

MODELING TRAVEL TIME SAVINGS IN PLATFORM-BASED PASSENGER TRANSPORT

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Abstract: *Urban mobility is undergoing continuous transformation. Traditional modes of transport – such as public transportation, walking, and private car use – have been supplemented by emerging mobility models, including shared mobility. Moreover, travellers increasingly express diverse expectations regarding how their journeys should be conducted. In addition to demands related to safety, comfort, and cost, the time required to complete a journey has become a significant consideration. Modern technologies, particularly digital platforms, represent a crucial factor influencing current mobility modeling. These platforms can facilitate travel and enable the use of shared mobility systems. The aim of this article is to propose a theoretical model of time savings in passenger transport. This model considers two forms of mobility – public transport and shared mobility – and incorporates the essential components of travel associated with each mode, including pre-trip, in-trip, and post-trip activities. Three urban travel scenarios are proposed: (1) travel using only public transport, (2) travel using only shared mobility, and (3) a combination of both modes. An algorithm has been developed to calculate travel time based on the chosen travel method. However, the proposed model has not yet been validated; therefore, it is not currently possible to definitively determine the extent of time savings that may result from the use of digital platforms in urban travel.*

Key words: *digital platform, transport demands, urban mobility*

JEL codes: R41, O18, R0

1. Introduction

The dynamic nature of cities influences the functioning of transport and exposes urban areas and urban transportation to various risks. An efficiently functioning urban transport system

enables residents to carry out both mandatory and discretionary trips more effectively. Travellers strive to meet their transport needs efficiently by selecting the most effective mode of transport available to them. They also hold a set of expectations toward the urban transport system, which can be linked to the perceived satisfaction with the chosen mode of transport. Furthermore, they expect an appropriate quality of the transport services offered, which can be described through transport service demands – these represent a set of characteristics desired by transport users, and the transport services offered by operators should align with these demands as closely as possible. These expectations can be categorized into: (Marszałek, 2001).

- basic – these are typical features of demand that determine its occurrence, if a given market lacks the capacity to meet demand as defined by these features, the demand decreases or is postponed,
- auxiliary – these relate to the quality of the transport services offered, such as the technical condition of vehicles, the organization of the transport process, or the efficiency of staff.

Nevertheless, it should be noted that transport service demands are primarily developed in relation to public transportation. This is due to the fact that the quality of car travel and its competitiveness compared to other modes of transport are generally higher. Therefore, a fundamental set of transport service demands in public transport can be defined as follows (Wyszomirski, 2008):

- cost – pertains to the minimization of travel expenses,
- time – the entire “door-to-door” journey consists of several phases; therefore, this demand includes components such as walking to the stop, waiting, travel time, transfers and walking to the destination. It also depends on the speed of the transport mode, frequency and punctuality of services, accessibility of stops and the possibility of a direct journey,
- safety – on one hand, this includes the number of accidents, injuries, and fatalities; however, it can also be considered more broadly as aspects affecting travel safety, such as the technical condition of stops (lighting, designated passenger islands) and vehicles, time of day, behavior of other passengers or road conditions,
- comfort – also assessed in relation to the entire travel process. Overall perceived travel comfort is influenced by numerous factors, including the fare system, ticket purchasing, route information, timetables, walking access to stops, technical condition of vehicles, and broadly understood visual and aesthetic aspects.

Additionally, the time-related demand, since it encompasses many components of the journey, can also be further specified. This allows for the creation of an extended set of transport service demands. The extent to which these demands are met will influence the passengers' perceived quality of the journey (Tomanek, 2004):

- frequency – the number of services (departures) within a unit of time (hour, day, week),
- rhythmicity – the regularity of intervals between successive departures of the transport mode,
- regularity – the consistency of service, related to the inclusion of a specific departure in the timetable, e.g., repeated departures on a specific route,
- punctuality – departures occur within a pre-established time tolerance,
- accessibility – can be defined in two ways:
 - temporal accessibility – the time required to reach transport points,
 - spatial accessibility – the density of the transport network,
- safety – accident rates and the security of transport services,
- comfort – a synthetic demand composed of many elements, including e.g. simplicity of the fare system, ease of ticket purchase, accessibility of information systems, access to stops, clarity of timetables, visual and technical condition of vehicles and stops, service staff's culture and competence, etc.,
- price – a non-quality-related demand concerning the cost of transport services, which can be measured by the number of tickets that can be purchased for, for example, the minimum wage.

