

Article

# A Framework for Dynamic Advanced Traveler Information Systems

Filippo Carrese <sup>1</sup>, Stefano Carrese <sup>2</sup>, Sergio Maria Patella <sup>3,\*</sup> , Marco Petrelli <sup>2</sup>  and Simone Sportiello <sup>2</sup>

<sup>1</sup> Department of Civil, Constructional and Environmental Engineering (DICEA), University of Rome “La Sapienza”, 00184 Rome, Italy; filippo.carrese@uniroma1.it

<sup>2</sup> Department of Engineering, Roma Tre University, 00146 Rome, Italy; stefano.carrese@uniroma3.it (S.C.); marco.petrelli@uniroma3.it (M.P.); simone.sportiello@uniroma3.it (S.S.)

<sup>3</sup> Faculty of Economics, Universitas Mercatorum, 00186 Rome, Italy

\* Correspondence: sergiomaria.patella@unimercatorum.it

**Abstract:** This paper presents the framework for a dynamic Advanced Traveler Information System (ATIS). The ATIS currently in use provides users with stereotyped travel options, but the set of available modes in a given place and time is not the same for each traveler, and such a personal choice set varies within the context of daily trip chains. The research presented in this paper addressed these limitations by including dynamic features in the proposed system. The activity chain that the user performs as well as the personal mode availabilities are modelled simultaneously to define the logical architecture of an innovative information system. Such a technology was intended to assist travelers in performing their daily trip chaining. In order to provide some insight regarding the efficacy of the proposed procedure, a pilot test was performed using real travel time information. Results have shown that the ATIS proposed in this study might generate a significant reduction in travel times.

**Keywords:** Advanced Traveler Information Systems; Intermodal Journey Planners; multimodal networks; intermodal trips; trip chaining; activity based models



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## 1. Introduction

The new generation of Advanced Traveler Information Systems (ATIS), based on the concepts of multimodal network and individual profiling, has become a focus of attention. People willing to choose the best alternative in a multimodal context find a large set of unimodal alternative and different mode combinations (intermodality). ATIS currently in use provide the users for travel information without taking into account the personal set of mobility resources that each traveler owns. Moreover, the personal set of mobility resources is not static, but it varies during the progression of traveler’s daily activity chain.

This work proposes the logical architecture of a dynamic ATIS profiled on actual user’s mode availability. Such a technology is intended to accompany the traveler during the whole daily trip chaining. Rehrl et al. [1] introduced the concept of ‘personal travel companion’ developing a prototype of a tool able to support the user in a transfer situation.

A vast scientific literature focused on the mode choice with an activity-based approach. According to Bhat and Singh [2], the daily chain is divided into sub-patterns, which contain tours. A tour is defined as a circuit that begins at home and ends at home (home-based tour) or begins at work and ends at work (work-based tour). Cirillo and Axhausen [3] showed that in most cases these tours involve only one mode. Ramadurai and Srinivasan [4] investigated within-day dynamics and variability in mode choice at the activity level. Hensher and Reyes [5] studied the relation between the complexity of a tour and the use of public transport. They found that as the trip chains become more complex, the utility of public transport decreases. Ho and Mulley [6] proposed a new approach for the mode choice at the tour level taking into account not only the number of activities chained into the tour but also their spatial distribution. Their findings indicated that as

the spatial dispersion of the activities increase, the tour is more likely to be car oriented. Esztergár-Kiss et al. [7] provided an activity chain optimization method in a multimodal context, proving that significant travel time savings can be achieved considering temporal and spatial flexibility of the activities.

The aim of this work is to bridge the gap between the mode choice in the context of the daily trip chaining and the ATIS. For this scope, a dynamic approach is proposed to address the complexity resulting from the enumeration of all the single-mode alternatives and their intermodal combinations.

As indicated earlier, modern ATIS provide predefined solutions without taking into account which are the mobility resources actually held by the user. By approaching this issue from the standpoint of the dynamic, one can observe that the range of mode solutions (single mode or combinations) depends both on user's specific resources and on the progression of the user's trip chaining. Normally, the transition between the static and dynamic approaches makes transportation modelling more complex. In this case, the dynamic approach simplifies the problem.

