the mind of movement

PTV BALANCE

USER MANUAL

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1 Introduction

This document describes methodology and data provision for PTV Balance. The document is in a preliminary form and shall not be forwarded beyond the original recipients.

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). Numerous other projects followed in which the system and its algorithms were tested, evaluated and improved.

PTV Balance consists of a macroscopic traffic model that estimates flows in accordance to detector data, a control model and a mesoscopic traffic flow model in order to calculate the effects of a specific signal plan, and most importantly different optimization algorithms. Additionally it is possible to replace the macroscopic traffic model by external superordinate models that are able to take a whole conurbation into account. Currently PTV Balance can use PTV Optima and DRIVERS (the latter Gevas software see Systementwicklung und Verkehrinformatik GmbH 2012a) as superordinate traffic models. They allow PTV Balance to access the results of systems which use highly specialized and partially microscopic models for the calculation of the current traffic situation.

PTV Balance is independent of 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. Its ideal partner is the sister product PTV Epics, as it adds strong local adaption, has full transit signal priority and is integrated with PTV Balance from a technical and a methodological point of view already.

PTV Balance is seamlessly embedded into the environment of the PTV Vision suite. The road network and the traffic demand are modelled in PTV Visum. Signal control related data and parameters are provided with Vissig, a module of either PTV Visum or PTV Vissim. PTV Balance's input formats are shared with PTV Vissim and Vissig, the former being able to fully simulate the effects of the Balance control, thus enabling an elegant way of testing, calibrating and evaluating the effects on the road network.

2 Functionality

2.1 System Architecture

2.1.1 Basic Idea

In order to understand the functionality of the adaptive network control, the basic system architecture will be explained first.

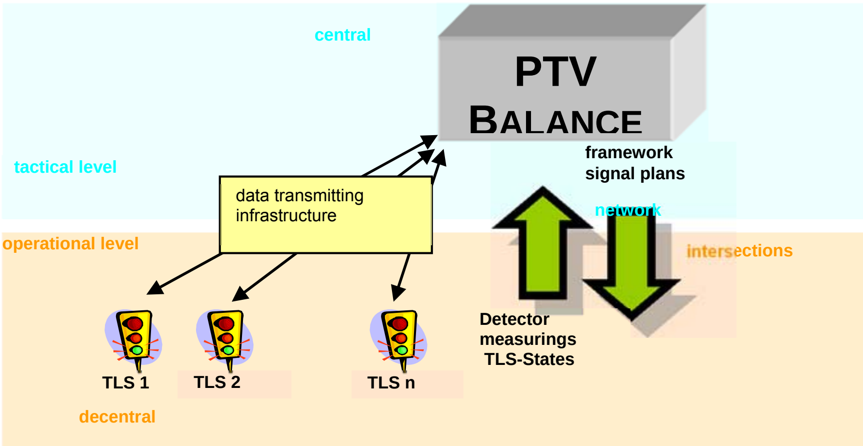


Figure 1: Two-Level-Concept of PTV Balance

The system architecture is characterized by the two-level-concept. In this concept, the functionality of the TLS-Controlling is divided hierarchically into two levels (see Figure 1)

- An efficient microscopic controlling method looks at short-term changes of the traffic volume, like during the prioritization of public transport, on the local, respectively the operational level of the intersection. Usually the local controlling method works on a second-by-second basis.
  In general any local traffic control system control can be applied, as long as it integrates an interface for the parameters which are created by PTV Balance (so-called framework signal plans. This flexibility was one of the main goals during the development of PTV Balance, in order to be able to apply the system quickly without changing the local traffic light system control. Currently PTV Epics, the Trelan/Trends-System (Gevas software Systementwicklung und Verkehrinformatik GmbH 2010a/b) and the VS-PLUS-Control (Verkehrs-Systeme AG 2012) are used for the local control. Simulation tests with the American ring barrier controller have also been conducted.
- The actual PTV Balance-algorithm works as macroscopic system on the tactical level of the TLS-Network. It covers the middle- and long-term area (5-15 min) of the traffic-adaptive control by sending framework signal plans to the intersections in that interval. A framework signal plan defines static- and variable areas for the single phases of the local control for all traffic light system of a group with the same cycle time. Inside the variable areas, the local control can adapt to the current traffic volume by using its local detection. Nevertheless, a basic structure for the single traffic light systems is provided by the framework signal plans. The green times of the signal groups can vary inside this framework.

The reduction of delay by the traffic adaptive coordination of traffic signal systems among each other (offset-optimization, green wave) and by the rough adaption of the green times of the signal groups is processed centrally on the level of the network. A second-by-second adaption of the green times is processed in the local controller. If there is no local detection or traffic responsive control available at the intersection, the Balance framework signal plans can also be used directly as fix time-program.

A PTV Balance-System can control a sub-net of up to 100 intersections, which are divided into one or more control groups, when used with a standard PC. In general, this additional division is required in order to distinguish different areas of the network with different traffic related characteristics. This way, they can be controlled adequately. This especially concerns the selection of a signal program with an adequate cycle time, which is defined for all traffic light systems of a group by the network control.

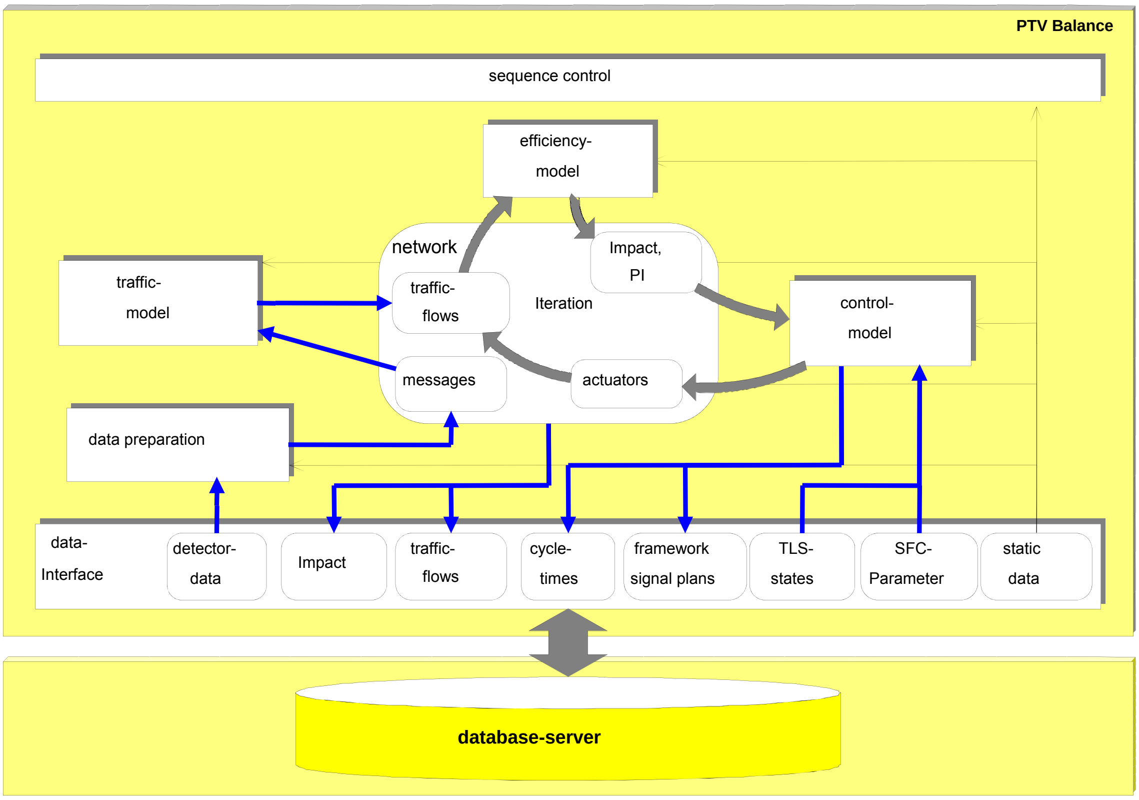


Figure 2: Block-diagram of the PTV Balance network control

The central database structure in PTV Balance is the network model. The street network is represented internally as a graph in form of nodes and edges at first. Figure 3 illustrates this aspect at the example of a small net with two intersections.

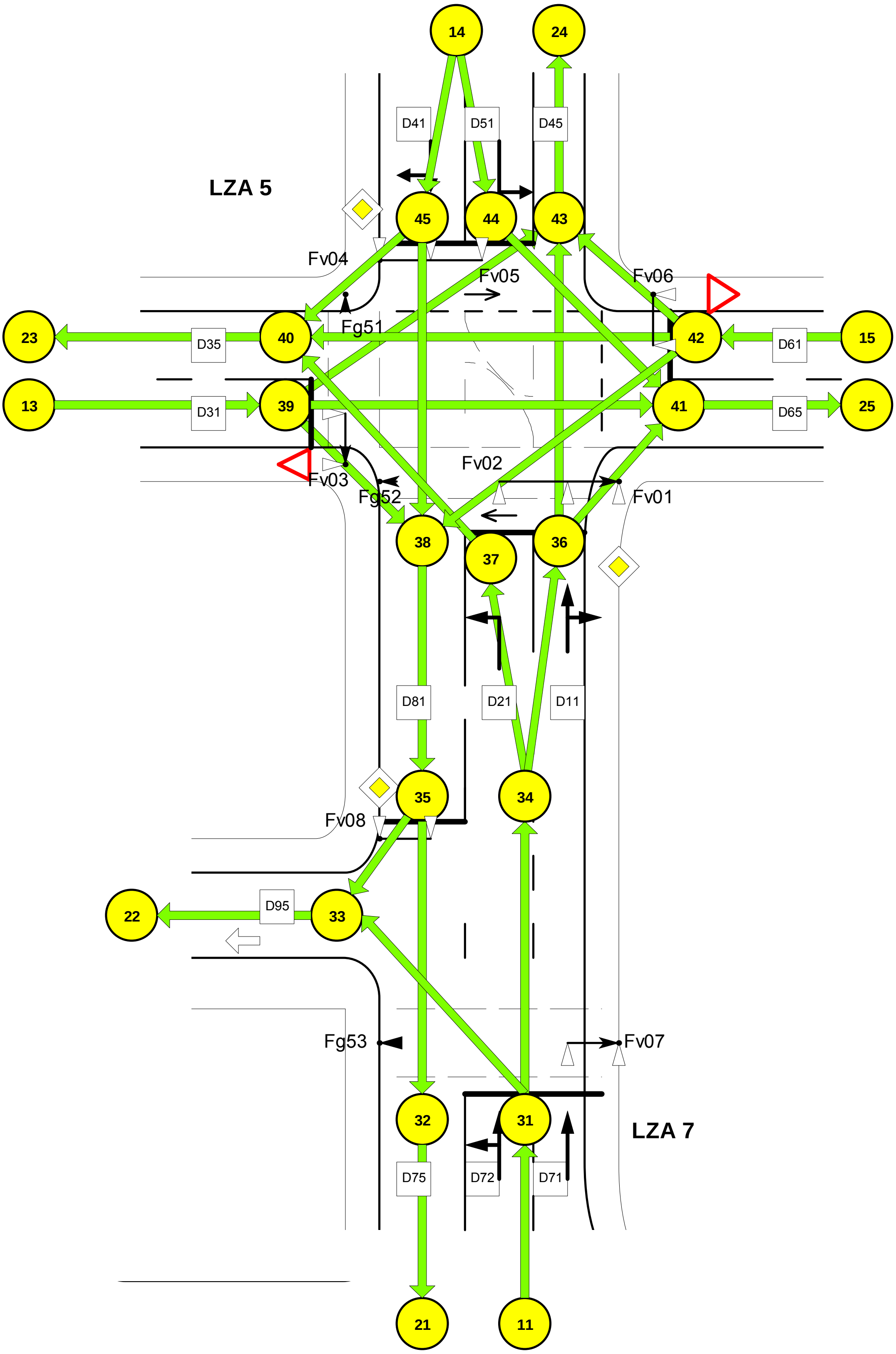


Figure 3: Example of a simple network model

A general (spatial) relation for the data which is generated, respectively requested, by the different components of the control, is given by the edges of the graph. Therefore, the edges are the central container for the traffic data within the PTV Balance-System. In general, the procedures of the PTV Balance-Controlling system can be divided into five functional groups:

- Collection and Preparation of data
- Illustration of the traffic
- Determination of efficiency and evaluation of control alternatives
- Creation of the control alternatives
- Data interface

Moreover, there are system functions available for the control of the internal process or for database accesses, etc. Although, these functions are not discussed further in this manual, the next chapters will shortly describe the functional groups mentioned above.

2.1.2 Collection of Data

Before the actual optimization of the traffic control can start, it is necessary to estimate the current traffic state the road network as good as possible. The traffic situation in the controlled area is collected by detectors in the form of aggregated or disaggregated measurements for the current calculation interval. The detector data is gathered by the controllers and delivered to the central database, where it is stored. Of course also detectors which are not connected to a traffic light system can be utilized by PTV Balance. Moreover, there are additional kinds of dynamic data of the traffic light systems which are also collected. For example the currently running signal program, respectively the cycle time or different working modes of operation of the traffic light-unit or the detector-unit.

In addition to the definition of available detectors, there is also information about the assigned road link respectively the assigned lane in the data of the control. This way, a clear allocation of measurements to links and lanes of the graph is given by the index of the detector. The measured values of the detectors are tested considering their plausibility. Afterwards, the measurements are calibrated and aggregated in relation to their edge and lane. Because of the varying interval lengths of the measurements and the different number of detectors on the edges, the vehicle counts are also standardized to hourly values:

$$q(a) = \frac{\sum_{D \in Det(a)} \sum_{t=tAkt-Int}^{tAkt} (k_D \cdot ms\_Val(D,t) \cdot ms\_Len(D,t))}{\sum_{D \in Det(a)} \sum_{t=tAkt-Int}^{tAkt} (ms\_Len(D,t))} \cdot 3600 \cdot lanes(a) [Veh/h]$$

Where

D	index of detector
a	index of edge
Det(a)	number of detectors on edge a
kD	factor of calibration for detector D
tAkt	current time
Int	interval length for aggregation (here 900 sec)
t	timestamp of measured value

ms_Val(D,t)	traffic count for detector D at point in time t [veh]
ms_Len(D,t)	length of the aggregation interval of the measured value of detector D at point in time t [sec]
lanes(a)	number of lanes of edge a

The standardized measured values are saved into the edge structures and form the base for the further modelling of the traffic state.

The positioning of detectors should be done regarding the requirements of the traffic model according to the following rules (Gevas software Systementwicklung und Verkehrsinformatik GmbH 2012c):

1. There have to be single- or double loop detectors on every lane that leads to an intersection controlled by the traffic light. The distance to the stop line should be at least 20m and not more than 50m. The ideal detector position is 40-50m in front of the stop line.
2. Every lane has to be detected on its own. No detector may cover more than one lane.
3. In case of turn-off lanes, the detector should also be placed according to the distances suggested in 1. if it is possible. If the turn-off lane is shorter, the detector should be placed on the turn-off lane so that it is as far as possible from the stop line and measures all turning vehicles. If this is not possible, the second criterion is more important. It may be necessary to do an on-site inspection in order to decide this. In addition, single loop detectors should be placed on the main lanes 50m in front of the sop line.
4. At the edges of the area which is selected for the measuring of the traffic situation (usually the main road network), detectors which measure the outflow may be placed (about 30m behind the stop line) if there are big differences between the incoming and the outflowing traffic during the day. This improves the quality of the origin-destination estimation of the network model.

According to this, the detectors which are suggested here are normal single loops which can also be used for the time gap control. It is also an option to use other means of detection, but only if it is guaranteed that the cars are reliably counted even under adverse weather conditions and under heavy saturation.

