The Journal of Transport and Land Use jtlu.org
Vol. 19 No. 1 [2026] pp. 441-473
https://doi.org/10.5198/jtlu.2026.2906

JTLU

Transport revolutions and urban development: Historical trajectories and possible futures

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Abstract: The configuration of cities has experienced profound changes over time, and one of the lenses through which these shifts can be interpreted is the emergence of successive transport technologies and systems, giving rise to major transport revolutions. Most of the first six of such revolutions have historically contributed to shaping urban morphology. This paper addresses this via the "one-hour city" hypothesis that combines the Travel Time Budget (TTB) assumption with the average travel distance and the speed allowed by the prevailing transport technology. Today, a seventh transport revolution is potentially unfolding, propelled by decarbonization, autonomous driving, and the introduction of digital mobility services. This ongoing transition holds the potential to reshape both the spatial and functional dimensions of cities, although overall effects are still unpredictable. These changes have been widely researched in recent years but often with reference to specific features. This paper presents research results in a holistic view, proposing two extreme, opposing scenarios. The first is based on a model of car ownership similar to the present, only based on autonomous cars. This scenario will be labelled as the "autonomous-car city." Research results suggest an increase in car demand and congestion, as well as a decrease in public transport ridership. Conversely, the "post-car city" scenario shifts from ownership to a "car-as-a-service" paradigm using shared, electric autonomous fleets. This transition drastically reduces parking footprint, enabling urban space reclamation and better separation between motorized and active transport modes. In both scenarios, public transit and individual mobility blur into Demand-Responsive Mobility Services. As for city dimensions, the analytical model would suggest that, given that the commercial speed of future services is arguably comparable to the present, spatial dimensions will depend on the value of average TTB. This paper concludes with some policy recommendations to steer future cities toward more sustainable trajectories.

Keywords: Transport revolutions, one-hour city paradigm, smart mobility, decarbonization, autonomous driving; city scenarios

1 Introduction

Throughout history, the form of cities and the development of transport systems have been closely intertwined to the extent that the transformation of one cannot be understood without the other. The basic principle is that cities are a group of residential, service to people, and economic activities that are in close connection with each other, significantly more so than with similar activities located out of the city (Jacobs, 1961; Koolhaas, 1978; Le Corbusier, 1935; Lynch, 1960).

Available transport technologies not only affect the dimensions of the city but also its structure, settlement configurations, density, land use, etc. (Alonso, 1964; Calthorpe, 1993; Christaller, 1933; Hall, 1998; Mumford, 1961; Sassen, 1991; Vuchic, 2007).

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Received April 24, 2026; Revised September 24, 2026; Accepted October 26, 2026; Available online November 16, 2026

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

Historically, the evolution of cities has been closely associated with successive transport revolutions, each of which has contributed to shaping urban form, structure, and spatial organization. Of course, transport technology revolutions have not been the only factor causing the changes in city structure and dimension, but it can be argued that without these revolutions, city changes couldn't have occurred. In particular, most of the first six transport revolutions can be interpreted as having a direct and measurable impact on the physical expansion and morphology of cities, influencing their size, density, and spatial configuration (Cascetta et al., 2021a, 2021b; Cascetta et al., 2025).

Ongoing technological innovations in the areas of decarbonization and energy transition, AI-supported autonomous vehicles (AV) and digitalization, and online availability of new transportation services have the potential to significantly impact the economy and society, qualifying to support a seventh transport revolution (Cascetta et al., 2021b; Cascetta and Henke, 2023; Cascetta et al., 2025). This revolution will likely impact also on cities structure and dimensions, even though these changes may follow different paths.

In this context, the present work adopts a holistic perspective based on the concept of transport revolution, aiming to interpret both past and ongoing transformations within a unified framework.

Accordingly, the study is organized around one overarching research question, which is addressed through four sequential and interdependent component research questions, each providing the conceptual basis for the subsequent analytical step; together, they build towards its answer.

Overarching Research Question: Can the impacts of transport revolutions be interpreted within a unified analytical framework capable of both explaining historical urban development and anticipating some possible scenarios arising from the effects of the ongoing seventh transport revolution?

It is addressed through the following four interdependent lines of inquiry:

(RQ1) Can the relationship between transport performance and urban structure be formalized through a simplified analytical model?

(RQ2) Can this analytical framework explain the mechanisms through which the first six transport revolutions influenced urban form and city size?

(RQ3) Can the same analytical framework be extended and redefined to capture the potential effects of the ongoing technological revolution under possible different scenarios of its deployment?

(RQ4) What is the role of public urban policies in orienting the deployment path of the seventh revolution for individual cities?

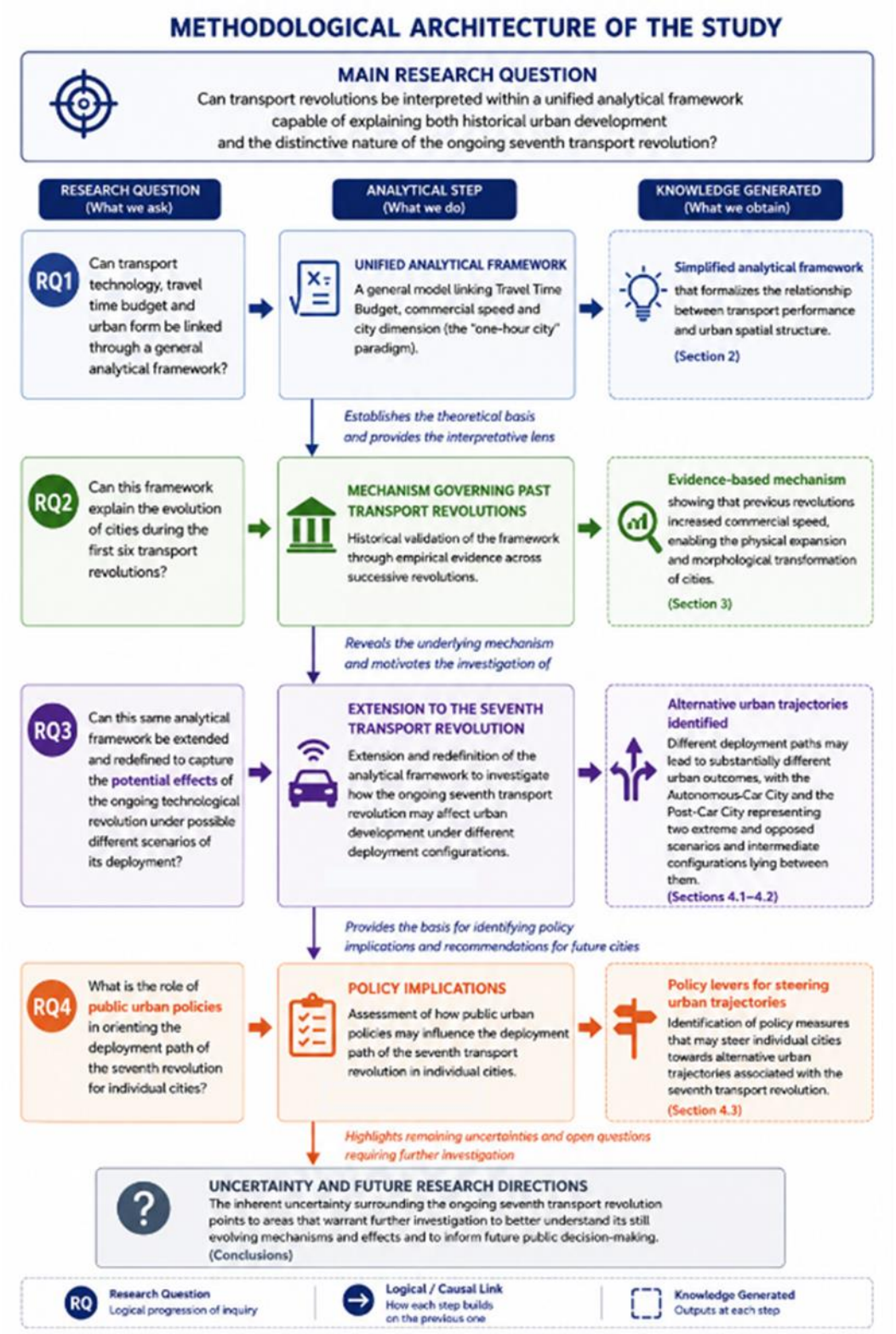


Figure 1. Overall conceptual framework and research design

Figure 1 summarizes the conceptual framework of the study, illustrating how the four research questions are sequentially connected and how each phase of the investigation contributes to the goal.