This research presented in this paper represents a first attempt to define a framework for a dynamic information system. In fact, ATIS systems currently in use support the traveler on the single trip to be carried out; each trip is seen as an independent event for which the traveler makes a new, separate decision for the mode choice.

The remainder of the paper is organized as follows. Section 2 reviews the literature on the ATIS. Section 3 outlines the framework of the proposed system, with results presented in Section 4. Section 5 concludes the paper including remarks on the limitation of this study, and discusses directions for further research.

## 2. Background

Advanced Traveler Information Systems were born to support users in travel decisions. In step with the technological advance of these systems, one can observe the progressive adaptation of users to a travel choice made on the basis of information obtained from different sources. Information on the congestion of the road network, as well as on the expected travel time of public transport, are constantly provided in real time to the community of users. The role of information on the mobility-linked choice process is gaining in importance in modeling transport demand [8–10]. An overview of the current sources of information and their diffusion can be found in Boakye et al. [11].

Technological developments led to a fast evolution of ATIS. A first generation of ATIS, largely based on information provided through variable message panels or through radio channels, was followed by a second generation of in-car-portable GPS, whose main function was to suggest the shortest route (i.e., without any information about the real-time traffic condition of the network). The current generation, that we assume to be the third, consists of applications able to provide real-time information on public and private transport system, able to support multimodal networks, and set to be profiled on the decision maker [12]. By organizing the ATIS experiences into three generations, we have updated and refined the classification of ATIS made by Adler and Blue [13].

In the early 1990s, with the scope to assess the impact on travelers' behavior, the study of ATIS was approached from the random utility models perspective. Researchers have focused on the two distinct levels of information acquisition (pre-trip and en route), as a result of their different impacts on the four-stage model.

Polak and Jones [14] focused their studies on the effects of pre-trip information on travel behavior using a stated preference approach. They underlined the need to make progress in the pre-trip information systems, which largely offer only unimodal information, suggesting multimodal pre-trip travel information systems.

Khattak et al. [15] modeled the revealed and stated response to ATIS when people face unexpected congestion at the pre-trip stage. They found an incentive effect of the information's quality and quantity on commuters' diverting decision in unusual delay situation, i.e., changing from their habitual modes and routes.

Srinivasan and Mahmassani [16] introduced the concepts of inertia and compliance studying route choice behavior under real-time information. They assumed that inertia and compliance are behavioral mechanisms that can be incorporated in the real-time route choice process. Their findings indicated that inertia and compliance are influenced by: network loads, commuters' past experience in traffic, system performance measures, and information quality.

Using an interactive simulator, whose technology was defined by Chen and Mahmassani [17], Mahmassani and Liu [18] focused on the day-to-day dynamics of the commuters' decision processes in response to real-time information. They provided interesting insights in the pre-trip departure time and in the route-switching decision both at pre-trip and at en-route stage. Ye et al. [19] have recently proposed a dynamic model for the day-to-day evolution of traffic flows in a road network where travelers receive information from ATIS.

The effects of information quality on the mechanisms of choice were examined by Chen et al. [20] both at pre-trip and en-route stage; their analysis focused on three aspects characterizing the ATIS: the nature of information (descriptive or prescriptive), its reliability (synthesized in six levels) and the type of feedback that the device provides users *ex post facto*. Another aspect highlighted by Srinivasan and Mahmassani [16] is the role of congestion in driver decision-making processes under varying degrees of traffic loads.

The findings of the aforementioned studies reinforced already strong technological pressure on the third generation of ATIS able to support multimodal network and to provide real-time information.