As can be observed, this set of transport service demands has been primarily extended to include factors related to travel time. Therefore, it can be assumed that the time factor is significant for urban travellers and that it holds value for them. However, when considering a specific time interval (e.g., one hour), this value of time may depend on the traveller's subjective assessment of how that time is utilized. Activities perceived as purposeless are likely to be rated lower by travellers than those considered meaningful (Festjens, Janiszewski, 2015). In the context of urban travel, time spent onboard vehicle, or uninterrupted journeys are typically rated more positively than activities such as waiting for a bus or transferring between modes of transport (Wojan, Wysocka, 2011), which may introduce additional stress due to delays or malfunctions. The value of time in transport is one of the key elements in travel demand modeling and in analyzing the social costs of transportation investments. One of the primary objectives of all types of transport-related investments is to improve travel time predictability

and reduce total travel time. Therefore, the value of time savings will play a crucial role in travellers' final decision-making processes (Small, 2012).

However, not only infrastructural investments can serve as a significant factor in reducing travel time in urban environments. Attention should also be directed toward modern information technologies, which development and widespread implementation may contribute to changes in travel time. One such technology includes digital platforms, which can be utilized by travellers using various modes of transportation. Digital platforms are based on the widespread availability of continuously evolving information technologies, such as cloud computing, databases, and big data analytics solutions (Hein, et al., 2019). In the context of urban mobility, such digital platforms can be identified in every branch of transportation. For individual (private) transport, digital platforms provide access to parking information, assist with navigation, deliver real-time traffic data, and enable payment for travel or parking (Siuhi, Mwakalonge, 2016). In public transport, they facilitate travel planning, ticket purchasing, and transfer optimization (Szincsaák, Vágner, 2014). The advancement of digital platforms has also enabled the development of shared mobility, which is now inextricably linked to creating an account on a dedicated platform. Through such platforms, it is possible to unlock and rent a selected vehicle, or to simplify the process of ordering one in the form of a taxi (Stehlin, et al., 2020).

This article primarily focuses on public transportation, which should constitute the foundation of urban mobility (Ceder, 2020) as well as on shared mobility, which may serve as a complementary transport mode to public transport – particularly in the context of first- and last-mile connectivity. Shared mobility can also be regarded as a more sustainable alternative (Shaheen, Chan, 2016) to private car travel, which is not considered within the scope of this study.

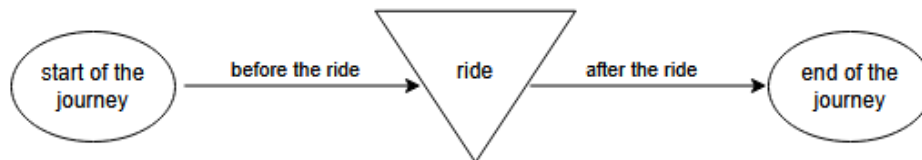
The objective of this article is to propose a theoretical model of urban travel time that incorporates both public transport and shared mobility. The model is based on the assumption that public transport and/or shared mobility can be used to form a chain of movements within the urban environment. Public transport may be optionally supported by digital platforms (whereas in the case of shared mobility, such platforms are essential for trip execution), which may contribute to achieving certain time savings. Additionally, the article presents algorithms for calculating travel time based on the choices made by travellers with respect to transport modes and the use of digital platforms across various elements and phases of the journey. The

proposed model has not been empirically validated in this article, as it constitutes a conceptual contribution intended as a foundation for further research.

2. Methodology and Data

The development of a theoretical model of time in urban mobility began with the presentation of a simplified travel chain in an urban journey (fig. 1).

Fig. 1 Simplified chain of city movements



Source: own elaboration based on: Szoltysek, 2008

Figure 1 illustrates a simplified travel chain, which also includes elements preceding the actual movement as well as those occurring after the journey. Each of these stages comprises numerous components essential for undertaking a trip using a selected mode of transport. Table 1 presents the constituent elements of urban travel, divided according to the two aforementioned types of movement. The symbols shown in parentheses will be used to construct the theoretical model of time in urban mobility proposed in the Results and Discussion section.