Accordingly, the contributions of this paper are fourfold. First, it develops a simplified analytical framework linking transport performance and urban spatial structure, providing the theoretical basis for the subsequent analyses. Second, it uses this framework to identify the mechanism through which the first six transport revolutions influenced urban morphology and city expansion. Third, it extends and redefines the same framework to explore the potential effects of the ongoing seventh transport revolution under different deployment scenarios, showing that its transformative potential may lie primarily in function-driven changes in urban organization and mobility practices, while further urban expansion would be primarily linked to changes in average Travel Time Budget. Fourth, it discusses the role of public urban policies in steering the deployment path of the seventh transport revolution in individual cities, identifying policy levers that may influence their trajectories towards alternative urban futures. Given the inherent uncertainty surrounding an ongoing technological revolution, the analysis also points to areas that warrant further investigation to better understand these still-evolving mechanisms and effects and, ultimately, to inform future public decision-making.

It is worth noting that although innovations driving the 7th transport revolution have already been studied diffusely in the literature, most papers refer to individual innovations such as decarbonization (Li et al., 2024; Sun et al., 2022; Wagner et al., 2023; Yang et al., 2024) or autonomous driving (Cugurullo et al., 2020; Dantsuji & Takayama, 2024; Silva et al., 2021; Yang & Oguchi, 2020). The urban development paths considered in the literature encompass both micro and macro changes. The former includes, for instance, the disappearance of traffic lights and road signs in general, enabled by V2I and V2V communication technologies (Lu et al., 2022), or the emergence of charging stations due to the increasing presence of greener vehicles (von Wahl et al., 2022). On a macroscopic scale, significant transformations can be expected as well. As shown by Duarte and Ratti (2018), for instance, in the case of autonomous vehicles, reduced demand for parking spaces and increased urban sprawl may occur as a result of greater ease in undertaking trips. Similarly, interesting insights into the impacts on travel demand and modal split, as well as urban sprawl, can be found in Chase (2015), Nahmias-Biran et al. (2021), Oh et al. (2020), and Oke et al. (2020).

Concerning decarbonization, instead, the more likely outcome goes in the opposite direction, i.e., improved central environmental conditions and a reduction in polluting traffic may render city centers more attractive for both residential and commercial purposes, thus promoting densification and urban reorganization in this direction (Kang et al., 2025).

Compared with the extensive literature on transport-related impacts, research addressing the effects of ongoing mobility innovations on urban structure remains comparatively limited (e.g., Guan et al., 2021; Llorca et al., 2022; Pimenta et al., 2023; Stead & Vaddadi, 2019).

The number of research papers dealing with expected effects of technological innovations not yet or only marginally available is very large and steadily increasing over the years, suggesting that the scientific community expects major changes even though these changes are difficult to anticipate at this time. This paper analyses a large body of literature results, putting them in the holistic perspective proposed. It must be stressed that almost all the research contributions are based on the results of computer simulations based on specific hypotheses on demand behavior and technological and economic performances (e.g., users' costs) as real-scale applications of emerging technological

changes, especially in autonomous driving, are in a very early stage with few, limited-scale applications (e.g., robotaxi services).

The remainder of the paper is structured as follows. First, an analytical model linking transport technology, accessibility, travel time budget, and urban spatial structure is proposed. Second, by adopting a sort of reverse assessment, the effects of the past transport revolutions on the structure of cities are discussed, and the "one-hour city" paradigm is derived. Then, the ongoing 7th transport revolution is examined with a discussion on innovative mobility services. In the following, two possible scenarios, both compatible with available developments and research results, will be formulated, together with their impacts on city structure and dimensions, using results from the analytical model. Finally, some concluding remarks are reported.

2 An analytical model to simulate the impact of transport technologies on the maximum dimension of an isotropic circular city under average travel time budget

The idea that travel times and speed affected city dimensions was first introduced by the German geographer and economist Walter Christaller. He is regarded as the founder of the central place theory, which interprets the spatial distribution of settlements and services through the concepts of range and threshold (Christaller, 1933). The range defines the maximum distance individuals are prepared to travel to access a specific good or service, while the threshold indicates the minimum level of demand required for that good or service to remain economically viable. In periods when mobility depended largely on walking or animal-drawn wagons, the distance that could be covered within approximately one hour became the key parameter for determining the range of essential services. Christaller observed that people typically accepted journeys of about one hour on foot, roughly equivalent to 4 kilometers, to obtain basic goods and services. Although Christaller's theory was initially conceived for pre-industrial societies, its methodological framework has proven valuable for contemporary regional planning. Indeed, the concept of the one-hour city persisted even beyond the pre-industrial era.

In this paragraph, we will formalize analytically the relationship between cities' dimensions, the commercial speed allowed by transport technology, and the maximum time people are willing to travel under simplifying assumptions.

2.1 The concept of Travel Time Budget (TTB)

The Travel Time Budget (TTB) represents the average amount of time individuals are willing to allocate daily to travel activities. Empirical studies conducted worldwide over nearly five decades have surprisingly found that this quantity is characterized by a stable average value of approximately 60 minutes per day, with the dispersion around this mean mainly depending on sociodemographic factors, economic features, and urban domain structure.

Early contributions in this field include the pioneering work of Zahavi (1974), which provided initial estimates of TTB across major U.S. metropolitan areas. Comparable magnitudes were later reported in subsequent studies by the same author (Zahavi & Ryan, 1980; Zahavi & Talvitie, 1980). Similar findings were also obtained by Hupkes (1982), who estimated an annual travel time expenditure of approximately 430 hours per person, as well as by Bieber et al. (1994), who identified a range between 50 minutes and 1.1 hours per day. Additional studies have reported values of about 1.3 hours per person per day (Vilhelmson, 1999) and 1.1 hours per person per day (Schafer & Victor, 2000), further reinforcing the general consistency of these estimates. More recent studies (Ahmed & Stopher, 2014; Eliasson, 2022) largely confirm these patterns and, in line with

earlier contributions, emphasize the strong relationship between travel time expenditure and urban structure, spatial organization, and planning strategies.

While the mean value appears relatively stable, the variability around this average is far from negligible. In particular, the standard deviation tends to increase with the spatial scale of the urban system, reflecting longer travel distances, and is strongly influenced by factors such as modal split and urban form. For example, more dispersed (extensive) urban structures are typically associated with greater variability in travel time compared to more compact (intensive) urban configurations (Joly, 2004). Therefore, although the TTB is influenced by multiple factors, including accessibility, transport policies, and individual preferences, the empirical regularity observed over decades remains a robust and well-documented feature of human mobility behavior.

From a methodological perspective, it is important to note that the TTB has historically been derived from cross-sectional travel diary data, in which individuals are typically observed for a single day. In this traditional approach, the total daily travel time is computed for each individual based on one-day observations, and the well-known empirical regularity emerges as an average across individuals, rather than from repeated observations of the same individual over time (Mokhtarian & Chen, 2004). This implies that, in its classical formulation, the stability of the TTB mean should be interpreted as a population-level statistical regularity, rather than as a behavioral constraint directly observable at the intra-individual level on a day-to-day basis.

More recent contributions have addressed this limitation by making use of multi-day and longitudinal datasets, including GPS-based tracking, smartphone data, and panel surveys, which allow the same individuals to be observed repeatedly over time. These studies make it possible to distinguish between two key dimensions: (i) day-to-day intra-individual variability in travel time expenditure, and (ii) the potential stability of individual averages over longer time horizons, such as weeks, months, or even years. Also in these studies, a certain degree of regularity emerges when travel time is averaged over longer periods, suggesting that individuals may exhibit relatively stable long-term mobility patterns despite short-term fluctuations. For example, Stopher et al. (2017) use multi-day and multi-year panel data to investigate travel time expenditures and find evidence of relative stability, with average values around one hour, when considering longer-term averages rather than daily observations.

A city can be understood as a community of individuals whose lives and activities are interwoven to a far greater extent than in pre-urban societies. In this context, interaction is inseparable from mobility: to encounter, to collaborate, or to access resources inherently requires movement across space. The city, therefore, emerges not merely as a physical agglomeration of buildings, infrastructures, and common spaces, but as a dynamic system in which mobility underpins the possibility of contact, cooperation, procurement of goods, and collective life. Hence, for an urban system to operate effectively, it must allow individuals to access essential functions, such as workplaces, education, markets, services, and leisure, within a time considered acceptable. This requirement introduces the notion of a time threshold governing accessibility within urban systems. The dimension of the city can thus be related to the interaction between the available travel time and the prevailing commercial speed.