Nuzzolo et al. [21] proposed the framework for a third-generation tool that supports traveler on multimodal networks with real-time personalized information. A recent algorithm for the real-time optimal route guidance information for car drivers has been proposed by Chen et al. [22]. Dotoli et al. [23] presented an advanced traveler information system for public and private transportation, including vehicle sharing and pooling services. Further experiences, as indicated by Zhang J. et al. [24], are those of Trapeze (Mississauga, ON, Canada), Jeppesen (Englewood, CO, USA), Google (Mountain View, CA, USA), Logica (Reading, UK).

It is worth underlining the substantial difference between multimodal network and intermodal transport, which are often confused in the literature. The first concept (multimodal network) refers to the transportation supply, which is modeled through several layers that represent the corresponding modes of transport. Van Nes [25] provided a comprehensive description of the features of such networks and suggested a hierarchical approach to their definition.

The second concept (intermodal transport) refers to transportation demand in terms of mode choice. The mode choice can involve a single-mode alternative or a sequence of modes and transfers (intermodal choice). Intermodal choice is very frequent in different contexts and in different combinations. The alternative of the car followed by public transport (park and ride) is very frequent for people commuting from suburbs to the city center. Also, the combined use of bicycle and public transport for one trip is very frequent in urban context. In recent years, because of sharing mobility penetration, the combined use of carsharing and public transport is spreading in urban areas.

Information systems able to provide a traveler with an itinerary for an intermodal transport journey are named Intermodal Journey Planners (IJP). An overview and a classification of journey planners can be found in [26]. Zhang, L. et al. [27] design the app PATH2go, implemented for a field study along the US-101 corridor in the San Francisco Bay Area; the app supports driving, driving-to-transit, transit and bicycling. Other examples of systems of this type are: Onlymoov, Grand Lyon (France), using real time IJP made by Cityway; Triplinx; Grand Toronto (CANADA), using Cityway's IJP; TripGo, covering 120 cities, it is specialized in finding optimal interchanges between public and private transport; Transport for London, using the IJP by Mentz Datenverarbeitung GmbH; UK Regional Traveline, using the IJP's of Trapeze Group, JourneyPlan and Mentz Datenverarbeitung; Journey.fi is an IJP for planning trips across Finland, using IJP by Logica; OV9292 for the

Netherlands; reseplaner.trafikken.nu in Stockholm compares public transport, car, bicycle, walk and combinations in one search; TravelWits.com, provides routes that combine flight, car and other modes of travel.

### 3. Logical Architecture of the Dynamic Advanced Traveler Information System (ATIS)

Mode choice, either unimodal or intermodal, represents a choice that a person makes among the mobility resources held at a certain time in a given place in order to make a trip. The set of mobility resources that each individual owns defines a personal portfolio [28]. Mobility resources are not exclusive; a person's portfolio may include one, several, all or none.

Each individual chooses a mobility portfolio within all available portfolios. The traditional mobility resources are three: car, bicycle, and public transport subscription. In general terms,  $R$  resources imply  $2^R$  separate and distinct portfolios. Each of these enables the use of a set of modal alternatives.

The standard full-resources portfolio includes car, bicycle and public transport subscription. It enables the following unimodal choices in urban areas: drive car, ride public transportation without paying for single trip, ride bicycle, walk, take taxi, ride public transportation paying per single trip, ride as car passenger. Thus, there are seven different unimodal choices. Dropping the hypothesis of unimodal choice and considering also shared mobility alternatives, the choice set includes many more possible combinations.

The mode choice made by the user, regardless the fact that it was recommended or not by the ATIS, produces an effect on the portfolio. Choosing public transport as the first mode of the trip chaining directly empties the user's portfolio out of all the private mobility resources (if they were initially present). Likewise, when private resource (e.g., car or bicycle) is used to reach a public transport station as a feeder mode, then they are parked in the exchange node; and thus, they are 'erased' from the portfolio, and the following trips of the chain will be performed with other available modes.

This represents a simplification of the enumeration of the modal alternatives available to the user at given moment of the daily trip chaining. In other words, the dynamic progression of the availability of the resources allows the set of feasible modes to be cut; this is the reason why the dynamic perspective simplifies the static problem.

