Models for Optimising Dynamic Urban Mobility

D1.2: Specification of Field Trials Summary

WP1: Analysis of Low-carbon Mobility Requirements

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MODELS FOR OPTIMISING DYNAMIC URBAN MOBILITY

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Glossary of Acronyms

Acronym	Definition
D	Deliverable
WP	Work Package
EC	European Commission
T	Task
M	Month
NCC	Nottingham City Council
MODUM	Models for Optimising Dynamic Urban Mobility
Consumer	Within MODUM we use the term consumer to refer to two types of users according to the situation and context. The first use of consumer refers to people who travel to their place of work on a regular / daily basis; these commuting people will eventually use the MODUM app to make informed decisions about which mode of transport to use. The second use of the consumer refers to traffic control and management authorities, in the form of Nottingham City Council and Sofia Centre for Mobility. Such authorities can use MODUM outcomes (e.g. algorithms and mechanisms) to optimise their management of traffic and improve their service.
MODUM app	Is the Android application for a smartphone that will be developed within MODUM with the main goal of encouraging people to use sustainable modes of transport and reduce the use of cars.

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1 Executive Summary

This deliverable sussinctly summarises the work undertaken and results obtained within WP1 of the European-funded project, MODUM. The main output of this deliverable is a set of requirements for low-carbon and efficient mobility, a framework for low carbon mobility and traffic management, and an evaluation plan for the project.

WP1 (i.e. Analysis of Low-carbon Mobility Requirements) primarily focuses on capturing and specifying diverse requirements, both technology and user related, and setting future validation tests for the ideas, techniques, and prototypes to be developed within the EC-funded project MODUM. To this end, five separate, yet complementary, tasks were outlined and carried out. The first 3 tasks of WP1 (T1.1, T1.2, and T1.3) spanned over the first three months of the project (M1 to M3) and centred around eliciting relevant user and technological requirements for efficient and low-carbon mobility in Europe through:

- a review and analysis of state-of-the-art technological infrastructures and capabilities for traffic management (T1.1);
- a review and analysis of state-of-the-art theoretical approaches for low carbon mobility and traffic management (T1.2); and
- requirement elicitation studies (in the form of online surveys, interviews and focus groups) for efficient and low carbon mobility (T1.3)

The remaining tasks of WP1 (T1.4 and T1.5) spanned over the next three months of the project (M4 to M6) and focused on analysing the raw data collected from the first 3 tasks of WP1, formulating a framework for low-carbon traffic management framework, and specifying validations techniques and field trials for WP6.

This deliverable (i.e. D1.2) summarises the scientific methods and presents the main findings from activities of WP1. A more detailed description of the techniques used, explanation of results, and implications to sustainable travel are documented in deliverable D1.1.

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2 Introduction

2.1 Explanation of the Deliverable

Deliverable D1.2 briefly summarises the work undertaken within WP1 of the European-funded project, MODUM. The main output of this deliverable is a set of requirements for low-carbon and efficient mobility. These requirements were gathered through three sets of user studies, and a thorough analysis of relevant literature and existing projects addressing sustainable travel issues. Herein the deliverable lists, prioritises, and sets success criteria for the requirements. In addition, the deliverable outlines the evaluation and validation strategies to be performed within evaluation Work Package, WP6.

2.2 Purpose and Scope

Deliverable 1.2 aims to succinctly document the technological and user requirements relevant to MODUM without going into much detail about the requirements elicitation process. As such, for each specified requirement we state its relevance and priority in regard to the success of MODUM, and clearly identify ways for methodologically evaluating the requirement (i.e. Fit criteria). The compiled requirements will act as a guide for MODUM partners especially the developers in order to develop prototypes and proof of concepts that demonstrate the scientific ideas and models behind MODUM. In addition deliverable D1.2 highlights the evaluation strategy for validating the results of MODUM.

2.3 Structure of Document

The remainder of deliverable D1.2 is structured as follows. Section 6 summarises the research methods used to involve prospective consumers (e.g. travellers and policy makers) into the requirements elicitation exercises, and presents the results in the form of user requirements. Section 7 provides a short summary of the technical constraints and requirements. Section 8 discusses a framework for reducing CO_2 emissions and improving commuting experience. Finally, Section 9 outlines a set of appropriate techniques that will be used to assess the field trials within the Evaluation Work Package, WP6.

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3 User Requirements

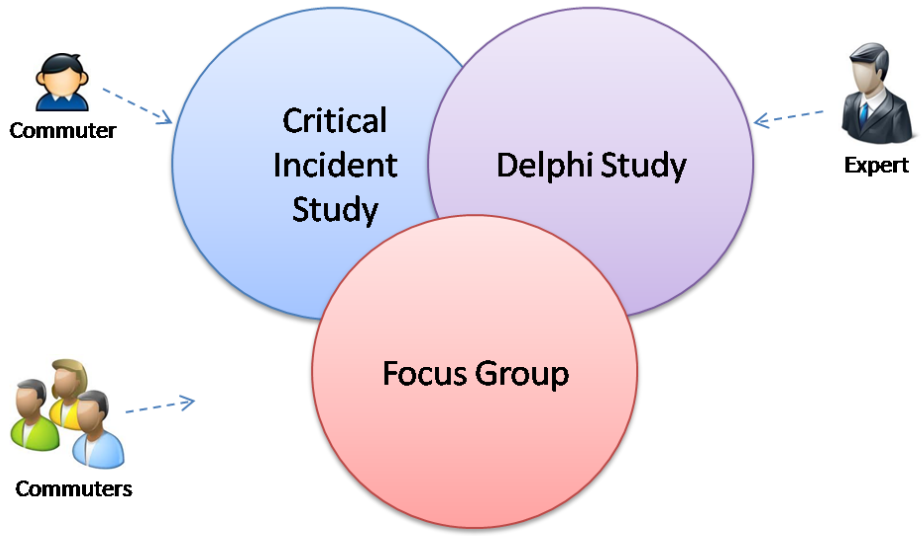
This section briefly outlines the research techniques used to capture current commuting practices and experiences, summarises the profile of our participants, and lists the user and technical requirements relevant to MODUM app.

