PTV OPTIMA

the mind of movement

PTV OPTIMA

PRODUCT DESCRIPTION

Karlsruhe-Roma, 18 June 2020

Contents

1 Overview

Chapter 1 of this document provides capabilities, use cases and a general overview of the functionality of PTV Optima.

Chapter 2 resembles a full list and short explanation of each module of PTV Optima.

Capabilities

PTV Optima collects and enhances information from real-time data sources, in order to improve the service quality of traffic management centers and connected services by providing information that is more valuable.

In a nutshell, the core capabilities of PTV Optima's are:

- Collecting real-time data feeds and real-time events, which provide information on the traffic state on the road.
- Fusing various sources of information into one comprehensive view.
- Using a variety of analytical, simulation and machine learning tools in order to provide traffic and mobility estimation and forecasts, both in real-time and offline
- Using such simulations, events and fused data information to be used for:
  - Operational and tactical decision support for traffic and transit operators and managers
  - Multimodal traffic information to drivers and commuters
  - Smart messaging on Variable Message Signs
  - More robust and flexible adaptive traffic light management and traffic control

Use cases

The core of PTV Optima is a system aimed at providing reliable traffic forecasts in real-time in a multi-modal ITS environment. This provides benefits for traffic management and operational planning decisions, the individual traveler on the road, public transport users and public transport operation control centers.

PTV Optima combines state of the art traffic modelling methods with "common" detection methods as traffic counts and speeds from e.g. loop detectors or more "advanced" data sources like travel times from FCD or ANPR-systems.

PTV Optima is based on advanced methodologies constituted by models and algorithms for the dynamic simulation of road traffic. These models allow the estimation of time varying travel times, traffic flows and vehicle queues, and, compared to common methodologies, require less measured data.

The simulation can consider the impact of planned (e.g. roadwork) or unplanned events (e.g. accident) and traffic management strategies (e.g. traffic signals or variable message signs). PTV Optima allows simulating several “what-if”-simulations with different strategies in parallel.

The results of PTV Optima are especially valuable for congested networks with a high within-day variability of traffic flows.

PTV Optima is the key component of any traffic management center, providing refined information for everyone and everything else that is connected - be it the operator or the individual traveler.

In particular, PTV Optima addresses the following use cases for metropolitan areas and statewide networks:

- collect continuously information about current measured traffic conditions from a variety of data sources and of different kind (traffic states, signal states, vehicle trajectories, incidents, road works, …);
- map match, validate and fuse different traffic measurements;
- infer a coherent and comprehensive observed traffic state (speeds, vehicular densities, and presence of queues) on all network elements, from measurements, including vehicle trajectories;
- extend the measurements made on only a few elements both on the rest of the unmonitored network, and over time, thus obtaining an estimation of the traffic state of the complete network and the evolution of this traffic state in the future;
- exploit a combination of analytical traffic assignment and simulation models and machine learning procedures in order to enhance the traffic estimation and prediction;
- forecast the traffic state with respect to current incidents and traffic management strategies (e.g. traffic signal control or variable message signs), improving the decision-making capabilities of the operators even before problems occur;
- calculate customizable Key Performance Indicators (KPI) to provide quickly current situation awareness and aggregated assessment of the results of decision scenarios;
- calculate the forecast based on “alternative realities” where the traffic operators simulate different combinations of traffic counter-measures, comparing the different KPIs and giving an indication of the best counter-measure to be adopted
- provide current and forecasted travel times to journey planning engines, thus improving route recommendations;
- provide calculated traffic flows estimation and forecast, queues and delays to Urban Control and Adaptive Signal Control Systems, allowing for proactive Traffic Management and Control;
- provide calculated public transport Estimated Times of Arrival (ETA) to public transport operations control centers,
- rise alerts to the operator that trigger on customizable conditions in the network;

- distribute both collected and calculated traffic information via a variety of communication protocols and channels, ensuring high interoperability degree and thus acting as a “traffic data and information hub”;
- operate in real time, that is continuously updating the estimates on the state of the network and the travel times based on data collected continuously over time;
- calculate mid-term and long-term forecasts, with alternative scenarios, for any time window in the future: from the very next hours/days (e.g., 1-7 days) to any custom time frame (according the configuration and the model extension) in order to support event impact analysis;
- give multimodal and intermodal (park & ride, shared mobility services) route advices to the drivers and commuters, considering all the fused data, events, ETA of the public transport, shared vehicles current and planned availability.

Functional description

PTV Optima uses state-of-the-art models and algorithms for the dynamic simulation of road traffic, allowing for the off-line and real-time estimation and forecast of time varying travel times, traffic flows and vehicle queues.

PTV Optima is deployed within a project, which consists of an offline preparation part and the online application in real-time.

The offline part consists of the construction and calibration of a transport demand model, the so-called “base model”. This base model uses historical data and represents the traffic behavior and conditions for the typical days of the area.

The online part uses the base model and combines it with measures from the field, information on accidents, traffic management strategies etc. This input is used in real-time to automatically correct the “typical day” into the “current day”.

Figure 1 in the next page outlines this approach. The following paragraphs describe the concept in more detail. Take note that **bold text** represents an element in the figure.

The base **transport model** is built in PTV Visum. This preparation step is essentially the standard use case of PTV Visum, adding specific preparations for PTV Optima. It is possible to update an existing PTV Visum demand model for PTV Optima or to create a new model from scratch. Within this step **network data**, **census data** and **historical data** are used to build and calibrate the base model.

The first level result from the **offline** part for the **online** part is the description of the supply i.e. **network data** and the demand i.e. **OD matrices** calibrated with historical flows. This is typically done for different day types, e.g. the typical working day, the typical weekend.

The base model uses the dynamic traffic assignment **TRE Offline**. TRE in a different configuration is also the simulation of PTV Optima in the online part. For the offline part, TRE calculates how, over the course of 24 hours of a day, the demand distributes within the network. The results are called **Base Path Choices** and **Typical Traffic Estimation**, describing turn rates and traffic states over time. These two are the next level of results from the **offline** part for the **online** part

For operational planning activities, TRE also allows to model, test and prepare control and management **offline scenarios** which can then be activated in real-time. Hence, these are the last piece of information forwarded to the **online** part.

You need a proper transport model in Optima only when you want to use TRE and its related modules (Short-Term Forecast, Real-Time Scenario Evaluation, Mid-Term Forecast, Operational Planning and Smart Display). For the remaining modules you just need to edit in PTV VISUM the supply model (e.g. the network, the PUT schedule with its attributes and so on)

The information from the **offline** part, describing the typical day(s), is corrected in the **online** part by real-time traffic data. Sources for real-time traffic data are displayed in the upper part of Figure 1:

- **GPS trajectories** coming from single vehicles, commercial fleets or public bus fleet etc. allowing to derive speeds or travel times.

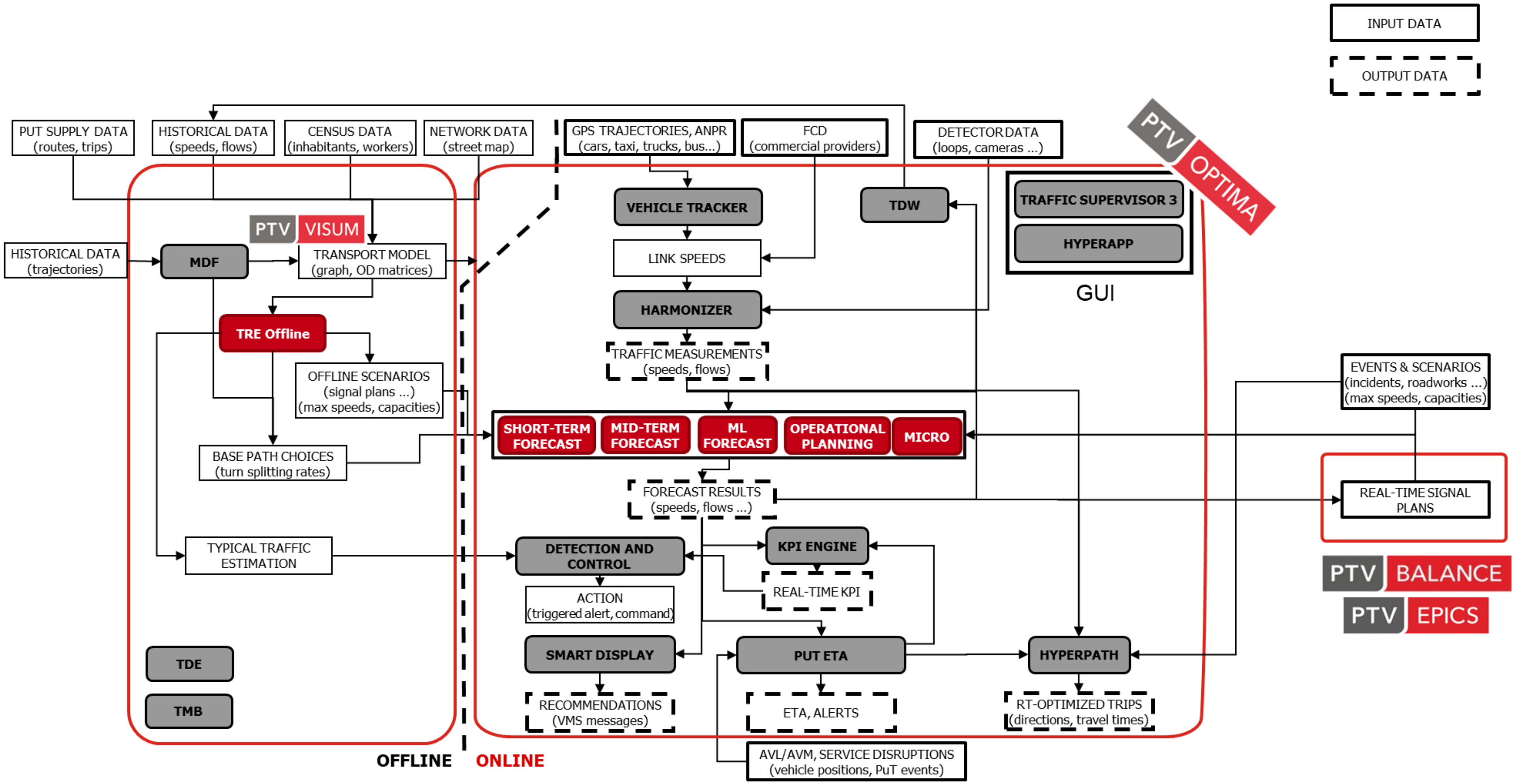


Figure 1: PTV Optima, scheme of the functional architecture.

- Travel times derived from Automatic Number Plate Recognition (**ANPR**) based detectors.
- Speed measurements from commercial Floating Car Data (**FCD**) providers like TomTom, Inrix or HERE.
- Roadside **detector data** delivering traffic counts (flows) and/or speeds.

The component **Vehicle Tracker** processes “raw” GPS data. It uses an online map-matching procedure in order to calculate measured speeds on the links of the network.

The component **Harmonizer** (part of Optima Base module) completes the traffic data pre-processing by fusing all observed measures into comprehensive **traffic measurements** (flow and/or speed) on the links of the network.

The **traffic measurements** correct the online simulation of TRE **short-term forecast**. This configuration of TRE does not simulate the 24 hours of a typical day but runs in a rolling horizon mode. In this mode a simulation typically covers the next 60 minutes, its starting state is defined by the previous simulation, its starting time continuously moves forward in real-time and it is corrected by **traffic measurements**.

Mid-term forecast (MTF) covers the forecast for the rest of the current day up to the next few days. MTF is a specific configuration of TRE that considers known events like construction sites in its forecast.

Similarly, **Operational Planning** covers the forecast of any custom time frame of the Optima model, with customizable configuration. Operational Planning differs from MTF in the freedom of choice of the simulation period and in the trigger of the computations, which is *on-demand*, while MTF provides a service continuously running: thus, the former can accommodate more demanding computations, too.

Traffic measurements represent and correct the traffic state in terms of measured flows or speeds. Another source of real-time corrections are changes to the supply in terms of capacities or speed limits. This can be unplanned, like accidents or planned, like construction sites or different traffic signal programs. **Events & scenarios**, **real-time signal programs** and **offline scenarios** represent their impact on simulation engines. The online configuration of TRE can run several so-called “scenario simulations” in parallel, each with a different set of active **offline scenarios**. In this case, PTV Optima becomes a decision support tool for real-time traffic management. Strategies need to be prepared a priori, like the base model, but can be combined in real-time in any combination and simulated in parallel to the base simulation as additional scenarios.