Trip chaining consists of an orderly sequence of trips that occur when an activity is to be achieved after the fulfillment of the previous. Each of these trips cannot be performed with resources no longer available. Similarly, a trip whose optimal mode choice is a private resource involves a constraint on all the previous trips, starting from the first one of the chain.

The following formulation provides an approach based on the decomposition of the chain into single activities and trips.

Let  $A_i = \{1, 2, \dots, j, \dots, J\}$  be the set of activities  $A$  that the individual  $i$  performs in their daily activity chain. At the beginning of the day these activities are all yet to be completed. At a generic time of the day, indicated as  $t + \Delta t^h$ , after a trip to reach the generic activity  $h$  and its fulfillment, a reduction of the activity set occurs:  $A_i(t + \Delta t^h) = A_i(t) - \{h\}$ . Every couple of activity following one other is linked with the trip  $s_j^m$ , i.e., the trip that links the fulfilled activity  $h$  with the incipient activity  $j$  using the mode  $m$ . The last trip of the chain, indicated as  $s_{\emptyset}^m$ , occurs when the last activity is completed or, in other word, when  $A$  is empty:  $A_i = \{\emptyset\}$ . This trip brings the portfolio back to its initial state. We associate with each trip  $s_j$  an average travel time  $t_j$ . It is calculated as the minimum travel time among all the modes enabled by the portfolio to perform the trip  $s_j$ , i.e.,  $t_j = \min_m \{t_j^m\}$ . We define  $s_{j^*} = s_j : \max_j \{t_j\}$  as the critical trip for which the maximum travel time is experienced among all the trips within  $A_i$ . The mode choice at the activity chain level pivots around the critical activity  $j^*$  and its related trip  $s_{j^*}$ , which binds the choice of the first mode used to perform the first trip of the daily chain. The set  $A_i$  entered by the user  $i$  is decomposed into the single activities it is made of. Once identified the critical activity  $j^*$  and its related critical trip  $s_{j^*}$ , it is processed as a normal O/D pair; the best mode choices are evaluated

through a simulation process aimed at minimizing travel times according to user portfolio (modes availabilities).

An example can make a better idea. Imagining that the first trip of the chain is quite short and the best alternative, suggested by the ATIS, would be walking. This choice has implicitly removed the car from the portfolio (if it was available) unless an expensive return at home. This example demonstrates the need to take into account all the activity set. The private car certainly is the most binding mode; driving the car for the first trip implies driving for the last trip of the chain. The choice to perform the critical trip with a private resource binds the mode choice of the whole trip chaining from the beginning of the chain (trip  $s_1$ ). Note, however, that there may exist tours within the chain, e.g., a work-based tour, such that the private resource can be parked at the workplace and then the tour is performed with other feasible alternatives.

The proposed framework, shown in Figure 1, consists of the following steps:

1. **USER CHARACTERISTICS** (top left of the framework). The user defines the personal portfolio of holdings (box PORTFOLIO in the framework); here, the parameter  $n$ , which represents the number of available resources, is defined.
2. **INPUT OF THE PROCEDURE** (bottom right of the framework). User's query (box QUERY in the framework) enables two distinct procedures:
  - 2a. In the simpler case of a single O/D pair, the system provides the mode alternative with the shortest travel time. Next, the portfolio is updated on the basis of the actual choice made by the user (dashed thick arrow from CHOICE to PORTFOLIO in the framework).
  - 2b. In the more complex case of a set of activities, the set  $A_i$  is decomposed as previously indicated, and the most critical activity is identified. Through a simulation procedure, like in the case of single O/D pair, the optimal solution for the critical activity is identified. The choice of this alternative for the critical trip could binds the mode choice for the first trip of the chain (MODE CONSTRAINT ON  $s_1$  in the framework). In this case, not only is the portfolio (as in the case of a single O/D pair) updated on the basis of the choice made, but also the set of activities (dashed thick arrow from CHOICE to  $A_i$ ).
3. **UPDATE** (dashed thick arrow in the framework). Based on the choice made by the user  $i$  (box CHOICE in the framework) the update procedure occurs: portfolio update for the case 2a; portfolio and the set of activities for the case 2b.