3.1 Summary of Input Acquisition Exercises

The set of user exercises were conducted using three differing research qualitative techniques [1]: critical incident [2], Delphi policy study [3], and focus group [4] (as shown in Figure 1). Combining different research techniques and methodologies to inquire and investigate the same issues is referred to as triangulation [5]. Triangulation empowers researchers to double check the results, extend existing knowledge, and most importantly overcome biases and problems stemming from one single research method [6]. Thus, the user studies included an online questionnaire to collect critical incidents from everyday commuters in the UK (City of Nottingham and City of Manchester) and Bulgaria (City of Sofia), a 2-round Delphi study to collect views from actual representatives of traffic control and management authorities, and focus groups to collect views from prospective commuters. These studies aimed to fulfil the following objectives:

- Gain an in-depth understanding of current commuting behaviour and practices and the factors that influence such behaviour and practices as viewed by everyday consumers;
- Elicit relevant requirements for a clean, efficient, and low-carbon mobility; such requirements will be used to guide the development of MODUM models and prototypes.

Figure 1 Research techniques for collecting MODUM user requirements



Critical incident technique [2] is a method for collecting realistic observations and incidents of human behaviour that have a significant effect on user perception and experience. Critical incidents focus on true observations experienced personally rather than ungrounded opinions. Critical incidents were collected from individual commuters through an online questionnaire.

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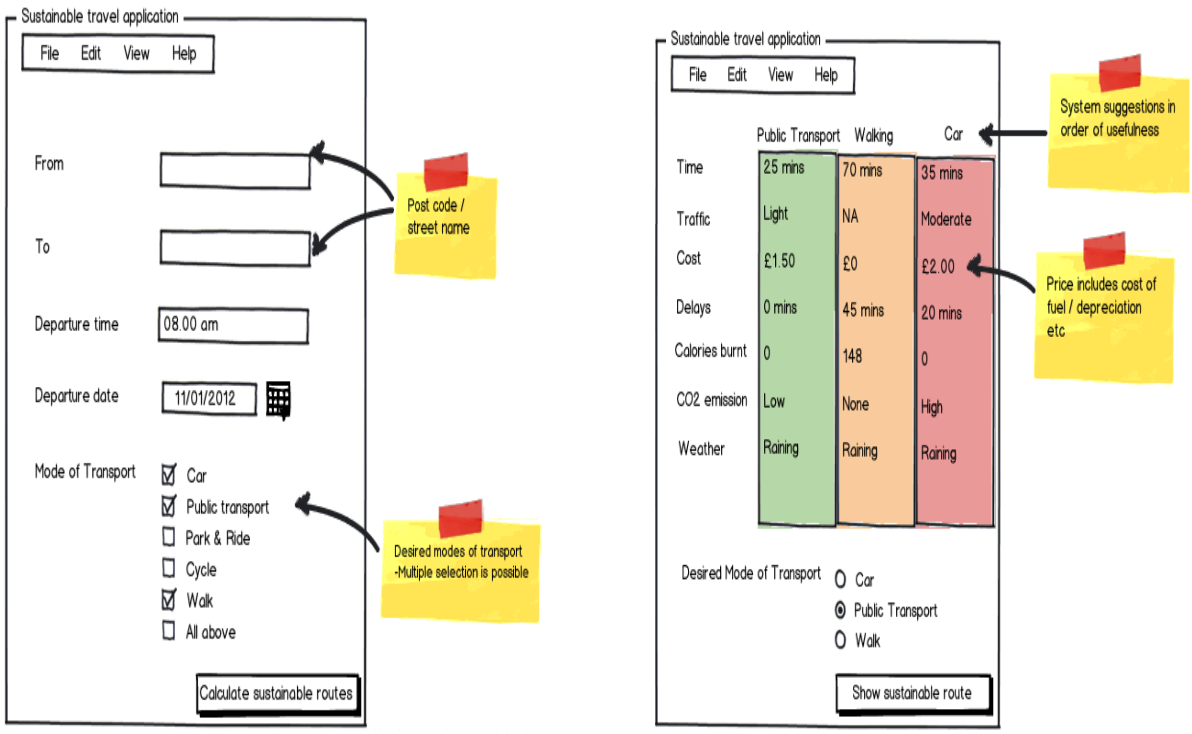
Delphi study [3] is a structured and systematic research method whereby a panel of experts answer a number of questions and express the views of their organisations in regard to a selected number of issues and topics. Usually a Delphi study consists of two or more data collection rounds. Following each round the facilitator collates and compiles an anonymous summary of the experts' views and ideas and circulates to the experts again for further revision until a consensus is obtained among the experts. In our case, we chose to limit the number of rounds to two (i.e. the stop criteria) as a Delphi study is quite a time-consuming process. Experts were representatives from traffic control and management centres in Nottingham and Sofia.

Focus group [4] is a group discussion which includes 6 to 12 people whose opinions are sought about a particular topic in the form of perceptions, attitudes and expectations. A moderator guides the discussion about specific themes but remains neutral, ensuring free flow of ideas, and the discussion is recorded for follow up analysis. Focus group participants were everyday commuters.

To facilitate the focus group discussions and motivate participants to share their opinions in regard to the relevant requirements, we designed and used early mock-ups [8] of the envisaged app, as shown in Figure 2.

All output from the three user studies were recorded and transcribed. The transcriptions were then analysed using mainly the thematic analysis technique [7]. During the analysis we focused on major patterns or themes emerging from participants' responses. At the end of the analysis process, we revised the emerging themes to ensure conflicting and redundant themes were eliminated and obscure themes were clarified.

