DIT4TraM

Distributed Intelligence & Technology
for Traffic & Mobility Management

# D6.2: Future traffic and mobility management system architecture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 953783.

DIT4TraM

Distributed Intelligence & Technology for Traffic & Mobility Management

## Quality control

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## Release approval

| Name | Role | Date |
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| Marco Rinaldi (TU Delft) | Reviewer | 10/02/2023 |
| Sascha Hoogendoorn Lanser (TU Delft) | Project coordinator | XX/MM/YYYY |



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## List of abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| ADT | Amsterdam Digital Twin |
| API | Application Programming Interface |
| AVL | Automated Vehicle Location |
| DNTM | Distributed Traffic Network Management |
| DRT | Demand Responsive Transport |
| EPFL | Ecole Polytechnique Fédérale de Lausanne |
| ESB | Enterprise Sservice Bus |
| EU | European Union |
| FCD | Floating Car Data |
| GDPR | General Data Protection Regulation |
| GNV | Gecoordineerd Netwerkbreed Verkeersmanagement |
| GTFS | General Transit Feed Specification |
| GUI | Graphical User Interface |
| IoT | Internet of Things |
| MoS | Mobility operating Systems |
| INM | Integrated Network Management |
| I2V | infrastructure-to-Vehicle |
| LOS | Level Of Service |
| OBU | On-Board Unit |
| OD | Origin-Destination |
| PT | Public Transport |
| TMB | Transports Metropolitans de Barcelona |
| TMC | Tradable Mobility Credit |
| V2I | Vehicle-to-infrastructure |
| V2X | Vehicle-to-Everything |
| VoT | Value of Time |
| WP | Work Package |



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# 1. Introduction to the project

DIT4TraM is focused on identifying, developing, and deploying cutting-edge methods for distributed traffic monitoring and control, including approaches based on learning, self-organization, and mechanism design. Cyber-physical systems using the Internet of Things (IoT) and other data sources to measure and represent the state of the system in real-time will be used, along with smart components adaptively responding to information, and capable of learning. The DIT4TraM vision is to provide seamless, sustainable, connected, and autonomous urban mobility enabled by cooperative and decentralized traffic management. Therefore, the overall goal is to develop, implement and test a generic distributed control paradigm, which shall employ novel technologies to solve the pressing urban mobility issues.

Key objectives of DIT4TraM:

- Develop a multi-modal generic, scalable, adaptable, and secure paradigm for distributed management of transport systems
- Design fair and equitable incentive-based mechanisms for cooperative, connected micro-dynamic traffic management
- Develop a new distributed dynamic traffic management approach w/ multi-level, multi-modal perimeter control and information exchange
- Develop distributed demand management schemes via tradeable travel permits to balance user-centric vs. system-optimal objectives at an urban scale
- Develop fair cooperation schemes based on pricing and prioritization

DIT4TraM will test its solutions in six demonstration areas, consisting of four pilot areas (P1-P4): Bordeaux (France), Utrecht (Netherlands), Amsterdam (Netherlands) Glyfada (Greece), and two simulation areas (P5-P6): Athens (Greece) for urban applications and Mediterranean highway - AP7 (Spain) for interurban application.


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Deliverable 6.2 presents an overview of the overall system architecture of the DNTM system within DIT4TraM. The six pilot case studies – Amsterdam, Utrecht, Glyfada, Bordeaux, Athens (virtual), and Med. highway (virtual) provided input and feedback on the system architecture. This deliverable contains the tailored versions of the system architectures for all these pilot case studies.

The inputs gathered from all pilot site stakeholders provided valuable input for this document. With that input, the generic system agents and the pilot-specific system agents have been identified. For each pilot, this document describes the architectural characteristics within the conceptual blueprint, the information flows, and the decision-makers.

The document has an overview of the generic platform system agents, including a description of the specific requirements for these system agents.



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# 2. High-Level System Architecture

The main concept of the DNTM system is a multi-agent system of multiple interacting intelligent agents.

Agents in a multi-agent system have several important characteristics[1]:

- **Autonomy**: agents are at least partially independent, self-aware, and autonomous;
- **Local views**: no agent has a full global view, or the system is too complex for an agent to exploit such knowledge;
- **Decentralization**: no agent is designated as controlling other agents (or the system is effectively reduced to a monolithic system).

Multi-agent systems consist of agents and their environment. The environment for all system agents in the DNTM is provided by the pilot study environment or virtual environment from the simulation system.

This means that pilot case studies cannot be seen independently of the work packages 2 to 5 and vice versa.

## 2.1. System agents design blueprint

During the DIT4TraM meeting in Glyfada (October 4-5, 2022) we presented and discussed the system agent design blueprint as a starting point for this deliverable. Figure 1 shows this blueprint at that time.

[1] https://en.wikipedia.org/wiki/Multi-agent_system



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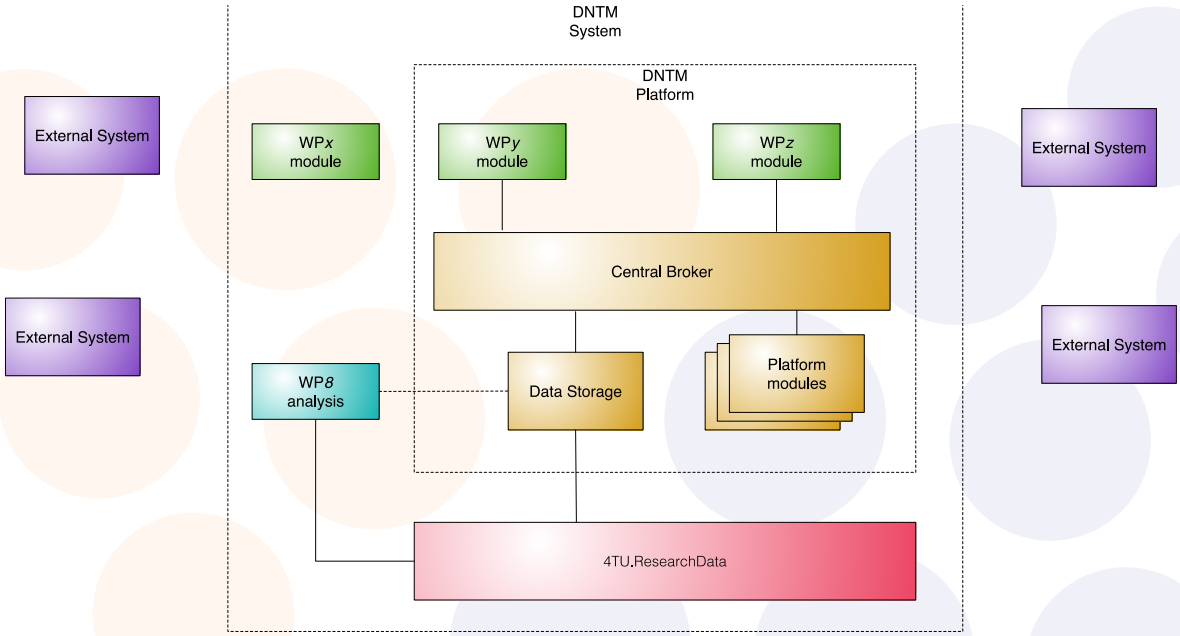


Figure 1: High-level architecture (blueprint, October 4-5, 2022)

The key decision in this architecture was a clear separation between the DNTM System as a whole and the technical, supporting DNTM Platform. Therefore, the **DNTM System** represents the complete system for a particular pilot case or work package including all pilot-specific system agents (green and blue). The **DNTM Platform** (yellow) is part of the DNTM System and provides a common, reusable platform for all pilot system agents and provides the communication layer between all system agents. Finally, **External Systems** (purple), e.g. traffic light controllers or banking systems, are elements not in the control or responsibility of any agent directly but needed for the specific use case.

At the moment of designing this blueprint, it was envisioned that **4TU.ResearchData**[2] (red) would be an agent as well within the **DNTM System**, but after further investigations, it made more sense to classify the 4TU system as an external system as a possible location to store data.

