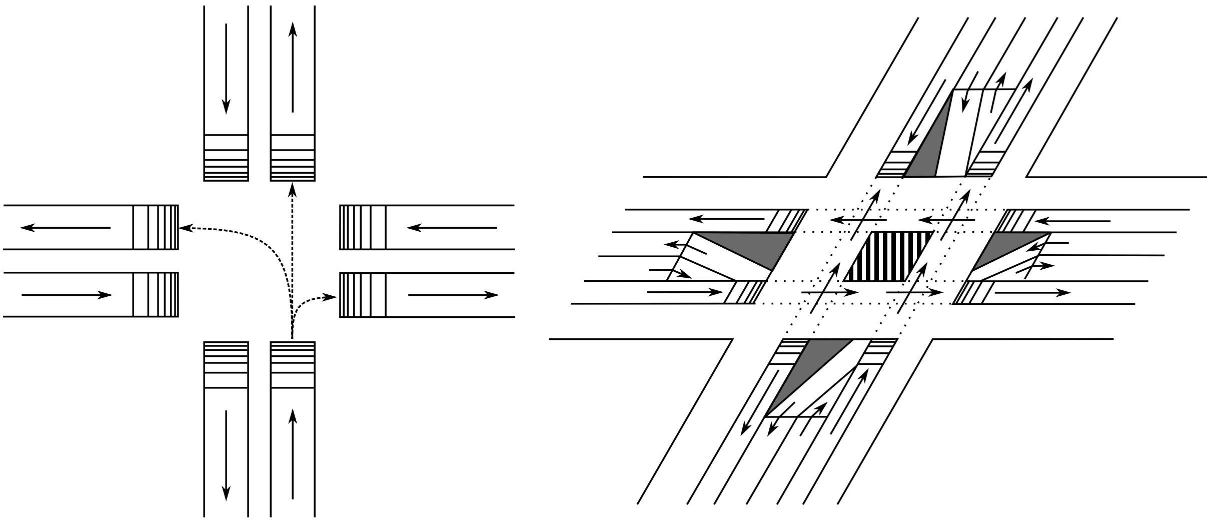


Figure 3: Possible intersection designs: (a) single-layer intersection and (b) multiple-layer intersection with expressways. Adapted from Rojanawisut (2015).

Rojanawisut (2015) for a review of possible intersections. We only assume the presence of expressways able to span across intersections without conflicting with other AMWs.

4.2 Types of accelerating moving walkways

Based on the method used to achieve acceleration and deceleration, AMWs can be categorized into four types: in-line belts, sliding parallelograms, accelerating/decelerating rollers and sliding pallets.

In-line belts

A number of short MWs with slightly different speeds are placed one after another, end to end. The in-line belts have increasing speeds at each entrance, such that they accelerate passengers to a high-speed MW in the middle section. Approaching the exit, another series of short MWs with decreasing speeds decelerates passengers, see Figure 4(a). This mechanism was used in the Loderway system (Loder, 1998), which was tested for public use in Brisbane Airport, Melbourne Airport and Degraves Street Subway in Melbourne, Australia. A similar system, named Speedmove, was also built by Fujitec (Kazuo *et al.*, 2003).

Sliding parallelograms

A series of parallelograms form a continuous tread way. At the entrance, the parallelograms are aligned along the long side, and they move at a low speed for a short distance. Then, while continuing to move forward, each parallelogram begins to rotate progressively sideways with regard to the parallelogram behind it. The result of the forward moving and the sideway rotation creates an acceleration zone, see Figure 4(b). The parallelograms stop rotating once they reach the target top speed. The method is

