SAPIENZA
UNIVERSITÀ DI ROMA

Integration of PTV Optima and Balance aiming at Intelligent Traffic Management System (ITMS)

Department of Civil, Constructional and Environmental Engineering

Master of Transport Systems Engineering

By: Pedram Tafazoli

Supervisor: Prof. Guido Gentile

Autumn 2018

Integration of PTV Optima and Balance aiming at Intelligent Traffic Management System

(ITMS)

1 Contents

2 Abstract

An excellent Intelligent traffic management system must be efficient, robust, proactive and complete to cover all elements of traffic principal perfectly. In this thesis the Integration of PTV Optima-Balance is exploited aiming at easing the congestion and accomplishing a higher utility for users and traffic control authorities. The underlying concept of PTV Optima is General Link Transmission Model (GLTM) which will be explained at length. Moreover, the compatibility of two PTV products, Optima and Balance, brings them as an entity of integrated system which is capable to predict the traffic state in short term and adapt the signal controllers correspondingly. Thus, the traffic performance indexes will be enhanced, and the opportunity of proactive action be provided to traffic authorities.

Since the forecasting tool is a traffic model, the calibration of supply and demand play a crucial role in not only the efficiency of integrated system per se but also the reliability of application among users and authorities. Because, simply the system comes up with en-routing commuters from over loaded paths via VMS and provides extra potential actions to authorities which won't be respected unless being witness of resemblance trend in the result of traffic model and the traffic observation of real world. The taken strategies in calibration and assessment of traffic model are elaborated fully in this thesis as well.

Eventually, to illustrate the benefits out of integration of PTV Optima-Balance, the deployment of system on Taichung city proves the mitigation of performance indexes of traffic like travel time, served vehicles and seamless flow propagation.

3 Introduction

With the increasing number of people living in cities and urban areas, traffic management has become a serious issue. According to studies, by the year 2030, 70% of the world’s population will be living in cities. The consequences of an increase in urban population are a scarcity of living space, a higher utilisation of the infrastructure, hence an increase of traffic and shortage of parking spaces. Traffic and citizen’s mobility have a strong impact on the quality of life and the potential development of a city. In addition, noise, pollution, infrastructure planning and maintenance are all impacted by deteriorated traffic condition as well; even, the economy and growth can be boosted or neglected. If we consider cities as living organs, traffic is their bloodstream; if it is inefficient, slow, or collapses, the city is likely to die.

Mobility has been reshaped in the last decade thanks to rapid advancement in technology which leads cities to confront a new forms of mobility solutions such as Waze, Google Maps, Uber and Lyft. These new features are going to enable people to move and live more comfortably; However, in some concern, this statement is just a myth unless an entity manages the traffic proactively. Statistics says, Over the last four years Uber and Lyft have put an additional 50,000 cars into New York City, causing more congestion than ever. Also, Waze and Google Maps circumvent congested highways, which can shift heavy traffic into residential areas. On the other hand, keeping pace with worldwide growth will require an estimated $3.3 trillion in annual infrastructure investment until 2030 which is not only costly but also unsustainable environmentally. Hence, a smarter way would Save up to 35% on infrastructure investment as a result of Intelligent Transport System (ITS) deployment with quicker results.

Once ITS brings the capability of moving from a reactive to a proactive approach to traffic management and infomobilty, the wonders pop up like what if an incident disturbs a typical pattern of traffic? Is it producing congestion? How long will it take to get back to normal conditions? Or, in decision making level such as, should we close the road completely to accelerate clearance operation or should we leave one lane open to allow some traffic through? What message can inform the users better and dissolve the congestion faster?

How the statement of proactive reaction would come true? Evidently, advanced technology has facilitated us with the provision of broad real-time data, while the question is, whether the observation is sufficient to predict the future, or how about the statistical approaches, is the statistical approach able to consider unplanned and sudden events in a traffic forecast? Frankly, both methods are necessary but not sufficient and reliable enough to accomplish our goal_ **proactive reaction**. Simulation approach is what we are looking for. Because, not only fusing the big real-time data and considering them in the forecast intelligently but also, by mimicking the human's behaviour and traffic principals, the fact of reliable and effective foreseeing traffic will be turned to a tangible claim. The table below compares the capability of three methods.

	Traffic Estimation "What is going on?"	Traffic Forecast "What is going to happen?"	Scenario Evaluation & Decision Support "What would happen if?" "What should we do?"
Observed Data	Maybe (with extensive measures)	X	X
Statistical Approach	✓	"Usual" conditions only	X
Simulation Approach	✓	✓	✓

Table 1 Three methods for traffic estimation, evaluation and forecast

Most cities are already well equipped with sensor infrastructure to monitor traffic intensity, volume and flow in real time. Moreover, Cities are equipped with controllable field units (e. g. traffic lights, variable message signs, etc.) to influence the current traffic situation. Thus, almost all vital components exist today to face the traffic challenges in major cities. But there is still one building block missing which is extremely significant for proactive management of traffic. A robust traffic model like

PTV Optima-Balance would fulfil this demand that is the composition of macroscopic dynamic traffic model, PTV Optima, and automatic adaptive signal controller, PTV Balance. PTV Optima is an on-line system producing in real-time a comprehensive traffic state estimation which can effectively use a small sample of traffic measurements from any available data source to measure a nowcast and forecast for travel time, flow, speed and queue for each element of network. Moreover, Optima is not only a simulation engine but also it is a profound assistant decision-making tool in which the fused data, nowcast and forecast measurements and evaluation of measures are all provided in a web base interface called traffic supervisor. Then, a proper decision is taken by authority using the PTV Optima-Balance solutions and informing commuters to escape from heavy congestions by en-routing their path via VMS. High compatibility of PTV Optima allows PTV Balance to be integrated conveniently and feed the Optima and local controllers with fresh and updated signal programs aiming at a seamless and optimized traffic flow.

4 State of Art

Traffic management system is not an unfamiliar term in even classic transport engineering field while adding the prefix of “Intelligent” makes it fashionably fancy state which its applicability just has been provided in 21st century. In fact, Intelligent Transport system has defined, by the directive of the European Union 2010/40/EU, as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport.

Intelligent traffic management system addresses the usual trouble wherever the interaction among different modes or users of mobility exist. In the contest of private transport of urban network, Intelligent traffic management system deals with congestion. In the technical words, this statement is translated into a cost function expressed in terms of the traffic states: traffic flows, traffic densities, average speeds etc. As the name cost function states, the cost associated with an undesirable traffic state with congestion needs to be higher than the cost associated with a traffic state with less congestion. This way, finding a traffic state without congestion or where the congestion is as small as possible corresponds to looking for the traffic states with the lowest value of the cost function. The cost in the urban network is implied resulting from the volume of traffic flow and its characteristics, physical attributes of network, and controlling systems where there is conflict among road users so called intersections. But, how can the cost be measured? Traffic model is the solution to cope with definition of cost function corresponding to the real world. There are plenty of models which can be classified according to their properties. A full description concerning various properties of models and the content of each class is given in [5]

Initial traffic models had been built under the subclass of Grey Box model (by parameterizing equations between the states of the motorway and fine tuning these parameters by fitting the input-output relation of the traffic model). As an example of this intermediate approach, the traffic models of Lighthill, Whitham [1955] and

Richards [1956] and Payne [1971] are mentioned which are elaborated in more detail in [5]. Since traffic management task is usually performed in an extended scale like entire city or a neighbourhood, macroscopic model would be much more suitable to be utilized. In macroscopic model, there exists a level of aggregation of variables[1] representing the traffic situation. Furthermore, vehicles move along the network elements under assumption of fluid paradigm[2]. Typically, a macroscopic model defines a relation between the traffic density, the average velocity and the traffic flow by introducing Kinematic wave theory _ KWT. Relation among the influential parameters of KWT is distinguished by fundamental diagram of links which has various shapes under different traffic theory assumptions.

The dynamic nature of traffic in time and space has brought the attention to the creation of corresponding dynamic model with possibility of assignment of demand on a network containing the traffic variables in space and time. Besides, In the context of within-day Dynamic Traffic Assignment (DTA) the spatial propagation of flow takes time which depending on the use of network _space-continuous or Space- discrete network. The elaboration of space-continues network is beyond the scope of this thesis while following description illustrates how space-discrete network works. The Continuous Dynamic Network Loading (CDNL) problem consists in determining the links flow corresponding to given transport demand and route choices through a performance model yielding travel times as a function of flow, where all such variables have temporal profiles [4]. The significance of a performance model would be handled with the definition of KWT by implying the macroscopic flow principals on links.

The most popular approach to solve the CDNL based on the simplified KWT, where the fundamental diagram has a triangular shape, is the Cell Transmission Model (CTM) proposed by Daganzo[7]. Cell Transmission Model was limited to exploit only triangular fundamental diagram which is perceived as a weakness of model because it

---

[1] An aggregate traffic variable is a variable that summarizes information about multiple vehicles. E.g. the average speed contains information on the speed of all the vehicles present in a given section of the road.

[2] Vehicles are represented as particles of a mono-dimensional partially compressible fluid.

does not perfectly reflect the traffic states pattern according to the observation data. Besides from a computational point of view, it suffers the spatial discretization of links both in terms of efficiency and accuracy.

Recently, Link Transition model (LTM) introduced by YPERMAN coped with the spatial discretization while the constrain of triangular fundamental diagram is still considered as its drawback. In fact, links and nodes constitute the network of LTM where traffic flow propagates through links depending on the KWT parameters and nodes play the role of gates to let the flow pass from upstream to downstream based on the predefined priorities and capacities in the node model. A full description is given in [7]. LTM has been revised and mitigated by the General Link Transition Model (GLTM). GLTM contains the improvements that is the extension of the LTM to any concave fundamental diagram and node topology which is elaborated in [6].

But how about controlling elements in an urban mobility contest? We know that traffic is a dynamic phenomenon with high variability in the quantity and quality. Traffic flow propagates through links and encounters the conflict areas like intersections which are meant to be controlled for the sake of safety and higher traffic performances. Therefore, the operation management of intersection plays a crucial role in the efficiency of entire traffic network as well. Thus, a smart adaptive traffic signal controller will be substantially beneficial in the view of the fact that traffic does not have a steady condition and fluctuates constantly. Adaptive signal controllers deal with both an isolated junction and a group set of network junctions where seamless coordination among their operation would enhance the traffic profoundly.

There exist a rich history behind the literature addressing optimization and coordination of signal controllers which its explanation is beyond the scope of this text, nevertheless it is available in [9], [10], [11] and used coordination methods in [12],[13] and [14].In addition to the science and methodologies, there are plenty of commercial software which have been developed regarding the mentioned studies. TRANSYT is developed in 1969 to cope with delay by Robertson [15]. and then Cohen[16]. modified the software to handle the coordination issue by maximum bandwidth hypothesis. In addition to that, SYNCHRO[17] , PASSER [18] are other commercial software based on static models after TRANSYT. However, to deal with the dynamic status of traffic such software could not be sufficient in real-time solutions whereas they will be useful to build further tools as references.

Adaptive signal control system has been extended all around the world with wide variety of products in the market. Among them, SCOOT is today the most popular system, with hundreds of installations in the world. SCOOT[19] is a direct derivation of the TRANSYT strategy, determining the optimal green and offset for a network of signalized junctions, based on traffic flows detected through traffic sensors. UTOPIA [20] is a regulation system which performs in real-time a bilevel optimization. Applications of UTOPIA can be found in the Italian cities of Rome, Turin and Bologna. OPAC was developed after UTOPIA by Gartner [21]. It is a fully demand-responsive system, mostly performing each time step a new plan selection and then adopting a rolling-horizon strategy. OPAC's main installations are overspread in the US. BALANCE [1] is a product of the German academy. BALANCE focuses on the system modularity; thus, it is immediately scalable. It explicitly allows to include public transport systems and to apply specific strategic policies (e.g. transit priority). A detailed description concerning its methodology is given in the **Chapter 5**.

After an exhaustive review on the history of traffic model concepts and signal control optimizer systems, studying the applications integrating dynamic traffic model and automatic adaptive signal controller in an individual entity is remained. Theoretically, these two systems of dynamic simulation and adaptive signal controllers would lead traffic productivity to a desirable level once a robust integrated system includes both simultaneously. In the other words, the mutual influence of each of which on each other and both on the traffic LOS is inevitable, on account of the fact that, systematic optimal outcome is what makes the urban traffic congestion lighter.

There are a wide variety of applications addressing such integrated system, however not all of them are available in the market yet. A real-time traffic forecast tool has been identified by the Atos Scientific Community as vital for intelligent traffic systems extending today's solutions by proactive decision support. This tool is deployed in the Proof of Concept (PoC) in Berlin project which proved quite successful result. It exploited the historical traffic state in forecasting the traffic statues up to 4 hours ahead while the calculation time is less than a minute**.** PoC is powered with a neuron network engine which falls into the realm of data science and can be categorized as a white box model described in [5]. The second integrated tool is deployed in Metropole of Lyon as an ITS tool providing multimodal information in real-time, and strategic Decision Support Tools (DST). A fully integrated decision support tool using AIMSUN Online simulation system to forecast the traffic 1 hour ahead of time. The result was outstanding, created one-hour traffic prediction tools that are 80% reliable and potential savings of 20% of road capacity are the considerable ones. An adaptive signal controls are brought by SPIE aimed at offering traffic operators the best traffic signal timing scenario or delaying upcoming congestion or limiting its impact. AIMSUN receive the real-time feed and real-time incidents, then match them with a predetermined demand patterns to be assigned in the network and forecast the traffic situation. In fact, a set of predefined demand are measured regarding distinguishable patterns based on historical data. Thus, according to the characteristics of received data, a pattern from the pattern library will be triggered and assigned to the network[23]. Last but not least, the integrated traffic management system of PTV_Optima-Balance been introduced recently in which the interaction of two software is provided under the architecture of PTV_Optima. PTV_Optima is a dynamic simulation software which has the capability of being launched both offline and online (rolling horizon mode). Its methodology will be discussed at length in the Chapter 7.

5 PTV Balance Methodology

The adaptive network control PTV Balance (“**BAL**ancing **A**daptive **N**etwork **C**ontrol m**E**thod”) was originally created within the research projects “Munich Comfort” (Friedrich and Mertz 1996) and “Tabasco” (Friedrich et al. 1998).

PTV Balance deploys both macroscopic and mesoscopic traffic model as its own internal engine, although a superordinate traffic model like PTV Optima can also be replaced with Balance macroscopic traffic model. The optimized signal plans are driven by inserting the given flow into the objective function of optimization. In fact, PTV Balance optimizes the signal plans according to the temporal flow volume (the output of mesoscopic traffic model) to have the best network performance index. Eventually, Framework signal plans _FSP_ are the result of PTV Balance optimization which would be sent to a local controller like PTV Epics, VS-Plus, ring-barrier-control etc. In the other words, PTV Balance is independent from the local control method that is used in the field as long as the local traffic control is able to utilize the frame signal plans calculated by PTV Balance. Then the local controller might modify the signal plan providing that the flexibilities are defined with the Balance controller and internal safety protocols of local controller. Basically, local controller comes to action in such cases like actuation of public transport or local and temporary variation of flow between the gap of two consecutive Balance optimizations.

PTV Balance system is composed of three main models. Also, it could be integrated with a simulator like PTV Vissim or PTV Optima which are the convenient used cases to be utilized. Three models are Traffic model, Efficiency model and Control model shown in the Figure 1.

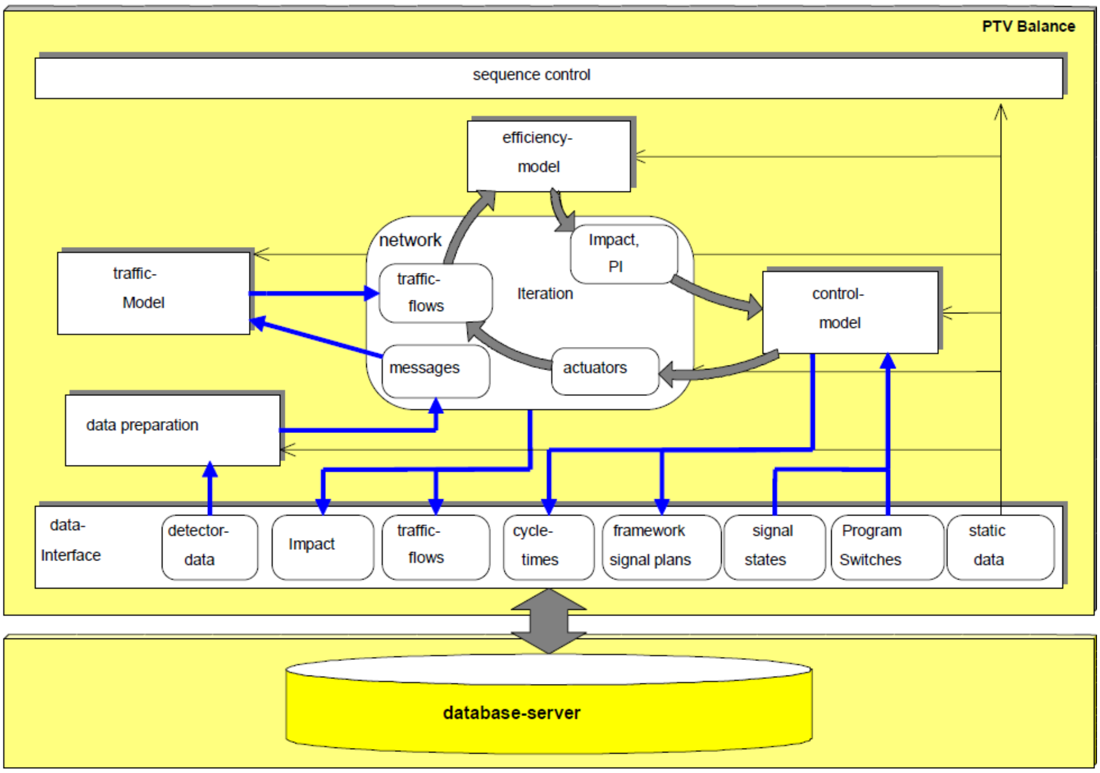


Figure 1 Balance System Architecture

5.1 Detectors

Before the optimization of the signal control, it is necessary to estimate the current traffic state in the road network accurately. Local detectors collect the traffic condition in the controlled area in the form of aggregated or disaggregated observation to be utilized in real time by Balance. This data is gathered from detectors connected in each controller and delivered to the central database. Detectors which are not connected to a controllers can also be utilized by PTV Balance. Additional kinds of dynamic data of the traffic light systems are also collected. For example, the currently running signal program, the cycle time or different operation modes of the controller or the detector. The positioning of detectors for Balance should be done according to the rules in [1].

5.2 Traffic model

PTV Balance has two layers of traffic model which are Macroscopic and Mesoscopic, and both have the same street network. The street network is represented internally as a graph in form of nodes and edges (links). Figure 2 illustrates this aspect at the example of a small network with two intersections.

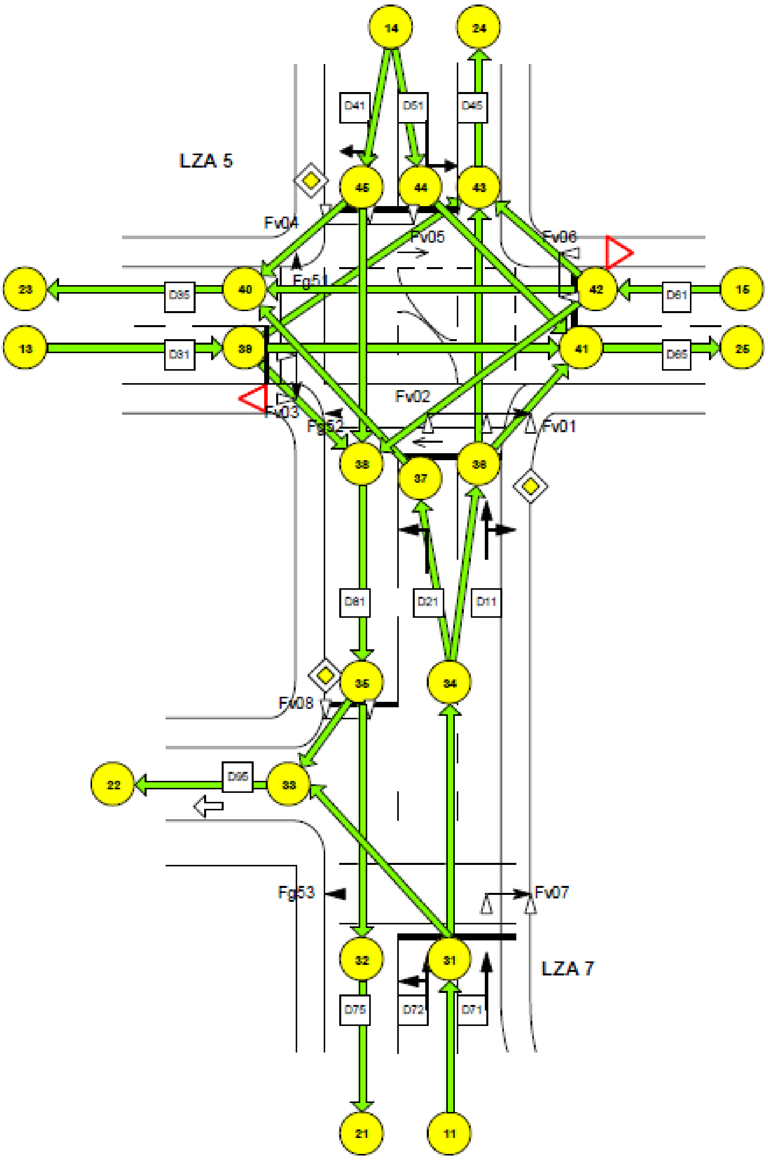


Figure 2 Traffic Model _Street Network

PTV Balance receives the traffic flow and valid signal plans as inputs. The input of traffic flow comes either from superordinate traffic model like PTV Optima or internal macroscopic traffic model of Balance. Then, the mesoscopic traffic flow model involves the influence of the valid controllers signal plans to compute traffic flow profiles qFl(a,t) [Veh/sec] for each link. Thus, the inflow and outflow for all links of network dynamically is accomplished [Figure 4]. The graph below shows the Balance macroscopic and mesoscopic traffic model.

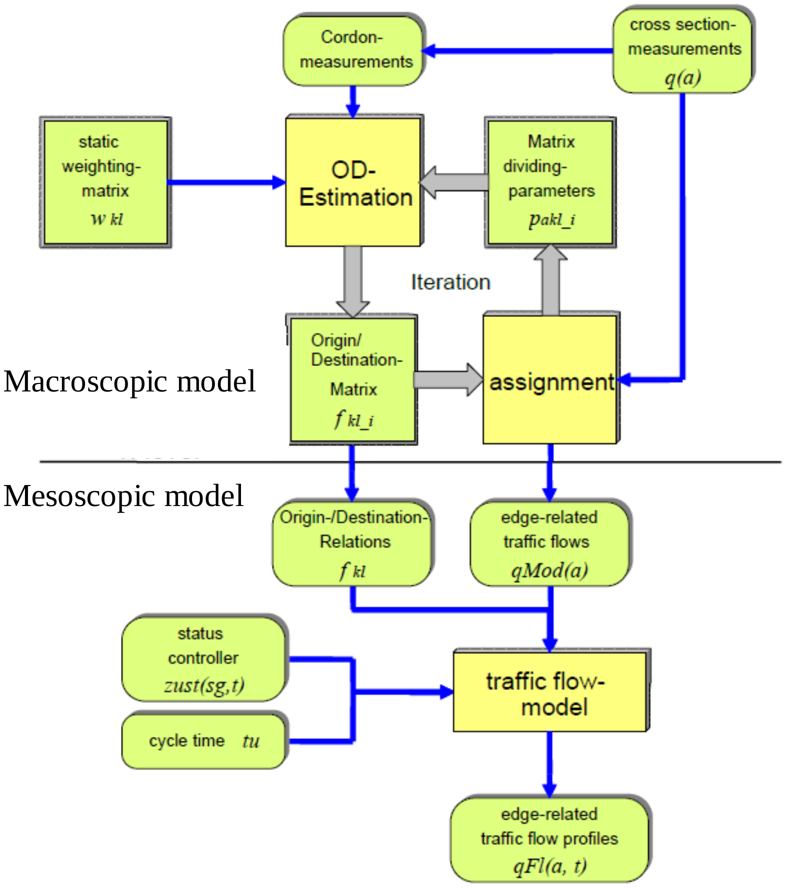


Figure 3 PTV Balance Traffic model

In the graph below tU shows the cycle time.

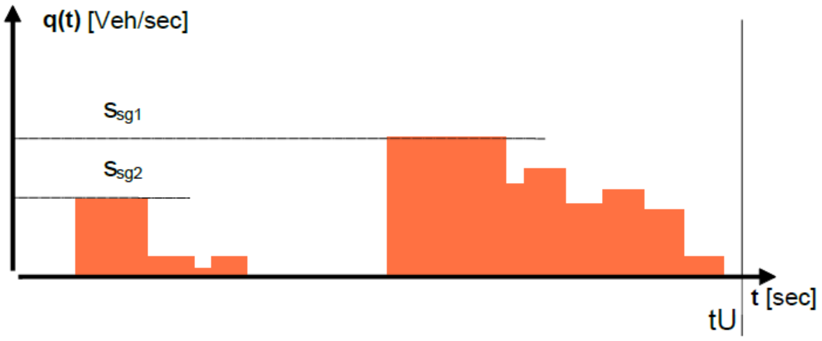


Figure 4 Mesoscopic Traffic Model

5.3 Efficiency and Control model

Dynamic inflow and outflow are the input of Efficiency model to determine performance index of controllers based on defined optimization algorithm (Hill-climbing or Genetic Algorithm). Balance alter the variables step by step and compute performance index iteratively. The performance Index utilized by the efficiency model is shown below.

$$PI(x,y) = \sum_{sg \in SG} \left(\alpha_{sg}\, D(x,y,sg) \cdot W_D + \beta_{sg}\, H(x,y,sg) \cdot W_H + \gamma_{sg}\, L(x,y,sg) \cdot W_L \right)$$

Where

SG	all the signal groups in the sub-net
α_{sg}, β_{sg}, γ_{sg}	weighting of waiting times/stops/queue lengths of signal group sg
D, H, L	vehicles waiting times/stops/queue lengths of signal group sg
W_D, W_H, W_L	master-weights Waiting time/stops/queue length
x	vector of control parameters (the signal plans of each intersection)
y	vector of traffic parameters (traffic volumes)

Regarding the convergence factors the optimum solution is chosen for the creation of real time signal plans called frame signal plan_FSP, the output of control model. The frame signal plan will be sent to local controller and further actions are taken by the local controller. The best solution would achieve from not only optimization but also synchronization of consecutive controllers. Synchronization can be subjected regarding the relevant coordination group in which up to 30 controllers can be set in a group. Besides, the spatial distance, cycle time and disturbance factors like intermediate intersection should be considered among controllers in a coordination group.

5.4 PTV Balance Calibration and Evaluation

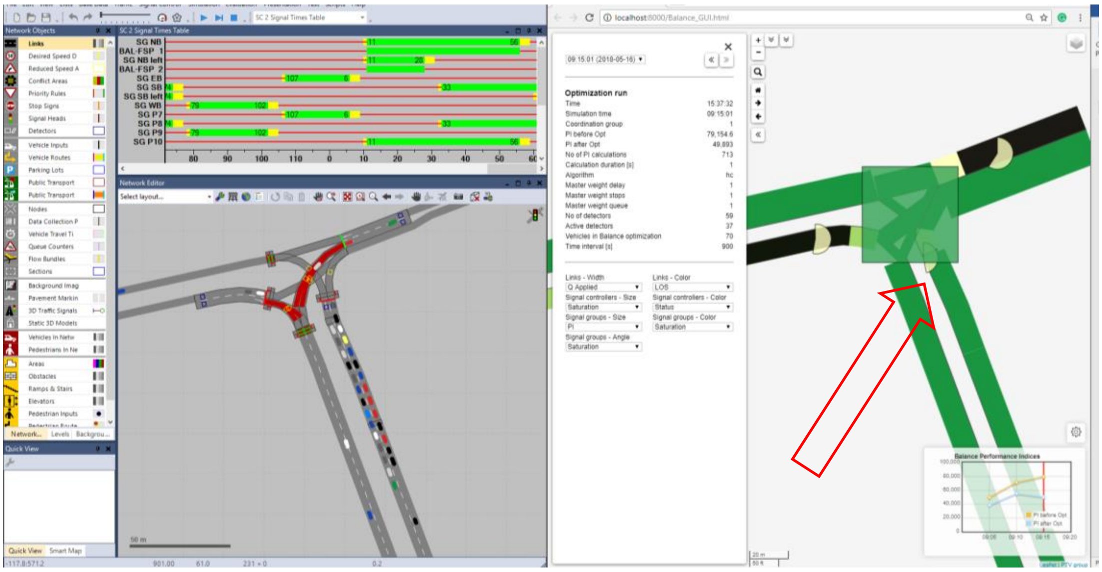
Balance traffic model needs to be perfectly representative sample of the real world so that the necessity of calibration comes to fore. The calibration of PTV Balance traffic model is up to several parameters which is embedded within the Visum model and Balance command line. Moreover, the efficiency of PTV Balance should be evaluated whereas without simulation environments like PTV Vissim (micro simulation) or PTV Optima (dynamic macro simulation) it is nearly impossible.