Figure 2 Four Low-fidelity Prototypes of Envisaged MODUM app



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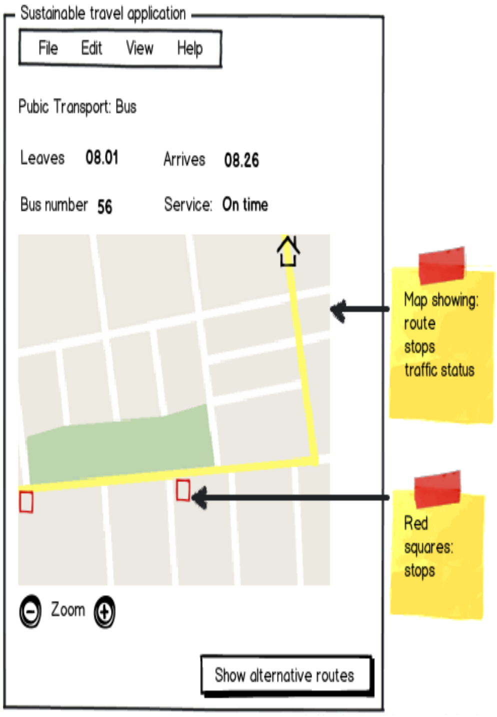

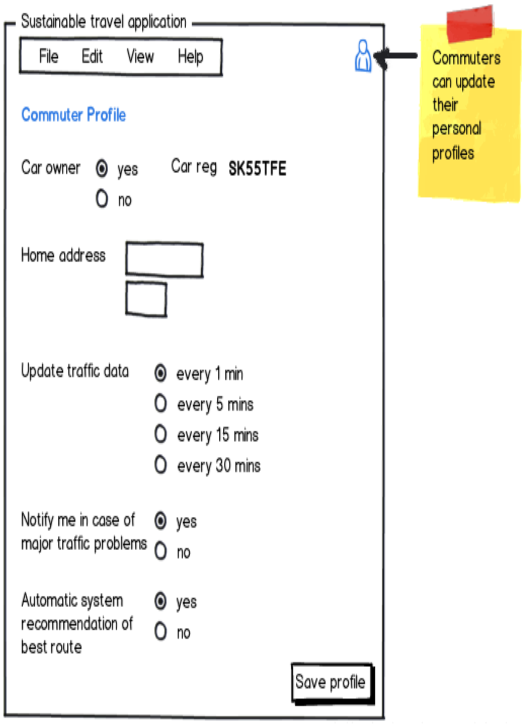

3.2 Profile of Participants and Participating Cities

We have selected four European cities as target cities for conducting our input acquisition exercises for a number of qualifying reasons as follows:

The Description of Work states: "*MODUM has chosen to have two test sites because Nottingham, UK represents a site with high degree of concentration of traffic control facilities (high end of traffic control technology, but not very big at the same time), while Sofia, Bulgaria is at the other end of the spectrum with very few traffic control systems deployed in the city. It is anticipated that the degree of adoption of the MODUM approach in other EU city will fall in between the adoption appropriate for Nottingham and the adoption appropriate for Sofia"*.

Therefore, the cities of Nottingham and Sofia were naturally selected as the main cities for collecting data and testing the MODUM systems and innovations. Nottingham represents the top of the spectrum in terms of road, public transport, and bicycle infrastructure capabilities whilst Sofia represents the bottom of the spectrum in terms of road, public transport, and bicycle infrastructure capabilities.

To add more diversity to the number of participating cities and to enable the up-scaling of the results of this project we expanded our end users to include the cities of Manchester and Leuven. Manchester is a contemporary city with advanced travel infrastructure and urban travel behaviours, whilst Leuven falls somewhere in the middle of the spectrum with a robust travel network. Partly, these two cities were also selected for strategic and convenience reasons where two project partners come from. It is worth noting that these two cities will provide input to contribute to the definition of MODUM requirements, but will not be part of the evaluation process for logistic reasons (i.e. no traffic data is available to for these two cities to test the system). Only the cities of Nottingham and Sofia will host the evaluation studies to validate MODUM models.

For selecting our participants, we used a non-probabilistic sampling approach as we needed participants who fulfil a number of criteria:

1. Participants who live in the participating cities (i.e. Sofia, Nottingham, Manchester, and Leuven). This was a key criterion as we needed to ensure that the systems we are developing satisfy the needs and requirements of these cities, especially Nottingham and Sofia, where the systems will be tested.
2. Participants who are daily commuters, and use at least one of the following modes of transport: car, public transport, and bicycle. Children were excluded in this case as commuters should include people who able to independently commute (i.e. able to make a choice) to work or place of study.
3. Participants who work for a traffic control and management centre; these were representatives of the traffic control and management authorities and participated in the Delphi study.

Next, we proceeded by publishing a recruitment advertisement looking for volunteers through all available channels, e.g. mailing lists, notice boards and word-of-mouth, in our urban traffic control centres (in Nottingham and Sofia) and universities (Manchester and Katholic University of Leuven). At this point, we received interest from potential participants who were checked to ensure they are relevant for our studies. In research this is called a self-selection sample, which is perfectly suitable for the purpose of our studies, as we ethically needed consent from people before inviting them for the studies. Reasons for choosing to take part in a research study may include having a strong interest in the research, having strong feelings about the research, or wanting to help out the researcher. Despite the potential self-selection bias, self-selection sampling technique is a very popular and effective sampling technique in many fields of science [10].

It is important to note here that we did not accept all volunteers to take part in our qualitative studies, but rather applied the above selection criteria, and balanced the type of commuters in each focus group to create a heterogeneous sample (i.e. incorporating a mixture of transport mode users to enrich the results and take into account diverse opinions and requirements). The Delphi study necessitated the recruitment of people who are experts and work in the urban traffic management and control centres. Therefore, the sampling technique was also judgmental or purposive [10].

In respect to the size of a study sample, Lee et al [13] argued that studies which use more than one research method require fewer participants. The total number of participants who took part in our studies was **208**, which is much higher than the qualitative research recommendations [11, 12].

Table 1 and Table 2 summarise the number of participants and their profile for each social input acquisition exercise taken within MODUM. It is worth noting that we do not report on the percentage (%) of use per mode of transport for the experts (instead this is marked as NA in (Table 2) owing to: firstly the small number of experts involved in the Delphi study (12 experts), and secondly we were not concerned about our experts' practices but rather their expert views on the different topics discussed.

The number of participants in MODUM user studies added up to 208 commuters. Of which 122 commuters responded to our online questionnaire, 74 commuters participated in focus group discussions, and 12 representatives from traffic control and management centres in Nottingham (UK) and Sofia (Bulgaria) took part in a 2-round Delphi study.