[2] 4TU.ResearchData was established in 2008 within the 4TU.Federation as an initiative of three technical universities: Eindhoven, Delft and Twente. See: https://data.4tu.nl/info/en/



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## Assumptions

- All **yellow** modules, e.g., **Central Broker**, **Data Storage,** and supporting **Platform Modules** are provided by WP6;
- All other colors, e.g, **green**, **purple**, **red**, etc. are provided by **pilot stakeholders**, like Work Packages, Pilots, or partners.


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# 3. Pilot architectures

This chapter defines all system agents as identified in the pilot case studies and work packages. Each pilot case study will have a similar section with the same structure:

a) A quick overview of facts and figures;
b) A **requirement analysis** using the D6.1 Requirement and use case inventory;
c) A system overview that maps the agents and **requirements** of the architecture including **information flows**;
d) A list of all **system agents** in the pilot case study;
e) A list of all **decision-makers** in the pilot case study.

The requirements (b) are based on the results of the D6.1 Future traffic and mobility management system requirements and use cases report including the four separate system layers:

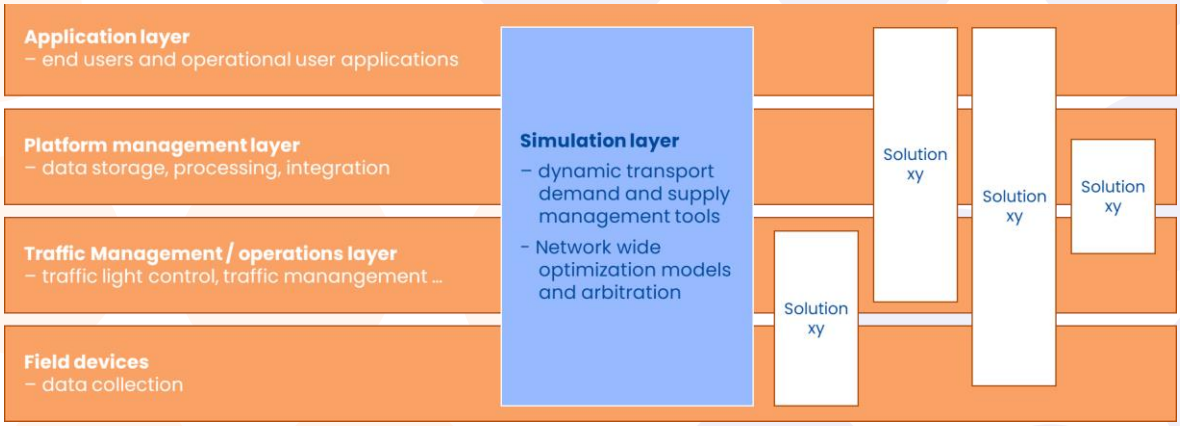


Figure 2: DNTM system layers (source: DIT4TraM D6.1 Figure 7).

## 3.1. Amsterdam

### a) Facts & figures

Amsterdam is the capital and most populous city of the Netherlands and ranks among the 20 largest cities in the European Union. The municipality of


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Amsterdam has more than 900,000 inhabitants (2022) and the agglomeration Groot-Amsterdam has almost 1.4 million inhabitants (2021).

Amsterdam lies on the canalized river Amstel and the former estuary IJ. The city's port is connected to the North Sea by the North Sea Canal and is the second largest in the Netherlands. Amsterdam is world-famous for its canals.

Many Dutch companies, such as the Heineken brewery and the electronics group Philips, have their headquarters in Amsterdam.

Amsterdam has two universities. The Science Park is home to the University of Amsterdam's Faculty of Science, Amsterdam University College, dozens of renowned research institutes, and around 130 companies - from start-ups to multinationals. They work in information technology, life sciences, chemistry, high technology, instrumentation and physics, and sustainability.

Tourism is an important source of income for the city. In 2015 there were 142 calls by cruise ships in the port of Amsterdam. With more than seven million tourists from abroad every year, the city ranks fifth among the most visited cities in Europe.


Figure 3: Map of Amsterdam



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(source: Google Maps)

## b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Amsterdam pilot representatives.

This document contains the following analysis, which maps the requirements on the overall DNTM System and DNTM Platform using the D6.1 layered approach:

| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- Web Based User Interface | **Application Layer**<br>- Back-End for simulation control |
| **Platform Layer**<br>- WP4 Algorithms<br>- WP5 Algorithms | **Platform Layer**<br>- Data security<br>- Data storage |
| **Traffic Management Layer**<br>- No specific requirements | **Traffic Management Layer**<br>- No specific requirements |
| **Data generation / Field device layer**<br>- Socio-economic data<br>- Tracking data<br>- Transaction data and wallet balance<br>- Vehicle-wallet coupling<br>- Buying/Selling price data | **Data generation / Field device layer**<br>- Data storage |

The requirements in the *DNTM System column* shall be covered by the pilot case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.


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## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Amsterdam pilot case.

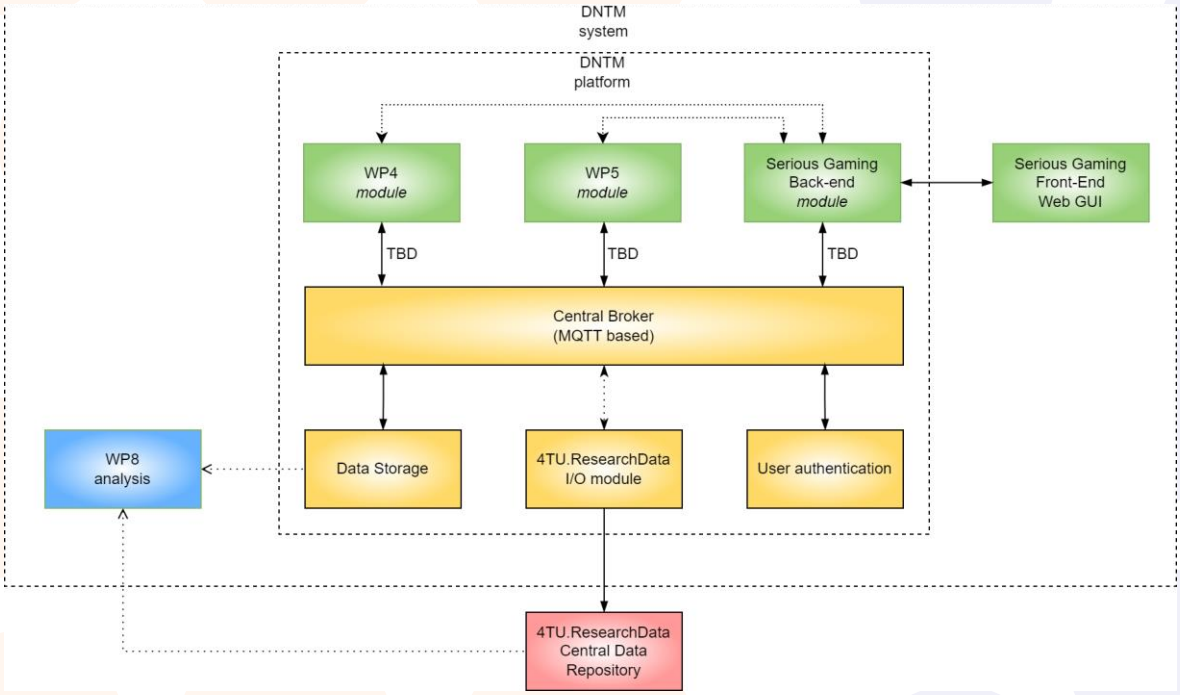


Figure 4: Amsterdam Pilot Architecture

## d) System Agents

The system agents for the Amsterdam pilot consist of the following:

- **WP4 algorithmic module**. This agent represents WP4's work on *Decentralised demand management schemes via tradable multi-modal travel permits*. The inner elements of the agent are left out of scope for this document. The agent communicates with the **Central Broker** element for data exchange with other agents, and is connected to the **Serious Gaming Back-End module**.
- **WP5 algorithmic module**. This represents WP5's work on *Fair cooperation schemes for urban mobility management in future multi-actor settings*.


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The inner elements of the agent are left out of scope for this document. The agent communicates with the **Central Broker** element for data exchange with other agents, and is connected to the **Serious Gaming Back-End module**.