Tab. 1 The process of moving in public transport and shared mobility

Journey stage	Public transport	Shared mobility
Before the journey (B)	Familiarization with the timetable and location of stops (k)	Familiarization with available operators in a given area (o)
	Buying a ticket (b)	Creating an account on the appropriate platform (a_{SM})
	Getting to the stop ($w1$)	Getting to the selected means of transport ($w3$)
	Waiting (e)	
	Random component (α)	Renting a vehicle (s) Random component (δ)
Ride (R)	Ride (r)	Ride (g)
	Transfer (c)	
	Random component (β)	Random component (ϵ)

Journey stage	Public transport	Shared mobility
		Identifying the appropriate place to return the vehicle (<i>i</i>)
After the journey (<i>A</i>)	Getting to the destination (<i>w2</i>)	Paying the fare (<i>p</i>)
	Random component (<i>γ</i>)	Getting to the destination (<i>w4</i>)
		Random component (<i>θ</i>)

Source: own elaboration

In the case of public transport, it can be observed that the number of pre-trip components is comparable to those present in shared mobility. Table 2 discusses the individual components of a journey using public transport.

Tab. 2 Components of public transport travel

Public transport travel	Description
Familiarization with the timetable and location of stops (<i>k</i>)	The aspect of locating stops will be particularly important when traveling in a new place. By default, timetables are available at stops in printed form, but dynamic passenger information systems and websites with timetables are also being developed, where it is also possible to become familiar with departure and arrival times at individual stops located on a map. The duration of this aspect may depend on the user's proficiency in using the described systems, knowledge of the transport system in the given area, or the complexity of the journey (e.g., required transfers)
Buying a ticket (<i>b</i>)	An essential aspect of every public transport journey, the time required to complete this element depends on the available forms of ticket purchase (e.g., in a store, at a ticket machine) and their location in relation to the stops. It may be extended in situations where the ticket sales network is not sufficiently developed
Getting to the stop (<i>w1</i>)	In urban mobility, an average walking speed of 4 km/h is assumed (depending on age or weather conditions, see: Willberg, et al., 2023), as well as an access radius to a stop of approximately 500 meters (depending on the transport mode, see: Tiran, et al., 2022). Based on these assumptions, it is possible to calculate the maximum possible time required to reach a stop (and similarly, to walk from a stop)
Waiting (<i>e</i>)	A variable independent of the passenger, as this time will be extended in the event of delays or breakdowns; however, it should be assumed that passengers arrive at the stop a certain time before the vehicle's scheduled arrival, see: I. Kaparias, et al., 2015)

Public transport travel	Description
Ride (r)	A variable independent of the passenger; the duration of this stage can be determined based on the timetable, however, it is important to consider random events that may cause this stage to be extended
Transfer (c)	This element largely depends on the network of connections within the given transport system. Its duration may be influenced by the type of transfer (e.g., between the same or different modes of transport), the location (e.g., the distance between two stops or the departure of another line from the same stop), as well as the degree of timetable coordination between lines. This aspect does not have to occur in every journey; however, it may affect the final decisions of passengers who aim to minimize the risk of being late to their destination
Getting to the destination (w_2)	Another stage that requires the passenger to walk; however, its assumptions are consistent with those applied to walking to the stop
Random components (α, β, γ)	These account for risks associated with travel, such as problems with ticket purchase, prolonged waiting due to delays, extended travel times caused by traffic conditions, or any other events that lead to an increase in total travel time

Source: own elaboration

The variables described in Table 2, pertaining to public transport, constitute the components of a trip; however, it is important to note that not all of these elements must occur during every journey. Additionally, some of them may be supported by a digital platform, which can modify their duration, as presented in Table 3.

Tab. 3 Modified components of public transport travel

Component of travel	Not platform aided	Platform aided
Buying a ticket	A passenger may purchase several single-use tickets for future use or a monthly pass; nevertheless, this remains a key aspect of the journey	The ticket purchase may occur directly before the trip (while waiting at the stop) or onboard the vehicle (during the travel time), and the moment of purchase may depend on the platform used. This can reduce the walking time to the stop (e.g., avoiding the need to reach a particular shop or ticket machine, which could otherwise extend the route). However, in such case, the time required to set up an account on

Component of travel	Not platform aided	Platform aided
		the relevant digital platform must be included; in the model, this will be denoted as a_{PT}
Timetable checking, trip planning, waiting	During regular travel along a fixed route, it may not be necessary to check vehicle departures and arrivals each time	The ability to track vehicles in real time (and any potential delays) allows for better adjustment of the walking time to the stop. This optimization will be denoted as e' in the travel time model. It can be assumed that in the case of delays or breakdowns, the travel mode may change
Transfer	In the case of direct connections, no additional time will be included for transfers (changing the mode of transport or walking to another stop)	The use of a digital platform enables optimization of the waiting time at the stop; therefore, in the model, the time for such a transfer will be denoted as c'

Source: own elaboration

The second mode of transportation considered in this article is shared mobility. In this case, the digital platform is essential for undertaking the journey, and its components are described in Table 4.

