PTV BALANCE

the mind of movement

PTV BALANCE

USER MANUAL

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Imprint

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Contents

1 Introduction

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, most notably the research project TRAVOLUTION (2006-2009) with the development of the genetic optimization algorithm and the projects TRISTAR (2013-2015) and Lublin (2015-2016) that established Balance in Poland, the latter together with PTV Optima as a comprehensive traffic management system.

The inner core of PTV Balance consists of four parts:

1. A macroscopic traffic model that estimates flows in accordance with detector data,
2. A control model that emulates the local intersection control,
3. A mesoscopic traffic flow model that calculates the effects of a specific signal plan,
4. And most importantly different optimization algorithms.

Furthermore, it is possible to replace the macroscopic traffic model with external traffic state estimating programs that are able to take a whole conurbation into account. To this end Balance can be embedded into PTV Optima, which is the traffic management platform and decision support system developed by PTV. The main advantages are that Optima is able to predict traffic, enabling an optimization for the near future, and also allows to take much more traffic data than just detectors into account, e.g. floating cars and ANPR data.

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. The 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 Architecture and algorithms

2.1.1 Basic Idea

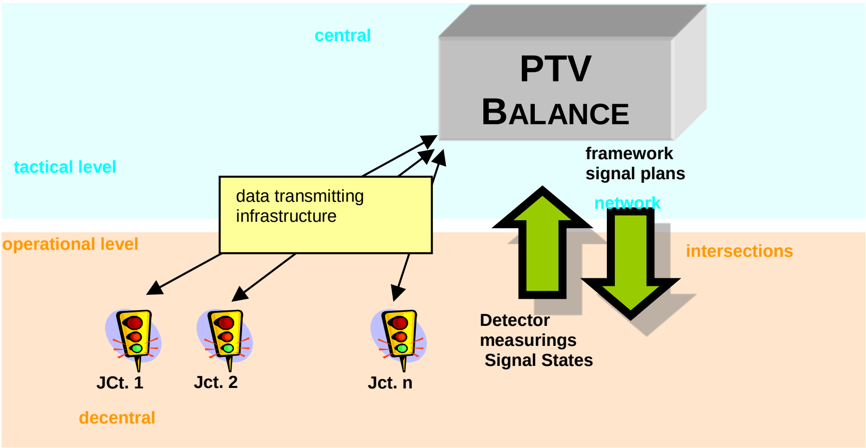


Figure 1: Two-Level-Concept of PTV Balance

The system architecture of Balance is characterized by a two-level-concept, where the functionality of the traffic light system is divided hierarchically (see Figure 1)

- An efficient microscopic controlling method looks at short-term changes of the traffic volume, e.g. during the prioritization of public transport, based on the current detector values and signal status. The local controlling method works usually on a second-by-second basis or even shorter.
- PTV Balance works as macroscopic system on the tactical level of the adaptive network control by sending framework signal plans to the intersections every 5 Minutes. A framework signal plan defines static and variable areas for the phases of the local control for all controllers within a group that have 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.

Any local traffic control system control can be applied, as long as it integrates an interface for the frame signal plans which are created by PTV Balance. This flexibility was one of the main goals during the development of PTV Balance, 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), the VS-PLUS-Control (Verkehrs-Systeme AG 2012) and the SIEMENS TL/PDM-System have been used as local control strategy. Tests with the American ring barrier controller have also been conducted.

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 all intersections of a town, but it is necessary to divide them into several control groups, with a size of 1-30 intersections in each group. This additional division is required to distinguish different areas of the network with different traffic related characteristics. One important point is that Balance selects a signal program with an adequate cycle time at once for all controllers in a group. Performance issues play a role here, and a limitation of the search space for optimization is also good to avoid being stuck in local optima.

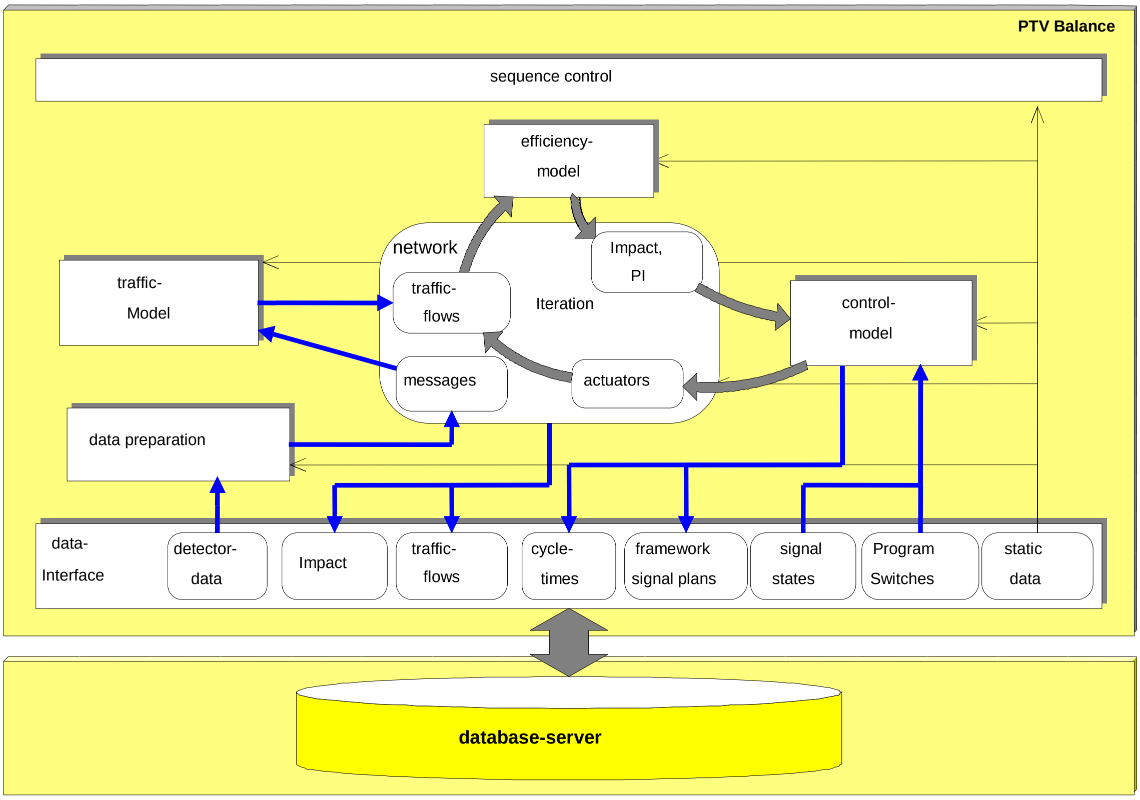


Figure 2: Block-diagram of the PTV Balance network control

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. Figure 3 illustrates this aspect at the example of a small net with two intersections.

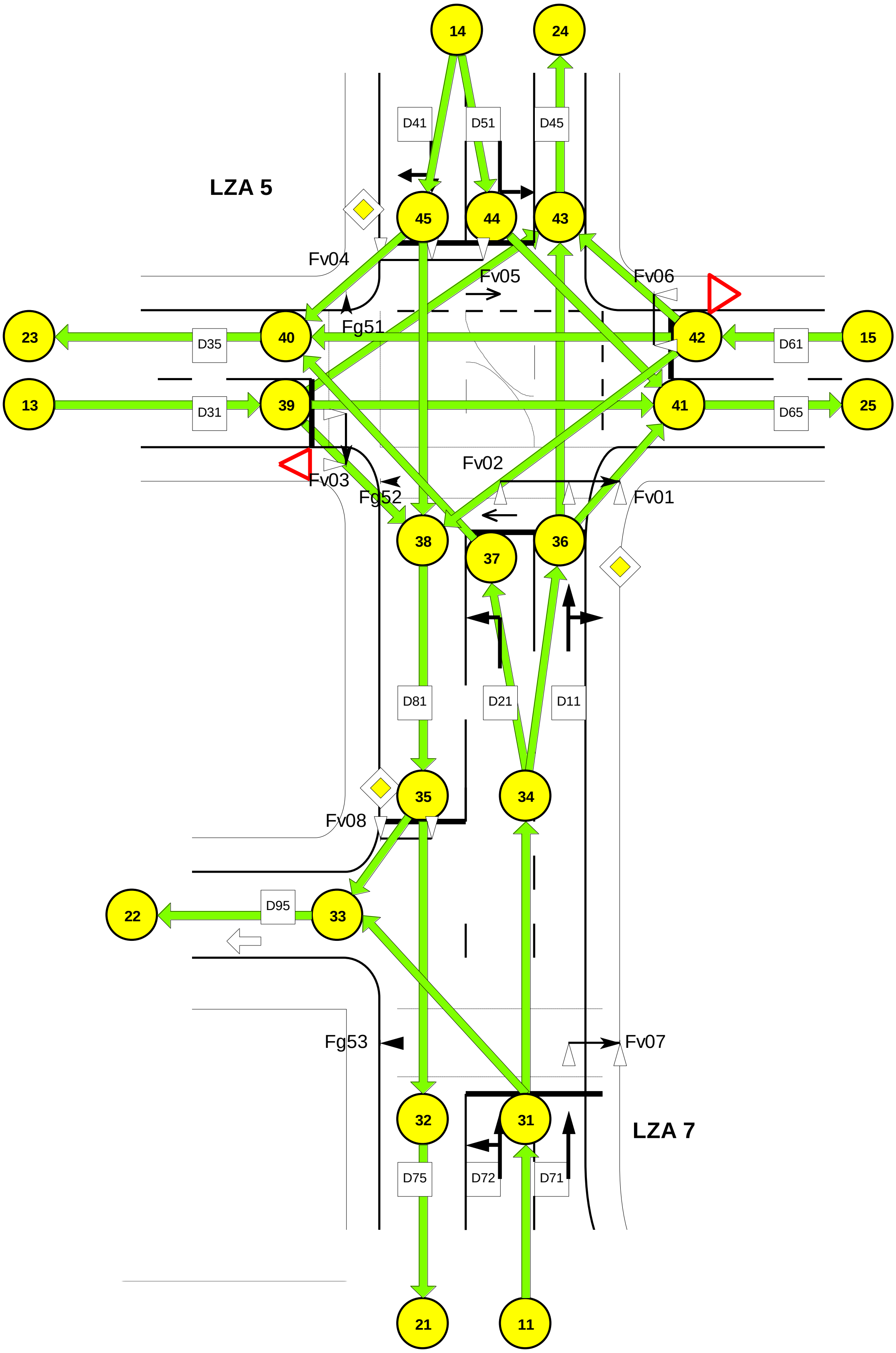


Figure 3: Example of a simple network model

The edges are the central container for the traffic data within the PTV Balance-System. 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

There are more system functions available for the control of the internal process or for database accesses, etc, but these functions are not discussed in this manual. The next chapters will shortly describe the functional groups mentioned above.