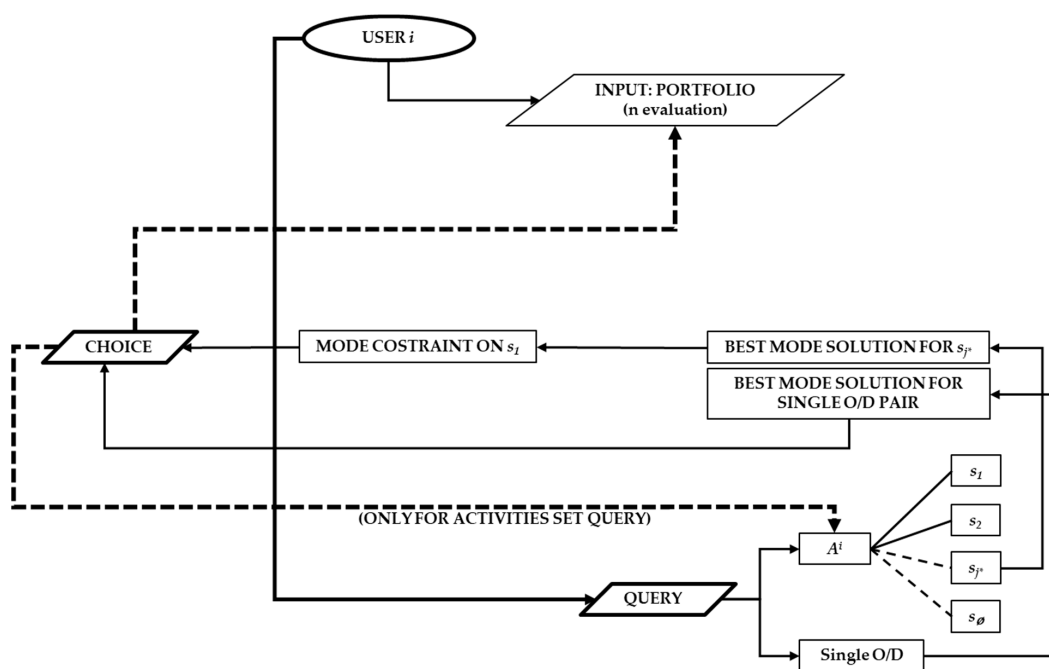


Figure 1. The logical architecture.

#### 4. Results from a Pilot Test in Rome (Italy)

The purpose of this pilot study was to test the efficacy of the dynamic system to provide an optimal mode choice at the activity chain level. To this end, six different multi-activity trip chains were defined, including the following sequence of trips (Figure 2): Home–Work (H–W), Work–Lunch–Work (W–L–W), Work–Leisure (W–L), Leisure–Home (L–H). Note that those chains contain a work-based tour: Work–Lunch–Work. The workplace, the lunch location, as well as the leisure location were randomly selected, whereas the homeplace was a variable depending on the single interviewee’s residence location.

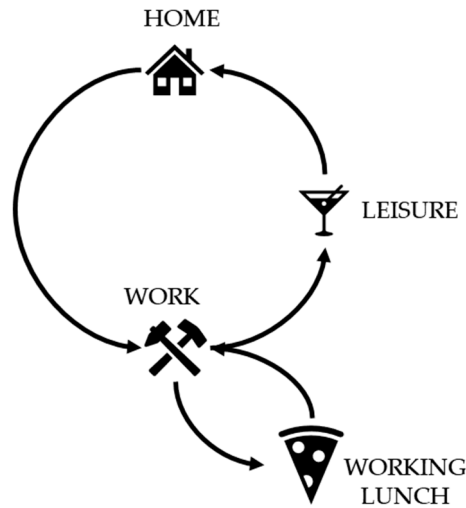


Figure 2. Activity chain scheme.

Each of these chains (an example is reported in Figure 3) was submitted to five randomly selected respondents, obtaining a dataset of 30 interviews.