2.1.3 Traffic Model

The PTV Balance-traffic model builds an internal spatial/ chronological representation of the current traffic situation out of traffic flows measured at different measuring sections. Basically it consists of three different functional parts which are arranged in two different levels (see Figure 4):

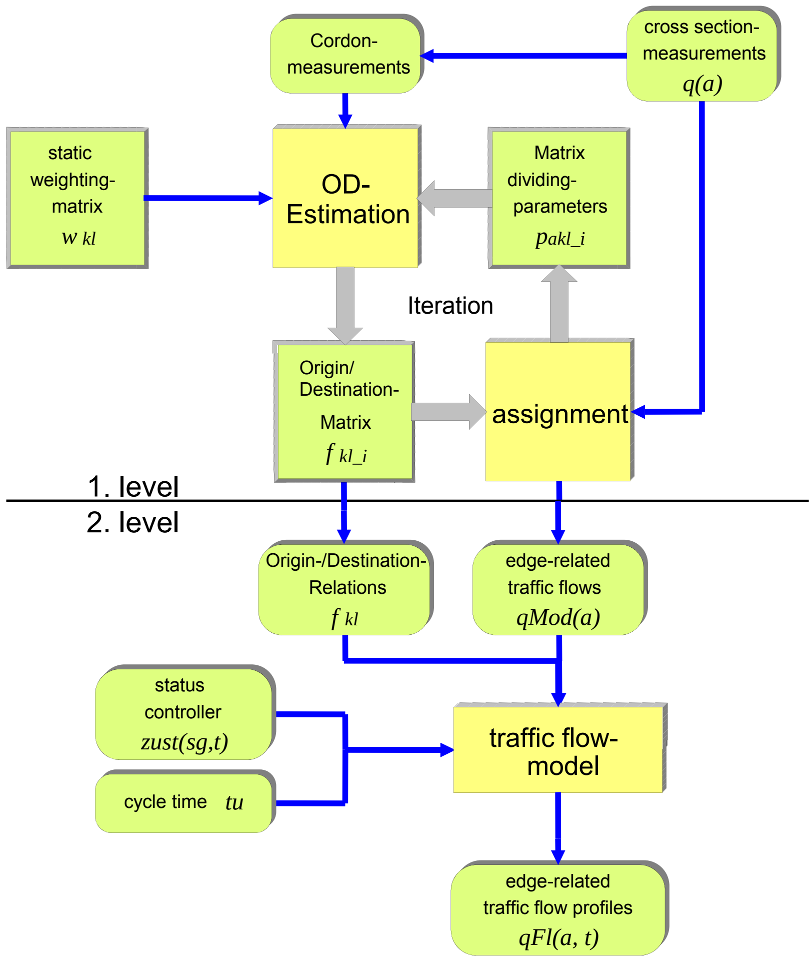


Figure 4: block diagram of the PTV Balance-traffic model

The first level (see chapter 2.1.3.1) consists of a macroscopic traffic model (Ploss 1993), which is called only once every operation step. It consists of:

- An OD-Estimation for the approximate determination of the origin-/destination-relations in the sub-net and
- A traffic assignment for the allocation of the traffic flows to the road edges in the network

The second level (chapter 2.1.3.3) is a mesoscopic traffic flow model, which periodically generates traffic flow profiles out of the macroscopic traffic parameters of the first level. This takes place during every step of the signal plan-optimization process inside PTV Balance.

2.1.3.1 Macroscopic traffic model (1. Level)

An estimation of the matrix (fkl_0) of the traffic flows [veh/h] from an entry-edge k to an exit-edge l is processed according to a static weighting-matrix (wkl) and to the in- and outflows at the edges of the net (OD-Estimation). The entropy-maximizing algorithm of (Van Zuylen and Branston 1982) is used for the OD-Estimation.

In the first step, the in- and outflows at the edges on the border of the controlled area are estimated. This goal is achieved either by using already existing measurements, or by estimating the traffic, based on the historic weighting matrix and the measured values which are available. Afterwards, the existing weighting-matrix is adapted to the previously calculated in- and outflows, by using the „Furness-Algorithm".

The matrix of the origin-destination-relations is the input parameter for the traffic assignment, which distributes the traffic to the streets in the network using an incremental multiple-assignment-algorithm. The traffic is assigned to the edges in shares of 10%, 20%, 30% und 40%. After every step, a route-searching algorithm is conducted. This algorithm calculates the fastest route according to impedances in the net (like travel times) and assigns the whole traffic of this step to the respective edges (All-Or-Nothing Assignment).

The result of the traffic assignment are the modelled, edge-related traffic flows qMod(a) [Veh/h] and also the matrix of the distribution parameters (p_{akl}), that defines which share of the traffic relation f_{kl} drives over edge a. Therefore, the following correlation exists:

$$qMod^i(a) = \sum_{k \in E} \sum_{l \in A} p^i_{akl} \cdot f^i_{kl}$$

Where

i	step of iteration
a	index of edge
k, l	index of origin/destination
E, A	number of entries/exits respectively origins/destinations in the network
p^i_{akl}	share [0...1,0] of the traffic relation fkl which uses edge a

The relative deviation X(a) between traffic model and reality can be calculated with the help of the estimated traffic flows qMod(a) and the real traffic flows q(a) measured on the edges a in the network. The deviation is used in combination with the distribution parameters pakl in order to correct the estimation of the origin-destination relations in an iterative process. Criteria for the cancellation of the so called internal iteration are the exceeding of a previously defined number of iterations or the shortfall below a given value of the standard deviation between measured and estimated value.

The procedure after the „Furness-Algorithm", described above, is repeated until a given number of iterations is reached. The first level of the traffic modelling is done by finishing the external iteration. Afterwards, macroscopic traffic volumes qMod(a) [Veh/h] are defined for all edges a of the network, and especially for edges where no measured values are available. Other results of the first level are the matrix of the origin-destination relations (fkl) in the network and the distribution parameters (pakl).

2.1.3.2 Embedding into superordinate traffic models

A superordinate traffic model like PTV Optima can also be embedded instead of the macroscopic traffic model discussed above. PTV Optima's model is dedicated to traffic state estimation based on a wider range of detection sources (loops, ANPR, FCD...) and can calculate the real traffic situation in a network more precisely. As input PTV Balance requires the traffic volumes of every edge and the turn-off rates of the intersections of the network control. The values should be delivered at least every 5 minutes.

2.1.3.3 Mesoscopic traffic model (2. level)

Traffic flow profiles qFl(a,t) [Veh/sec] are created for all edges based on the data of the traffic model (1. Level) or a super ordinate traffic model and the states of the signal groups in the network, given by the control model. The length of the flow profiles represents the homogeneous cycle time tu of the particular control group (see Figure 5).

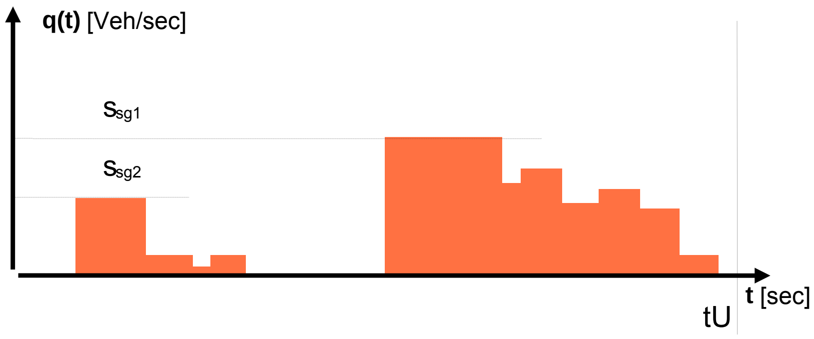


Figure 5: Illustration of the traffic flow profile of the second level of the traffic model

The mesoscopic traffic flow model takes the influence of the traffic lights, the travel times and the dissolving of the queues through changing speeds on the groups of vehicles into account. Therefore the outflow zFl(a,t) at the end of an edge a is defined as follows:

$$zFl(a, \mathrm{mod}\, tu(t+tr)) = \begin{cases} 0 & \text{if there is no release at point in time } t \\ s_{sg} & \text{if } sg \text{ is released at } t \text{ and} \\ & \text{the queue } l(a,t)+qFl'(a,t) > ssg \\ & \text{otherwise } l(a,t)+qFl'(a,t) \end{cases}$$

With the estimated average travel time on the edge

tr(a) = len(a) / v(a) [sec]

The dissolving of the vehicle-groups is modelled over the length of two intervals 2L by moving average determination

$$qFl'(a,t) = \frac{1}{2L+1} \sum_{t'=t-L}^{t+L} qFl(a,t')$$

With the given whole-number length of the interval L

$$L = \left(k(a) \cdot len(a)\right) DIV\ v(a)$$

where

t	periodical base of time [1... tu sec]
sg	index of signal group sg, controlled by edge a
s_{sg}	saturation of signal group sg [Veh/sec]
l(a, t)	queue length [Veh] on edge a at point in time t
k(a)	calibration of the dissolving
len(a)	length [m] of edge a
v(a)	estimated average speed [m/sec] on edge a
DIV	whole-number division

The periodic traffic flow model q(a, t) at the beginning of an edge results from the additive connection of the outflows zFl(a´, t) of the incoming edges a´. These outflows are distributed to the following edges, according to their share of the whole traffic volume:

$$qFl(a,t) = \sum_{a' \in In(a)} p(a',a) \cdot zFl(a',t)$$

The distributing factors p(a´, a) contain the share [0...1.0] of the total traffic volume on edge a, which comes from edge a´. This share is calculated by using the traffic volumes qMod which were defined in the first level of the traffic model:

$$p(a',a) = \frac{qMod(a')}{\sum_{\bar{a} \in In(a)} qMod(\bar{a})} \cdot \frac{qMod(a)}{\sum_{\bar{a} \in Out(a')} qMod(\bar{a})}$$

where

In(a)	number of entry edges of edge a
Out(a´)	number of exit edges of edge a´
qMod(a)	modelled traffic volume [Veh/h] on edge a

At the beginning of the traffic flow modelling, the flow profiles are initialized for the cordon-edges. Here an equally distributed flow profile is assumed:

$$qFl(a,t) = \frac{qMod(a)}{3600} \qquad for \ \ t = (1 ... tu)$$

Starting from the edges at the network entrances, this procedure is executed periodically for all edges in the network. At the end of this process the traffic flow profiles qFl are defined for all edges in the network. The flow modelling is processed for every edge of the sub-net during every step of the optimization. Usually there are some thousands optimization-steps processed during every PTV Balance-call. It is clear that the traffic flow model had to be implemented very efficiently.

2.1.4 Determination of Efficiency and Evaluation of Control Alternatives

With the help of the effect model, the impact of the control alternatives is predicted (calculated) for the next step in time. Afterwards, the control alternatives are evaluated by a performance index. The relevant variables for the calculation of the index are: weighted vehicle waiting times, number of stops of vehicles and queue-lengths.

$$PI(x,y) = \sum_{sg \in SG} (\alpha_{sg} D(x,y,sg) + \beta_{sg} H(x,y,sg) + \gamma_{sg} L(x,y,sg))$$

where

SG	number of signal groups in the sub-net
α_{sg}, β_{sg}, γ_{sg}	emphasis of waiting time/ stops/ queue-lengths for signal group sg
D, H, L	vehicle waiting times/ stops/ queue-lengths for signal group sg
x	vector of control variables
y	vector of traffic related variables

The variables of efficiency are generated by two models: Every second, a high-resolution mesoscopic model calculates the deterministic share by assuming a steady maximum speed and saturation flow. The well-known stochastic part at the stop lines is determined by a macroscopic queue-model that takes overloads into account (see Figure 6).

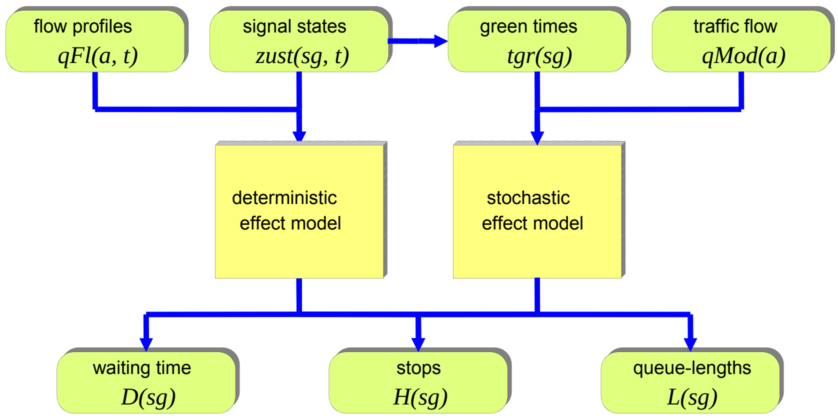


Figure 6: Block-Image of the PTV Balance-efficiency model

The deterministic effect model is based on the flow profiles of the traffic model qFl(a, t) and the cycle time, defined green times of the controllers zust(sg,t). It calculates the impact of the adjacent control alternatives in a numerical, simulative way. The calculation for every second enables the modelling of the traffic related impact of green time-lengths and offsets between adjacent signal groups.

The optimization of green times of a signal group in a TLS-network always has an impact on the traffic related states of signal groups which are located downstream. Therefore, the optimization of the green time is processed for the whole subnet at the same time. Although this holistic solution requires a lot of computing capacity, compared to a heuristic procedure, it considers all relations between the objects in the network.

As it is already mentioned above, the optimization of green times of a signal group in a TLS-network always has an impact on the traffic related states of signal groups which are located downstream. Therefore it is very important to give the downstream signals information about the changes in green time of the upstream signals. In order to do this it is necessary to use the flow profiles of the links which lead out of the subnet, as input variables for the signal groups which are located downstream. Like it is described in chapter 2.1.4.3, the traffic flow profiles of the entry-links of a sub-net are initialized with equally distributed profiles. If there is a traffic flow profile available for an exit-link of an adjacent sub-net, the equally distributed profile will be overwritten. This way it is guaranteed, that the traffic light systems at the edges of the sub-nets get realistic traffic flow profiles.

The deterministic effect model is built similar to the models in the well-known planning system Transyt (Robertson 1969) and the adaptive control SCOOT (Hunt et al. 1981). A simulation of the impact of the controllers on the traffic flow is processed in order to get the efficiency variables vehicle waiting time, number of stops and mean queue-length. The traffic is not modelled as single vehicles (microscopic modelling) but with the help of the macroscopic parameter traffic volume. However, this parameter is available for every second (mesoscopic modelling). Figure 7 illustrates the procedure of the model. The applied formulas are described in the following sub-chapters.