2.2 General formulation of the analytical model

Let $\Omega \subset \mathbb{R}^2$ denote the urban domain, and let a trip be characterized by:

- an origin location $x \in \Omega$,
- a destination location $y \in \Omega$.

The Euclidean travel distance between the origin and the destination is defined as

$d := \| x - y \|$.

Following classical continuous-space formulations of spatial interaction models (Wilson, 1971), trips are assumed to arise from all feasible origin-destination pairs within the urban domain, each contributing according to a non-negative, distance-dependent weighting function.

Formally, the resulting trip-length probability density function is defined as:

$$p_{\text{trip}}(d) = \frac{\int_\Omega \int_\Omega \delta(\| x-y \| - d)\, W(\| x - y \|)\, \mathrm{d}x\, \mathrm{d}y}{\int_\Omega \int_\Omega W(\| x - y \|)\, \mathrm{d}x\, \mathrm{d}y}, d > 0, \quad (1)$$

where:

- $\delta(\cdot)$ denotes the Dirac delta distribution (Dirac, 1927; Schwartz, 1950),
- $W(\cdot)$ is a generic non-negative weighting function depending only on distance.

The function $p_{\text{trip}}(d)$ represents the probability density of observing a trip with Euclidean length equal to d.

The Dirac delta function, by definition, enforces the constraint $\| x - y \| = d$.

As a result, for the numerator of Equation 1, any distance-dependent term can be evaluated at *d*; i.e., $W(\| x - y \|) = W(d)$.

This implies that Equation 1 becomes:

$$p_{trip}(d) = \frac{W(d) \int_\Omega \int_\Omega \delta(\| x - y \| - \mathrm{d})\, \mathrm{d}x\, \mathrm{d}y}{\int_\Omega \int_\Omega W(\| x - y \|)\, \mathrm{d}x\, \mathrm{d}y} \quad (2)$$

It is worth noting that the above substitution applies only to the numerator, since the Dirac delta function appears exclusively within that term. In the denominator, the absence of such a constraint implies that all admissible distances contribute to the integral, so that it remains in the same form.

To derive a tractable spatial specification of the general formulation, we consider uniformly distributed origin–destination pairs within a simplified urban domain.

Specifically, the following assumptions are introduced.

a. The urban domain is modelled as a circular disk of radius $R > 0$:

$$\Omega = \{z \in \mathbb{R}^2 : \| z \| \leq R\}.$$

where z denotes a generic spatial point in the urban domain Ω.

b. Origins and destinations are independently and uniformly distributed over Ω (spatial homogeneity).

Moreover, let

- $X, Y \in \Omega \subset \mathbb{R}^2$ be two random variables representing, respectively, the origin and destination of a trip, assumed to be independently and uniformly distributed over the urban domain *Ω;*
- $Z, K \in \Omega \subset \mathbb{R}^2$ be another pair of random variables with the same distribution;
- $(x, y) \in \Omega x\, \Omega$ and $(z, k) \in \Omega x\, \Omega$ be two origin–destination pairs.

Under assumptions (a) and (b), the Euclidean distance between independently and uniformly distributed origin-destination pairs is characterized by a geometric probability density, denoted by $p_U(d)$, depending on the assumptions made on the probability density function of different trip lengths.

2.3 Distance decay specification of the interaction process

Having identified $p_U(d)$ as the geometric component, we then consider a particular case of the general formulation. Specifically, a distance-dependent interaction process in which the interaction probability decreases with distance is introduced. Accordingly, $W(d)$ is assumed to be a decreasing function of d.

Under such an assumption and expressing the geometric component of Equation 2 through $p_U(d)$, Equation 2 becomes:

$$p_{trip}(d) = \frac{W(d)\ |\Omega|^2 p_U}{\int_\Omega \int_\Omega W(\| x - y \|)\, \mathrm{d}x\, \mathrm{d}y} \tag{3}$$

Due to spatial homogeneity and isotropy, any generic integrable function $f(\cdot)$, depending only on the distance $\| x - y \|$, i.e., $f(\| x - y \|)$, satisfies the following identity:

$$\int_\Omega \int_\Omega f(\| x - y \|)\, \mathrm{d}x\, \mathrm{d}y = | \Omega |^2 \int_0^{2R} f(d)\ p_U(d)\, \mathrm{d}d.$$

To avoid any misunderstanding, it is worth noting that $\mathrm{d}d$ is used to denote the differential of the integration variable d; it does not refer to a derivative of distance.

Obviously, this is also valid for the weighted function $W(\| x - y \|)$. Therefore, the denominator of Equation 3 can be modified as follows:

$$p_{trip}(d) = \frac{W(d)\ |\Omega|^2 p_U(d)}{|\Omega|^2 \int_0^{2R} W(s) p_U(s) ds} \Rightarrow p_{trip}(d) = \frac{W(d)\ p_U(d)}{\int_0^{2R} W(s) p_U(s) ds} \tag{4}$$

It is worth noting that, in the denominator, the weighting function is expressed as $W(s)$ rather than $W(d)$, as the integral spans all possible distances and serves a normalization role; accordingly, the distance remains a free integration variable rather than a fixed one as in the numerator.

Under the exponential specification $W(d) = \exp(-\beta d)$, where $\beta \geq 0$ is a decay parameter governing the sensitivity of trip-making behavior to distance, Equation 4 can be specified as follows:

$$p_{trip}(d) = \frac{p_U(d) \exp(-\beta d)}{\int_0^{2R} p_U(s) \exp(-\beta s) ds}$$

The corresponding mean trip distance is therefore given by:

$$\mathbb{E}[D] = \frac{\int_0^{2R} d p_U(d) \exp(-\beta d)\, dd}{\int_0^{2R} p_U(d)\, exp(-\beta d)\, dd}$$

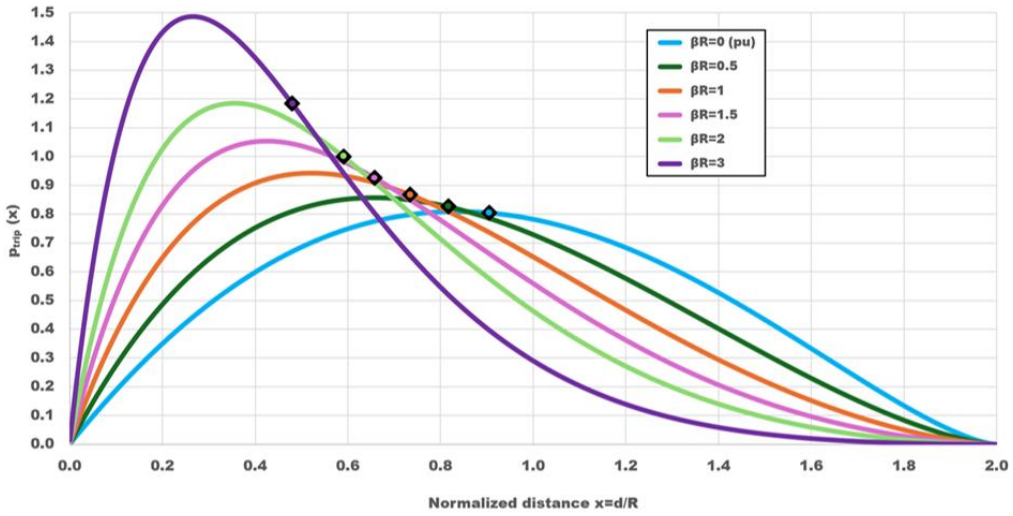


Figure 2. Normalized trip-length probability density functions under the exponential distance-decay specification W(d)=exp(−βd) for different values of the normalized decay parameter βR. Diamond markers denote the corresponding normalized mean trip distances 𝔼[D]/R.

Figure 2 illustrates the effect of the exponential distance-decay specification *W(d)=exp(−βd)* on the trip-length distribution. As the distance-decay parameter increases, longer trips become progressively less likely, shifting the probability mass towards shorter travel distances. The progressive leftward shift of the distributions is accompanied by a monotonic decrease in the normalized mean trip distance, represented by the diamond markers. Hence, Figure 2 summarizes not only how the entire trip-length distribution changes with the behavioral parameter β, but also how these changes translate into a systematic reduction in average travel distance.