2.1.2 Detector positioning and data gathering

It is necessary to estimate the current traffic state in the road network as good as possible, before the optimization of the signal control can start. Local detectors collect the traffic situation in the controlled area in the form of aggregated or disaggregated measurements for the current calculation interval. This data is gathered by the controllers and delivered to the central database. Detectors which are not connected to a traffic light system can also be utilized by PTV Balance. Additional kinds of dynamic data of the traffic light systems are also collected. For example, the currently running signal program, the cycle time or different operation modes of the controller or the detector.

The positioning of detectors for Balance should be done according to the following rules:

1. There should 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 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 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 borders of the area which is selected for the calculation of the traffic state (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.

The detectors which are suggested here are normal single loops which can also be used for the time gap control or counting purposes. 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.

It is usually not necessary to have more or different detectors for Balance than for Epics. So, if the junction is controlled by PTV Epics, everything should be fine regarding detection.

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. It consists of three different functional parts which are arranged in two different levels (see Figure 4):

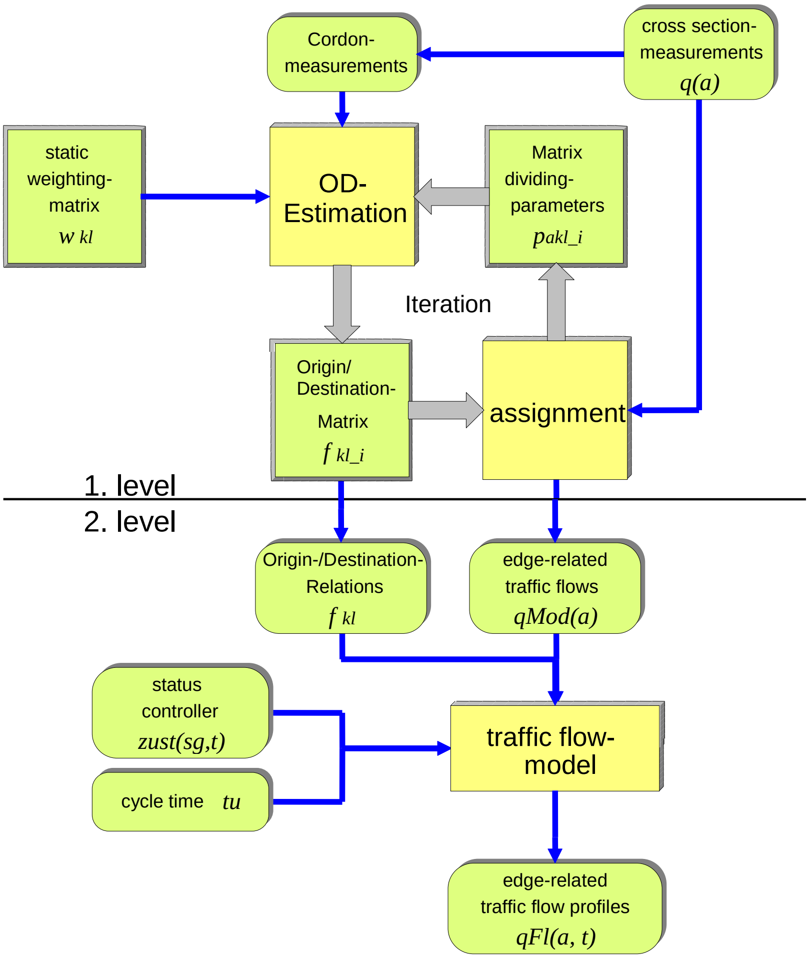

Cordon-measurements
cross section-measurements $q(a)$
static weighting-matrix w_{kl}
OD-Estimation
Matrix dividing-parameters p_{akl_i}
Iteration
Origin/ Destination-Matrix f_{kl_i}
assignment
1. level
2. level
Origin-/Destination-Relations f_{kl}
edge-related traffic flows $qMod(a)$
status controller $zust(sg,t)$
cycle time tu
traffic flow-model
edge-related traffic flow profiles $qFl(a, t)$

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 for every optimization. It consists of:

- An OD-Estimation for the 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.

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 results of the traffic assignment are the traffic flows qMod(a) [Veh/h] per edge 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.

This procedure is repeated until a given number of iterations is reached. The main results are macroscopic traffic volumes qMod(a) [Veh/h] for all edges a of the network, and especially for edges where no measured values are available. Other results 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 for every edge and the turn-off rates at 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 control group (see Figure 5).

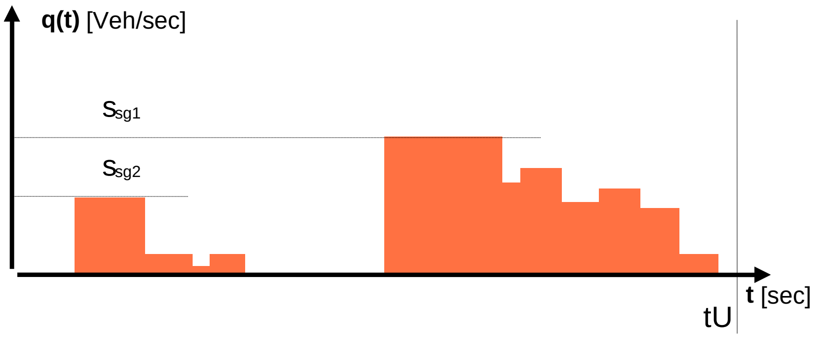


Figure 5: Illustration of the traffic flow profile of the second level of the traffic model

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:

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

With the estimated average travel time on the edge

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

The platoon dispersion 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:

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

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 thousand optimization-steps processed during every PTV Balance-call. Therefore 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 calculated for the next step in time. 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 stochastic part at the stop lines is determined by a macroscopic queue-model that takes overloads into account (see Figure 6).

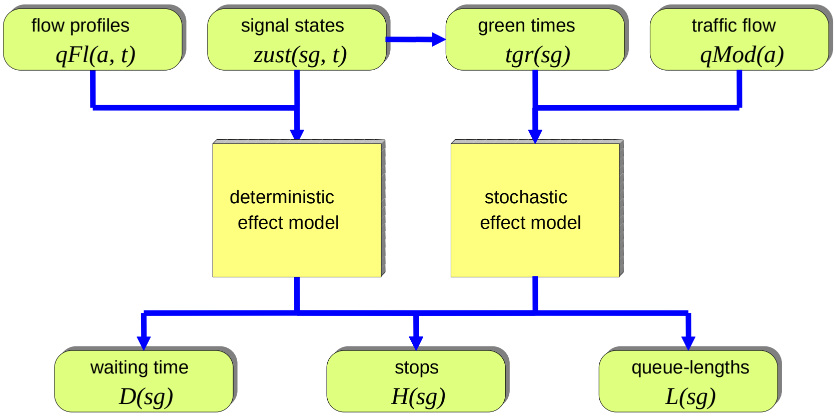


Figure 6: Block-Image of the PTV Balance-efficiency model

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 traffic network always has an impact on the signal groups which are located downstream. Therefore, the optimization of the green time is calculated 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 signals and links in the network.

For 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. As 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 links 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). The applied formulas are described in the following sub-chapters.

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:

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

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 results 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 7). 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.

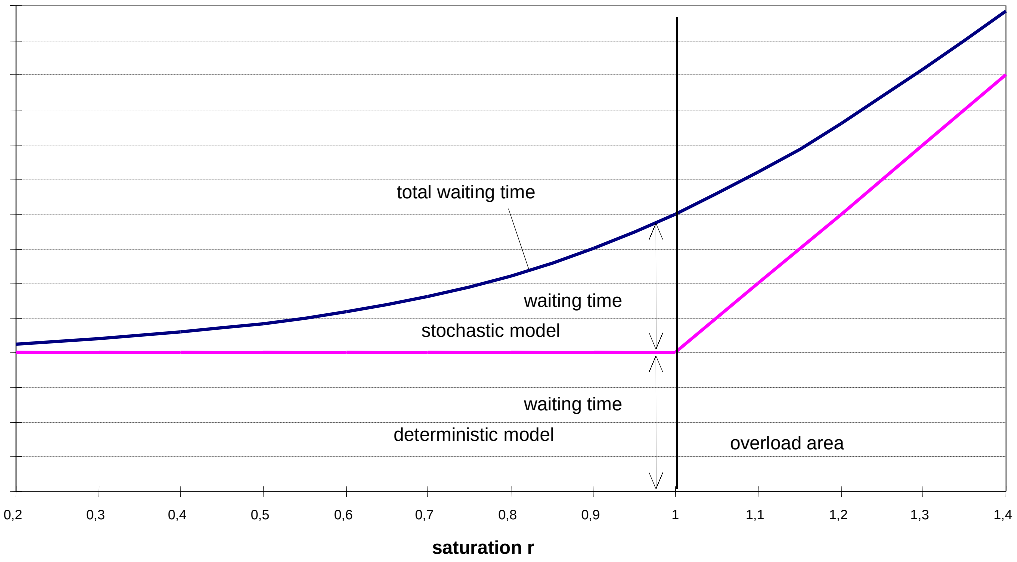


Figure 7: Schematic waiting times with deterministic and stochastic model

2.1.5 Optimization process

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

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

PTV Balance was originally designed to use a Hill-Climbing (HC) algorithm for optimization. In 2008 an additional optimization procedure was developed and implemented in the German research project TRAVOLUTION: The Genetic Algorithm (GA). One important advantage of a Genetic Algorithm is its ability to 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 TRAVOLUTION showed that the GA significantly improved the optimization quality in terms of a better performance index in Balance and, more importantly, also on the road. But it also is consuming more calculation time. This is not so big an issue in a real-world traffic centre, but 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 user can switch between them through an entry in the initialization file. The GA in Balance has been patent-protected

2.1.5.1 Calculation of split and offset

The Balance control model creates framework signal plans for all traffic lights in the sub-network every 5 minutes and sends them to the controllers. A framework signal plan (FSP) contains the length (split) of the green 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 8).

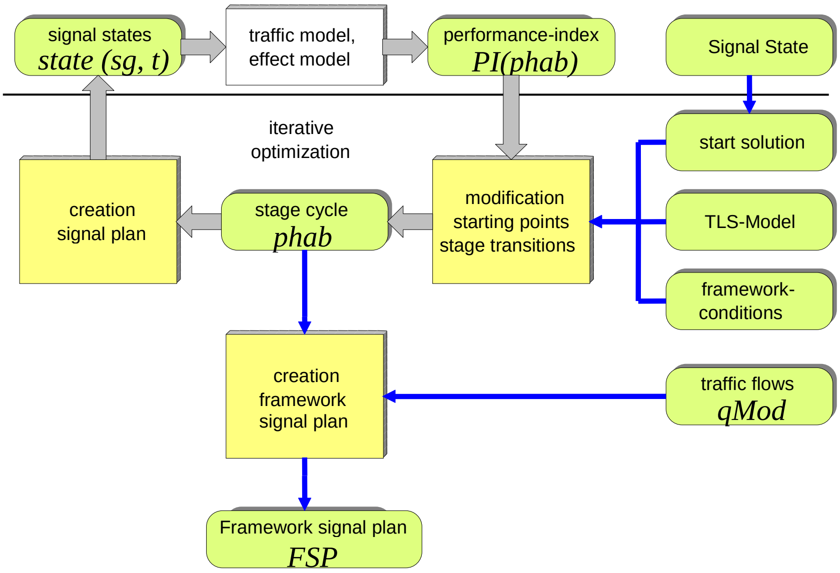


Figure 8: Block-Image of the PTV Balance control model

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 green 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 current fixed-time program of the traffic light. 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 phab_0, the control model successively creates new solutions by changing the local parameters. The starting points are increased for each interstage of the stage cycle (Figure 9) respectively the modification is interpreted in a way, which allows the following solutions phab_i to be valid, too. This means, that the solutions are compliant with the framework conditions and therefore give a valid signal plan for each traffic light controller.