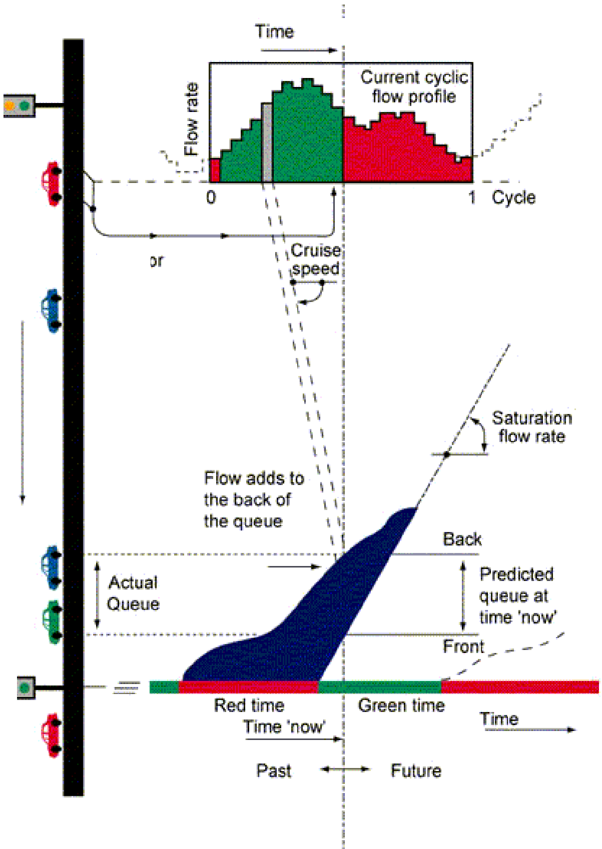


Figure 7: Overview of the deterministic effect model

2.1.4.1 Calculation of delay

The signal group-related vehicle delay D results from the summing up of the queue lengths l(t) which denote the vehicles that have stopped during time frame T. l(t) is defined as the sum of the inflows Q(t) at an origin or entrance (demand process) and as the sum of the outflows Z(sp,t) at an exit or destination (service process) until the point in time t :

$$D_{sg}(sp) = \sum_{t=0}^{T-1} l_{sg}(t) = \sum_{t=0}^{T-1} (Q_{sg}(t) - Z_{sg}(sp,t))$$

where

SG	number of signal groups
sp	signal plan which is evaluated
Q_{sg}	sum of the vehicles which have entered at signal group sg until t
Z_{sg}	sum of the vehicles which have left at signal group sg until t
D_{sg}	sum of the vehicles waiting times at signal group sg during time frame T

The following formula defines the request process Q

$$Q_{sg}(t) = \sum_{t'=0}^{t} q_{sg}(t') \; [FZ]$$

with $q_{sg}(t)$ = inflow [Veh/s] to signal group sg at time t.

The inflow profile $q_{sg}(t)$ is the input parameter for the effect model and is defined as described above.

2.1.4.2 Calculation of the vehicle stops

The following formula represents the sum of vehicles H_{sg}, which are forced to stop due to the creation of a signal plan of the length T at a signal group sg

$$H_{sg}(sp) = \sum_{t=0}^{T} h_{sg}(sp,t)$$

where

sp	signal plan which is evaluated
h_{sg}	sum of the vehicles which have to stop at signal group sg at time t

A vehicle has to stop if it reaches the end of a queue or the stop line while the inflow is greater than the outflow (normally when the signal is red). Therefore, the stops h_{sg} at point in time t are defined as follows:

$$h_{sg}(sp,t) = \begin{cases} q_{sg}(t), if\ t > 0\ and\ Q_{sg}(t) > Z_{sg}(sp,t) \\ 0, else \end{cases}$$

2.1.4.3 Calculation of the queue lengths

In case of the queue lengths, time-related-, current-, average- and maximum queue lengths are distinguished.

The current queue length lsg is calculated by the difference between the incoming and the leaving traffic:

$$l_{sg}(sp,t) = Q_{sg}(t) - Z_{sg}(sp,t)\ for t = (0,\ldots,T-1)$$

The average queue length L and the maximum queue length Lmax can be derived from the formula mentioned above:

$$Lmax_{sg} = max_{t=0}^{T-1}\ (l_{sg}\ (sp,t))$$

$$L_{sg} = \frac{1}{T}\sum_{t=0}^{T-1} l_{sg}(sp,t)$$

The maximum queue length is important for the protection of congestion spaces or to prevent the congestion to reach into previous intersections. It is the maximum queue length that is applied in the performance index of PTV Balance.

2.1.4.4 Modelling of stochastic deviations

The analytic queuing model of (Kimber and Hollis 1979) is used to include stochastic deviations resulting from capacity overloads in the calculation. It only requires the degree of saturation of an entry as macroscopic input parameter. It is calculated by the average traffic volume qMod of an entry and the cycle time-related length tgr(sg) [sec] of the green times of the signal groups:

$$r(sg) = \frac{\sum_{a \in A} qMod(a)}{tgr(sg) \cdot s_{sg}} \cdot \frac{tu}{3600}$$

where

A	number of edges which are controlled by signal group sg
r	degree of saturation
tu	cycle time [sec]
s_{sg}	saturation [Veh/sec] of signal group sg

The result of the macroscopic effect model are the waiting times and average queue lengths created by the random deviations of the traffic flow. They are added to the waiting times of the deterministic effect model (Figure 8). The sum of both models serves as input parameter for the performance index.

The formulas for the stochastic waiting time WKB, sg for signal group sg are defined as follows:

$$W_{KB,sg} = \frac{1}{2}(\sqrt{P^2 + Q} - P)$$

$$P = \frac{1}{2}(1 - r) * T - \frac{g_0 - C}{q}$$

$$Q = 2C\frac{T}{q}\ (r + 2 * \frac{g_0}{qT})$$

Where

r= r(sg)	the degree of saturation calculated above,
g0	the start queue length before signal group,
C	a constant (usually C=0,4 in PTV Balance),
q	capacity in [Veh/s] for the signal group (saturation flow respecting green share)
T	the time frame (usually 300 seconds in PTV Balance).

The stochastic delay is added to the deterministic delay for each signal group.

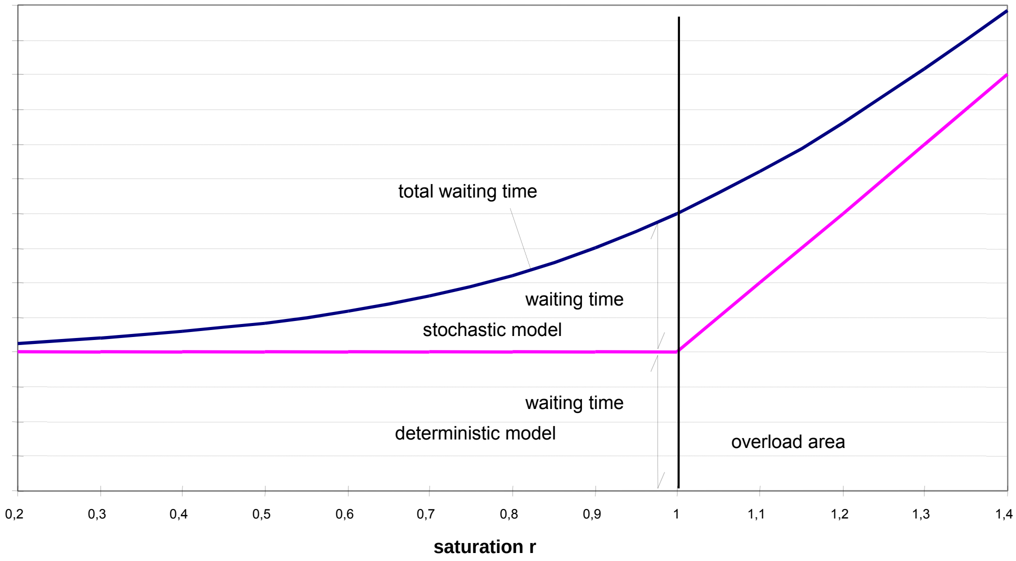


Figure 8: Schematic waiting times with deterministic and stochastic model

2.1.5 Creation of Control Alternatives

The control model of the PTV Balance-network control optimizes the following control parameters:

- Length of the release times (split)
- Chronological location of the release times according to their equal cycle time (offsets)
- Length of the cycle time

PTV Balance was designed using a Hill-Climbing (HC) algorithm for the optimization. In 2008 an additional optimization procedure was developed and implemented into PTV Balance in the German research project TRAVOLUTION: the evolutionary algorithm. One important advantage of an evolutionary algorithm is that it can optimize all control parameters at the same time. The other advantage is that it tends to avoid local optima by applying a parallel search through the solution space. The research project showed that the genetic algorithm significantly improved the optimization quality in term of a better performance index in Balance and, more importantly, also on the road. But it also is consuming much more calculation time. This is not so big an issue in a real world traffic centre, but dramatically slows down the speed when used in conjunction with a micro simulation, e.g. PTV Vissim. That’s why still both algorithms are contained in Balance. The uses can switch between them through an entry in the initialization file.

2.1.5.1 Calculation of split and offset

In contrary to the cycle time, the control model creates framework signal plans for all traffic lights in the sub-network during every call of PTV Balance and sends them to the controllers. A framework signal plan (RSP) contains the length (split) of the release times of all signal groups of the traffic light system and their chronological location (offset) according to the cycle time which is equal for all objects in the control group. Both control variables are optimized together in an integrated approach, which calculates a framework for the starting points of the interstages for every possible periodical stage cycle (see Figure 9).

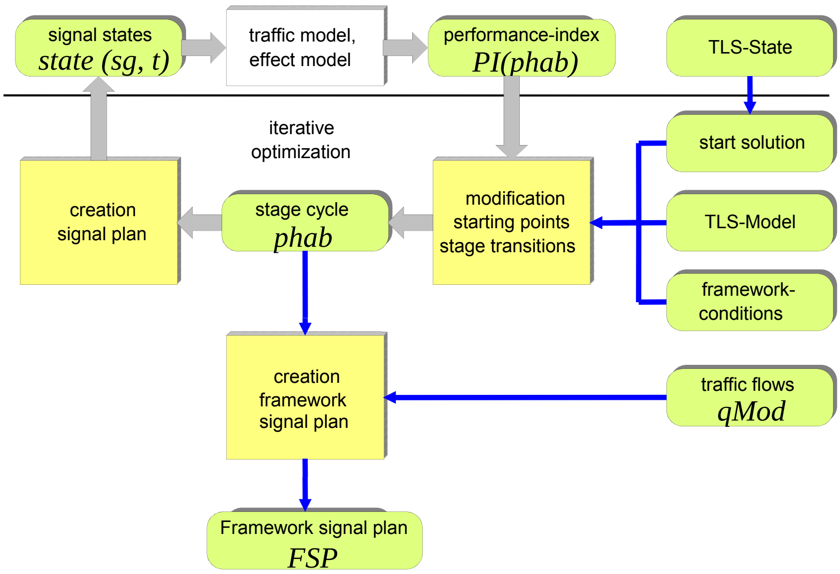


Figure 9: Block-Image of the PTV Balance control model

Base of the optimization is the modelling of the relevant control parameters in the control model. These are:

- The signal groups (index and type)
- The stage definition (index, belonging signal groups)
- The definition of the interstages (index, Start- and target-stage, switch on- /switch off-points in time of the signal groups, index of belonging signal groups)
- The signal programs (index, cycle time, type)
- Program-related framework conditions (minimum/maximum release times of the signal group , earliest and latest starting points of the interstages

The optimization itself is processed for each intersection as a search in the solution space. The solution space is defined by the parameters described above. At first, a valid starting solution is created with the TLS-Model and the current state of the TLS. A valid solution is represented by a periodical stage cycle. This describes a vector, which consists of the indexes of the interstages and their starting points:

$$phab = ((pu_1, T_1), (pu_2, T_2), \dots, (pu_n, T_n))$$

Where

pu_i	index of interstage i
T_i	starting point of interstage i [1 ... tu sec]
n	length of stage cycle, number of stage transitions

Starting with the start solution phab0, the control model successively creates new solutions by changing of the local parameters. The starting points are increased for each interstage of the stage cycle (Figure 10) respectively the modification is interpreted in a way, which allows the following solutions phabi to be valid, too. This means, that the solutions are sufficient to the given framework conditions and therefore give a valid signal plan for the particular traffic light controller .

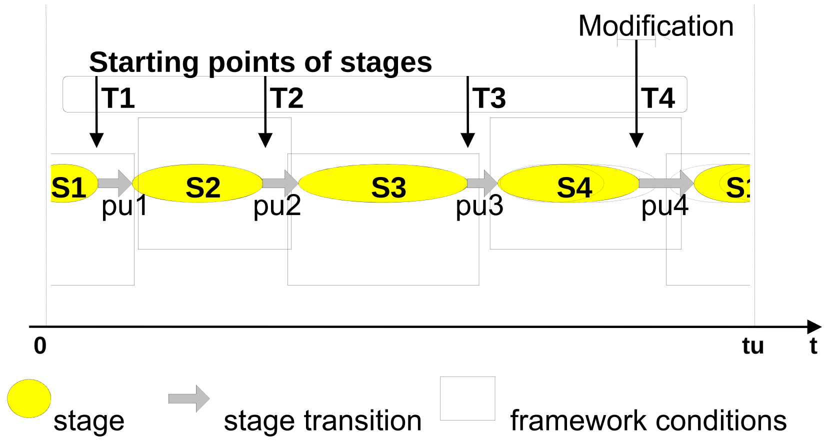


Figure 10: Example modification of the stage cycle

The particular stage cycle is transformed into a signal plan sp by the control model. It describes the states of the signal groups during the cycle time of the control group:

$$sp = \begin{pmatrix} state(sg_1, 1) & \dots & state(sg_1, tu) \\ . & \dots & . \\ state(sg_m, 1) & \dots & state(sg_m, tu) \end{pmatrix}$$

Where

sg_i	index of signal group
m	number of signal groups
state(sg, t)	state [free, blocked] of signal group sg at point in time t in signal plan sp

Now the traffic related impacts of the solutions can be calculated by the traffic model because the states of the signal groups in relation to cycle time are given by the signal plan. The solutions can be evaluated by the effect model according to the given performance index PI (see chapter 2.1.4). Now the optimization model should ideally find the optimal solution according to the PI.

However, the problem of the network-optimization is more complex. Therefore, simple optimization strategies, like the gradient procedure or linear optimization lead to suboptimal results or are not applicable at all. Because of that, the global optimum can only be found securely by an exhaustive search of the solution space. However this procedure is not working if there are too many input parameters (number of intersections, number of stages per intersection, etc.) because the size of the solution space is growing exponentially with the number of input parameters.

Nevertheless, a heuristic optimization procedure is used in order to refuse local minimum: the Tabu-Search (Domschke et al. 1996): Solutions, which are worse than the solutions which have yet been found, are accepted in the beginning of the search of the solution space. This way, the search can partly get out of local minimum again. Although it has to be mentioned, that the use of this procedure does not guarantee to find the global optimum.

The Tabu-Search is switched off after a given number of optimization steps. Afterwards, only solutions which represent an improvement of the previous state are accepted. Therefore, the next local minimum is focused. This procedure corresponds to the Hill-Climbing Algorithm (Domschke and Drexl 1998), which is also used by many other TLS-network control procedures like, for example, Scoot (Hunt et al. 1981) and Transyt (Robertson 1969).

The procedure mentioned above is executed multiple times for every intersection of the respective control group with a limited number of searching steps. In this way the TLS can adjust to each other. The best solution for every TLS, according to the performance index, is realized in a framework signal plan FSP. The points in time which are defined for each stage in the stage cycle are divided into stage-related core times and variable times in the cycle. The core times have to be switched by the local control under any circumstances but stages can also be stretched or cancelled according to the local detection during the variable times.

The framework signal plan is defined clearly by the beginning and the end of the variable times mentioned above, respectively the earliest and latest starting points of the interstages during the cycle:

$$FSP = ((TA_1, TB_1), (TA_2, TB_2), \ldots , (TA_n, TB_n))$$

Where

TA_i, TB_i	earliest/ latest starting point for the interstage i [1...tu sec]
n	length of the stage cycle, number of interstages

A framework signal plan is created for every LSA which should be controlled. They are sampled together with information about access control and data saving and then saved to the database and sent from the central computer to the local control.

2.1.5.2 Calculation of the ideal cycle time

The calculation of the cycle time is done for all controllers of a control group at the same time in order to create an equal cycle time within the group. The same performance index function as the one which is used for the definition of the other control parameters is minimized. However, the adaption is processed more slowly and in larger intervals than the changing of the other control parameters.