A limiting case is obtained when the interaction probability is independent of distance, i.e., $W(d)$ is constant with respect to d. Specifically, under the exponential specification adopted above, this condition corresponds to $\beta = 0$.

For a circular domain, $p_U(d)$ admits a closed-form expression (Santaló, 1976) and, therefore, it can be stated that:

$$p_{trip}(d) = p_U(d) = \begin{cases} \frac{4d}{\pi R^2}\left[arccos\left(\frac{d}{2R}\right) - \frac{d}{2R}\sqrt{1-\left(\frac{d}{2R}\right)^2}\right] & if\ 0 < d \leq 2R \\ 0 & otherwise \end{cases}$$

Likewise, the first and second moments of $p_U(d)$ can also be obtained in closed form (Santaló, 1976; Bäsel, 2014):

$$\mathbb{E}[D] = \frac{128}{45\pi} R \approx 0.905\ R$$

and

$$Var\ (D) = \mathbb{E}[D^2] - (\mathbb{E}[D])^2 = \left(1 - \frac{128^2}{2025\pi^2}\right) R^2 \approx 0.180\ R^2$$

For graphical representation and numerical illustration, distances are expressed in normalized form as follows:

$$x = \frac{d}{R}, \qquad X = \frac{D}{R}$$

where lowercase symbols denote realizations of random variables (i.e., *d, x*), while uppercase symbols denote the corresponding random variables (i.e., *D, X*), and *R* is the radius of the urban domain.

This normalization allows results to be presented independently of the absolute scale of the city.

Figure 3 illustrates the geometric probability density of normalized distances between two uniformly distributed points in a circular urban domain. As already stated, although origins and destinations are assumed to be uniformly distributed in space, the resulting distribution of pairwise distances is not uniform, but instead reflects purely geometric constraints, assigning relatively low probability to very short and very long distances.

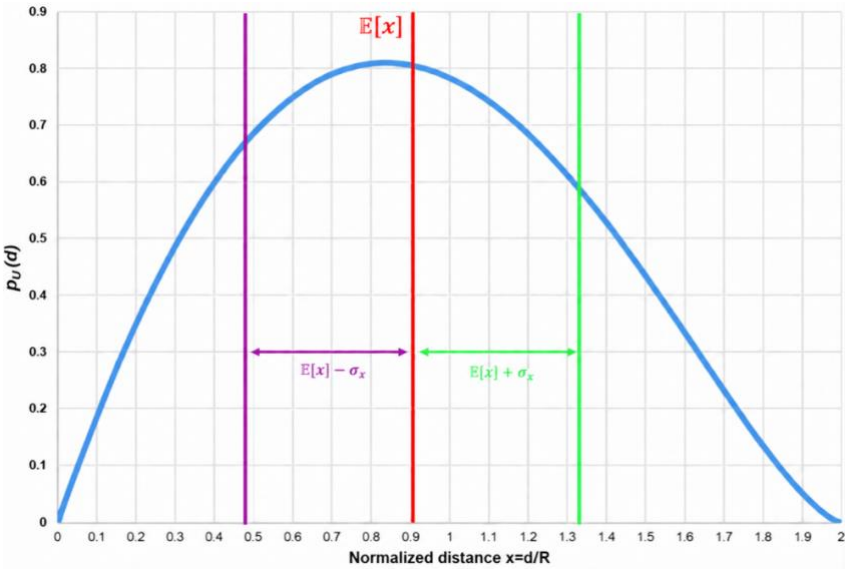


Figure 3. Geometric probability density of normalized distance

2.4 Travel Time Budget and the upper bound to city dimensions

We are now in the position of expressing the upper bound of city radius *R* as a function of the Travel Time Budget and the commercial speed allowed by the prevailing transport technology.

Considering the travel time budget as a constant value equal to *TTB*, and recalling that the average value of the travelled distance of a single trip, expressed as a random variable *D*, is indicated by $\mathbb{E}(D)$, it can be stated:

$$\frac{n\ \mathbb{E}(D)}{v_{comm}\ (\theta)} \leq TTB$$

where *n* is the average number of daily trips.

In order to express the maximum city dimension compatible with a given technology, we can assume that the average number of daily trips is 2, i.e., a symmetric origin-

destination-origin daily travel pattern; since we have also shown that the average one-way trip distance is at most R ($0.9R$ to be precise), the maximum city radius compatible with the transport technology and TTB would be:

$$R \leq v_{comm}(\theta) \cdot \frac{TTB}{2} \Rightarrow \Phi = 2R \leq v_{comm}(\theta) \cdot TTB$$

with Φ denoting the diameter of the urban domain.

In the more realistic case in which travel time budget is a random variable with mean $\mathbb{E}(TTB)$ and variance $Var(TTB)$, it would be:

$$\mathbb{E}(\Phi) \leq v_{comm}(\theta) \cdot \mathbb{E}(TTB)$$

and

$$Var(\Phi) = {v_{comm}}^2(\theta) \cdot Var(TTB)$$

Taken together, these results clarify the role of transport technology in shaping trip distances and, consequently, the urban physical dimension. If the average total time budget is assumed to be one hour, we get the maximum city radius compatible with the "one-hour city paradigm."

Of course, not all cities reach the maximum dimension allowed by transport technology, as several other factors are at play to define their population and dimensions. It could be argued that as the maximum dimension increases, so do "average" city dimensions, other things being equal. This conjecture should be further researched.

3 The "one-hour city" and its configuration throughout history

When innovations in transport technology occur, they induce long-run spatial adjustments in the location of activities and residences. Not all such innovations significantly change commercial speed. According to the transport revolutions theory, as discussed in Cascetta et al. (2021a), Cascetta et al. (2021b), Cascetta and Henke (2023), transport innovations can be interpreted through the dual principles of "revolution" and "evolution." In this framework, a revolution refers to a cluster of transport innovations that, emerging within a relatively short time span, triggered, or allowed to trigger, significant socio-economic changes and shaped subsequent developments. By contrast, evolutions unfolded over longer periods, improving the performance of mobility systems without altering the socio-economic structures in which they occurred. Six such revolutions were identified in history, and four of them significantly modified terrestrial commercial speed and contributed to changing the dimensions of cities. These are animal traction and the wheel with carts, steam engines with railways, internal combustion engines with cars, trucks and buses.

Historically, transport revolutions have often shared two features:

i) heterogenesis of objectives, in which innovations, initially driven by different needs or objectives, produced unforeseen outcomes, generating and/or allowing significant societal changes.

ii) super-additivity, where the benefits of a new technology exceeded the simple sum of improvements offered by prior systems, by complementing and amplifying them.

While direct estimates of travel time budgets are not available for historical periods, this phenomenon can be inferred indirectly by reversing the analytical approach described in the previous section, by relating the maximum dimensions of cities observed

to the commercial speed of the prevailing transport technologies. This relationship is illustrated in Figure 4, which provides empirical evidence of how urban spatial extent has evolved consistently with changes in transport speed across different historical phases and an average Travel Time Budget of about one hour.

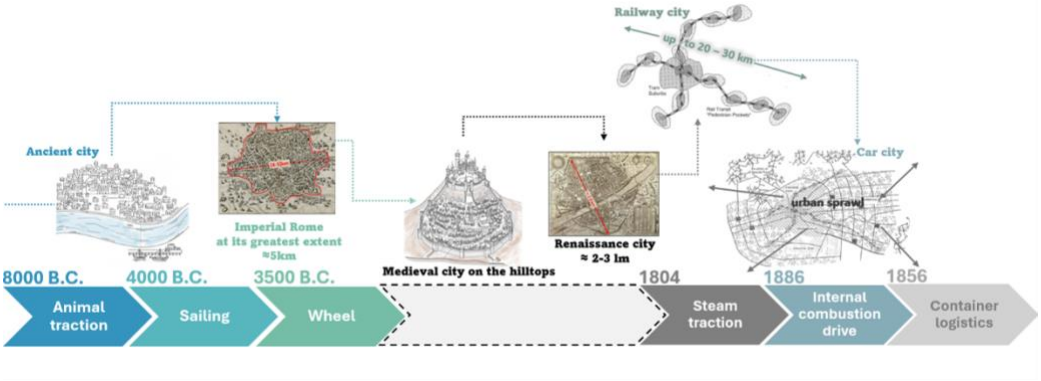


Figure 4. The "one-hour city" through history

In early civilizations until the 19th century, land-based mobility remained constrained by low speeds and limited infrastructure. In antiquity and the Middle Ages, transport systems based on walking and animal traction imposed strict limits on urban size, leading to relatively compact cities. For instance, in ancient times, the predominant terrestrial transport mode was the wagon, typically drawn by horses or mules, with an average speed of about 5 km/h. This constraint is reflected in the spatial structure of cities such as Rome, where the maximum distance across the Aurelian Walls was approximately 5 km at the peak of the Empire (i.e., the one-hour city).