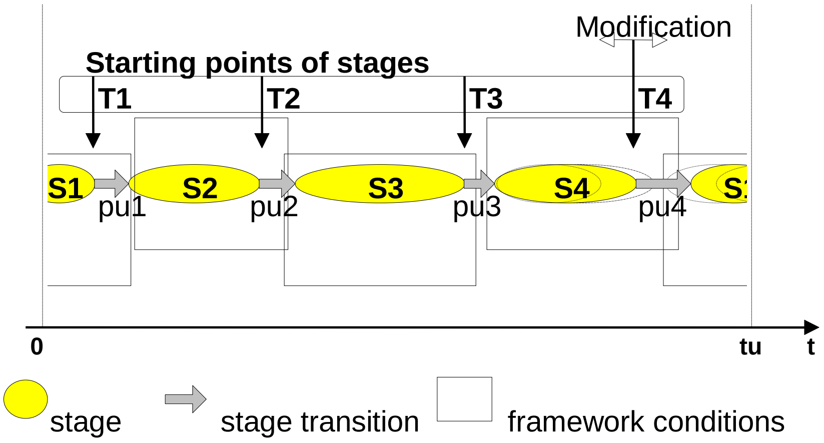


Figure 9: Example modification of the stage cycle

The 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 goal of the optimization model is to find the optimal solution according to the PI.

Unfortunately, the problem of traffic network optimization is very complex and not mathematically solvable. Simple optimization strategies, like the gradient procedure or linear optimization lead often 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. 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, so the calculation time would grow to infinity regardless of the speed of the computer.

Calculation with the Hill-Climbing Algorithm

The Hill-Climbing approach is a heuristic procedure which moves starting times of interstages in the cycle and calculates the performance index of the resulting signal plan. Only solutions which are better than the previous state are accepted. This is done iteratively for all stages and all controllers. The performance index is always calculated for the whole network at once, so changes that will deteriorate the downstream traffic will be rejected. This procedure corresponds to the Hill-Climbing Algorithm (Domschke and Drexl 1998), which is also used by many other adaptive network control procedures like Scoot (Hunt et al. 1981) and Transyt (Robertson 1969).

The procedure mentioned above is executed multiple times for each intersection of the respective control group with a limited number of calculation steps, until no improvement can be achieved anymore. This best solution for each traffic light, according to the performance index, is realized with its framework signal plan FSP and sent down to the controllers. At the local site, stages can also be extended or skipped according to the local detection.

Calculation of split and offset with the Genetic Algorithm

The Genetic Algorithm was conceived in the Bavarian research project TRAVOLUTION and tested in the city of Ingolstadt at 50 intersections. It proved an improvement of over 10% in terms of delays and stops in comparison to the Hill-Climbing Algorithm, and over 20% compared to the vehicle-actuated control that was in place before.

The whole work-flow of the optimization is illustrated in Figure 10. It consists of the following main components:

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

The traffic model creates an internal 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, determines 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 control of the traffic light at each intersection reacts on short-term changes of the traffic flow each second (operational level).

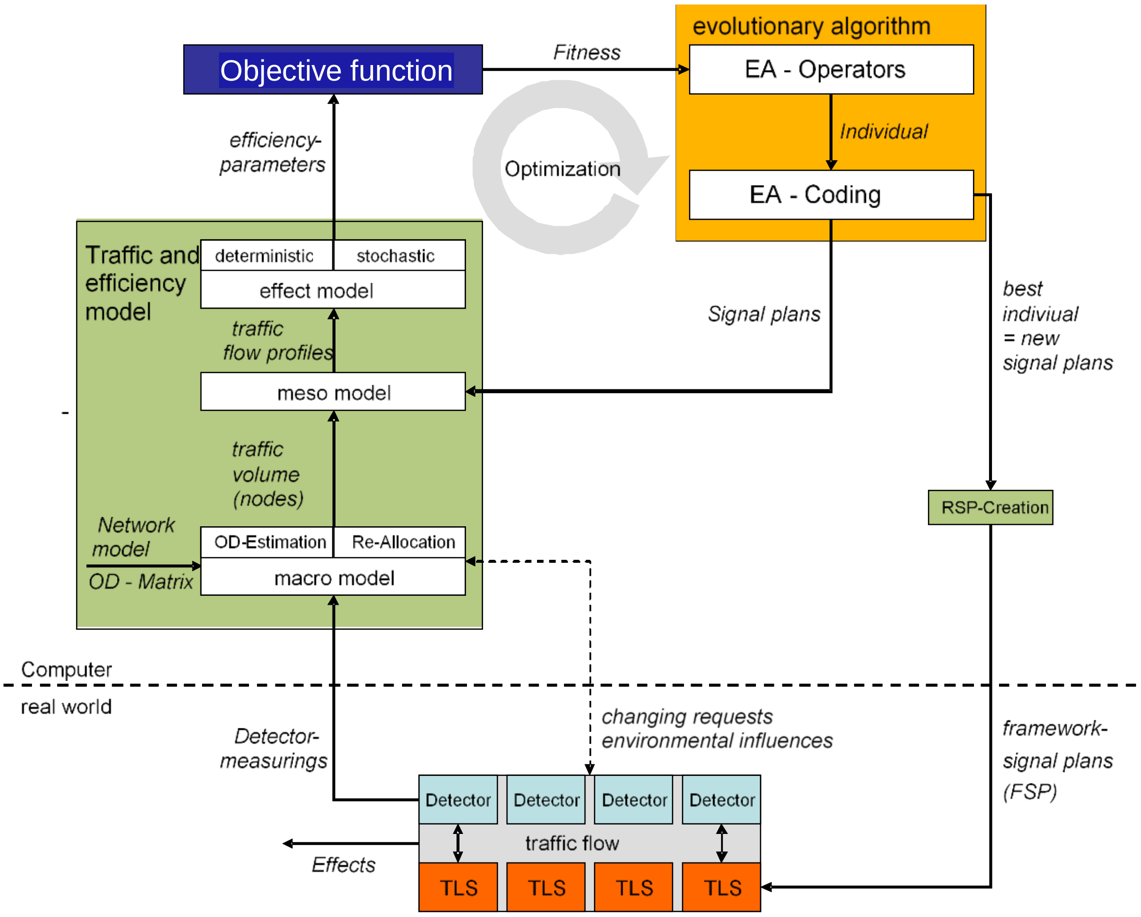


Figure 10: Procedure of online-optimization

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 to the individual. 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 green times)
- Framework conditions of the local traffic-dependent control

The framework conditions for the time interval control, which is very common in Germany and the world, are illustrated in Figure 11.

The framework signal plan for the local, measurement-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 traffic lights 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.

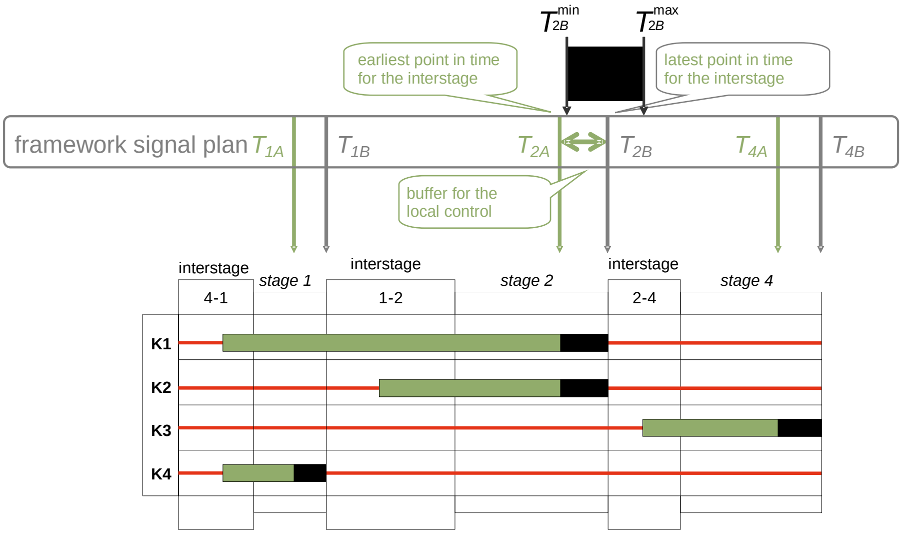

T_{2B}^{min}
T_{2B}^{max}
earliest point in time for the interstage
latest point in time for the interstage
framework signal plan T_{1A}
T_{1B}
T_{2A}
T_{2B}
T_{4A}
T_{4B}
buffer for the local control
interstage
4-1
stage 1
interstage
1-2
stage 2
interstage
2-4
stage 4
K1
K2
K3
K4

Figure 11: 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 for the *m* intersections of the network which are 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 *ϴ* 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) and is protected by patents. Besides the necessary framework conditions, like the adherence of intergreen times, it also integrates the framework conditions of the local traffic-dependent control. The achievement was to create only valid individuals in each optimization.

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 must be aligned 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). A mutation takes only 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 12 illustrates an example for the different behaviour of the Hill-Climbing-Algorithm and the evolutionary algorithm in an identical network with identical traffic volumes.

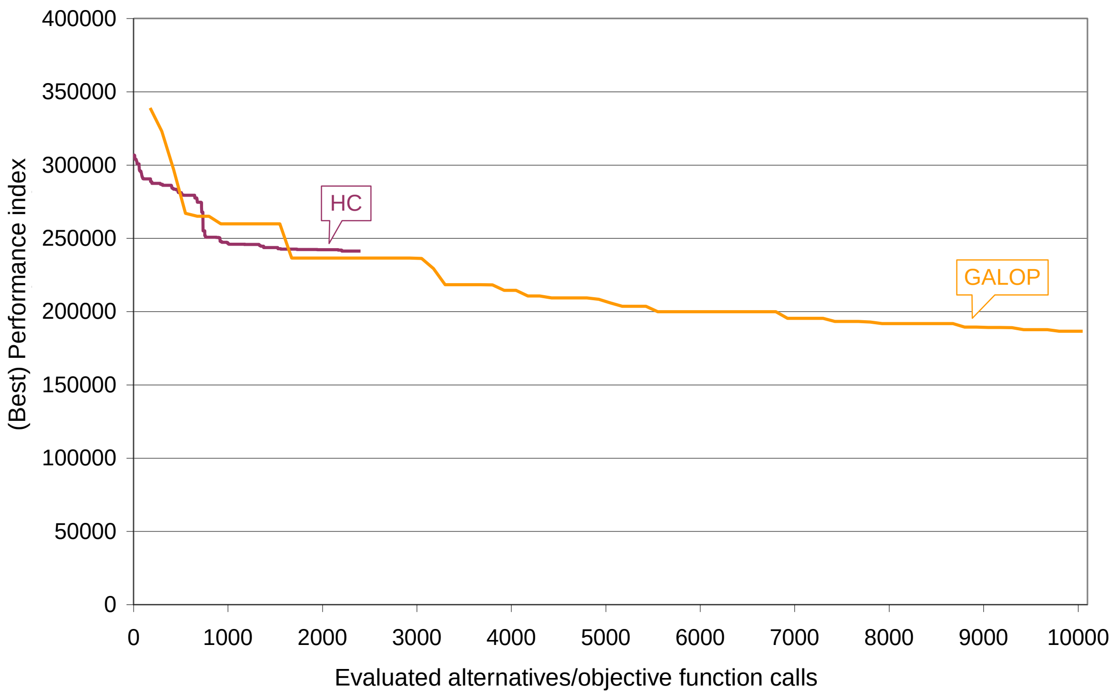


Figure 12: Comparison of the development of the fitness of the GA and the HC

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.