Not only simulation environment helps the calibration but also the mitigation in the network performance indexes is facilitated. Thus, the Balance attributes could be altered with the goal of reaching a better traffic situation comparing to the default configuration of PTV Balance. Furthermore, the calibration of balance is not such an extraordinary and a complex action. A couple of parameters including Balance Saturation Flow Rate, Interstage flexibility, Min and Max green time, priority of an approach (signal group weight) and Balance.ini parameters play crucial role in calibtation.

The key factor in the calibration is the **saturation capacity**. A neatly fine tuning of saturation capacity gives a true perception to PTV Balance out of the saturation degree of controllers in various time slices of a day. It should be set to the maximum number of vehicles passing through a link, turn or main turn regarding the green share within a cycle time. The attribute of saturation capacity is defined for turns main turns and link manoeuvre in PTV Visum model separately. See the formula below.

$$\boldsymbol{Satuaration\ Capacity} = \frac{Vehicles\ crossing\ during\ a\ cycle}{gren\ period} \times 3600$$

The example below illustrates the uncalibrated North bound approach. The perceived saturation degree is pretty low by PTV Balance _yellow pie chart on right hand picture _ while PTV Vissim shows a crowded leg _ left hand picture.



localhost:6000/Balance_GUI.html

09:15:01 (2018-05-16)

Optimization run

Time	15:37:32
Simulation time	09:15:01
Coordination group	1
PI before Opt	79,154.6
PI after Opt	49,893
No of PI calculations	713
Calculation duration [s]	1
Algorithm	hc
Master weight delay	1
Master weight stops	1
Master weight queue	1
No of detectors	59
Active detectors	37
Vehicles in Balance optimization	70
Time interval [s]	900

Links - Width: Q Applied
Links - Color: LOS
Signal controllers - Size: Saturation
Signal controllers - Color: Status
Signal groups - Size: PI
Signal groups - Color: Saturation
Signal groups - Angle: Saturation

Figure 5 Uncalibrated approach

In addition to the saturation capacity, PTV Balance compares its traffic model flow and received traffic states from detectors. This comparison is converted to GEH indicator, thus reaching a desirable GEH is the other indicator for calibration.

But how the PTV Balance model can be enhanced for a higher efficiency? The response is, several parameters existing in Performance index and the configuration of signal controllers as Vissig files. For instance, signal group weights and master weights, The flexibility of Balance in optimisation, and restriction of local controller in accepting the Balance FSP and optimization methods _ hill climbing or Genetic algorithm.

The list below illustrates the role of each variable in the mitigation of PTV Balance model.

- **Signal group weights**: desirable path of synchronization_ major road, dealing with a critical approach with high traffic volume. These weights can be changed from PTV Vissig files which is an add-in for PTV Visum. Value "1" is a good start while one wants to change to higher value under some conditions like:

- A left- or right-turning movement with a rather short pocket lane, so that spillback on this pocket lane will reduce the capacity on the street.
- A T-crossing, where there is a lot of traffic on the through street, but also a lot on the side road. Then it might be good to increase the weight for the side road a bit.
- You really want coordination in one direction, with disregard for the other routes. Then you should increase the weight for all signal groups in this direction.

- **Master weights:** an emphasis on a parameter of objective function _ performance index _ like delay, queue length and number of stops. The modification should be done from the file called “Balance.ini” storing the PTV Balance parameters.

- **Optimization methods:** Using Genetic algorithm leads the optimization to a better point usually, however it happens at the cost of computation time. Besides, there are a lot of parameters in the Genetic algorithm that impacts on the goodness of optimizations, for instance the number of given population and the convergence criteria. The Figure 6 shows the fact of better optimization (reaching a lower performance index) while it happens in more than 3 times iterations with respect to the hill climbing optimization.

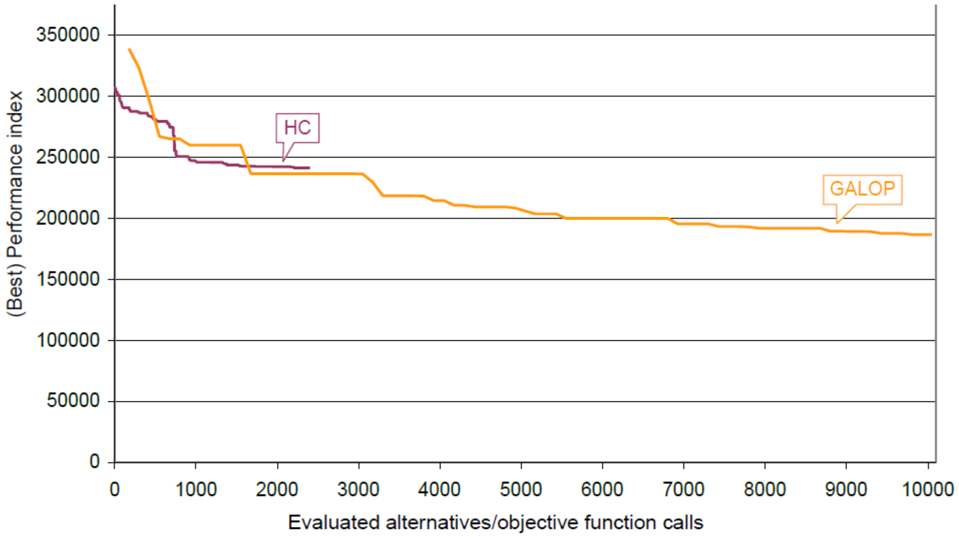


Figure 6 Comparison of Hill Climbing and Genetic algorithm

6 PTV Optima Methodology

PTV Optima uses state-of-the-art models and algorithms for the dynamic simulation of road traffic, allowing for offline and real-time estimation and forecast of time-varying travel times, traffic flows and vehicle queues. Optima supply model is composed of node and links model which characterized by the recent methodology of General Link Transition Model[6]. Optima is not only a traffic model but a complex system containing several engines which are integrated to come up with multi-purpose traffic solutions. In fact, PTV Optima, that is deployed within a project, consists of an offline preparation part and an online application in real-time.

The offline part includes the construction and calibration of a transport model, from so-called “base model”. This base model uses historical data and represents the traffic behaviour and conditions of typical days in the respective area. In more detail, PTV Visum is exploited for preparation of base model to be compatible with PTV Optima standards whereas some extra dynamic attributes of network elements and PTV Optima system configuration should be introduced in the Optima environment later on.

The online part uses the base model configured in PTV Visum and combines it with measures from the field, information on accidents, traffic management strategies etc. There is an internal calendar structure connecting the validity of network and demand corresponding to the date of real time data. Thus, this input is used in real-time to automatically turn the “typical day” defined in the model into the “current day”. In the other words, a chronological matching algorithm distinguish which elements should be activated in the launching of a simulation. The figure below illustrates how the architecture of PTV Optima is constituted.

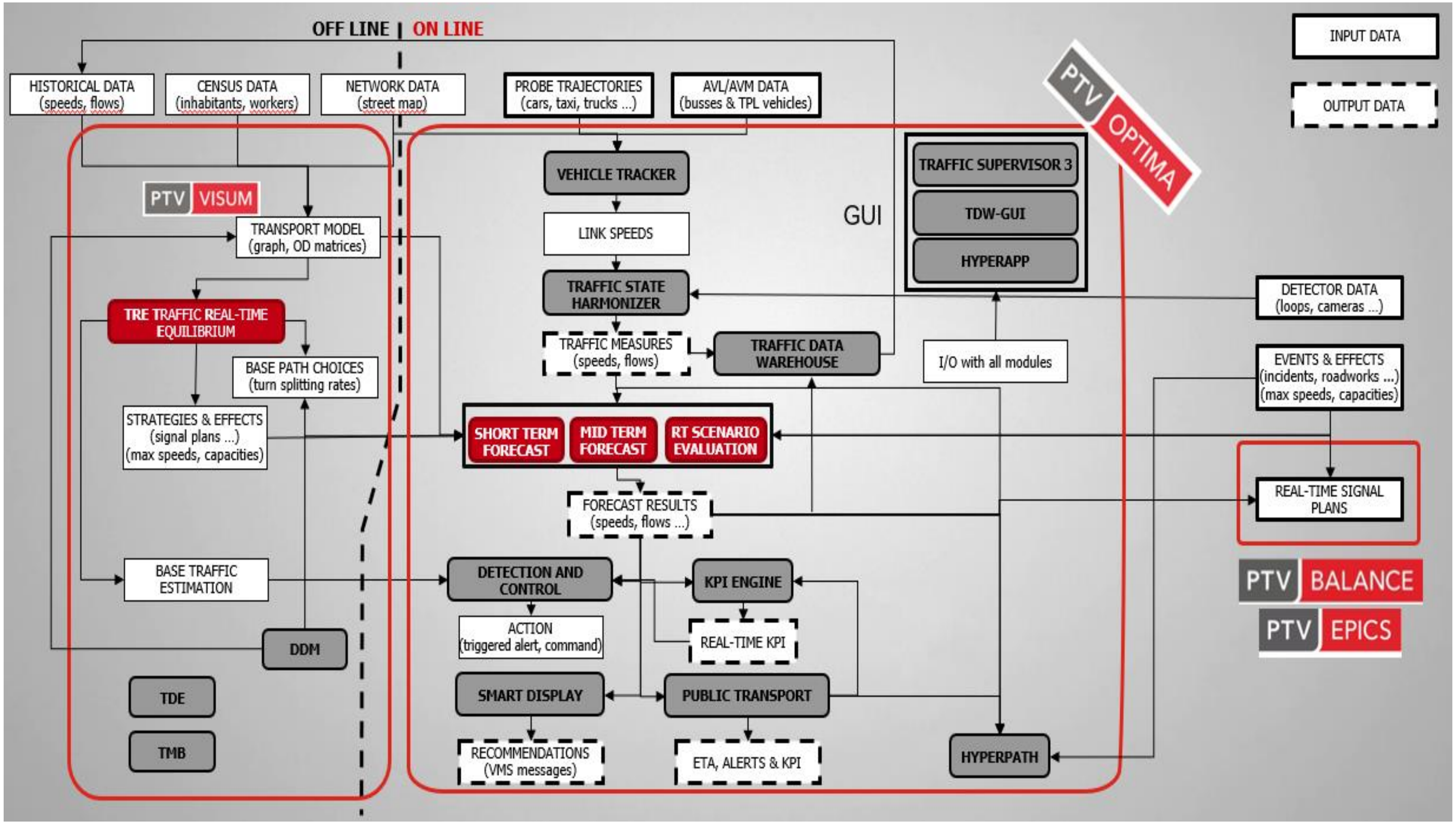


Figure 7 PTV Optima Architecture

6.1 PTV Optima-Offline

Any transport model contains two main sections of supply and demand, PTV Visum model is not an exception. Supply includes all elements of network which are represented in macro level_ link-based model. Moreover, unlike microscopic traffic models in which the traffic propagation depends on the embedded behaviour of users (car fallowing model), Macroscopic traffic models propagate the traffic through network regarding the individual attributes of supply elements. Therefore, the calibration of supply attributes is substantial.

Majority of required supply attributes are modelled through default objects of PTV Visum although the rest of attributes should be constructed in order to being compatible with the dynamic nature of PTV Optima. Some essential dynamic attributes are DUE fundamental diagram, Due Wave speed, Due space per PCU, Dval and Time Varying Attributes. Their definition is as following:

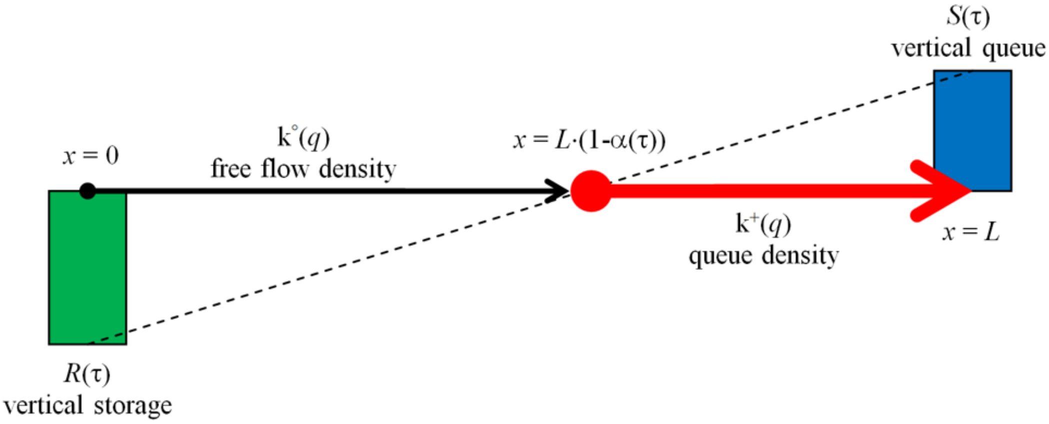
- **DUE fundamental diagram (FD)**: the fundamental diagram typology (triangular or parabolic_ while a wider range of concave shapes can be modified in PTV Optima separately)
- **Due Wave speed:** It's kinematic wave speed which has been explained in [3], [4]and [6]. In fact, Wave speed is the speed of Spilling back from stopping statues (jam density) of a vehicle to the critical state of motion.
- **Due Space per PCU:** It elaborates the bumper to bumper distance of vehicles while queuing (affecting on the value of Jam density in FD)
- **Dval:** It illustrates the availability of supply elements like closure of a link in specific days.
- **Time Varying Attributes:** Just in the case of temporal availability of elements for instance the temporal closure of links in limited traffic zones.

Moreover, other objects of supply model should be defined rationally, and their attributes be configured correspondingly. Those objects are nodes, main nodes, links, zones, connectors, count locations and detectors.

6.1.1 Links

Links are the one of the most significant elements of network which requires coding in plenty of attributes to define the role of links in entering and exiting flow volume to/from a link dynamically, also to see a proper prorogation of traffic along network. For each link there should be an accurate modelling of attributes including link capacity, free flow speed, kinematic wave speed, typology of Fundamental Diagram, number of lanes and hierarchical road type level (major road, connector or local road).

GLTM defines two parameters of vertical and storage queue [5] that is an indicator to see if the spilling back of hypercritical traffic state of current link would reach to the upstream link and when. Besides, the parameters of capacity and out-capacity representing the entrance and exit capacity of links influencing on the sending and receiving flow (see 6.1.2). Furthermore, exit capacity might differ from entry capacity thanks to the existence of signalized junction in the tail of links or having wider geometry because of either slip roads or pocket lanes.



6.1.2 Node and Main Nodes

Nodes are an essential element of for PTV Optima since they play the role of bottle necks on the basis of GLTM [5]. Figure 8 elaborates two nodes as bottlenecks and running segment as link.

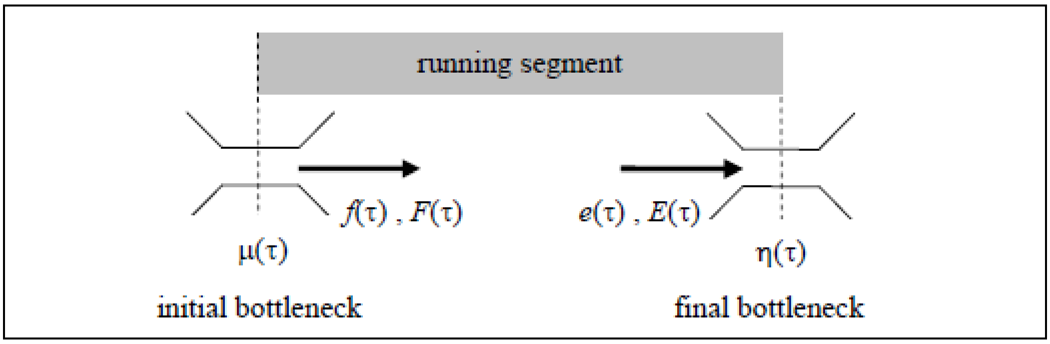


Figure 8 Node model based on GLTM

Besides, Nodes and Main nodes decide which percentage, how and which priority, an upstream flow should tranfer to the downstream link. Thus, nodes and main nodes are technically gates determining the sending and receiving flow of their legs (links) by considering their link storage capacity and sending flow. The figures below show two cases of merging and diverging phenomena in nodes.

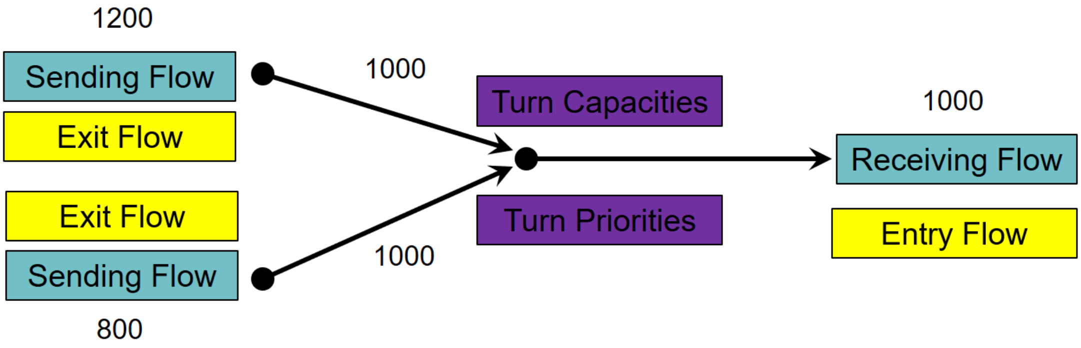


Figure 9 Merging Node

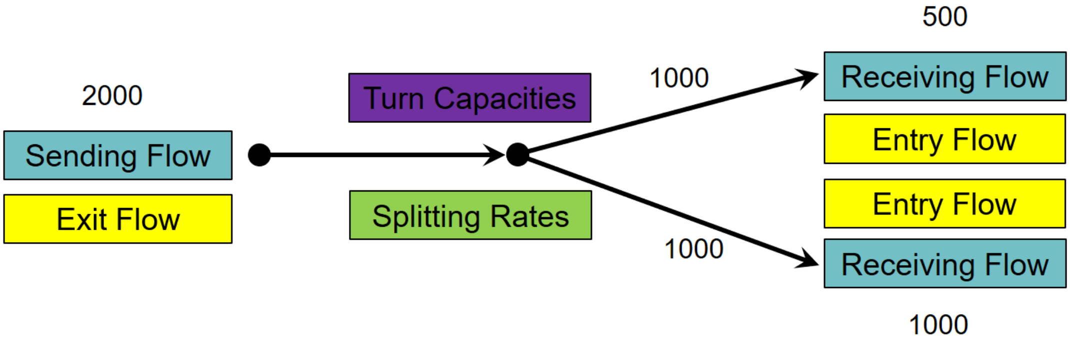


Figure 10 Splitting Node

The link model presented in the previous chapter provides the main input for the node model, that are the sending and receiving flows. In turn, the output of the node model are the inflow and outflow rates, that constitute the main input for the link model [5]. In addition, the path choices are performed by knowing the splitting and merging rate in nodes when DNL mode of assignment is meant to be chosen in PTV Optima. Hence, Path choice is represented here by the splitting rate p_{ab}, expressing the probability that the next link of the path is b∈FS(x) for vehicles coming from link a∈BS(x), so that the sending flow s_{ab} of turn ab is given by:

$s_{ab}= s_a\cdot p_{ab}$ [5]

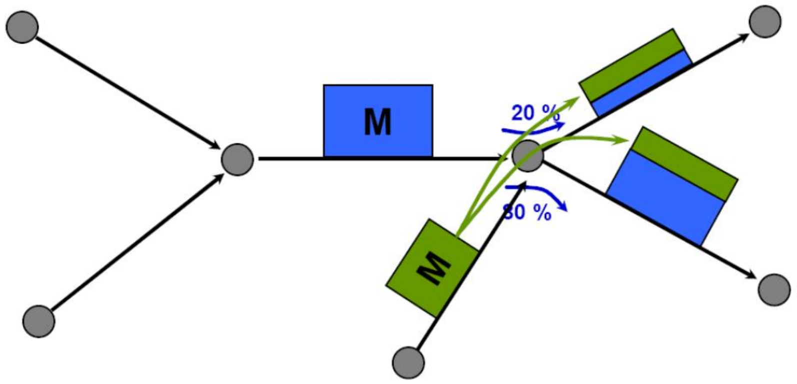


Figure 11 Turn Probability in Nodes

In the context of within-day Dynamic Traffic Assignment (DTA) the spatial propagation of flow takes time which depends on the use of the network. Also, The Continuous Dynamic Network Loading (CDNL) problem. consists in determining the link flows corresponding to given transport demand and route choices through a performance model yielding travel times as a function of flows, that all such variables are temporal profiles. Thus, route choices are calculated as a temporal turn probability in nodes and main nodes derived from the described logics.

Also, GLTM introduces a hypothesis in which drivers do not occupy the intersection if they can’t cross it due to the presence of a queue on their successive link but wait until the necessary space becomes available. Indeed, our model is not capable of addressing the deterioration of performances due to a blocking of the intersection capacity. See the figure below to wrap up the idea of Link-Node model.

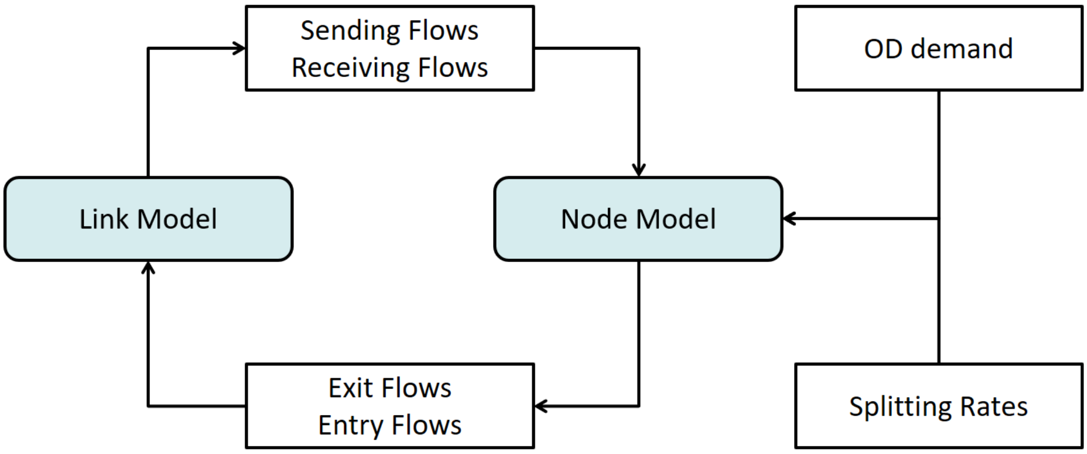
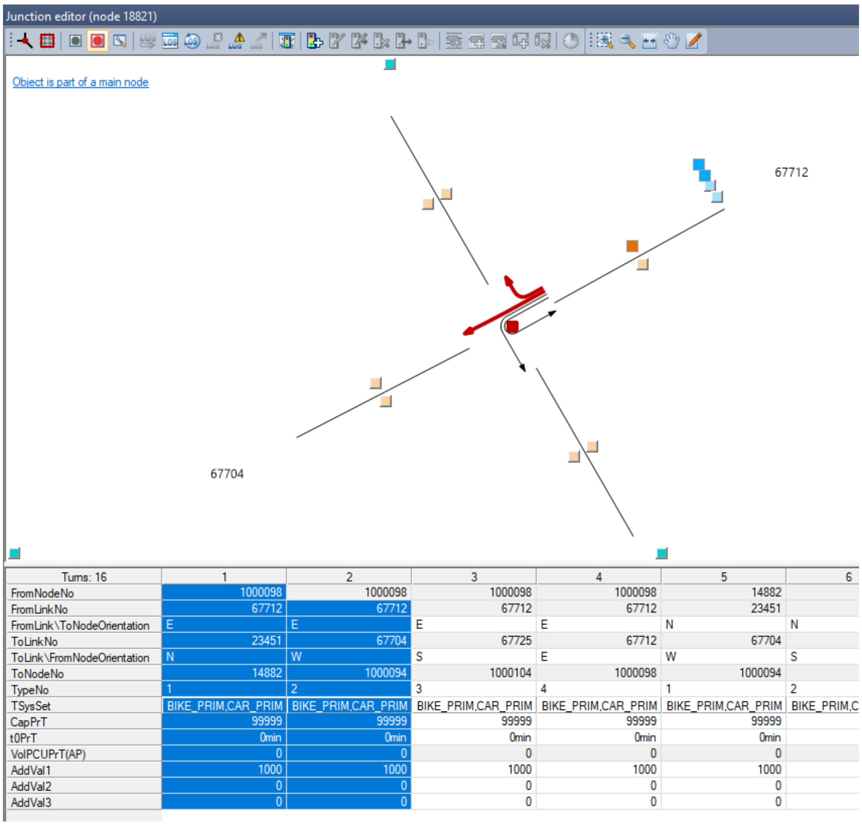


Figure 12 Link_Node model

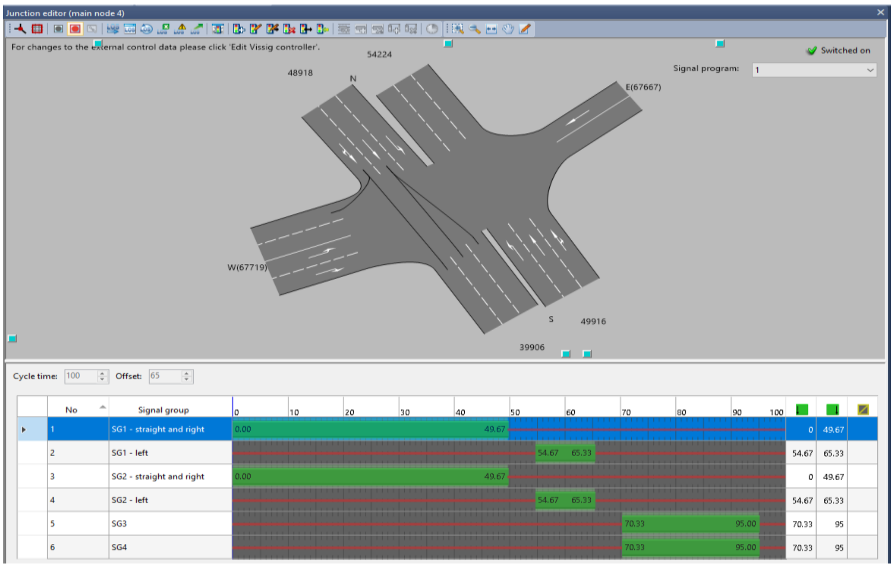
Apart from the expression of node modelling based on GLTM, there exist several points to be respected in modelling of nodes and main nodes in PTV Visum. Nodes and main nodes can be modelled via junction editor which is a visual window to illustrate how turns and manoeuvre are defined where each turn is characterized with the allowed typology of vehicles (transport system_ TSYS), capacity and travel time. Besides, the control type of nodes and main nodes should be defined, whether the conflicting area is controlled with gap acceptance or signalized logic. In the second case, the typology of signal, whether fixed time plan or adaptive plan controller by an exterior application like PTV Balance and Epics, could be defined. Figure 13 and Figure 14 elaborates the mentioned facts.



Object is part of a main node

Turns: 16	1	2	3	4	5	6
FromNodeNo	1000098	1000098	1000098	1000098	14882	
FromLinkNo	67712	67712	67712	67712	23451	
FromLink\ToNodeOrientation	E	E	E	E	N	N
ToLinkNo	23451	67704	67725	67712	67704	
ToLink\FromNodeOrientation	N	W	S	E	W	S
ToNodeNo	14882	1000094	1000104	1000098	1000094	
TypeNo	1	2	3	4	1	2
TSysSet	BIKE_PRIM,CAR_PRIM	BIKE_PRIM,CAR_PRIM	BIKE_PRIM,CAR_PRIM	BIKE_PRIM,CAR_PRIM	BIKE_PRIM,CAR_PRIM	BIKE_PRIM,C
CapPrT	99999	99999	99999	99999	99999	
t0PrT	0min	0min	0min	0min	0min	
VolPCUPrT(AP)	0	0	0	0	0	
AddVal1	1000	1000	1000	1000	1000	
AddVal2	0	0	0	0	0	
AddVal3	0	0	0	0	0	

Figure 13 Turns of a node



For changes to the external control data please click 'Edit Vissig controller'.

✓ Switched on

Signal program: 1

Cycle time: 100 Offset: 65

No	Signal group	0 10 20 30 40 50 60 70 80 90 100	🟩	🟩	▨
1	SG1 - straight and right	0.00 49.67	0	49.67	
2	SG1 - left	54.67 65.33	54.67	65.33	
3	SG2 - straight and right	0.00 49.67	0	49.67	
4	SG2 - left	54.67 65.33	54.67	65.33	
5	SG3	70.33 95.00	70.33	95	
6	SG4	70.33 95.00	70.33	95	

Figure 14 Signalized node

6.1.3 Zones and Connectors

Zoning system comes from a base model which might be sufficient on condition of representing the realistic generation an attraction of users in the network. In the other words, we should see what the discretization level of study area is by zoning system. Figure 15 illustrates the red symbols as not proper dispensed zoning system(zone centroides) while blue symbols show how the generation and attraction is meant to be happening in the network.