Until the late eighteenth century, urban expansion was fundamentally constrained by limited innovation in transport technologies. This changed dramatically in the nineteenth century with the advent of the steam engine and the railway, marking what has been described as the fourth transport revolution (Cascetta et al., 2021b). The emergence of the railway city allowed urban areas to expand up to 20–30 km from the center, consistent with the speeds of early locomotives (Atkins et al., 1975; Maggi, 2021). Urban development increasingly followed railway lines, with settlements concentrating around major transport nodes and exhibiting growing functional specialization. London provides a paradigmatic example of this rail-enabled metropolitan expansion, with Greater London measuring more than 17 miles (27 km) across by 1901, while it measured only about 5 miles (8 km) from east to west by the end of the eighteenth century (Heblich et al., 2020). In the twentieth century, the widespread adoption of the internal combustion engine and the automobile led to a profound transformation of urban structure. Cities evolved from compact and centralized forms into more dispersed and decentralized configurations. This transition gave rise to urban sprawl (Indovina, 1999; Jacobs, 1961), characterized by the spatial separation of functions such as residential areas, workplaces, and leisure zones as well as lower densities.

An overview of the main impacts on city structure provided by transport revolutions is shown in Table 1.

Of course, cities founded in past centuries retain traces of their past configurations: dense city centers with narrow streets and a diameter of a few kilometers, rail expansions with denser areas around the stations of the nineteenth century and expanded suburbs forming the car city.

Table 1. Overview of the main impacts of the first 6 transport revolutions on city structure

	Year	Transport revolution	Urban scheme	Main impacts on city structure
I	8000 BC	Animal traction	The wagon/horse city	Allowed the birth of cities.
II	4000 BC	Sailing		Maximum diameter constrained to 5 km.
III	3500 BC	Wheel		Settlements emerged along rivers and coastal areas to facilitate agriculture, fisheries, as well as trade and interaction with the surrounding regions. Medieval cities concentrated on hills and no longer on the coast for defensive reasons. During the Renaissance, symmetry and geometry became key principles guiding urban planning.
IV	1804	Steam traction	The railway city	Urban expansion extended up to 20–30 km, with settlements concentrated along railway lines and around industrial hubs located near rail stations.
V	1886	Internal combustion engine	The car-city	Urban sprawl and a greater distinction between zones serving different purposes, like living, working, or commercial activities.
VI	1956	Container logistics	-	Logistic revolution with no significant urban impacts.

4 The seventh transport revolution and possible impacts on future cities

It has been argued that disruptive technological innovations currently underway have the potential to generate the seventh transport revolution (Cascetta et al., 2021b; Cascetta & Henke, 2023; Cascetta et al., 2025). These innovations can be grouped into three interdependent trajectories: the decarbonization of energy systems, the diffusion of autonomous driving technologies, and the emergence of digital mobility services aimed at improving efficiency and new transportation modes. They are not isolated but mutually reinforcing, potentially generating super-additive effects whose outcomes remain uncertain due to their different levels of technological maturity (Table 2).

Table 2. Drivers of the 7th transportation revolution and possible applications for urban mobility

Driver	Basic components	Combined systems
Decarbonization and new energy vectors	Biofuels with ICEs Battery Electric Vehicles (BEV) Hybrid Electric Vehicles (HEV) Hydrogen Fuel Cell Vehicles (HFCV) Hydrogen ICEs	Shared Autonomous Vehicles (car sharing + autonomous driving)
Autonomous and connected vehicles	Autonomous rail Autonomous bus Autonomous car (SAE Level 3-5) Advanced Driving Assistance (ADAS) SAE Level 1-2	Collective Mobility on Demand with electric autonomous vehicles
Smart mobility and innovative services	Demand Responsive Mobility Services (DRMS) Smart control Smart pricing Sharing mobility	Smart control (decarbonization + smart mobility)

Autonomous driving represents a key component of the ongoing transition. According to the SAE J3016 taxonomy, driving automation is classified into six levels, from Level 0 (no driving automation) to Level 5 (full driving automation). Levels 1 and 2 provide driver assistance and partial driving automation, respectively, with the driver remaining

responsible for supervising the driving task. Level 3 introduces conditional driving automation, while Levels 4 and 5 correspond to high and full driving automation, respectively. Current market development, however, does not follow a simple linear progression across these levels. In the private-car market, manufacturers are increasingly developing so-called Level 2+ (or advanced Level 2) systems. L2+ is not an official SAE category, but an industry designation for increasingly sophisticated Level 2 driver-assistance systems, some of which allow hands-off driving while requiring continuous driver supervision ("hands-off, eyes-on"). Although some manufacturers have introduced certified Level 3 systems, current commercial strategies largely prioritize advanced Level 2 solutions because of their broader possibility of application and fewer regulatory and operational constraints. By contrast, Level 4 automation, which allows driverless operation within defined Operational Design Domains (ODDs), is currently emerging mainly in fleet-based services (e.g., robotaxis).

Robotaxis provide driverless, on-demand rides to individual users or travel parties; commercial services are already operating in several urban areas, particularly in the United States and China, with Waymo providing fully autonomous ride-hailing in multiple U.S. metropolitan areas, including Phoenix, San Francisco, Los Angeles, Miami and Orlando, while operators such as WeRide are expanding commercial services in cities such as Abu Dhabi. (Kelkar et al., 2026; Richardson et al., 2026). Pooled SAV services, by contrast, allow different users to share the same ride (Rahman & Thill, 2025).

Shared autonomous mobility can also extend towards collective transport through larger-capacity vehicles such as robo-shuttles and robo-buses, thus providing a natural connection with the broader evolution of collective transport. Robo-buses typically operate on fixed or semi-fixed routes within predefined ODDs. Compared with robotaxis, these more constrained operating conditions reduce the complexity associated with routing, perception and decision-making, potentially facilitating Level 4 deployment in structured urban environments. Fully operational Robobus services are currently deployed in a limited number of jurisdictions. The most mature and large-scale implementations are found in China, including Guangzhou, Hengqin and Shenzhen, where Level 4 autonomous shuttles have been integrated into regular public transport services (Leggett, 2025; Quanlin, 2025). More recently, commercial operations have also been introduced in selected European locations, notably France (WeRide, 2025) and Belgium (Monika, 2026), where regulatory frameworks have begun to accommodate autonomous public transport systems. At the same time, Robobus deployments continue to expand globally through pilot projects and pre-commercial trials (Feng, 2025; WeRide, 2026), reflecting growing interest in their potential to improve first- and last-mile connectivity, enhance public transport efficiency and support more flexible urban mobility systems.

Within collective transport, conventional high-capacity services are likely to retain a central role, particularly along dense corridors. Rail-based systems, in particular, remain essential for accommodating high passenger volumes, while automation can improve their operational efficiency and flexibility. Automated and driverless metro systems already operating in several cities illustrate this trajectory, reducing operating costs while allowing extended service hours and more flexible timetabling (Cartenì et al., 2019; Jansson et al., 2023; Wang et al., 2016). For road-based collective transport, high-demand corridors may continue to rely on high-capacity right-of-way solutions such as BRT and tramways, combining service capacity and reliability with more efficient use of road space (Navarrete-Hernandez & Zegras, 2023).

Taken together, these developments point towards a continuum of service configurations rather than a rigid distinction between individual and collective transport.

Within a MaaS framework, conventional public transport, SAVs, and other mobility services can be integrated and coordinated within a broader portfolio of alternatives, differentiated in terms of travel time, waiting time, comfort, flexibility and cost, effectively creating a "transport menu" for users (Strömberg et al., 2018). Increasingly adaptive forms of service provision, also conceptualized as Flexible Mobility on Demand (FMOD) or Demand Responsive Mobility Services (DRMS), require integrated demand forecasting, service coordination and fare management (Cascetta & Henke, 2023). Such integration also enables more adaptive service and pricing strategies, further aligning transport supply with evolving demand patterns and providing new instruments to manage mobility demand and regulate the use of urban transport networks and spaces.