Table 1 Number of participants per social input acquisition exercise

Study	Round	Manchester	Nottingham	Sofia	Leuven	Total
Critical incidents study	1st	30	92			122
Delphi study	1st		6	6		12
	2nd		6	6		
Focus Group	1st	15				74
	2nd			29		
	3rd		17			
	4th				13	

The highest percentage of respondents to the critical incidents study used public transport to commute to work (43%), followed by cyclists (24%) and car users (23%). However participants of the focus groups were approximately equally-distributed across the different modes of transport (24% car users, 24% public transport users, and 19% cyclists).

Table 2 Profile of participants (%) per social input acquisition exercise

	Gender (%)		Mode of Transport (%)			
	Males	**Females**	**Car**	**Public Transport**	**Bike / Walking**	**Other (Mix)**
Critical incidents study	43.36	56.64	23	43	24	10
Delphi study	83.33	16.16	NA	NA	NA	NA
Focus Group	59.45	40.55	24.32	24.32	18.91	32.43

3.3 List of Requirements

We elicited user requirements by combining results from the above three user exercises undertaken: critical incidents, Delphi study, and focus group sessions. The requirements serve to fulfil three main objectives:

1. Guide the development and implementation efforts of technical partners within Work Package 2, Work Package 3, and Work Package 4 of MODUM;
2. Act as an evaluation reference for Work Package 6 at the end of the project; and
3. Summarise user needs and preferences for an interactive system aiming to improve mobility and commuting experience; this would be useful lessons for other research projects and initiatives targeting the same goal as MODUM's.

It is quite important to highlight the distinction between two systems: the demonstration system and the production system. The demonstration system is the interactive prototype that will be produced within MODUM; it will act as a proof of concept demonstrating the

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techniques and methods developed within MODUM. The production system, however, is the commercial system that might be implemented by transport-focused companies in the future to improve traffic management and reduce congestion on roads.

The subsequent requirements (Table 3) were then thoroughly discussed in a face-to-face meeting between all partners of the MODUM project in the plenary meeting in Gouda (Netherlands) which took place beginning of M6 of the project. We call this a requirements review meeting which aimed to finalise the requirements and solve any conflicts. The tasks partners went through in this meeting are as follows:

1- Go through each requirement and:

- Judge its feasibility within the MODUM project (on a scale: possible, not possible) given the time scale and resources where:
    - Possible: doable and relevant to the project
    - Not possible: not possible to achieve within the timescale of the project or out of scope
- If the requirement is too general, make it more specific
- Prioritise its importance for the success of the MODUM project following the MoSCoW model [9] (scale: Must-have, should-have, Nice to have, Will not have) where:

  Must have: vital requirements without which the final system fails

  Should have: high-priority requirements that should be included in the final system if it is possible

  Could have: desirable requirements in the final system but not necessary. These requirements will be included if time and resources permit

  Will not have: requirements that will not be considered for in the final system, but may be included in future developments and projects
- Specify a fit criterion for each requirement (i.e. how is success of the requirement measured in the validation stage?) for instance: a fit criterion for the requirement "system responds quickly" could be: "the system should take less than 2 seconds to respond to user actions"

2- Identify conflicting requirements, if any, and resolve conflicts by merging requirements together, rewriting the requirements, or removing the irrelevant requirement.

Table 3 compiles the final list of requirements focusing mainly on describing, prioritising, and establishing a fit criterion for each requirement. Each user requirement has been numbered with an ID (**UR.Integer**). The analysis of the results yielded 43 distinct requirements. Every identifiable requirement will be tested at the end of the project in the validation work package to ensure it has been satisfied. The validation/fit criteria ensure that the requirements can be tested in a quantifiable manner, e.g. yes or no, or against a desired rating score.

Table 3 Final list of user requirements

Requirement description	Priority	Fit criteria
COST & AFFORDABILITY		
UR1. Application responds quickly	Must have	The system should take less than 3 seconds to respond to user actions

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		and interactions, such as: showing a sustainable route on a map, or showing diverse suggestions
UR2. Application is free for public use	Must have	The application will have a free mode for the android version where can users enjoy the features of the system for free In the long-term: consumers who allow for tracking their location, will use the system for free. Those who do not allow tracking will have to buy the premium version
ACCESSIBILITY		
UR3. Application needs to target consumers who are older than 65 years of age	Could have	The system may be well received by other generations including the older generations. We may include, depending on time and resources, a couple of elderly in the validation stage to test their satisfaction with the system
UR4. MODUM should consider different groups of people and their 'characteristics' when calculating routes/means of transport	Should have	We will include 2/3 disabled people in the evaluation of the system to capture their views in a debrief interview to test whether the system considers their needs. By disabled people we mean people with physical incapabilities (e.g. wheelchair users, people using crutches due to injury). Other disabilities such as deafness and blindness are outside the scope of MODUM
UR5. Application should be accessible from different devices and platforms (e.g. Web, and mobile phones)	Should have	Consumers will access the application primarily using Android-based smart phones. Their personal profile is also accessible and customisable using the web
QUALITY of traffic information and suggestions: application needs to		
UR6. Provide a map to show/visualise journey routes	Must have	For the free version of the system, we will use Google maps to render the journey routes. However, for production / commercialisation version a different mapping service application will be used
UR7. Visualise alternative journey routes on a map	Must have	Consumers feed the system with their journey plans and the system