2.1.5.2 Calculation of the ideal cycle time

The calculation of the ideal cycle time is done for all controllers of a control group at the same time, to achieve an equal cycle time within the group. However, the adaption is processed more slowly and in larger intervals than the changing of the split and offset parameters, because a change of cycle time usually requires synchronization at the local controllers. This can take several cycles, is disruptive for the individual traffic and hence frequent changes should be avoided.

Moreover, this 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. Only a limited number of signal programs can be supplied for each controller. Therefore, Balance determines the signal program that has a cycle time nearest but bigger to the currently ideal cycle time.

The switching procedure for the traffic-dependent selection of the signal plan automatically calculates the required cycle time out of the saturation ratio of the signals with an optimized signal plan from Balance. Considering the green time *tgr* and the saturation ratio *μ* for a signal group, the additional green time Δt_0necessary to reach a desired saturation *α* (e.g. 90%) with the same cycle time is determined as follows:

$$\Delta t_0 = \left(\frac{\mu}{\alpha} - 1\right) t_{gr}$$

If you increase the green time by this value, the cycle time also changes, so that it's necessary to adjust the green share again to reach the desired value. This leads to the following formula for the cycle time change *Δt* for the whole intersection:

$$\Delta t = \frac{\sum \Delta t_{i,0}\, tu}{tu - \sum t_{i,gr} - \sum \Delta t_{i,0}}$$

With $t_{i,gr}$ the green time of the critical signal group in stage *i* and $\Delta t_{i,0}$ the additional green time for stage *i* determined with above formula (*tu* is the currently running cycle time). The intersection that gives the biggest value of *Δt* in a control group is the most critical intersection and thus determines the necessary cycle time as *tu*+*Δt*. Consideration of the available signal programs and their cycle times allows to choose the signal program that has minimum cycle time longer than the desired one. Thresholds can be applied for the number of repetitions of this calculation, before an actual switch is done in the field. These thresholds can be set differently for switching into longer or shorter signal programs.

2.2 Definition of control groups

For the network control you should define several control areas marking the traffic light systems which should be controlled in one go. These control areas are defined according to the following guidelines:

- Distance between intersections
- Different cycle times
- Coordination areas

There shouldn't be more than 30 intersections in one signal control, and as few as 1 is permitted, if the intersection is separated from its surrounding. The greater the number of intersections, the more degrees of freedom are in the optimization, enhancing the risk to stick to a local optimum.

The maximum distance between the traffic light systems which belong to one control area should be in the range of 700-1200m. 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 signal controller. Therefore you would have to check and calibrate the control group again after you have added a controller, 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.

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

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 lengths (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 2017a) is serving as simulation software. PTV Balance is integrated into Vissim systems as a DLL-file. 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 optimized 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 there are other connections with other methods open.

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 2017a/b/c).

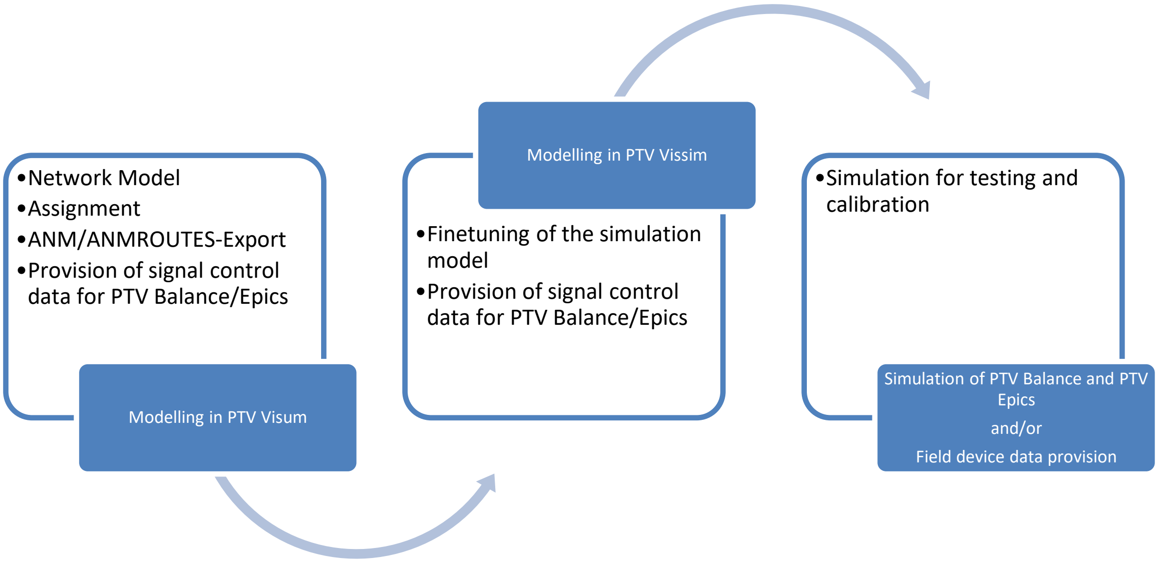

•Network Model
•Assignment
•ANM/ANMROUTES-Export
•Provision of signal control data for PTV Balance/Epics
Modelling in PTV Visum
Modelling in PTV Vissim
•Finetuning of the simulation model
•Provision of signal control data for PTV Balance/Epics
•Simulation for testing and calibration
Simulation of PTV Balance and PTV Epics
and/or
Field device data provision

Figure 13: 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 2017b “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 2017b “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.
- define parameters for PTV Balance and PTV Epics (or do that after Step 5: in PTV Vissim)

> 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 2017b) to quickly create good starting signal programs for a large number of intersections (also see Step 3: PTV Visum - assignment specifics).

3. Define signal coordination groups and assign the signal controllers to these groups.
4. 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.
5. 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 2017b "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 2017b "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 2017b "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 2017b "Matrix correction using TFlowFuzzy").
3. Use an assignment with ICA for the peak hour demand (see PTV AG 2017b "The procedure of assignment with ICA").
4. (Optional)
   - Use "Signal cycle and split optimization" and "Signal offset optimization" (see PTV AG 2017b) 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 2017b "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 large networks with several signal coordination groups in a timely manner in PTV Vissim, cut subnetworks corresponding to signal coordination groups for PTV Balance.

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 2017a "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 2017b “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:

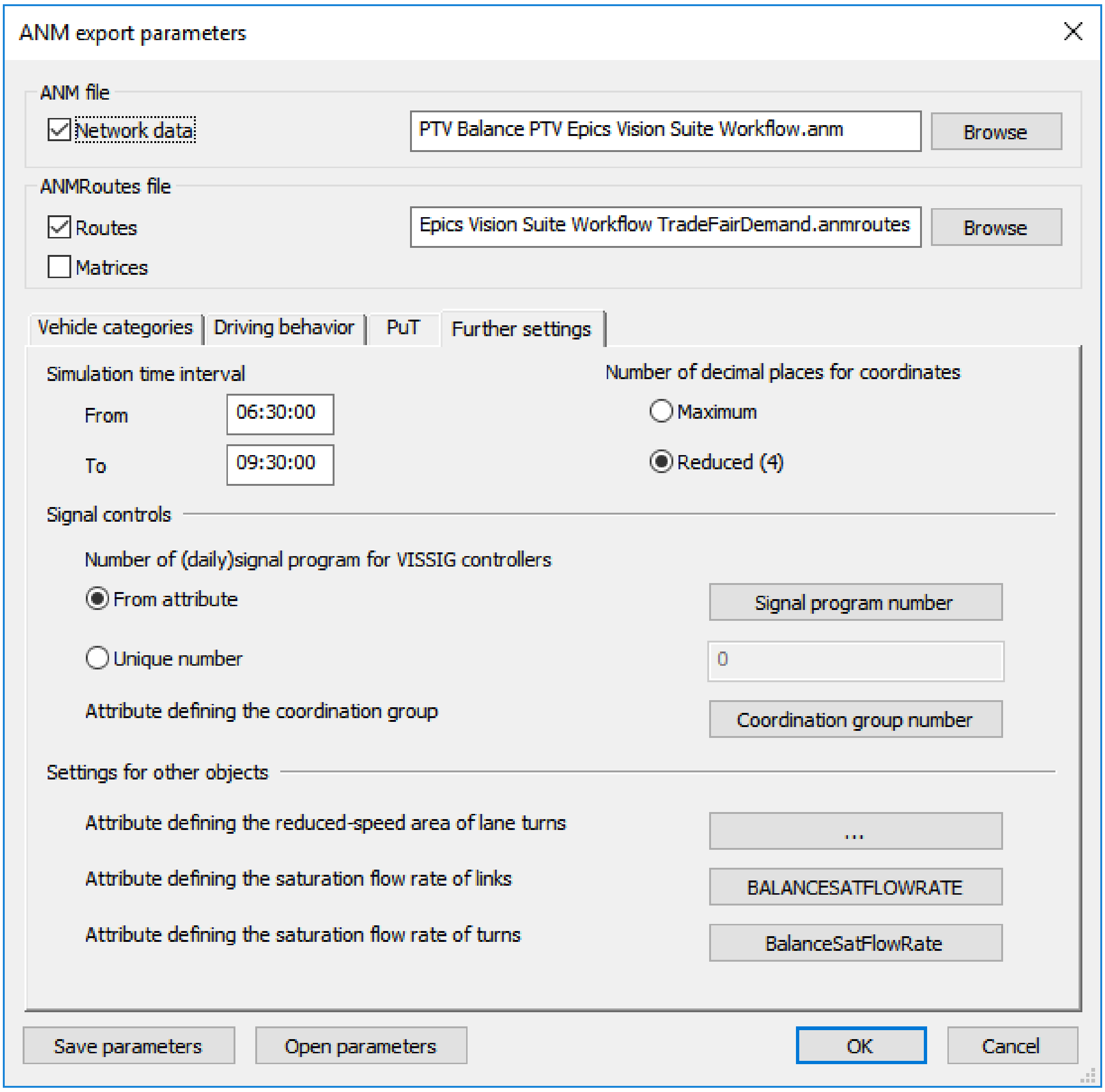
1. Open anm export parameters.
2. Click on **Further settings**.
3. In **Signal controls** click on the button next to **Attribute defining the coordination group**.
4. Choose any attribute.
   Fill the chosen attribute with the corresponding values.