More broadly, digital technologies expand the range and flexibility of instruments available to public authorities for managing mobility demand and urban access. Smart control systems can support increasingly differentiated forms of access regulation, including restricted areas, limited parking, low-emission and speed-controlled zones (Ceccato et al., 2024). At the same time, digitalization enables the evolution of road-pricing instruments, widely investigated in the literature (Hosford et al., 2021; Walker, 2018), beyond conventional schemes based on fixed charges for entering a defined area, such as those implemented in Milan, London and Stockholm (Croci, 2016; Keat Tang, 2021; Lichtin et al., 2024). More advanced approaches can differentiate charges according to congestion, emissions or available modal alternatives (Cascetta & Cartenì 2017; Gu et al., 2020) and increasingly operate at the level of individual trips. These include trip pricing, which assigns costs to specific multimodal travel alternatives (Cascetta & Montanino, 2022), and mobility-credit schemes, which use credits or incentives to encourage more sustainable travel choices (Jalota et al., 2023).

Such instruments can influence travel choices and traffic flows as well as accessibility patterns and the spatial distribution of activities, while contributing to the regulation and reallocation of scarce urban space. Evidence from existing road-pricing applications shows reductions in car traffic and improvements in traffic conditions (Baghestani et al., 2020; Tsai & Lu, 2018), together with air-quality benefits (Beevers & Carslaw, 2005; Johansson et al., 2009; Perera et al., 2020) and shifts towards public transport and active modes where adequate alternatives are available (Agarwal & Koo, 2016; Cornago et al., 2023; Eliasson, 2009). Their effects, however, depend on policy design and on the availability of viable mobility alternatives, making smart control and pricing important instruments through which the mobility and urban impacts of the seventh transport revolution can be steered.

In light of the above, it appears clear that these innovations, taken individually, produce mainly evolutionary impacts: electrification reduces emissions and improves energy efficiency; automation and connectivity enhance safety and traffic management; and demand-responsive services expand transport options, fostering more flexible and less car-dependent systems. However, they will likely have system-wide impacts changing travel demand, supply performance and, consequently, cities. While they will share some effects, the magnitude and direction of others, according to the present literature, may be very different according to the evolutionary scenarios of car ownership and use models.

4.1 Possible common effects on urban mobility and city dimensions

New on-demand services for individual trips (personal car sharing or robotaxi), new on-demand services for collective transit, and new possible smart pricing schemes are likely to be available in several cities in the next few decades. Almost all simulation studies show that under different scenarios, individual modes (and mostly cars) will

remain the most used ones, while possible improvements on collective services will only marginally erode their share (Oh et al., 2020; Oke et al., 2020). This can be explained by the present urban structure based on individual cars in most cities, including historical ones. The density of large parts of urban and peri-urban settlements, as well as the structure of households and commercial activities, are such as to exclude momentous changes in the mobility structure in the medium term, as has been the case for parts of cities built around wagon and rail technologies.

Compared with autonomous passenger mobility, the application of autonomous vehicles to freight transport and city logistics has received less attention so far. Autonomous driving can be applied to freight transport at different spatial and operational scales. Autonomous trucks are primarily conceived for middle- and long-haul freight transport, while, at the urban scale, autonomous vans and other purpose-built autonomous delivery vehicles can operate on the road network for last-mile distribution. Smaller Autonomous Delivery Robots (ADRs), in turn, are designed mainly for the final segment of the delivery chain, carrying goods from a vehicle, micro-hub or other logistics facility to the final customer.

However, preliminary studies suggest potentially significant impacts on the organization and costs of last-mile distribution. Lemardelé et al. (2025), using a continuous approximation model and Monte Carlo uncertainty analysis, estimate that a two-echelon delivery scheme in which heavy-duty vehicles cooperate with ADRs through an urban logistics micro-hub could reduce last-mile operating costs by more than 10% on average in small- and medium-sized European cities, under adequate operational conditions. Yu et al. (2020) model a two-echelon urban delivery system in which unmanned vehicles perform second-echelon distribution, particularly suited to parcels and other small commodities delivered in pedestrianized areas, campuses and residential clusters. More recently, Montero-Vega and Estrada (2025) model a fully driverless two-echelon system combining Autonomous Hub Vehicles (AHVs) and ADRs and estimate delivery-cost reductions of 40–55% compared with Business-as-Usual (BaU), together with lower global warming potential and urban-space occupation, while identifying a trade-off between operational costs and the occupation of urban space. One of the main factors contributing to cost reductions is the absence of drivers (Alverhed et al., 2024), while, from a traffic perspective, silent electric autonomous vehicles could enable night-time distribution by combining the operational flexibility provided by automation, which removes constraints related to driver availability and working hours (Bray & Cebon, 2022), with the lower noise levels provided by electrification (Uhm et al., 2026).

These prospective impacts are already accompanied by real-world deployments at different scales. In China, more than 100 cities had launched pilot programmes placing autonomous delivery vehicles on public roads by June 2025 (XinhuaNet, 2026). In the United States, autonomous freight is also moving into commercial operation: since April 2025, Aurora Driver-powered Class 8 trucks have performed regular driverless commercial deliveries for Uber Freight and Hirschbach between Dallas and Houston (Aurora, 2025). Europe remains comparatively less advanced, with autonomous freight and delivery applications still largely concentrated on pilot and demonstration projects, although large-scale deployment is currently being promoted at EU level (European Commission, 2026).

These developments suggest that the seventh transport revolution may extend well beyond passenger mobility, potentially affecting the cost structure, operational organization and spatial configuration of freight and last-mile distribution. However, the magnitude of these impacts will depend on the specific autonomous technology, demand patterns and the configuration of the logistics system.

As for effects on maximum city dimension, it will depend – as shown in Section 2 – on the value of average commercial speed and TTB. From the first point of view, most studies (Cai et al., 2024; González-González et al., 2019; Rahman & Thill, 2026) argue that there will not be substantial changes w.r.t. present values. Marginal improvements from better traffic control will possibly be compensated by increasing traffic volumes.

As for the value of TTB, it will depend on whether the time spent in autonomous vehicles will be considered differently, given the possibility of carrying out other activities. Limited experiments show that the possibility of engaging in other activities while travelling may increase travellers' willingness to accept longer travel times (Harb, Xiao, et al., 2018; Harb, Walker et al., 2022; Lehtonen et al., 2022), but no conclusive large-scale results are available. This point deserves more research attention in the coming years, given the possible impacts on city dimensions and further urban sprawl (Kakujo et al., 2024).

4.2 The autonomous-car city

A possible scenario is related to the substitution of personal human-driven cars with their autonomous counterparts.

Several studies envisage a number of negative effects, especially on traffic levels, congestion, and the use of public spaces.

Among them, the papers by Oke et al. (2020) and Oh et al. (2020) present a common modeling framework based on SimMobility Mid-Term to assess the systemic impacts of Automated Mobility-on-Demand (AMOD) across different urban settings. AMOD refers to the mobility service as a whole, from the on-demand trip request to its fulfilment. It can encompass different operating configurations, ranging from robo-taxi to collective on-demand transit with different pricing schemes, all operated with autonomous vehicles. The framework integrates an activity- and agent-based travel demand model with multimodal network and fleet simulation, allowing demand and supply to interact through iterative within-day and day-to-day learning. The analysis covers three markedly different urban settings: Auto Sprawl, a low-density and highly car-dependent U.S. prototype based on Baltimore; Auto Innovative, a denser and more congested car-dependent prototype with greater public transport availability, based on Boston; and Singapore 2030, representing a dense, transit-dependent metropolitan system.

Overall, the results show that AMOD does not simply substitute private-car travel: it can also draw demand away from public transport, while increasing total vehicle travel, as measured by VKT, and worsening congestion, as measured by TTI (Table 3). The magnitude of these effects is strongly dependent on the urban context, with larger network impacts in denser settings. Integration with public transport can mitigate or reverse PT cannibalization and, in some settings, reduce congestion impacts, although it does not necessarily eliminate the increase in VKT.