The results of the **online** TRE are **forecast results** in terms of speeds, flows and queues on all links of the network for time intervals covering a forecast of typically up to 60 minutes. These **forecasts results** can be used in various ways:

- **KPI engine** (Key Performance Indicators), representing an aggregated view on the results, like the average speed in the network or the total queue length in a specific part of the city. KPIs are customizable for each project. They are especially useful for a fast comparison of different “scenario simulations”. Depending on available data, KPI can also be “environmental” or “safety” indicators.

- The module **Detection and Control** allows the definition of customizable triggers and alerts based on **forecast results** and/or **typical traffic estimations**. For example, it is possible to create an alert for the traffic operator if the travel time along a specific route is higher than the typical travel time.
- The module **Smart Display** provides **recommendations** for the content of a variable message sign (VMS). **Smart Display** uses the **model** and known **Events** to calculate the importance of specific **events** with respect to the position of the given VMS.
- The module **PuT ETA** (Public Transport ETA) addresses the needs of a multi-modal ITS system. **PuT ETA** uses real-time positions of public transport vehicles and the **forecast results** of TRE in order to calculate estimated times of arrival (ETA). The module can also calculate and forward connection alerts and public transport KPI. This helps the service quality of connected systems like e.g. a public transport operations control center. *This module can work also without TRE using only the available real time data*
- The **forecast results** of flows can be forwarded to a signal optimizer. This configuration is available together with **PTV Balance** (PTVs network wide signal optimization) and improves the potential of **PTV Balance**. At the same time, the returned optimized signal programs are fed to the simulation of PTV Optima, improving the forecast.
- In a similar fashion, journey planners like the **HyperPath** module or third-party service providers, which are able to use forecasted travel times, can use the real-time forecasts to improve their service quality.

The module PTV Optima **Micro** combines PTV Optima and PTV Vissim, which is used as a microscopic simulation engine. PTV Optima Micro allows to provide forecasts for subnetworks, which are typically a smaller selection of the overall large-scale city or state wide macroscopic model of PTV Optima. PTV Optima Micro is specifically useful to improve decision support in areas or for traffic management actions, for which the interaction between and the behavior of individual vehicles and signal controllers is critical. It provides the right methodology and tool where you need it and when you need it.

Finally, **Traffic Supervisor** is the GUI of PTV Optima that allows to analyze and control the full scope of PTV Optima. Nevertheless, PTV Optima offers an API that allows integration of its functionality in third party traffic information systems.

Figure 2 depicts PTV Optima's system architecture. PTV Optima has a star radial structure with an online PostGIS geographic database in the center, to which all software components connect in order to obtain their input and/or provide their output.

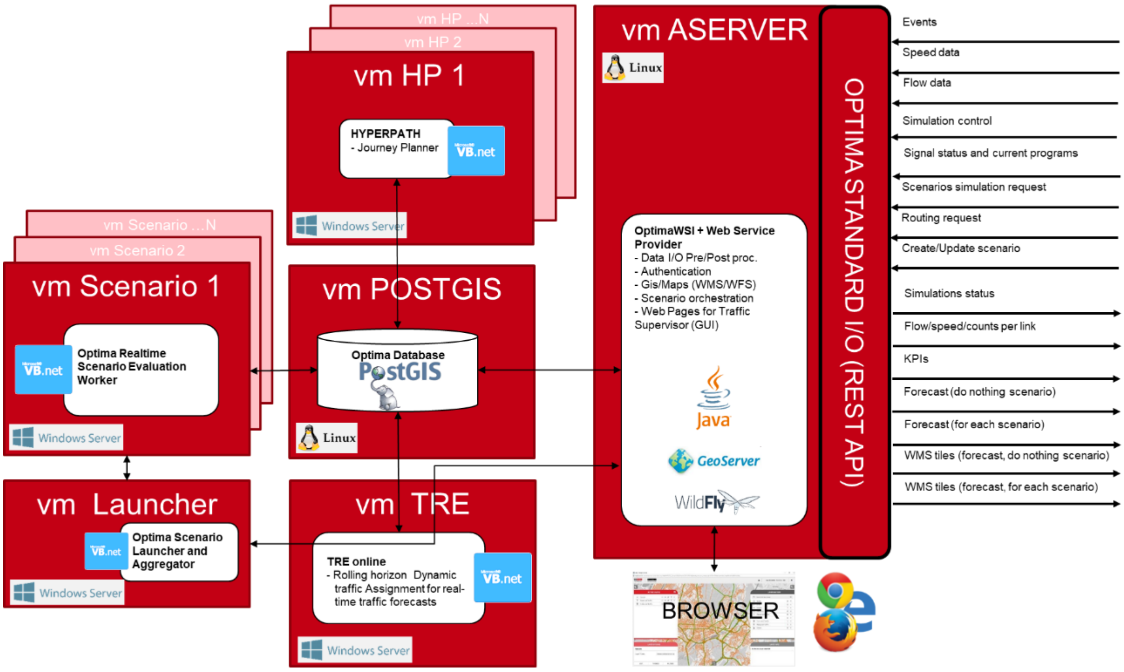


Figure 2: PTV Optima, typical scheme of the system architecture (not every module is present)

High performance & scalability

PTV Optima uses a continuous macroscopic simulation model for traffic flows and user behavior. This means that temporal and spatial discretization are not a constraint but are chosen in order to achieve the best compromise between accuracy and runtime requirements.

PTV Optima can handle different temporal discretization for different aspects of the model. Temporal discretization can range from:

- seconds, to represent traffic signals;
- 5-15 minutes, to represent flow and queue dynamic results;
- 15-90 minutes, to represent temporal evolution within demand matrices.

The spatial discretization may span from links with a length from a few meters up to several kilometers, allowing to efficiently representing urban and motorway roads within the same network.

In general, the memory usage and calculation times for a dynamic assignment are proportional to the number of links, the number of zones and the number of time intervals. To a lesser extent, also the number of detectors and FCD are affecting the performance.

The performance is independent of the level of demand or the number of vehicles in the network. This contrasts with a microscopic simulation, which would slow down or require more computational power during the peak hours with a higher number of vehicles.

PTV Optima is a distributed system and its simulation is multi-threaded. This means that providing appropriate computational resources can counter runtime bottlenecks. As a reference the table below shows runtime measurements for a 60-minute forecast on an AMD dual core 2.8 GHz CPU.

Links[1]	80,000
Nodes	25,000
Zones	2,000
OD components[2]	10,000,000
Day-types	4
Count locations	665

RAM requirements for dynamic equilibrium	5 Gb
RAM requirements for real-time propagation	2 Gb
Import & Process Measures[3]	3-30 sec
Perform Route Choice Update	2 min
Perform Dynamic Network Loading	1 min 30 sec
Export results into Database	20 sec
Total for a single run	**4 min 20 sec**

Figure 3: Performance evaluation: size on the network (left side, numbers rounded) and runtime measurements (right side) to calculate a 60-minute forecast.
[1] The represented network covers over 300,000 Navteq links.
[2] Per day-type and with respect to several matrices, representing different demand segments.
[3] Depending on the number of data sources (counts, traffic states, events...).

2 Modules

PTV Optima is solution oriented and its modules represent packages of functionality relevant for specific use cases, rather than a 1:1 mapping of software components. This module-based approach allows the selection of the required modules according to the needs of a specific installation. Offers for and the pricing structure of PTV Optima relies on these modules.

2.1 PTV Optima Base

PTV Optima Base includes the basic components for a PTV Optima implementation. This includes the PTV Optima preconfigured database (PostgreSQL), standard I/O web interfaces, measure validation, data fusion and administration components to handle access policies.

2.1.1 Data model

Data management of PTV Optima is realized with a database. The data model conforms to the PTV Vision schema for Transport modelling and traffic management.

Postgres along with its spatial extension PostGIS is used as database management system.

The data model is open and fully documented, allowing the owner of the system complete access to all data stored within the PTV Optima system, and enabling the widest interaction with any other subsystem.

2.1.2 Database management

A specific component, called DBWorker, is devoted to maintain performances and consistency of the database at the desired level. As an example, this component is typically configured to erase old or not needed data from the database, to optimize indexes and similar tasks.

Process start time and the process repetition rate can be specified. The corresponding processes are triggered at the times specified.

2.1.3 User management and authentication

All services of PTV Optima require that the calling client authenticates itself. In this context, the client can be either a person, a computer or a system. Thus, authentication rules are highly configurable and can be a combination of username/password, IP restrictions, LDAP authentication and any REST end-point authorization rules.

This allows primarily to protect the PTV Optima installation against unauthorized access. In addition, through authentication of the client with the access data, user-specific configurations for individual processes are called. This allows the same process to be used but with different configurations on two separate clients. E.g., it is possible to allow a user to modify the events layer adding an event, while a second user shall have read-only access on the same layer.

Authentication is implemented by OptimaWSI, the communication component between any client and PTV Optima. It and all the information between clients and the interface are XML/JSON based.

OptimaWSI implements an http REST service and acts as a “proxy” between clients and the PTV Optima internal modules and database; all the authentication processes are thus hidden to the clients, and are done by REST method invocations.

2.1.4 Configuration and administration

The Administrator Console of PTV Optima provides the option of viewing all important configurations on a web user interface. This includes the User Management and Rights configuration, the data interface settings (datasources, format, scheduled import time interval) as well as administration of all the components of PTV Optima (e.g. start/stop/reload).

The Web Admin service with a Logfile Viewer and the Web Services with a list of WSDL files for module administration can also be found there.

On the server side, the component OptimaWSI (introduced in section 2.1.3) exposes toward the administrator console all the configuration information (according to the client authentication level), including user specific configuration (like language, user information and such) and system configurations, like URLs and web addresses of different services within the solution (like the mapping server). Methods to set and to change abovementioned user and system settings are also exposed.

Finally, other services that allow the settings and overviews of the application server is the WildFly Web Console.

2.1.5 Logging

All PTV Optima components generate standardized incident and error logs that contain all essential operation and transaction information. Logs allow monitoring of the whole system and trouble-shooting.

The log is configurable (also at runtime) both in terms of log channels (trace output files) and in terms of log level (e.g. FATAL, ERROR, WARNING, INFO, DEBUG).

All components offer a web-service to display their log file.

2.1.6 System monitoring

Thanks to its modular and distributed architecture, PTV Optima can use many computers on which various services can be run. Often external systems are connected via interfaces, for example to receive online detector data. In order to ensure interplay between these services and quickly locate a possible system failure the individual components are monitored.

PTV Optima utilizes the open-source software Check_MK for system monitoring. In addition to the basic functions, used to monitor hardware and processes, extended functions have been developed allowing to monitor:

- quality of input data (freshness and boundary values)
- output consistency
- internal module status

A standard configuration setup for monitoring of PTV Optima is provided, while the complete setup of a monitoring environment for each specific PTV Optima installation is part of the professional services related to a PTV Optima installation.

2.1.7 Standard data categories

The deployment of all PTV Optima functionalities, with particular reference to traffic estimation and prediction, requires the transfer of real-time and historical data from external systems to PTV Optima. Within this document the following standard data categories are defined and used:

- **Detector data**: traffic data (number of vehicles, occupancy rate, speeds, level-of-service, ...) provided by individual detectors/count sites.
- **Traffic States**: all observed traffic measurements (speeds, volumes, occupancies, …) on individual links or link sections of the read network. In comparison to **Detector Data** this allows to respect spatially diverse data sources that have already been aggregated e.g. speeds on links from third party FCD or ANPR.
- **Events**: information about traffic conditions (e.g. traffic jam alerts) planned incidents (e.g. road works, road closures) or unpredictable events (e.g. accidents) that may affect road network performances and/or level of service.

- **FCD/Trajectories**: all observed vehicle trajectory points, collected from Probe Vehicles, ANPR, CCTV or Mobile phone data, that have only spatial reference
- **Signal Control Plans/ITS Strategies**: all signal programs and existing bespoke response strategies that can be activated in the field.
- **Signal Control Status**: current status of each signal control group (current green and cycle times, phases etc.)

Table 1 provides information on how the different categories are used within PTV Optima.