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		will show alternative routes
UR8. Show a comparison of alternative journeys in terms of associated cost, time and other comparable criteria	Should have	This feature will be implemented in the demonstration system For each potential route, a table of associated cost, time, delays, and other criteria will be shown to the user
UR9. Show problems associated to each alternative route (e.g. closed roads, traffic jams) for each mode of transport	Should have	Associated problems, if any, for each suggested mode of transport will be shown as text
UR10. Utilise available information to suggest best route to commuter	Must have	The system will capitalise on and combine the information provided by the user from his profile, and other available traffic news and information to make recommendations
UR11. Show expected delays	Should have	For the selected mode of transport by the user, the delays will be shown as text
UR12. Show time of services (e.g. departure and arrival times)	Must have	For the selected mode of transport by the user, time of services –if applicable- will be shown as text
UR13. Show expected journey times	Should have	For the selected mode of transport by the user, length of journey will be shown as text
UR14. Show essential information (e.g. service number, bus stops and location of changes)	Should have	Users who select public transport as their preferred mode of travel will receive such information as text. Some of this information will be rendered on a map
UR15. Show a breakdown of fares for each alternative mode of transport	Should have	This feature will be implemented in the demonstration system and will be shown as text
UR16. When calculating overall cost of travel, take into account all costs (e.g. road tax, insurance parking, and travel fares)	Should have	This feature will be implemented depending on the available information. The system will use as much information provided by the user (such as cost of road tax) as possible and calculate overall cost. The cost, in local currency, will be shown as text
UR17. Be reliable (i.e. work as expected every time)	Could have: for the demonstration system Must have: for the production system.	Should not present wrong, inaccurate or dated information. There should be a precision range (+/- 5 min different to RTA). System available 80% of time We will probe test subjects in the evaluation stage to rate the reliability of the system on a 5-point scale. We aim to achieve a minimum of 3.5/5 rating score
UR18. Have information about public	Could have	Incorporate estimates based on the

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transport (e.g. knowledge of capacity of PT and number of people on board) to make accurate suggestions		time of travel and density of the area to make suggestions
UR19. Provide accurate and correct information as allowed by the infrastructure	Should have	Test subjects will evaluate the accuracy of the provided information on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 rating score
UR20. Provide up-to-date (i.e. real-time) information to PT users (e.g. report service delays as they happen)	Should have	The delivery system must act quickly, as soon as information is received it must processed within 30 seconds by the system
UR21. Provide and communicate up-to-date (i.e. real-time) information to car users (e.g. traffic situation and jams) on the need to know basis to allow them to make a more determined choice	Should have	The delivery system must act quickly, as soon as information is received it must processed within 30 seconds by the system, and communicated 5 minutes before the user needs to make an action
UR22. Show additional information (e.g. weather condition, travel shops in area, gas stations, local car parks, and bike sheds)	Could have	If time and resources permit, we will show other information such as the weather condition in the form of text or render it on the map
USABILITY		
UR23. Application is easy to use	Must have	This requirement will be measured in the evaluation studies to be conducted within WP6. Test subjects will rate the ease of using the application following interaction on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 average rating score
UR24. Application is easy to learn to use	Must have	Test subjects will rate the ease of learning to use the application following interaction on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 rating score
UR25. Application is user friendly	Must have	Test subjects will rate the user friendliness of the application following interaction on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 rating score
UR26. Application is interactive (i.e. accepts input and provides output to specify preferences). However interaction should be limited whilst driving for safety reasons.	Should have	Users will be empowered to enter their preferences and criteria in the form of text (e.g. destination) and selection (e.g. which mode they prefer)
UR27. Application is specialised to different types of users/communities.	Could have	This requirement is relevant only for the production system. As such if time permits this requirement will be explored further MODUM should consider different groups of people when calculating

		routes/means of transport
UR28. Layout of screen is well structured and presented depending on the device	Could have	This requirement is relevant only for the production system. Therefore, if time permits we will ensure the layout is well-presented as received by test subjects. We aim to achieve a minimum of 3.5/5 average rating score on the statement "layout is well structured"
DISSEMINATION of traffic information		
UR29. Exploit social networks to disseminate travel information and updates	Will not have	This is out of the scope of MODUM
UR30. Traffic information is disseminated to any type of smart mobile phones	Should have	Traffic information and recommendations will be delivered in the form of text to any Android-based mobile phones
UR31. Traffic information is delivered to regular mobile phones via text messages	Could have	This requirement is a nice feature to have in the demonstration system but not necessary. However for the production system, it is a must have feature. People who do not necessarily own a smart phone should still be able to receive traffic updates to their regular phones if they wish to
FEEDBACK and expected benefits		
UR32. Calculate and show gained benefits for a selected journey, e.g. calories burned, money saved, time saved	Should have	A small summary will be shown on the system to reveal the benefits gained following the recommendations of the system. Alternatively, an email will be sent to consumers informing them of the gained benefits
UR33. Calculate and show impact on environment (e.g. CO_2 emissions)	Should have	A small summary will be shown on the system to reveal the positive impact on the environment following the recommendations of the system. Alternatively, an email will be sent to consumers informing them of the gained benefits
UR34. Show positive encouraging and possible customised messages to consumers (e.g. thank you for contributing towards a more greener environment)	Should have	Appraisal messages will be shown by the system after each use for following the recommendations of the system
PRIVACY and security of personal information		
UR35. Application maintains confidentiality and privacy of consumers' information (e.g. journeys they perform)	Must have	This requirement is valid for the production system, all data must stay anonymous and no personal information will be maintained.

- Use of system functions depends on the level of information shared by users (create levels)		Various techniques will be employed to ensure this is the case: use anonymous profiles, introduce noise, and design the system not to keep profiles As for the demonstration system, users need to sign up to and share some data, such as: address, how you travel, for efficient and personalised recommendations. However, this information will not be linked to personal names ensuring confidentiality and anonymity
UR36. Application protects and ensures personal data is not passed on to third parties	Must have	Both the demonstration and production systems will ensure no personal data is passed on to independent third parties unless consent is granted by the user
PERSONALISATION and customisation		
UR37. Application needs to know the commuter's preferred ways of travel within the solution space (e.g. on a train, a bus, a bike, or a car – solution space) to make the appropriate suggestion	Must have	Users will be asked to input their preference prior to providing a recommendation
UR38. Application enables consumers to create and customise personal profiles to incorporate preferences and constraints (e.g. need to drop off children to school). As such the application will provide personalised suggestions. For example, users should able to 'pick and mix' specific services (e.g. bus timetable service, weather forecast service) to form a personalised service-based app as per their needs and interests	Should have	One dedicated page will capture information about user preferences and constraints for an optimised recommendation
UR39. Application enables consumers to create travel routines to minimise configuration efforts of application	Could have	If time permits, we will enable consumers to create everyday travel routines
UR40. Application enables consumers to create a detailed plan of their daily journey (e.g. from door to door including other unnecessary trips such as shopping on the way to work)	Could have	If time permits, we will enable consumers to create detailed plans for their journeys
UR41. Application maintains a typical/usual journey	Could have	If time permits, we will enable consumers to save their journeys
UR42. Application enables consumers to save preferred settings	Should have	To minimise configuration, we will ensure consumers save their preferred settings
UR43. Application allows consumers to submit traffic information, such as delays	Should have	For the demonstrator system, the GPS will provide that information.