Element	Description
Attribute defining the coordination group [-]	Numerical attribute that assigns the signal control to a signal control group. PTV Balance optimizes all signal controllers of one group together. Design control groups based on the topology of the network and runtime restrictions (depending on network size and computational power usually up to 50 signal controllers are feasible). It is possible to provide several signal control groups in the same anm-file. Use the global parameters of PTV Balance in PTV Vissim (see chapter 3.3.2) to optimize a specific group together with PTV Vissim. Nevertheless, in order to simulate large networks in a timely manner with PTV Vissim, cut subnetworks in PTV Visum, that correspond to the desired signal control groups.

5. 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**.

6. Choose any attribute.
   Fill the chosen attribute with the corresponding values.

Element	Description
Attribute defining the 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.
Attribute defining the 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.



ANM export parameters

ANM file

☑ Network data — PTV Balance PTV Epics Vision Suite Workflow.anm — Browse

ANMRoutes file

☑ Routes — Epics Vision Suite Workflow TradeFairDemand.anmroutes — Browse

☐ Matrices

Vehicle categories | Driving behavior | PuT | Further settings

Simulation time interval

From: 06:30:00

To: 09:30:00

Number of decimal places for coordinates

○ Maximum

● Reduced (4)

Signal controls

Number of (daily)signal program for VISSIG controllers

● From attribute — Signal program number

○ Unique number — 0

Attribute defining the coordination group — Coordination group number

Settings for other objects

Attribute defining the reduced-speed area of lane turns — ...

Attribute defining the saturation flow rate of links — BALANCESATFLOWRATE

Attribute defining the saturation flow rate of turns — BalanceSatFlowRate

Save parameters | Open parameters | OK | Cancel

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 2017b “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.

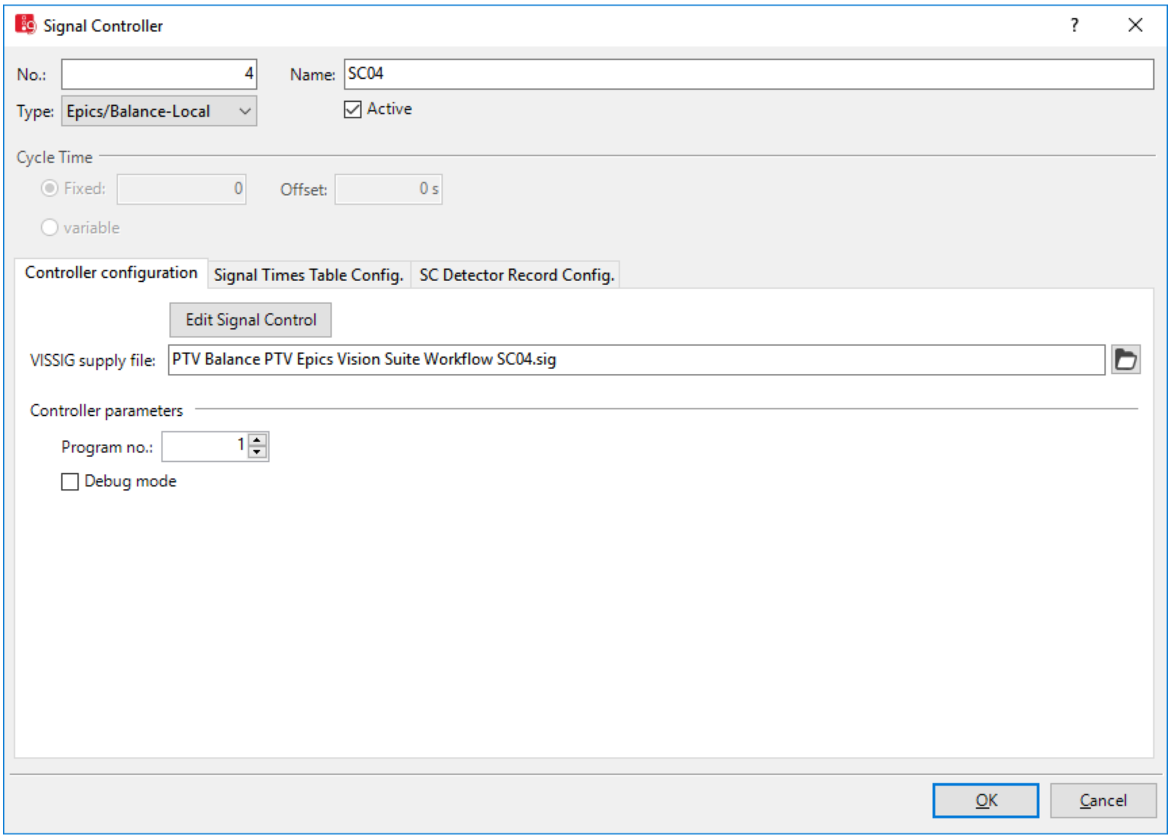
3.3 PTV Balance Parameters and Signal Control Data

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.*



Signal Controller

No.: 4
Name: SC04
Type: Epics/Balance-Local
☑ Active

Cycle Time
● Fixed: 0
Offset: 0 s
○ variable

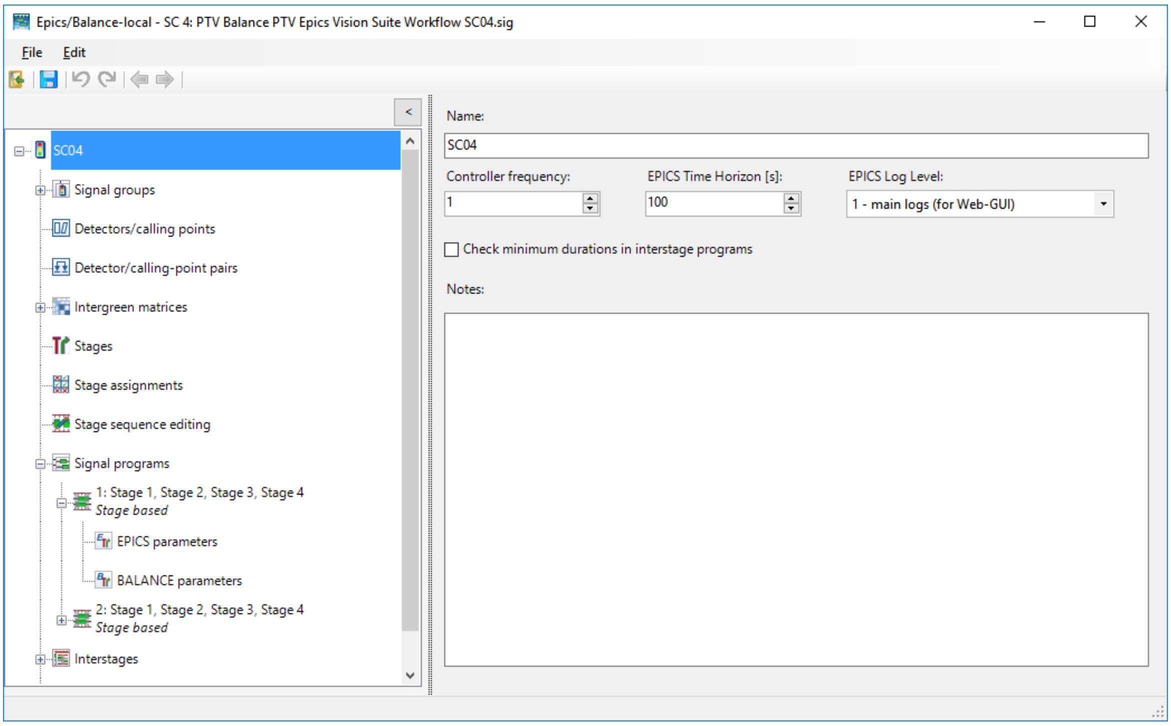
VISSIG supply file: PTV Balance PTV Epics Vision Suite Workflow SC04.sig

Controller parameters
Program no.: 1
□ Debug mode

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.



Name: SC04

Controller frequency: 1

EPICS Time Horizon [s]: 100

EPICS Log Level: 1 - main logs (for Web-GUI)

□ Check minimum durations in interstage programs

Notes:

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 and stage dependent parameters that define priorities and constraints for the optimization.

Overview of signal program parameters

PTV Balance has parameters concerning time and duration constraints of stages and allowed interstages. These parameters are signal program dependent and are set to default values during the automatic creation. Some of the default values are derived from the fixed-time signal program (e.g. original start of an interstage).

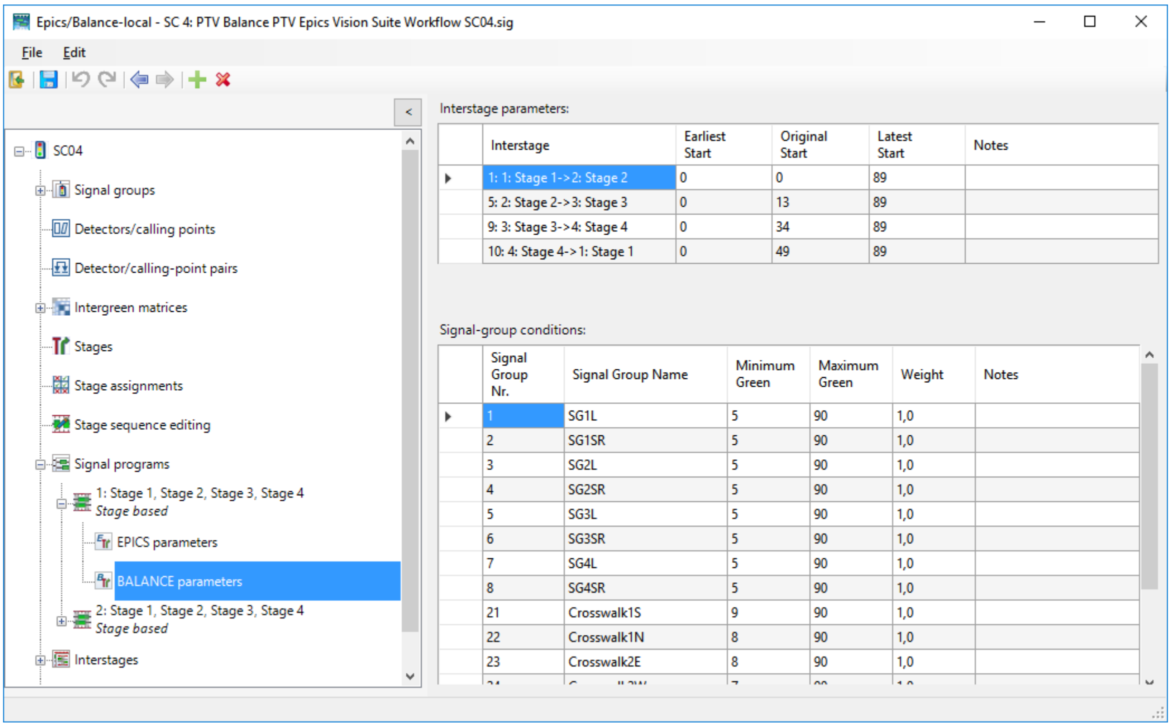
These parameters govern the optimization function of PTV Balance.