Connectors are the connecting elements among zones and network elements (Nodes or links). Similarly, they should represent the dispersion of demand in the network. Some connecting points which must be avoided are:

- Signalized intersections
- Main Roads like highways, freeways and tunnels
- One-way roads

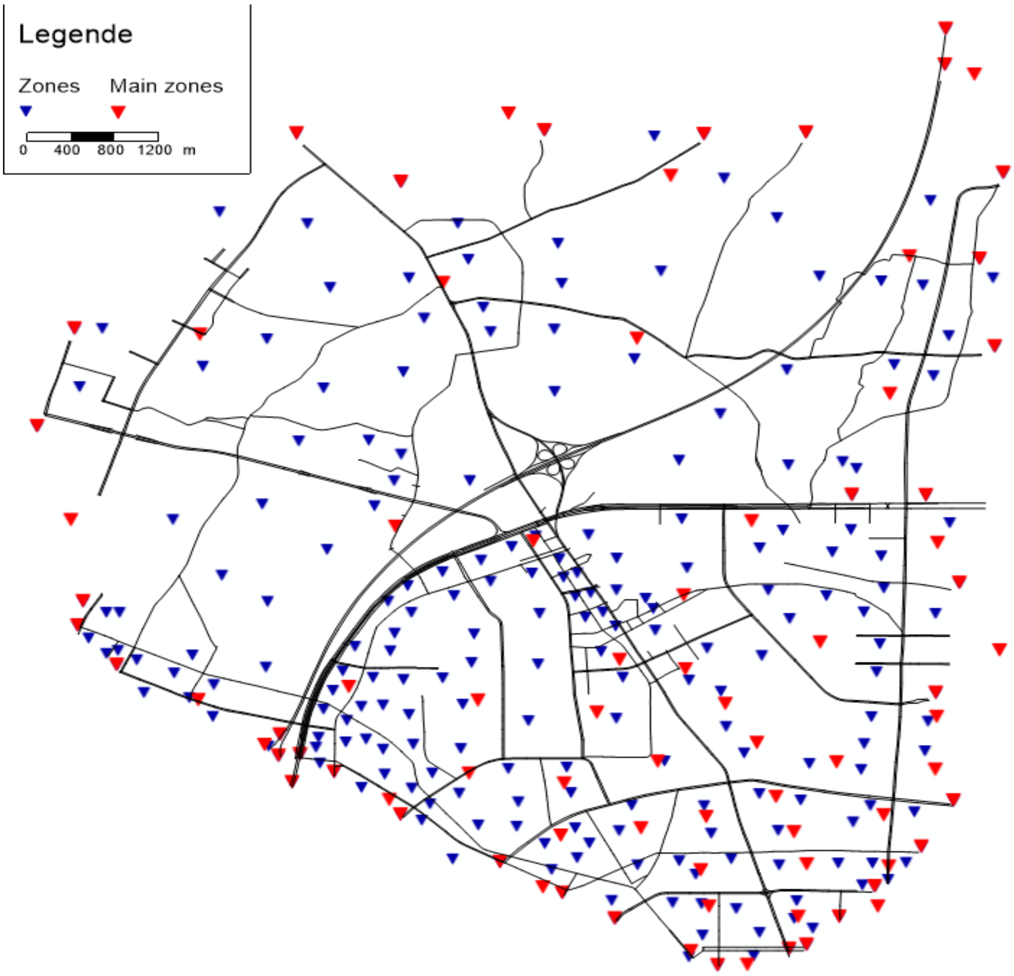


Figure 15 Zoning system

6.1.4 Count locations and detectors

Count locations are specific elements with high priority for PTV Optima since they define the aggregation level of detectors and map-matching historical or real-time traffic data to the network. While detectors are responsible to connect to the on-site detectors and collect the data according to their identifier. The identifier can vary from a case to case although their connection to the count location should be constructed carefully otherwise data cannot be stored and utilized in PTV Optima DB. The identifier of detectors, exploited in PTV Balance, are a bit different from the individual system of PTV Optima online (extra attribute called Channel No)

Moreover, PTV Visum presents two type of detectors which are detectors based on signal controller (used in PTV Balance) and the detectors in a middle of stretchs.

6.1.5 PTV Optima- Demand

Transportation consist not only of the physical and organizational elements that interact with each other to produce transportation opportunities (transport supply), but also of the demand that takes advantage of such supply to travel from one place to another.

Travel-Demand model represents, in a synthetic way, the trips performed by the users in the study area. The travel-demand model aims to reproduce the total number of trips performed with road vehicles on the study area. In fact, the origin-destination and departure time of trip are the key information.

Demand model estimation is not what usually is dealt with in the PTV Optima projects, whereas an approximate zoning system and relevant generation and attraction values are given in the base model and only demand calibration will be performed on the demand model according to historical data. Although, demand model is composed of various modes of transport, PTV Optima considers all them together as an equivalent vehicle.

PTV Optima needs temporal demand matrices which are characterized with attribute of Day types (example: weekdays, weekend days) and triggered based on the current day of simulation. Moreover, demand discretization is defined by the definition of demand segments depending on the project proposes. Basically, demand segments are distinguished by

- The scope of the trip (example: home-work trips, business to business trips)
- The vehicle type (example: "using only PCU"; "disaggregated by vehicle type like car, truck,")

Also, each demand segment is composed of several time series. Each of time series referring to a time interval like 7:00 to 8:00 AM. Thus, Demand matrices can be either allocated to a demand segment in which a sequence of time series show the temporal distribution of a demand matrix or demand segments are divided into plenty time series, then matrices are allocated directly to each time series. Figure 16 shows the second case.

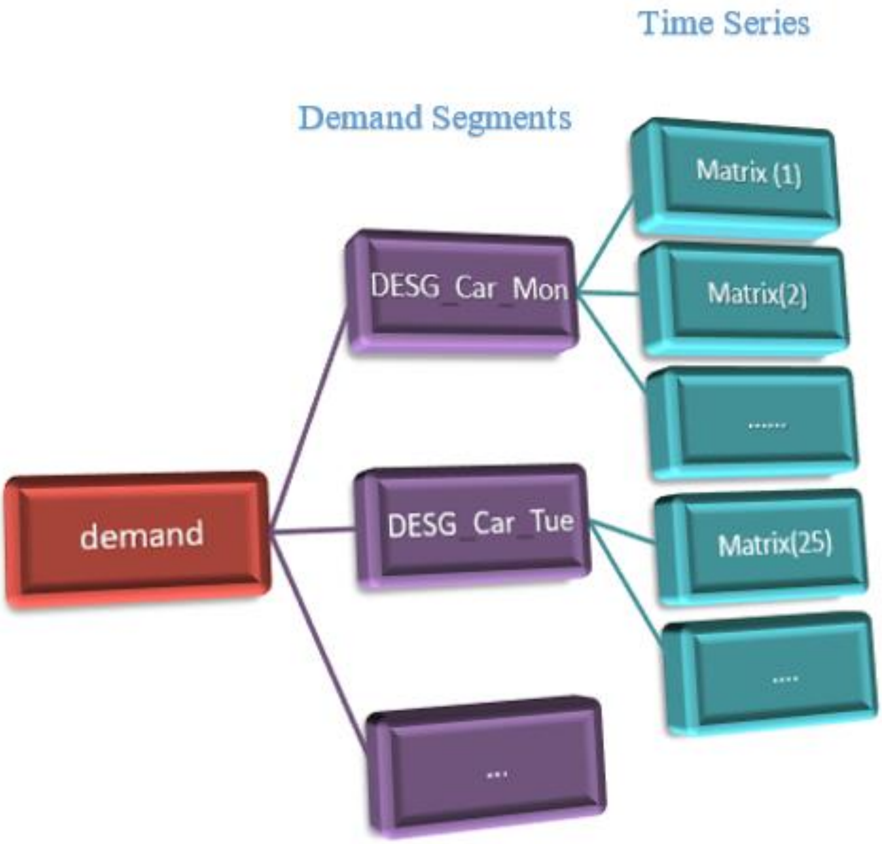


Figure 16 Demand Structure

Furthermore, there exist a structure which makes a connection among the defined day types and availability of network elements and demand segments. This structure works under a systematic logic to create a rational perception for PTV Optima to react automatically in the online mode to different days when the simulation is uprunning. See the Figure 17.

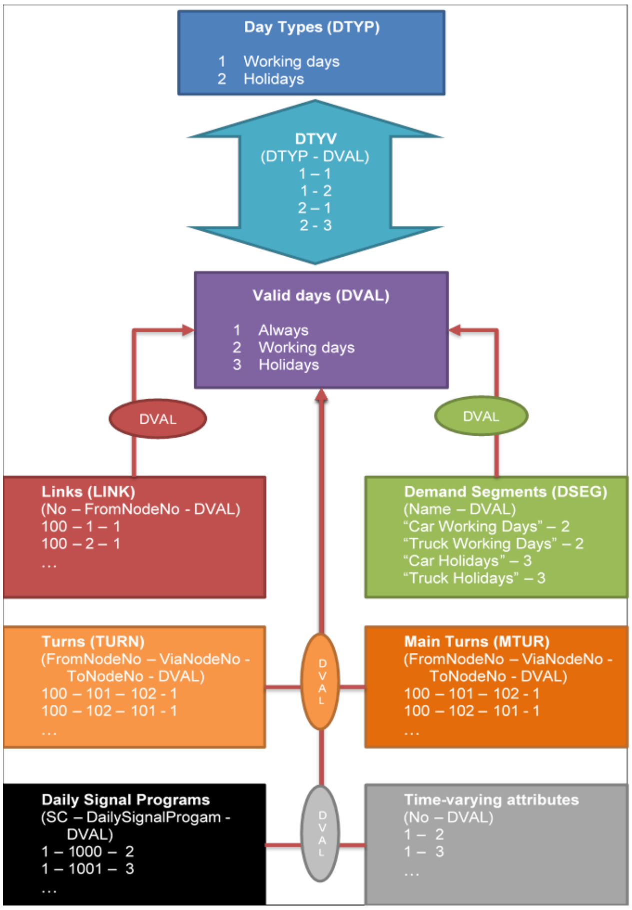


Figure 17 Day type_ Dval

Day types(DTYP) is the concept of typical day and valid days (DVAL) is the model attribute which defines whether an element is valid or not for a typical day. And DTYV is the systematic logic to build the connection among typical days of valid elements for a given day type. For instance, once simulation is launched, then the current day is dropped in a predefined day type, then through DTYV, a specific DVAL will be triggered which leads to the activation of some model elements.

The level of aggregation of the demand model (which is indicated as the number of day types, demand segments and time intervals) depends on the goal of the project, desired disaggregation level in the results of PTV Optima and the provided historical data. For example, if the Optima model aims to support control actions on heavy vehicles, it is mandatory to investigate separately the light vehicles demand and the heavy vehicles demand- This creates two different demand segments in the model. Other example, the sufficient number of day type and time interval is resulted from initial data driven. In the other words, if data provision has an hourly aggregation, demand calibration with the level 15 mins is impossible. Or, if the data elaboration is ended up with similar pattern in demand time profile for weekdays, dividing the day types to daily subclasses is not a rational decision although usually clients believe in finer demand classification better result! Chapter 10.1 illustrates clearly how day types can be defined in the case study.

The minimum requirements to describe a time series are either:

- A daily OD matrix associated with a time series by percentage that specifies the proportion of trips with the desired departure time within the respective time interval (see the Visum user manual).
- A matrix time series allocating a separate OD matrix that contains the demand with the desired departure time to each time interval.

6.1.6 PTV Optima Traffic Real Time Equilibrium (TRE)

TRE is the simulation engine of PTV Optima regarding the GLTM principals to propagate demand in macro level aggregation. TRE can be utilized both in off line and real time mode.

The traffic model prepared in the PTV Visum is the input of PTV Optima which should be stored to Optima data base_DB_ by TDE, although TRE-offline is capable to run the model directly from PTV Visum as well. TRE offline is a tool constructed for two purposes, firstly to propagate flow on the network dynamically to generate path choices (Path choices would be determined as turn probability stored in TPRB of DB) Secondly, TRE offline can be used for supply calibration.

6.2 PTV Optima-Online

Prior to dive into the sequence of procedures in PTV Optima Online, the figure below shows the entire engines and structural elements of Optima.

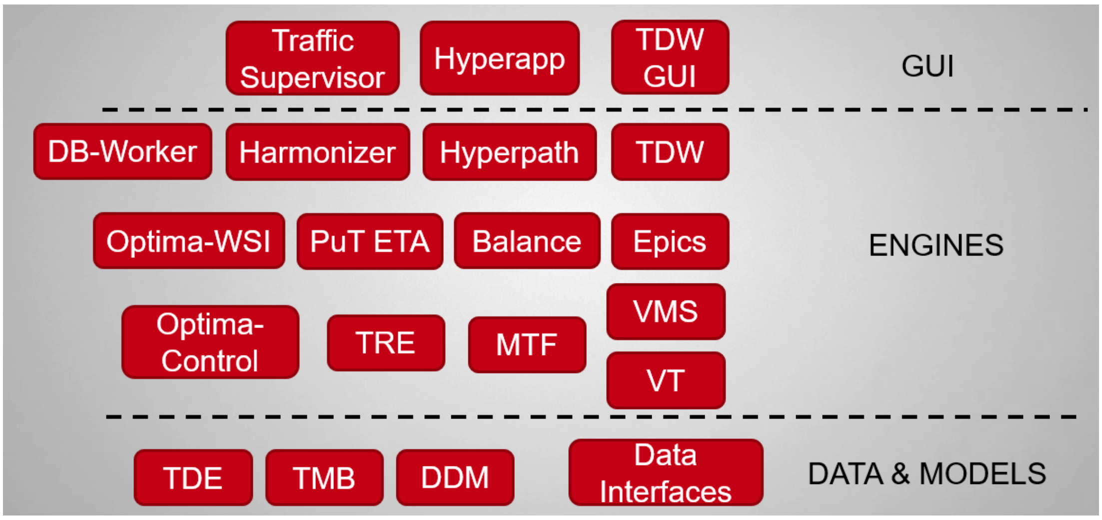


Figure 18 Modules of PTV Optima

The table below illustrates the essential modules of PTV Optima used in Private Transport.Further description is provided in [26]

Modules	Description
TDE	Tool of exporting Visum model to Optima data base
TMB	Graph simplification_ shrinking vast network models
VT (vehicle Tracker)	Real time and offline map matching of data providers, GPS, ANPR
Harmonizer	DATA FUSION engine of receiving data and filtering logic
Traffic Supervisor	Web GIS GUI, REAL-TIME traffic management
TRE	Dynamic Traffic Assignment _offline, short-term and Mid-term online
VMS	EVENT SUGGESTIONS on streets, based on a computed priority

Figure 19 PTV Optima Engines and Structural elements

The model is stored in the Optima DB. Hence, Once TRE-Online triggers the relevant supply and demand elements thanks to a valid DVAL attribute. Thus, the flow is propagating through the network regarding traffic flow principals in the rolling horizon mode. Meanwhile the harmonizer and Vehicle tracker engines are feeding the TRE simulation to come up with the online correction of flow and speed on those links where traffic states are provided. In addition to Harmonizer and Vehicle tracker, planned and unplanned events interacts with PTV Optima to update the characteristic of supply model. For instance, closure of a link or a lane for road maintenance purposes impacts the capacity of link. Or, an unplanned incident like failure of a signal control creates perturbation in an area of network. Events are provided in the DATEX II format.

PTV Optima is capable to forecast the traffic up to an hour which the goodness of forecast depends on not only the predetermined dynamic characteristics of supply elements, but also a representative demand model. In the other words, a perfect demand model assures the real generation and attraction of different modes in a proper time and a decent supply model lets the flow to be propagated correctly. Therefore, the significance of demand and supply calibration comes to fore which requires a considerable dedication of effort in initial data driven and further postprocessing by TRE offline, the monitoring of traffic supervisor and using Accelerated PTV Optima lab mode.

Rolling horizon is the way that sequential simulation in time is happening. This concept is shown in the Figure 20.

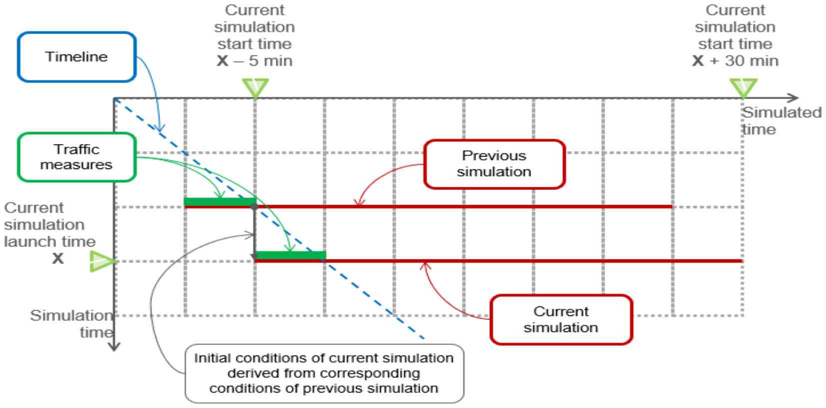
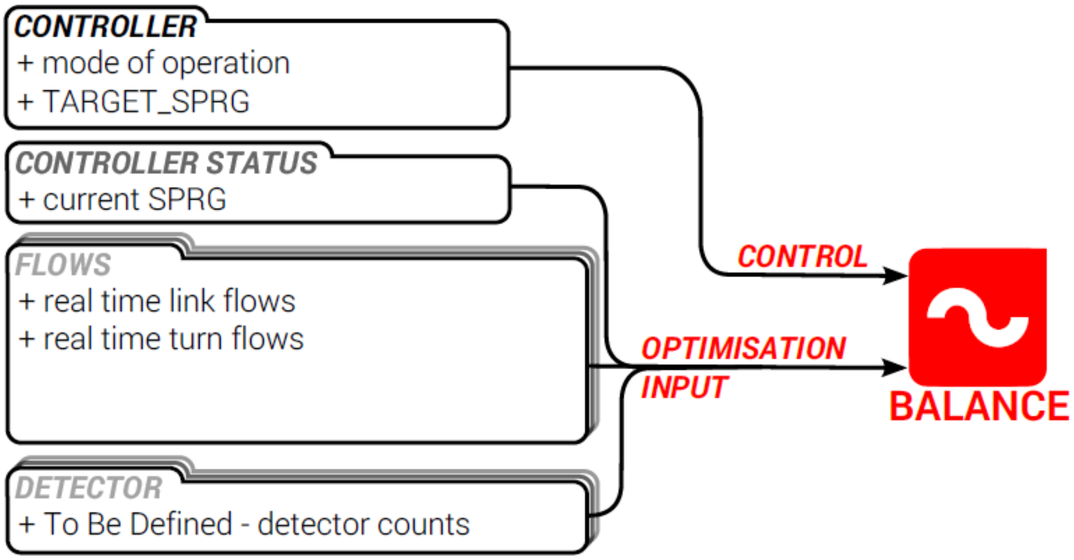


Figure 20 Rolling Horizon

7 Integrated PTV Optima Balance Methodology

The data base of PTV Optima is the central environment where all modules shown in Figure 18 are connected. Apparently, each module requires input taken from DB and their results are written in DB as output. PTV Optima is constructed such that the operation of automatic adaptive signal controllers is facilitated thanks to the provisions brought by Harmonizer and TRE online engines. On the other hand, the outcome of adaptive signal controller would lead in to a seamless and floated traffic condition over the network in which the disutility perceived by users drops considerably. Therefore, this mutual influence has made PTV Group to configures PTV Optima and the architecture of its database so that PTV Balance works seamlessly compatible with Optima interface.

PTV Balance like other modules is fed by DB with several inputs illustrated in the graph below.



Each signalised junction remotely controlled by OPTIMA is associated to a CONTROLLER object. Dynamic controller data is exposed to Balance and it concerns the current program and operation mode of the controller. Besides, fixed time signal programs which are the start point of Balance Optimizer are stored in the "*.sig" files. The more detail about the technical connection of Balance to Optima is provided in [25].

Although Balance utilizes Real-time flow by default configuration, the forecasts of flows can be forwarded to a signal optimizer as well. This configuration is available together with PTV Balance which improves the potential of PTV Balance. At the same time, the returned optimized signal plans feed to the simulation of PTV Optima, improving the forecast. In spite of the fact that in urban area the traffic condition in few minutes a head would not be substantially different from current traffic state, the forecast flow can be exploited for PTV Balance optimization on the condition of a considerable fluctuation of typical demand in short term prediction and having a profound and promising TRE forecast.

Integration of Balance into the PTV Optima world, relieves Balance from performing OD estimation and assignments and allows the optimisation process to account for the impact of events on the network such as road closures and accidents.

After the production of optimized and synchronized signal program called FSP, described in the chapter 5, the outcome will be overwritten in the DB tables shown in the Figure 21.

Optimized signal plans will be implemented as events that is addressing in which controller which signal program (SPRG RLTM) should be run, and how signal timing (STIM RLTM) is configured in the real time signal program.

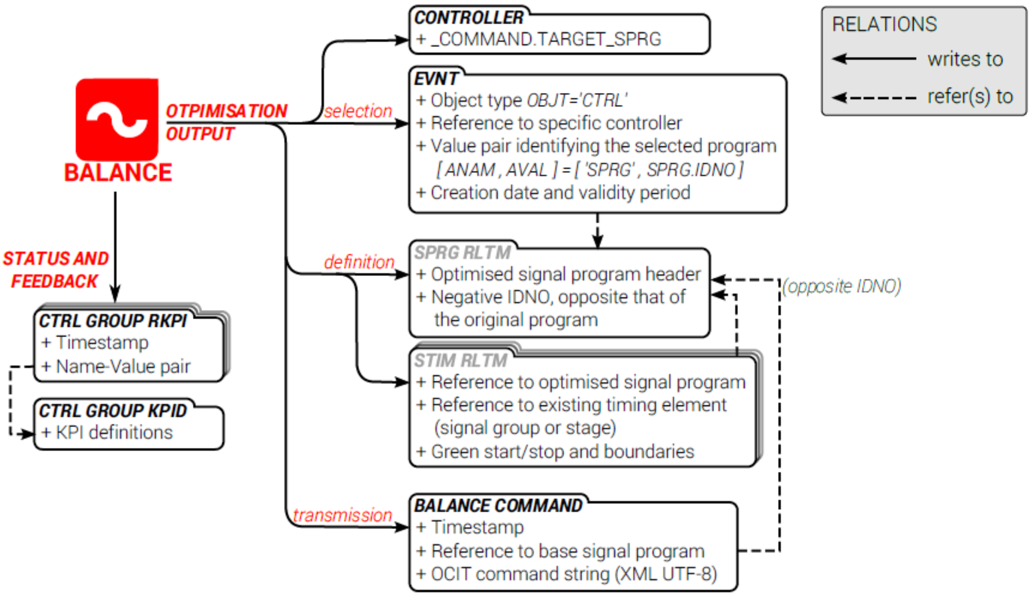
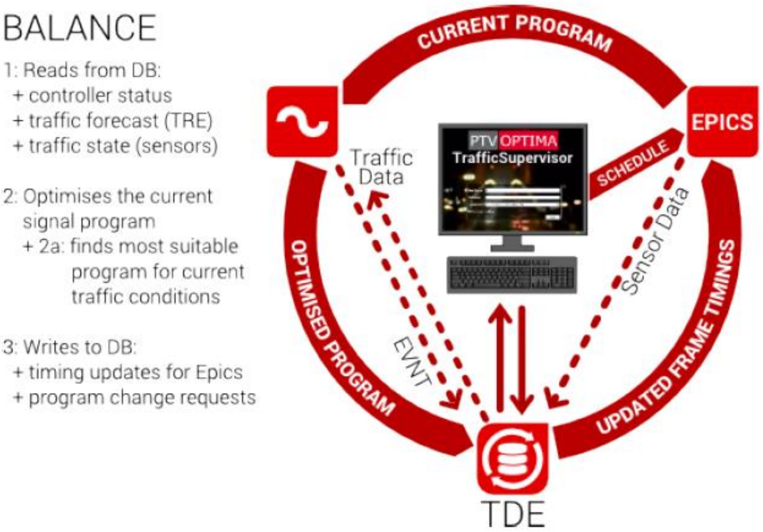


Figure 21 PTV Balance output on the DB

Furthermore, the real-time signal plans are used by local controller in which its own safety protocol and algorithm decides which plans and when they should be implied in the field. PTV Epics is the most compatible local controller with Balance as well. See the Figure 22.



BALANCE

1: Reads from DB:
  + controller status
  + traffic forecast (TRE)
  + traffic state (sensors)

2: Optimises the current signal program
  + 2a: finds most suitable program for current traffic conditions

3: Writes to DB:
  + timing updates for Epics
  + program change requests

EPICS

1: Runs on the controller

2: Receives the desired signal program number via IP from schedule or user request

3: Selects the corresponding signal program or its optimised version from Balance if available

4: Adjusts interstage times with 1" frequency, based on local sensor data

5: Returns status, sensor and timing information

Figure 22 PTV Optima-Balance and Epics

In order to understand where and how each Balance output affects PTV Optima see the hierarchal architecture of signal controller in PTV Optima shown in Figure 23.

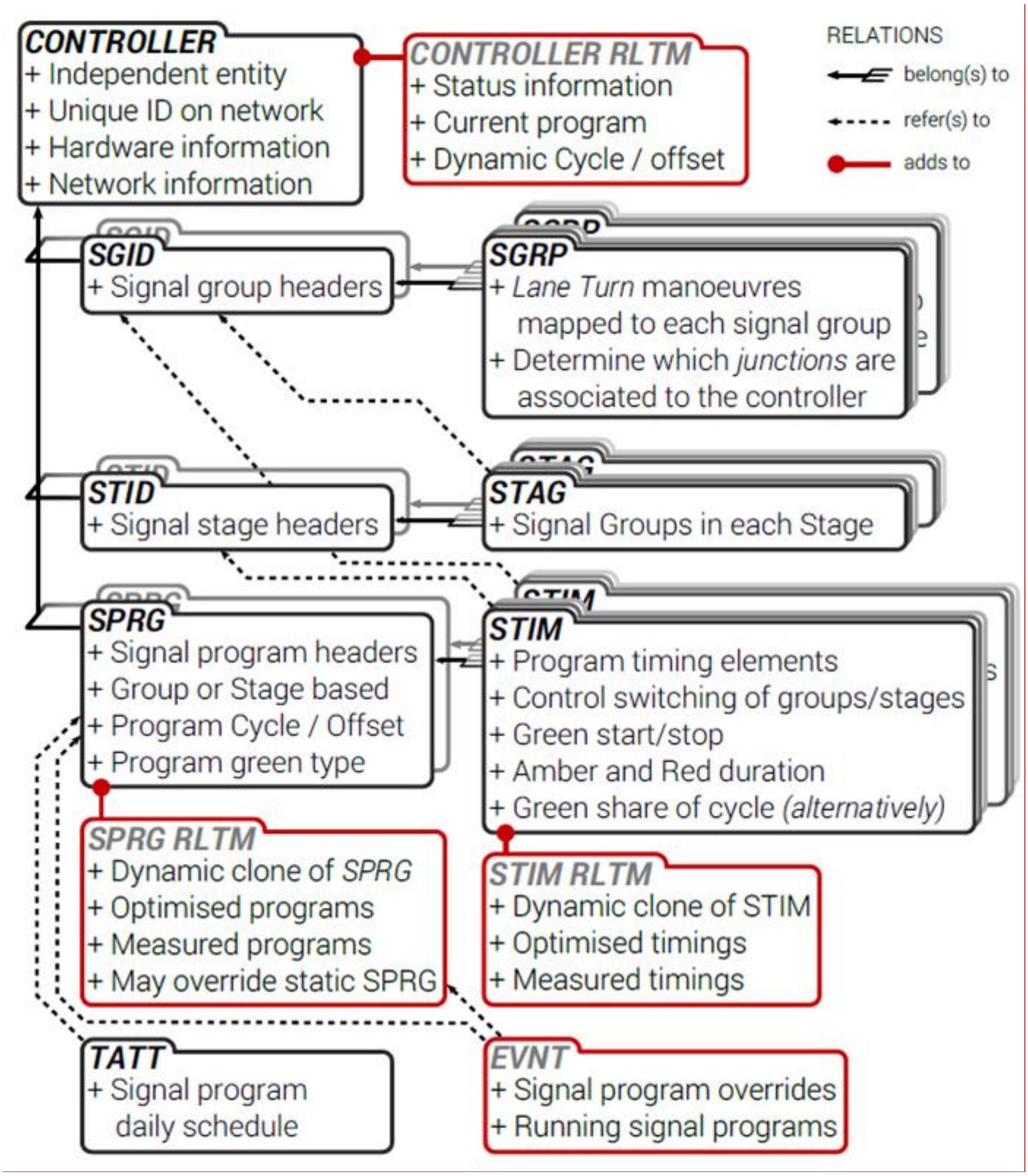


Figure 23 signal controller architecture_ PTV Optima

Eventually, PTV Optima considers the optimized signal plans in the next iteration of rolling horizon simulation by Events. And the result of TRE-Online is written on the database containing the nowcast and the series of rolling horizon forecast.