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and queues, to the system		For the production system, non subscribers should be able to push that information into the system

Table 4 compiles the final list of technical requirements which are required for fulfilling user requirements listed in table 10. Each technical requirement has been numbered with an ID (**TEC.Integer**), which has resulted in 9 distinct cases. The last column in table 11 lists the user requirements that correspond to each technical requirement.

Table 4 List of Technical Requirements

ID. General Requirement	Detailed Technical Requirements	Priority	Fit Criteria	Addressed User Requirements
TEC 1. Quick System Response	**1.1.** The system will use efficient route finding algorithms such as Notice-Board and Distributed-Dijkstra which will be running on a very fast VM (MECA), **1.2.** The system will use 3G and potentially 4G/LTE for communication with mobile phones, **1.3.** The system will benefit from web-based fast and reliable communication mechanisms such as XML-RPC and SOAP to obtain travel time forecasts and communicate with mobile devices.	Must have Must have Must have	The system should take less than 5 seconds to respond to user actions and interactions, such as showing a sustainable route on a map, or showing diverse suggestions.	**UR1**
TEC 2. Software Versions	Two versions of the Android application will be uploaded to Android market (Google Play): **2.1.** A free version with location tracking as unavoidable, **2.2.** A premium (non-free) version with the option of disabling the location tracking.	Must have Must have	Both versions of application must be available and downloadable from Google Play.	**UR2**
TEC 3. Design and Functionalities of Interfaces	**3.1.** Simple process of route finding on Android interface with minimum user interactions, **3.2.** GPS will be used for setting the current location as origin, **3.3.** A list of easily	Must have Could have	In the validation stage, depending on time and resources, the application will be validated by a number of normal users, a number of elderly people, and	**UR3, UR4, UR23, UR24, UR25, UR26, UR28, UR32, UR33, UR34**

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	selectable favourite destinations will be shown, **3.4.** A number of check-boxes or radio buttons will be used for specifying the preferences, **3.5.** Context menu on mobile application and report tab on web-based interface will be used to present gained benefits and impact on environment.	Could have Should have Should have	a number of disabled people. Test subjects will rate the ease of usability and the accessibility on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 average rating score.	
TEC 4. Compatibility of Mobile Interface	**4.1.** Android application will be portable to Android phones and tablets of any screen size, **4.2.** The application will support various versions of Android operating system, **4.3.** Traffic information is delivered to regular mobile phones via text messages, **4.4.** A web-based interface will be created to provide route request functionality on desktop PCs, laptops, and mobiles/tablets with operating systems other than Android.	Should have Should have Could have Should have	The system will be tested to provide service to Android smart phones as well as other non-smart phones. Test subject will rate the availability of service on different type of the phones on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 average rating score.	**UR5, UR28, UR30, UR31**
TEC 5. Visualisation	**5.1.** OSM (Open Street Map) or Google map as interactive means for journey request which can visualise the routes such as eco-friendliest and fastest routes on mobile interfaces, **5.2.** OSM visualisation of current traffic situation on web-based interface (using Leaflet API), **5.3.** Visualisation with various traffic attributes (using radio buttons) on web-based interface, **5.4.** Visualisation of forecasted travel times on web-based interface (changing the window size to 0,5,10,15,20,25,30 minutes	Must have Must have Should have Should have	Each of the functionalities in the visualisation as listed in technical requirements will be tested on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 average rating score.	**UR6, UR7, UR8, UR9, UR10, UR11, UR12, UR13, UR14, UR15, UR16**

	ahead for forecasted travel time), **5.5.** Operator functionality of route request on web-based visualisation (map-click to set origin and destination), **5.6.** Operator functionality of closing road segments on web-based visualisation.	Must have Could have		
TEC 6. System Reliability	**6.1.** Reliable web-based communication technologies such as SOAP and XML-RPC will be used, **6.2.** Agent system (UNIMAN MECA) and Ant system (KUL MECA), that can work with or without dependency to each other, **6.3.** With the modularity of the system through SOAP, XML-RPC, and MECAs, each unit can be replaced by their alternatives.	Demo system – Could have Production system – Must have	Should not present wrong, inaccurate or dated information. There should be a precision range (+/- 5 min different to RTA). System available 80% of time We will probe test subjects in the evaluation stage to rate the reliability of the system on a 5-point scale. We aim to achieve a minimum of 3.5/5 rating score.	**UR17**
TEC 7. Traffic Info Dissemination	**7.1.** Different means for traffic info will be used including simulated road traffic by SUMO; sensory data will be fed into the simulator from UTMC system (SCOOT), alternative infrastructure devices such as Bluetooth scanner, and in-car devices, **7.2.** As additional sources of up-to-date traffic information, GPS enabled mobile devices will send journey reports.	Should have Should have	In the evaluation stage, the consistency of all traffic information sources such as UTMC, infrastructure devices, and in-car devices will be evaluated. A test subjects will evaluate the accuracy of the provided information on a 5-point rating scale. We aim to achieve a minimum of 3.5/5 rating score.	**UR19, UR20, UR21, UR43**
TEC 8. Customisability of Mobile Interface	**8.1.** The preferences, routine journeys, and list of favourite destinations will be saved and maintained by using Shared Preferences or SQLITE on	Should have	A test subjects will evaluate the performance of customisability on a 5-point rating	**UR37, UR38, UR39, UR40, UR41, UR42**

	Android platforms.		scale. We aim to achieve a minimum of 3.5/5 rating score.	
TEC 9. Maintaining Privacy and Security	**9.1.** Various techniques will be employed to ensure this is the case: use anonymous profiles, introduce noise (encryption techniques), design the system not to keep profiles, and use VPN for system administrators, and protect MECAs behind a Firewall.	Must have	A test case generator will create user profiles; the confidentiality of users will be tested throughout the system before, during, and after each request/response loop for each test case (user).	**UR35, UR36**

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4 Technological Capabilities and Requirements

We performed a comprehensive survey of agent applications and models in traffic and transportations system, and an assessment of current technological capabilities in two test environments, Nottingham (UK) and Sofia (Bulgaria). The reviewed applications have been classified into four main categories: theoretical approaches for traffic management, architectures and platforms, distributed ad-hoc networks, and a review of projects similar to MODUM. For the sake of brevity, the full survey is documented in deliverable D1.1.