Data category	What for?	When needed?	How is the data used?
Detector Data **Traffic States**	Traffic Estimation Traffic Forecast Incident Detection	Continuous real time data input	On-line correction (or calibration) of the real-time traffic estimation and forecast model, in order to adjust the simulation to reproduce and then predict actual traffic conditions Incident detection triggers
Events	Traffic Estimation Traffic Forecast	Planned events should be imported before they are active. Unplanned incidents should be manually or automatically detected and introduced	Used to update network supply constraints (capacities, speeds) within the real-time traffic estimation and forecast model
FCD/Trajectories	Traffic Estimation Traffic Forecast Incident Detection	Continuous real time data input	These data are transformed into Traffic State data and used accordingly
Signal Control Plans **ITS Strategies**	Traffic Estimation Traffic Forecast Traffic Management Traffic Control	Stored in the predictive modelling platform and updated continuously	Used to estimate current or expected delays and capacity restraints at signalized junctions within the real-time traffic estimation and forecast model Used also to assess and compare in real-time alternative management strategies
Signal Control Status	Traffic Estimation Traffic Forecast	Stored in the predictive modelling platform and updated continuously	Used to estimate current or expected delays and capacity restraints at traffic junctions within the real-time traffic estimation and forecast model

Table 1: Overview of the PTV Optima Standard Data Objects.

2.1.8 Traffic State Harmonizer

This component has the capability to compute a unique traffic state (flow, speed, density) on each link from heterogeneous and partial traffic states coming from different sources (e.g. speed coming from FCD data and flows coming from detectors on the same link).

The Traffic State Harmonizer handles the following tasks:

- collection of traffic state measurements from different sources of different types (FCD, Detectors, etc.);
- harmonization of traffic measures, represented as (possibly incomplete) flow, speed, and/or density triplets coming from different sources;
- estimation of traffic states based on the harmonized data;
- export of the harmonized data into the PTV Optima database.

The harmonized traffic state on a given network element and time interval is calculated based on the reliability of the data source and the reliability of each of its values; specifically:

- Reliability of data source: each incoming data source are characterized by a reliability, that is a weight coefficient that influences all measures coming from it. The weight coefficient of each source is a configuration parameter of the harmonizer, specified during the system calibration phase.
- Reliability of individual measures: each single measure value can be associated to a measure reliability, i.e. a weight coefficient; e.g. a speed measure reliability may depend (or be equal) to the number of vehicle samples that produced it. The rule used to calculate reliability of individual values is configurable separately for each data source.

Then, the harmonized traffic state defined above is calculated as a weighted mean of all traffic state measures occurred on the same network element during the same time interval, in which the weights are represented by the product of the individual measure reliability and of the corresponding data source reliability.

2.1.9 IO data interface

PTV Optima offers interfaces that can be used to import or export the data categories mentioned in chapter 2.1.7 into and from the PTV Optima environment. PTV Optima provides a high degree of interoperability, acting as a “Traffic data Hub” at the heart of a complete Traffic Information System or Service.

PTV Optima adopts parts of the DATEX interface, bidirectional DATEX II 2.0 interface (in accordance to www.datex2.eu), OCIT-C and OpenLR.

An extensive documentation is available for the growing number of interfaces in general and the API of PTV Optima.

The Optima IO data interface exposes both input and output functions as standard REST web services.

The Optima IO data interface can feed Optima with various data, such as:

- Real-time traffic states as produced by fixed sensors (speeds and flows measured by speed cameras, inductive loops, signal controllers)
- Floating car data (FCD), coming either from GPS devices, ANPR or Bluetooth portals or from commercial providers - PTV Optima has readily available interfaces (in alphabetical order) with
  - HERE (OpenLR based)
  - INRIX (OpenLR based)
  - TomTom (OpenLR based)
- The real-time status of field devices (variable message signs, signal controllers)

The Optima IO data interface can expose different output data, such as:

- Traffic forecast
- Real-time traffic states as a result of data fusion
- Suggested messages to be published via variable message sign signs (VMS)
- Key Performance Indicators (KPIs) about network status

The API of PTV Optima allows to control the

- simulation engine
- scenario engine
- Smart Display module
- Public Transport ETA module

2.2 Short-Term Forecast

2.2.1 Features

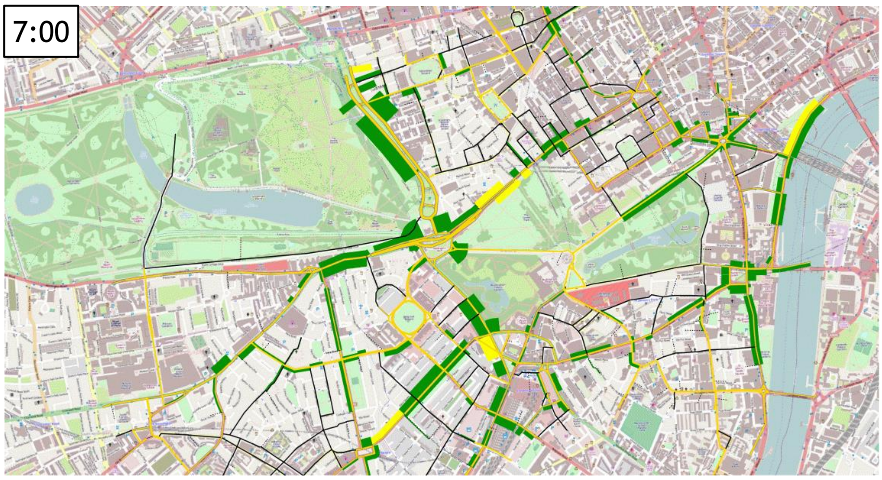
The PTV Optima Short-Term Forecast module is an on-line simulation engine for traffic estimation and forecast. The simulation engine uses a PTV Visum transport model in conjunction with a real-time traffic data stream.

The Short-Term Forecast module relies on the TRE component (Traffic Real-time Equilibrium), a macroscopic dynamic traffic flow and assignment model and methodologies that:

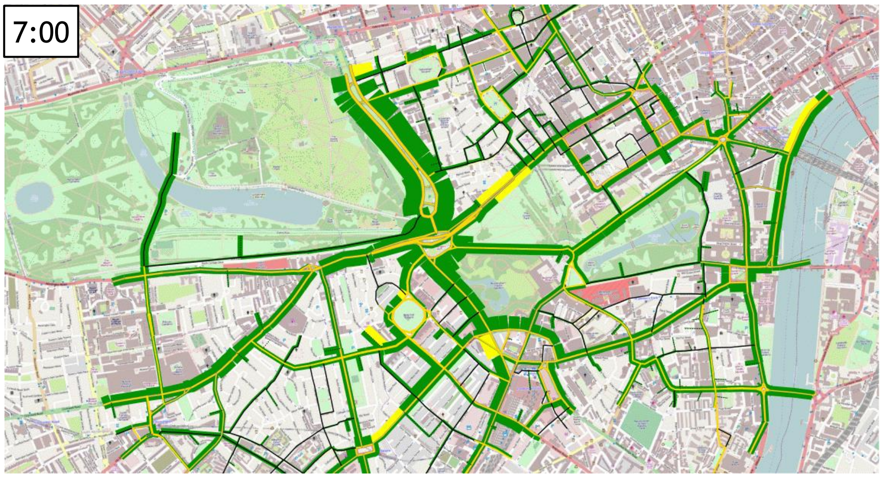
- adapt the base supply and demand within the observed network, provided by the PTV Visum transport model, with respect to incidents (e.g. roadworks or accidents);
- adapt the current traffic states with respect to any measured data;

- perform a sequence of Dynamic Traffic Assignments over the network, providing a reliable and realistic traffic state estimation and forecast up to a configurable amount of time (typically up to one hour), with particular reference to queues and spillbacks over junctions, even under conditions (i.e. combinations of incidents in the network) that have not been observed in the past;
- operate in rolling horizon, updating every few minutes (typically 5-10 minutes interval) traffic estimation and forecast based on freshly updated traffic data.
- can simulate on-trip re-routing that reflects the impact of incidents on the behavior of travelers in a realistic way;
- Ability to suitable combine into the prediction measure forecasts (both speeds and traffic counts) produced by machine learning techniques, if and where available, in order to further enhance the forecast quality and reliability

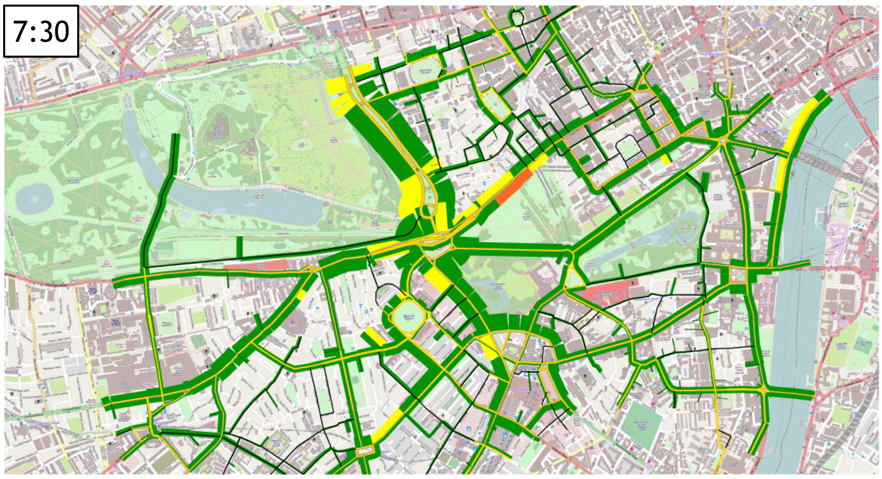
The Short-Term Forecast module thus allows for the calculation of a comprehensive model based traffic state on all links of the network, considering the available input data sources as it is depicted in Figure 4.



Traffic states that are available on some links of the network through the means of detection...



...are extended in space...



...and time with the traffic flow model of the Short-Term Forecast module.

Figure 4: PTV Optima Short-Term Forecast module.

2.2.2 The rolling horizon dynamic traffic assignment model

The Rolling horizon Dynamic Traffic Assignment model is implemented by a component named TRE (Traffic Real-time Equilibrium). TRE is an innovative tool providing real-time forecasts concerning the use (vehicle flows) and the performances (travel times) of the road networks, aimed at reproducing as closely as possible the real operation of the whole network in terms of current traffic state (density, speed and capacity of each link) and of its evolution over time, producing every few minutes the estimation and forecast of the actual traffic flow condition on the network.

To this end, TRE exploits an advanced methodology for modelling transport demand and vehicle congestion, through which the behavior of drivers and the propagation of queues are explicitly represented. The connection to current traffic conditions is guaranteed by field measures at discrete points (loop detectors, speed radars, video cameras, probe vehicles) that are collected in real-time and sent to TRE, which is able to reconstruct the current and future traffic pattern on the entire network, hence extending the available data in time and space to provide useful information for driver navigation and transport optimization.

The modelling paradigm adopted within TRE, primarily based on the physical interpretation of the traffic phenomena, differs substantially from the mere interpolation of field measures through artificial intelligence methods. Most monitoring systems apply, in fact, data mining techniques to match the current time-series with historical patterns, thus providing forecasts only on local and typical conditions. However, the statistical inference alone may not allow to deduce the traffic state of unmonitored links from the observed data or to forecast the consequences of unpredictable atypical events such as road accidents.

TRE is thus specifically conceived for metropolitan contexts, where the congestion is strongest, while the day-to-day variability and the within-day fluctuation of vehicle flows and travel times is not negligible; but it can also be installed in extra-urban frameworks, that are less complex by their nature.

The mathematical model underlying TRE is based on an explicit representation of traffic phenomena, with reference to flow and congestion propagation. In particular, this method adopts as its simulation engine the GLTM (General Link Transmission Model, Gentile 2008), which is a macroscopic dynamic network loading model based on the Simplified Kinematic Wave Theory. Key features of the GLTM are: the possibility to adopt a fundamental diagram with general shape; complete representation of general intersections, even signalized; no need for spatial discretization of links (contrary, for example, to the Cell Transmission Model). Thus, the proposed modelling approach is opposed to micro-simulation, in which individual vehicles are operated as separate elements. Therefore, the GLTM is computational wise a lot faster than microscopic simulations - this in turn allows the simulation of larger or more detailed networks.