Tab. 4 Components of shared mobility travel

Shared mobility travel	Description
Familiarization with available operators in a given area (o)	Depending on the individual needs of the user, as well as the number of operators in a given area, it is necessary to become familiar with the available transport offer and the location of vehicles
Creating an account on the appropriate platform (a_{SM})	This is a one-time activity yet still required from the user if they intend to use the services of a selected operator. Additionally, depending on the digital platform, it may be necessary to create an account in order to view the locations of vehicles in the given area
Getting to the selected means of transport ($w3$)	This is one of the more variable factors in the stage preceding the actual ride. This variability results from the changing locations of e-scooters or rental cars (the location of bike stations is fixed; however, the absence of available bikes at a given time and place must be considered). The location of vehicles may also influence the passenger's final decision whether to use this mode of transport

Shared mobility travel	Description
Renting a vehicle (s)	It includes the process of unlocking the vehicle. Depending on the selected mode of transport, the time required to prepare the vehicle for travel may be longer (e.g., in the case of cars, where a vehicle inspection is required) or shorter (e.g., in the case of e-scooters or bicycles, it involves only scanning a QR code, see: www1)
Ride (g)	Travel time depends on the passenger and the route they choose; however, the passenger has no influence over traffic conditions or the available infrastructure
Identifying the appropriate place to return the vehicle (i)	The duration of this aspect depends on the selected type of vehicle, as well as the designated zones within the area where vehicle returns are permitted and their visibility on the digital platform
Paying the fare (p)	A process occurring after the ride, in situations where the user engages in the appropriate interaction with the platform
Getting to the destination ($w4$)	Depending on the selected mode of transport and the availability of return locations, this time may vary; however, it can be assumed that the passenger will seek a location closest to the destination of the journey, over which they may have more influence than in the case of public transport
Random components ($\delta, \varepsilon, \theta$)	These are all risks associated with the use of shared mobility and mobility platforms for urban travel. In this case, such time-extending risks may include, among others, issues with the functioning of the digital platform, the unpredictability of vehicle distribution, or technical problems with the vehicle

Source: own elaboration

The journey components of public transport and shared mobility, as presented in the above section, served as the basis for the development of the time model and the time-saving model enabled by digital platform support. These models are presented in the Results and Discussion section.

3. Results

The simplified travel chain presented in Figure 1 can be expressed using Formula 1, which accounts for the time associated with each stage of the journey.

$$TT = TT(B, R, A) \quad (1)$$

This is a simplified formula, where TT denotes travel time. However, as outlined in Section 2 of this article, each of these stages may vary in terms of their constituent elements

depending on the mode of transportation. In the case of public transport, the journey may proceed in a traditional manner, without digital platform support (PT_{NPA}), and the travel time in such a case is represented by Formula 2.

$$PT_{NPA} = B(k, b, w1, e, \alpha) + R(c, r, \beta) + A(w2, \gamma) \quad (2)$$

Conversely, when the user chooses to utilize digital platforms for ticket purchasing, real-time information tracking, or transfer modification, the travel time model in such a journey will depend on the components outlined in Formula 3.

$$PT_{PA} = B(k, a_{PT}, w1, e', \alpha) + R(r, c', \beta) + A(w2, \gamma) \quad (3)$$

where:

PT_{PA} – time allocated to public transport travel supported by mobility platforms.

The use of digital platforms during the journey is also a matter of individual traveller preference; however, it is worth noting that they primarily affect the pre-trip stage. Instead of the traditional ticket purchase, time must be allocated to account creation on the relevant platform, and they allow for optimization of waiting and transfer times.

In the case of shared mobility, the digital platform is essential for executing the trip; therefore, the time model in this case is represented by Formula 4.

$$SM = B(o, a_{SM}, w3, s, \delta) + R(g, \varepsilon) + A(i, p, w4, \theta) \quad (4)$$

In the case of travel using shared mobility, it is important to note that one of the major variables that may influence the traveler's final decision to choose this mode of transport is the location of available vehicles (they are more likely to be used when nearby than when located farther away).