The target in MODUM is a combination of existing infrastructure and an ICT based traffic coordination service. Simultaneously, MODUM does not impose specific choice mechanisms on the users, but provides a solution on which those choices can be executed. MODUM generates traffic behaviour predictions given a high penetration/participation (cf. with the use of mobile phones) in which travellers self-prescribe their routing and its timing. The project develops its solutions centred on these points and subsequently expands the applicability range of its systems and mechanisms (e.g. for lower penetration/participation). In addition to the above technical requirements listed in Table 4, MODUM also have the following aspects:

- MODUM will develop a class of mesoscopic model. This model class does not aggregate travellers but simultaneously refrains from modelling and simulating physical traveller behaviour.
- Fast execution/simulation (e.g. for usage in the on-line generation of predictions).
- Software-in-the-loop for simulation models (e.g. to simulate any decision mechanism).
- Individual travellers and resources (e.g. use of a lane, parking space) can be modelled (needed in any case) as well as their aggregates such as traffic flows through subnets (when and where needed/opportune).
- Models include (through software in the loop):
  - Local policies of resources
  - Self-prescribed routing/timing of travellers
  - The enforce-ability and commitment/certainty level for the above
- Variable participation rates for travellers and resources
- Policies and self-prescription that have access to the generated predictions (by the software in the loop)
- Policies that depend on the self-prescribed behaviour and its commitment/enforce-ability
- Self-prescribed behaviour depending on policies (granting conditional rights)
- MODUM adopts the active roles for all real-world entities in its models (agent technology).
- MODUM includes its Intelligent Traffic Systems (ITS) in the models (software-in-the-loop).
- MODUM makes the results of its model execution available to its Intelligent Traffic Systems ITS, also in simulation.
- The MODUM system is to be deployed in two different environments; one mature in terms of traffic management (Nottingham), and one immature (Sofia).

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- The strategy, however, is to develop a set of functionalities that allow scientific investigators to concentrate on the functionality of their approaches without having to worry unduly about the practical deployment of the resulting code in the field.

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5 A Low-carbon Traffic Management Framework

The framework is constructed with the principal aim of guiding the development and progress of the MODUM project to ensure successful fulfilment of all objectives at the end of project lifetime as stated in the Description of Work. The framework acts as a summary for the (expected) contributions of MODUM, the methodology adopted within the project, and also its expected societal and economic impact. Particularly, we have set the following objectives for our framework:

- Link and frame the different research activities of MODUM within one unique framework
- Model and predict how commuter behaviour and decision making process are influenced using MODUM outcomes as interventions (especially the demonstration system); thus how travellers are encouraged to participate towards a clean and efficient mobility
- Highlight how travel experience is improved based on real traffic information and traffic optimisation models

In summary the framework focuses on two main parts: 1) modelling and influencing commuter behaviour; and 2) optimising mobility towards CO_2 emissions reduction. Basically the results of the input acquisition exercises (results of T1.3) yielded interesting results in regard to which and how many factors govern consumers' decision making process. Factors range from instrumental factors, such as cost of travel and length of journey, to psychological factors, such as: comfort, prestige, and confidence. Also of main interest, is past commuting experience with public transport, whether being negative or positive. Negative past experiences inhibit sustainable travel behaviour whereas positive past experiences encourage sustainable travel behaviour. Such factors and constraints altogether interact and inter-relate when decisions are made in regard to which mode of transport to choose. In MODUM, we plan to introduce the results, in the shape of an android app, as a technological intervention to mediate the travel decision making process in favour of a more sustainable society. Thus MODUM will improve fuel-efficiency of road traffic by reducing congestion and idle time, especially in scenarios with high participation rates.

The second part of the framework addresses the research themes which will brand the innovative character of MODUM towards a clean, optimised mobility. Such themes are derived from the scientific literature review and the analysis of related projects. The themes are the following:

- **Optimisation**: One of the key elements towards clean mobility consists of optimising the use of the infrastructure, i.e. having travellers to move through less congested roads, have more mobility choices by combining different modes of transport, and have access to reliable, up-to-date information about transport. All this is possible by investigating models which aggregate transport information to optimise the use of the infrastructure resulting in a reduction of CO_2 emissions.

- **Prediction**: Anticipating events that will likely create or contribute to an increasing deterioration of the mobility flow can help reacting faster to minimise such deterioration. Prediction also allows optimisation to be more precise and thus contribute to reducing CO_2 emissions. Therefore, it is important to investigate mechanisms for predicting events, the size and scope of such events, and the likelihood of how they will affect mobility throughout the transport network.

- **Adaptation**: It is well known that transport is a highly dynamic environment and as such it is hard to say that all potential events can be predicted. Accidents, infrastructure faults, unexpected overload, etc. suddenly happen affecting the mobility flow. Thus, it is important to investigate mechanisms for detecting such events as quickly as possible and reacting to them in an optimal manner. Such adaptations can be in the forms of redirecting affected mobility flows, updating the likelihoods of predicted events, recalculating multi-modal journeys, and so on. An important aspect of adaptation is determining a cascading effect of unexpected sudden events (e.g. an accident) in the transport network.

Overall, we expect the framework to make an impact on three main fronts:

- **Individual level**: a positive influence on consumers' perception, satisfaction, and eventually practices leading to "sustainable behaviour becoming a habit in our lives".
- **Societal and economic level**: reduction in CO_2 emissions leading to a greener society, and nurturing of a more sustainability-aware and tolerant society toward public transport and cyclists.
- **Traffic control and management level**: reduced pressure on traffic control and management centres enabling them to dedicate their human and financial resources into improving the infrastructure and service quality of public transport.

