optimising railways

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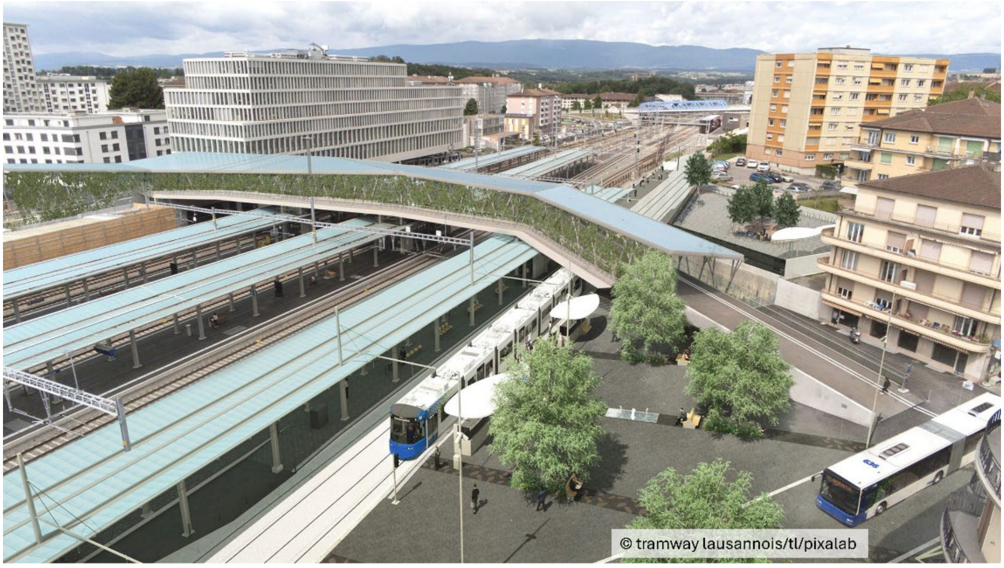
Operational and robustness study of the Lausanne tram line



1 Summary

The Lausanne tram line project is part of the Lausanne-Morges agglomeration mobility strategy (PALM) and aims to strengthen Lausanne's public transport network. The first phase of the project connects Lausanne to Renens-Gare, with service scheduled to begin in 2026, followed by a planned second phase in 2030 for an extension to Villars-Ste-Croix.

SMA supported Transports publics de la région lausannoise SA (tl) in developing the timetable for the tram system through an iterative process integrating infrastructure, rolling stock, and service objectives.

Timetable planning for this project represented a major challenge as it involved designing a standard-gauge tram network from scratch. This project is notable and requires innovate solutions as this is the first time it has been done in Switzerland.

The assumptions made during the project, particularly the choice of reserve times added to the timetable to ensure operational feasibility, are based on SMA's international expertise and were shared with tl. The robustness of the timetable was assessed using simulations incorporating both deterministic and random perturbations to services, and throughout the study SMA's Viriato timetable planning software was used for this analysis.

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A comprehensive assessment of the system robustness under different operating scenarios was made using Viriato, and the results showed that the added perturbations were absorbed without having a significant impact on other traffic, allowing the timetable to be considered robust under the simulated conditions.

However, as part of a two-stage implementation process, real life data collected from initial operations will be used to refine some of the assumptions used in the pre-construction analysis to optimise the final timetable.

2 Context and objectives

The Lausanne metropolitan area currently has two metro lines, an extensive bus and trolleybus network, a regional railway line (LEB) and an efficient RER system on the SBB network. To strengthen this public transport network, the mobility strategy of the Lausanne-Morges agglomeration project (PALM) includes the creation of several "major axes", including a third metro line, BRT (bus rapid transit) and a tram line which is the subject of this article. This tram project will be implemented in two stages:

– Stage 1: The link between Lausanne-Flon and Renens-Gare, with work started in 2021 and services scheduled to commence in 2026.