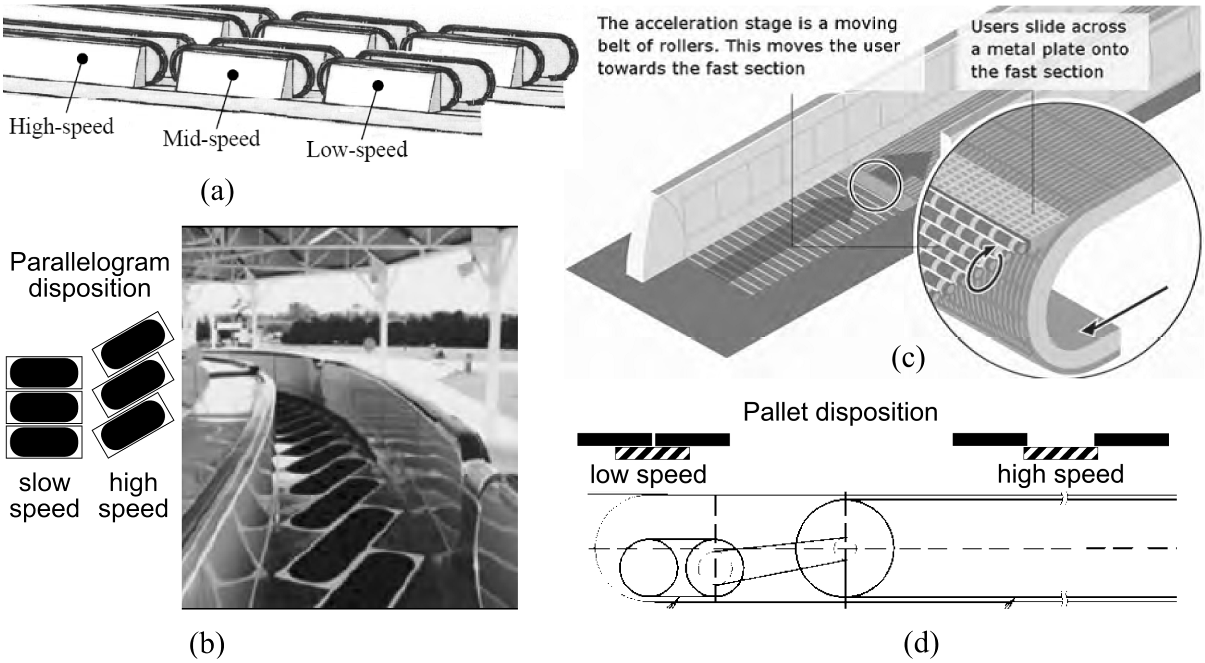


Figure 4: Accelerating moving walkway types. (a) in-line belts, adapted from Loder (1998). (b) sliding parallelograms, adapted from Todd (1974). (c) accelerating/decelerating rollers, adapted from Cote and Gempp (1998). (d) sliding pallets, adapted from Gonzalez Alemany and Cuello (2003).

reversed for deceleration at the exit. This mechanism was used in the Dunlop Speedaway (Todd, 1974), which was installed for public trial at the Expo '70 in Osaka, Japan, and at the Battelle Institute in Geneva, Switzerland. The Mitsubishi Speedwalk (Shirakihara, 1997), which was demonstrated at the Seaside Park in Fukuoka, Japan, also adopted this mechanism. This specific AMW had an S-shape, showing a possible solution for a curvy path. At the curves, the rotation and the forward moving of each parallelogram result in accelerating or decelerating zones adjusting the speed.

Accelerating rollers

In this mechanism, a "carpet" of metal rollers at the entrance accelerates passengers onto a high-speed belt conveyor. Approaching the exit, another series of metal rollers decelerates the passengers, see Figure 4(c). The mechanism was adopted by the Gateway system (Cote and Gempp, 1998), which was installed in 2002 for public demonstration in the Paris Montparnasse metro station.

Sliding pallets

There are a number of different variations in the way the pallets slide. One system accelerates and decelerates individual main pallets by sliding them over continuous auxiliary pallets (Ikizawa *et al.*, 2001). Another design uses an array of pallets that slightly overlap one on top of the previous at the entrance, each of which then progressively slides forward to accelerate passengers (Abe *et al.*, 2001). These two systems were only tested

(a) (b)

Figure 5: Accelerating moving walkway real implementations. (a) TurboTrack, Toronto airport, Canada, and (b) Gateway Paris subway, France. Adapted from Gonzalez Alemany *et al.* (2007), and Gautier (2000).

in the factory. A more successful variation is the TurboTrack system (Gonzalez Alemany and Cuello, 2003), which employs auxiliary pallets and main pallets, see Figure 4(d). At the entrance and exit, this AMW type looks like present-day metal-pallet MWs. The auxiliary pallets "hide" underneath the main pallets at the extremes, and progressively extend or retract to accelerate or decelerate passengers. In the low-speed zones, auxiliary pallets are non-visible, and main pallets have no space between them. In the high-speed zone, auxiliary pallets are visible and much longer than the main pallets. In the central zone, the auxiliary pallets are fully extended, forming a continuous tread way with the main pallets. This mechanism allows different speeds for the boarding, central and exiting zones.