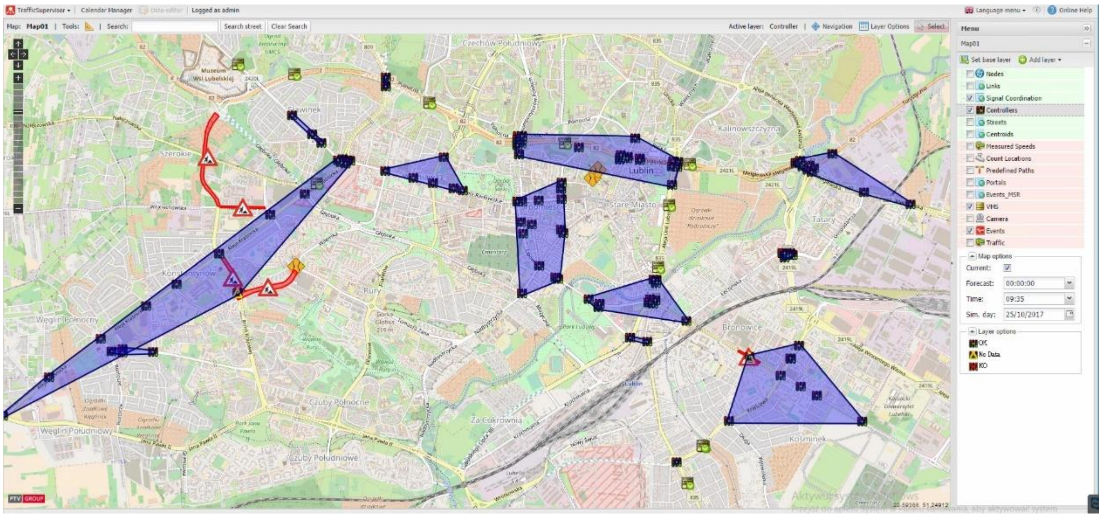
Additionally, all information goes online through Traffic supervisor including nowcast and forecast flow after each iteration, recorded traffic states for both flow volume and speed, events and predefined KPIs, integrated system of Public transport operation, scenario management and suggested and implied VMS.

Traffic supervisor supplies the traffic management authorities with an intelligence tool to cope with complex issue of traffic operation which is tied up with exterior incidents, for instance, the event of road closure affecting on not only the service level of the street or junction where event is located but also approaching links toward the event. Despite, figuring out how far in time and space would this perturbation be extended in the network is beyond the analysis capability of human being, its where the significance of traffic supervisor comes to action by helping operator to run the TRE-online involving the event and come up with a proper proactive action based on the forecast. Moreover, a smart and quick logic behind PTV Optima overwrite a suitable VMS to avoid the potential disutility for users. In addition to the private transport management purposes, Traffic Supervisor can be integrated with public transport as well. Scenario management and assistance decision making is the other beneficial feature of traffic supervisor where operator can utilize the predefined KPIs to evaluate various scenarios simultaneously.

On the other hand, traffic supervisor can be counted as an assessment tool for modeller to evaluate the goodness of forecast and demand calibration by excluding manual analysis of DB; Although, investigating into DB is highly recommended where the customized KPIs of supervisor is not effective enough.

8 Use Cases

PTV Optima and PTV Balance have been deployed separately in several urban and extra urban contexts addressing traffic management issues while the recent integrated system of PTV Optima-Balance has experienced fewer used cases. The very recent project is the implementation of intelligent traffic management system in Taichung city elaborated in the following chapters of this thesis. Another successful use case has been deployed in the city of Lublin which had far more extended network than the project of Taichung city phase one. The Lublin authorities asked for a delivery of an effective transport system to contribute to the economic growth, quality of life, and environmental sustainability of the citizens. The mission was to regulate, plan, and develop an efficient and well-integrated transport system that serves the public interest by enhancing mobility and delivering safe, secure, and environmentally responsible Public Transport. In this context the Client installed in Lublin city the PTV Real-Time software (PTV Optima, PTV Balance) in order to exploit a new traffic control system, able to monitor real-time traffic, to give traffic forecast up to 1 hour, to produce data useful for informing in real-time drivers through available Variable Message Signs. See the Figure 24. This project contains 66 intersections under the control of PTV Balance accomplished to the mitigation of network performance index shown in the Figure 25.



Map: Map01 | Tools: | Search:

Active layer: Controller

Map01

☐ Nodes
☐ Links
☑ Signal Coordination
☑ Controllers
☐ Streets
☐ Centroids
☐ Measured Speeds
☐ Count Locations
☐ Predefined Paths
☐ Portals
☐ Events_MSR
☑ VMS
☐ Camera
☑ Events
☐ Traffic

Current: ☑
Forecast: 00:00:00
Time: 09:35
Sim. day: 25/10/2017

Figure 24 The project of Lublin_ PTV Optima-Balance

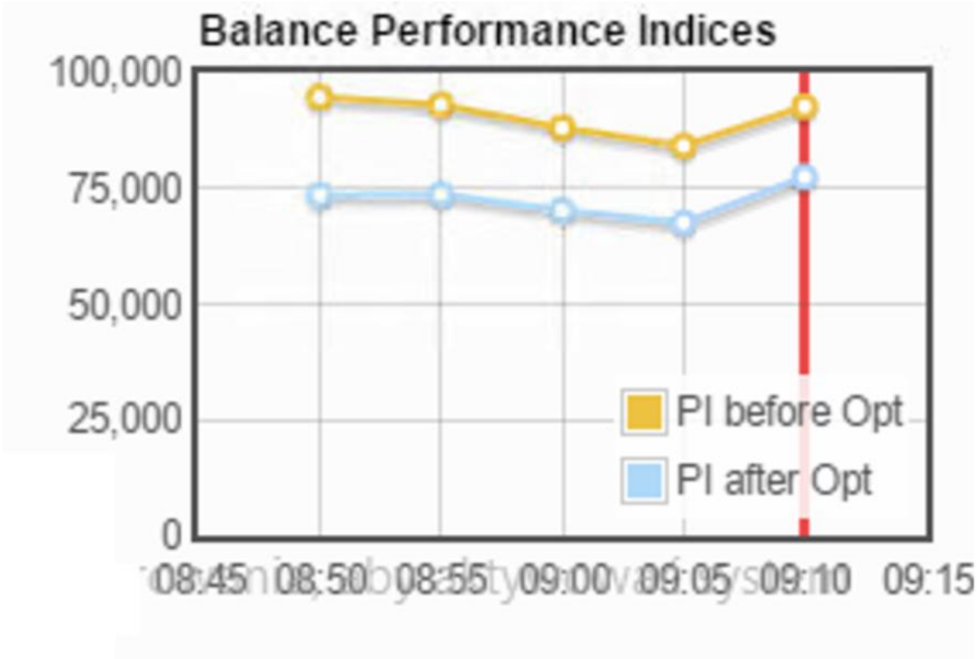


Figure 25Lublin_ PTV Balance

9 Study Case overview

Taichung city have been growing dramatically over the last years and a considerable surge in the traffic congestion has been evident due to the recent economical and industrial developments in downtown and suburban area. The heart of transport corridor at city of Taichung experiences a heavy traffic congestion specially during peak hours impacting commuter’s utility drastically. The main affected roads are the ramps of Expresway 74 (Beitun District One, Beitun District Two, Xitun District One, Xitun District Two, Nantun District Two) form at-grade road intersections with Zhongqing Road, Huan-zhong Road, Taiwan Boulevard, Wuquan West Road and Freeway 1 [2]. Besides, a highway ramp metering causes additional troubles by spilling back the congestion to the local roads where the portion of spilled traffic volume is incomparable with the urban flow volume. There is also reoccurring congestion during Holidays as a result of high number of trips made by residents of other cities returning to their hometown in Taichung. During the rush hours, the loss of network efficiency is caused by over saturated signal controllers which are struggling with serving the traffic properly in time and space.

Therefore, the authority of Taichung City has issued a tender for developing an Intelligent Traffic Management System (ITMS) including traffic monitoring, prediction and signals coordination for the City of Taichung aiming at easing traffic congestion in specific areas of the city and specifically around key Freeway 1 and Expressway 74 interchanges that are connected to important industrial and commercial areas of Taichung.

The project aims at effectively enhance the operational efficiency of the Ramp, Access Road and Road Intersection, improve traffic safety and improve road traffic congestion. PTV Real-Time solution (integrated PTV Optima-Balance) is the chosen tool to deliver a smart city approach to the management of road traffic by making use of the advanced decision support functionality of integrated PTV Optima- Balance and to develop the ITMS centre. Besides, PTV system should be connected to the local signal controllers called Topis to have a unique and robust system as an entity. See the figure below.

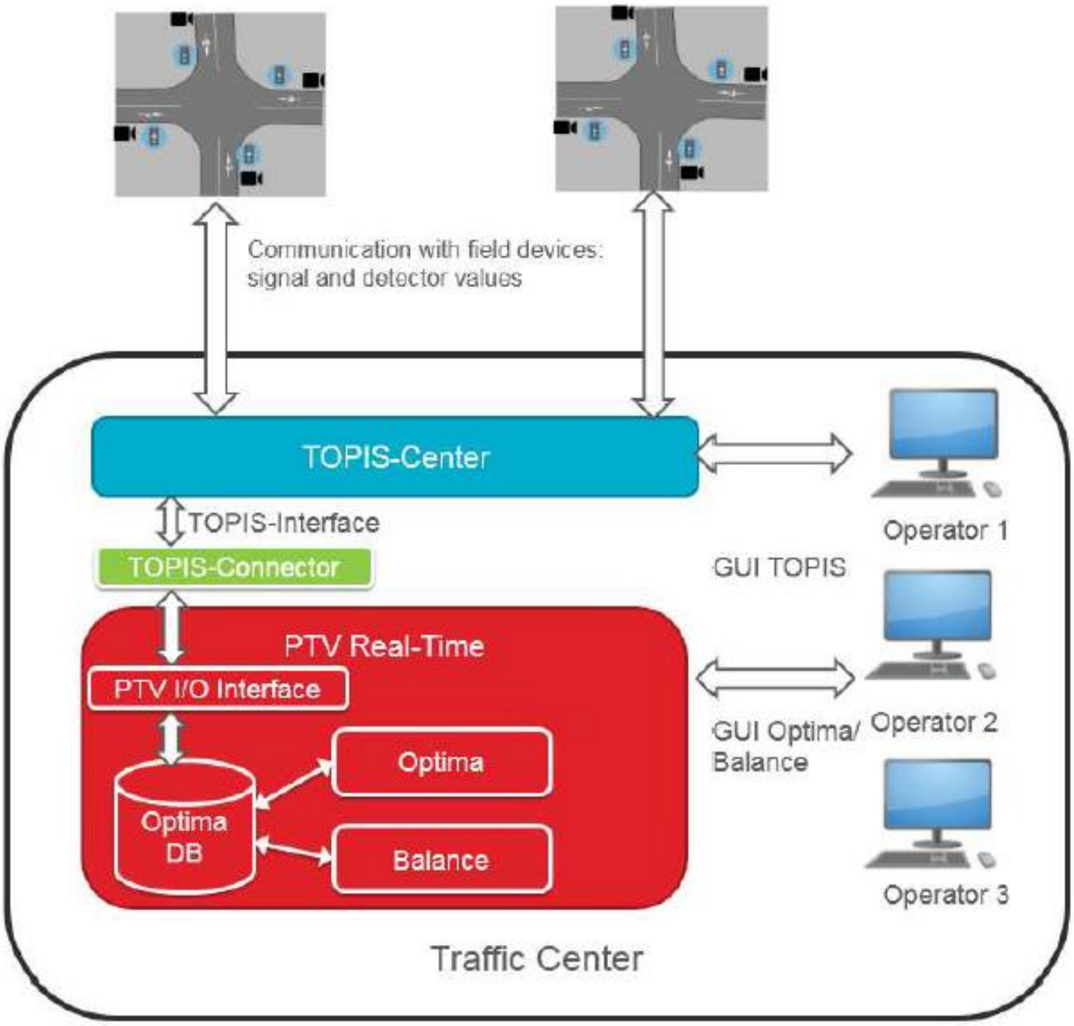


Figure 26 ITMS of Taichung city

The project divided to two phases which the first one contains the central area of City and the second one expands the horizon to a further area which has connection to the first phase as well. The scope of first phase includes the Freeway 1 Daya Interchange, Expressway 74 Beitun One, Beitun Two Ramps and its associated surrounding at-grade intersections and the main purposes defined such that the solutions come up with an intelligent transport management system to provide short-term traffic forecast, dynamic route guidance and automated adaptive signal controllers.

The Considered study area contains the 25% of population where the main elements of network are 535 km of roads and streets, 61 signalized intersections and 83 count locations. See the Figure 27 where red dots illustrate the main intersections to be dealt with.

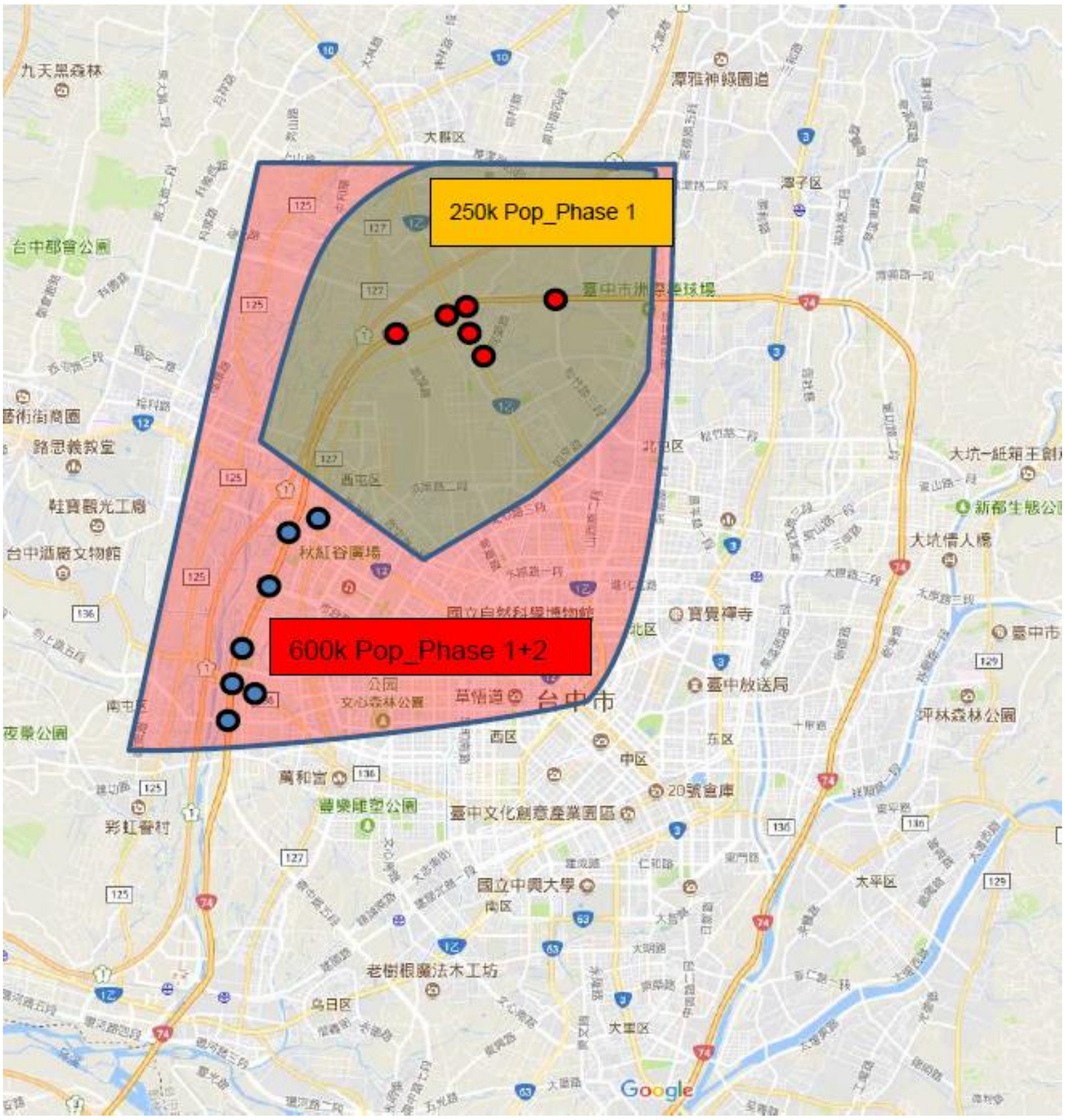


Figure 27 Study Area and Main Intersections

9.1 Probable causes and Feasible solutions

In the project area, congestion problem need to be resolved. During peak hours, due to highway 1 ramp metering control on the Daya Ramp slowing down cars heading north to enter the highway, the urban roads are typically strongly affected. The worst case usually happens during holidays since the highway 1 needed to maintain its level of service to deal with heavy traffic volumes on holidays, the ramp metering usually decreases green time to control flow rate as 800~1,400 veh/hr.

The Ramp metering usually leads to the congestion and over saturation to the intersections next to the Ramp and the associated urban roads. In the worst case, it could lead to 45 minutes delay for cars driving on Huanzhong Road from east to west. Also, there is significant delay for cars on Zhongchin Road travelling from south to north.[2]

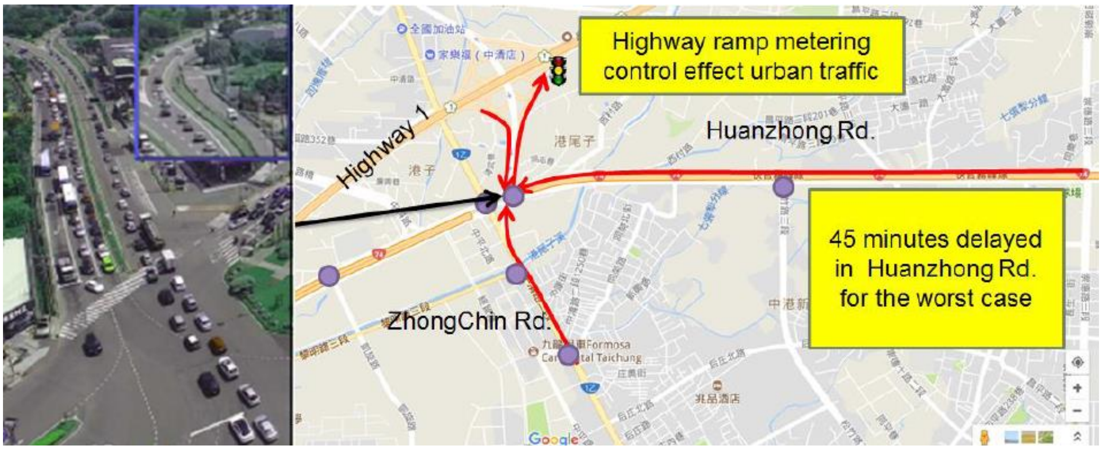


Figure 28 Highway ramp metering

Besides, the fix time signal controllers could not respond properly to the traffic volume at rush hours, and more importantly, there have not been any dynamic coordination among signal controllers to propagate a seamless and smooth traffic flow. On the other hand, the lack of smart traffic management system impacts the level of service of network since commuters would not be informed about rerouting alternatives in such circumstances like an unplanned event or a sudden raise of demand on an artery.

All the mentioned troubles have a resolution to cope with, which is the integrated traffic management system of PTV Optima-Balance. In fact, the reciprocal influence of PTV Optima and Balance makes the system quite proactive to the potential events and unpredicted demand variation because PTV Optima foresee the traffic thanks to its dynamic traffic engine and PTV Balance adapts the signal controllers to fit on the fluctuation of real-time traffic flow.

To have an overview on the features of integrated system individually, PTV Optima is a Real-time traffic management and perdition system which is capable to foresee the result of running different scenarios simultaneously in order to establish a congestion response and alternative route guidance strategy able to effectively alleviate heavy traffic loads at ramps and intersections around Freeway 1 and Expressway 74. Thus, the risk of decision decreases once authorities should come up with a rerouting alternative to the user in the administrative level. On the other hand, Balance is an adaptive signal controller in the macro level that aims to minimize delays, queues and stops of traffic in the road network. It is an integrated system and thus able to take incidents and strategic decision support into account for signal optimization. The geolocation of signal controllers managed by PTV Balance is showed below.

Figure 29 PTV Balance controllers

10 Application of the Integrated PTV Optima-Balance

The implementation PTV Optima- Balance requires a substantial dedication in model preparation since this unique entity is not only composed of several modules working chronologically but also the preparation from the initial steps involves PTV Visum, Vissim and Vissig and data driven strategies to conclude a suitable integrated model ready to work in real time management system.

The initial transport model had kicked off with the base PTV Visum model. The base model is provided by client which was representing the entire Taichung City. The supply model was extended far beyond the agreed area of phase 1 and the level of detail was too fine which includes all local roads where neither there was monitoring on them nor they were fitted within the scope of traffic management purposes. On the other side, demand model structure requires modification and calibration since the predefined zones were not representative enough concerning the generation and attraction volume of various residential and commercial spots, the level of aggregation was too general so that the hourly fluctuation of demand over a day was not respected and typical demand pattern was not defined like working days or holidays ,and more importantly, the demand matrices were not calibrated with the historical data.

Hence, to prepare the model as we wish, historical data should be analysing by several data driven methods. The historical data are provided by client containing two series of data, the first one was two years of traffic flow aggregated hourly for each day of a week and the second series was a months of traffic flow and speed aggregated every 5 minutes after the first implementation of Optima system (Harmonizer output) in Taichung city. The second series used for the final demand and supply calibration (weekdays between 24.01.2018 to 14.02.2018 except 07.02.2018) and validation (07.02.2018).

The first series was not only geolocated differently from the second series of data but also the type of detectors were different. In fact, the initial series was the mix of inductive loops and Video detectors (VDs) whereas the second series includes only VDs which usually records more reliable data. In addition to the historical data, plenty of CCTV displays has been dispersed on the crucial and crowded roads provided by client as well. CCTV can be utilized for calibration of saturation capacity of links and turns approaching to the signal controllers in PTV Balance_ see chapter 10.2.1. See the available CCTV in Figure 30.

Figure 30 CCTV Geolocation

PTV Optima online exploits Dynamic network loading (DNL) on the account of the fact that the historical traffic measures need to be respected which is impossible in Dynamic User Equilibrium (DUE) assignment. Moreover, the convergence of equilibrium is time consuming which is out of reach in the tight gap among the sequential assignment of TRE online. Hence, we need to stick to a constant route choice which is driven from calculation of turn probability through static assignment in PTV Visum model. However, the concept of detour route can be performed in PTV Optima online in the case of existing any incidents along the predefined routes. This feature is embedded in the sneaking parameter of PTV Optima which makes users capable to choose a local deviations from the fixed routes based on the valid impedances of network.

Eventually the traffic model building will be finalized in PTV Visum environment, then further supply calibration is undergone considering PTV Optima offline mode, accelerated lab mode and online mode. Follow the calibration procedures in the chapters 10.1 and 10.2.

PTV Balance uses as same road network as PTV Optima does for its internal calculations. This way there is no need to supply the same network twice. Although, PTV Balance is fed with the PTV Optima simulation and real-time detectors measures ,and in the following, mesoscopic traffic model of PTV Balance is responsible to compute the temporal traffic profile flow see the chapter 5.2. Therefore, couple of parameters related to the traffic model and efficiency model should be fine-tuned by considering historical data, CCTV and Vissim Model. Such parameters are saturation capacity, signal group weights, master weights and the degree of freedom of for the individual signal controllers. PTV Balance calibration is elaborated in 10.3.

Moreover, the configuration and architecture of signal plans are done according to the sheet-based signal plans provided by client. The sheet-based signal plans, which had been implied in the field so far, are fixed time signal plans. Thus, all of them should be coded in PTV vissig add-in and allocated to the nodes and main nodes of PTV Visum model. These fixed time signal plans are the initial state of PTV Balance efficiency model to reach the optimal solution.

10.1Demand Model Calibration

Prior to dive into data driven calibration methods of Demand model, the structure should be built properly regarding the PTV Optima requirements in both supply and demand based on the descriptions in the chapter 6.1.

Both series of traffic states described in the chapter 10 has played a crucial role in the demand calibration. Although the higher reliability of second series is evident, the various geolocation of detectors in either series forced the demand calibration in two steps, firstly considering only first series of traffic states and then the second series separately, to see the influence of both on the demand model. In fact, this separation is significant since the recoding date and typology of detectors are quite deferent in two series. See the figure below illustrating the geolocation of first series by red symbol and the second one with blue.