- **Serious Gaming Back-end module**. This module creates the technical back-end for the interaction with WP4 and WP5 modules and the **Serious Gaming Front-End Web-GUI**. It connects to the other two agents and the **Central Broker** for the exchange of data with agents.
- **Serious Gaming Front-End Web-GUI**. The Web-GUI is the front end that users will use for serious gaming. It interacts with the back end.
- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.
- **Central Broker**. This DNTM Platform key element offers the central way of communication. It uses an IoT-standardized protocol based on MQTT.
- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **User Authentication**. This module is used for authenticating users/systems which want to access the **Central Broker** and the **Data Storage**.
- **4TU.ResearchData I/O module** (external agent). This module takes care of pushing data from the Data Storage to the TU Delft's 4TU.ResearchData facility.

### e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Amsterdam
- **Operational level**
  - Commuters (participants in the virtual pilot)

During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.


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## 3.2. Utrecht

### a) Facts & figures

Utrecht is a Dutch municipality and the capital of the province of Utrecht with a population of about 360,000 (agglomeration: 660,000). The fourth largest city in the Netherlands is located in the center of the country. Therefore the Utrecht Centraal train station is of great importance for long-distance connections. Utrecht has an important university, a conservatory and a university of applied sciences.

The city has a diverse industry. Many institutions such as the trade unions of the Netherlands and the Dutch railway company Nederlandse Spoorwegen have their headquarters in Utrecht. Utrecht is the fastest growing city in the country.

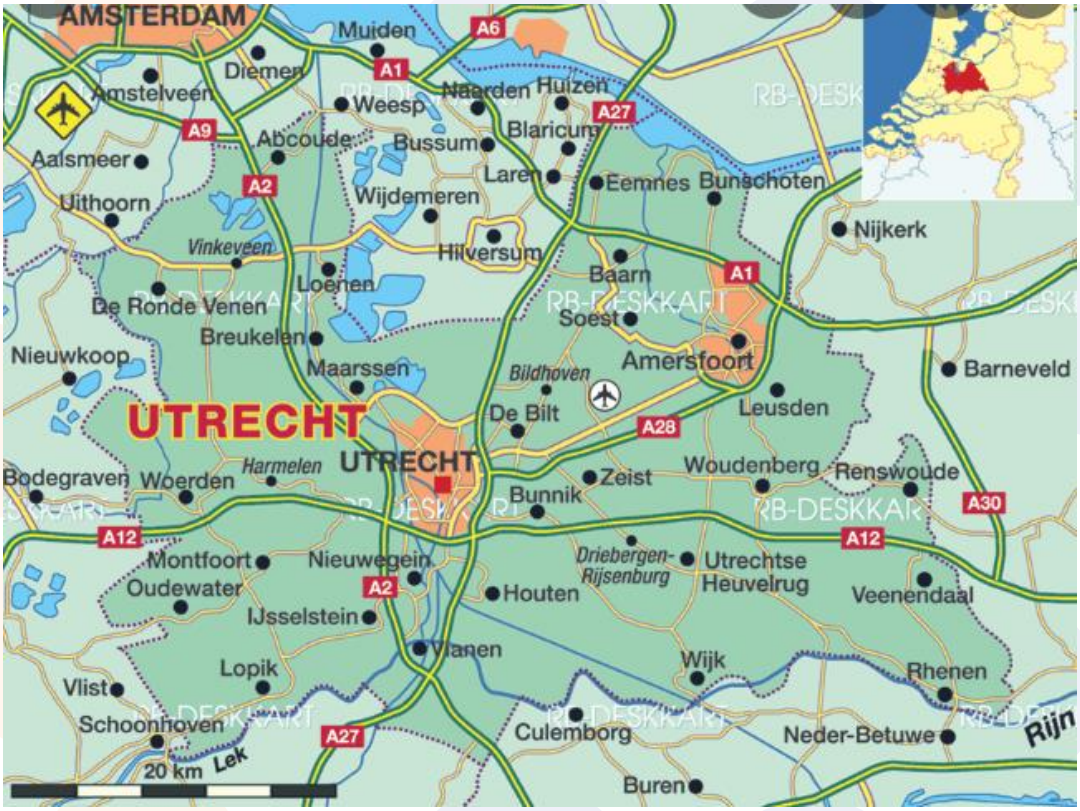


Figure 5: Map of Utrecht
(source www.weltatlas.de)



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## b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Utrecht pilot representatives.

This document contains the next analysis that maps the requirements on the overall DNTM System and DNTM Platform using the D6.1 layered approach:

| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- GUI | **Application Layer**<br>- |
| **Platform Layer**<br>- Enterprise service bus (ESB)<br>- Data security<br>- Data storage (historical, with GUI and API)<br>- Analysis tool | **Platform Layer**<br>- |
| **Traffic Management Layer**<br>- GNV[3] functionality<br>- Tactical error handling<br>- Optional: prediction of traffic patterns | **Traffic Management Layer**<br>- |
| **Data generation / Field device layer**<br>- Existing sensors and actuators<br>- Optional: Travel time per road segment<br>- Optional: Intersection data (traffic signal data and loop detector data)<br>- Optional: bike sensors | **Data generation / Field device layer**<br>- |

The requirements in the *DNTM System column* shall be covered by the pilot

[3] Gecoördineerd Netwerkbreed Verkeersmanagement


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case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.



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## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Utrecht pilot case.

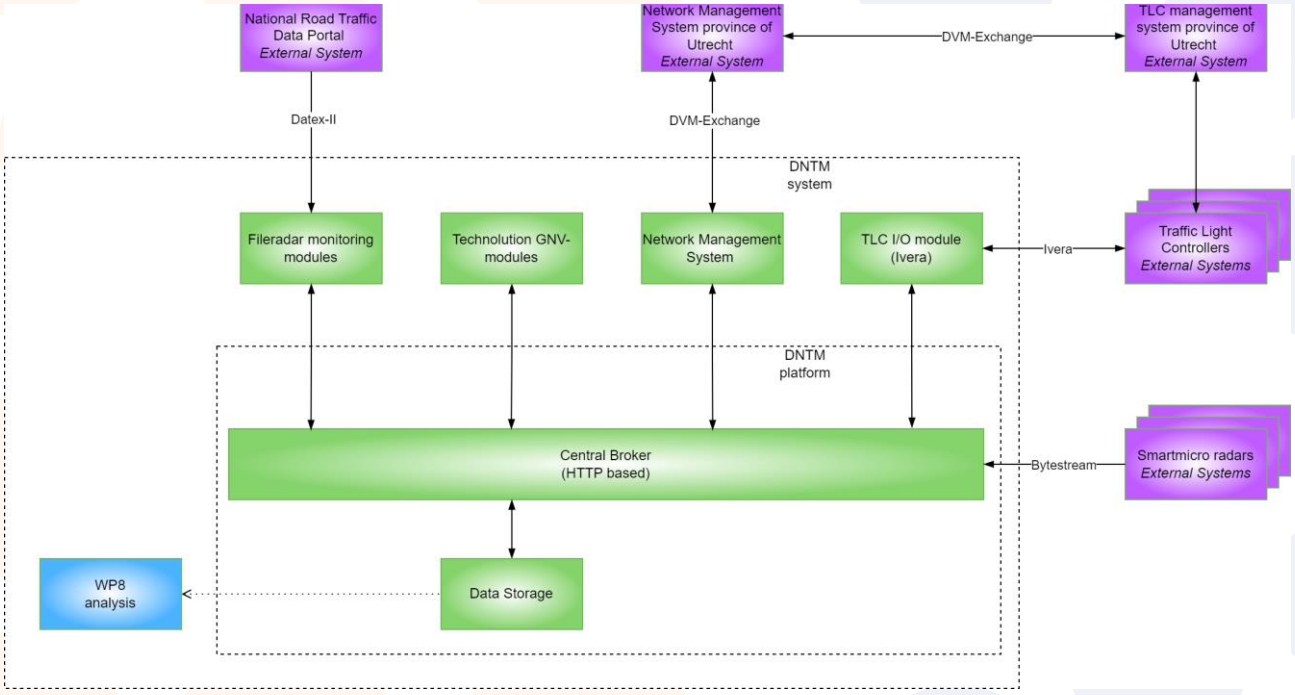


Figure 6: Utrecht Pilot Architecture

Please note that an existing system is already in place which is why existing modules will be enhanced instead of using the DNTM platform which is developed in WP6. The existing system already conforms to the DNTM platform architecture.