Moreover, the adaption can only be processed in discrete steps, because it is realized on intersection-level by the selection of signal programs with a given cycle time and only a limited number of signal programs can be provided for each TLS. The framework conditions mentioned above can hardly be integrated into the definition of a performance index. Therefore, the traffic-dependent changing of the cycle time is not processed directly by PTV Balance. Instead, only a cycle time recommendation is created which is evaluated by the strategy module SFC/SAW with additional information and processed further into a command for program switching.

The switching procedure for the traffic-dependent selection of the signal plan automatically calculates the required cycle time out of the lanes´ traffic loads on the relevant intersection of a PTV Balance control area. The procedure calculates the required cycle time out of the detector counts of the last 15 minutes, according to the guidelines of the HBS (manual for traffic engineering) (Forschungsgesellschaft für Straßen- und Verkehrswesen 2009). The result serves as base for the decision of the switching procedure. The following formula contains the base idea for switching (formula 6-13 in the German “Handbuch für die Bemessung von Straßenverkehrsanlagen 2001” [Road capacity manual]):

$$t_U = \frac{T_Z}{1 - \sum_{i=1}^{p} q_{maßg,i} / q_{Si}}$$

With

TU	optimal cycle time
TZ	sum of “relevant” intergreen times
P	number of relevant stages
$q_{maßg,i}$	the maximum measured traffic on one lane in the stage i
q_{Si}	the theoretical maximum amount of traffic on this lane

Here the sum of “relevant” intergreen times TZ is divided by 1 minus the saturation level of the relevant stages. The calculated optimal cycle time is then matched with the available signal programs and switched accordingly.

2.1.5.3 Optimization with the genetic algorithm

The whole procedure of the optimization is illustrated in Figure 11. It consists of the following main components:

- Traffic- and Efficiency-Model
- Objective function
- Optimization procedure

The traffic model creates an internal spatial-temporal representation of the current traffic state out of the traffic volumes measured at the measuring sections. The effect model, which is based on the traffic model, serves the purpose of determining the efficiency parameters which in turn, are the input parameters for the objective function. The result of this function is the fitness of an individual, which means a scalar quality value for a control alternative (signal plans of the network). The fitness in turn is the input variable for the optimization procedure which optimizes the signal plans of the whole network and determines the best control alternative (=the best individual) for the current traffic flow. All of the main components and the framework signal plan creation (FSP-Creation) represent the traffic adaptive network control PTV Balance which delivers a new framework signal plan every 5 minutes (tactical level). Based on that, the local traffic-dependent control of the TLS at each intersection reacts on short-term changes of the traffic flow each second (operational level).

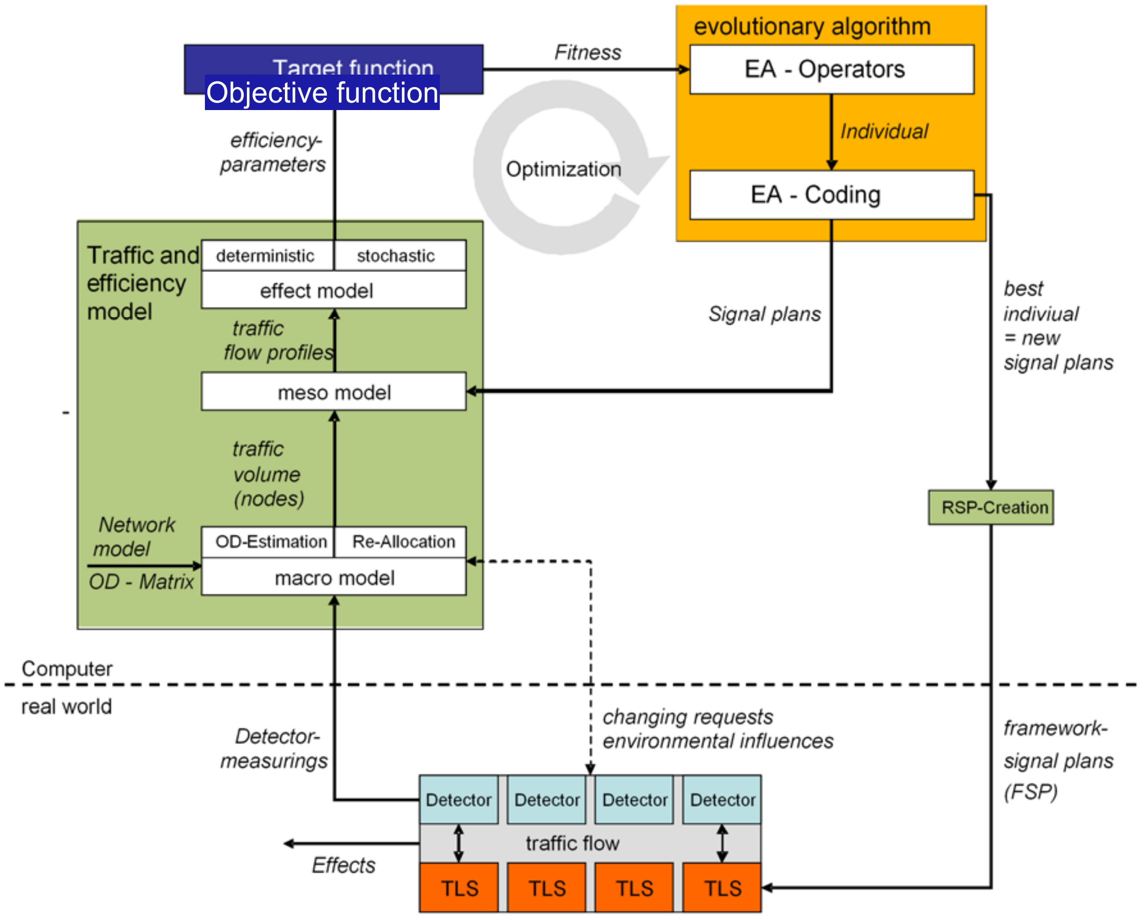


Figure 11: Procedure of online-optimization

The coding of the control parameters has significant meaning for the quality and the functional ability of the optimization. In case of an evolutionary algorithm, coding means the translation of signal plans for an individual, which can be edited by an evolutionary algorithm. In case of the given problem, the following specific framework conditions are relevant for the coding:

- Conditions of the planning (allowed cycle times, allowed cycle procedures)
- Necessary framework conditions (intergreen times, minimum release times)
- Framework conditions of the local traffic-dependent control

The framework conditions of the measurement-based conventional (time interval)-control, which is pretty common in Germany, is illustrated in Figure 12.

The framework signal plan for the local, measure-based time gap control is defined by the T-Time-Limits (T_{iA}, T_{iB}). The latest starting points of the interstages T_{iB} are optimized for all TLS in the control area. An interval [T_{iB}^{min}, T_{iB}^{max}] is defined for T_{iB} in order to assure the functionality of the local control.

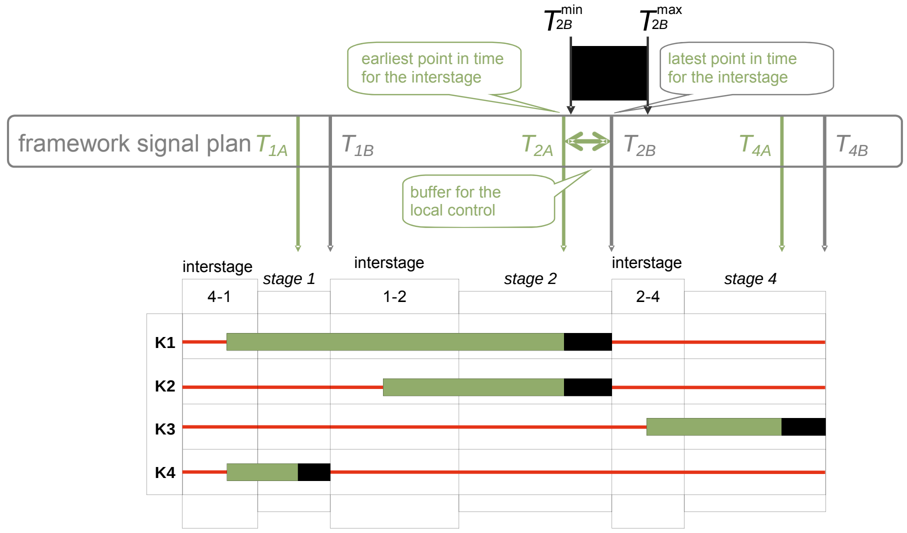


Figure 12: T-Time-Limits of the local control

The optimization procedure GALOP (GALOP-Online – ein Genetischer Algorithmus zur netzweiten Online-Optimierung der Lichtsignalsteuerung, Braun and Kemper 2008) represents the control alternatives by the so called coding of the individuals. An individual has the following expression:

$$\{\varphi, (\sigma_1, \omega_1, o_1, \theta_{11}, ..., \theta_{1m_1}), (\sigma_2, \omega_2, o_2, \theta_{21}, ..., \theta_{2m_2}), ..., (\sigma_n, \omega_n, o_n, \theta_{n1}, ..., \theta_{nm_n})\}$$

It contains a gene φ for the cycle time as well as n so called chromosomes and n intersections of the network which is to be optimized. Every chromosome consists of multiple genes: one gene σ for the definition of the stage cycle, one gene ω for the global offset, one gene o for the local offset, as well as m genes Ѳ for the stage durations respectively the starting points of the interstages. Every gene has a real value between 0 and 1.

The genes remain inactive for the local and the global offset in the version of the algorithm which is implemented in TRAVOLUTION because of the offset limits and framework conditions of the local traffic dependent control. A special sequential coding was developed. Its principle is described in (Braun and Kemper 2008) and in (Braun 2008). Besides the necessary framework conditions, like the adherence of intergreen times, it also integrates the framework conditions of the local traffic-dependent control. This way, only valid individuals are created.

The arrangements of the operators of the evolutionary algorithm and their parameterization have a great influence on the quality of the optimization procedure. The operators have to be adjusted to the coding because one individual represents all intersections in the network. An intersection in the individual is illustrated as set of genes (chromosome). During the recombination, single genes from the parent-individuals are used for the creation of offspring-individuals by default. The recombination-operator was developed concerning the probability p that a recombination will also be applied to the complete chromosomes (intersections). Regarding the mutation of genes, you have to bear in mind, that a mutation takes place inside T-Time-Limits. Therefore, the length of the steps can either be adjusted individually for each gene or for the whole individual which makes an adaption on demand possible.

The Hill-Climbing Algorithm can only optimize the control parameters sequentially in contrary to the evolutionary algorithm which optimizes all control parameters at the same time. Therefore, the created control alternative depends on the chosen order. As soon as no better control alternative can be found for a control parameter in one direction, the search will be continued for another direction. Figure 13 illustrates an example for the different behaviour of the Hill-Climbing-Algorithm and the evolutionary algorithm in an identical network with identical traffic volumes.

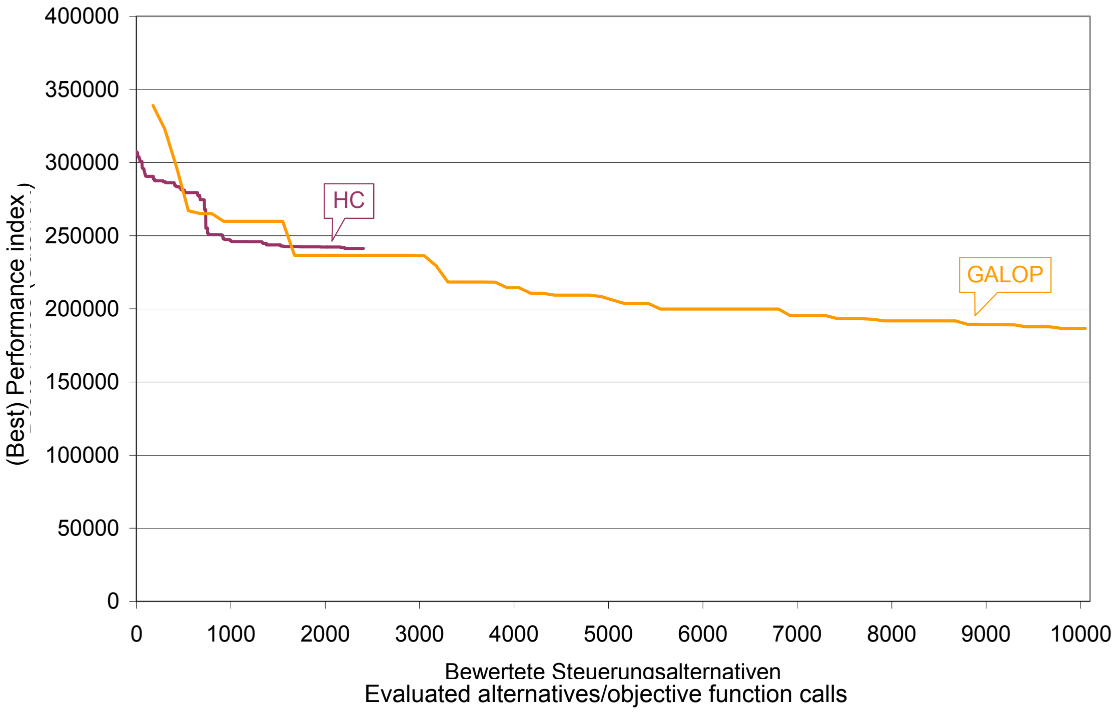


Figure 13: Comparison of the development of the fitness of the EA and the HC

The Hill-Climbing-Algorithm starts with the signal plans of the basic control that already have a good quality. In contrary to that, the evolutionary algorithm begins with a random start population. The best individual of the first generation (after 175 evaluated individuals) does not reach that quality yet. However, the Hill-Climbing Algorithm stops after 2.404 evaluated control alternatives with a quality value of 241.742, because it can´t find a better control alternative (it is stuck in a local optimum). Instead, the evolutionary algorithm has reached a fitness of 236.556 after 2.300 individuals in the 18th generation. The evolutionary algorithm has even reached a fitness of 186.559 after 80 generations and 10.050 control alternatives.

2.2 Dynamic Group Selection

For the network control you have to define control areas marking the traffic light systems which should be controlled first of all. These control areas are defined according to the following guidelines:

- Distance between intersections
- Different cycle times

- Coordination areas

The distance between the traffic light systems which belong to a control area should not be more than 700-1000m. A larger distance prevents a possible coordination, because the queue dissolving processes increases with a larger distance.

Different cycle times in a control area also prevent the coordination of the respective traffic light systems. A certain coordination is still possible if the different cycle times are a multiple to each other, like i.e. 60s and 120s. No coordination and therefore no good optimization of the network can be processed if the cycle times are not uniform.

In order to guarantee a good optimization it is important not to divide coordination areas by a control area. A coordination area should be integrated into the control area because in general, coordination areas already fulfil the first two conditions: the distance between the intersections and the uniform cycle times.

The groups are defined statically, according to geographical issues and traffic-related coherences. Because of queue dissolving-processes, it is useless to add traffic light systems which are far away from the group. Moreover, it has to be regarded, that the traffic light systems of a group have to run in the same cycle time. The defined groups are checked and calibrated before the actual operation in the streets by simulations and quality management plans. The whole system changes by adding a single TLS. Therefore you would have to check and calibrate the control group again after you have added a TLS, in order to guarantee an error-free operation of the group. Because of that, the integration of a completely dynamic change of the group compositions would not make sense.