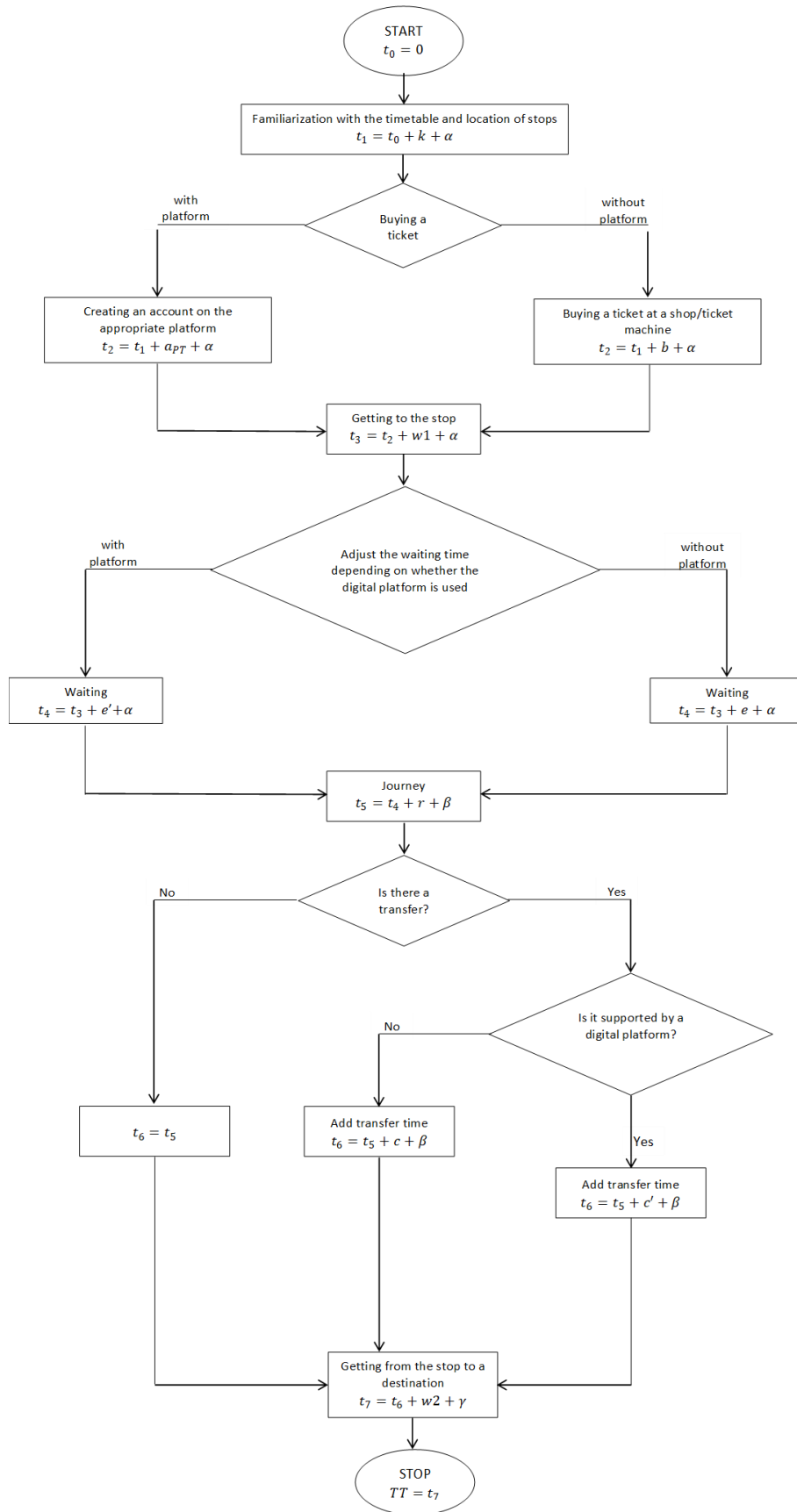
The two modes of urban travel presented in this article – public transport and shared mobility – allow for the identification of three possible travel scenarios. These scenarios may differ not only in terms of the transportation modes used but also in the extent of digital platform usage. Furthermore, for each of the presented scenarios, algorithms have been developed to represent the time required for travel depending on the selected mode of movement and the use of digital platforms. The aim of each algorithm is to indicate the total travel time based on the decisions made by the traveler.