4.3 Example of existing accelerating moving walkways

We review two examples of AMWs, underlining working characteristics and implementation problems.

TurboTrack, Toronto airport

The TurboTrack is a successful installation of an AMW currently in service, Figure 5(a). It is located in Toronto Airport, Canada, between Terminals 1 and 2, and it was built in 2007 by ThyssenKrupp Elevator (Gonzalez Alemany *et al.*, 2007). The technology of this AMW is based on sliding pallets. The entry speed is 2.34 km/h, which is like conventional moving walkways. This speed assures the same safety as MWs for boarding. In the middle area, the top speed is 7.2 km/h, three times faster than the entry speed. When pallets are fully extended, people can walk on the AMW to travel even faster. The length of the TurboTrack is 270 m, and one AMW for each direction is built. It allows people to travel that distance in only 140 seconds, while previous MWs took 415 seconds, thus reducing the travel time by two thirds. Acceleration and deceleration zones, i.e. the transition between low-speed and high-speed zones, measure around 13 m each. In about

10 seconds, the AMW reaches the top speed. This implies an acceleration of 0.14 m/s^2. The TurboTrack has a width of 1.2 m, which is the most common width used for MWs as well. It allows two columns of passengers, which permit the overtaking of standing passengers. The system has a capacity close to 7,000 passenger per hour, as calculated using the empirical equation defined by CEN (1998).

Gateway, Paris subway

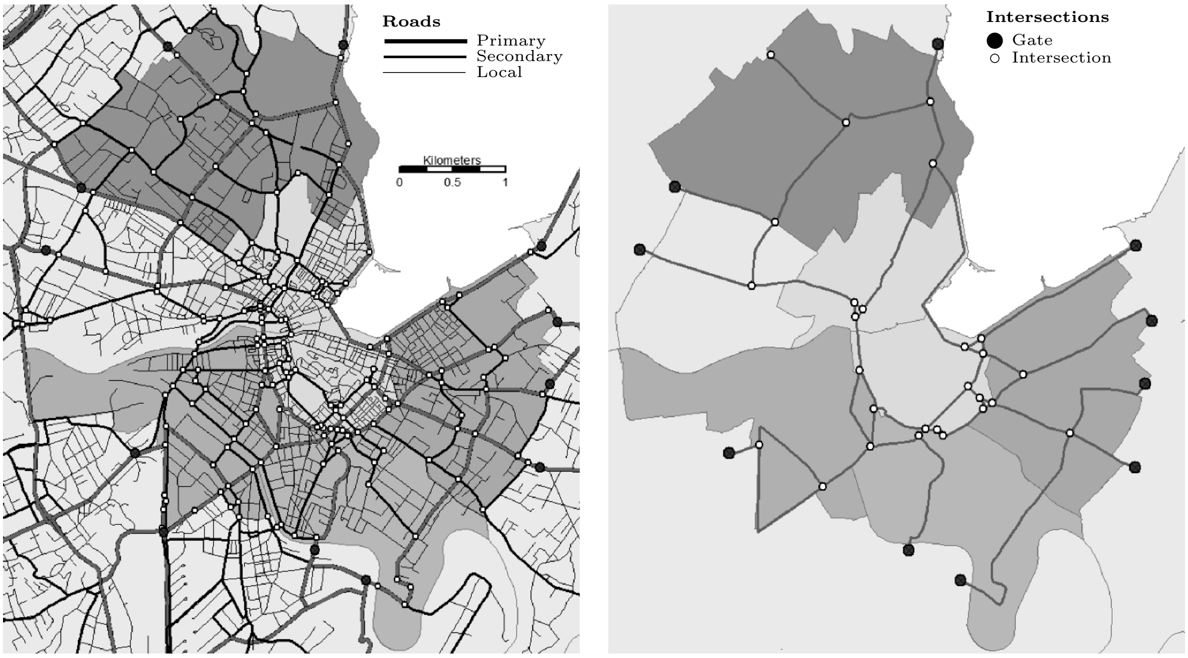
The one-lane Gateway AMW in Paris, France, at Montparnasse station, was inaugurated in July 2002 (Gautier, 2000), Figure 5(b). It was built to connect the subway station to the train station. The acceleration/deceleration rollers were subject to frequent maintenance due to breakdowns. The technology used for the acceleration section was considered not safe from many users, and it led to numerous passenger falls. Due to the presence of one lane only, it was perceived that the direction of travel was often in the wrong way. When tests were made before the Gateway opened for the public, the initial top speed was set to 10.8 km/h. However, it was reduced to 9 km/h due to safety problems. As the entire system speed and acceleration profile are interdependent, the entry speed was also reduced proportionally from 2.7 km/h to 2.2 km/h. The main problems were on the acceleration and deceleration zones. The most problematic issues were not the maximum speed in the constant speed section, but the acceleration itself. Initially, the acceleration was fixed to 0.43 m/s^2 (for high-speed of 10.8 km/h), however due to many problems related to feelings of unbalance or even falls, the value of 0.28 m/s^2 was chosen. The acceleration and deceleration parts measured about 10m, and, as the TurboTrack, the Gateway width is 1.2 meters and the capacity is close to 7,000 passenger per hour.