More details about the framework are documented in Deliverable 1.1.

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6 Specification of Field Trials

The trials under the MODUM project will address the two tiers of beneficiaries targeted by the aims of the project – traffic control and management centres – public/private bodies tasked with the management of the traffic in the cities and the individual consumers going on their day-to-day journeys, as summarised in Table 6.

In addition to evaluating commuters' experience, the trials will evaluate the quality of the traffic simulation modules:

1. Microscopic Traffic Simulation Model,
2. Agent-Based Traffic Control and Management System,
3. Ant-like agents for Traffic Management,

and to a certain degree the quality of integrated data in the ad-hoc networking algorithms for collection and integration of traffic data and identifying traffic conditions through ad-hoc wireless networking.

In total, 3 sets of trials will take place in Nottingham involving the relevant beneficiaries as explained in Table 6. For Sofia, the evaluation approach will follow exactly the same pattern as on the Nottingham scenario with the only difference being underground travel included in the multimodality (Nottingham has no underground).

Table 5 and Table 6 summarise the available system components at our two test sites, Nottingham and Sofia, and the appropriate evaluation methods to be used.

Table 5 Available Systems Components

System components:	Nottingham	Sofia
Traffic Lights Control System real-life data feed	□	-
Public Transport (buses, trams, etc) real-life data feed	□	□
Other UTMC (traffic control centre) information feeds	□	-
Traffic Users Smartphone or car – multimodal	□	□
Ad-hoc wireless mobile networking (cars with wireless integrated data)	□	□

Table 6 Three Set Evaluation Framework

Beneficiary	Evaluated Element	Evaluation Method
Commuter	Individual Journeys– 3-5 cars and up to 20 users chosen representatively (time, stops, emissions, improvement etc.)	Comparing journey's characteristics with and without MODUM framework present
Traffic Control Centre	Creating single model of the traffic in the city based on all heterogeneous data available in MODUM, extrapolating the traffic data through simulation to areas not covered by real-time data systems collection areas	Generating traffic simulation data based on real-time feeds for areas with already existing real-time data input and comparing the simulated and real-time data
Traffic Control	Overall traffic management in the	Indirect evaluation of the quality of

Centre	city	the traffic management through extrapolating the improvement in journey characteristics to the overall characteristics of the traffic management in the city through simulation

7 Conclusions

This deliverable, D1.2, briefly summarises the main outputs of WP1 of the MODUM project. It starts by describing the research techniques used to collect and elicit requirements for the MODUM project. In particular, we used (1) the critical incident technique to collect realistic experiences that actual consumers have had with current modes of transport and transportation system, (2) a two-round Delphi study to gauge opinions and views of representatives (or experts) from traffic control and management authorities in regard to current practices and issues of transportation system, and finally (3) focus groups to further explore individual experiences and gather relevant requirements for our MODUM app using early mock-ups. Indeed these three input acquisition exercises were effective and complementary in forming a complete picture about consumers' choices and their decision making process. Next, the deliverable lists the user requirements following the MoSCoW prioritisation technique [9] for an app that would encourage consumers to reduce reliance on cars in favour of a more sustainable transportation system.

The deliverable concludes by highlighting the evaluation plan and evaluation activities that will be carried out at two designated test sites, Nottingham City Council and Sofia Transport Centre, towards the end of the project. The evaluation plan will be used to guide the validation Work Package, WP6.

In essence, the innovations and added values of WP1 are demonstrated, and can be summarised in the following key points:

- MODUM project is the only transport research project which uses the **triangulation research methodology** to acquire user requirements, thus reducing bias and achieving higher levels of reliability. As such WP1 contributes a methodology for understanding user needs and requirements in the domain of urban transport,
- MODUM project follows the **user-centred design** approach whereby potential target users are involved in shaping the design of MODUM systems,
- A **high number of participants** (208 people) took part in WP1 studies, ranging from public transport users, car drivers, cyclists, and pedestrians, enriching the results and creating **a multi-perspective view of the traffic issues**. This is very important since one of MODUM's innovations is to provide **flexible solutions that utilise multiple modes of transport**,
- The requirements resulting from WP1 were defined through **a rigorous process with three different research methods performed in four European cities** (i.e. Nottingham, Sofia, Leuven, and Manchester) where each city has its unique transport infrastructure capabilities and specific travel patterns,
- The user requirements revealed on a number of important findings that could lead to **behaviour change for sustainable travel**, specifically the delivery of ***real-time and accurate*** traffic updates to make people aware of traffic disruptions, jams, and accidents, the need to show **expected gains** (e.g. money and time) and **incurred costs** (e.g. CO_2 emissions) for specific journeys, the need to show flexible **multi-modal journey routes** (e.g. route solutions using a car, public transport…etc), the need to ***personalise*** travel route solutions to user preferences, circumstances, and abilities,

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- WP1 also contributes a **low carbon traffic management framework** that coordinates the various activities of the MODUM project, and helps envisage how MODUM outputs will be used as an intervention to change travel behaviour,
- WP1 studies used **low fidelity prototypes** to envisage the final system of MODUM which will be used by actual end users. This enabled us to collect relevant and detailed requirements for the MODUM project,
- The inclusion of representatives (experts) from actual urban traffic control and management centres of our test sites (i.e. Nottingham and Sofia), thus integrating their current views with that of the actual commuters' to create **an all-rounded perspective of user needs and requirements**,
- The analysis of the requirements used the **MoSCoW technique** to classify and prioritise the requirements and define appropriate validation measures. The requirements identified in WP1 were a result of collaboration and involvement of potential end users (i.e. commuters), experts from urban traffic management and control centres, and project partners, and
- The expert analysis of other traffic management tools and architectures performed in WP1, e.g. Table 11, clearly demonstrated the innovative aspects and advancements that MODUM will bring about. Three key innovations missing in existing architectures but are endeavoured in MODUM: use and delivery of real-time traffic information and updates, calculation of carbon dioxide emissions, and provision of flexible multi-modal journey solutions.

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