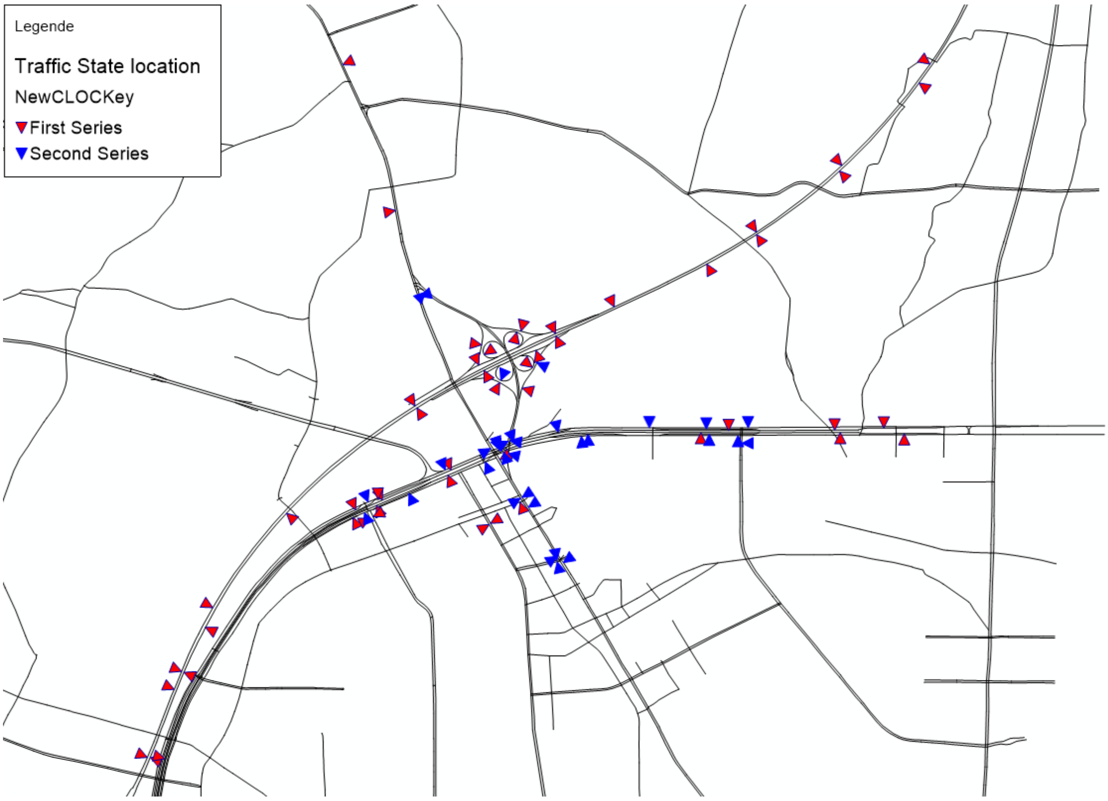
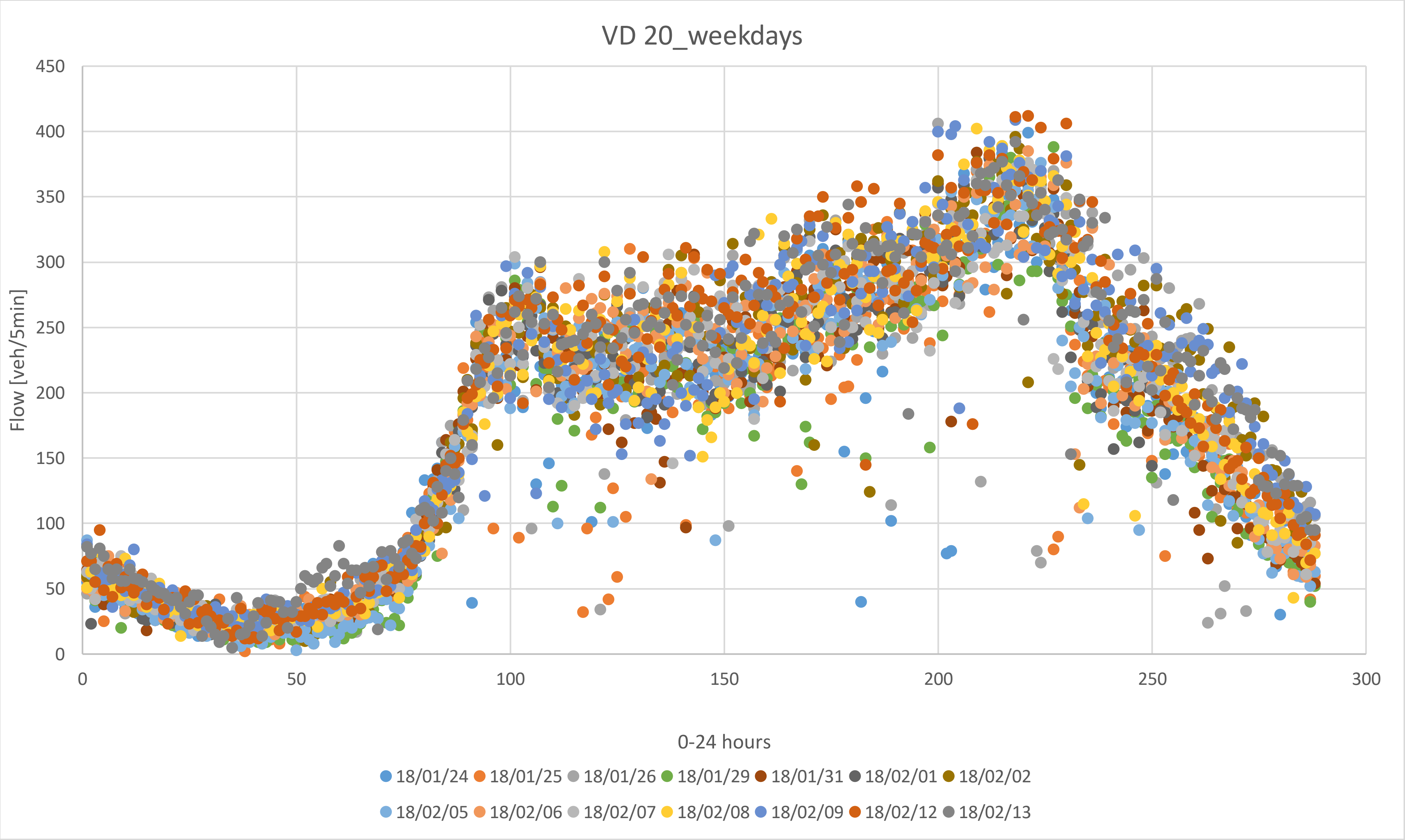
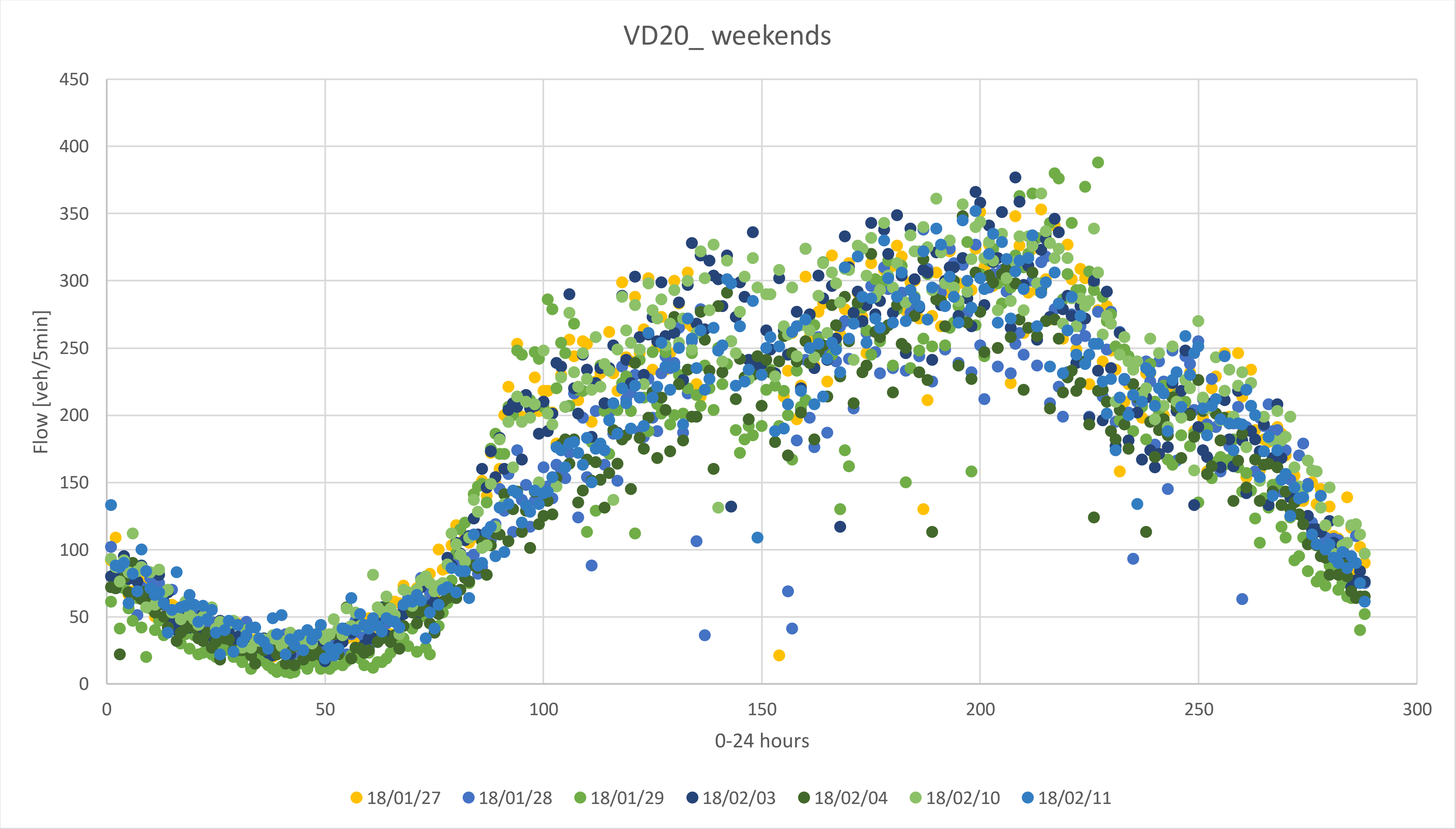


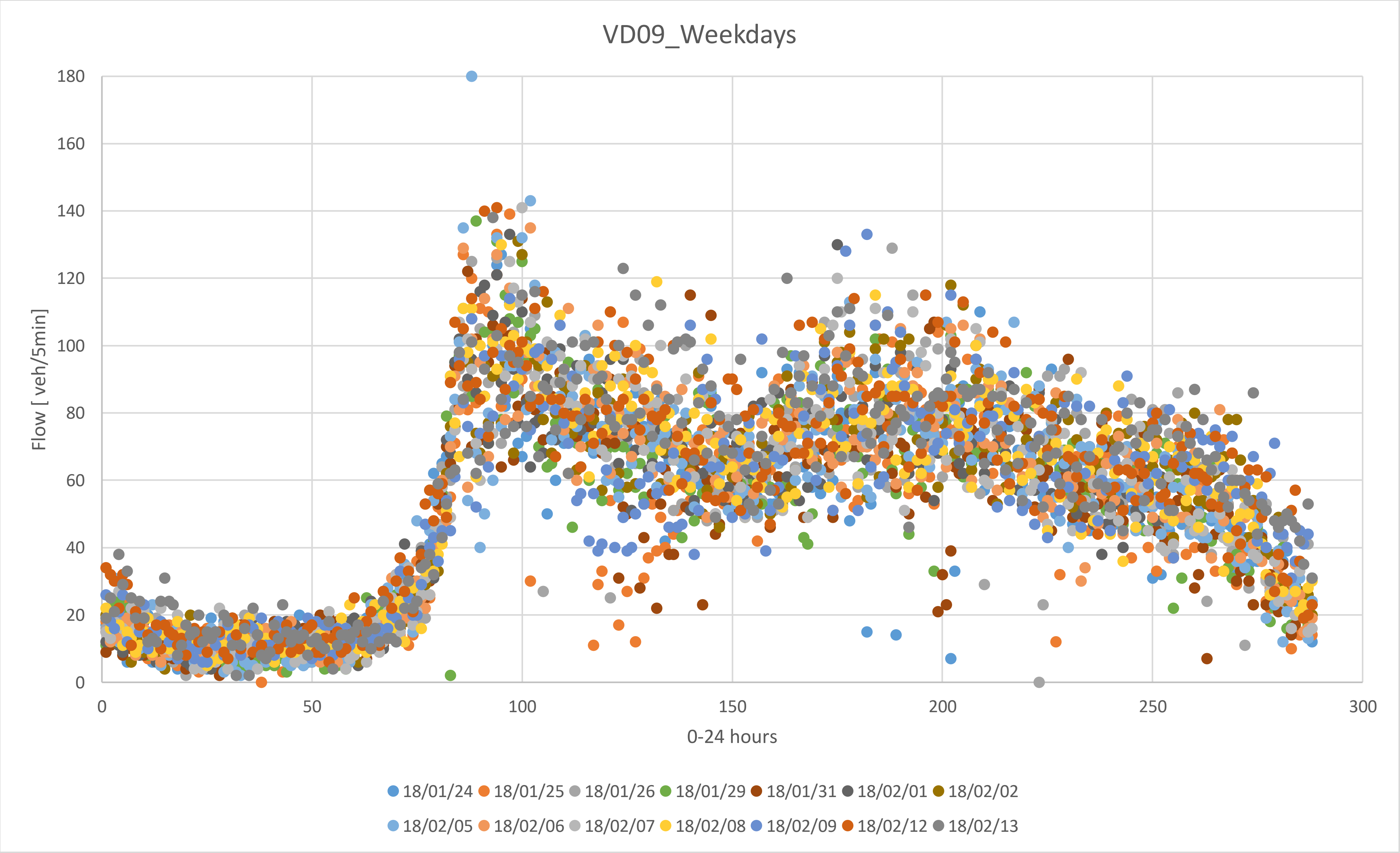
Figure 31 Traffic states geolocation

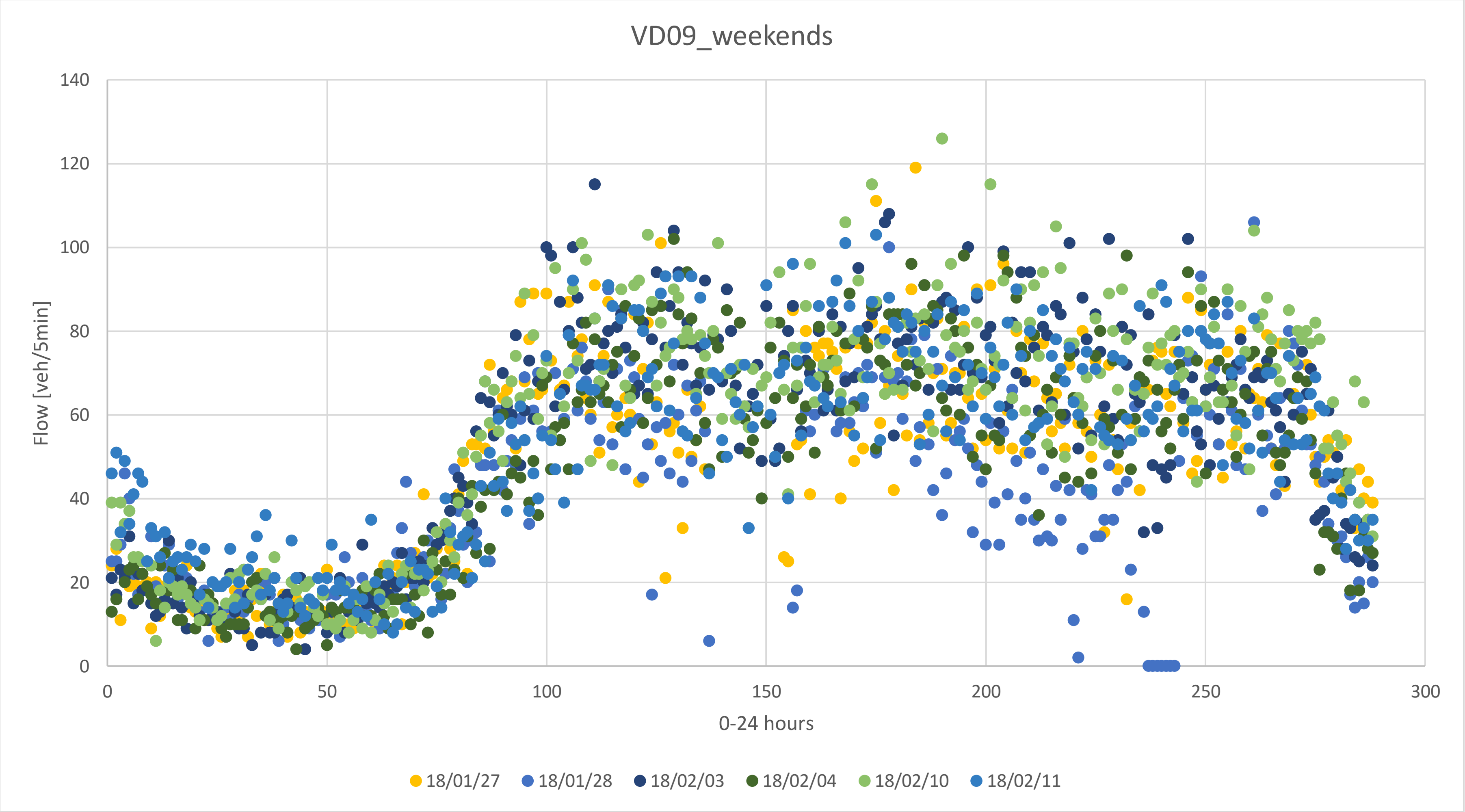
Number of typical days called day types in PTV Optima structure, explained in 6.1.5, is determined by data analysis of second series of traffic states containing 33 VDs. The analysis has been done on a random selection of VDs. The recorded flow is plotted to figure out how many patterns for day types are distinguished. Accordingly, there has been a fair distinguishable pattern once data are distributed to the classes of weekdays and weekends. Couple of plots on some VDs are brought to you in this thesis in the following figures. Determining a representative day type is not only crucial for the Optima structure but also depicts how historical data should be aggregated in time; Even though, client's interest should be respected, sometimes is impressed by the myth of more disaggregation leads into a quality model. Frankly, Traffic state is defected from a wide variety of causes like weather condition, high density of flow, hypercritical traffic condition, low precision of detectors and so on which impacts the data horribly and includes bugs as well. Thus, choosing a proportional aggregation level of traffic state regarding the precision and reliability of data is fundamental. Indeed, exclusion of defecated data and a proper aggregation method brings us a desirable demand model which is prone to less real-time correction.

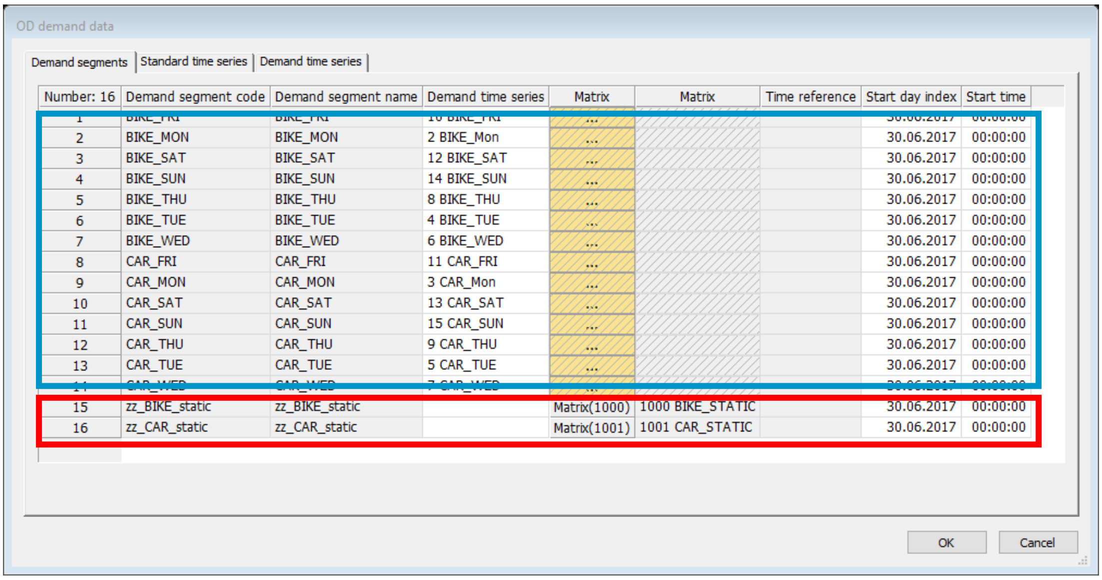
Furthermore, zoning system has been modified from the base model which does not have an enough detailed, and the new zones replaced as it is shown in Figure 15 (zones in PTV Optima are practically centroids regardless of their spatial area) . Then, blank hourly matrices are created and connected through demand time series to demand segments, explained in 6.1.5, later these blank matrices will be filled according to the implementation of demand calibration. The Figure 32 illustrates the Optima demand segments and the static demand segments with blue and red squares respectively. One converts static demand structure defined with constant matrices and two transport system to Optima demand structure in which daily demand segments are subdivided by demand time series. Demand time series contain hourly matrices. Hence, the process of demand calibration helps us to go through static demand structure, correct their value by aggregated traffic states (hourly and by transport system) and eventually overwrite the corrected values in the corresponding blank hourly mortices.


VD 20_weekdays
Flow [veh/5min]
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
0-24 hours
18/01/24
18/01/25
18/01/26
18/01/29
18/01/31
18/02/01
18/02/02
18/02/05
18/02/06
18/02/07
18/02/08
18/02/09
18/02/12
18/02/13


VD20_ weekends
Flow [veh/5min]
0
50
100
150
200
250
300
350
400
450
0
50
100
150
200
250
300
0-24 hours
18/01/27
18/01/28
18/01/29
18/02/03
18/02/04
18/02/10
18/02/11

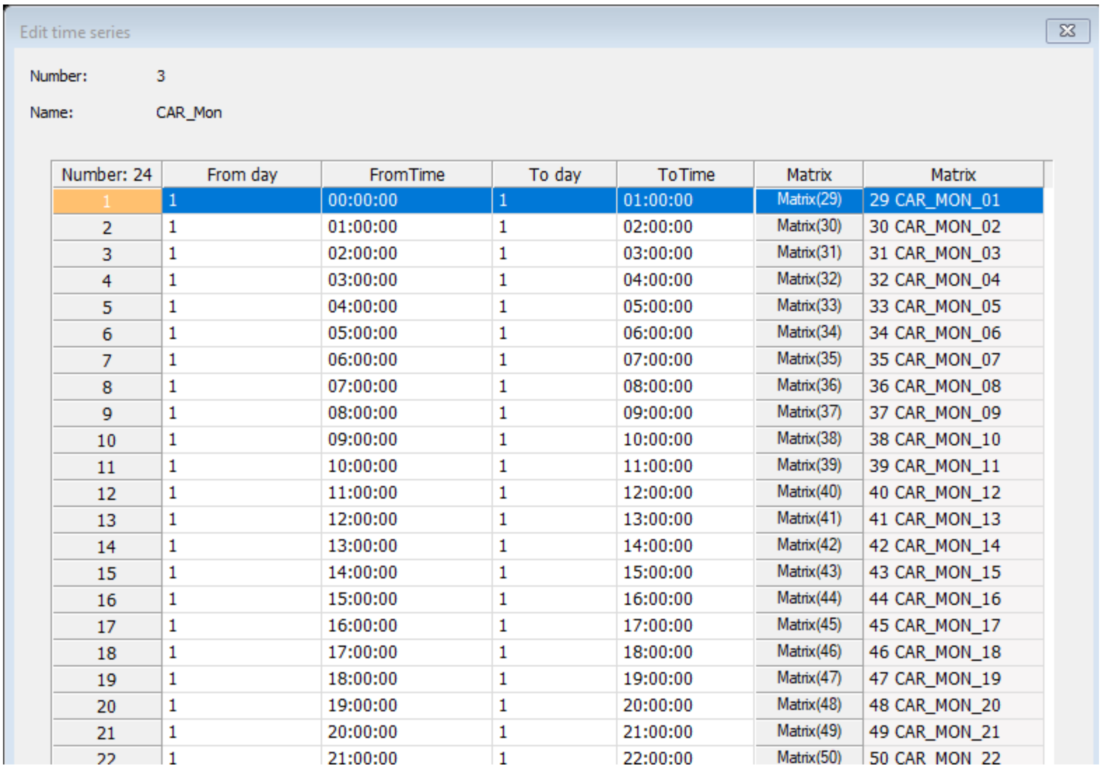

VD09_Weekdays
Flow [veh/5min]
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
250
300
0-24 hours
18/01/24
18/01/25
18/01/26
18/01/29
18/01/31
18/02/01
18/02/02
18/02/05
18/02/06
18/02/07
18/02/08
18/02/09
18/02/12
18/02/13


VD09_weekends
Flow [veh/5min]
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
0-24 hours
● 18/01/27
● 18/01/28
● 18/02/03
● 18/02/04
● 18/02/10
● 18/02/11



Number: 16	Demand segment code	Demand segment name	Demand time series	Matrix	Matrix	Time reference	Start day index	Start time
1	BIKE_FRI	BIKE_FRI	10 BIKE_FRI	...			30.06.2017	00:00:00
2	BIKE_MON	BIKE_MON	2 BIKE_Mon	...			30.06.2017	00:00:00
3	BIKE_SAT	BIKE_SAT	12 BIKE_SAT	...			30.06.2017	00:00:00
4	BIKE_SUN	BIKE_SUN	14 BIKE_SUN	...			30.06.2017	00:00:00
5	BIKE_THU	BIKE_THU	8 BIKE_THU	...			30.06.2017	00:00:00
6	BIKE_TUE	BIKE_TUE	4 BIKE_TUE	...			30.06.2017	00:00:00
7	BIKE_WED	BIKE_WED	6 BIKE_WED	...			30.06.2017	00:00:00
8	CAR_FRI	CAR_FRI	11 CAR_FRI	...			30.06.2017	00:00:00
9	CAR_MON	CAR_MON	3 CAR_Mon	...			30.06.2017	00:00:00
10	CAR_SAT	CAR_SAT	13 CAR_SAT	...			30.06.2017	00:00:00
11	CAR_SUN	CAR_SUN	15 CAR_SUN	...			30.06.2017	00:00:00
12	CAR_THU	CAR_THU	9 CAR_THU	...			30.06.2017	00:00:00
13	CAR_TUE	CAR_TUE	5 CAR_TUE	...			30.06.2017	00:00:00
14	CAR_WED	CAR_WED	7 CAR_WED	...			30.06.2017	00:00:00
15	zz_BIKE_static	zz_BIKE_static		Matrix(1000)	1000 BIKE_STATIC		30.06.2017	00:00:00
16	zz_CAR_static	zz_CAR_static		Matrix(1001)	1001 CAR_STATIC		30.06.2017	00:00:00

Figure 32 Demand Segment_ Study case



Number: 3

Name: CAR_Mon

Number: 24	From day	FromTime	To day	ToTime	Matrix	Matrix
1	1	00:00:00	1	01:00:00	Matrix(29)	29 CAR_MON_01
2	1	01:00:00	1	02:00:00	Matrix(30)	30 CAR_MON_02
3	1	02:00:00	1	03:00:00	Matrix(31)	31 CAR_MON_03
4	1	03:00:00	1	04:00:00	Matrix(32)	32 CAR_MON_04
5	1	04:00:00	1	05:00:00	Matrix(33)	33 CAR_MON_05
6	1	05:00:00	1	06:00:00	Matrix(34)	34 CAR_MON_06
7	1	06:00:00	1	07:00:00	Matrix(35)	35 CAR_MON_07
8	1	07:00:00	1	08:00:00	Matrix(36)	36 CAR_MON_08
9	1	08:00:00	1	09:00:00	Matrix(37)	37 CAR_MON_09
10	1	09:00:00	1	10:00:00	Matrix(38)	38 CAR_MON_10
11	1	10:00:00	1	11:00:00	Matrix(39)	39 CAR_MON_11
12	1	11:00:00	1	12:00:00	Matrix(40)	40 CAR_MON_12
13	1	12:00:00	1	13:00:00	Matrix(41)	41 CAR_MON_13
14	1	13:00:00	1	14:00:00	Matrix(42)	42 CAR_MON_14
15	1	14:00:00	1	15:00:00	Matrix(43)	43 CAR_MON_15
16	1	15:00:00	1	16:00:00	Matrix(44)	44 CAR_MON_16
17	1	16:00:00	1	17:00:00	Matrix(45)	45 CAR_MON_17
18	1	17:00:00	1	18:00:00	Matrix(46)	46 CAR_MON_18
19	1	18:00:00	1	19:00:00	Matrix(47)	47 CAR_MON_19
20	1	19:00:00	1	20:00:00	Matrix(48)	48 CAR_MON_20
21	1	20:00:00	1	21:00:00	Matrix(49)	49 CAR_MON_21
22	1	21:00:00	1	22:00:00	Matrix(50)	50 CAR_MON_22

Figure 33 Demand Time Series_ Study case

10.1.1 Procedure

This chapter describes the methodology used to calibrate the O-D matrices by Traffic Counts. TFlowFuzzy calibration method is exploited which is described at length in [26]. Also figure below illustrate the generic demand matrix correction loop.

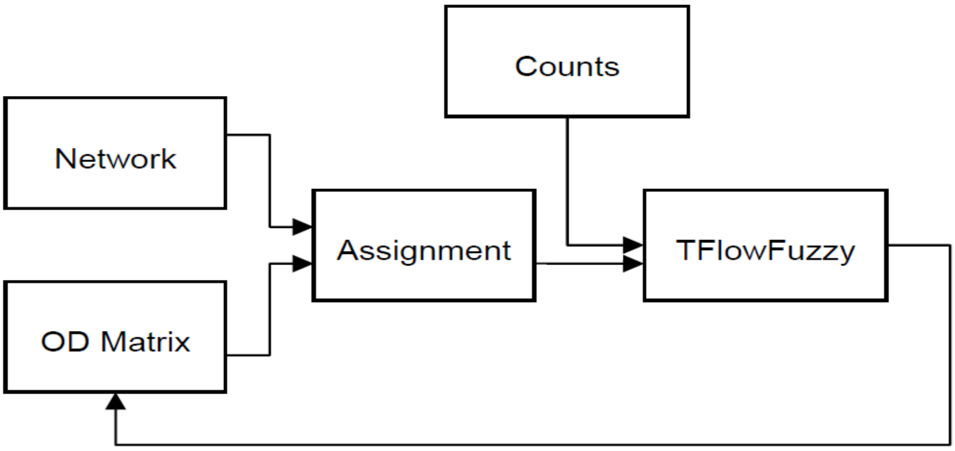
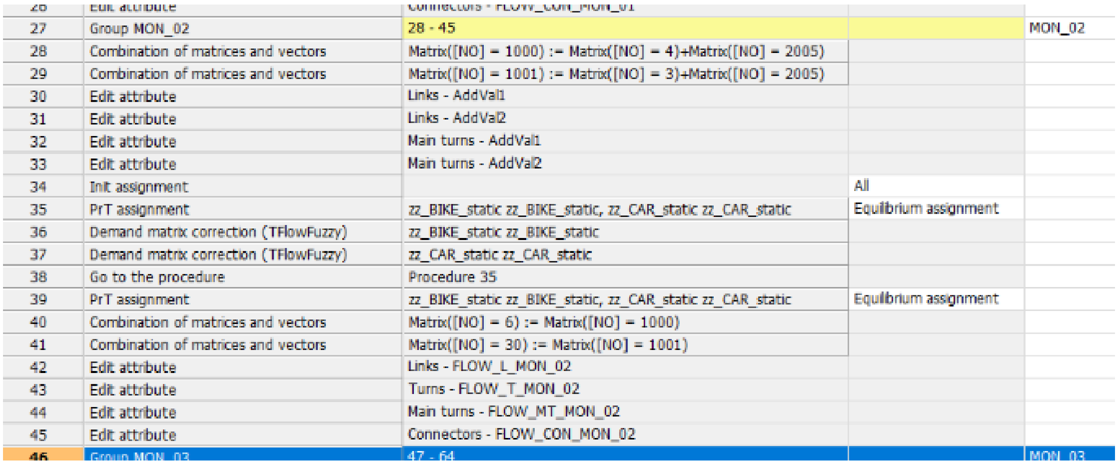


Figure 34 TFlowFuzzy matrix calibration

The TFlowFuzzy procedure has been implied for each time interval (every hour) of each Day Type. In overall, 170 groups of TFlowFuzzy procedure run to calibrate 340 matrices, each group includes both Transport systems simultaneously and represents each hour of a day. Figures below illustrate the configuration of TFlowFuzzy procedure for each hour Which is composed of (numbers below refer toFigure 35):

- Relevant matrices both bike and car _numbers 28 and 29.
- Given Addvalue attribute defining the precision threshold of simulated flow from the traffic state_ numbers 30 to 33.
- Private assignment with equilibrium assignment (default parameters) _ number 36.
- Demand correction (TFlowFuzzy)_ numbers 36 and 37.
- Loop over assignment and demand calibration (e.g. 15 times) _ number 38
- Overwriting the calibrated matrices to the hourly matrices_ numbers 40 and 41.
- Overwrite the attribute of flow values on link and main turn_ numbers 42 to 45.