Table 3. Simulated impacts of AMOD across different urban settings

Urban setting	AMOD scenario	Travel-demand/modal impacts	Total VKT	Congestion
Auto Sprawl (Baltimore archetype)	AMOD replaces existing MoD	On-demand +170%; private car −7%; PT −21%; induced demand ≈ +4%	+9%	TTI +9%
Auto Innovative (Boston archetype)	AMOD replaces existing MoD	On-demand +240%; private car −7%; PT −13%; induced demand ≈ +2%	+26%	TTI +43%
Singapore 2030	AMOD; 75–125% taxi fare; moderate adoption	AMOD share 5.8–8.9%; at 75% fare: PT −7.9%, car −8%, on-demand +83%, induced demand <0.1%	+11–17%	At 75% fare: TTI +14% morning peak; +5.7% daily
Singapore 2030	Same pricing; high adoption	Higher AMOD uptake and modal shifts	+25–42%	At 75% fare: morning-peak TTI ≈ +28%

Source: Oh et al. (2020), Oke et al. (2020).
VKT = Vehicle Kilometers Traveled; TTI = Travel Time Index, the distance-weighted ratio between simulated and free-flow travel times and therefore an indicator of network congestion.

Other studies arrive at similar results, suggesting that extra km driven by cars, sometimes with no driver, could increase in the range of 20–30% (Garus et al., 2024; Llorca et al., 2022; Pimenta et al., 2025).

As for public space allocation, emerging mobility technologies may intensify competition for scarce urban space, particularly between stationary storage and moving road space. With AVs, parking is no longer necessarily the endpoint of a trip: vehicles can remain in circulation ("parking in motion"), shifting demand from parking space to road space and potentially magnifying congestion. This changes the pricing problem itself, as parking prices need to be coordinated with the pricing of in-motion road-space use, while parking pricing becomes an instrument for allocating AVs between storage and motion (Inci, 2025; Inci et al., 2026). Last but not least, in this scenario, the transition to electric vehicles and resulting benefits on GHG emissions and noise should be slow, as shown by simulation studies for Italy (Beatrice et al., 2024; Di Domenico et al., 2025; Henke et al., 2024). The turnover of privately owned car fleets is relatively slow in OECD Countries. For example, the annual vehicle scrappage rate in the United States is approximately 4.5%, while annual new passenger-car registrations in the European Union correspond to only about 4% of the existing car fleet (ACEA, 2026; S&P Global Mobility, 2025). These already low values may be further reduced due to the extra cost of autonomous driving cars (Rezaei et al., 2023).

4.3 The post-car city and the use of urban spaces

An alternative scenario is based on a significant transition from private vehicle ownership to access-based models, where mobility is increasingly delivered through fleets of shared, electric, and autonomous vehicles (Burlando et al., 2019; Dandl & Bogenberger, 2018; Feys et al., 2020; Fronteli et al., 2023; Iacobucci, 2024; Sandes et al., 2019; Smirnov et al., 2023). These fleets, operated by specialized providers, would offer differentiated services, achieve higher utilization rates, and reduce costs through more efficient asset and energy use. From this perspective, ownership gradually loses its central role, yielding to shared and more flexible mobility solutions—car sharing being the most prominent example—a trend already observable due to increasingly available sharing services (Diepolder et al., 2025; Silvestri et al., 2024). Operating within connected networks, they could reduce the total number of vehicles while accelerating technological diffusion through faster replacement cycles. Problems related to the

cleaning and refueling of large fleets have been underlined, but they appear to be solvable with distributed, largely automated plants. In this framework, mobility evolves into a real Mobility-as-a-Service system, integrating modes and blurring the distinction between private and public transport in non-high-flow, separated mass transit lines.

The introduction of fleets of autonomous electric vehicles could also ease some problems of charging electric vehicles during low solar energy availability (mostly at night), as observed by Zhang and Chen (2020).

At the same time, the combined use of these innovations may significantly lower mobility costs for individuals and firms through shared ownership, energy efficiency, and system optimization, while reducing emissions, pollution, congestion, accidents, and space consumption. Research results suggest a potential for Total Cost of Operation reduction for autonomous car sharing services ranging from 2 to 10 times w.r.t. the present TCO of privately owned vehicles (ARK, 2021; Hagenmaier et al., 2026).

A systematic use of autonomous shared vehicles should reduce the number of owned cars. This effect is known in the literature as *Car Replacement Ratio*. Some empirical evidence on the reduction of car ownership thanks to the presence of car-sharing services has been provided in the literature. For instance, Liao et al. (2020) examined the impact of car-sharing on non-corporate car ownership and car markets in 35 large German cities, finding that the addition of one station-based car is associated with a reduction of approximately nine privately owned vehicles. In Kolleck (2021), a stated choice experiment using latent class models on a sample of 1,003 respondents randomly drawn from the Dutch national panel (Panelclix) was performed. The results show that approximately 40% of car drivers are willing to substitute some of their private car trips with car-sharing, and 20% indicated that they might refrain from a planned vehicle purchase or give up a currently owned car if car-sharing becomes available in their area. Further, in Liljamo et al. (2021), a survey conducted among 1,000 Finnish citizens revealed that 58% of respondents would no longer wish or need to own a private car if a mobility-as-a-service solution were available. The willingness to give up ownership rises further, reaching 65%, in a scenario where all circulating vehicles are autonomous, confirming the strong synergy between MaaS and the deployment of autonomous vehicles.

However, the majority of these studies rely on single surveys, which raises concerns regarding their generalizability. Indeed, several factors may contribute, such as the type of system (e.g., free-floating vs. station-based), service density, user awareness, availability of alternative mobility options, and the urban or geographic context (Moulga et al., 2025).

Several simulation-based studies arrive at even more dramatic results (Bischoff & Maciejewski, 2016; Fagnant et al., 2015; ITF, 2015; Moreno et al., 2018) with substitution rates ranging from 1-to-5 to 1-to-15. Assuming a value of 5, a fleet of 10% of the current car stock could substitute 50% of the privately owned cars.

Considering that the car ownership rate in EU Countries ranges between 40 and 80 cars per 100 inhabitants (Eurostat, 2024) and that a parked car occupies a minimum space of 10 square meters, it can be stated that between 4 and 8 square meters per inhabitant are dedicated to parked cars in the car-city in several ways, such as housing off-street parks, curbside parking lots, dedicated parking spaces, and buildings. Significant reductions in the car fleet size (e.g., 50%) would free 2 to 4 square meters per inhabitant, meaning 2 to 4 million square meters (i.e., 200 to 400 hectares) for a 1 million inhabitant city.

Table 4. Parking space fraction occupied in some exemplificatory cities

City	Population [millions]	Total area [ha]	Population density [people/ha]	Reclaimed land area [ha]	Reclaimed land area [%]
Naples (municipality)	0.9	11,727	77.2	181–362	1.5–3.1
Naples (metropolitan area)	2.9	117,100	25.2	580–1,160	0.5–1.0
Rome (municipality)	2.7	128,736	21.3	540–1,080	0.4–0.8
Rome (metropolitan area)	4.2	535,200	7.9	840–1,680	0.2–0.3
Paris	2.1	10,540	203.6	420–840	4.0–8.0
New York City	8.8	78,500	112.2	1,760–3,520	2.2–4.5
Los Angeles	3.8	129,050	29.6	760–1,520	0.6–1.2
Tokyo	14.1	219,405	64.2	2,820–5,640	1.3–2.6

To give an idea, the surface area thus recovered would be broadly comparable to that of Central Park in New York (341 hectares) and a significant fraction of some exemplificatory cities (Table 4). As expected, denser cities have the largest fraction of car-reclaimed area percentages.

Furthermore, the optimization of autonomous vehicle routing combined with the principles of mobility-as-a-service suggests the prospect of a substantially "lighter" car presence in cities. On one side, cars exclusively used in cities tend to have smaller dimensions than cars for general use (Chukreiev, 2025; Meridor, 2025; Red, 2019).

The implications of this systemic change extend beyond fleet size and parking needs. Transitioning from ownership to use implies a "depersonalization" of the car, historically perceived as a status symbol (Nitschke, 2020; Pojani et al., 2018; Verhoef & van Wee, 2000). Individual vehicles will increasingly be selected according to functional requirements – compact models for everyday urban travel, sports cars or family–oriented vehicles for leisure activities. Moreover, although the overall number of cars may decrease, shared fleets will be more intensively utilized and therefore more frequently renewed. Parking areas, and in some cases elevated highways, could be reconsidered in terms of urban reintegration (Badami, 2023; Robinson & Myvonwynn, 2011; STIRworld, 2023). This approach can be defined as "car space reclamation." It mirrors processes of land reclamation from the sea and is intended to reassign spaces once monopolized by unused, parked vehicles. Redeveloped areas may host priority transit corridors, redesigned carriageways in synergy with pedestrianization strategies, or traffic calming interventions aimed at improving urban walkability (De Vos et al., 2022).