In order to obtain a continuous update of the traffic forecast, the GLTM is sequentially applied with a rolling horizon schema, exploiting both the Base Transport Model and the traffic measures and events gathered from monitored links.

Specifically, a continuously updated traffic flow forecast is achieved by performing a sequence of real-time dynamic traffic propagations over the network in rolling horizon. In order to correctly implement the rolling horizon context, each simulation will not start from empty network initial conditions, but instead will adopt as initial conditions the traffic state calculated by the previous simulation in correspondence of its initial instant; this way, the congestion situation will be “transmitted” from one simulation to the next one. Making sure that previously calculated queues and/or measure-derived variations are inherited.

This concept is schematically depicted in the example provided in Figure 5: within this example, a new simulation is launched every 5 minutes; each simulation has a simulation horizon of 35 minutes, spanning with respect to the launch time, from 5 minutes in the past (this way the current simulation takes into account all the measures and events arrived to the system between the launch time of the previous simulation and the launch time of the current simulation) to 30 minutes in the future (in order to allow producing e.g. 15 and 30 minutes forecasts).

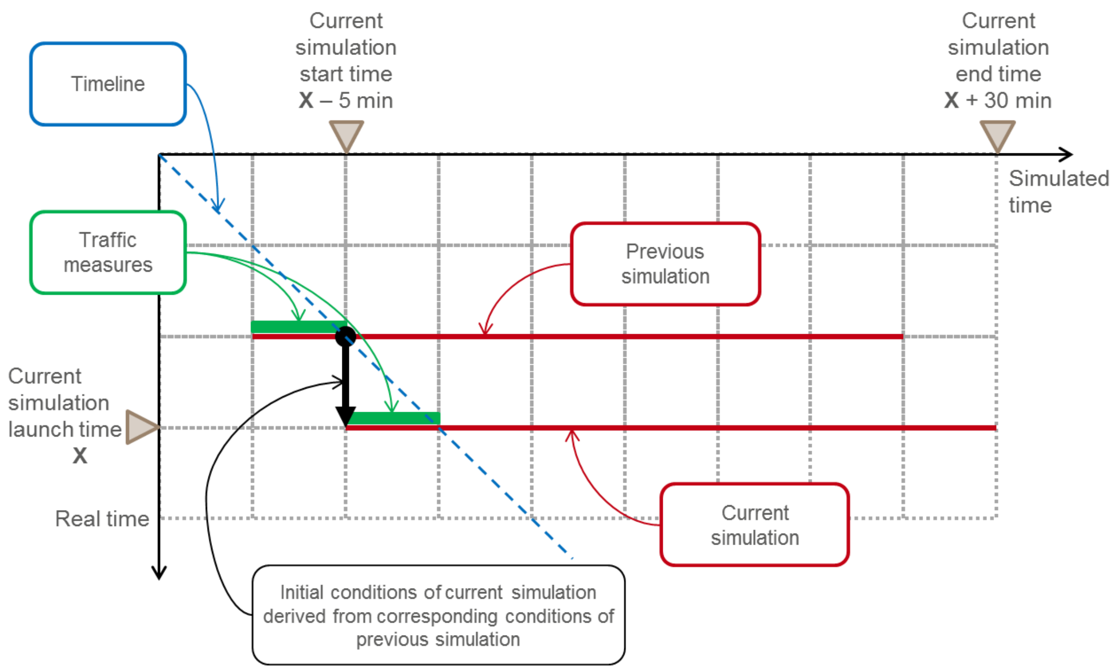


Figure 5: Example of simulation timeline.

2.2.3 Considering real-time traffic measures and events in order to correct current traffic forecast

As already mentioned, traffic measures and events collected continuously from the field, are used on-line to correct the propagation of the demand flows produced by GLTM on the network.

In more detail, on each monitored link and time interval an additional flow will be introduced (in algebraic sense) equal to the difference between the observed value and the value calculated by the network loading model for the same time interval, which will eventually be propagated on the network. Moreover, if the measured flow is recognized to be critical, indicating that the effect of an active downstream capacity constraint reached (in the form of a vehicle queue) the monitored link, then the capacity of the link is set equal to the measured flow.

While the simulation runs, the above corrections will propagate on the network, in coherence with traffic flow theory implemented within GLTM, from the road section where they were generated both upstream (as queues) and downstream (as flow variations): thus, evolution over time of link flows will result from three contributions:

- one produced from the demand loaded on the network;
- one obtained by the downstream propagation of additional flows generated on all monitored links;
- one produced by the upstream propagation of queues generated by capacity constraints imposed in correspondence of hypercritical observed flows.

Within this context, it is worth noticing that the propagation of observed measures through the traffic flow model within TRE overcomes the need to modify demand matrices in real time (which was actually a typical approach when applying static assignment tools for real time traffic estimations). At the same time, this method achieves a higher reliability and realism of its estimations.

2.2.4 Scientific references

Models underlying TRE were presented at several international conferences and are described, among others, within the following papers:

- Gentile G. (2008) The General Link Transmission Model for dynamic network loading and a comparison with the DUE algorithm, in Proceedings of the Second International Symposium on Dynamic Traffic Assignment – DTA 2008, Leuven, Belgium;
- Meschini L., Gentile G. (2010) Real-time traffic monitoring and forecast through OPTIMA – Optimal Path Travel Information for Mobility Actions, in Proceedings of Models and Technologies for Intelligent Transportation Systems, International Conference Rome 2009, ed.s G. Fusco, Aracne, 113-121, ISBN 978-88-548-3025-7 – (MTITS2009)

2.3 Machine Learning Forecast

PTV Optima Machine Learning Forecast (ML Forecast) provides insights on the real time traffic information data evolution for the next 30-60 minutes, based on historical measurements (speeds and/or traffic counts) collected in the past (typically 6 or more months).

PTV Optima ML Forecast gives the customer a measurement based forecast functionality by providing forecast on segments where there is real time data available (speeds, traffic counts, or both) and clearly the historical training dataset.

This module produces a traffic forecast by using acquired knowledge based upon historical data to predict what will happen on road segment with real time data.

It represents a simpler forecasting approach with respect to the short-term module described above because:

- It does not require a traffic model
- It works well with daily recurring traffic events (e.g. typical rush hour highway traffic jams)
- It is quicker to deploy than Short Term Forecast

If used alone as a unique source forecasting engine this module predicts only observed measures, where and when available, and does not support Real Time Scenario Evaluation.

However, this module can work in full combination with the Short Term Forecast module already described and the real-time scenario evaluation module described in the following:

the ML module in fact can feed the short-term forecasting module with enhanced measure predictions, greatly enhancing the quality of the forecast.

ML forecast can be retrieved via API and inspected on map (the latter requires Traffic Supervisor module)

In conclusion, this module:

- Can automatically ingest and store historical traffic data (both speeds and traffic counts) for several months on specific count locations and/or road sections;
- Periodically (automatically and upon request) can recognize typical within-day pattern on each road segment or count location, suitably identifying and treating outliers;
- Is able produce a traffic forecast by using acquired knowledge based upon historical data to predict what will happen on road segment or count locations where real time measurements are available, without requiring an explicit traffic simulation or analytical model
- Can be seamlessly combined with analytical Short Term forecasting modules in order to enhance quality of the traffic prediction

2.3.1 Methodology

The Machine Learning Forecast engine roots its methodology into an unsupervised clustering technique called Affinity Propagation where a cross correlation measure of similarity between speed and/or flow profiles is used into the process. The machine learning approach used has its strong point in detecting autonomously the most typical and recurrent traffic conditions in term of numerosity and trend. This information is created during the training phase of the system and can be also updated regularly.

Once PTV Optima is running in real-time, whenever a speed and/or flow data is gathered, if the trained model is available, the ML Forecast engine is capable to use the last measurements received from the field and produce a forecast up to one hour making a proper decoding of the embedded historical information with the real ones.

It is important to stress the fact that by design the ML Forecast component is conceived to be scalable with respect the amount of data received given that nowadays there is a concrete possibility to receive a huge amount of real-time data, especially speed measurements.

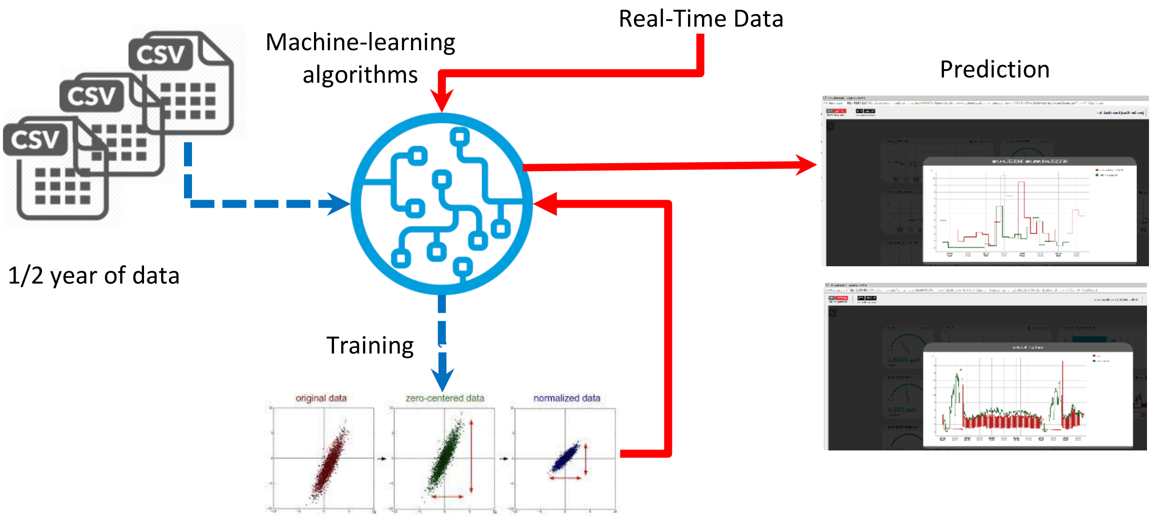


Figure 6: Machine Learning workflow. Building the training models from the historical data and in real-time use it with live data to perform the prediction. Dashed blue arrows indicate the training phase, while red solid arrows indicate the real-time forecast process.

2.3.2 Scientific references

Methodology underlying ML Forecast was presented at several international conferences and are described, among others, within the following papers:

- Attanasi A, Meschini L, Pezzulla M, Fusco G, Gentile G, Isaenko N (2017). A hybrid method for real-time short-term predictions of traffic flows in urban areas. In: 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2017 - Proceedings. p. 878-883, Institute of Electrical and Electronics Engineers Inc., ISBN: 9781509064847, Hotel Royal Continental, Napoli, Italia, 2017, doi: 10.1109/MTITS.2017.8005637
- Attanasi A, Pezzulla M, Meschini L, Gentile G (2019). A scalable approach for short-term predictions of link traffic flow by online association of clustering profiles [Under Submission]
- Frey, B. J. & Dueck, D. Clustering by passing messages between data points. Science 315, 972–976 (2007)

2.4 Real-Time Scenario Evaluation

PTV Optima's Real-Time Scenario Evaluation module adds the capability to forecast the current traffic state with respect to scenarios that are any combination of available traffic management strategies like e.g. traffic signal controls, variable message signs or lane closures. The forecast can be done in parallel for multiple scenarios and allows for a quick comparison of the results based on customizable key performance indicators. This module requires PTV Optima's Short-Term Forecast.

Basically, the Real-Time Scenario Evaluation module extends the capabilities of the Short-Term Forecast module with the possibility to simulate several forecasts or scenarios in parallel. Every scenario describes changes on the supply side of the model in the form of capacities and/or free flow speeds on links and/or turns as a combination of traffic management strategies. These strategies are prepared offline e.g. with PTV Visum and reflect the impact of e.g. green shares of traffic signal programs on turn capacities (also see 2.1.7 Standard data categories). The interfaces within PTV Optima allow to control the activation of combinations of strategies and the simulation of scenarios, while the results are stored and accessible through the PTV Optima database.

In conjunction with PTV Optima's graphical user interface Traffic Supervisor, the Real-Time Scenario Evaluation module provides quick and comfortable means to control the scenario evaluation as well as the assessment of results of the simulated scenarios (see from Figure 7 to Figure 13 below).