## d) System Agents

The system agents for the Utrecht pilot consist of the following:

- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.



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- **Central Broker**. This DNTM Platform key element offers the central way of communication. Because the existing broker already uses an HTTP based protocol, we will not use the DNTM Platforms default broker based on MQTT.
- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **Fileradar monitoring modules**. These modules process data from the **National Road Traffic Data Portal** (in Dutch: NDW) and the Smartmicro radars Into data that Is used by the **Technolution GNV-modules**.
- **Technolution GNV-modules**. These modules process data from the **Fileradar monitoring modules**, determine the traffic state and calculate changes in the traffic light green times to optimize traffic based on policy rules.
- **TLC I/O module (Ivera).** Communicates with the signal controllers using the IVERA protocol which is a standardized protocol in the Netherlands for communicating with the **Traffic Light Controllers**. It reads the current state from the controllers and sends green time changes to the controllers.
- **Network Management System**. The NMS is used as a GUI for the operators to monitor the state of the system and also to communicate with other Network Management Systems using the DVM-Exchange protocol.

### e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Utrecht
- **Operational level**
  - Commuters

During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.


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## 3.3. Glyfada

### a) Facts & figures

Glyfada is a city in the Greek region of Attica and belongs to the Athens metropolitan area. It is located on the Athens Riviera along the Athens Coast.

The population is approx.. 90,000 (based on 2011 census) and increased by almost 50% in the last 30 years.

Glyfada is one of the most elegant and luxurious suburbs of Athens with a booming economy.

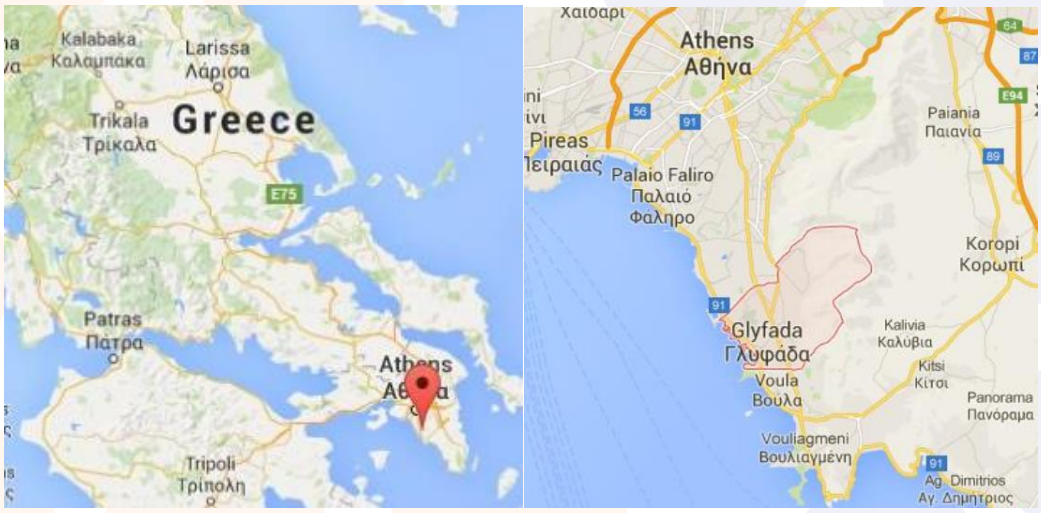


Figure 7: Maps of Glyfada
(source: googlemaps)

### b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Glyfada pilot representatives.

This document contains the next analysis that maps the requirements on the overall DNTM System and DNTM Platform using the D6.1 layered approach:



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| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- Connection to Oseven applications | **Application Layer**<br>- No specific requirements |
| **Platform Layer**<br>- Connection to bank account interface<br>- Smartphone data through O7App | **Platform Layer**<br>- Data security<br>- Data storage<br>- Data sharing with OSeven |
| **Traffic Management Layer**<br>- | **Traffic Management Layer**<br>- Real-time travel times<br>- Network conditions |
| **Data generation / Field device layer**<br>- Connection to Google API<br>- GPS sensor of smartphones | **Data generation / Field device layer**<br>- Request-related data (e.g., passenger O/D)<br>- Vehicle-related date (e.g., position)<br>- Network-related data (e.g, travel times) |

The requirements in the *DNTM System column* shall be covered by the pilot case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.

## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Glyfada pilot case.


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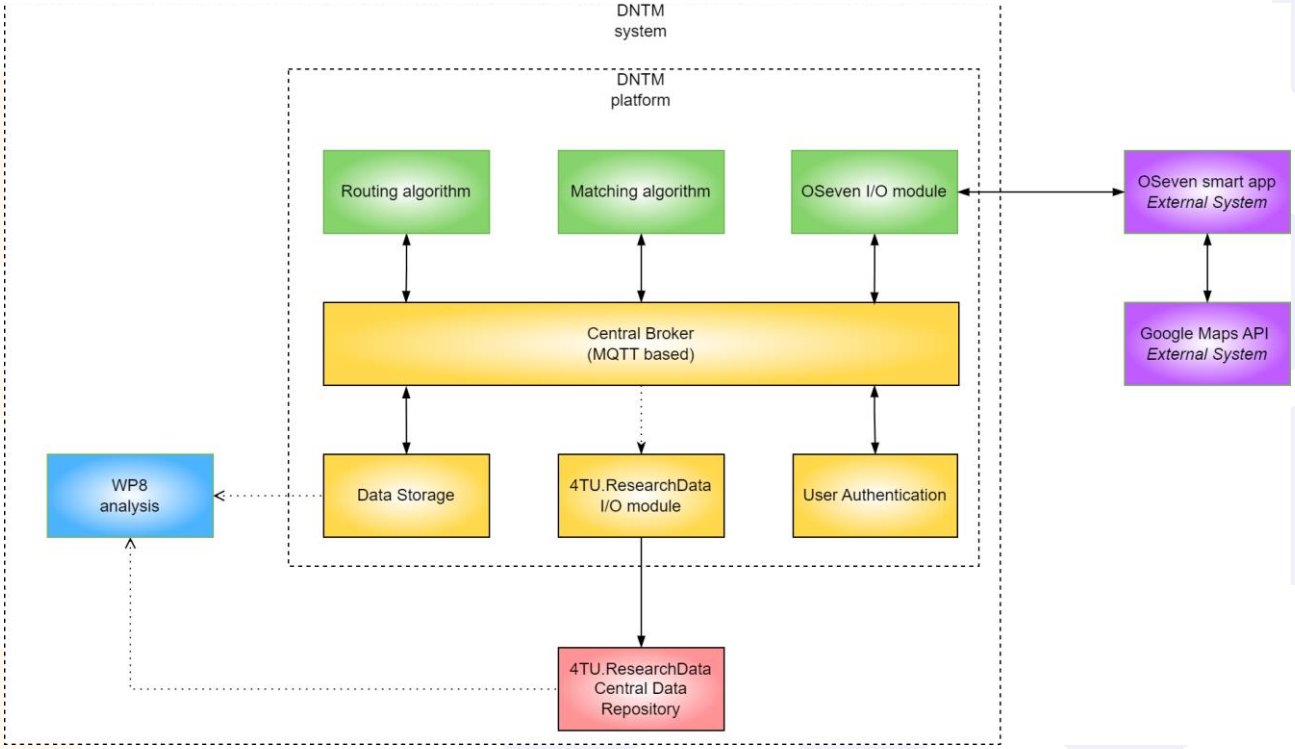


Figure 8: Glyfada Pilot Architecture

## d) System Agents

The system agents for the Glyfada pilot consist of the following:

- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.
- **Central Broker**. This DNTM Platform key element offers the central way of communication. It uses an IoT-standardized protocol based on MQTT.
- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **User Authentication**. This module is used for authenticating users/systems which want to access the **Central Broker** and the **Data Storage**.
- **4TU.ResearchData I/O module** (external agent). This module takes care of pushing data from the Data Storage to TU Delft's 4TU.ResearchData facility.