Present urban standards implicitly assume that the car ownership model is not going to change, as they impose a minimum ratio of parking area to floorspace. However, in some high-density urban contexts, a clear paradigm shift is emerging: parking facilities, particularly multi-story car parks, are no longer conceived as rigid, single-purpose infrastructures, but as adaptable urban assets and latent reserves of regenerable space. Within this broader trend, different cities are adopting distinct approaches while converging on the same underlying principle.

In Singapore, for instance, the approach is strongly policy-driven and embedded within long-term planning strategies (URA, 2026; Villamin, 2023). National agencies explicitly recognize that underutilized parking spaces can be repurposed as demand decreases, in line with the broader ambition of becoming a "car-lite" society. Policy frameworks increasingly support the conversion of surplus parking capacity, and parking infrastructure is progressively being reframed as adaptable rather than permanently fixed. Hong Kong, by contrast, follows a more incremental and case-based approach, focusing

on the adaptive reuse of existing parking structures in response to emerging needs. Notable examples include the transformation of underused or abandoned multi-storey car parks into community-oriented facilities, such as youth centers (BHA, 2012). At the institutional level, the Hong Kong Housing Authority has also acknowledged the issue of surplus parking provision and has explored strategies to reallocate these spaces to alternative uses. This reflects a pragmatic, demand-driven model in which transformation occurs through specific interventions rather than as a pre-emptive design principle (HKHA, 2011; HKHA, 2014). Evidence from Australia also highlights how specific design standards—such as higher floor-to-floor heights—can facilitate the future conversion of parking structures to alternative uses (Harvey, 2020). These examples illustrate a broader redefinition of parking infrastructure: from static support systems for private mobility to flexible urban resources capable of accommodating new social, recreational, and community functions. As mobility patterns continue to evolve, this reframing is likely to become increasingly central to sustainable urban development strategies.

Summing up, several city transformations could occur in the post-car city. Potential areas of transformation include:

- Street-space reallocation, aimed at strengthening the separation between motorized, pedestrian and cycling flows, thus enhancing safety for the latter groups. Data published by the Italian National Institute of Statistics and referring to 2023 show that pedestrian and cyclist mortality rates are, respectively, about four and two times higher than those of car occupants (ISTAT, 2024).
- Re-use of building interiors previously dedicated to parking, both in public structures and private garages. Examples include the Traversi garage in Milan—transformed in 2023 from a multi-storey car park into a luxury retail facility (Crivelli, 2023)—and a former ground-floor garage in Palermo converted into a restaurant in 2021 (Archiportale, 2021). Private conversions, such as the transformation of garages into residential units, are also becoming increasingly common (Del Vaglio, 2022).
- Substitution of parking-dedicated buildings, increasing the density of built-up areas with residential, commercial, or office spaces.
- New design approaches for future buildings during the transition phase with parking spaces designed for alternative use.
- Creation of "share-ports", large facilities designed for overnight storage, maintenance, and charging of shared autonomous fleets.

It is worth noting that the different role of car-as-a-service, possibly emerging from the seventh transport revolution, is different from the notion of a "car-free city." This idea has long been present in academic and policy debates. Early contributions identified the structural limitations of car-centered urban models (Jacobs, 1961; Kunstler, 1994) and were followed by pioneering proposals for entirely car-free urban environments (Crawford, 2000). More recent studies further highlight the socio-economic and environmental benefits of reducing private car access (Aumann et al., 2023; Herbert, 2023; Nieuwenhuijsen & Khreis, 2016; Yang et al., 2022). To date, however, such approaches have only been concretely implemented in circumscribed city districts where access has been restricted. The present urban structure of car-cities has a built environment that, outside dense historical centers, is not compatible with exclusive use of other mobility systems such as non-motorized or transit modes. Today, autonomous and shared mobility open the way to rethink this model through new theoretical and operational frameworks.

4.4 Some policy implications for future cities

In future cities, privately owned and shared autonomous vehicles are likely to co-exist, and the two scenarios previously described correspond to the extremes of a continuous distribution. If this will be the case, cities may steer their evolutionary trajectory toward the preferred one with a number of policies. The autonomous-car scenario is closer to the present one, and urban policies could be aimed at reducing its possible negative effects, e.g., by pricing or banning zero-occupancy cars altogether to partly reduce extra vehicle kilometers.

On the other hand, the post-car scenario is based on the significant shift from car ownership to car-as-a-service. Policies to promote this shift may include:

- Capacity allocation for autonomous shared vehicles such as dedicated lanes and parking lots for idling time.
- Pricing schemes transferring revenues from private cars to further reduce prices of individual and collective automated vehicle services.
- Reclamation policies for private car parking spaces, especially public ones, and their alternative use.
- Attraction policies for autonomous shared car service operators, including space for positioning share-ports and street mapping.
- Active promotion of sharing culture.

It is possible that the availability of autonomous cars both for private and shared use will be simultaneous, and path dependency may favor early adopters of the post-car city vision.

5 Concluding remarks

The emergence of new mobility technologies and paradigms has historically shaped the urban fabric and dimensions, with contemporary historic cities representing a layered outcome of successive transport revolutions; from the wagon-based city to the railway city and, more recently, the car city.

This paper has shown that, despite their structural and morphological differences, urban systems are consistently constrained by the need to access key destinations within acceptable time thresholds. By linking maximum urban dimensions to the commercial speed of available transport technologies, the analysis extends the concept of the Travel Time Budget to historical contexts, leading to the formalization of the “one-hour city” paradigm as a simplified analytical model.

Building on this framework, the ongoing seventh transport revolution, driven by the interaction among decarbonization, autonomous and connected vehicles, and digital mobility services, is likely to introduce different trajectories of urban transformation.

Unlike previous revolutions, which primarily influenced urban expansion and morphology through increasing average speed, the possible seventh revolution is expected to act mainly on the functional organization and use of urban space. Maximum city dimension should mostly depend on increases in Travel Time Budget due to the possibility of carrying out other activities while being driven by autonomous vehicles. This possibility is purely theoretical at the moment, and it should be thoroughly researched. Based on available research results, the combined effect of the innovations characterizing the seventh revolution may change urban transportation and cities’ use of public spaces according to two extreme scenarios and their intermediate combinations. The first autonomous-car scenario is based on the progressive substitution of privately owned cars with their autonomous and electric versions. This scenario is likely to increase travel demand, including that due to zero-occupancy vehicles, road congestion and a possible reduction in public transportation. The second is based on the transition

from ownership-based to use-based mobility systems. The post-car scenario is likely to reduce vehicle fleets, decrease parking demand, and enable the reallocation of urban space towards alternative functions such as public spaces, green areas, pedestrian infrastructure, and surface transit systems. These changes support the emergence of more walkable, accessible, and people-oriented urban environments, improving overall urban livability. At the same time, the integration of public and private transport services within MaaS frameworks, combined with advanced demand management tools such as pricing and access regulation, is expected to enhance system efficiency while acting as a lever for spatial and functional reorganization. These transformations highlight the increased role of governance and policy design in guiding the transition, particularly in relation to the allocation of urban space, accessibility conditions, and potential equity implications. The availability of a wider array of policy implementation tools could give rise to more differentiated city structures with respect to the past.

The long-term outcomes of the seventh transport revolution remain uncertain, as many of the new technologies, although individually available, are in the early stages of their application. This paper provides a coherent interpretative lens to analyze the potential impacts of the possible seventh revolution. It will be essential to closely monitor these changes in the coming decades, questioning the current organization of mobility systems and urban space and exploring innovative design approaches that fully integrate the emerging technologies and services of this new era.

Author contribution

The authors confirm their contribution to the paper as follows. Conceptualization, E. Cascetta, M. Botte; Methodology, E. Cascetta, M. Botte; Investigation, M. Botte, A. Limmatola; Supervision, E. Cascetta; Writing – original draft, E. Cascetta, M. Botte; Writing – review & editing, E. Cascetta, M. Botte, A. Limmatola. All authors have read and agreed to the published version of the manuscript.

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