A possible way to avoid this problem is to integrate a dynamic adaption of the groups according to predefined group compositions. Those compositions can be selected dynamically by the user (on demand) or by strict rules. Therefore, multiple sub-groups can be defined (see Figure 14). The main group is optimized by PTV Balance during a defined period of time. The sub-groups are optimized during the rest of the time. Therefore, the sub-groups could be running in different signal programs with different cycle times during off-peak times. That way, smaller groups can adapt to the demand of higher capacity or shorter cycle times. Moreover, predefined groups guarantee an error-free operation of the network control.

The impacts of the optimization inside the groups are delivered to the super ordinate traffic model via length and location of the green times as well as the currently running signal program. The traffic model can create an updated traffic situation for the whole network with this information and the current detector data.

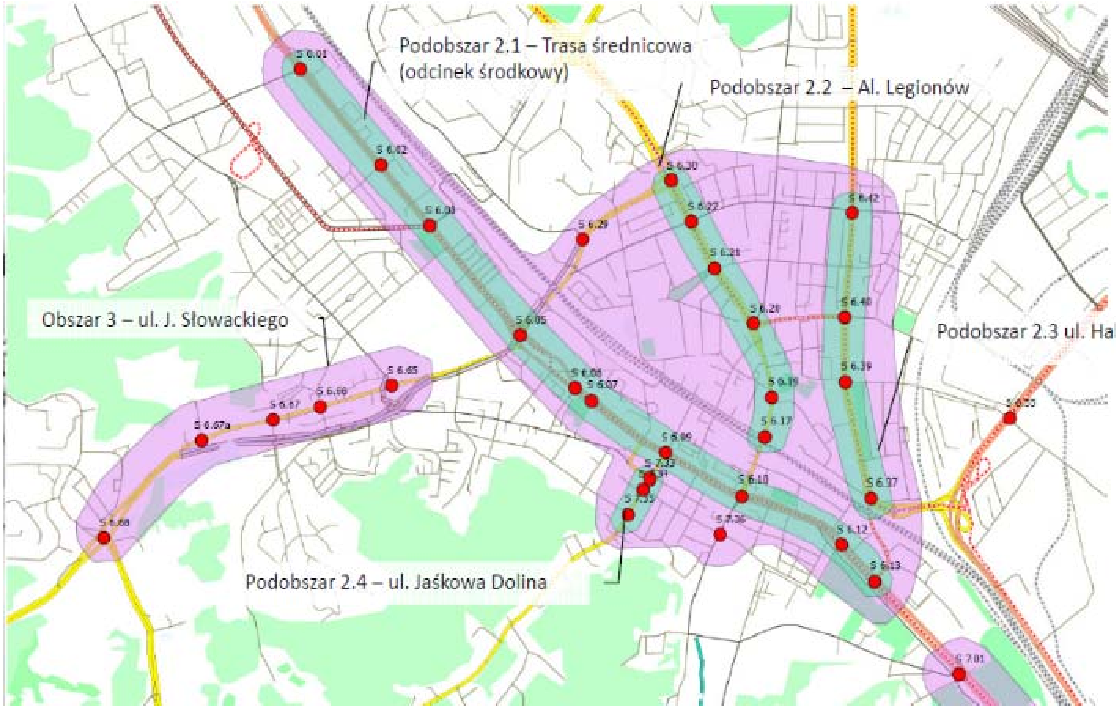


Figure 14: Possible flexible group segmentation

2.3 Changing the Objective Function

A dynamic change of the objective function is realized by additional master-weights. The single summands of the objective function are multiplied with additional factors WD, WH, WL, which are valid for the whole group. Therefore, either single impacts can be disregarded by the factor 0 or different combinations of impacts can be regarded.

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

Where

SG	number of 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
WD, WH, WL	master-weights Waiting time/stops/queue length
x	vector control parameters
y	vector traffic parameters

These factors can be changed dynamically by the user to create an optimization of the objective function with the respective weights. The following optimization-possibilities are available for the user:

- Minimization of the number of stops
- Minimization of delay times (which is the same as minimizing the travel times)
- Minimization of the queue length (which is the same as maximizing the traffic flow)

2.4 Online-/Offline-System

In the previous chapters, the network control was mentioned in combination with the live-, respectively the online-system. However, it is also possible and useful to build the network control in an offline system. PTV Vissim (PTV AG 2015a) or Nonstop (Gevas software Systementwicklung und Verkehrinformatik GmbH 2012b) are serving as simulation software. PTV Balance is integrated into both systems by DLL-Files. The data provision of PTV Balance is created by Network-XML-Files which are exported from the data provision tool PTV Visum and by a signal controller data-file shared with PTV Epics and Vissig. The data provision itself is done similar to the data provision for the online system. Further information about this topic can be found in chapters 3 and 4.1.

The offline system offers multiple ways to test the behaviour of the network control because the functionality of the network control is not affected. It is possible to test possible changes and calibrate the whole system including the network control. It is important to test changes at an intersection inside the offline mode before they are applied in the online system, because the changes at one intersection of the network control could have impact on the whole system. Therefore, it is important to test changes of the weighting, the objective function, the control or of the network itself, in a simulation.

2.5 Possibilities for the Local Control

2.5.1 PTV Balance With PTV Epics

It is possible to operate the network control PTV Balance with PTV Epics. PTV Balance as network-wide system takes the task of overall coordination and traffic control. The model-based system PTV Epics assumes the local holistic optimization on the node including public transport. Thus, the traffic-dependent control is realized within seconds and can react to changes in the traffic very quickly.

2.5.2 TRENDS-Kernel With Normal TRELAN-Logic

A further possibility is to combine a rule-based traffic-dependent control by means of TRELAN-Logic (Gevas software Systementwicklung und Verkehrinformatik GmbH 2010b) with the network control PTV Balance. Every 5 minutes the frame signal times on which local traffic-dependent control is based are indicated by PTV Balance. The public transport is considered only by the local control.

2.5.3 VS-Plus (Verkehrssysteme AG)

It is also possible to couple VS-Plus controlled controllers with PTV Balance. The parameterized frame signal plan in VS-Plus is replaced by PTV Balance. This way the local traffic actuated control logic of VS-Plus is preserved. VS-PLUS receives from its superordinate network control dynamically adapted frame signal plans that improve the traffic flow throughout the network.

2.5.4 Ring-barrier-controller

The North American Ring Barrier control system was already equipped with PTV Balance as a superordinate network control system. This has been tested in a simulation study.

2.5.5 Dynamic Fixed Time Control

In network control is also possible to bypass the local control function and to use a so-called dynamic fixed time. The earliest and latest starting points of the interstages as part of the frame are reduced to one point. Is the local control set in a way that the requirements of PTV Balance are strictly adhered, a dynamic fixed time control is switched that changes the green times and offsets every 5 Minutes. There is no local traffic dependency needed. This control method is a valid option if transit signal priority is not used and traffic demand is rather static.

2.5.6 Other Methods

As you can see the network control PTV Balance can be coupled with many local control systems so that there are other connections with other methods open.

2.6 Objectives of Adaptive Network Control

A major goal of the adaptive network control is to reduce the delay times in the main road network. Car drivers, but buses as well lose less time at red lights and therefore can drive more fluently.

Another objective is improvements and adaptations of the coordination of the current traffic conditions. Each stop at a traffic signal, each start and each brake application consume fuel. The network control optimizes the road network in a way that the best possible Green Wave can be switched at every time of the day – the whole fuel consumption in Ingolstadt is reduced significantly. This means that CO2 air pollution and particulate matter can be reduced as well.

The network control saves money not only through less fuel consumption. The overall savings of time can be calculated as well, since all the minutes wasted during traffic congestions sum up to a time period which can be used much more productive. It is much more efficient to make better use of the existing infrastructure that to build a new road.

The network control can also be used as a planning tool by certain routes are preferred by better coordination. Through skilful distribution of the weights for the individual signal groups of traffic signals, a preferred direction of optimization are established. Through this concentration of traffic on one or more routes in the network, a more compatible and faster flow of traffic can be realized.

3 Data Provision

The PTV Vision suite allows data provision for PTV Balance in a seamless way for simulation and calibration. PTV Balance data provision consists of the following parts:

- A network model of the road network and the traffic demand
  PTV Visum provides this information in the anm/anmroutes format. This step uses the same standard export and import functionalities that are used to convert a PTV Visum model to PTV Vissim.
- Parameters of PTV Balance and signal control data
  - Local parameters e.g. signal control data and parameters that are intersection related
    The signal controller "Epics/Balance-Local" is used to provide signal control data. This signal controller is available in PTV Visum and PTV Vissim. Vissig, PTV Balance and PTV Epics use the same sig-file format that can be shared between the different models.
  - Global parameters e.g. optimization algorithm
    Global parameters for PTV Balance are provided using the traffic signal controller "Balance-Central" in PTV Vissim.

For details regarding PTV Vissim, PTV Visum or PTV Epics please refer to their respective manuals (PTV AG 2015a/b/c).

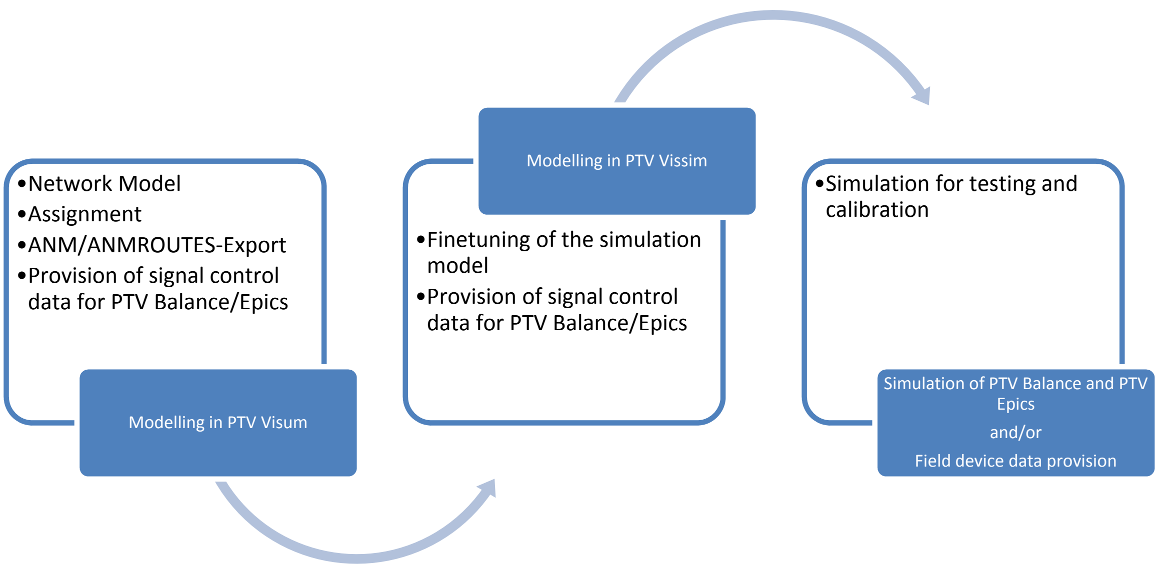


Figure 15: Workflow for data provision in the PTV Vision suite.

> Hint: PTV Balance is a network control that optimizes signal plans typically every five minutes. It has local and global parameters. It requires a local signal controller to apply the optimized signal plans. Therefore, PTV Balance is modelled with two types of signal controllers - “Epics/Balance-local” and “Balance-Central”. The local controller “Epics/Balance-local” can accomplish several tasks. It can be a pure executor of PTV Balance, it can be the local traffic signal optimization PTV Epics and it can be the combination of both.
>
> For guidelines on using PTV Epics and PTV Balance within the PTV Vision suite, please see chapter 3.1.

3.1 Guidelines for using PTV Balance within the PTV Vision suite

This chapter provides guidelines for the data provision for PTV Balance and PTV Epics within the PTV Vision suite. The guidelines are a recommendation, there are other means of handling the related tasks and the necessity of specific steps depends on the actual project.

Step 1: PTV Visum - base model

Provide a suitable base model in PTV Visum in terms of:

- Supply with hourly capacities on links and turns, vehicle restrictions, free flow speeds etc. and public transport if required for simulations with PTV Epics.
  The network needs to be suitable for an anm ex- and import i.e.
  - connectors must not be connected to nodes that represent a physical intersection
  - every node must not have more than one connector per direction
  - every zone must not have more than one connector per direction
- Demand matrices for the relevant days and times of day for which PTV Balance shall be designed and calibrated (e.g. Mon-Fry morning peak, Mon-Fry mid-day, Sat/Sun morning peak etc.).
  Ideally, these matrices have already been assigned and are corrected with TFlowFuzzy for hourly counts (see PTV AG 2015b “Matrix correction using TFlowFuzzy”). See also Step 3: PTV Visum - assignment specifics.

Step 2: PTV Visum - PTV Balance (and PTV Epics) data provision

> Hint: Use the Add-In “Preprocess Balance/Epics” in order to create specific user defined attributes for PTV Balance and load an appropriate layout for the junction editor.

1. Set the PTV Visum project directory for “External control” to the directory of the ver-file.
2. Provide detailed information for all nodes that shall be controlled by PTV Balance using the junction editor. For any of these nodes:
   - create a signal control of the type “Epics/Balance local”
   - edit the signal control “Epics/Balance local” (see chapter 3.3.1 and PTV AG 2015b “Editing a signal control in Vissig”).

- add only the signal groups and return to the PTV Visum junction editor

> Hint: In the next steps signal groups will be assigned to lane turns. After this step, the GUI of “Epics/Balance local” can draw direction arrows for the specific signal groups, making further steps much easier.

- define the geometry of legs, lanes, lane turns and crosswalks
- assign the signal groups to their lane turns
- add detectors to the lanes and assign the appropriate signal control and channel number

> Hint: Log-in detectors for public transport prioritization for PTV Epics can be at a long distance upstream of the node of the signal control. It is possible that the link approaching the signalized node is too short and the detector is located on a link further upstream. In that case, add the detector to the appropriate upstream node and make sure that the assigned signal control of that detector is correct.

- make sure that allowed traffic systems of turns and lane turns are consistent
- edit the signal control “Epics/Balance local”
- define intergreen matrices, stages, signal programs etc.

> Hint: Ignore parameters of PTV Balance and PTV Epics for now. These parameters can be provided using the signal control “Epics/Balance-local” from either PTV Visum or PTV Vissim. However, when providing the parameters from PTV Vissim you have the advantage of a simple detector synchronization from PTV Vissim to “Epics/Balance-local” which reduces effort and errors. When PTV Epics is not used this does not matter.
>
> Hint: When signal control design starts from scratch (i.e. no fixed time signal programs available) you can use the PTV Visum procedures “Signal cycle and split optimization” and “Signal offset optimization” (PTV AG 2015b) to quickly create good starting signal programs for a large number of intersections (also see Step 3: PTV Visum - assignment specifics).

3. After finishing the data provision of all signal-controlled nodes, run the Add-In “Preprocess Balance/Epics” again. This updates the saturation flow rates with respect to the updated lane turns.
4. Use the network check “Viability for Balance / Epics” and make sure that all checks are “ok”.

Step 3: PTV Visum - assignment specifics

PTV Balance requires an anm export with an anmroutes-file containing routes. An anmroutes-file can contain matrices and/or routes. The latter describing an assignment result from PTV Visum. This in turn means that one has to calculate an assignment in PTV Visum and export the results via an anmroutes file containing routes to PTV Vissim and PTV Balance. This is also a very comfortable way of defining vehicle inputs and vehicle routes in PTV Vissim. All of the below is valid for anmroutes-routes, specifically the interaction of anmroutes-matrices and time validities is different.

There is no general limitation to the assignment method. However, the following things are of importance:

- Impact of signal control
  This can either be considered directly by an assignment with ICA or by suitably derived capacities on turns e.g. from an assignment with ICA (see PTV AG 2015b "The procedure of assignment with ICA").