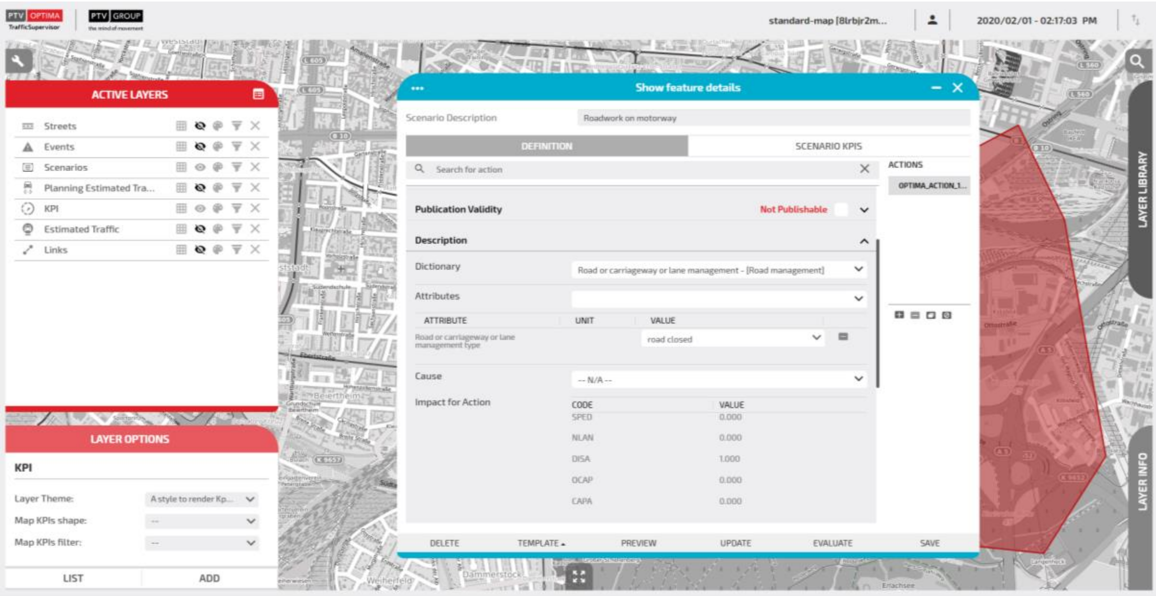


Figure 7: Creation of a custom scenario (representing a traffic management event or strategy). Here, a motorway section closed for roadworks.

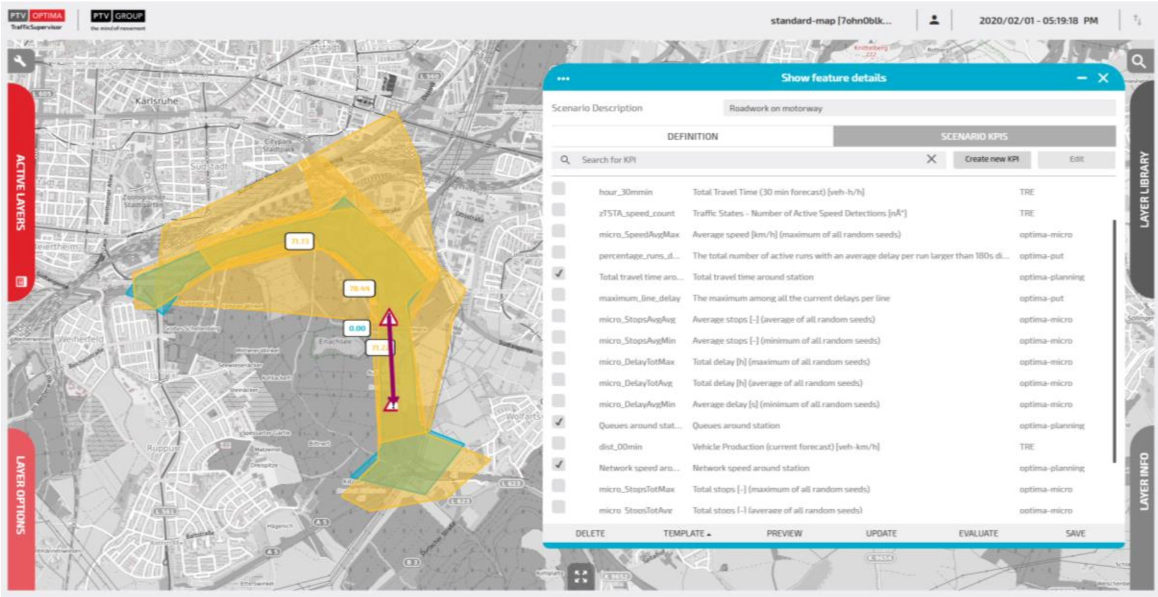


Figure 8: A set of indicators can be created and linked to each scenario, to measure its traffic impacts.

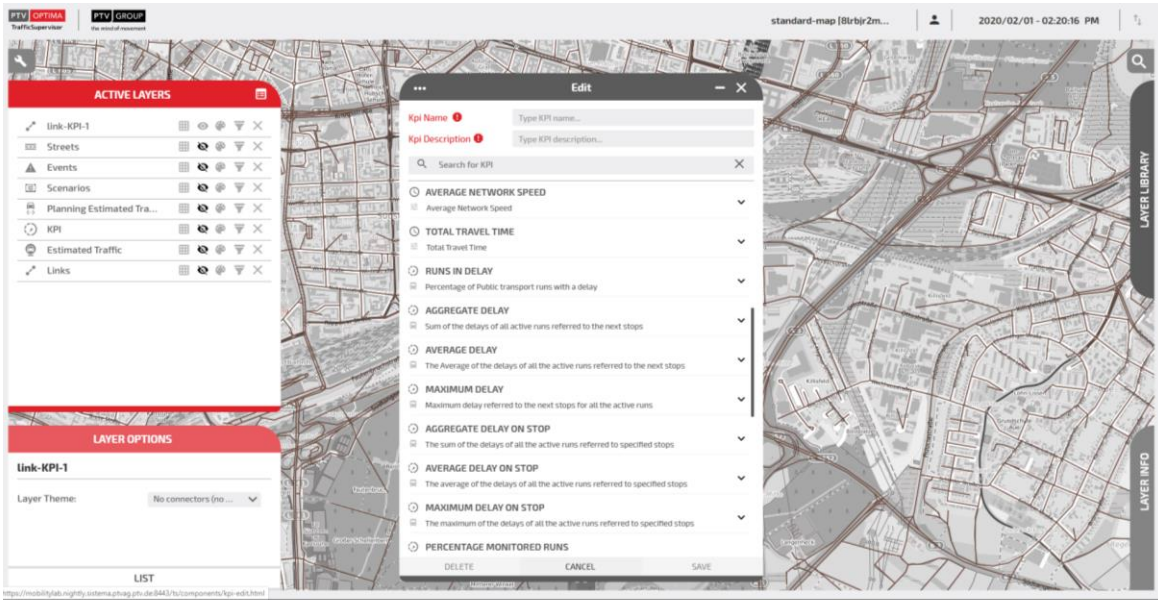


Figure 9: Indicators can be created from a list of common available KPI types, ranging from private traffic to public transport.

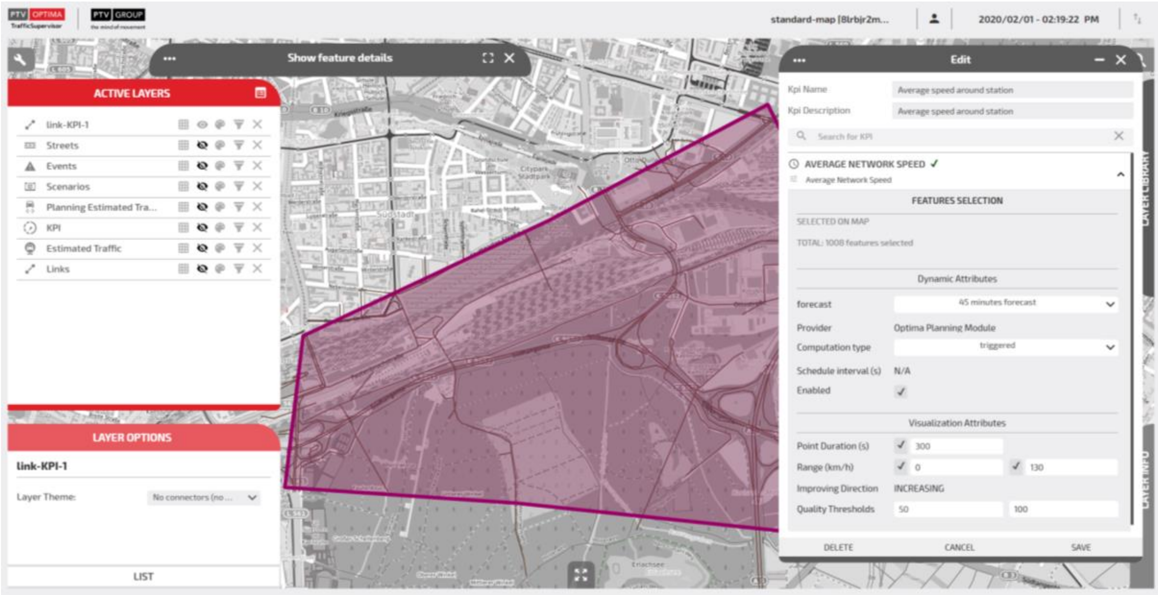


Figure 10: each KPI can be further customised in terms of location and other attributes (e.g.: reference time or indicator quality thresholds).

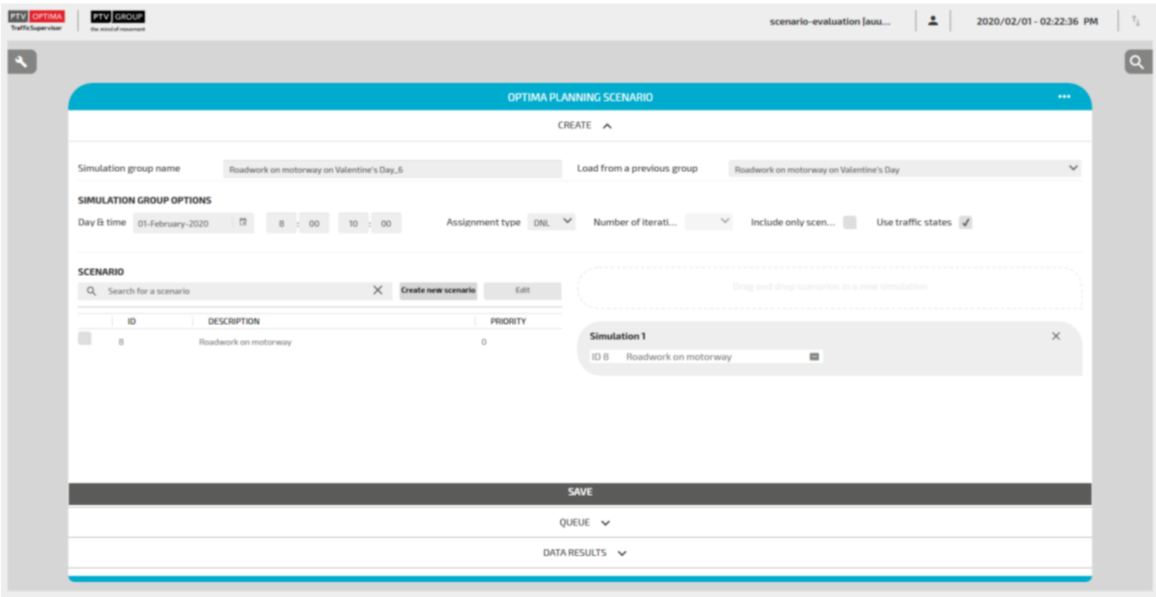


Figure 11: a simulation group can contain one or more simulations to be compared against the "base" (*do nothing*) scenario. Each simulation can activate one or more of the scenarios previously created.