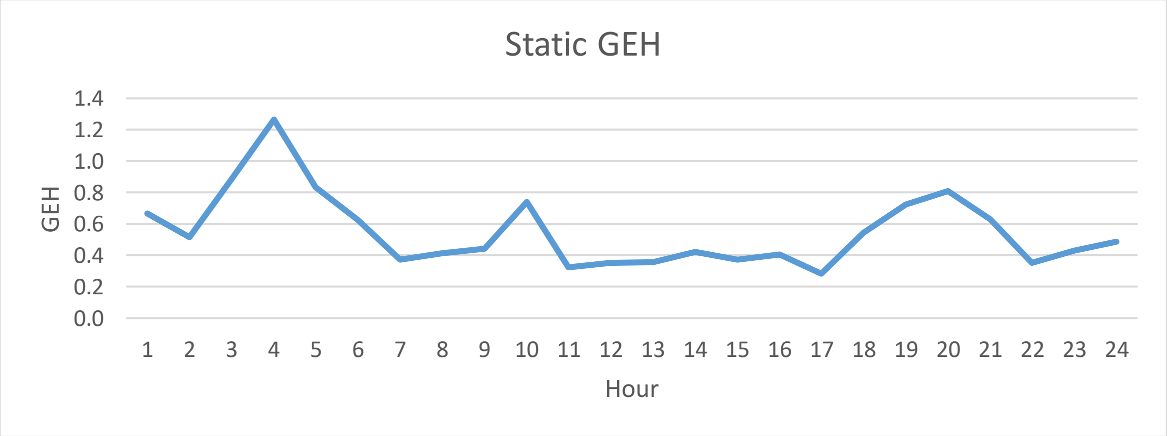


26	Edit attribute	Connectors - FLOW_CON_MON_01		
27	Group MON_02	28 - 45		MON_02
28	Combination of matrices and vectors	Matrix([NO] = 1000) := Matrix([NO] = 4)+Matrix([NO] = 2005)		
29	Combination of matrices and vectors	Matrix([NO] = 1001) := Matrix([NO] = 3)+Matrix([NO] = 2005)		
30	Edit attribute	Links - AddVal1		
31	Edit attribute	Links - AddVal2		
32	Edit attribute	Main turns - AddVal1		
33	Edit attribute	Main turns - AddVal2		
34	Init assignment		All	
35	PrT assignment	zz_BIKE_static zz_BIKE_static, zz_CAR_static zz_CAR_static	Equilibrium assignment	
36	Demand matrix correction (TFlowFuzzy)	zz_BIKE_static zz_BIKE_static		
37	Demand matrix correction (TFlowFuzzy)	zz_CAR_static zz_CAR_static		
38	Go to the procedure	Procedure 35		
39	PrT assignment	zz_BIKE_static zz_BIKE_static, zz_CAR_static zz_CAR_static	Equilibrium assignment	
40	Combination of matrices and vectors	Matrix([NO] = 6) := Matrix([NO] = 1000)		
41	Combination of matrices and vectors	Matrix([NO] = 30) := Matrix([NO] = 1001)		
42	Edit attribute	Links - FLOW_L_MON_02		
43	Edit attribute	Turns - FLOW_T_MON_02		
44	Edit attribute	Main turns - FLOW_MT_MON_02		
45	Edit attribute	Connectors - FLOW_CON_MON_02		
46	Group MON_03	47 - 64		MON_03

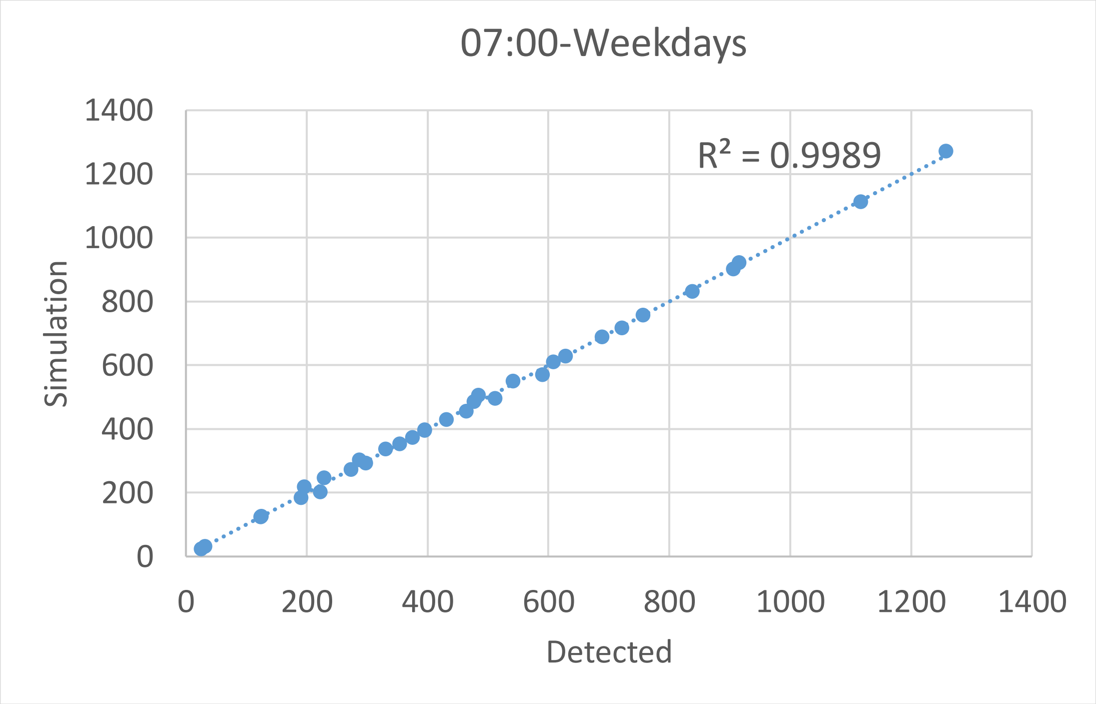
Figure 35 The procedure of Demand model

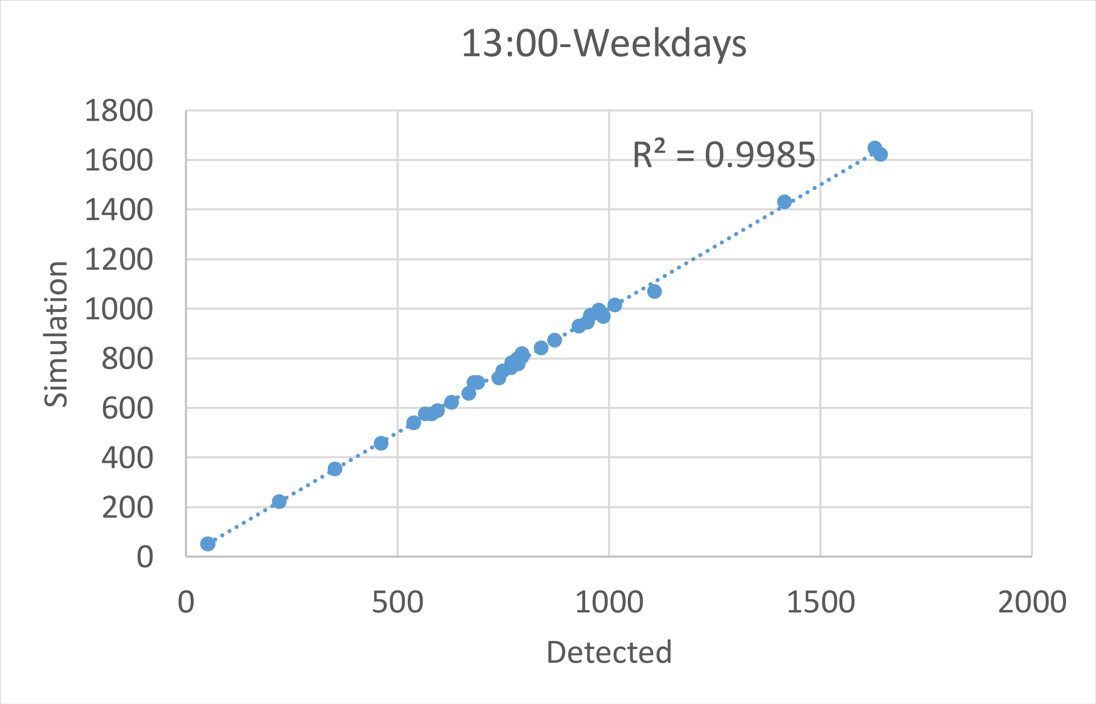
10.1.2 Result

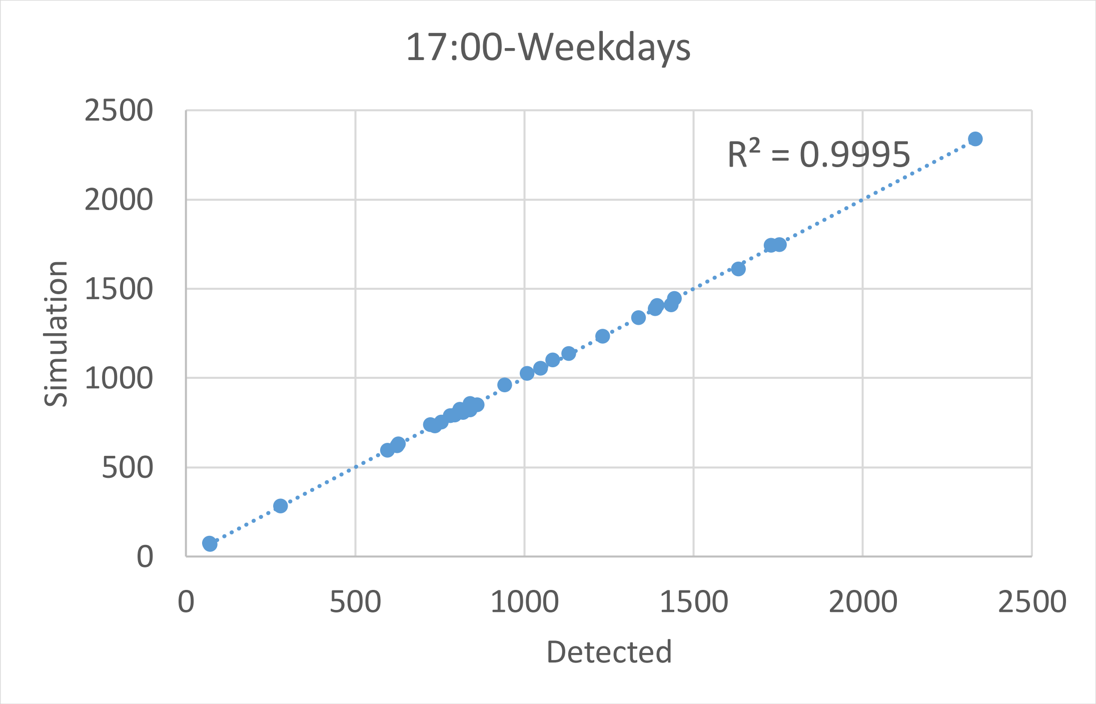
The main result of the TFlowFuzzy Procedure is the modification of 340 O-D matrices calibrated with historical traffic state. In fact, this report contains the final result of calibration after implying both series of data consequently. The overall GEH of static model comparing the fitness of simulation versus detected flow (hourly aggregated) is 0.6 for a day in weekdays day-type. The chart below elaborates the fluctuation of GEH trend in a day.



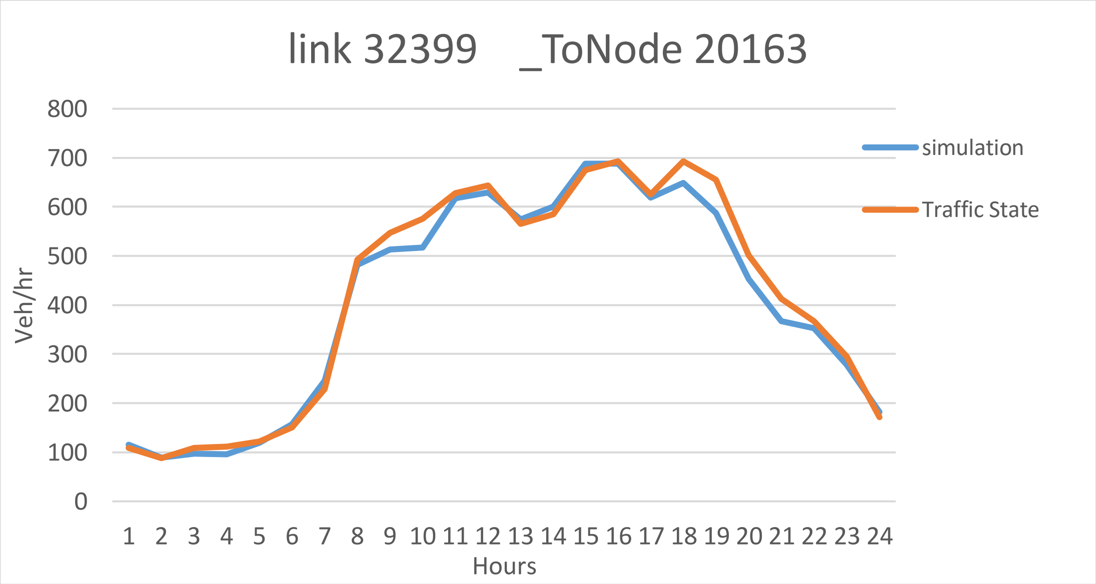
Furthermore, in the following charts, the comparisons between detected flows and model flows are reported for some time intervals chosen randomly.

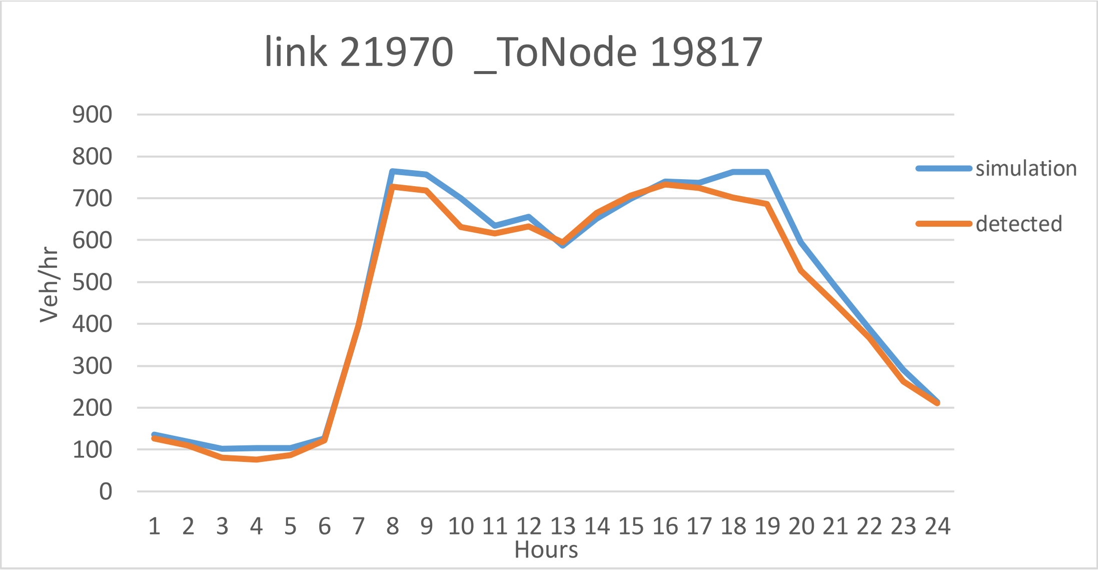

07:00-Weekdays
R² = 0.9989
Simulation
0
200
400
600
800
1000
1200
1400
Detected
0
200
400
600
800
1000
1200
1400


13:00-Weekdays
R² = 0.9985
Simulation
0
200
400
600
800
1000
1200
1400
1600
1800
Detected
0
500
1000
1500
2000



Except couple of links, the rest had an outstanding match between simulation flow and the aggregated traffic states. Some malfunctioning links are as figures below.





Further discussion addressing the static demand model calibration is beyond the scope of this thesis.

10.2PTV Optima Supply Model Calibration

Except the essential attributes of network within nodes, main nodes, links, turns and signal controllers which can be modified simply in PTV Visum model, a couple of extra attributes characterizes the principal of macroscopic dynamic model based on GLTM. Thus, firstly the required modification in supply model should be implied according to the chapters 6.1.1_4. Then, the additional attributes, defining the structure of KWT by macroscopic fundamental diagram (MFD), should be calibrated in the PTV Optima DB.

MFD has been recently proposed in[27].which proves the relationship between flow and density, as normally measured at the link level, also under certain conditions, it exists either for larger areas such as neighbourhoods and districts or for links with the same characteristics on which the drivers behave in the same way. According to this theory, the MFD is an approximate property of a network's structure that does not depend on demand. The Figure 36 illustrates such attributes which are also listed below.

- **Free-flow speed v0**: equals to the slope of the function q(k) in the origin;

- **Capacity φ**: equals to the maximum flow that can run through the link;
- **Critical density**: the density if q= φ
- **Jam density**: the density if v= 0 and q=0
- **Wave speed (W):** equals to the slope of the function q(k) in the jam density point

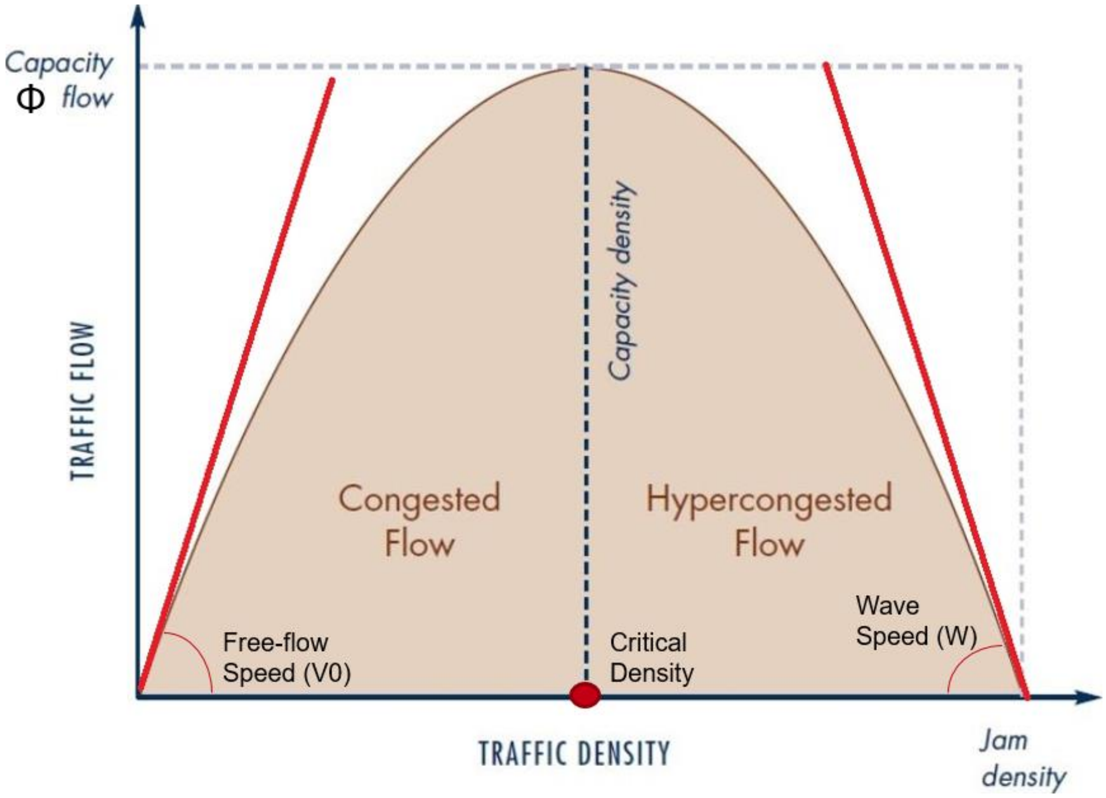


Figure 36 MFD

10.2.1 offline

To calibrate the attributes of MFD properly, links should be clustered based on their physical characteristics including:

- Free flow speed
- Number of lanes
- Link type

- Zone
- User defined

Furthermore, there should be sufficient number of quality detectors in each cluster to contain all states of traffic_ hypocritical, hypercritical and critical state shown in the Figure 37. A quality detector must have at least flow and speed volume and it's titled according to its location with respect to the objects of network like before/after a bottleneck, the type of detector (VDs, Loop or RFID), its historical reliability and so on.

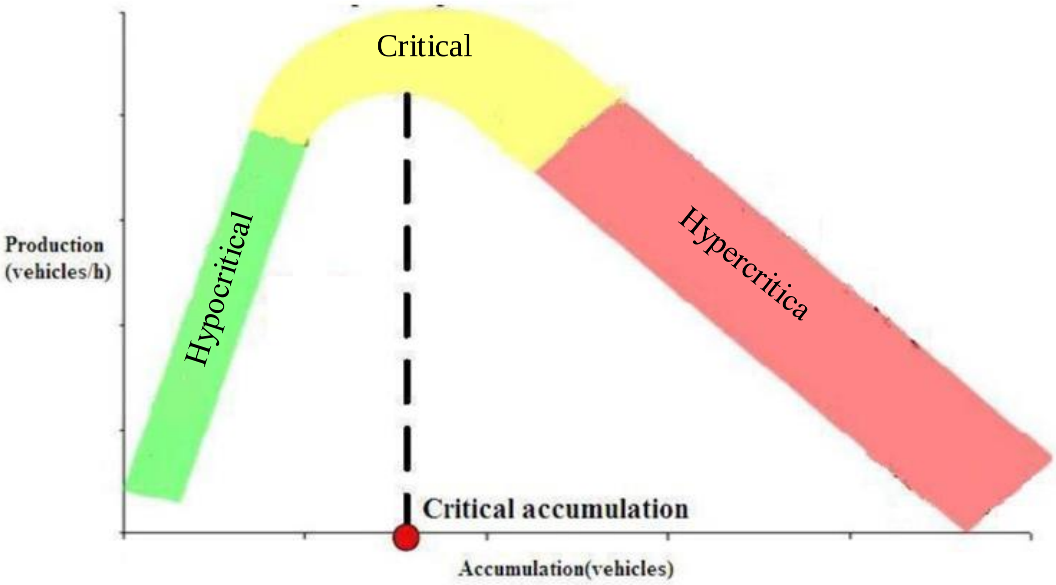


Figure 37 Fundamental Diagram

The historical data of each cluster should be aggregated and plotted on flow_density scatter chart, obviously a coherent cloud of dots should form a resemblance shape of parabolic MFD. Then, the calibration of each cluster is followed by matching the calibration parameters in the following chapters to the cloud of historical data in the scatter plot.

10.2.1.1 Hypocritical branch

The hypocritical branch of the macro fundamental diagram is described by the following equation:

$$k(q) = 1000 * \gamma^{\circ} * \frac{\Phi}{v_0} * \left(1 - \left(1 - \frac{Q}{\Phi}\right)^{\frac{1}{\gamma^{\circ}}}\right)$$

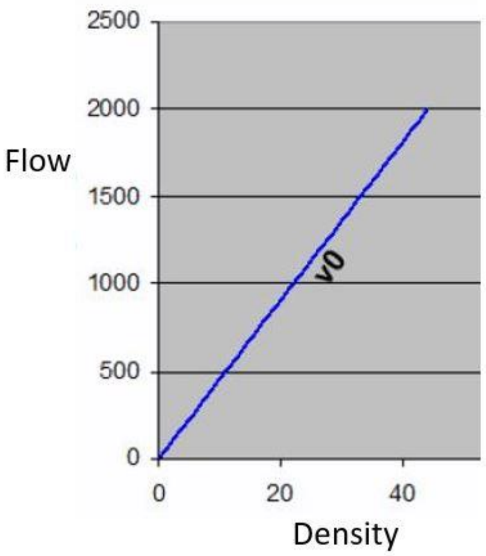
Where:

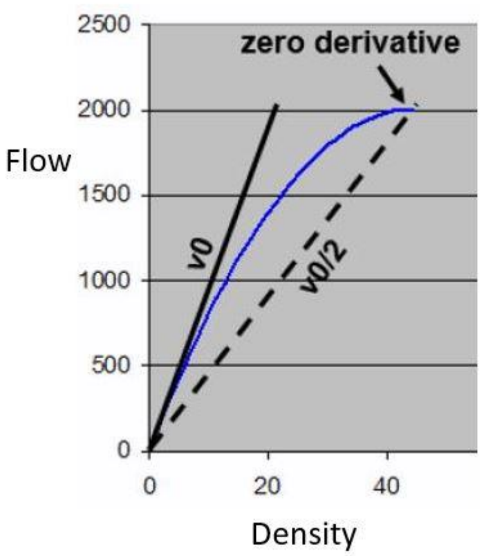
- V0: Free-flow speed
- ϒ° : shape of the hypocritical branch
- Φ Capacity
- Q flow in veh/h.

Calibration parameters are:

- V0: Free-flow speed (v0PrT in Visum):
- ϒ° (non-calibratable in Visum)
- Φ (CapPrT in Visum): that is the point corresponding to the critical hypocritical density

Gamma hypo (ϒ°) defines the curvature of the hypocritical branch. It’s a number that belongs to the interval [1;2] where ϒ°=1 defines a linear hypocritical branch and ϒ°=2 defines a parabolic hypocritical branch (where the maximum point, with derivative equal to zero, correspond to the line having a slope equal to v0/2).





10.2.1.2 Critical and Hypercritical branch

It's important to underline that traffic data with higher density values are usually not recorded at all. Hence, the hypercritical branch will be almost defined on the critical points. This lead as a consequence the hypercritical part of the MFD (that is by definition a cloud of points) to be heavily affected by errors of approximation.

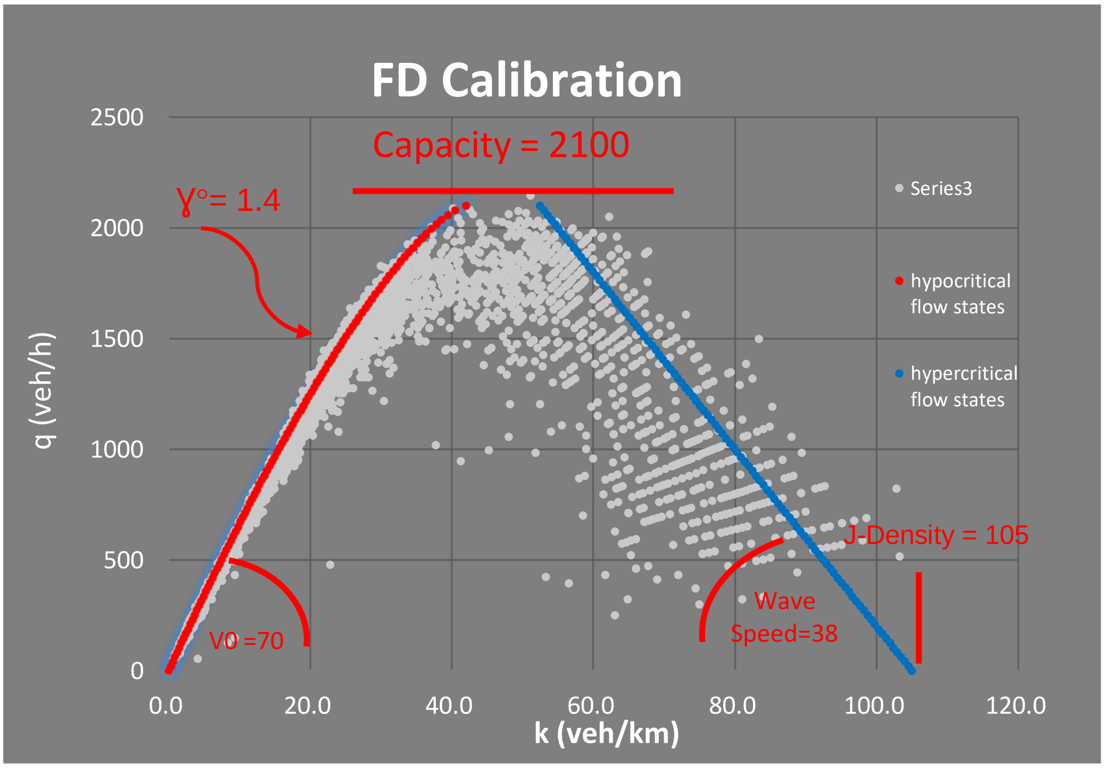
Moreover, PTV Optima is not capable to handle the parabolic or any curvature trend of hypercritical branch. The hypercritical branch of the macro fundamental diagram is described by the following equation:

$$k(q) = 1000 * (K_{jam} - \gamma^{+} * \frac{\Phi}{W} * (1 - \left(1 - \frac{q}{\Phi}\right)^{\frac{1}{\gamma_{+}}})$$

Thus, the **calibration parameters** are:

- Kjam: is the jam density
- γ^{+} is the hypercritical gamma
- Φ is the nominal capacity
- W is the wave speed

As an example, the second series of data (one month of observation) on a detector located on a ramp is plotted below. This figure is exceptionally representative for all states of fundamental diagram whereas resemblance perfect plot is a rare phenomenon.