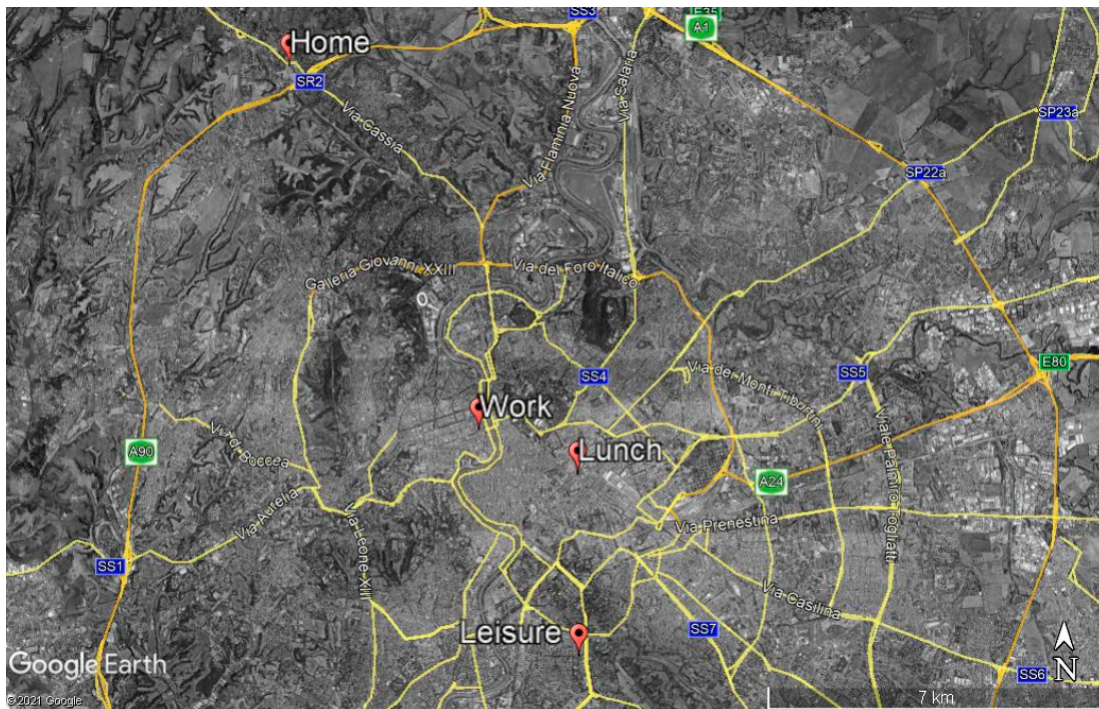


Figure 3. Example of activity pattern from the survey.

The survey was conducted in June 2021 and the interviewees were contacted via email. The questionnaire included some basics info such as: age, residential address, Household size, number of license holders within the household, mobility portfolio (car ownership, bike ownership, public transportation subscription, sharing mobility subscription). Table 1 summarizes the sociodemographic information.

**Table 1.** Sociodemographic information from the survey.

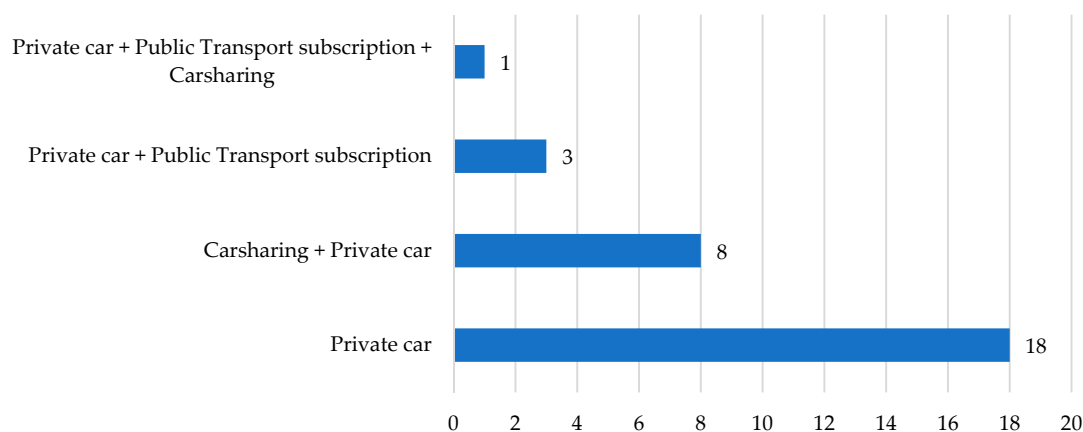
Age	18–25	26–35	36–45	46–55	56–65
%	3%	53%	17%	3%	23%
Household size	1	2	3	4	5
%	7%	20%	23%	47%	3%