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- **OSeven smart app.** This software is developed by OSeven and interacts with the users and the **Google Maps API**. Communication between this software and the **Central Broker** is handled by the **OSeven I/O module.**

### e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Glyfada
- **Operational level**
  - Fleet owners
  - Commuters

During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.

## 3.4. Bordeaux

### a) Facts & figures

Bordeaux is a university and port city on the Garonne River in southwestern France. It is the political, economic, and scientific center of southwest France. Bordeaux has a reputation as France's "second capital" as the seat of government was temporarily moved here from Paris in the past.

Bordeaux has 260,958 inhabitants (as of January 1, 2019). The narrower metropolitan area of Bordeaux has around 773,542 inhabitants and includes 26 surrounding communes organized in the Bordeaux Métropole commune association. This association is part of an agglomeration that includes the wider catchment area with a total of 51 municipalities and a population of 1,215,769. It is the largest city in the Gironde department and the Aquitaine region and the ninth largest city in France.

The Garonne flows right through Bordeaux. The area inside the former city walls is the historical heart of Bordeaux. Delimited by the annular structure of the main roads and the banks of the Garonne, it is divided into two main axes. From north


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to south runs a 1 km long pedestrian area. From east to west, the Pont de Pierre, the only bridge is crossing within the historic center.

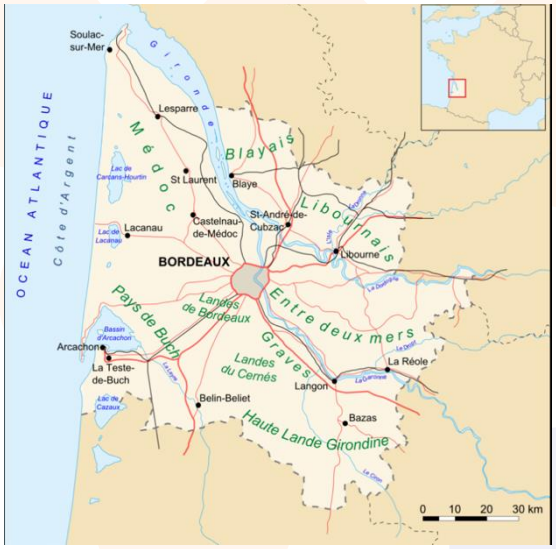


Figure 9: Map of Bordeaux
(source: Wikipedia)

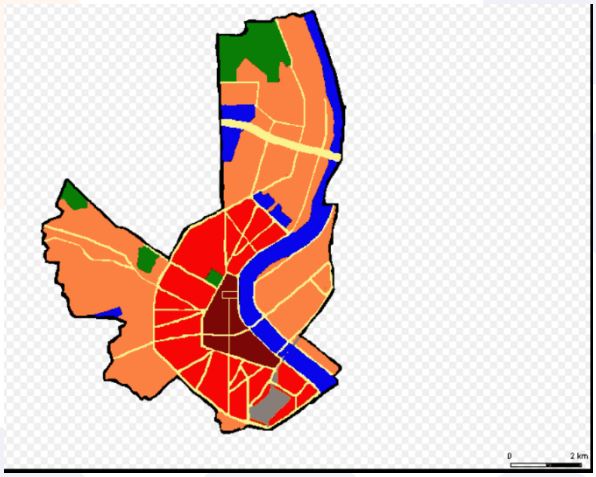

Figure 10: City structure dark to bright
Old town; inside the boulevard; outer parts of the city (source: Wikipedia)

Bordeaux was late in becoming an industrial location and only a short time later fell into a structural crisis. After overcoming these, five industrial focal points in Bordeaux are counted as strategic location factors: aerospace, electronics, chemicals and pharmaceuticals, automotive engineering, and building materials.

Trade, transport, and services play a crucial role in the local economy. Wine and maritime trade are the most important economic factors as well as trade fairs, congresses, and tourism. There is also the University of Bordeaux and institutes such as the Institute for Oenology.

## b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Bordeaux pilot representatives.

This document contains the next analysis that maps the requirements on the


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overall DNTM System and DNTM Platform using the D6.1 layered approach:

| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- User interface / Smartphone app | **Application Layer**<br>- No specific requirements |
| **Platform Layer**<br>- WP2 Algorithms<br>- Algorithms for data modeling<br>- Payment handling with interfaces to transaction banking services | **Platform Layer**<br>- Authentication<br>- Data security<br>- Data storage<br>o Value of Time<br>o Bi-directional and real-time communication<br>o Historical data |
| **Traffic Management Layer**<br>- Traffic state estimations<br>- Demand predictions | **Traffic Management Layer**<br>- Data storage<br>o Traffic state<br>o Queue lengths<br>o Demand data |
| **Data generation / Field device layer**<br>- Data storage<br>o Queue lengths per direction<br>o Position of different users with respect to the intersection,<br>o Speed of the vehicles and occupancy,<br>o Intended turning direction<br>o Controller state<br>o Public Transport timetables<br>o Vehicle classes | **Data generation / Field device layer**<br>- No specific requirements |



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| DNTM System | DNTM Platform |
|---|---|
| ○ Users' actual VOT per class or individually<br>○ Predicted/regular demand at intersection level | |

The requirements in the *DNTM System column* shall be covered by the pilot case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.

## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Bordeaux pilot case.

Note: Bordeaux during pre-production, the Pilot will already use the Gertrude systems and the WP2 modules as shown in the same architecture. The data connection with the Broker might be less secure in that pre-production phase.

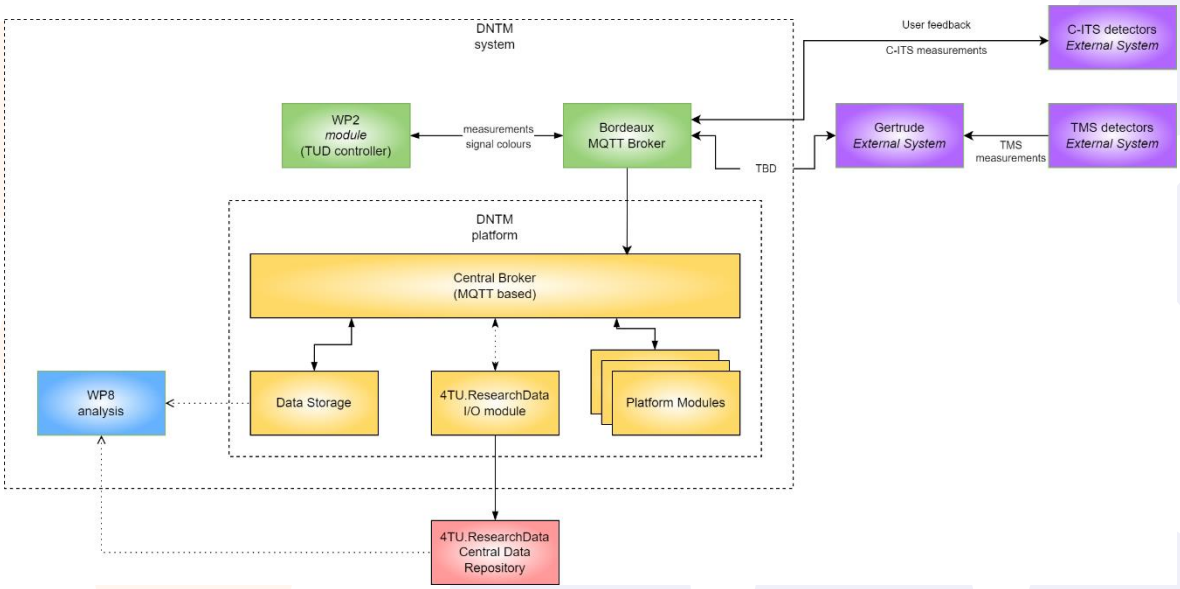


Figure 11: Bordeaux Pilot Architecture



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## d) System Agents

The system agents for the Bordeaux pilot consist of the following:

- **WP2 module (TUD controller).** WP2's research results are embedded in the TUD Controller that leverages the incentive mechanism for a signalized intersection.
- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.
- **Central Broker**. This DNTM Platform key element offers the central way of communication. It uses an IoT-standardized protocol based on MQTT.
- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **User Authentication**. This module is used for authenticating users/systems which want to access the **Central Broker** and the **Data Storage**.
- **4TU.ResearchData I/O module** (external agent). This module takes care of pushing data from the Data Storage to TU Delft's 4TU.ResearchData facility.
- **Bordeaux MQTT broker** connects the external systems with the WP2 module. Data is also exchanged with the **Central Broker**. The Gertrude system refers to Bordeaux' TMC system provided by the Gertrude company (http://www.gertrude.fr/).