10.2.1.3 *Links approaching the signalized intersections*

The supply calibration of Urban contest is considerably impacted by signalized intersections in which either the green share is modelled as a link attribute (Green and Cycle as UDA) and implicitly the Webster delays affects the travel time and outflow of a link is computed, or explicitly a signal program is modelled as it is configured in the reality, stop and go phenomena, which creates pulsing system resulting in queue and delay. Integrated system of PTV Optima-Balance utilizes the second case which raise the complexity of supply calibration. Evidently, PTV Optima is a macro level simulator which has the capability of handling such detailed signalized intersections (containing Vissig files) in the event that, nodes, main nodes (turns, number of lanes, length of pocket lanes, geometry etc) and Vissig files are modelled perfectly. In case of mismodelling of an element, the performance of dynamic flow propagation fails, therefore, to compensate the possible careless modelling for all elements extended on the network (time consuming task), the calibration of link attributes is suggested which consist of more relevant attributes addressing the nature of macroscopic dynamic propagation. Concluding, the gates of GLTM (nodes and main nodes) are modelled with less constrains except realistic bottlenecks while links play a more important role.

Firstly, by regarding the queueing and spilling back phenomena of link model based on GLTM, short approaching links should be avoided specially once there are more than one stage in an approaching link because the queueing phenomena firstly occupies the lane length and afterward queue block all upstream lanes regardless if its preserved lane or lanes with different manoeuvre allocation. It is not desirable incidence. Then, goodness of node and main node should be checked to realize if all elements are modelled carefully like number of approaching lanes, length of pocket lanes, signal group allocation, signal plans, turns and so on. Eventually, approaching link attributes should be fine-tuned including nominal capacity, free flow speed and jam density (space per PCU), kinematic wave speed.

Having balance optimized signal plans including variable green share over a day leads the nominal capacity measurement through the steps below

- Clusters the approaching links according to their physical characteristics like number of lanes, the configuration of manoeuvre considering their conflict area, free flow speed and link type
- Plotting the flow-density diagram for all intervals of study period within the unique clusters
- The maximum through flow depicts the **effective capacity** which is affected by temporal green share of link
    - The temporal green share of links is composed of aggregation of stages available in an approaching link
- According to the maximum effective capacity, imply the nominal capacity to all approaching lanes in a cluster by customizing each approach through its own minimum green share

$$\text{Minimum Green share} = Min\ (\frac{Temporal\ outcapacity - capasity\ of\ link}{capacity\ of\ link})$$

$$\text{Nominal Capacity of each link} = Min\ (\frac{Max\ effective\ capacity\ of\ Cluster}{Min\ green\ share\ of\ each\ link})$$

10.2.2 Online

This chapter describes some essential configuration of PTV Optima command line in order to running TRE in DNL mode with fix turn probability in diverging nodes since the real time solution needs the simulation with rolling horizon concept having forecast and nowcast in each iteration of simulation.

One might ask, what if an event occurs and users need to change the fixed path choice. Events and Sneaking are the parameters giving the flexibility of local rerouting. Sneaking attributes is stored in the Command line of TRE which has the threshold of [0,1], 0 no sneaking and 1 total sneaking. When users are stock behind a node which its downstream link is grid lock and the queue has not been resolved for a while, upstream vehicles start sneaking toward the other links than they meant to be. Sneaking parameter needs to be calibrated on basis of user behaviour in which the patience capacity of users is as equal as the expected waiting time once the downstream is blocked. Sneaking can occur within a link from a lane to the other, within a node from a maneuverer to the other; and prior to get into a link with receiving capacity of null.

Moreover, there is a traffic data tab in Optima Command line to determine the reaction of PTV Optima to real-time traffic states, both speed and flow. Traffic states are provided either for speed or flow or both together. Hence, the treatment with each of which varies according to the configuration of this tab. For instance, if the data with flow and speed don’t fit on the defined FD trend, especially data between two branches of FD, TRE should decide whether treat the given traffic state as a hypocritical or hypercritical situation. A particular data analysis defines The Critical Speed Ratio parameter which means the speed ratio (current speed/ free flow speed) lower than the critical speed ration will be projected on the hypercritical branch and higher ratios on the hypocritical branch. In fact, this ratio is driven from plotting the Flow-Time and Speed-Time graphs to distinguish how much speed drops once flow reaches to capacity. See the Figure 38. An analysis has performed on random selection of links containing both speed and flow data to drive the Critical Speed Ration parameter equal to 0.68.

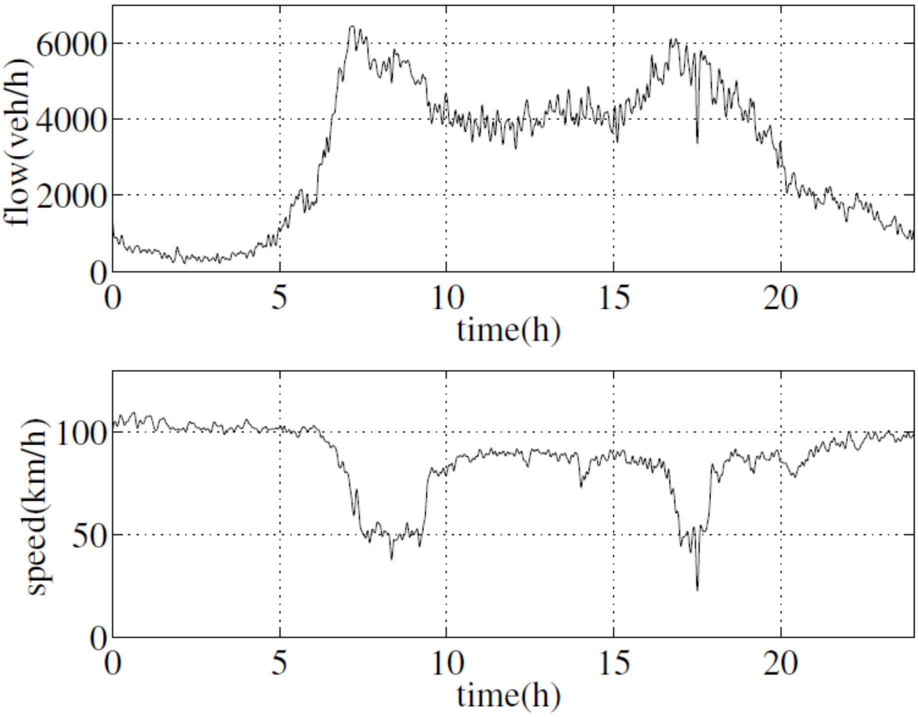


Figure 38 Critical Speed Ratio

10.3PTV Balance calibration

Balance calibration needs a deep understanding about its methodology, subjective parameters, calibration variables, and Objective function which are explained at length in the chapter 5.

Balance Saturation capacity has been computed according to the data analysis of historical data once PTV Optima-Balance was not deployed yet and controllers were managed by fixed time controllers. The computation formula is described in the section 5.4. Also, a visual monitoring has been done through traffic control cameras (CCTV). This analysis has performed by the team of PTV Munich.

As this network is very delay-sensitive, but not dependent on a dynamic green wave due to high distances between intersections, additional intersections not under Balance control in between, and the overall rather high cycle times, we set the Master weight for delay (MD) in the Balance.ini file to the value of 5 as unlike to the usual 1. This way Balance will optimize on the delay rather than on stops or queue lengths. The other Balance parameter stay as usual. Thus, the objective of efficiency model turns to be like:

$$PI(sp) = \sum_{sg \in SG} \alpha_{sg}\big(MD * D(sg,sp) + ML * 10L(sg,sp) + MS * 50S(sg,sp)\big)$$

Where:

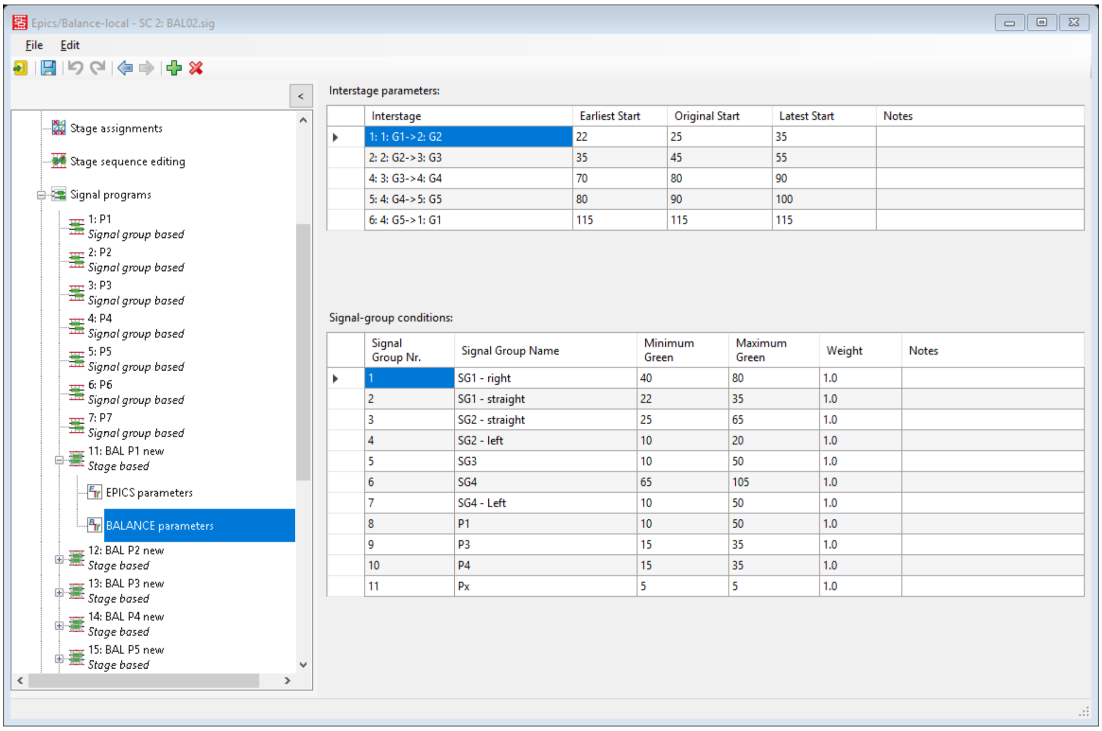
- MD, ML and MS are master weights of Delay, queue length and stops
- α_{sg} is the signal group weight.
- D, L and S absolute values of delay, queue length and number of stops
- Sg stands for signal group
- Sp stands for signal program

The signal group weight is defined in the Vissig files. In addition to this parameter, flexibility of PTV Balance in optimizing of stages is lie behind the variables listed below:

- **Interstage Parameters**
    - **Earliest Start and Latest start**: restricted to "+/- 10 seconds" of the original value
    - Besides, since there are several perturbation factors like signalized intersections between Balance controllers and pretty far Balance controllers from each other, the global synchronization is locked by holding earlies and latest start of interstages equal as original start
- **Signal-group conditions**
    - **Minimum and Maximum green**: is chosen proportional to original green time (based on fixed time plans) and logical restriction of a threshold like -/+ 20 secs or -/+ 10 secs
    - **Signal group weights:** This variable is kept as default value of "1"
- **Cycle time optimization:** this factor can be achieved thanks to several predefined signal programs for each controller and for each slice of time.

However, optimizing cycle time has not been implied in the project of Taichung phase one.

The Figure 39 illustrates the mentioned facts for the signal controller 2. The rest of Balance controllers have pretty similar configuration as well.



Interstage parameters:

	Interstage	Earliest Start	Original Start	Latest Start	Notes
▶	1: 1: G1->2: G2	22	25	35	
	2: 2: G2->3: G3	35	45	55	
	4: 3: G3->4: G4	70	80	90	
	5: 4: G4->5: G5	80	90	100	
	6: 4: G5->1: G1	115	115	115	

Signal-group conditions:

	Signal Group Nr.	Signal Group Name	Minimum Green	Maximum Green	Weight	Notes
▶	1	SG1 - right	40	80	1.0	
	2	SG1 - straight	22	35	1.0	
	3	SG2 - straight	25	65	1.0	
	4	SG2 - left	10	20	1.0	
	5	SG3	10	50	1.0	
	6	SG4	65	105	1.0	
	7	SG4 - Left	10	50	1.0	
	8	P1	10	50	1.0	
	9	P3	15	35	1.0	
	10	P4	15	35	1.0	
	11	Px	5	5	1.0	

Figure 39 Vissig file of SC3

11 Accelerated Lab-mode of PTV Optima-Balance

A recent configuration of PTV Optima gives the capability of mimicking to PTV Optima online simulation without the cost of waiting time for fresh traffic states, Thus TRE run iteratively without gap between sequential iteration. Nevertheless, the traffic states should be stored in Optima DB in advance alike Harmonizer does for upcoming real time data. This new configuration is called "PTV Optima Accelerated Lab Mode"; But one might ask what is its advantage? The key feature is the forecast quality assessment prior to the deployment of system in the field.

Besides, if the real time signal plans of are available, they can be embedded in to the simulation of accelerated lab mode to see if the real time signal plans consider the fluctuation of demand properly.

The configuration of TRE is as similar as TRE online except deactivation of waiting time among subsequent simulations and unchecking the parameter of future traffic state involvement. Moreover, the resolution of output and maximum horizon of forecast should be defined according to the expected analysis and assessment tests.

The real time signal plans on 07.02.2018 optimized by PTV Balance are stored in the Optima DB to have a as similar environment as PTV Optima-Balance online has. The optimized signal plans are coming to action as an event in the online mode while later on they are removed from DB. Hence, the online optimized plans should be converted from the Balance log file called "AllStageTransition" and be activated in a proper time with time varying attribute (TATT table).

To wrap up the benefits of accelerated lab mode of PTV optima:

- Generic Supply assessment
- Demand time series assessment
- Reliability of forecast under the condition of a resemblance real time demand pattern with respected to the provided historical data used in the calibration

11.1 Forecast quality assessment

What forecast assessment proves is practically the quality of supply and demand calibration per se regardless of involving real time traffic states in flow correction of simulation (if the chosen interval of assessment is far enough in time to avoid the impact of demand correction by real time traffic states). In fact, the forecast assessment is defined as the comparison between forecast flow or speed and the measured data corresponding to the taken forecast interval. Thus, within forecast assessment, demand and supply would be evaluated which are interacting within the model. To have a clear mind about each of them individually their relation should be cut. Therefore, a resembling pattern of validation data to the ones we have calibrated the demand earlier is selected. This strategy helps us to assure that we cannot blame demand model if forecast assessment fails (although this hypothesis is valid if the offline demand evaluation is accomplished a good score of GEH and the intervals of demand matrices are chosen properly).

The data from 24.01.2018 to 14.02.2018 is available. An analysis has been done to elaborate which days should be taken for the calibration of data and which day be regarded as the validation day. If there is a general fitness among calibrating and validating data, we expect the good result in the forecast as well. And what if it’s not achieved? the supply has not been calibrated properly or demand has not been break downed enough, which are indicators we are looking for. The validation data is 07.02.2018 which has a desirable fitness with the aggregated calibration data. According to the graph below we expect that forecast assessment reaches a bit high GEH in view of the fact that the calibration data and validation data mismatch over the peak hours. However, going beyond this GEH trend, uncalibrated supply or inappropriate demand time series are suspected in the failure.

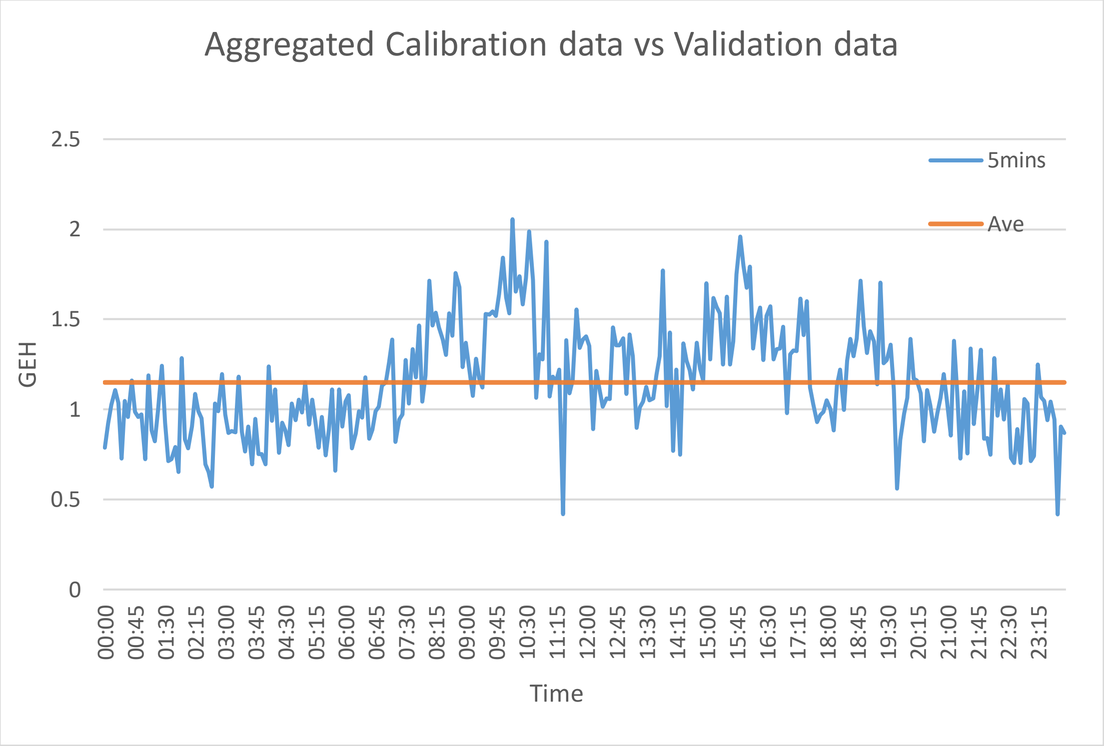


Figure 40 GEH of Aggregated Calibration data vs Validation data

Forecast assessment needs to deal with huge amount of data in data base, just imagine the division of 24 hours to 5minutes intervals in which there are 5 values (nowcast and forecast up to 5,10,15,20 minutes) for each link of the network. Therefore, a python script has been developed in PTV SISTeMA which is customized for this thesis aiming at forecast assessment. The flow volume is under assessment via the GEH formula as below.

$$GEH = \sqrt{\frac{2 * (M - C)^2}{(M + C)}}$$

- M: Model flow for Forecast of (n mins)
- C: Traffic state flow (recorded time + n mins)
- n: the initial interval of 5 minutes interval e.g. n=10 refers to the forecast interval of 10’ to 15’

Short term traffic forecast is a cutting-edge feature which its evaluation has not been standardized yet. Nevertheless, PTV group has defined some criteria in which thresholds are state of the art, based on the previous experiences of PTV Group. The flow forecast assessment

Goal	Check, whether there are systematic differences in predicted simulated traffic flows (15min & 30 min) and measured flows.
Long description	Systematic differences can give hints for problems with the demand model.
Results	1. GEH= $\sqrt{\frac{(f-m)^2}{\frac{(f+m)}{2}}}$ 15min forecast: GEH<12 for at least 65% of all links with valid detectors 30min forecast: GEH<15 for at least 65% of all links with valid detectors

The initial and eventual iteration (before and after calibration) of Lab mode reached the GEH trends as if it is illustrated in the Figure 41 for n = 5, 10 ,15 respectively. As far as the effect of real-time traffic state is available in the network we are witness of better GEH which has been expected, on account of the fact that the local fluctuation of flow and speed are recorded every 5 mins while demand is structured with hourly aggregation. Besides, lack of data for all elements of network leads supply calibration to be approximated which is resulting in non-perfect propagation of demand over the network as well. For instance, this project was equipped with few number of reliable detectors which are located mainly on signal controller inbounds or ramps, none of them represents the attributes of neither local streets over a corridor without signal controller nor highways. Hence, the supply calibration requires high level of assumption since the attributes of elements having data should be extended to the attributes of rest of network.

Before analysis of GEH, Figure 41 illustrates an abrupt surge of GEH for a short interval of [6:30 -7:00] for the forecast n = 10 and 15, this sudden change is investigated by looking on the Accelerated lab mode simulation. Left hand graphs are initial condition of forecast while the right hand is the result after modification described below.

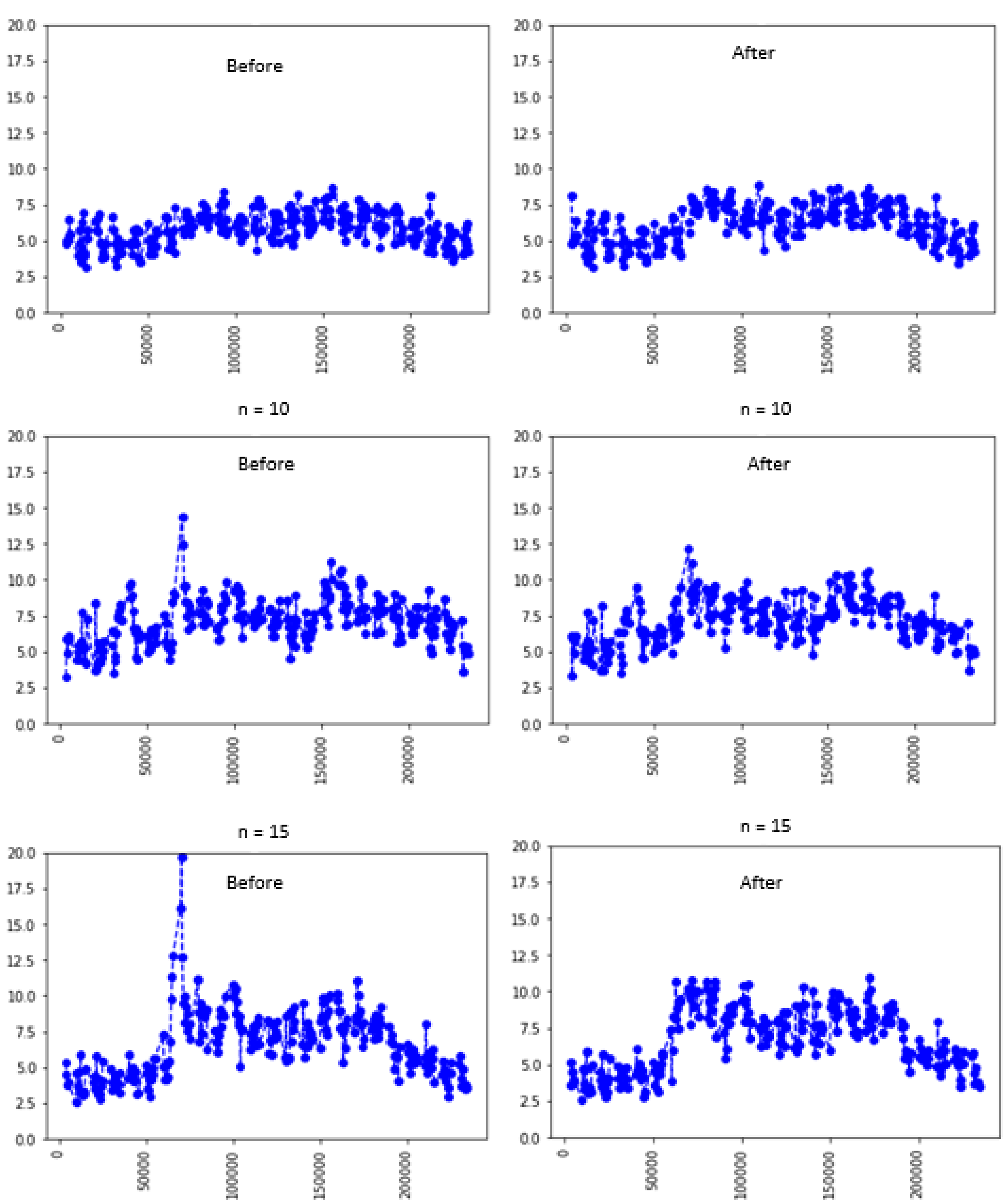


Figure 41 forecast assessment; ***Y*** *axis: GEH and* ***X*** *axis: time*

The simulation forecast (n = 15) is compared with corresponding traffic state (15-20 minuets a head) on the mentioned awkward GEH interval shown in the Figure 42. In fact, the forecasted network experiences lighter congestion than it should be. The reason is the sudden rise of demand matrix from one interval to the next one (06:00-07 to 07:00-08:00) while reality is witness of smoother transition every 5 minutes. Thus, the demand structure and matrix for the interval of 06:00-07:00 are break downed to 4 subintervals corrected new demand calibration to produce seamless transition of demand. The table below elaborates the mentioned fact.

	before break down		After break down			
Interval	06:00_07:00	07:00_08:00	06:00-06:15	06:15-06:30	06:00-06:45	06:45-07:00
ToT Trips	22394	51923	5820	9076	10548	14547

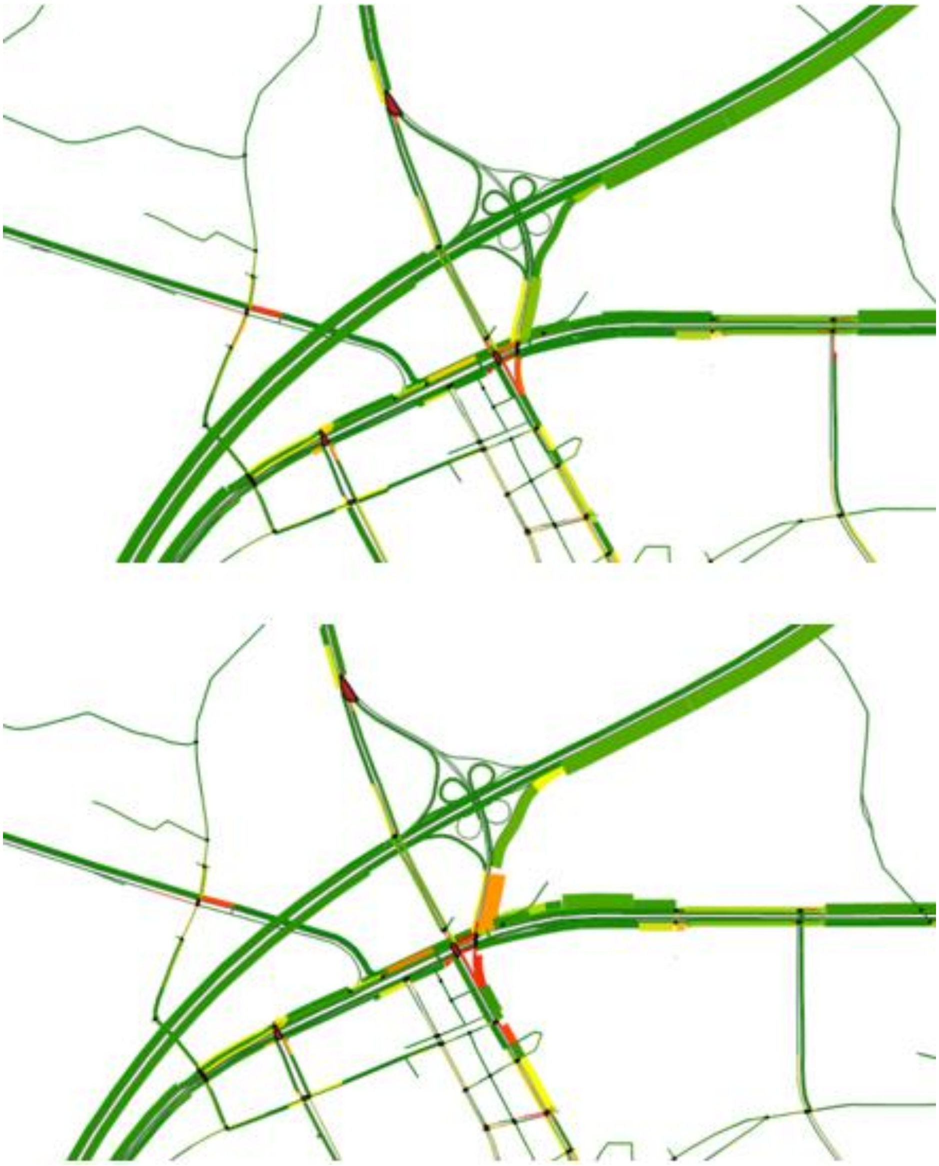
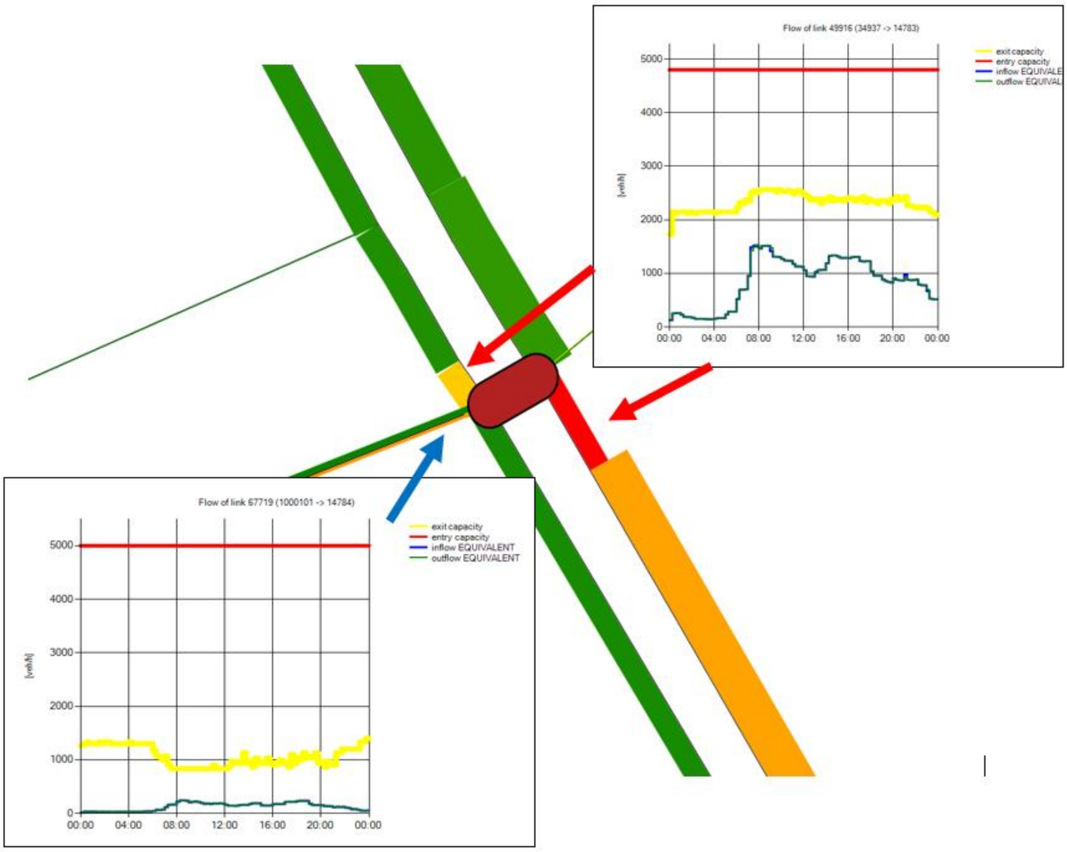


Figure 42 Upper image: forecast and lower image: traffic state

11.2 Real-time Signal plan assessment

The dynamic signal plans are activated in the accelerated lab mode simulation. Hence, checking their impact on the network performance and their proactive reaction to the demand fluctuation are significant. The impact of dynamic signal plan by giving variable green share to a stage leads to the fluctuation of out-capacity of links approaching to intersections. Moreover, since the minimization of delay, queue length and stops in the objective function of PTV Balance is weighted by the volume of flow, the higher green share is dedicated to the major approaches as well. The figures below are driven from TRE viewer.