1. scenario 1 – the passenger chooses public transport for the entire route, with walking used to access and leave the transit stops. Transfers may occur during the trip. In this scenario, the traveller may use digital platforms to e.g. access information about available transport services, plan the journey, and purchase tickets (Fig. 2),

2. scenario 2 – the passenger chooses shared mobility to complete the entire journey (fig. 3),
3. scenario 3 – a combination of public transport and shared mobility. In this case, the passenger may use shared mobility systems to reach a selected transit stop, from which the journey continues using public transport. In this scenario, the passenger is free to choose the transfer point, which does not necessarily have to be the same initial stop as in Scenario 1 but may instead be a larger interchange hub that increases comfort or provides more travel options (Hanusik, Kozień, 2017). In the time model, this type of transfer (between shared mobility and public transport or vice versa) is denoted as c'' . Additionally, travel times are marked as r' and g' for public transport and shared mobility, respectively, as these times are modified and refer to the subsequent part of the journey (Fig. 4).

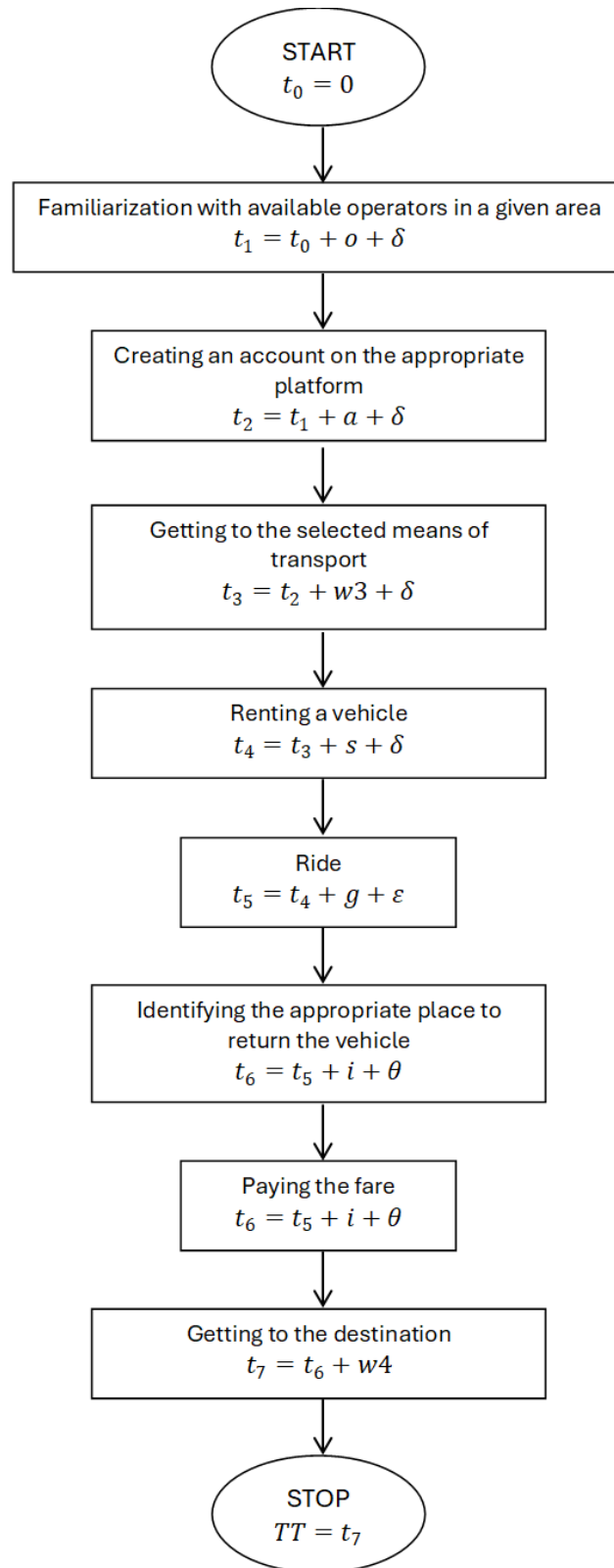
The algorithms presented in Figures 2-4 correspond to the formulas proposed for calculating travel time within one of the three outlined scenarios. It should be emphasized that these represent simplified cases, each involving a single chain of movement, as illustrated in Figure 1.