5 Network design of a transport system based on accelerating moving walkways

In this section, we study the use of AMWs at a large scale. First, we describe the optimization framework developed for this scope, and then we apply it to a real case study.

The network design aims to identify the set of AMWs that could best satisfy the passenger demand minimizing the total travel time in the city. A street network of interconnected roads, an operational budget and an origin-destination demand are the inputs of this problem. The result defines for each road, if it is equipped with an AMW, and if so, the speed profile and capacity of the installed walkway. To identify the solution, we evaluate only the travel time and the operational costs to run the system on an hourly basis. Other factors such as accessibility, comfort and construction costs are not considered.

To solve this problem, first, we formulate the system mathematically based on the characteristics previously reviewed, then we use an algorithm with a structure similar to the ones used in the field of road network design (Yang and Bell, 1998; Farahani *et al.*, 2013). This structure has two main tasks: traffic assignment and network update. In our case, we start with an initial network equipped with all feasible AMWs, which we iteratively transform by removing AMW lanes on selected roads until the operational budget



(a) (b)

Figure 6: Case study road network: (a) original road network and (b) simplified road network.

limit is reached. We refer to Scarinci *et al.* (2016) for the details on the optimization framework.

We apply the optimization algorithm to a real case study. The city of Geneva, Switzerland, presents a suitable traffic demand and road network.The traffic demand is represented by an OD matrix with twenty-six zones, seven of which in the city centers (DGT, 2015). It has 117,349 trips during the morning peak-hour. The city roads are classified into three categories: primary, secondary, and local roads (SITG, 2015), see Figure 6(a). We decide to evaluate the installation of AMWs on the primary roads only for their spatial characteristics. Primary roads present a larger road section adapted to car mobility that provides more space available for the insertion of the AMW system. In addition, primary roads present a reduced intensity of use by pedestrians compared to secondary and local ones in favor of vehicular traffic. Moreover, having a higher speed is also more desired in primary roads compared to small local roads with dense and intense public spaces where "pausability" and spontaneity of movements are their constitutive values. Thus, the choice of big arteries is made to minimize a fundamental drawback of MW infrastructure (like many other infrastructures), that is the creations of edges (barriers) and the reduction of the network permeability and thus spontaneity of flows. Gates are placed around the study area through which incoming and outgoing traffic can flow. Figure 6(b) shows the simplified road network, composed of 47 links, 37 intersections and 10 gates for a total length of 32 km.