		Driving licenses				
		1	2	3	4	5
Household size	1	100%	-	-	-	-
	2	17%	83%	-	-	-
	3	-	43%	57%	-	-
	4	-	36%	43%	21%	-
	5	-	-	-	-	100%

Next, respondents were asked to state their mode choice intentions towards the proposed activity chain.

The aggregate data analysis provided reliable results, consistent with local mobility-related habits reported in previous studies [29,30]. In fact, as shown in Figure 4, the most frequent portfolio is composed only by car (60%), which is the most common mode of transport used in Rome; recent estimates from the Rome Mobility Agency [31] indicate that private car trips account for 51% of daily trips.



**Figure 4.** Portfolio of resources.

As for the mode choice at the trip chaining level, the results from the survey were compared with the results from the procedure described in Section 2. To summarize, the procedure consists in the following steps:

1. User portfolio acquisition from the survey;
2. Evaluation of the critical trip according to user resources availability (portfolio);
3. Evaluation of the best mode choice for the critical trip (constrain on the mode choice at the activity chain level);

4. Calculation of the overall travel time spent for the activity chain proposed in the survey.

The following Table 2 summarizes the results and shows that in 47% of cases users' mode choice for the critical trip  $s_{j^*}$  was not optimal. Car and public transport travel time calculation was performed with Google Maps services considering an average working day. Carsharing access time, which depends on the density of the carsharing fleet, was calculated by checking the availabilities on the web application of three companies currently operating in Rome: ShareNow (Berlin, Germany), Enjoy (Rome, Italy), Carsharing Roma (Rome, Italy). Although the subscription to carsharing providers is frequent among Roman citizens, carsharing use, as a habitual transport mode, is still very low in Rome due to the poor availability of vehicles [32,33].

The relative difference  $\Delta T_{chain}$  was calculated as:

$$\Delta T_{chain} = \frac{T_{chain}^{ATIS} - T_{chain}^{USER}}{T_{chain}^{USER}} \quad (1)$$

where  $T_{chain}$  represents the travel time spent for the activity chain. A negative value means that the mode choice suggested by the ATIS can shorten the travel time spent for the activity chain. Finally, the results of this pilot test show an overall decrease of 8% in travel times.