## e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Bordeaux
- **Operational level**
  - Commuters

During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.


This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 953783.

## 3.5. Athens (virtual)

### a) Facts & figures

Athens is the capital of Greece. It is the most populous and largest city in the country with approx. 640,000 people in the municipality and more than 3.7 mills. in the metropolitan area (in 2021). However, due to the lack of registration requirements, much higher numbers (up to 5 mill.) might be possible.

The lively business- and commercial city is the most important financial- and economic center of Greece. Above all, textile companies, chemical plants, oil refineries, and shipyards are located here. In addition, Athens has around 6 million foreign visitors a year (2005). Tourism is an important source of income but it also puts a strain on the transport system.

The industrialization and urbanization of the Attica peninsula, on which Athens is located, as well as increasing private transport since the 1950s, have led to increased air pollution. Although actions to reduce air pollution were taken as early as the 1970s, air pollution increased due to mass motorization. The situation reached a low point in 1987 when numerous people died due to extreme smog combined with a heat wave. Since then Athens realized that improvements are essential.


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Figure 12: Map of Athens

## b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Bordeaux pilot representatives.

This document contains the next analysis that maps the requirements on the overall DNTM System and DNTM Platform using the D6.1 layered approach:

| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- Simulation based-based pilot | **Application Layer**<br>- No specific requirements |
| **Platform Layer**<br>- Simulated vehicles to infrastructure<br>- Access to simulated loop data | **Platform Layer**<br>- Connection to DNTM Platform |



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| DNTM System | DNTM Platform |
|---|---|
| - Simulated traffic light control | |
| **Traffic Management Layer**<br>- No specific requirements | **Traffic Management Layer**<br>- No specific requirements |
| **Data generation / Field device layer**<br>- Geospatial data and OD Matrices<br>- | **Data generation / Field device layer**<br>- Access to existing data on the DNTM platform, e.g., existing loop data, OD matrices. |

The requirements in the *DNTM System column* shall be covered by the pilot case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.

## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Athens pilot case.

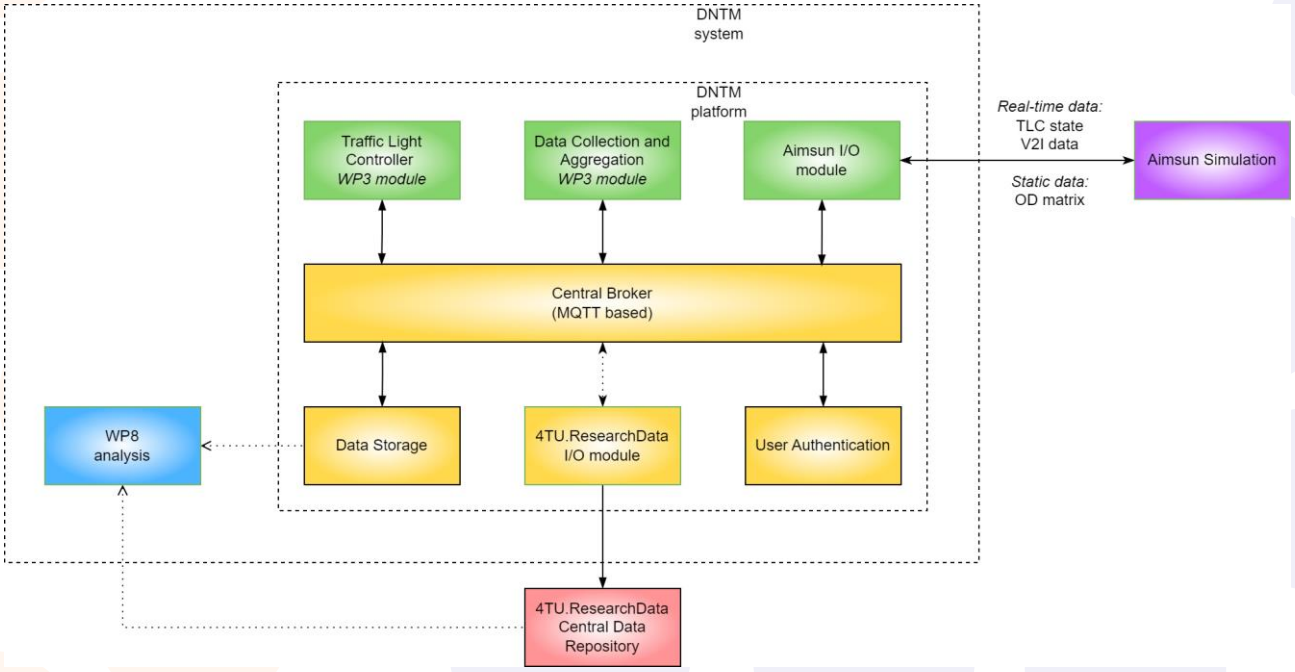


Figure 13: Athens Pilot Architecture



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## d) System Agents

The system agents for the Athens pilot consist of the following:

- **WP3 modules**. WP3 aims to develop a new distributed dynamic traffic management approach with multi-level, multi-modal perimeter control. Therefore, WP3 develops two modules: A Traffic Light Controller that implements the control strategy for critical bottlenecks and a Data Collection and Aggregation system for – as the name suggests – collection and aggregation of the required data for the WP3 algorithms.
- **Aimsun I/O module**. This system agent creates the gateway between the DNTM platform, WP3 modules, and to the **Aimsun Simulation** environment.
- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.
- **Central Broker**. This DNTM Platform key element offers the central way of communication. It uses an IoT-standardized protocol based on MQTT.
- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **User Authentication**. This module is used for authenticating users/systems which want to access the **Central Broker** and the **Data Storage**.
- **4TU.ResearchData I/O module** (external agent). This module takes care of pushing data from the Data Storage to the TU Delft's 4TU.ResearchData facility.

## e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Athens
- **Operational level**
  - Commuters
  - Attica Traffic Management Center


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During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.

## 3.6. Mediterranean highway - AP7 (virtual)

### a) Facts & figures

**Girona** is a city with around 100.000 inhabitants, approximately 100km north of Barcelona. The study area includes a portion of the AP-7 and N-II highways on the periphery of Girona, as well as the rail line (extended connection from Madrid to Barcelona – running via Girona and Figuera to France) along the AP-7 highway (trains are operated by Renfe). The secondary road network or the urban network in Girona is out of scope.

The focus will be on the NORTH-SOUTH and SOUTH-NORTH trips for the entirety of AP-7 and N-II (not from/to within the Girona region).