Fig. 2 Algorithm for scenario 1



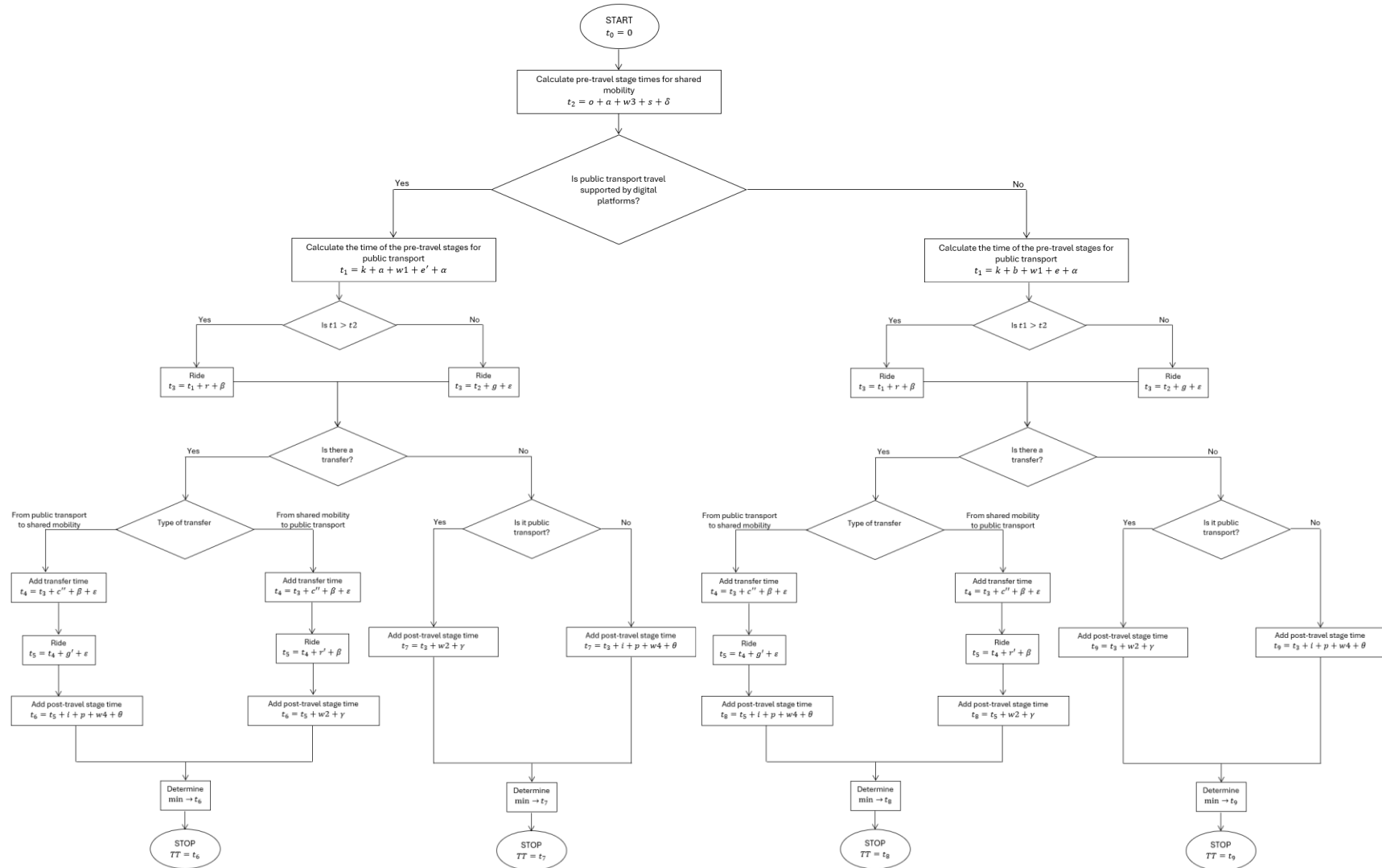
Source: own elaboration

Fig. 3 Algorithm for scenario 2



Source: own elaboration

Fig. 4 Algorithm for scenario 3



Source: own elaboration

4. Discussion

The formulas and algorithms presented in the Results section constitute a theoretical representation of travel time involving two modes of urban mobility. It should be noted that digital platforms may have broader applications beyond public transport and shared mobility. However, this article focuses specifically on the development of theoretical travel time models related to these two forms of movement within the urban environment.