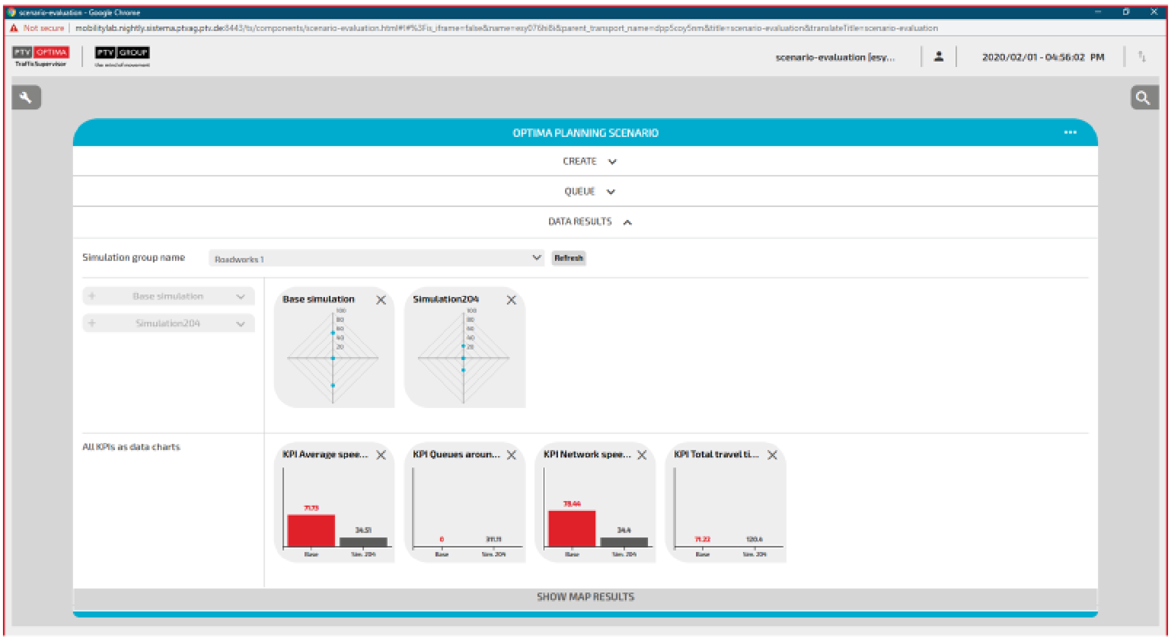


Figure 12: After computation, the set of assessment KPIs can be compared for each of the simulations within the same simulation group, to allow a quicker evaluation of the results of each single simulation.

Figure 13: Each simulation is also available on the map.

2.5 Mid-Term Forecast

PTV Optima's Mid-Term Forecast module is an automatic online simulation engine based on a dynamic traffic assignment that provides a traffic forecast for the next and following days (up to next 7 days, according hardware performances and network extension). The forecast considers any planned events like roadworks.

In detail, the Mid-Term Forecast module extends the capabilities of the TRE simulation engine already described within the Short-Term Forecast chapter, by explicitly considering the different impact of planned events that are known well ahead in time (e.g. road works) on the route choice of travelers. Specifically, the impact of planned events on the behavior of travelers in terms of route choice, is higher in contrast to the impact of an accident, which has to be calibrated accordingly. Therefore, the Mid-Term Forecast module focusses on reflecting the day-by-day adaption of travelers to the current supply situation and hence is - from a methodological point of view - a dynamic traffic assignment that has not yet reached equilibrium.

2.6 Operational Planning

2.6.1 Use cases and benefits

The module PTV Optima Operational Planning helps anyone who needs to execute the right tactical actions to minimize disruption or assess impacts on a transport network as a result of planned future events events such maintenance, roadworks, sport events, rallies, by assessing ahead in time their effects and potential mitigation strategies, all within an operational environment.

It is thus aimed at:

- traffic managers / operators that are responsible for a safe and efficient operating network where roadworks are being planned;
- police departments that are responsible for traffic management operations;
- construction companies that are tasked to execute road maintenance in a safe and efficient way as part of a tender

2.6.2 Features

PTV Optima Operational planning is based on the same dynamic assignment engine used for the PTV Optima’s analytical simulation components (Short Term, Mid-Term and Scenario evaluation). In this way, a strict coherence of results and evaluation is ensured across all different evaluation use cases.

In detail, the module extends the capabilities of the TRE simulation engine already described previously, by explicitly considering the different impact of events that have to be planned ahead of time (e.g. road works), including the route choice of travelers. Differently form shot and mid-term modules however, it allows freely to define the side conditions in terms of typical traffic conditions and time of the day.

PTV Optima Operational planning allows to:

- Plan scenarios (both int terms of disruptions and mitigation actions and corresponding KPI
- Define what kind of evaluation (with or without route choice)

- Chose typical demand conditions for the assessment
- Define length of the evaluation (whole day or only part of it)
- Combine different scenarios and run parallel simulations
- Compare results obtained in terms of KPI and on graphically on map (requires Traffic Supervisor module)
- Retrieve aggregated results (KPI) and detailed results via API, also for past simulation
- Allow to delete past simulations

2.7 Micro

The module PTV Optima Micro combines PTV Optima and PTV Vissim, which is used as a microscopic simulation engine.

PTV Optima Micro allows to provide forecasts for subnetworks, which are typically a smaller selection of the overall large-scale city or state wide macroscopic model of PTV Optima.

2.7.1 Use cases and benefits

PTV Optima Micro addresses two major use cases:

1. Operational use case
   PTV Optima Micro is used in a similar fashion as the short-term forecast module. In near real-time PTV Optima Micro provides forecasts for up to the next 60 minutes that are calculated by the microscopic simulation engine of PTV Vissim. These can be used as a complementary information to the results of the macroscopic scenario simulations with the TRE engine in the Real-Time Scenario Evaluation module. The microscopic simulation engine runs as fast as possible in the background, considers the current traffic state in terms of events, detector data etc. and serves as a decision support tool by allowing to run several scenario simulations in parallel with e.g. different traffic signal programs.
   Results are based on several random seeds and are presented as

- aggregated KPIs (see Figure 14 top) to provide fast decision support. Supported KPIs are aggregated by means of maximum, minimum, average and standard deviation for
  - total and average number of stops,
  - total and average delay,
  - average speed,
- Link based results as calculated in PTV Vissim in time intervals, providing
  - Outflows of links
  - Travel times along links

Link based results can be used within the general KPI engine of PTV Optima to derive customized KPIs e.g. travel times along paths within subnetworks.

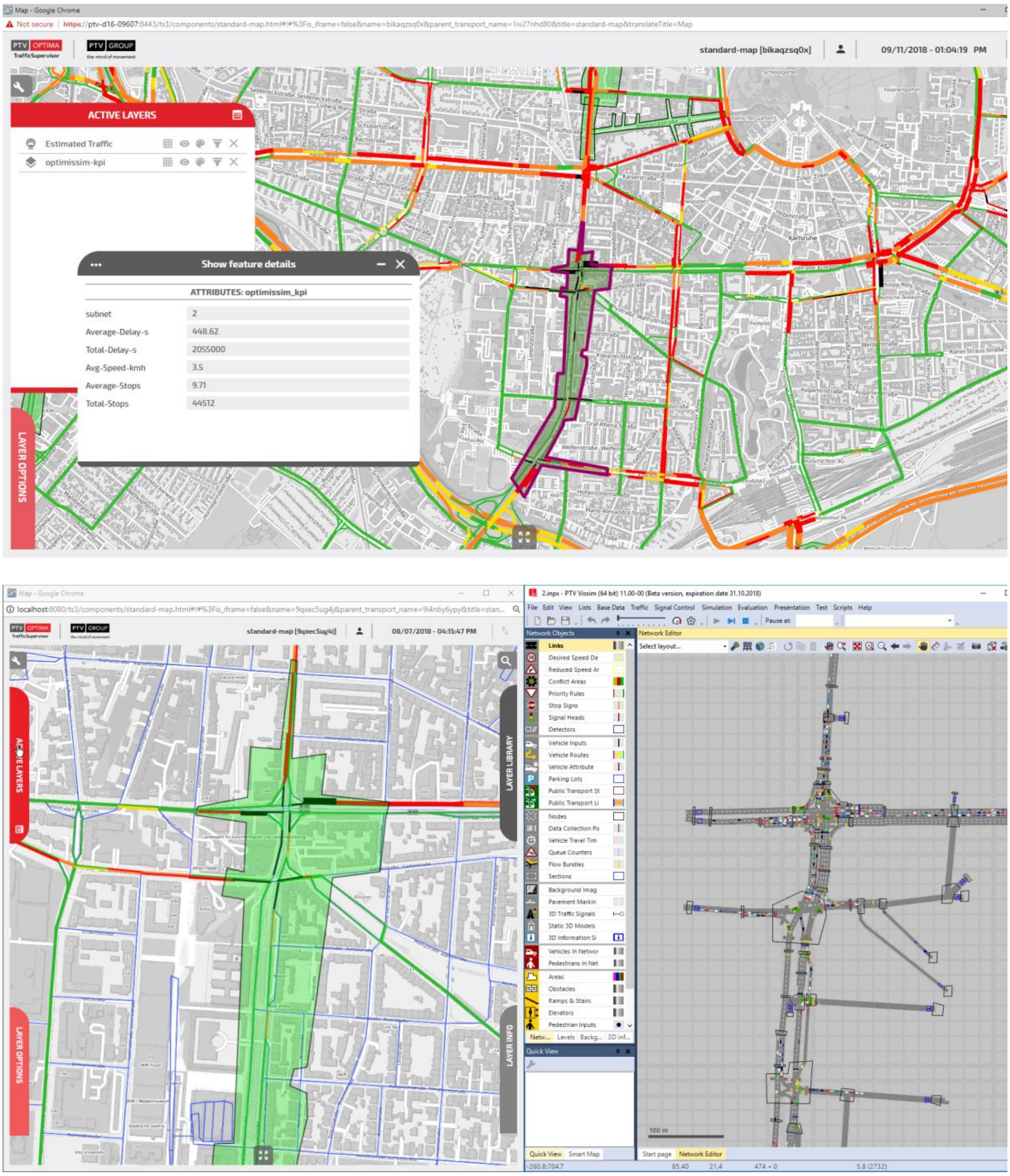


Figure 14: PTV Optima Micro KPI in Traffic Supervisor (top) and subnetwork in Traffic Supervisor and PTV Vissim (bottom).

2. Planning use case
   The exact microscopic simulation that is used in the operational use case is also available as an input for the “classical” desktop software PTV Vissim (see Figure 14 bottom). This allows to replay simulations to better understand and analyze the results in a planning environment to improve traffic management actions for the

next time in the operational environment.
Imagining for example an accident, blocking important streets and hence introducing a lot of additional traffic along alternative routes. The operator working in the traffic management center used the existing traffic signal strategies but could not mitigate the situation in a satisfying way. At the end of the day (or even the day after – or if watching moving vehicles asap is desired, also right away), it is possible to “wrap up” a PTV Vissim simulation package, that corresponds to the situation that the operator experienced, and hand this over to the traffic engineer to fine tune or design new strategies helping to deal better with similar situations in the future.

PTV Optima Micro is specifically useful to improve decision support in areas or for traffic management actions, for which the interaction between and the behavior of individual vehicles and signal controllers is critical. It provides the right methodology and tool where you need it and when you need it, e.g. PTV Optima Micro allows:

- Simulating public transport prioritization schemes in real-time and with the highest level of detail.
- Testing how different ramp metering scenarios influence your network’s throughput and average number of stops and delays using real-time traffic microsimulation
- Using microscopic simulation to improve your dynamic managed lane strategy in real-time (specifically different management schemes for express toll lanes (ETL) and high-occupancy toll (HOT) lanes).
- Scenarios where interaction with pedestrian (with a pre-coded number of persons) and vehicles are important to be evaluated (e.g. situation at an important bus stop during a strike in a very congested day)

2.7.2 High-level features in a nutshell

PTV Optima Micro offers microscopic simulation results to the operator for predefined subnetworks. The microscopic simulations are an additional decision support tool for high-quality traffic management decisions which

- are based on the current traffic state collected and aggregated by PTV Optima (from detectors, FCD etc.) and consider simulation results from PTV Optima thus also considering the large scale city-wide traffic situation, including the events that create a spillback effect inside the area of the microsimulation.
- are an upon request-alternative/addition to the existing macroscopic simulation of PTV Optima,
- consider link blocking events, producing queues, spillback and local re-routing,
- consider lane blocking events, that block e.g. a lane of a multi lane road due to an accident,
- consider link speed events, that e.g. change the allowed speed limit along a link,

- can be requested as scenario groups, consisting of several simulations with different traffic management actions to provide decision support,
- allow to evaluate different signal programs as traffic management actions,
- allow to evaluate dynamically generated stage based signal programs as traffic management actions (this requires existing interstages)
- can be retrieved as simulation packages for PTV Vissim allowing visualization, deeper inspection and fine tuning of traffic management actions,
- are reliable and timely because they are based on several random seeds and calculated in a distributed environment,
- provide results as aggregated KPI.