The optimal network design of AMWs is returned by the optimization framework. To investigate how this AMW network modifies when the budget decreases, the optimal AMW network is computed for a maximum budget of 125,000 EUR. Notice that the budget constraints the operational cost to run the system during the morning peak-hour. Then, this budget is gradually reduced to 100,000 EUR, 75,000 EUR and 50,000 EUR. Although empirical data are used, we have no ambition of designing a ready-to-use network. The goal is to have possible designs of AMW networks based on transportation considerations, i.e. travel demand and travel time, on a case study, and to draw useful information for discussing the feasibility of this system.

The resulting networks are presented in Figure 7, where the origin and destination node for each AMW are connected by a straight line. This allows a clear identification of expressways, otherwise overlapping with individual AMWs on the same road. In all cases, the networks are composed by one lane AMW for each direction, and they are almost exactly symmetric. This means that AMWs would be installed in both directions on the equipped links. We remind that one lane is 1.2 meters wide, and it has a capacity close to 7,000 passengers per hour. In comparison, a one lane urban road has the minimum width between 2.5 to 3.5 meters and a capacity ranging from 750 to 1,800 vehicles per hour depending on the intersection downstream (DfT, 2011). This means that it is possible to install two AMW lanes, one per direction, in a single vehicular traffic lane. For example, on a standard two ways street, it could be possible to preserve one lane for the AMW system (both directions) and to modify the viability to the remaining transport modes to one-way. Alternatively, AMWs could be installed instead of on-street parking slots at the road side. This could allow the integration of AMWs while maintaining the traditional mobility.

The main disadvantage of the system is the high capital cost. For this reason, its application can be imagined in city centers with a high transport demand and a limited space. AMWs could be a substitute for other means of transport able to free valuable spaces for other purpose.

6 Conclusions

In this paper, we explore the possible use of moving walkways as a transport system. We use different perspectives, from geography to urban planning to transport engineering, and we analyze the system in different historical periods. We draw the final conclusions starting from the latest perspective and the possible future development.

The results of the optimization framework allow us to analyze the use of AMWs at a network level, and to provide useful considerations to delineate the system feasibility. Given the high capacity of the system and the limited space required, AMWs are suitable for dense city centers with a high passenger demand. The travel time between two given points remains the main criterion of this technical solution, aimed at intra-urban commuters primarily. However, the solution also allows us to imagine a possible city without cars, dominated by pedestrian mobility. The resulting network cannot be considered a ready-to-use design of the AMW system. However, it is a valid starting point for discussions with town planners to evaluate the potential of AMWs as a possible transport mode in urban areas.

The AMW system allows pedestrian movements to and from small local roads with public spaces where "pausability" and spontaneity of movements are needed. This is possible thanks to the network structure of the system. The presence of multiple nodes for accessing/exiting the AMW system makes it permeable. The pedestrians leaving this