**Table 2.** Travel time comparison.

$i$	$s_{j^*}$	USER Choice ( $j^*$ )	$t_{j^*}^{USER}$ (Min)	ATIS Choice ( $j^*$ )	$t_{j^*}^{ATIS}$ (Min)	$T_{chain}^{USER}$ (Min)	$T_{chain}^{ATIS}$ (Min)	$\Delta T_{chain}$
1	L-H	Private Car	30	Private Car	30	112	112	0.0%
2	L-H	Public Transport	45	Private Car	35	142	110	-22.5%
3	W-L-W	Private Car	27	Private Car	27	130	130	0.0%
4	H-W	Private Car	36	Private Car	36	123	123	0.0%
5	H-W	Private Car	45	Private Car	45	137	137	0.0%
6	W-L	Private Car	40	Public Transport	30	150	110	-26.7%
7	W-L	Private Car	40	Public Transport	35	170	120	-29.4%
8	L-H	Public Transport	80	Private Car	45	180	165	-8.3%
9	W-L	Private Car	40	Public Transport	35	150	120	-20.0%
10	H-W	Private Car	50	Private Car	50	158	158	0.0%
11	L-H	Private Car	48	Private Car	48	166	166	0.0%
12	H-W	Private Car	45	Private Car	45	153	153	0.0%
13	H-W	Private Car	60	Private Car	60	160	160	0.0%
14	W-L	Private Car	40	Public Transport	38	145	118	-18.6%
15	L-H	Private Car	40	Private Car	40	155	155	0.0%
16	W-L	Private Car	40	Public Transport	38	145	128	-11.7%
17	W-L	Private Car	40	Public Transport	38	145	141	-2.8%
18	W-L	Private Car	40	Public Transport	38	140	131	-6.4%
19	W-L	Public Transport	38	Public Transport	38	128	128	0.0%
20	W-H	Public Transport	38	Public Transport	38	118	118	0.0%
21	H-W	Private Car	55	Private Car	55	170	170	0.0%
22	L-H	Private Car	55	Private Car	55	163	163	0.0%
23	H-W	Private Car	65	Private Car	65	190	190	0.0%
24	H-W	Private Car	65	Private Car	65	175	175	0.0%
25	H-W	Public Transport	57	Private Car	53	180	171	-5.0%



Table 2. Cont.

<i>i</i>	<i>s<sub>j</sub></i> *	USER Choice ( <i>j</i> *	<i>t<sub>j</sub></i> * USER (Min)	ATIS Choice ( <i>j</i> *	<i>t<sub>j</sub></i> * ATIS (Min)	<i>T<sub>chain</sub></i> USER (Min)	<i>T<sub>chain</sub></i> ATIS (Min)	$\Delta T_{chain}$
26	W-L-W	Private Car	45	Public Transport	40	172	144	-16.3%
27	W-L-W	Public Transport	40	Private Car	37	163	122	-25.2%
28	W-L-W	Public Transport	40	Private Car	37	167	127	-24.0%
29	H-W	Public Transport	45	Private Car	42	151	141	-6.6%
30	H-W	Public Transport	38	Public Transport	38	141	141	0.0%
<b>TOTAL</b>						<b>4579</b>	<b>4227</b>	<b>-7.7%</b>

## 5. Discussion and Conclusions

This study proposes the framework for a dynamic Advanced Traveler Information System (ATIS). The suggested system is intended to assist travelers in performing their daily trip chaining. The methodology takes into consideration two main concepts: (1) each individual owns a personal portfolio of holdings; (2) mobility resources availability varies dynamically during the progression of the activity chain.

In order to make feasible cuts to the set of alternatives, we developed a method based on the dynamic progression of the activity chain. The dynamic variation of the portfolio is exploited within the framework to reduce the dimension of the set of the alternatives available for the user during the trip chaining.

The results of the pilot test indicate that in 47% of cases users' mode choice sequence was not the optimal, and the ATIS proposed in this study might generate a significant reduction in travel times.

The approach proposed in this paper was intended to overcome the combinatorial complexity of the mode choice at the activity chain level. It would be too hard to process in real time all the alternative modes (unimodal and intermodal) and to estimate their associated travel times in the context of the daily trip chaining.

From the authors point of view, among all the activity of the daily chain there is a dominant activity and its related trip (called critical activity/trip) around which the mode choice (at trip chaining level) pivots. The critical trip is defined as the trip for which the maximum travel time is experienced among all the trips within the chain. Of course, this is a strong assumption since the critical trip might be defined by other factors such as the purpose of the activity or the delay elasticity. For this reason, the definition of the critical activity and its related critical trip should be a matter for future research investigation.

The optimal mode solution for the critical trip was calculated minimizing travel times, but travel cost, reliability, comfort, environmental awareness, etc., also are important factors when making a mode choice decision. Therefore, the personalization of the recommendations of preferences as the user interacts with the planner over time could be investigated by using two different approaches: (1) big data and artificial intelligence techniques; and (2) a behavioral approach based on random utility models (RUMs).

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