2.7.3 Requirements

Project and modelling

The subnetworks used by PTV Optima when executing real-time microscopic simulations are PTV Vissim models that must be prepared beforehand in the offline (Traffic Study) stage of the project. In similar fashion as the base model of PTV Visum which is used for the macroscopic simulation of PTV Optima, the PTV Vissim models will be developed from the base model of PTV Visum and retain zone and node data which co-ordinate with PTV Optima to facilitate the passing of real time and traffic forecast data (see Figure 15).

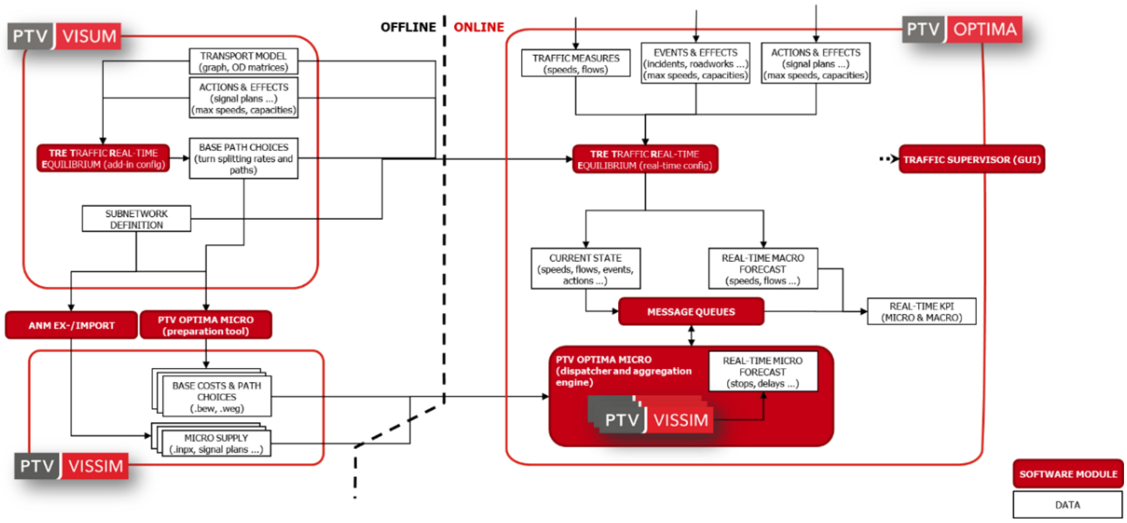


Figure 15: PTV Optima, scheme of the functional architecture with focus on PTV Optima Micro.

Hardware environment

- To provide a reliable evaluation of a scenario PTV Optima Micro automatically calculates and aggregates several microscopic simulations with different random seeds. We recommend to use at least 10 different random seeds for decision support and evaluation of a scenario.

- To provide results fast and while they are still meaningful, PTV Optima Micro can make use of many servers and run the microscopic simulations in a distributed environment (see Figure 16). A typical setup for PTV Optima Micro consists of an additional
  - 3 virtual machines as “PTV Optima Micro Message broker” for fail safe communication.
  - 5 virtual machines as “PTV Optima Micro Worker” for every scenario that shall be calculated in parallel (typically up to 4). Usually a machine can handle 2 microscopic simulations in parallel without a significant loss of performance, therefore 5 virtual machines allow a timely calculation of a scenario which is based on 10 microscopic simulations with different random seeds.
  - 1 physical license server or an environment with internet access (to be clarified within the specific project).

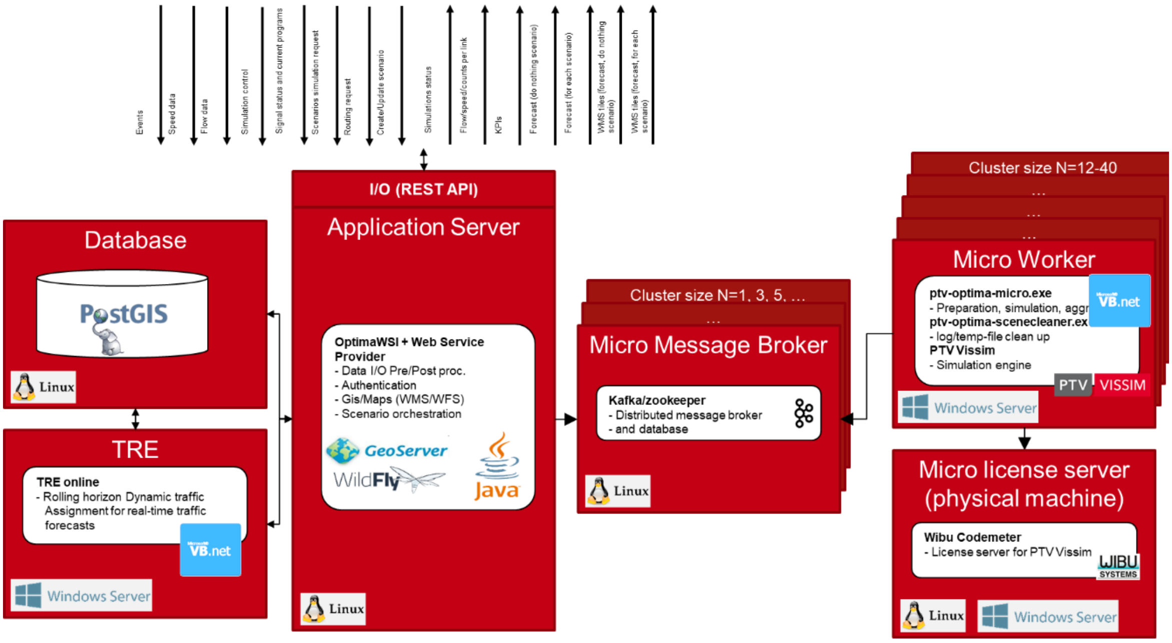


Figure 16: PTV Optima, scheme of the system architecture with focus on PTV Optima Micro.

2.8 Traffic Supervisor (GUI)

The Traffic Supervisor module is the Graphical User Interface (GUI) of PTV Optima. It provides a rich yet intuitive web interface for the operators of traffic management centers, allowing for:

- map-based traffic state monitoring, allowing to manage and visualize all model and traffic data;
- creation, editing and management of events;
- control and monitoring of the different simulation tools;
- scenario comparison and alert management.

The GUI is based on standard technologies and communication protocols (WMS, WFS) allowing for fast extension and inclusion of new functionalities and/or data to be displayed.

The interface allows selecting, inquiring and modifying of objects and data directly by clicking on the map.

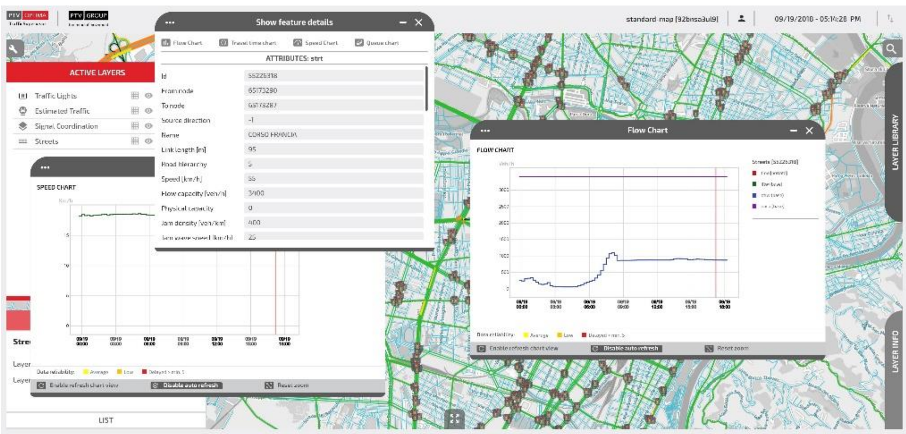
Traffic Supervisor allows the visualization and comparison of multiple traffic states, either measured, estimated off-line or forecasted in real-time, by means of dynamic flow bars layers and time-profile diagrams of flows, travel times and queues on the network.

In particular, it is possible to compare disruption and congestion events detected by the system against the corresponding temporal profiles of traffic states measures on the network by traffic detectors and/or FCD data.

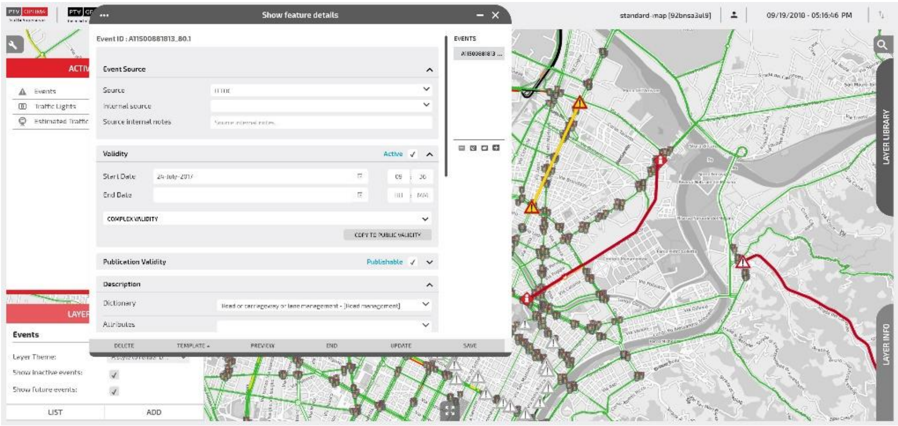
Traffic Supervisor includes a web based administration panel, allowing for configuration (including access and profiling policies) and monitoring of the system. The functionalities of the Traffic Supervisor module extend with the inclusion of several other modules like Real-Time Scenario Evaluation, Vehicle Tracker, Detection and Control or Smart Display.

Figure 17 presents some screenshots of Traffic Supervisor.

LOS-overview for current or forecasted traffic states, for the base simulation as well as scenario evaluation.



Detailed analysis with flowchart representation of simulated and observed data.



Representation of events (incidents, roadworks ...) and VMS.

KPI representations

Figure 17: Sample screenshots of the Traffic Supervisor module, PTV Optima's operator GUI.

2.9 Vehicle Tracker

PTV Optima's Vehicle Tracker module allows the usage of FCD (Floating Car Data) originating from e.g. dedicated probe vehicles or public transport fleets. This provides a valuable data source regarding current speeds and disturbances on links of the network.

Vehicle Tracker processes FCD raw data - space positions of any mobile device that is capable to acquire a GPS-based location and send this data. The data can be provided at any time interval (though shorter intervals are more precise), through a standard web service (Orca protocol or CSV) or directly in the database of PTV Optima.

Vehicle Tracker projects the space-time points on the road graph, filters data that imply unrealistic trajectories through a graph-matching algorithm, reconstructs the path followed by the vehicles and determines the trend of their speeds on each road link. Once all trajectories provided within a given time window are matched correctly, Vehicle Tracker calculates the resulting average speeds on links of the reference network from all available trajectories.

The Vehicle Tracker module can also receive and process travel time data provided on a TMC base and integrate them with FCD data.

2.10 Detection and Control

This module offers the capability to detect incidents automatically and to rise alerts in order to inform the operator of the traffic management center about incidents and locations that require attention. Incident detection and alert generation are based on customizable triggers that e.g. consider the deviation between forecasted traffic flows and the values that are usually expected.

The Detection and Control module allows the definition of triggers that are based on traffic states (flow, speed, density and queue) of a set of links in relation to definable thresholds. In addition, sql-queries allow the formulation of any kind of trigger. Based on the trigger several actions can be executed. Depending on the availability of other PTV Optima modules these can be simple alerts popping up in the GUI Traffic Supervisor, DATEX II messages for VMS or the evaluation of additional traffic management strategies via the Real-Time Scenario Evaluation module.

PTV Optima's Detection and Control module has access to the PTV Optima database and can send messages via HTTP "post" methods. The module always requires the Traffic Supervisor module and improves the capabilities of Smart Display and Real-Time Scenario Evaluation.