- Time validity of the demand
  Static assignments do not consider whether a demand matrix contains the demand for 1 or for 24 hours, though obviously the capacities of the network have to correspond. What does matter for PTV Vissim as well as for PTV Balance is that the demand information of the anmroutes file is connected to an appropriate time interval (see PTV AG 2015b "Saving an abstract network model").
  In general, it is perfectly fine to use a static assignment that e.g. assigns a 3-hour demand matrix and map this to a simulation time interval of three hours in PTV Vissim. However, that way it will neither be possible to use an assignment with ICA, that requires hourly values nor will it be possible to represent a demand in PTV Vissim that changes over time e.g. one hour with low demand, then one hour with high demand and then again one hour with low demand. In order to represent this, use an assignment with the Dynamic User Equilibrium (see also PTV AG 2015b "Parameters of Dynamic User Equilibrium (DUE)"). On the other hand, DUE cannot directly consider the impact of signal control on turn capacities.

Therefore, in order to consider both impact of signal control on capacities and a fluctuation in demand over time, a combination of an assignment with ICA and DUE is recommended. The former providing turn capacities for the latter and the latter providing the actual input for PTV Vissim and PTV Balance. If a simulation time of one hour is sufficient and demand fluctuations over time are not of interest, then skip sub-steps 5 and 6 in the recommendation below.

1. In **Calculate**->**General procedure settings**->**Prt settings**->**Assignment** set **Save paths** to **As connections**.
   This allows PTV Visum to save the routes of an assignment in the anmroutes file.
2. (Optional) use an assignment without blocking back and TFlowFuzzy to correct the demand matrices (see PTV AG 2015b "Matrix correction using TFlowFuzzy").
3. Use an assignment with ICA for the peak hour demand (see PTV AG 2015b "The procedure of assignment with ICA").
4. (Optional)
   - Use "Signal cycle and split optimization" and "Signal offset optimization" (see PTV AG 2015b) to provide new or update existing fixed time signal plans.
   - Recalculate the assignment with ICA to respect the updated signal plans.

Hint: While it seems tempting to set up an iterative process around sub-steps 2 to 4, this has to be avoided, as it is likely that this process has a positive feedback loop and will yield an unrealistic result.

5. Use the ICA capacities "ICAFINALCAP" as turn capacities. Apply a minimum turn capacity of 100 Veh/h.

6. Use the DUE assignment to calculate the final output for PTV Vissim and PTV Balance.

Step 4: PTV Visum - anm/anmroutes export

1. Export the network and the result of an assignment as anm/anmroutes-files.
   For general information on anm/anmroutes export see PTV AG 2015b “Saving an abstract network model” and for PTV Balance specific parameters see chapter 3.2.1 and 3.2.2.

> Hint: Set the project directory for “External control” of the PTV Visum ver-file and export of anm/anmroutes-file to the same folder. This way PTV Visum, PTV Vissim, PTV Balance and PTV Epics will share the same sig-files. Take note, that the anm export will provide a warning that the external control files will be shared.
>
> In order to simulate several demand scenarios, repeat the process starting from Step 3: PTV Visum - assignment specifics but only export the anmroutes file and specify a suitable name.

Step 5: PTV Vissim - anm/anmroutes import

1. Import only the anm-file in PTV Visum (see PTV AG 2015a “Importing ANM data”)
2. Check the result of the anm import and fine tune the network as desired. Typical tasks are:
   - Check detector positions.
   - On connectors that reduce additional lanes after an intersection, check if **Route->Lane change:** is short enough to make the vehicles use the additional lanes.
   - Depending on the maximum cycle time, adjust the **Waiting time before diffusion** of the **Driving Behaviors**.
   - Check conflict areas and positions of links, connectors and crosswalks. Specifically large intersections are likely to require corrections.
   - If desired, apply cosmetic changes e.g. number of splines on connectors, fix the splines on links (besides “inside intersection corrections”, typically links feeding the network that lead to an intersection with a central island require fixing) etc. Take note that, besides slightly changing the lengths of links and connectors, these changes do not affect the quality of the simulation.
3. Add a signal controller of the type “Balance-Central” and provide parameters (see chapter 3.3.2).
4. Save, this is your “base” network in PTV Vissim.
5. Import the anmroutes files as desired.

> Hint: The import of the anmroutes file can be repeated as long as the node structure in the inpx-file remains stable. This swaps the entire demand and allows a comfortable way of handling different demand scenarios within one inpx-file. In order to keep track of the results use the comment of the **Simulation Runs** list.
>
> It is also possible to “split” and maintain several inpx-files for every demand scenario, though this makes updates of the network for several inpx-files more tedious.

Step 6: PTV Vissim - simulation and calibration

1. Simulate and calibrate (see chapter 4)
   - Make sure that PTV Vissim behaves realistically (specifically due to anm based network generation).
   - Fine tune PTV Balance and/or PTV Epics parameters.

Hint: For PTV Balance the input file that describes the network is the anm-file. Therefore changes to the network, e.g. saturation flows for PTV Balance, adding detectors (or correcting the position in terms of placing the detector on another link) etc. anything that is stored in the anm-file need to be applied in PTV Visum and require a new export of the anm-file (and the import in PTV Vissim).

This does not apply to PTV Epics.

3.2 Network and Demand Data

3.2.1 Network Data

An anm-file describes the network data (links, turns, number of lanes, detectors etc.). Create these files with PTV Visum. PTV Vissim can import these files too. The anm-file is a parameter of the signal control Balance-Central.

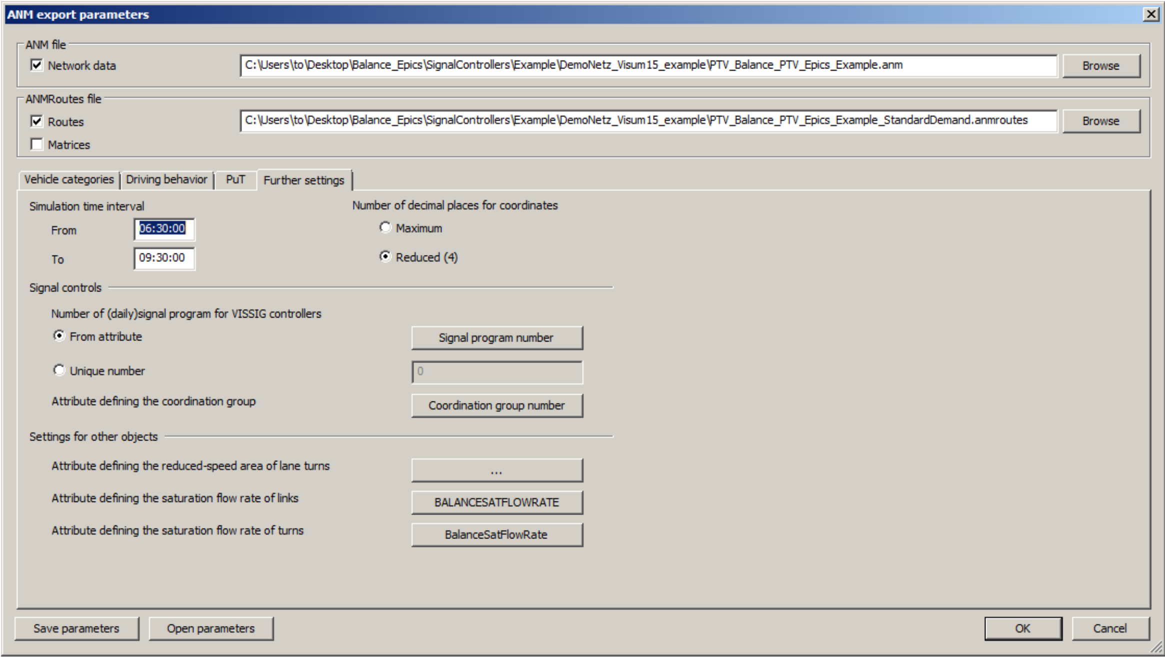
The anmroutes-file is used in the same way as for an export to PTV Vissim (see PTV AG 2015b “Saving an abstract network model”). In addition to that, it is required to define attributes describing the saturation flow for links and turns for the anm export in PTV Visum. The saturation flow corresponds to the capacity of a link or turn with no signal control.

The PTV Visum Junction Editor and Control add-on is required to model signalized intersections in the required level of detail.

To define the additional parameters in PTV Visum:

1. Open anm export parameters.
2. Click on **Further settings**.
3. In **Settings for other objects** click on the button next to either **Attribute defining the saturation flow rate of links** or **Attribute defining the saturation flow rate of links turns**.
4. Choose any attribute.
   Fill the chosen attribute with the corresponding values.

Element	Description
Saturation flow rate of links [Veh/h]	Saturation flow of the link respecting number of lanes, share of HGV, slope, etc. standard value is 1800 x number of lanes x reduction factors.
Saturation flow rate of turns [Veh/h]	Saturation flow of the turn respecting number of lanes, share of HGV, slope, direction (right turns tend to require a lower speed than straight turns) etc. standard value is 1750/1850/1800 (right/straight/left) x number of lanes x reduction factors.



3.2.2 Demand Data

An anmroutes-file describes demand data. Create these files with PTV Visum. PTV Vissim can import these files too. The anmroutes-file is a parameter of the signal control Balance-Central.

The anmroutes-file is used in the same way as for an export to PTV Vissim (see PTV AG 2015b “Saving an abstract network model”).

The anmroutes-file must contain only **Routes**. In PTV Visum **Calculate->General procedure settings->Prt settings->Assignment** set **Save paths** to **As connections**. This allows PTV Visum to save the routes of an assignment in the anmroutes file.

Hint: A static assignment in PTV Visum does not have any information about the time. Therefore, if exporting the result of a static assignment, make sure that the demand and the **Simulation time interval** in the **ANM export parameters** fit together. PTV Vissim and PTV Balance will respect these settings.

In order to test how PTV Balance reacts to unplanned changes in demand it is possible to use different anmroutes-files for PTV Vissim and PTV Balance.

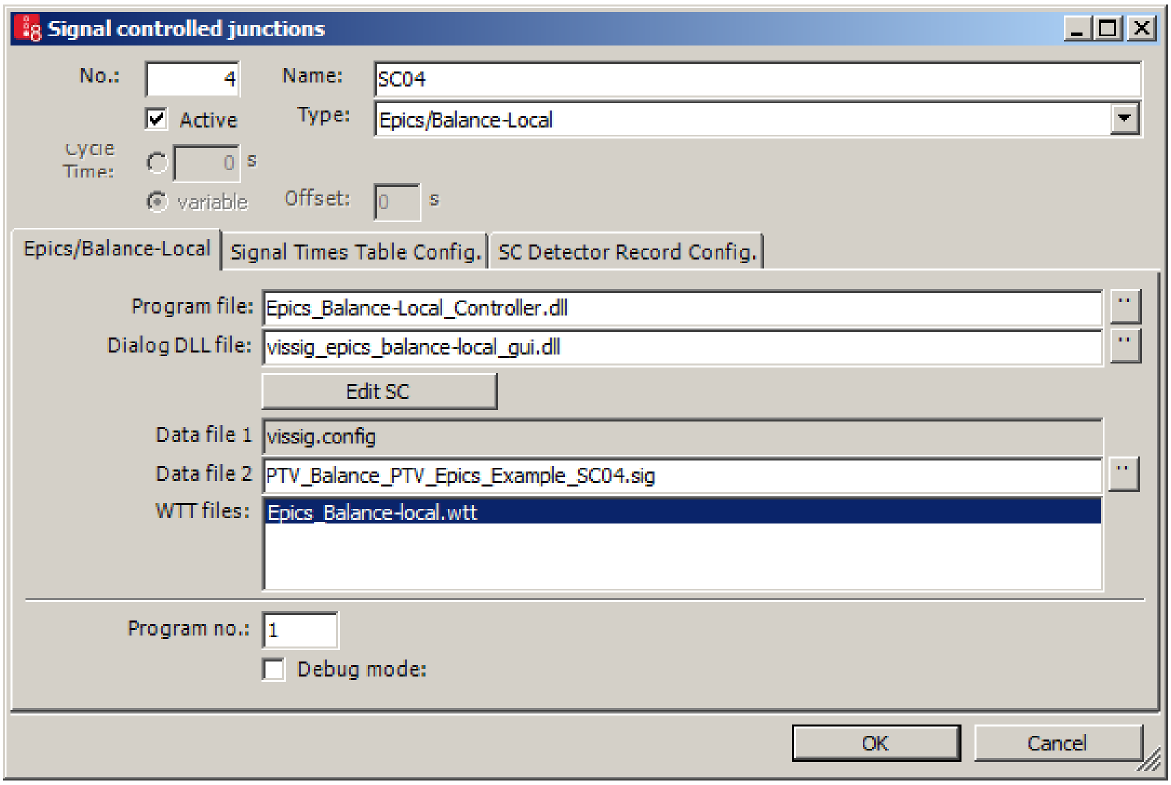
3.3 PTV Balance Parameters and Signal Control Data

3.3.1 Local Parameters and Signal Control Data

PTV Balance related parameters are provided with the GUI of the signal controller **Epics/Balance-local** that is an extended version of Vissig. This manual will only address additional data that are relevant for PTV Balance. Sections that are not covered are not required for PTV Balance.

PTV Balance requires a stage based design.

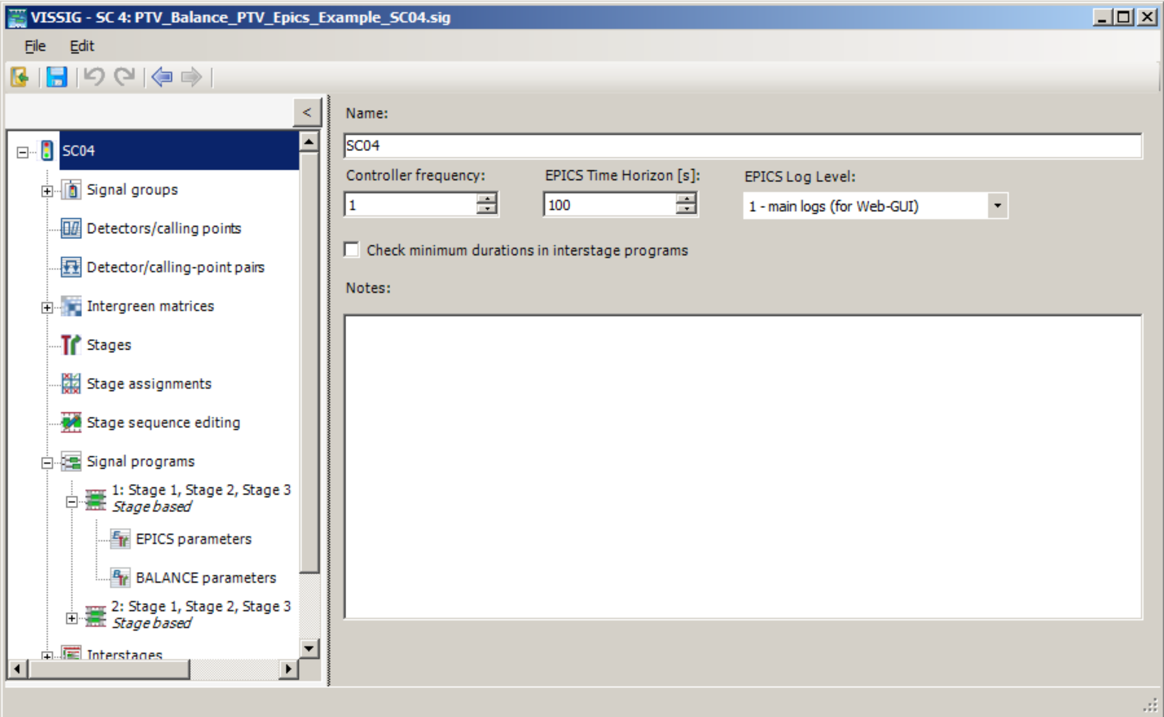
1. From the **Signal Control** menu, choose > **Signal Controllers**.
   *The **Signal Controller** list opens.*
2. Right-click the entry of your choice.
3. From the shortcut menu, choose **Edit** or **Add**.
   *The **Signal Control** window opens.*



4. In the **Type** field, select > **Epics/Balance-Local**
5. Edit the desired data:

Element	Description
Debug mode	If active, then the local controller creates log-files. Detailed log-files are created in the subfolder Epics_Log of the directory of the inpx-file. This significantly increases runtime.
All other elements	Please refer to help on Fixed Time control.