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.

Setting signal program interstage parameters

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



Interstage parameters:

Interstage	Earliest Start	Original Start	Latest Start	Notes
1: 1: Stage 1->2: Stage 2	0	0	89	
5: 2: Stage 2->3: Stage 3	0	13	89	
9: 3: Stage 3->4: Stage 4	0	34	89	
10: 4: Stage 4->1: Stage 1	0	49	89	

Signal-group conditions:

Signal Group Nr.	Signal Group Name	Minimum Green	Maximum Green	Weight	Notes
1	SG1L	5	90	1,0	
2	SG1SR	5	90	1,0	
3	SG2L	5	90	1,0	
4	SG2SR	5	90	1,0	
5	SG3L	5	90	1,0	
6	SG3SR	5	90	1,0	
7	SG4L	5	90	1,0	
8	SG4SR	5	90	1,0	
21	Crosswalk1S	9	90	1,0	
22	Crosswalk1N	8	90	1,0	
23	Crosswalk2E	8	90	1,0	

4. Make the desired changes of the **Interstage parameters**

Element	Description
Interstage	Interstage can be added, removed and changed (see hint).
Earliest Start	Cycle second [s] defining the earliest possible start of the corresponding interstage.
Original Start	Cycle second [s] defining the original start, typically as defined by the underlying fixed time signal program, of the corresponding interstage.
Latest End	Cycle second [s] defining the latest possible start of the corresponding interstage.
Note	Free text.

Hint: The interstages of PTV Balance and the underlying fixed time signal program may be different.

This is mainly of concern for real-word data provision, where the underlying fixed time signal program may be used as a fallback by the local controller. As a fallback option the underlying fixed time signal program must use all stages even e.g. non-regular PuT prioritization stages. But specifically these non-regular stages are not useful to be considered in the optimization of PTV Balance.

The PTV Balance interstages are set according to a newly created underlying fixed time signal program but can be changed manually.

Adding an interstage of a signal program

1. In the table, right-click the table cell.
2. From the context menu, choose **Add**.

Removing an interstage of a signal program

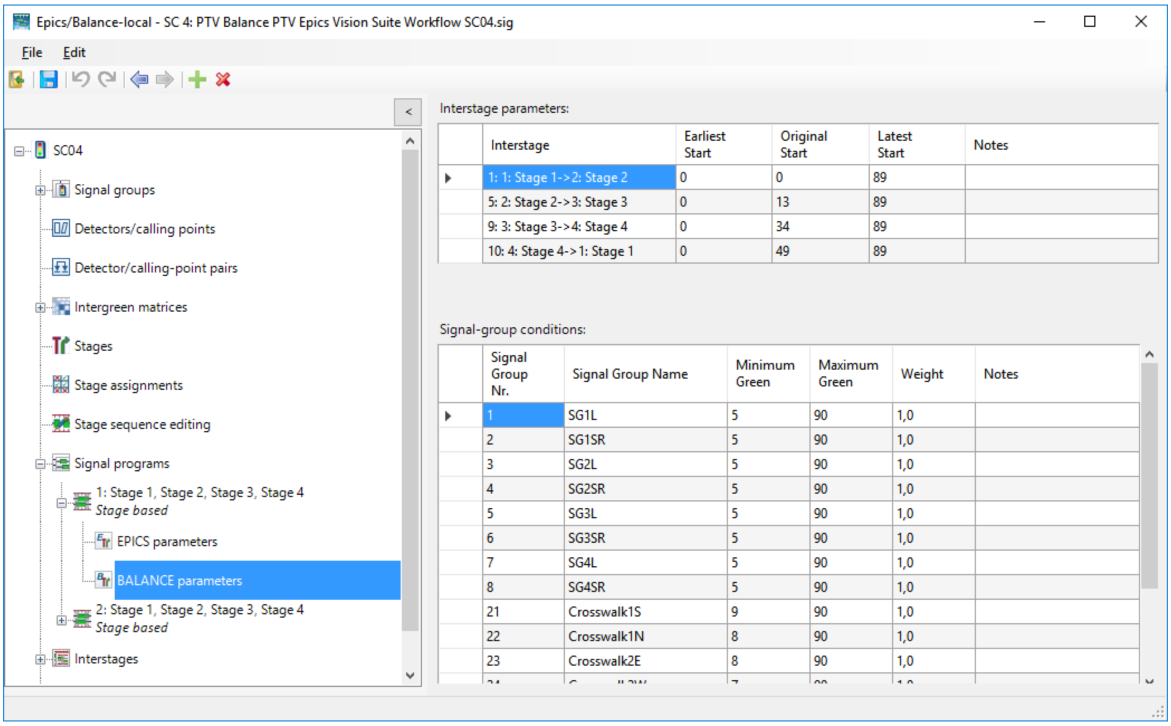
1. In the table, right-click the desired row.
2. From the context menu, choose the entry **Delete**.

Resetting interstage parameters of a signal program

1. In any table right-click the desired cell or column.
2. 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.

Setting signal program signal-group conditions

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



Interstage parameters:

Interstage	Earliest Start	Original Start	Latest Start	Notes
1: 1: Stage 1->2: Stage 2	0	0	89	
5: 2: Stage 2->3: Stage 3	0	13	89	
9: 3: Stage 3->4: Stage 4	0	34	89	
10: 4: Stage 4->1: Stage 1	0	49	89	

Signal-group conditions:

Signal Group Nr.	Signal Group Name	Minimum Green	Maximum Green	Weight	Notes
1	SG1L	5	90	1,0	
2	SG1SR	5	90	1,0	
3	SG2L	5	90	1,0	
4	SG2SR	5	90	1,0	
5	SG3L	5	90	1,0	
6	SG3SR	5	90	1,0	
7	SG4L	5	90	1,0	
8	SG4SR	5	90	1,0	
21	Crosswalk1S	9	90	1,0	
22	Crosswalk1N	8	90	1,0	
23	Crosswalk2E	8	90	1,0	

4. Make the desired changes of the **Signal-group conditions**

Element	**Description**
Signal Group Nr.	Non-editable as defined in signal groups.
Signal Group Name	Non-editable as defined in signal groups.
Minimum Green	The minimum length of the corresponding signal group [s].
Maximum Green	The maximum length of the corresponding signal group [s].
Weight	The weight reflects the importance of the signal group for the objective function of PTV Balance. Of specific concern is the relation of the weights of the different signal groups. If you want to put specific empathizes on a direction or if you experience queues in front of a specific signal group, increase its weight in relation to the other signal groups.
Note	Free text.