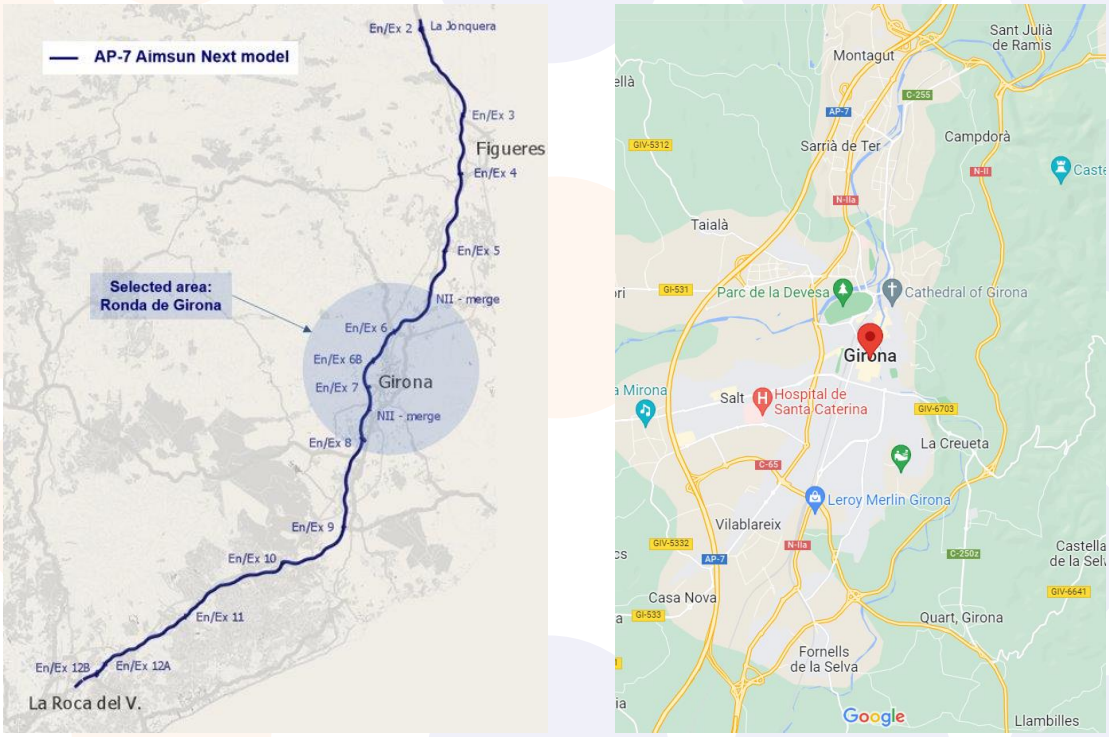


Figure 14: Map of AP 7 and Girona (Source. Google Maps, Aimsun)



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## b) Requirement Analysis

Deliverable 6.1 'Future traffic and mobility management system requirements and use cases' contains all detailed requirements as a result of workshops with the Med. highway pilot representatives.

This document contains the next analysis that maps the requirements on the overall DNTM System and DNTM Platform using the D6.1 layered approach:

| DNTM System | DNTM Platform |
|---|---|
| **Application Layer**<br>- Front-end user interface<br>- Simulation based-based pilot | **Application Layer**<br>- No specific requirements |
| **Platform Layer**<br>- Simulate credit market transactions<br>- Calculate travel cost estimations | **Platform Layer**<br>- Manage and store diverse data sets<br>- Manage and change the data<br>- User authentication |
| **Traffic Management Layer**<br>- No specific requirements | **Traffic Management Layer**<br>- No specific requirements |
| **Data generation / Field device layer**<br>- Wallet transactions and data<br>- Data on asks/bids<br>- Travel time estimations<br>- Train timetable data<br>- Resident registration data<br>- License plate data<br>- Blockchain technology | **Data generation / Field device layer**<br>- Access to existing socio-economic data<br>- Access to produced user tracking data<br>- Access to OD-matrices<br>- GDPR support |

The requirements in the *DNTM System column* shall be covered by the pilot case and other work packages as dedicated solutions. The requirements in the *DNTM Platform column* represents define the common needs for the DIT4TraM DNTM Architecture.


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## c) System Overview and information flow

The previously detailed requirements analysis results in the following architecture for the Med. highway pilot case.

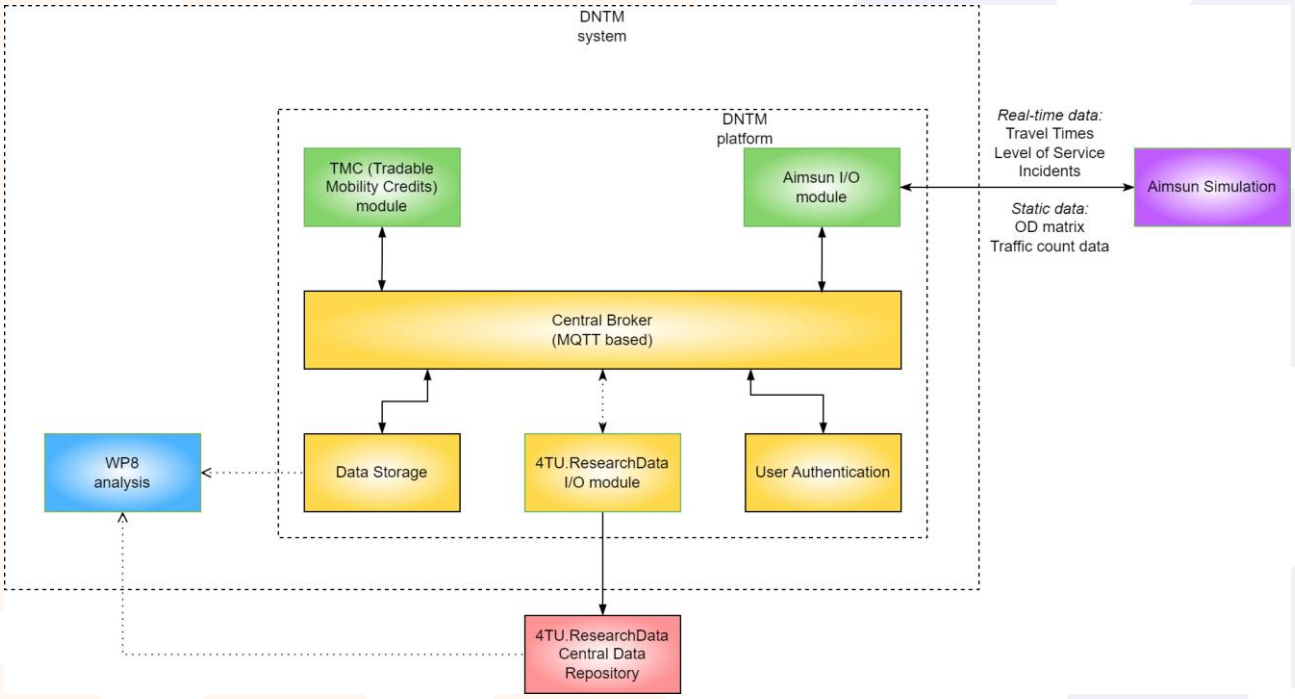


Figure 15: Med. highway Pilot Architecture

## d) System Agents

The system agents for the Med. highway pilot consist of the following:

- **TMC (Tradable Mobility Credits)**. The central system supports the shift in business models for road operators and authorities, and the mode shift since Spain removed the tolls from their highways.
- **Aimsun I/O module**. This system agent creates the gateway between the DNTM platform, TMC module, and the **Aimsun Simulation** environment.
- **WP8 analysis module**. This module primarily extracts information and results from the **Data Storage** and/or **4TU.ResearchData** system.
- **Central Broker**. This DNTM Platform key element offers the central way of communication. It uses an IoT-standardized protocol based on MQTT.


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- **Data Storage**. All relevant data available in and through the **Central Broker** is stored in the Data Storage at any time. This allows stakeholders to retrieve data from the DNTM platform for further research and analysis.
- **User Authentication**. This module is used for authenticating users/systems which want to access the **Central Broker** and the **Data Storage**.
- **4TU.ResearchData I/O module** (external agent). This module takes care of pushing data from the Data Storage to the TU Delft's 4TU.ResearchData facility.

### e) Decision Makers

The Decision Makers for this pilot can be identified at two levels:

- **Strategy/policy level**
  - Municipality of Barcelona
- **Operational level**
  - Commuters

During the development of the systems, modules, and system agents several decisions will be made, but these can be considered design decisions. We leave them out of the list above for sake of clarity.


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# 4. Platform requirements

The DNTM Platform requirements come from the previous sections on the individual needs of every pilot. When merging all pilot system architectures, we identify the common platform system agents and their technical requirements in this chapter. Figure 16 shows the generic pilot system architecture.