6. Click on **Edit Signal Control**.
   The SC Editor opens.



3.3.1.1 Signal groups

As required for any stage based fixed time control modelled with Vissig.

3.3.1.2 Intergreen matrices

As required for any stage based fixed time control modelled with Vissig.

3.3.1.3 Stages

As required for any stage based fixed time control modelled with Vissig.

3.3.1.4 Stage assignments

As required for any stage based fixed time control modelled with Vissig.

3.3.1.5 Stage sequence editing

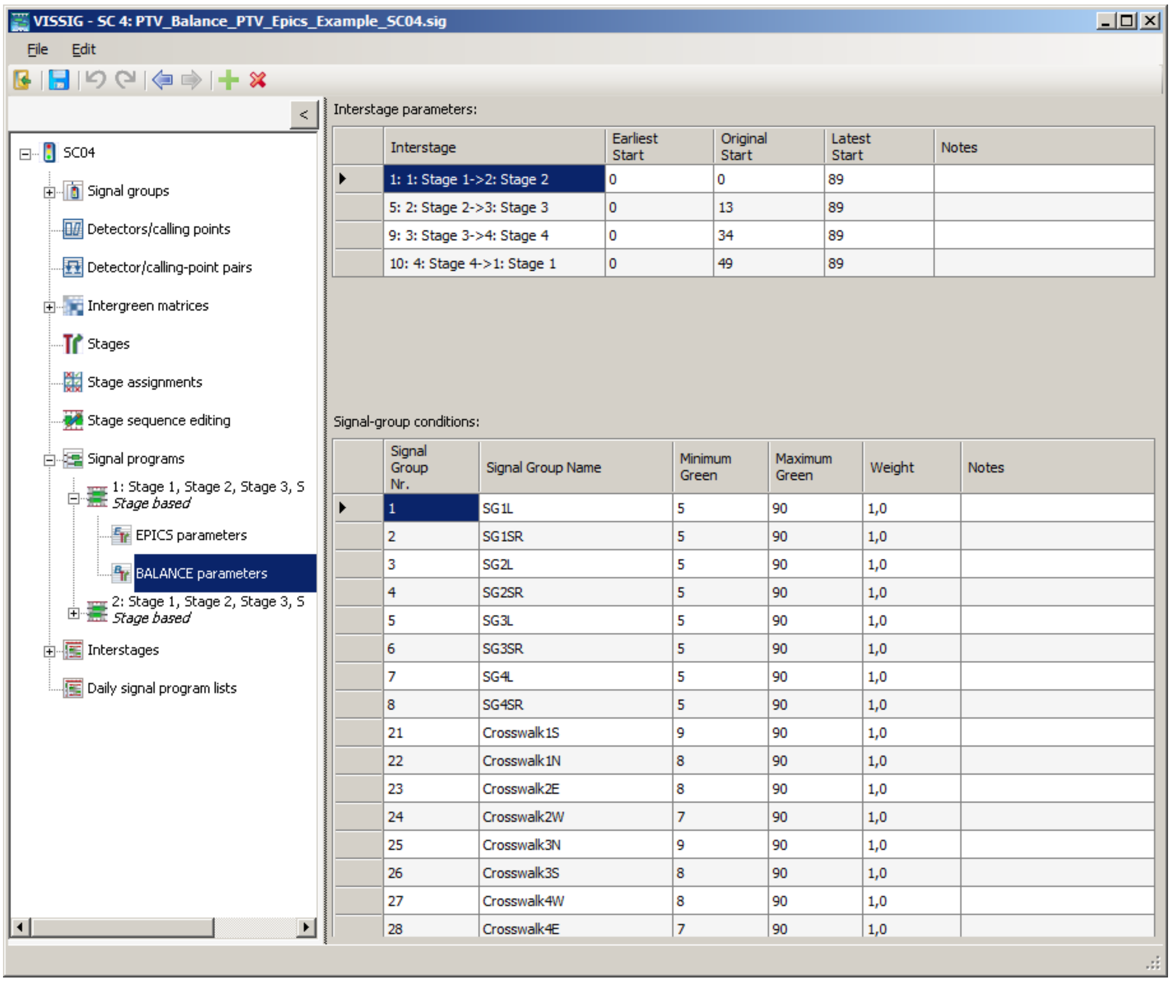
As required for any stage based fixed time control modelled with Vissig.

3.3.1.6 Signal programs

As required for any stage based fixed time control modelled with Vissig.

Additionally PTV Balance requires the provision of signal program dependent parameters that define priorities and boundaries for the optimization.

1. Select a stage based signal program.
2. Expand the Navigator.
3. Select **BALANCE parameters**.



4. Make the desired changes.

Hint: Every parameter for PTV Balance comes with a tooltip providing an explanation of its meaning. In addition, there are numerous plausibility checks with explanations.

When you have the license for PTV Balance and PTV Epics and you want to use only PTV Balance, then activate **EPICS parameters** > **BALANCE fixed-time control** to force PTV Epics to follow the results of PTV Balance exactly.

Resetting stage parameters of a signal program

5. In any table right-click the desired cell or column.
6. From the context menu, choose either **Reset values of table** or **Reset values of column ...**
   This resets either the whole table or the corresponding column to the default values.

3.3.1.7 Interstages

As required for any stage based fixed time control modelled with Vissig.

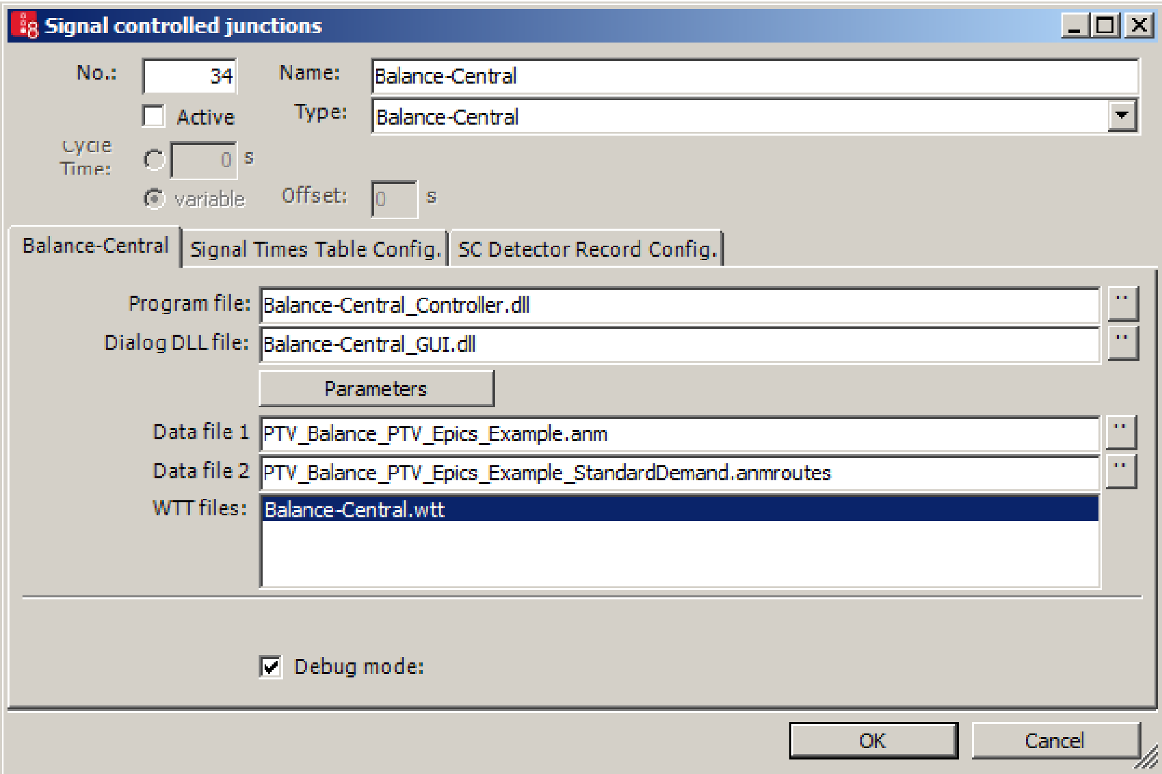
3.3.1.8 Daily signal program lists

Optional but as required for any stage based fixed time control modelled with Vissig.

3.3.2 Global Parameters

Global parameters are set by a signal control of the type **Balance-Central**. This signal control is not associated with any signal groups or signal heads. It is a virtual signal control, which represents the core of PTV Balance. There has to be only one instance of such a signal control.

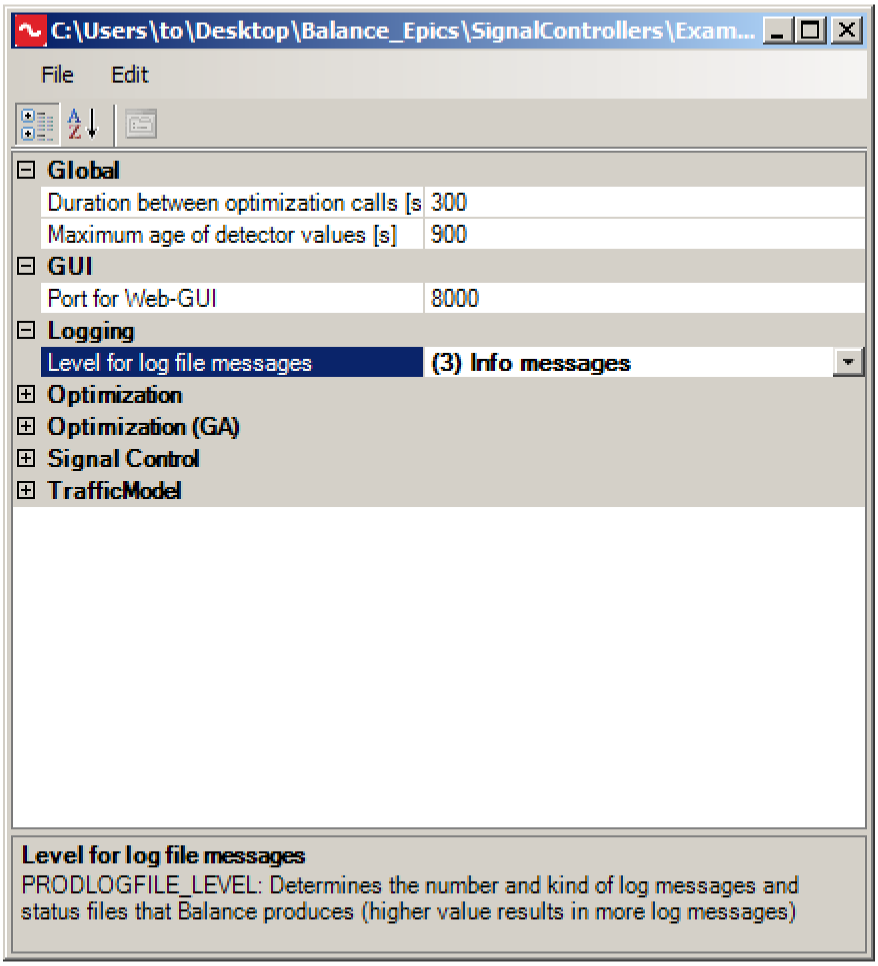
1. From the **Signal Control** menu, choose > **Signal Controllers**.
   *The **Signal Controller** list opens.*
2. Right-click the entry of your choice.
3. From the shortcut menu, choose **Edit** or **Add**.
   *The **Signal Control** window opens.*



4. In the **Type** field, select > **Balance-Central**
5. Edit the desired data:

Element	**Description**
Data file 1:	The anm-file describing the network.
Data file 2:	The anmroutes-file describing the demand.
Debug mode	If active, then PTV Balance creates log files (see chapter 4.1.2). The level of detail of the log files can be set in the Balance-Central Editor. This influences the number of produced log files. This increases runtime.
All other elements	Please refer to help on Fixed Time control.

6. Click on **Parameters**
   The Balance-Central Editor opens.



7. Edit the desired data.
   Categories group the parameters.
   The bottom of the figure displays a short description of the currently selected parameter.

4 Simulation, Calibration and Operation

Testing the efficiency of an adaptive signal control like PTV Balance is nearly impossible without a modern simulation environment like PTV Vissim. It is the only way to check whether all parameters are chosen and calibrated well and if all detectors are correctly defined

On the other hand a simulation is never a 100-percent mapping of reality. Therefore the step from the simulated network to the real road network has to be observed carefully.

4.1 Simulation With PTV Vissim

4.1.1 Data Provision

The microscopic traffic flow simulation PTV Vissim provides the possibility to test PTV Balance without access to any online system. PTV Vissim uses the same import/input format for network and demand data as PTV Balance providing a quick to set up test environment. PTV Visum, PTV Vissim and PTV Balance share signal control related data through the sig-files.

PTV Visum and PTV Vissim are the recommended way for data provision and calibration. See chapter 3.1 for guidelines on how to set up a PTV Balance project with the PTV Vision suite.

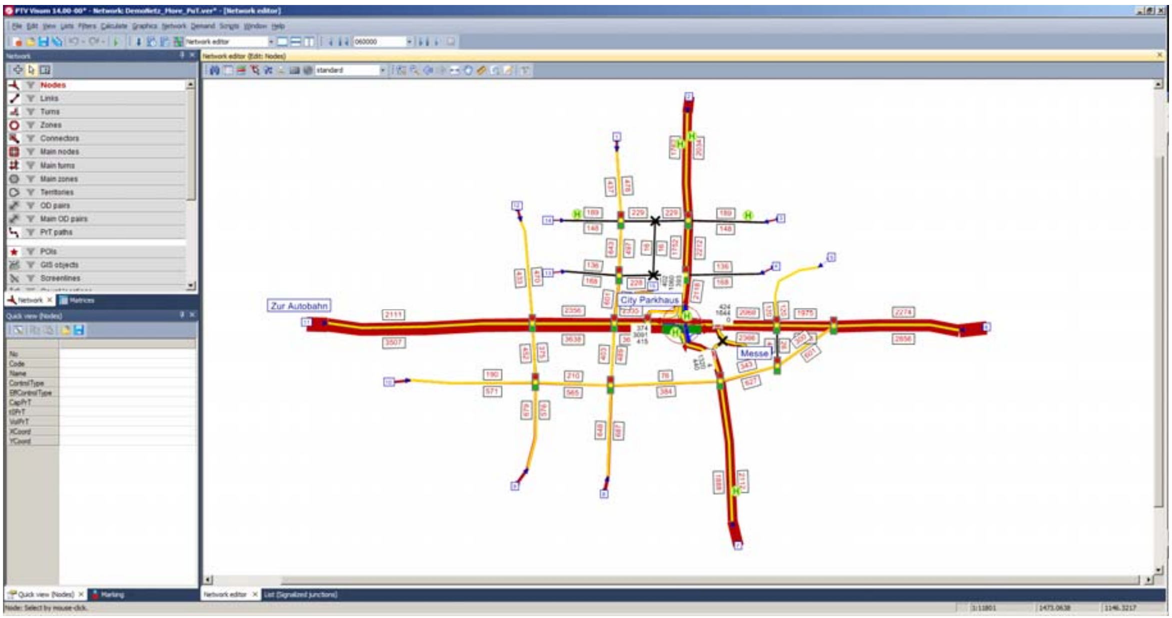


Figure 16: Network in PTV Visum.