The yellow trend illustrates the out-capacity while blue trends shows the out-flow.



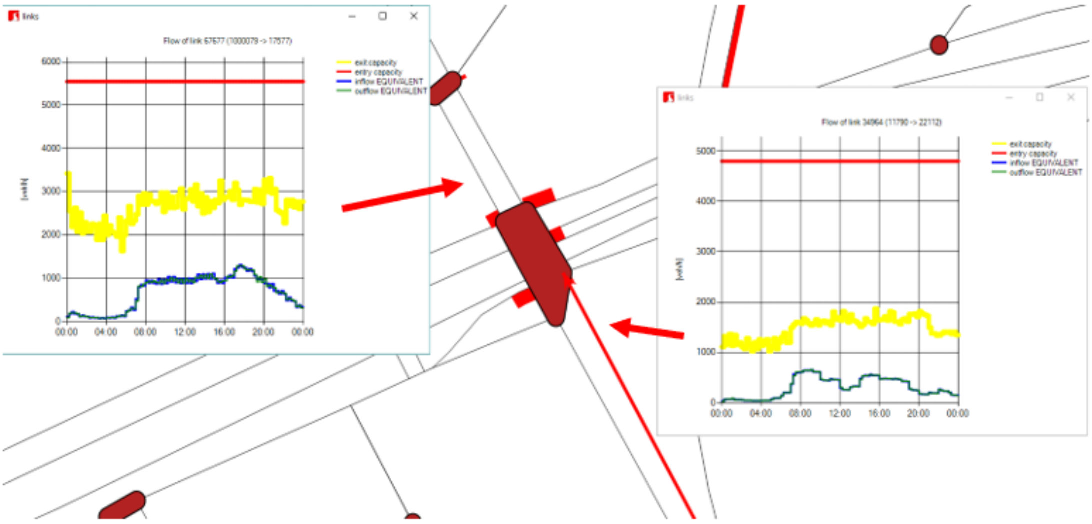


Figure 43 Balance intersections 05(above)and 03(Beneath)

The Figure 44 illustrates the reflective behaviour of PTV Balance to the fluctuation of flow along a day. Green duration is rising and dropping according to the perceived flow of PTV Balance. Q used is a trade-off between the detected flow and model flow, priority is with detected flow unless detectors are defecated or broken.

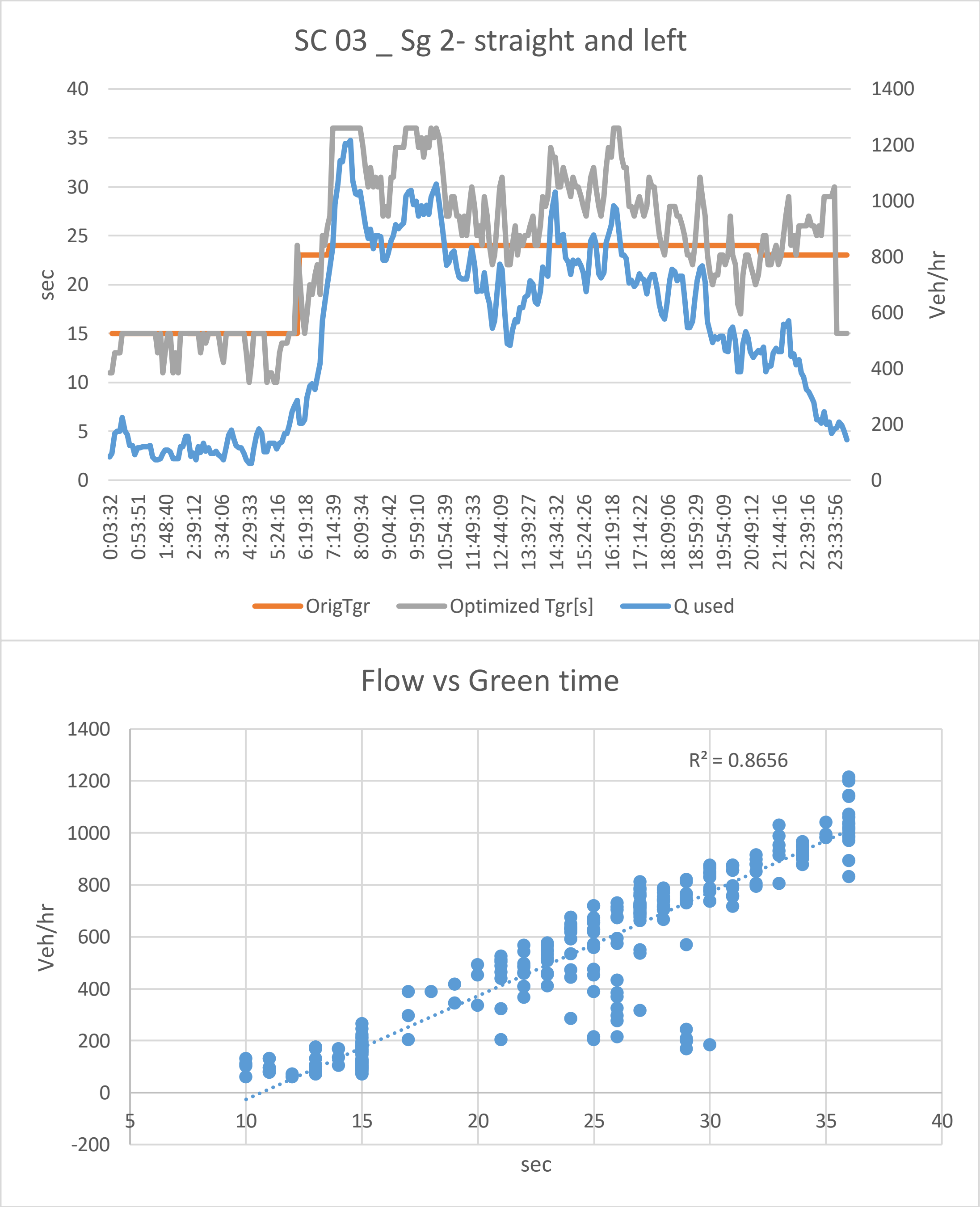


Figure 44 Controller2 signal group 3-straight and left

12 Results

After all internal evaluation of PTV Optima-Balance, it’s time to encounter the accomplishment of this integrated system on the traffic easing and mitigation of congestion.

Beyond the model performance indexes of integrated system like Optima KPIs, a survey and a travel time analysis have been performed to prove the enhancement of traffic condition by real data from the field.

12.1 Survey on the Balances intersections

A survey has performed twice, before and after PTV Optima-Balance implementation. Before survey refers to the period of 2017/12/15~2018/1/21 and After survey has been performing from 2018/1/29 to 2018/2/13. The used methodology considers the conditions below:

I. The methodology of average delay is based on Taiwan Traffic Engineering Manual.

II. Each approach in a junction should be prepared for at least 2 observers in the case of manual survey, one is responsible for counting, the other is responsible for record. In this project, survey company use video camera and record each approach’s queue length, so each approach could be done as 1 observer.

III. For each approach, the number of vehicles stops and pas through the stop line should be recorded.

IV. The Survey performed for an hour over the defined period twice a day_ Am, PM or weekends

V. Every 15 sec numbers of through or stopped vehicles are recorded.

VI. Therefore, collecting an hour will produce (4 * 60) =240 groups of 15 sec data.

VII. Total queue delay time = (number of queue vehicles in each group) *15 sec

VIII. Number of passing vehicles = total number of vehicle passing through the stop line.

IX. Queue delay per vehicle = VII / VIII

X. The queue length has measured considering the length of equivalent vehicle 5.5m.

XI. Computation of objectives are under three categories of approaching link, signal group and lane base.

In the other words, instead of exploiting the arrival and departure rate (like Webster delay computation), the intervals are assumed short enough so that delay is caused by all stops vehicle *15 sec and number of arrival is equal to the departure volume. And further assumption is the consistency of stopped vehicles over 15 seconds of observation (a bit overestimation of Delay value as there might be some vehicles with waiting time less than 15 seconds while their waiting time is rounded up to 15 seconds).

Eventually, the results are aggregated in the signal controller level. The Table 2 shows the aggregated result of each day. Delay, waiting and departure are stand for travel time delayed by stopped vehicle, number of stopped vehicles and number of through vehicles respectively. Weighted average has produced by considering having 4 records of weekends and 10 records of AM and PM over weekdays. According to the overall section of table we are witness of about 12 percent in serving more vehicles while the waiting factors has less proportionally increased, only 8 percent. However, delay has dropped by 5 percent which is the true interpretation of travel time.

The Figure 45 illustrates the objectives of survey just for weighted average out of all days. Percentage is driven by

$$Percentage = \frac{After - Before}{Before}$$

		SC3			SC6			SC5		
		Delay (%)	#Waiting	#Departure	Delay (%)	#Waiting	#Departure	Delay (%)	#Waiting	#Departure
After/ Before percentage	Weighted Ave	-4.25	-1.41	3.06	-19.92	-17.37	2.93	5.04	7.46	1.81
	Weekends	-15.64	-10.07	6.21	8.52	12.03	3.29	8.19	11.22	2.29
	AM_Peak	-6.63	-6.65	0.33	-34.73	-34.09	0.91	-1.99	-0.56	0.93
	PM_Peak	7.25	10.77	3.28	-27.87	-24.16	4.66	9.55	12.49	2.29

		SC4			SC1			Overall		
		Delay (%)	#Waiting	#Departure	Delay (%)	#Waiting	#Departure	Delay (%)	#Waiting	#Departure
After/ Before percentage	Weighted Ave	-3.69	1.08	4.39	18.12	18.38	-0.09	-4.70	8.15	12.11
	Weekends	-12.09	-5.52	6.37	31.39	41.48	8.07	20.37	49.14	26.23
	AM_Peak	-4.78	-2.50	1.86	12.81	9.14	-3.36	-35.32	-34.67	0.68
	PM_Peak	4.11	9.93	5.35	12.81	9.14	-3.36	5.86	18.17	12.23

Table 2 Intersection survey

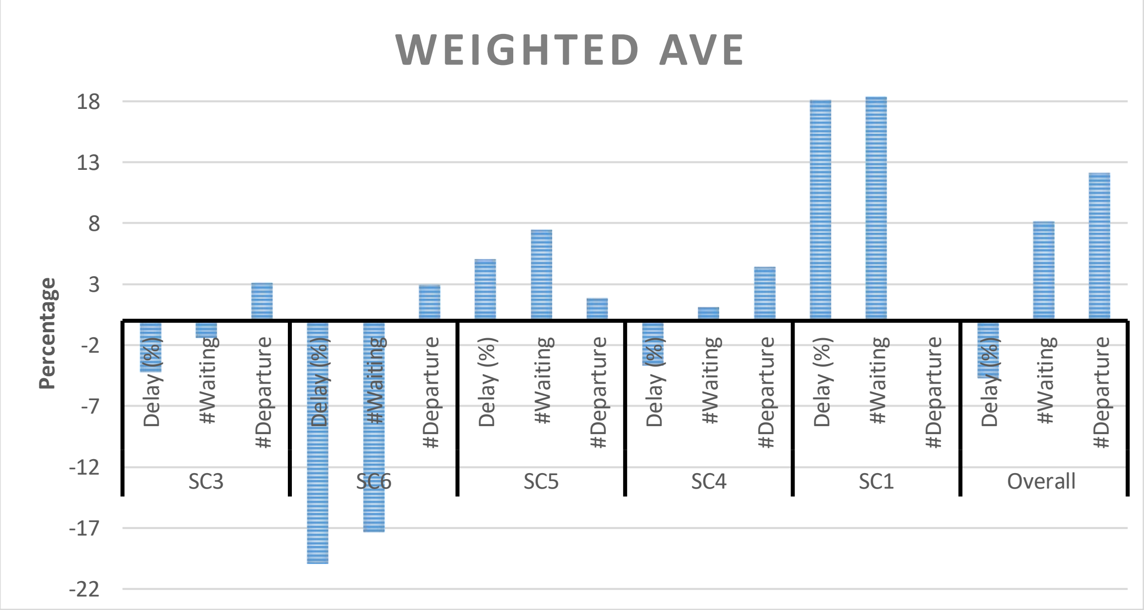


Figure 45 Weighted Ave of survey objectives

12.2 Travel time evaluation by E-Tags

There is a fairly good dispersion of E-tags over the Taichung city. See the Figure 46 . Accordingly, a vehicle is identified once it is passing from an e Tags, then by passing from second e Tags its chosen path and travel time can be recorded as well. There has been defined 33 predefined paths. The analysis of before/ after travel time on the paths claims a considerable reduction. Moreover, by extension of the previous survey result, surging demand by12 percent, on the entire network, the accomplishment of PTV Optima-Balance is amplified even more. Travel time analysis proves the reduction of overall travel time by 13% in spite of the fact that demand trend has been surged in after analysis period.

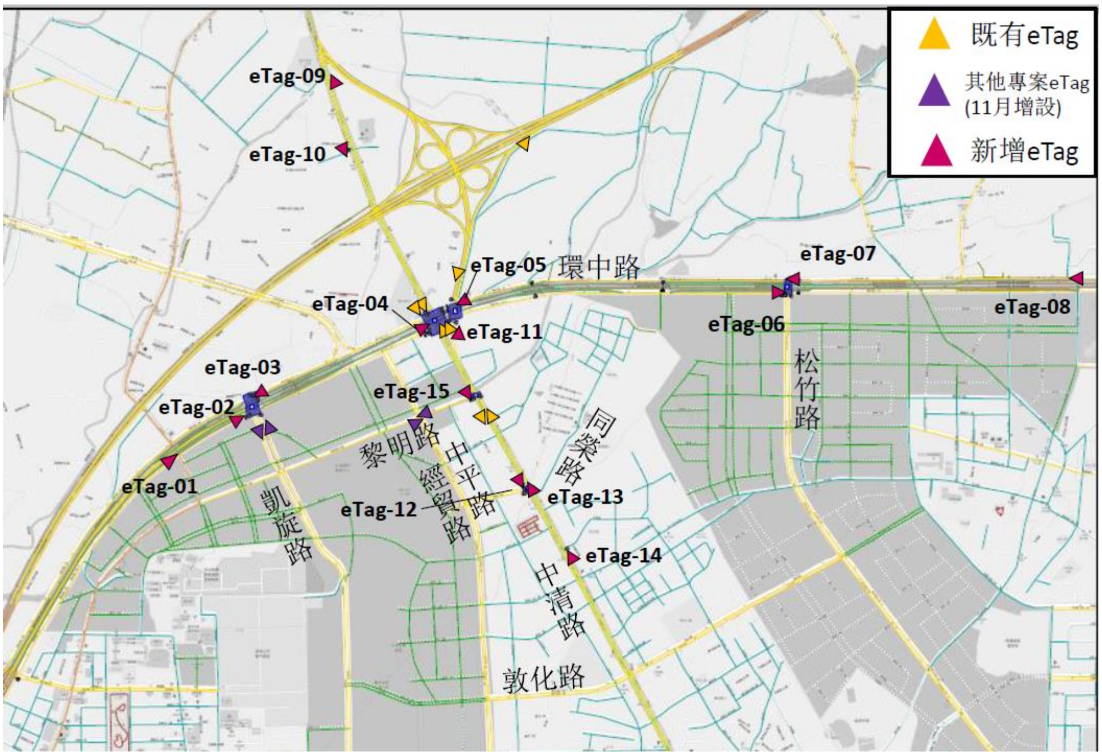


Figure 46 e Tags

The average travel time for 27 routes is illustrated hourly by the trends in the Figure 47, also travel time is aggregated to the daily value in minutes shown route by route and in overall average in the Figure 48.

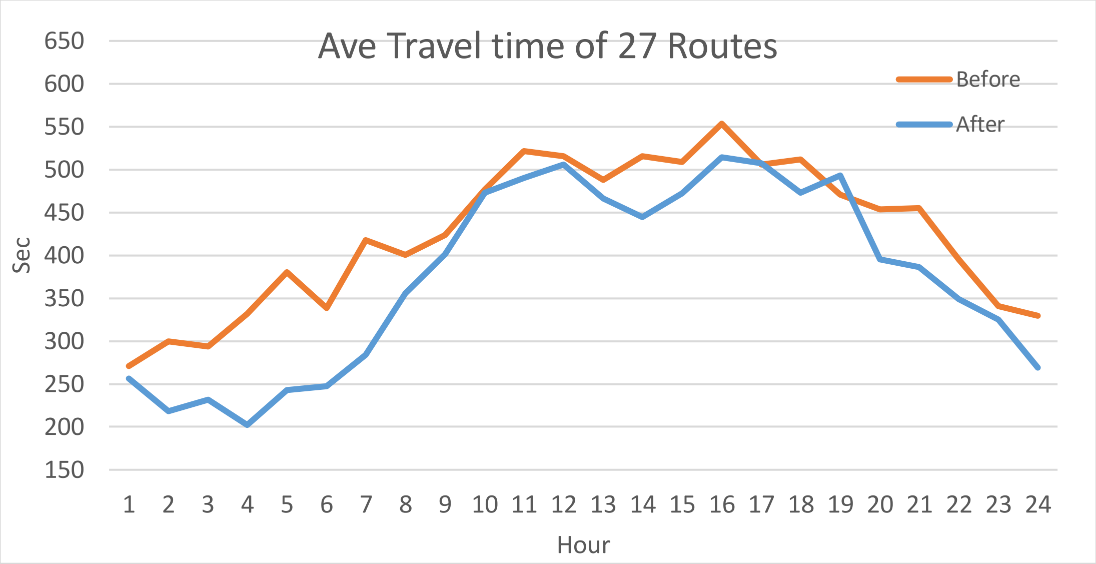


Figure 47 Ave Travel time- hourly

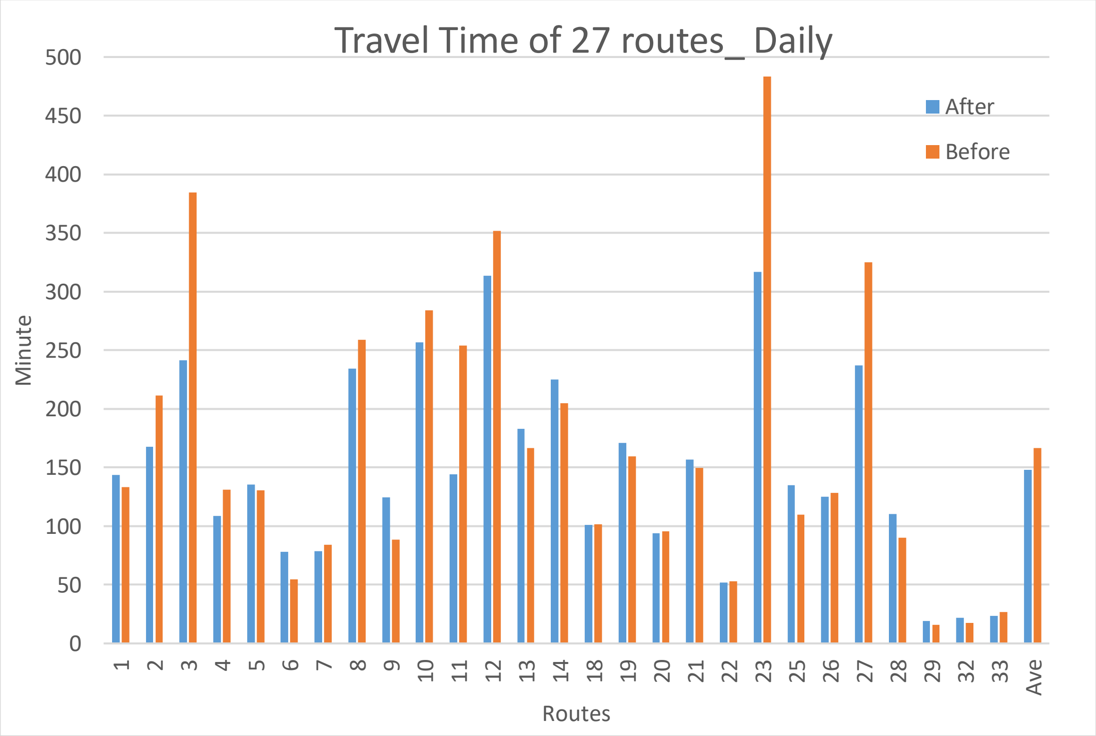


Figure 48 Travel time of 27 routes and Ave value

13 Conclusion

Recently Traffic Management has stepped into a new era thanks to the quick pace of technological development. Even though the principal of transport engineering has been enhanced enough theoretically to address common troubles of urban transport, a robust application with the capability of real time data integration has been missing block to imply transport state of art so far. Efficiency and accuracy of an application play a crucial role in the penetration of the application into the traffic management market which inevitability has direct relation with buried methodologies and concepts in the application.

Traffic model is proven as a good application containing both traffic concepts and the influence of real time data in an entity. Thus, recent powerful concept of GLTM [6] is exploited in a dynamic online traffic model simulation called PTV Optima. Even more, its performance has been improved by integrating PTV Balance as adaptive signal controller. Additionally, PTV Optima is equipped with several engines feeding the simulation engine with real time data including traffic data observation, adpted signal plans and incidences. Undoubtedly the satisfaction out of a traffic model can be accomplished providing that the supply and demand, two main components of traffic model, undergone a perfect fine tuning by the historical traffic data analysis.

Recently, downtown of Taichung city has faced typical urban traffic problem including heavy congestion, high perturbation impact of local roads on main roads, and high disutility of commuters out of malfunctioning of signal controllers. Thus, PTV Optima-Balance has been implemented recently aiming at real time traffic solutions. The integration system assists authorities in decision making which should be quick in real time solution and even provide solutions proactively. Being proactive does not make sense unless the application comes up with a reliable prediction even short time. Exceptionally PTV Optima-Balance was successful in this deed and attained a profound performance indexes like mitigation of travel time and volume of served vehicles which is illustrated in the chapter 12.

14 References

[1] PTV AG, Balance User Manual, November 2017, Karlsruhe, Germany

[2] Yi-Chuan Wang and Hui- Sheng Feng,2018, *Implementing Coordinated Real-time Regional Traffic Control System to Solve Traffic Congestion in Taichung City*, Transportation Bureau of Taichung City Government.

[3] Gentile.G., 2009, *The simplified theory of kinematic waves based on cumulative flows: application to macroscopic link performance models,* Transportation Systems Analysis: Models and Applications. Second Edition, Springer, pp.497-510

[4] NEWELL, G. F., 1993, *A simplified theory of kinematic waves in highway traffic,* Tronspn. Res:B. Vol. 27B, No. 4, pp. 281-287,

[5] Bellemans,T., Schutter, B. De., and Moor, B. De., 2002, *Models for traffic control,* Journal A, vol. 43, no. 3–4, pp. 13–22

[6] Gentile, G., 2008, *The General Link Transmission Model for dynamic network loading and a comparison with the DUE algorithm*, Proceedings of the Second International Symposium on Dynamic Traffic Assignment, Leuven, Belgium

[7] Daganzo, C. ,1994, *The Cell Transmission Model: Network Traffic*, UC Berkeley: California Partners for Advanced Transportation Technology Link Transmission model

[8] Tiddi, D., 2012, *Models for dynamic network loading and algorithms for traffic signal synchronization in congested networks*, Ph.D thesis, SAPIENZA University of Rome, Engineering faculty.

[9] Wong, S.C., Yang, H., 1997, *Reserve capacity of a signal-controlled road network,* Transportation Research Part B 31, 397-402.

[10] Allsop, R.E., 1968, *Selection of Offsets to Minimize Delay to Traffic in a Network Controlled by Fixed-Time Signals*, Transportation Science 2, 1-13.

[11] Gartner, N.H., Little, J.D.C., Gabbay, H., 1975, *Optimization of traffic signal settings by mixed-integer linear programming, Part I: the network coordination problem,* Transportation Science 9, 321-343.

[12] Little, J.D.C., 1966, *The synchronization of traffic signals by mixed-integer-linear-programming*, Operations Research 14, 568-594.

[13] Gartner, N.H., Assman, S.F., Lasaga, F., Hou, D.L., 1991, *A multi-band approach to arterial traffic signal optimization*, Transportation Research Part B 25, 55-74.

[14] Gartner, N.H., Hou, D.L., 1994, *Performance Evaluation of Multi-Band Progression Method*, 7th IFAC/IFORS Symposium on "Transportation Systems: Theory and Application of Advanced Technology", Tianjin, China.

[15] Richards, P.I., 1956, *Shockwaves on the highway*, Operations Research 4, pp. 42-51.

[16] Cohen, S.L., 1983, *Concurrent Use of MAXBAND and TRANSYT Signal Timing Programs for Arterial Signal Optimization,* Transportation Research Record 906, 81-84.

[17] Husch, D., Albeck, J., 2006, SYNCHRO 7 User Guide, Trafficware.

[18] Transportation Operations Group, 2006, PASSER V Guide, Texas Transportation Institute.

[19] Hunt, P.B., Robertson, D.I., Bretherton, R.D., Winton, R.I., 1981: SCOOT - *a traffic responsive method of coordinating signals*, TRRL Laboratory Report 1014.

[20] Donati, F., Mauro, V., Roncolini, G., Vallauri, M., 1984: *A Hierarchical Decentralised Traffic Light Control System. The First Realisation*: 'Progetto Torino', in Proceedings of IFAC 9th World Congress.

[21] Gartner, N.H., 1989, OPAC: *Strategy for demand-responsive decentralized traffic signal control*, in Proceedings of IFAC Control, Computers, Communications in Transportation, Paris.

[22] Friedrich, B., 2000, *Models for Adaptive Urban Traffic Network Control*, in Proceedings of the 8th International Conference of the European Working Group on Transportation, Rome.

[23] Robert, J., Montana, Ch., 2017, *Decision Support Tool for traffic management centre in urban environment*, 12th ITS European Congress, Strasbourg, France

[24] Abu-Lebdeh, G., Benekohal, R.F., 2003, *Design and evaluation of dynamic traffic management strategies for congested conditions*, Transportation Research Part A 37, 109-127.

[25] PTV SISTeMA, Balance/Epics Integration in Optima, edition 1.0, 2015, Rome, Italy

[26] PTV SISTeMA, Optima help centre,2018, access September 2018, http://ptv-optimahelpcenter.ptvag.ptv.de/

[27] Daganzo, C., Geroliminis, N., 2008, *An analytical approximation for the macroscopic fundamental diagram of urban traffic*, Institute of Transportation Studies, University of California, UCB-ITS-VWP-2008-3