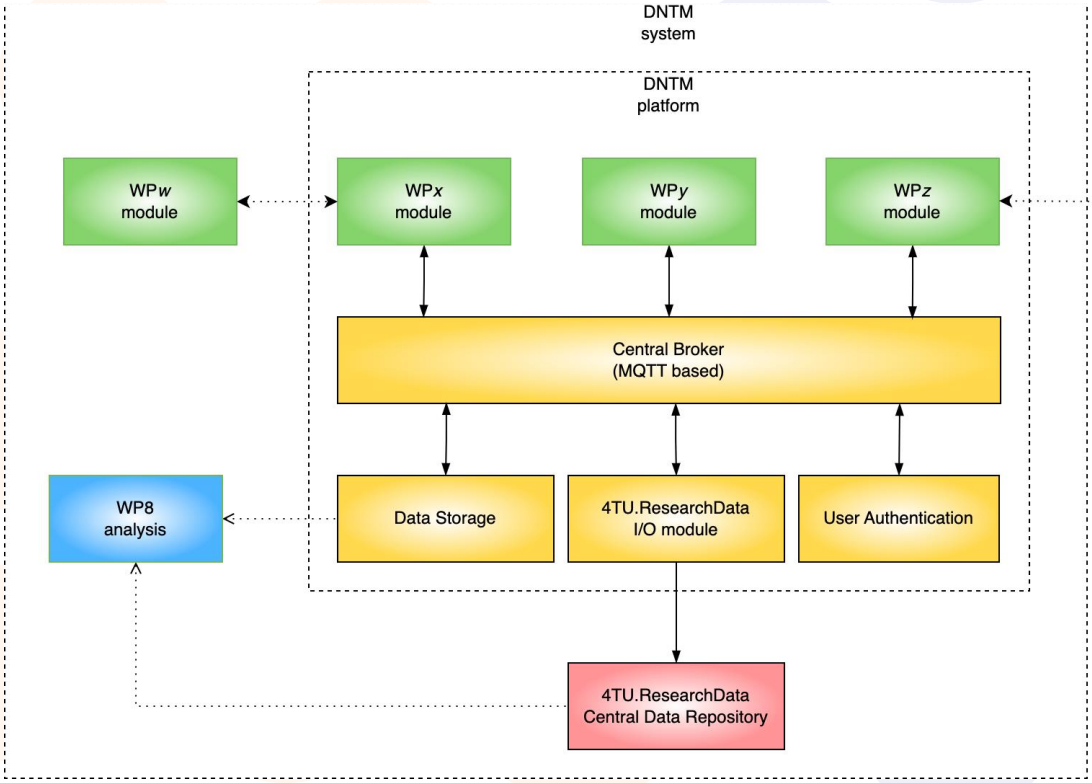


Figure 16: Generic Pilot System Architecture

## 4.1. Software requirements

The software requirements for the system agents in the DNTM platform are primarily focused on the generic modules. Pilot-specific components and agent requirements are within the pilot's scope.



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- **Central Broker**. The Central Broker uses MQTT[4] as a standardized means of exchanging data and information between all system agents. MQTT (originally an initialism of MQ Telemetry Transport[a]) is a lightweight, publish-subscribe, machine-to-machine network protocol for message queue/message queuing service. It is designed for connections with remote locations that have devices with resource constraints or limited network bandwidth. It must run over a transport protocol that provides ordered, lossless, bi-directional connections—typically, TCP/IP. It is an open OASIS standard and an ISO recommendation (ISO/IEC 20922). MQTT supports authentication of clients and data security using SSL/TLS.
- **Data Storage**. The Data Storage offers a generic method of saving data from all Pilot sites, like OD matrices, traffic states, queue lengths, etc. WP6 provides a MongoDB-based database that works as a Key-Value pair storage system. MongoDB is a source-available cross-platform document-oriented database program. Classified as a NoSQL database program, MongoDB uses JSON-like documents with optional schemas. MongoDB is developed by MongoDB Inc.
- **User Authentication**. Access to the system and Central Data-broker will be based on user authentication mechanisms. WP6 proposes a KeyCloak solution where connections to the other modules require a unique identifier/key. Keycloak is an open-source software product to allow single sign-on with Identity and Access Management aimed at modern applications and services.
- **4TU.ResearchData I/O module**. This agent facilitates the data storage from the Central Broker to TU Delft's system. It uses a configuration to know what topics on the Central Broker need to be transferred to the 4TU.Research system. The required translation from MQTT to 4TU is part of the module.

[4] The Utrecht pilot is an exception to this generic technology as that system uses an existing HTTP-based Central Broker.


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## 4.2. Hardware requirements

We propose a hosting environment for each pilot site, this eases the development of each pilot. It also lowers the hardware requirements as the computing effort will be distributed as well.

We propose the following hardware for the DNTM platform:

- 1 Virtual machine per pilot environment
  - 2 Cores
  - 8 GB RAM
  - 256 GB Storage
  - CentOS Stream 9

Please note that additional hardware/VMs might be needed for the pilot- or work package-specific modules.

## 4.3. Data governance

Data governance in general refers to the overall management of the **availability**, **usability**, **integrity**, and **security** of the data used in our DIT4TraM platform.

For DIT4TraM this means:

All relevant data on the Central Broker will be stored **automatically** in the Data Storage and made available through the system's Data Portal as part of the Data Storage. These systems run on the same hosting environment which ensures the availability of data. **Usability** is governed by all pilots as they are responsible for exchanging useful data between their system agents. The Data Storage will not check usability. **Integrity** and **security** are established through the KeyCloak security layer securing the data from unauthorized users.

It involves establishing **procedures**, and **standards** for collecting, storing, managing, and using data, and ensuring that these are followed by all stakeholders.

For DIT4TraM this means:


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The **standard** for data exchange will be **MQTT** where based on MQTT's principle of 'topics', each stakeholder can publish or subscribe to data with the right **authorization** credentials. A detailed design on the topic structure and how to obtain the right credentials is being planned for, and out-of-scope for this document.

Data governance also includes assigning **roles** and **responsibilities** for data management and implementing systems and tools to monitor and enforce compliance with these policies.

For DIT4TraM this means:

**Work packages** and **pilots** are responsible for exchanging useful data through the Central Broker between the individual system agents. The data shall be **JSON**-based messages.

The ultimate goal of data governance is to ensure that data is accurate, consistent, and protected and that it supports the project's goals and objectives.



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# 5. Next steps

The DNTM System and Platform will **not** consist of one single, centralized solution that all pilots have to connect to. The architectures are tailored for their purpose and each pilot site will have its own instance of a DNTM System. Each pilot has its own requirements for the different layers and having one instance for each pilot enables this tailoring. This also guarantees that a pilot site can be developed independently. At a later stage, the DNTM Systems can be interconnected for data exchange between pilot sites if this need is identified.

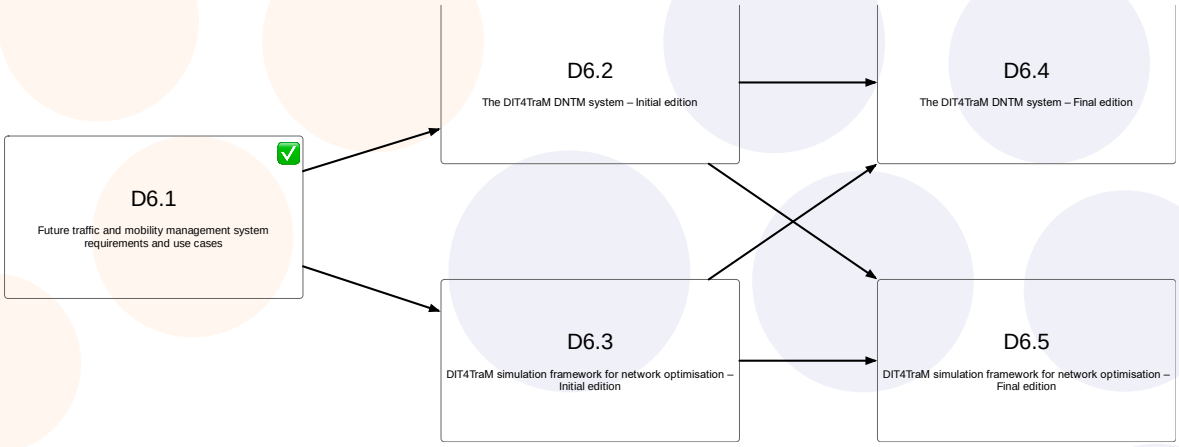


Figure 17: WP6 Deliverables

The document development path is shown in Figure 17 starting with the D6.1 report with all requirements and use cases, resulting in D6.2 (this document) and D6.3. D6.2 and D6.3 give input for the development of the DNTM System, DNTM Platform, and Simulation Frameworks for all Pilot sites.

The final versions (D6.4 and D6.5) of the DNTM System, Platform, and Simulation Platform gather all information, lessons learned, and conclusions after the completion of all Pilot projects.



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