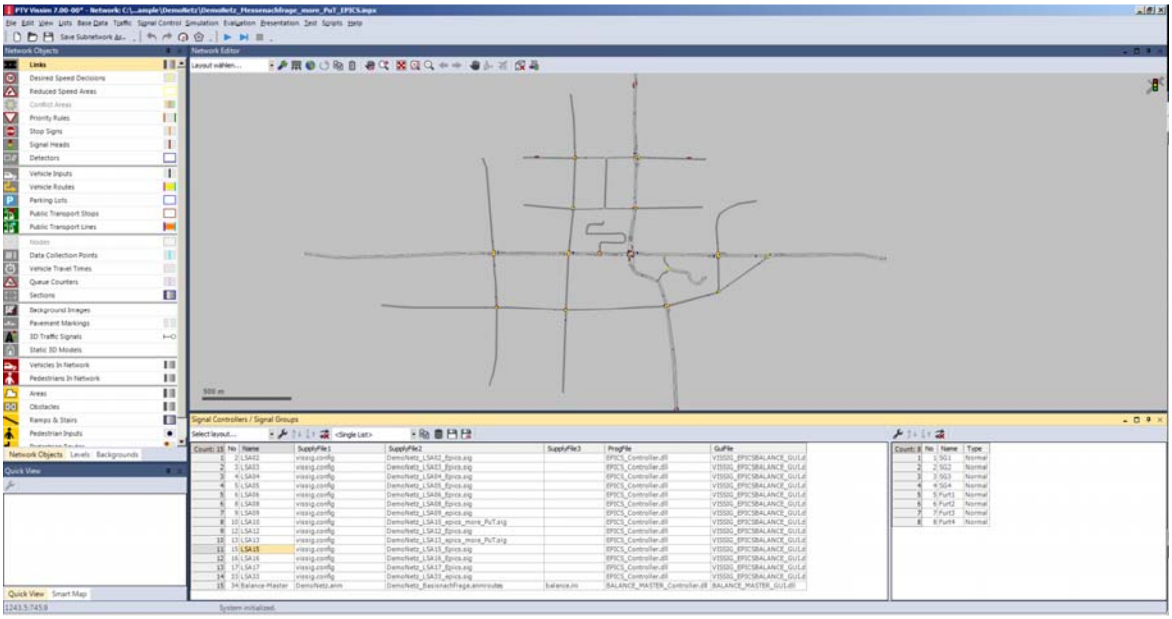


Figure 17: Network in PTV Vissim using anm-export and import functionalities.

4.1.2 Showing Additional Data in the Signal Times Window

You can show the current signal states and detector states during a simulation or during interactive tests of signal control logic in a window. Therein, the green times, yellow times and red times are represented graphically along a horizontal time axis for each selected signal control.

For details on the standard attributes and configuring the signal times window please refer the Vissim user manual (PTV AG 2015a).

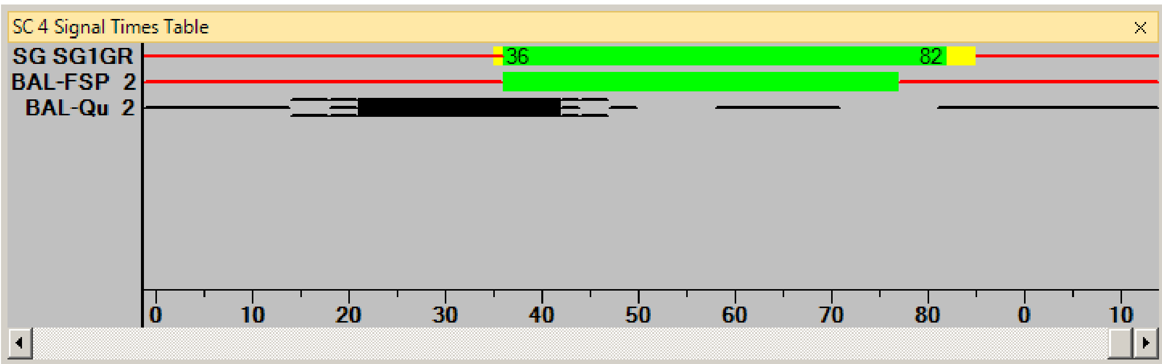
PTV Balance allows you to show additional attributes that are described below.

Result of evaluation of signal times tables, additional PTV Balance attributes

If you have selected the evaluation, each selected signal control is shown in a window during a simulation or a test run of the signal times table.

The colors indicate the current state of the respective signal group.

The state of the current time step is represented at the right edge of the window.



If the signal times table also contains PTV Balance frame signal plan BAL-FSP, the colors indicate the desired signal state of PTV Balance. BAL-FSP does only differ red and green states and it is subject to the local control whether the frame signal plan is respected or not.

If the signal times table also contains PTV Balance queues BAL-Qu, the colors indicate the queue state of the PTV Balance simulation model.

Queue color	**Description of the queue state**
nothing	no queue
black line	1-3 vehicles in queue
black frame	4-6 vehicles in queue
black line and black frame	7-8 vehicles in queue
solid black	>8 vehicles in queue

Hint: These attributes are not available before PTV Balance calculated an actual optimization. On the first call to PTV Balance, the network is empty, detectors have not yet delivered any data and therefore this initial call, does not yield optimization results.

4.1.3 Evaluating Additional Data in the Signal Control Detector Record

You can use the SC detector record to check control logic of external control procedures. For each SC, you can show a freely configurable, precise record of the SC values and detector values as well as internal parameters of the control procedure.

For details on the standard attributes and configuring the signal control detector record please refer the Vissim user manual (PTV AG 2015a).

PTV Balance allows you to show additional attributes that are described below.

Result of the SC detector record evaluation, additional PTV Balance attributes

Value type	**Meaning**
BAL-FSP	PTV Balance Frame Signal Plan BAL-FSP does only differ red and green states and it is subject to the local control whether the frame signal plan is respected or not. State of frame signal plan: ➨ . red ➨ I green
BAL-Qu	PTV Balance Queue Bal-Qu indicates the queue state of the PTV Balance simulation model: ➨ 0-9 vehicles in the queue ➨ X more than 9 vehicles in the queue

Hint: These attributes are not available before PTV Balance calculated an actual optimization. On the first call to PTV Balance, the network is empty, detectors have not yet delivered any data and therefore this initial call, does not yield optimization results.

4.1.4 The PTV Balance and Epics network view

PTV Balance and PTV Epics are distributed with PTV Vissim and their own data visualization tool "The PTV Balance and Epics network view". This tool is browser-based and shows many internal data and the results of PTV Balance (and some information of PTV Epics) and is a useful tool for understanding and calibrating PTV Balance (and also works in a real-world deployment). The interface is designed in a self-explanatory way, still future version of this manual are going to provide more documentation on this tool.

4.2 Log Files

PTV Balance provides several log files. These contain warnings, errors and results. The log files are an important tool to identify errors in the data provision and for calibration.

The level of detail of the log files can be set in the Balance-Central Editor. This influences the number of produced log files.

Log files are created in the subfolder of the directory of the inpx-file. The folder has the name of the anmroutes-file with suffix BAL_Log.

PTV Balance creates a new log file for every calendar day and appends information to existing log files for every optimization.

Most log files provide a short explanation of its content and their first two columns display the current time and the simulation time.

PTV Balance creates numerous log files of the following schemes and types:

- Balance_LOGTYPE_YYYY-MM-DD_log.txt
  - LOGTYPE identifies the type of the log file. The most important types are described below.
  - YYYY-MM-DD represents the current day.
- json files
  These are used internally by the visualization component.
- genetic algorithm files (sav files and last files)
  These are used internally to manage the genetic algorithm.

4.2.1 Balance_output_YYYY-MM-DD.log.txt

The main log file. It includes error messages, warnings and information of the initialization and the optimization.

The first two columns display the time stamp and the log level, followed by the message. Messages of log level 5 indicate an error and prevent an optimization. Messages of log level 4 indicate a warning and usually do not prevent an optimization but impact the achievable quality of the results.

4.2.2 Balance_summary_YYYY-MM-DD-log.txt

This file provides an aggregated summary of every optimization run. The summary is split up in the following parts:

- Optimization
  Static information about the optimization algorithm and parameters.
  Dynamic information about the achieved results and the reason for termination of the optimization.
- Signal control
  Overview of all signal controllers, the active signal program, cycle time and the saturation of every signal controller. The latter helps to identify critical spots for calibration.
- Input data
  Number of known and active detectors. When PTV Balance is used in combination with PTV Vissim, these numbers should be identical.
- Traffic state
  The top ten least and most saturated signal groups. The latter helps to identify critical spots for calibration.
- OD estimation
  The top nine signals with the biggest deviation between measured and modelled traffic flows. Helps to identify critical spots for calibration.

4.2.3 Balance_signals_YYYY-MM-DD-log.txt

An important file for the calibration is the file Balance_signals_YYYY-MM-DD-log.txt. This file shows the internal state of PTV Balance.

Column header	**Description**
Time	current time [hh:mm:ss]
Simulation time	current simulation time [hh:mm:ss]
SPR	active signal program
LSA	unique ID of the traffic light system
FVSGR	signal group name
Link	unique ID of this object type
LinkGisID	unique ID of this object type
Lanes	number of lanes
Tgr[s]	green time demanded by PTV Balance, based on the latest T-Times
Q[Fz/h]	measured traffic volume
Qmod[Fz/h]	traffic volume calculated by the traffic model
Start queue length	not used
queue length	queue length from queue estimator
Queue length [Fz]	mean queue length

Column header	Description
Queue lengthDet[Fz]	mean queue length from the deterministic model
Queue lengthSto (KiHo) [Fz]	mean queue length from the stochastic model
Waiting time[s/tInt]	total waiting time during the calculation interval of the objective function
Waiting time[s/Fz]	mean waiting time per vehicle
Waiting timeDet [s/Fz]	mean waiting time per vehicle from the deterministic model
Waiting timeSto (KiHo)[s/Fz]	mean waiting time per vehicle from the stochastic model
Saturation[-]	saturation of the signal group
MaxCap[Fz/h]	maximum capacity of the lane
NumberStops[/TU]	number of stops during a cycle time
ShareStopingVeh[-]	share of the stopping vehicles
PI(SGrelated)	performance index of the objective function, related to the signal group
Average speed	average speed [km/h]

4.3 Calibration

4.3.1 General

In order to calibrate PTV Balance it is necessary to know the determining factors and their effects. If the data provision is correct, the following parameters allow improving the performance of PTV Balance:

- Saturation flows of the edges:
  Saturation flows of the edges are a major factor in the calculation of the delay. Saturation flows represent the capacity of a link or turn considering HGV share, turning ratio, width, steepness etc. but not green shares of a signal control. The anm file defines saturation flows for links and turns and can be changed using PTV Visum. For calibration purposes, one has to consider that in general the real saturation flow is unknown. Therefore, careful deliberation and ideally measurements are helpful, especially for turning movements.
- Weights for waiting time, queue length and number of steps for every signal group:
  Weights are used in the objective function of PTV Balance (chapter 2.1.4). Specific local circumstances or objectives to emphasize specific directions within the optimization are modelled with the weights. In order to get effects from the change of weights at an intersection, all signal groups and the scale of their effects have to be considered.

4.3.2 Guideline for the Calibration

In order to assist the calibration process, the following chapters provide an outline of a structured approach. In general, calibration is an iterative process and it is advised to not apply too many changes at once.

4.3.2.1 Simulation without optimization

Generally there is always a With- and Without-Comparison. The simulation runs should always be processed with different random seeds and at least 10 different simulation runs to guarantee a solid data base with different traffic situations for the analysis of the comparison.

Bigger traffic related changes like morning maximum, traffic during midday or evening maximum should be simulated in different scenarios. The signal programs can be analysed separately, because usually different signal programs are switched during the different scenarios.

4.3.2.2 Simulation with optimization

In the beginning, the simulation with optimization is not processed with different simulation random seeds until a useful result is achieved. A soon as a positive result is achieved with a certain random seed, simulation runs with other random seeds can be tested.

Because PTV Balance is a network control, the delay, travel times and numbers of stops of the whole network should also be observed and evaluated during any simulation run. The traffic parameters which should be captured during the simulation are varying according to the objectives of the control. Because there is a vast array of possibilities for the analysis of those data offered in the simulation, almost every objective of the control can be achieved with these analysing methods. The analyses can be generated and visualized by PTV Vissim and can be used for the evaluation of the network control. Depending on the objective of the control, it may also be useful to analyse certain edge sections apart from the others using additional parameters which can be integrated into the calibration.

4.3.2.3 Observing the simulation

PTV Vissim offers many parameters for the evaluation of the performance of the network control. However, one should not only rely on these parameters only, but also observe the simulation. It is possible that the overall results are improving due to a congestion blocking one of the entrances of the network. In conclusion, less vehicles drive into the road network and the overall result gets better. If there are errors in the data provision or the optimization the reason can quickly be located by observing the simulation in a heavily congested network.

4.3.2.4 Analysing log Files

For details on the content of the log files please refer to chapter 4.1.2.

Balance_output_YYYY-MM-DD.log.txt

The main log file has to be checked for messages of log level 4 and 5 that either negatively affect or prevent an optimization.

Balance_signals_YYYY-MM-DD-log.txt

The values traffic volume, demanded green time, delay, queue length and number of stops should be compared to the values which have been calculated in the simulation. If there are significant differences, check the data provision. If the traffic volume is also plausible, the actual calibration can be started.

Balance_summary_YYYY-MM-DD-log.txt

The summary of every optimization allows for a quickly identification of critical spots.

Signal controllers and signal groups with the highest saturation should be examined in the simulation. If the behaviour of the simulation is plausible then these are the most promising locations to focus the calibration.

Large deviations between measured and modelled vehicle flows indicate either potential errors in detector data provision (wrong location or vehicles not travelling over a detector) or a low quality of the provided demand matrix.

4.3.2.5 Result evaluation

Result evaluation depends on the objective. PTV Vissim provides various possibilities to measure global indicators (e.g. total delay time) or to focus on more specific indicators (delay time for public transport busses, pedestrians or travel times along a specific direction). Suitable indicators have to be defined and observed to evaluate changes in the optimization parameters.

4.3.2.6 Tweaking calibration parameters

The following circumstances require special attention:

- Mixed lanes
  Tweaking saturation flows of edges is especially important if there are right turning vehicles and straight driving vehicles on the same lane. If the right turning vehicles progress independent of the straight turn, an estimation of the saturation traffic volume is difficult. If PTV Balances estimates waiting times significantly different from the simulation this indicates the need to adjust saturation flows.
- Left turns
  Left turns with separate short lanes that are signalled in separate stages can block the straight turns and deserve special attention.
- If single directions of the signal groups are estimated wrong, it is recommended to change the weight for the waiting time in order to perform a specific adaption of the signal group resp. the direction. It is important to consider the scale of the other weights of this intersection.
- If coordination is one of the most important objectives, the weight for number of stops should be changed at the respective signal groups. Every intersection should be checked one by one considering the objectives and the weights should be changed accordingly. This is an iterative process because changes at a single intersection can have effects on the whole network.

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