3.3.1.7 Interstages

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

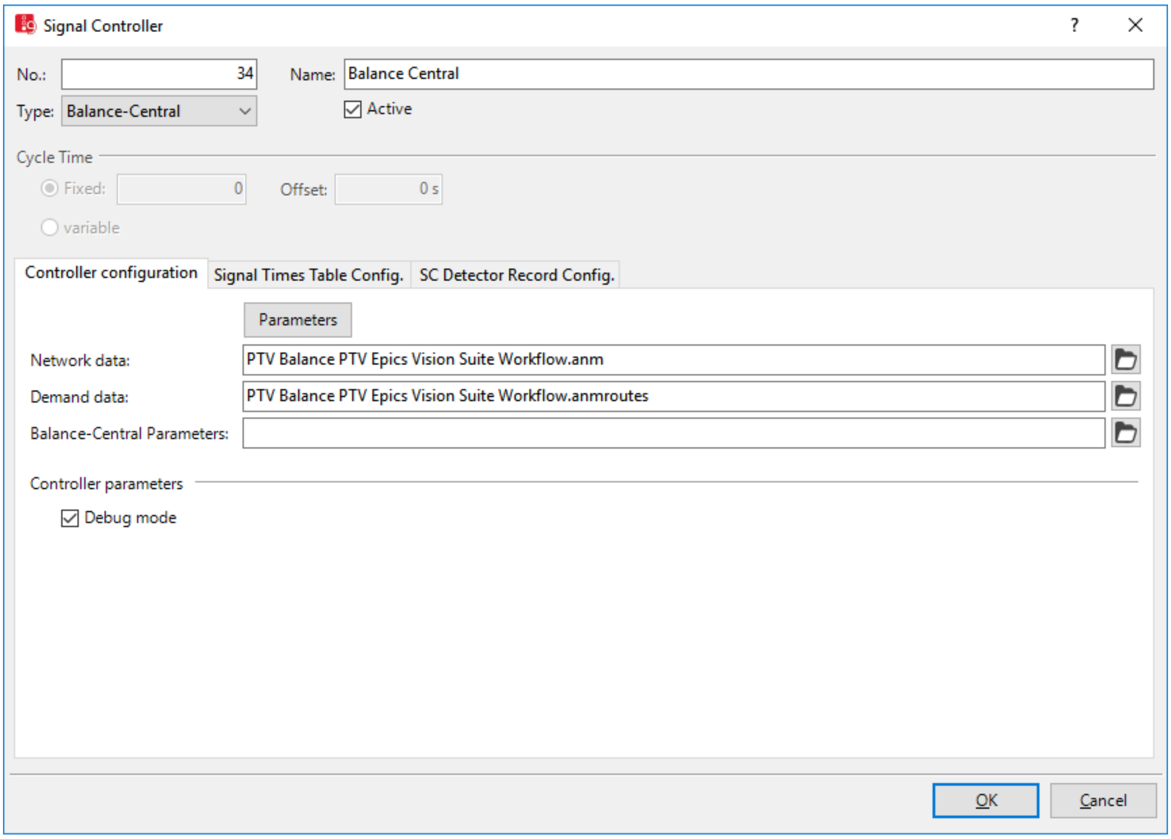
3.3.1.8 Daily signal program lists

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.*

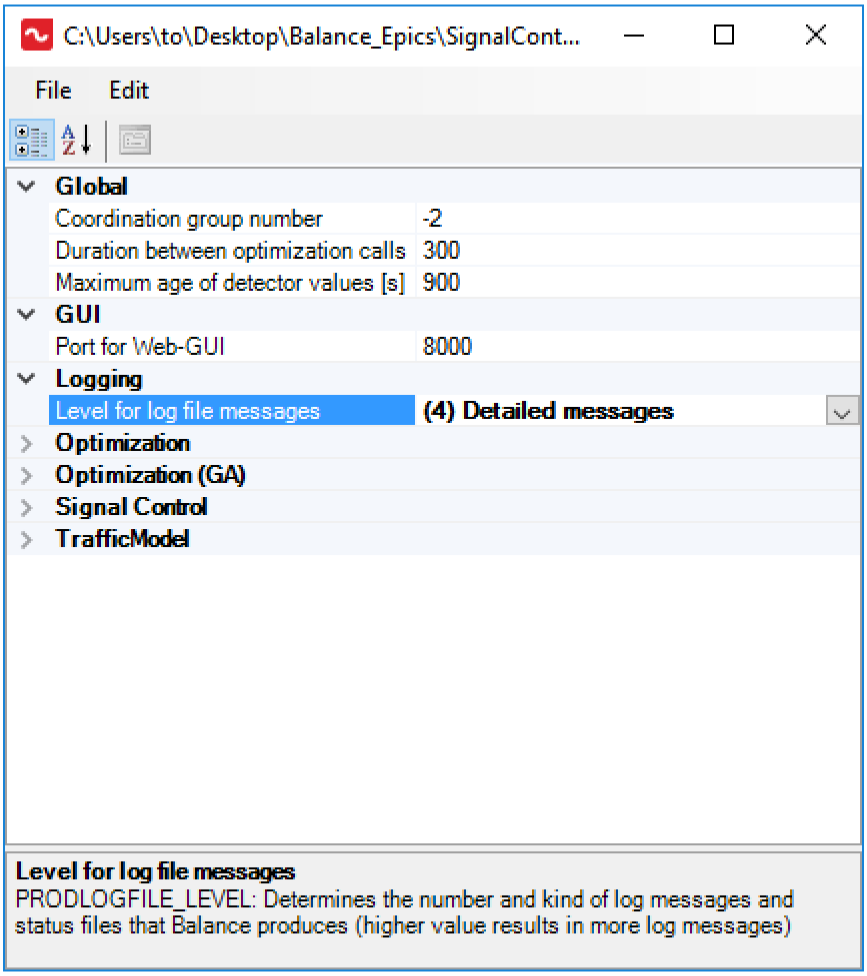


Signal Controller
?
No.: 34
Name: Balance Central
Type: Balance-Central
☑ Active
Cycle Time
● Fixed: 0
Offset: 0 s
○ variable
Controller configuration
Signal Times Table Config.
SC Detector Record Config.
Parameters
Network data: PTV Balance PTV Epics Vision Suite Workflow.anm
Demand data: PTV Balance PTV Epics Vision Suite Workflow.anmroutes
Balance-Central Parameters:
Controller parameters
☑ Debug mode
OK
Cancel

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.



Global

Coordination group number	-2
Duration between optimization calls	300
Maximum age of detector values [s]	900

GUI

Port for Web-GUI	8000

Logging

Level for log file messages	(4) Detailed messages

Optimization

Optimization (GA)

Signal Control

TrafficModel

Level for log file messages
PRODLOGFILE_LEVEL: Determines the number and kind of log messages and status files that Balance produces (higher value results in more log messages)

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

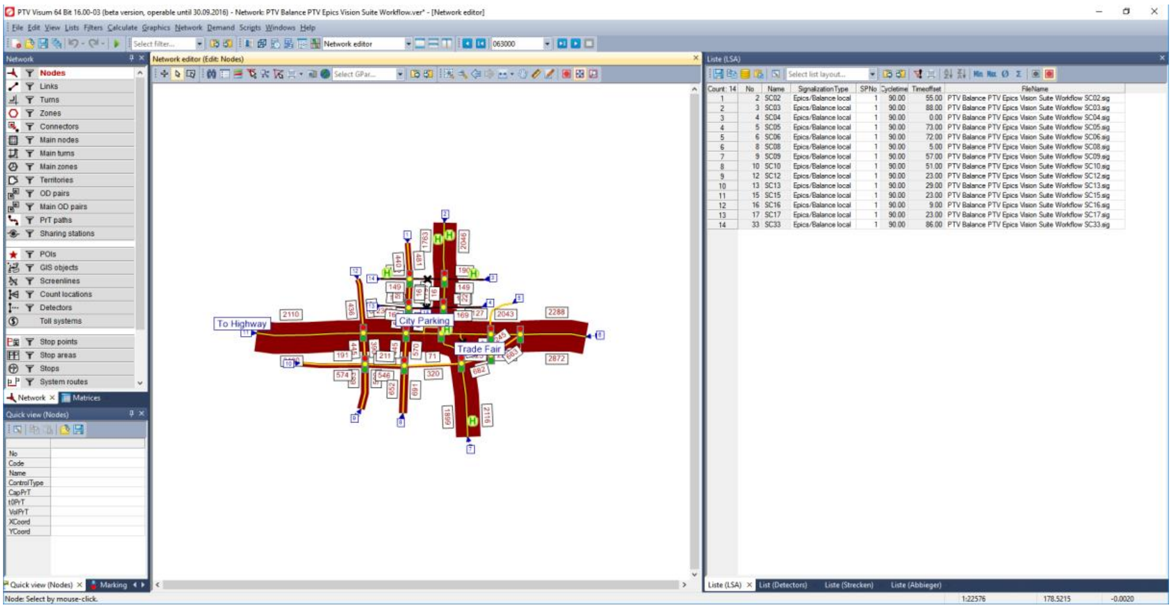
On the other hand a simulation is never 100-percent exact. Therefore the step from the simulated network to the real road network has to be taken with care – a recalibration might be necessary, at least for some approaches.

4.1 Simulation With PTV Vissim

4.1.1 Data Provision

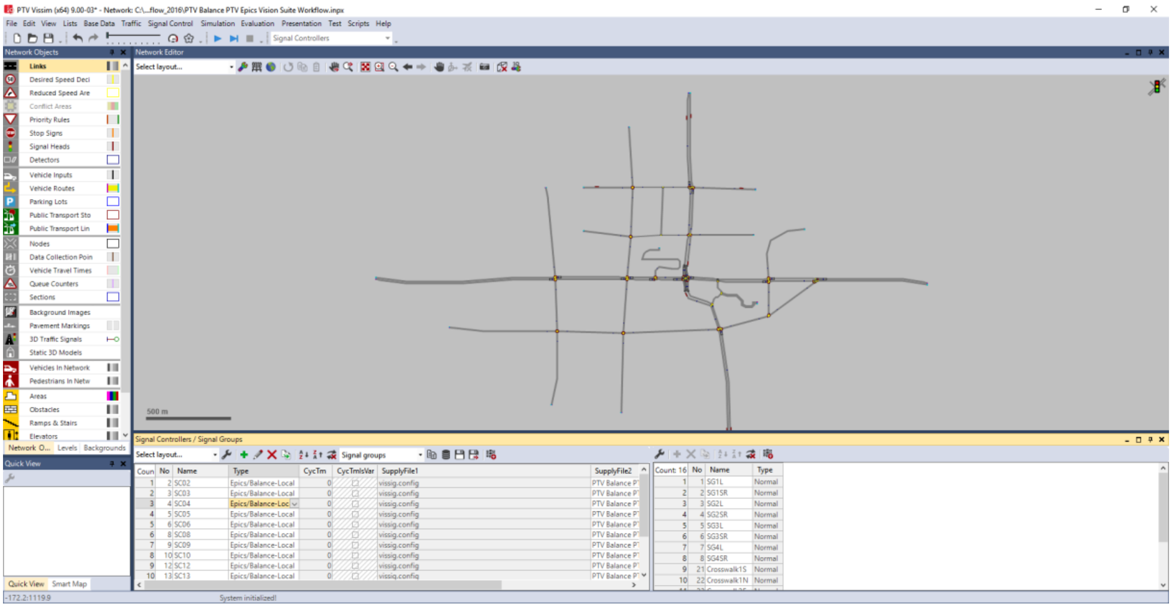
The microscopic traffic flow simulation PTV Vissim provides the possibility to test PTV Balance without access to any online system. PTV Vissim uses the same import/input format for network and demand data as PTV Balance providing a quick to set up test environment. PTV Visum, PTV Vissim and PTV Balance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



Count: 14	No	Name	SignalizationType	SPNo	Cycletime	Timeoffset	FileName
1	2	SC02	Epics/Balance local	1	90.00	55.00	PTV Balance PTV Epics Vision Suite Workflow SC02.sig
2	3	SC03	Epics/Balance local	1	90.00	88.00	PTV Balance PTV Epics Vision Suite Workflow SC03.sig
3	4	SC04	Epics/Balance local	1	90.00	0.00	PTV Balance PTV Epics Vision Suite Workflow SC04.sig
4	5	SC05	Epics/Balance local	1	90.00	73.00	PTV Balance PTV Epics Vision Suite Workflow SC05.sig
5	6	SC06	Epics/Balance local	1	90.00	72.00	PTV Balance PTV Epics Vision Suite Workflow SC06.sig
6	8	SC08	Epics/Balance local	1	90.00	5.00	PTV Balance PTV Epics Vision Suite Workflow SC08.sig
7	9	SC09	Epics/Balance local	1	90.00	57.00	PTV Balance PTV Epics Vision Suite Workflow SC09.sig
8	10	SC10	Epics/Balance local	1	90.00	51.00	PTV Balance PTV Epics Vision Suite Workflow SC10.sig
9	12	SC12	Epics/Balance local	1	90.00	23.00	PTV Balance PTV Epics Vision Suite Workflow SC12.sig
10	13	SC13	Epics/Balance local	1	90.00	29.00	PTV Balance PTV Epics Vision Suite Workflow SC13.sig
11	15	SC15	Epics/Balance local	1	90.00	23.00	PTV Balance PTV Epics Vision Suite Workflow SC15.sig
12	16	SC16	Epics/Balance local	1	90.00	9.00	PTV Balance PTV Epics Vision Suite Workflow SC16.sig
13	17	SC17	Epics/Balance local	1	90.00	23.00	PTV Balance PTV Epics Vision Suite Workflow SC17.sig
14	33	SC33	Epics/Balance local	1	90.00	86.00	PTV Balance PTV Epics Vision Suite Workflow SC33.sig

Figure 14: Network in PTV Visum.



PTV Vissim (x64) 9.00-03* - Network: C:\...flow_2016\PTV Balance PTV Epics Vision Suite Workflow.inpx

Signal Controllers / Signal Groups

Coun	No	Name	Type	CycTm	CycTmIsVar	SupplyFile1	SupplyFile2
1	2	SC02	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
2	3	SC03	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
3	4	SC04	Epics/Balance-Loc	0	☐	vissig.config	PTV Balance P
4	5	SC05	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
5	6	SC06	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
6	8	SC08	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
7	9	SC09	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
8	10	SC10	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
9	12	SC12	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P
10	13	SC13	Epics/Balance-Local	0	☐	vissig.config	PTV Balance P

Count: 16	No	Name	Type
1	1	SG1L	Normal
2	2	SG1SR	Normal
3	3	SG2L	Normal
4	4	SG2SR	Normal
5	5	SG3L	Normal
6	6	SG3SR	Normal
7	7	SG4L	Normal
8	8	SG4SR	Normal
9	21	Crosswalk1S	Normal
10	22	Crosswalk1N	Normal

System initialized!

Figure 15: 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 2017a).