A desired outcome of using mobility platforms in urban travel is the reduction of travel time, which can be expressed using Formula 5.

$$\Delta TT = t_{NPA} - t_{PA} \quad (5)$$

ΔTT – change in travel time,

t_{NPA} – travel time without the use of mobility platforms,

t_{PA} – travel time with the use of mobility platforms.

The presented indicator serves as a measure of the potential change in travel time that travelers may achieve using mobility platforms in their journeys. The values of this indicator can be interpreted as follows:

- $\Delta TT > 0$ – a noticeable time benefit; this represents the amount of time saved due to the use of mobility platforms at various stages of the journey. It may lead to increased trust in digital platforms and associated transport systems, representing a positive outcome for the traveler,
- $\Delta TT = 0$ – no noticeable benefit; the use of digital platforms did not shorten the travel time, but neither did it extend it. This is a neutral outcome for the traveller,
- $\Delta TT < 0$ – the use of digital platforms resulted in an increased travel time. This may lead to a loss of trust in digital platforms or the transportation systems used, representing a negative outcome for the passenger.

Nevertheless, the proposed model is not without limitations. One such limitation stems from the underlying assumptions regarding the modes of mobility under consideration. While the model enables an assessment of travel time changes, it does so exclusively within the scope of the two examined forms of urban travel. Additionally, Scenario 3 represents only a simplified situation in which shared mobility is used on a single segment of the journey. In practice, the travel chain could also include the use of shared mobility in additional segments (e.g., from the final public transport stop to the travel destination).

Moreover, it is important to acknowledge the wide variety of shared mobility options – ranging from cars to bicycles and electric scooters. Each of these modes is subject to specific constraints, such as availability within a given area or the requirement to return the vehicle to designated locations. Furthermore, travel time, as well as the potential segments for shared mobility use, will differ among these transport modes. This raises the question of whether the model, particularly Scenario 3, should be further detailed to account for the variability in travel time depending on the specific shared mobility mode employed. However, for the purposes of this article, such differentiation has been deliberately omitted, as the primary focus lies in evaluating the change in travel time facilitated using digital platforms, rather than in analysing how different forms of shared mobility contribute to that time change.

Another limitation of the model pertains to its verification. The duration of "pre-trip" components in public transport may vary over time – for example, with the development of on-site ticket vending systems. Additionally, model validation may be influenced by the discrepancy between actual waiting times and travellers' subjective perception of those times. Nevertheless, verifying the model would allow for an evaluation of the extent to which travel time is affected using digital platforms at various stages of the journey and even when combining different forms of transportation.

5. Conclusions

This article delineates the fundamental transport-related demands articulated by passengers, as well as an expanded set thereof. The extended set predominantly pertains to temporal dimensions of mobility, including the frequency, punctuality, and regularity of public transport services. These expectations are principally associated with public transportation, as their fulfilment constitutes a critical determinant of its competitiveness relative to individual modes of transport.

One of the factors influencing travel time variation may be the use of digital platforms. In the context of public transport, these platforms serve a complementary function, potentially affecting ticket purchasing processes, travel planning, and more accurate estimation of walking time to a stop based on real-time vehicle location data. In shared mobility systems, such platforms are indispensable for enabling the use of shared transport modes. Nevertheless, their application within urban mobility can also contribute to shifts in transport behavior, where they may assume a supportive role in relation to public transport.

The article proposes three travel scenarios: the first and second involve the use of a single mode of mobility – public transport and shared mobility, respectively – while the third scenario integrates both forms. A simplified travel chain is presented, serving as the foundation for the development of a theoretical time model dependent on the selected travel scenario. Additionally, simplified algorithms for each scenario are introduced, enabling the estimation of travel time based on passengers' decisions related to the use of digital platforms and the chosen modes of transportation.

The proposed theoretical model has not yet undergone empirical validation; thus, the potential change in travel time (ΔTT) attributable to the use of digital platforms has not been precisely quantified, although this represents a promising direction for future research. It is also pertinent to consider the extent to which heterogeneity in the areas where shared mobility and public transport operate, as well as the varying stages of development of these transport systems, may affect the model's ultimate outcomes.

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