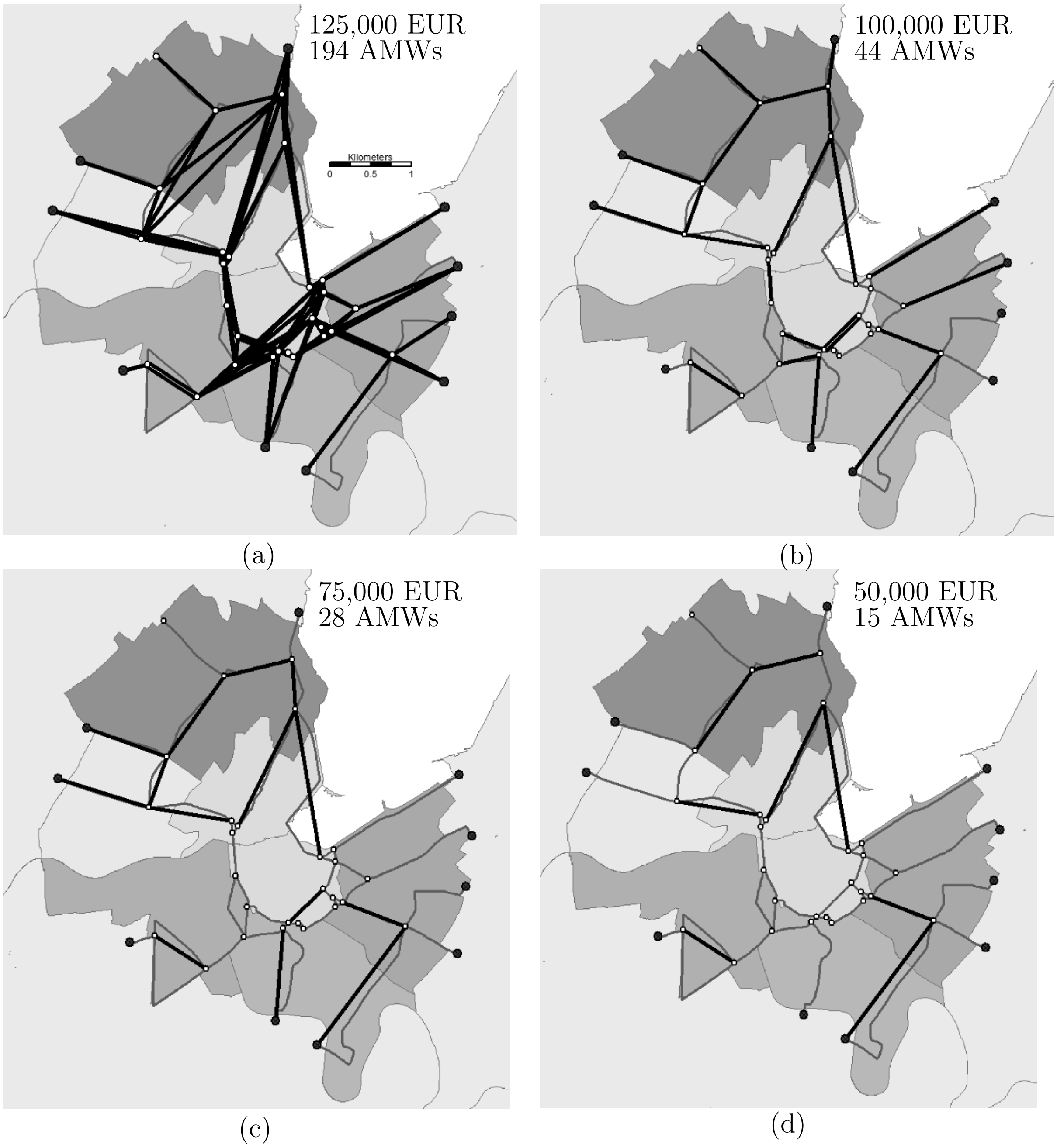


Figure 7: Case study results. Road network arcs equipped with AMWs for different operational budgets.

system of AMWs are directly liberated from the means of transport, i.e. they do not have to park the mobility device nor return back to it at the end of a journey. The experience of movement and the exposure to the surrounding environment is greater than in the closed space of a car. Interacting with other passengers during travel on the AMW is as in a public tramway or bus. This system could be a catalyst for a mobility paradigm shift. Nowadays, the transport system of the future is immagined being dominated by driver-less vehicles. However, AMWs, liberating the passengers by the vehicles, could incentive a future system composed by "vehicle-less" drivers, instead of "driver-less" vehicles. With this inversion of the paradigm, the individuals, and not the vehicles, are at the center of the mobility system.

Running in an ongoing fashion, moreover, the system does not force individuals to wait at public transport stops and generates, thus, a feeling of continuous flow similar to the pedestrian experience of the space. This happens also at intersections, thanks to the connections between AMWs and the presence of expressways, that allows a direct crossing of the junction. The continuous flow system lowers also the level of frustration experienced by drivers stuck in traffic jams and by pedestrians facing red lights on a road crossing. Thus, while allowing a gain in speed, the system does not prevent from taking advantage of the urban space. It might possibly contribute to liberate our cities from their twitchy rhythm imposed by car traffic into a space of continuous and unconstrained flow of social interactions. Replacing the car traffic, it should boost a more dense and vivid public space. In addition, the combined effects of promoting walking, fully electric system, low energy and space consumption could lead to a reduction of greenhouse gas emission and a more sustainable transport system.

The main limitations of the system are the architectural barriers that it creates inside the city center, the high capital cost, the acceptance of the system by the users and its accessibility. These aspects should be evaluated in further research, and the system feasibility defined more accurately.

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