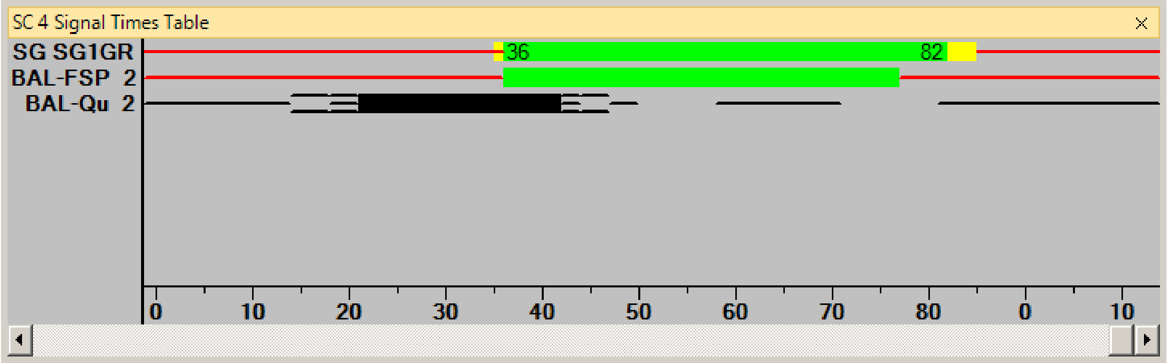
PTV Balance allows you to show additional attributes that are described below.

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 2017a).

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

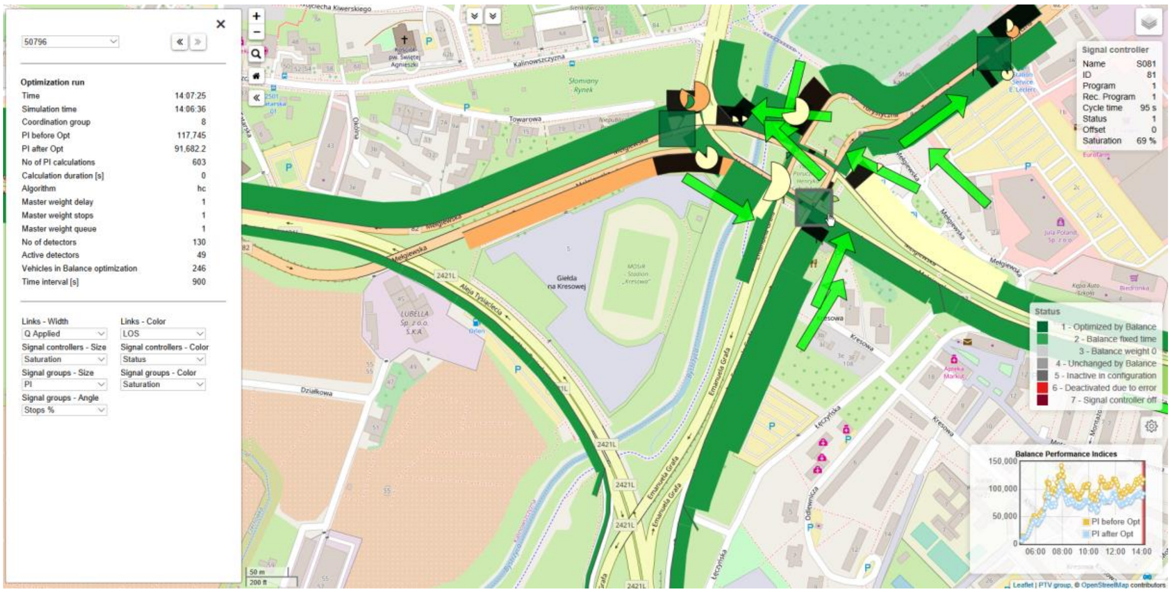
Result of the SC detector record evaluation, additional PTV Balance attributes

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 but shows the road network in grey.

4.1.4 PTV Balance and Epics network view

PTV Balance and PTV Epics are distributed with PTV Vissim and their own data visualization tool “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 (it is also used for real-world deployments). It opens automatically when a simulation is started in Vissim which contains a signal controller of type “Balance central” that has an activated check box “debug mode“ in its signal controller parameters.



50796

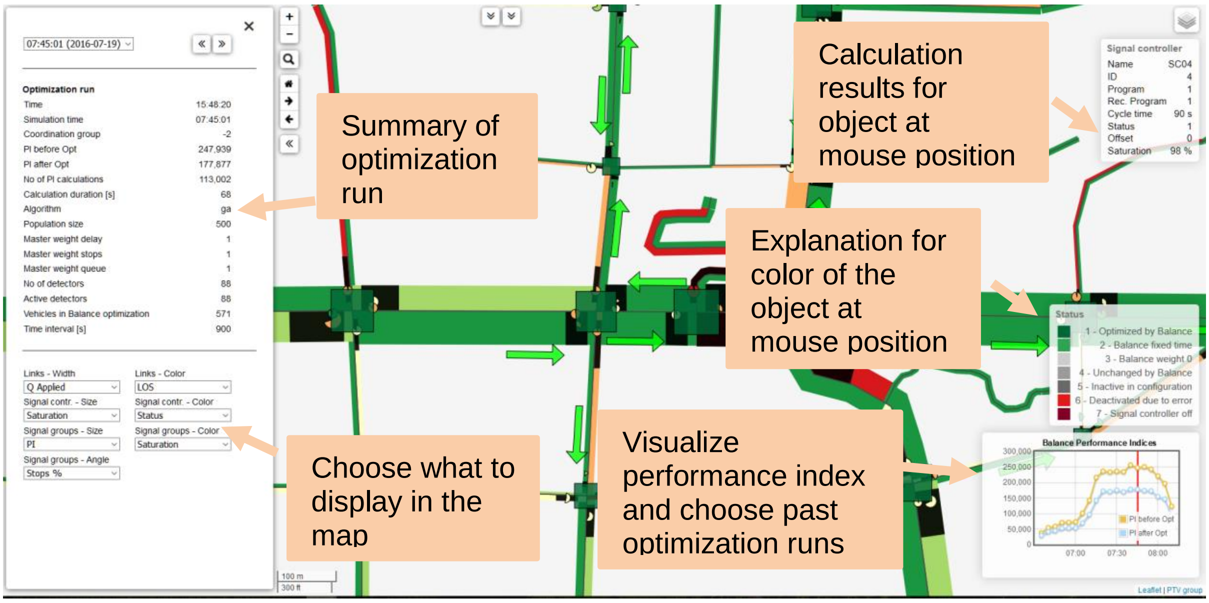
Optimization run	
Time	14:07:25
Simulation time	14:06:36
Coordination group	8
PI before Opt	117,745
PI after Opt	91,682.2
No of PI calculations	603
Calculation duration [s]	0
Algorithm	hc
Master weight delay	1
Master weight stops	1
Master weight queue	1
No of detectors	130
Active detectors	49
Vehicles in Balance optimization	246
Time interval [s]	900

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

Signal controller	
Name	S081
ID	81
Program	1
Rec. Program	1
Cycle time	95 s
Status	1
Offset	0
Saturation	69 %

Status
🟩 1 - Optimized by Balance
🟩 2 - Balance fixed time
⬜ 3 - Balance weight 0
⬜ 4 - Unchanged by Balance
⬛ 5 - Inactive in configuration
🟥 6 - Deactivated due to error
🟥 7 - Signal controller off

Right after the start of the simulation the Balance GUI can only show the network, but after the first optimization run it shows the results of the Balance calculation for each link, controller and signal. The GUI is mouse sensitive and always shows the data for the object under the mouse cursor. The button in the right upper corner allows to lay an Open Street Map under the network, if the coordinates fit.



07:45:01 (2016-07-19)

Optimization run

Time	15:48:20
Simulation time	07:45:01
Coordination group	-2
PI before Opt	247,939
PI after Opt	177,877
No of PI calculations	113,002
Calculation duration [s]	68
Algorithm	ga
Population size	500
Master weight delay	1
Master weight stops	1
Master weight queue	1
No of detectors	88
Active detectors	88
Vehicles in Balance optimization	571
Time interval [s]	900

Links - Width: Q Applied
Links - Color: LOS
Signal contr. - Size: Saturation
Signal contr. - Color: Status
Signal groups - Size: PI
Signal groups - Color: Saturation
Signal groups - Angle: Stops %

Signal controller

Name	SC04
ID	4
Program	1
Rec. Program	1
Cycle time	90 s
Status	1
Offset	0
Saturation	98 %

Status

- 1 - Optimized by Balance
- 2 - Balance fixed time
- 3 - Balance weight 0
- 4 - Unchanged by Balance
- 5 - Inactive in configuration
- 6 - Deactivated due to error
- 7 - Signal controller off

Summary of optimization run

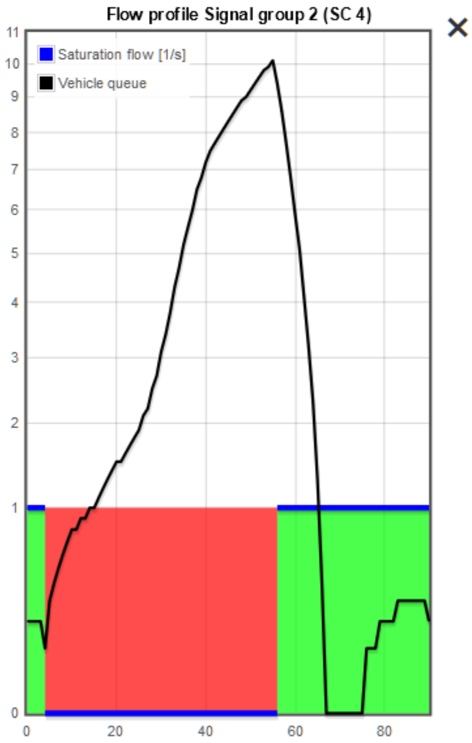
Calculation results for object at mouse position

Explanation for color of the object at mouse position

Choose what to display in the map

Visualize performance index and choose past optimization runs

Clicking on a signal group will display the **flow profile** that Balance calculated for this signal: For each second in the cycle, it displays



1. If it is green or red
2. When red, it shows the number of cars waiting at the stop line
3. When green, it shows the number of cars passing through the stop line

This allows to check the quality of coordination as Balance calculated and compare this with the Vissim “reality”.

The example to the left shows a signal group with a queue length of 10 cars in total at the beginning of green. These vehicles have passed the stop line after 10 seconds of green. Then there is a gap of 10 seconds. Finally a platoon arrives from the upstream intersection and passes the stop line. The majority of cars is arriving after 20 seconds of red time.

Clicking on an intersection (the square) allows to see the frame signal plan that Balance calculated as optimal.

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. The third column denotes the Balance group that created the message, followed by the message text. A log level of 5 indicates an error and usually prevents 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 Bxx_summary_YYYY-MM-DD-log.txt

This file provides an aggregated summary of every optimization run for group Bxx (with xx the group number). 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’s microscopic traffic model.

Column header	**Description**
Time	current time [hh:mm:ss]
Simulation time	current simulation time [hh:mm:ss]
Group	The number of the traffic control group
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
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 and turning movements:
  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 started with different random seeds and at least 5 repetitions to guarantee a solid data base with different traffic situations for assessment.

Bigger traffic related changes like morning peak, off-peak or evening peak should be simulated in different scenarios. The signal programs can be analysed separately, because usually different signal programs are used 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 rely on these parameters only, but also observe the simulation visually. It is possible that the overall results are improving due to a queue on 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.

Bxx_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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