2.11 Smart Display

PTV Optima's Smart Display module provides decision support for the selection of messages for variable message signs (VMS). The heart of the software is a mathematical model, which supports the operator in choosing the best message to be displayed on each VMS panel. This support is accomplished by calculating a ranking list of all events (e.g. incidents) for the VMS of interest.

The ranking considers the current network state and is based on an absolute and a relative priority. The absolute priority respects the importance of the event in form of the general relevance, the speed and capacity reduction caused by the event as well as the time the event has been present. The relative priority respects the position of the VMS and reflects the amount of traffic that passes the VMS and actually reaches the event- therefore the number of travelers that can actually make use of the displayed information.

The Smart Display module is implemented by associating each event to each panel using a suitable display priority: in other words, each panel will be the set of messages associated with active or pending publication ordered by priority. With reference to each panel, the set of messages can be reduced to an appropriate subset through threshold values.

The module either allows third party requests via HTTP or comes with a full integration in PTV Optima's GUI Traffic Supervisor.

PLEASE NOTE THAT Smart Display module has not a direct connection to real VMS on the ground and it should be considered as a decision support tool.

2.12 Public Transport ETA

This module allows the calculation of Estimated Time of Arrivals (ETA) at Public Transport stops, as well as transfer alerts on stops where transfer time exceeds defined thresholds due to delays. The approach is based on the fact that public transport lines that share the same road network with private transport, are affected by the traffic state conditions produced by the latter.

The Public Transport ETA module takes current speeds from the PTV Optima database; these could be either a result of the fusion engine Traffic State Harmonizer or from PTV Optima's Short-Term Forecast module. In the former case current and future traffic states will be dependent upon, where no measurements are available, the free-flow speed assumptions. The latter case allows to respect the full capability of PTV Optima to extend measurements in time and space to all links of the network, therefore providing the most useful data to calculate Public Transport ETA.

To calculate the ETA it is further required that, the underlying base model has full knowledge of public transport stops, lines, line routes, journeys, etc. and that the current position of any given public transport vehicle is provided in real-time to PTV Optima Public Transport ETA as well as the route the vehicle is serving.

Based on this information PTV Optima Public Transport will calculate the ETA at stops for the next journey, according to current and forecasted traffic states available within the network along the line route of the vehicle. ETA is obviously most precise for public transport lines sharing the network with the private transport traffic. The results are made available through PTV Optima standard interfaces and provide a valuable input for journey planners and public transport operation control centers alike.

On top of that, the module automatically calculates a specific set of KPI that are useful for a fast evaluation of the performance of the public transport system.

Calculation of KPIs are based on the actual knowledge of timestamp, vehicle identifier, positions of vehicles, runs, lines and delays at the stops which are monitored by PTV Optima.

Here it is the list of available KPIs with their definition:

- Total current delay: the sum of the delays of the all active runs and referred stops;
- Current delay per line: sum of the delays of the all active runs and stops of line;
- Current delay per stop: sum of the delays of the all next active runs through the stop;
- Average delay per run: total current delay divided by the number of active runs;
- Average delay per line α: It is defined as the current delay per line α normalized by the number of active runs of line α times the number of the active stops of line α;
- Average delay per stop β: total current delay per stop β divided by the number of active runs through the stop β;
- Percentage monitored runs: total number of monitored vehicles divided by the number of active runs;

- Percentage active runs with delay larger than x: total number of active runs with an average delay per run larger than x divided by the number of active runs;
- Maximum line delay: maximum among all the current delays per line α.

This module takes vehicle position information in the GTFS-R format, with a special extension in case the user wants to send also event information like line/stop disruptions.

2.13 HyperPath Road Server

The HyperPath Road Server module adds the capabilities of a **multi modal journey planner for dynamic routing to the Optima suite**. The module takes the real-time conditions, derived from Optima and all integrated data, and future conditions of road networks regarding travel times and costs that vary during the day, due to congestion or network disruptions (incidents, road works, etc.).

It can take several modes of transportation in a multi-modal transport network into account. Examples are travelling on foot, by car, bicycle, truck, and any other private modes the client may want use.

It is possible to request a custom journey request, setting several preferences and route choice criteria, such optimizing waiting times, fuel consumption, emissions, road slopes avoidance, type of roads, etc.

Based upon the desired departure time, the planner finds the dynamic shortest route in terms of generalized cost (i.e. a combination of time, distance and other attributes to be optimized like the fuel consumption); the single user can request even for personalized weights for each path request.

Upon a journey request the modules describes the resulting itinerary through a suitable sequence of textual travelling instructions, each one associated with a geometrical entity on a reference cartography. The journey planner answer contains directions and information about travel impacts on environment, total travel time and other statistics.

This server-side module is interfaced through a REST web interface that can be called from e.g. a web interface or from a third-party system.

2.13.1 Type of requests

The module can be queried for:

- Find path: finds the best path between an origin and a destination point (waypoints are also possible).
- Find alternative paths: find different paths for the same destination.
- Cost matrix search; returns the cost and time for N:M connections
- Contour lines (to produce heat maps); defines the contour lines based on travel time or cost according to a specific origin.

2.13.2 Road network and configuration

The road network that is being into account by HyperPath is managed in PTV Visum and it is the same as the Optima road network. It is possible to import shapefiles and routing maps in VISUM from different format and providers. The digital network is an exact copy of the real network, it can take turn prohibitions and access limitations, speed and intersection delay for each directional link into account. The software can handle any type of link attributes that are important for the routing of heavy vehicles, such as: tortuosity, steepness, bridges, tunnels, left and right turns at intersections, urban context, change of street hierarchy level, major roads. Each attribute can be scaled by a personalized weight in the computation of generalized costs. The topology of the **pedestrian network** can also be introduced explicitly together with the road network. Different speeds can be defined for each link to simulate “fast pedestrians” or “slow pedestrians.

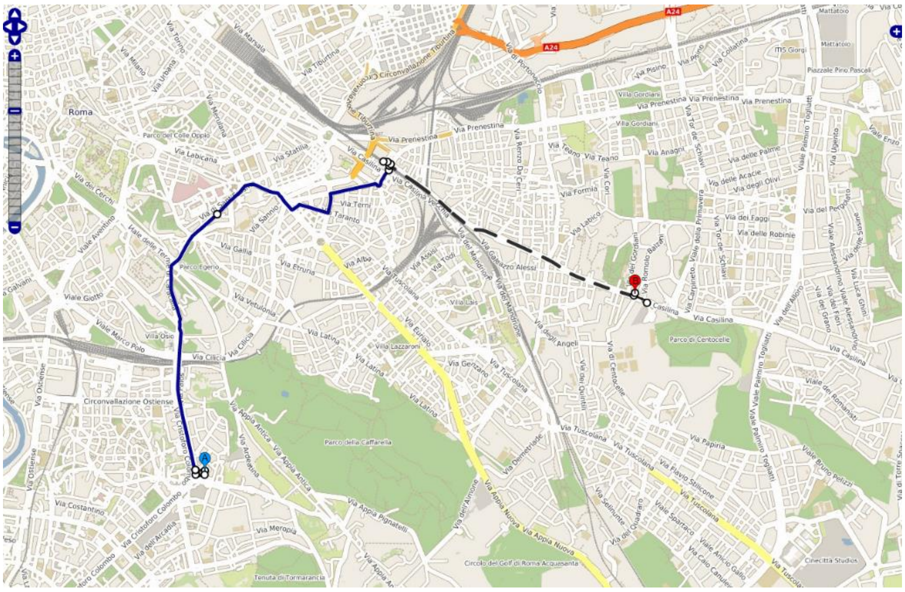
2.13.3 Realtime traffic state and events updates

Real time traffic state and events updates are fed in HyperPath through the “Optima base module” formats and channels. For traffic data HyperPath will use the result of the data fusion process as explained in the “Optima base module” and will use the events wherever they have an impact in term of speed and road closures.

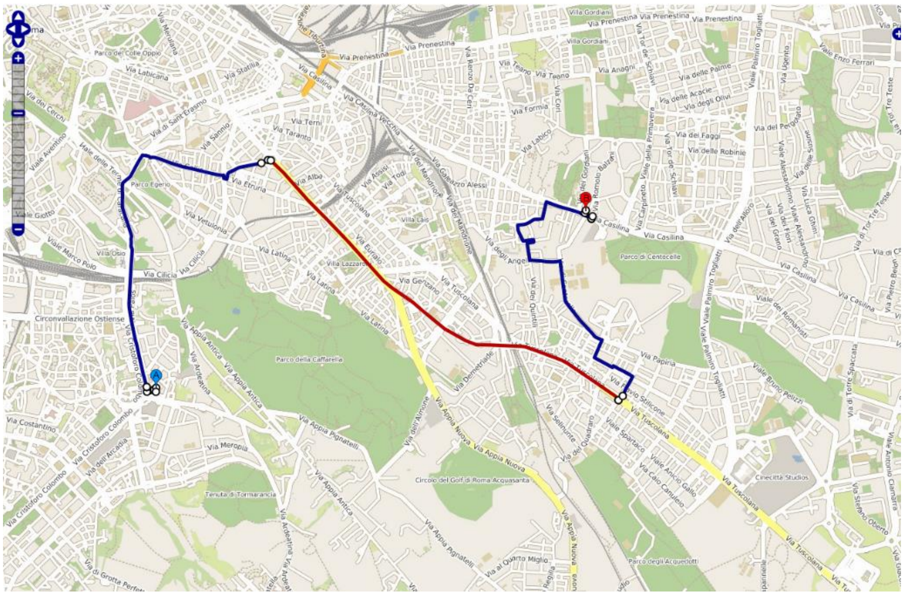
2.14 HyperPath Transit Server, park&ride

The HyperPath Transit Server module includes the capabilities of Public Transport journey planner with special focus on optimizing the **travel strategy** of the users.

The most important characteristic with respect to the route search on public transport networks, resides in the ability to provide the user with not only a path but a **complete travel strategy**. In fact, the search path in the case of public transport is different than the private one. In the case of the public one, the user before the real movement defines a so-called strategy of travel, which (as we can see from Figure 18) is composed of various alternative routes to reach the destination.



First case: the user waits 9 minutes at a stop and then uses a bus followed by a metropolitan train.



Second case: the user waits 4 minutes at the stop and then uses a bus followed by the subway and later another bus. Arrival time is the same.

Figure 18: Examples of clearly different hyper-paths.

Such strategy has the aim to reduce waiting times at bus stops; in fact since the user may use multiple lines to a single bus to reach destination, he may decide to take the first one that passes among those listed by the software in order to reduce waiting times .

3.2 Features

HyperPath supports frequency and scheduled based services or a combination of both. The transit line service can be characterized, given the stop sequence, in terms of headway distribution and travel times (frequency-based), or in terms of single runs (schedule-based). For example, at each stop we can deal at the same time and in the same framework with a given line passing on average every five minutes, and with a specific run departing at

8:00. As an alternative, all the necessary line attributes (e.g. frequencies and travel times; both varying during the day) can be automatically retrieved from the programmed schedule of the service, i.e. the data source typically available at transit companies.

Kilometric or boarding fees and costs can be explicitly considered, while more complex fare structures (areas, belts, sections) can be introduced whenever reducible to a zone based (origin-destination) matrix.

To fully meet the needs of the more demanding users, the software provides also the possibility of specifying manually the values of the cost weights, for each path request like disutility on exchanges, penalties on pedestrian movements, etc.

2.14.1 Park and Ride.

Optimal routing on intermodal trips which require to park a private vehicle at a commuting terminal is ensured by a specialized search procedure (this feature requires HyperPath road server engine). Time-varying delays and costs of each parking facility can be explicitly considered.

2.14.2 Network and configuration

The road network is managed in PTV Visum. The topology of the pedestrian network for PuT can be also introduced explicitly together with the road network. Different speeds can be defined for each link to simulate “fast pedestrians” or “slow pedestrians”.

The transit network can be specified in the PTV Visum format, GTFS format. In general, all the schedule formats that can be imported in PTV VISUM can then be utilized for HyperPath.

2.14.3 Connection with Public Transport ETA

In case “Public Transport ETA” is present the module is also able to calculate the directions considering the real position of PuT vehicles and the foreseen time of arrival at stops. In this case also special events like temporary line disruptions or stop closures are taken into account.