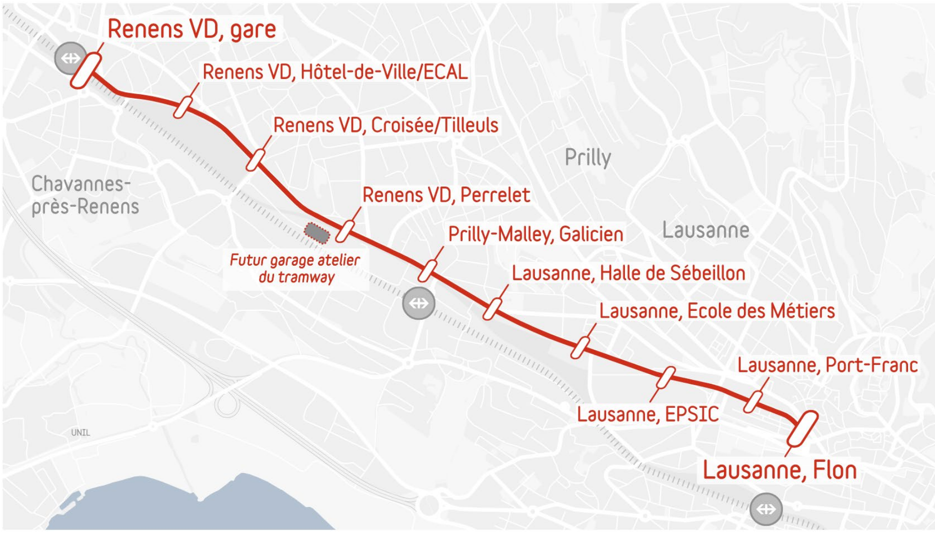


Figure1 : Stage 1 of the tram system (source: tramway-lausannois.ch)

– Stage 2: The Renens-Gare – Villars-Ste-Croix extension, scheduled to enter service in 2030.

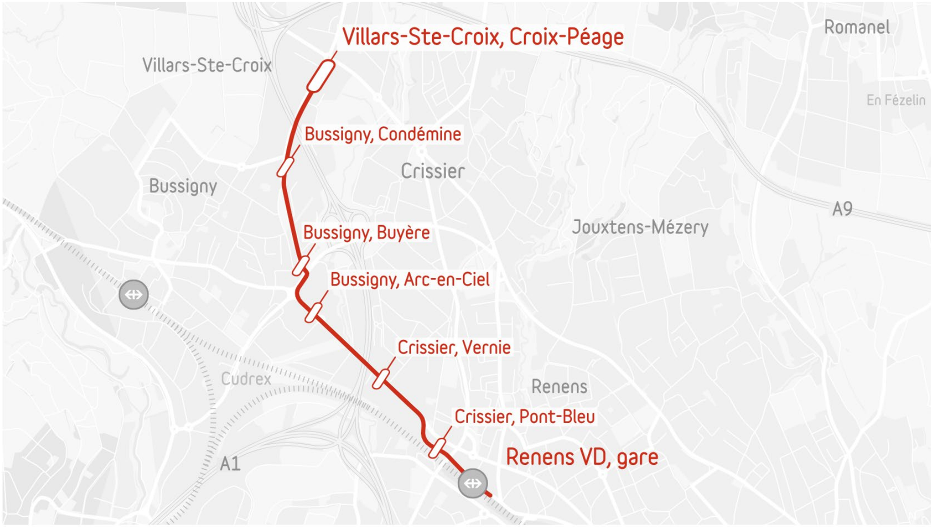


Figure2 : Stage 2 of the tram system (source: tramway-lausannois.ch)

The rolling stock required for this tram line has been ordered, with the first delivery expected in 2026, to enable the start of service for stage 1. Additional trams will be delivered later for stage 2. The service objectives are defined as delivering a 6-minute frequency during the main part of the day, with a 10-minute service frequency for the remainder of the operating times.

Since the project was launched changes to the route, better understanding of the rolling stock characteristics, new traffic regulations, particularly at intersections, and access to the depot/maintenance facility have led to an in-depth analysis of the operating conditions of this proposed tram system being required.

In this context, tl commissioned SMA to conduct a study to analyse the operation of the future tram line and test the robustness of the planned timetable. All analyses were carried out using SMA's Viriato planning tool for the entire line, including the connection to the depot/maintenance facility. Bus services, in particular the BRT to the Perrelet depot, were considered to include interactions with the tram system in this area. The study time horizon was set at 2030.

3 Timetable construction and optimisation

The development of the timetable was the first major step in the study, and this process was based on an iterative approach considering the infrastructure, rolling stock and service objectives.

3.1 Establishment of the speed profile

To construct the timetable, the speed profile had to be developed so that journey times could be calculated. This profile was determined based on the following elements:

– Track alignment (dedicated, protected, shared)
– The geometry of the route, including curvature, gradient profile and track cant
– Switches & crossings planned on the network
– Any specific applicable operating rules

A particular feature of the project is that it is Switzerland's first standard-gauge tram line and the specifications of the Railway Ordinance (DE-OCF) are not always sufficiently detailed for this new situation. tl, which does not yet operate any trams, has had to define appropriate standards in accordance with existing norms, under the supervision of the Federal Office of Transport (FOT).

Two sets of parameters were tested: **recommended values** and **exceptional values**. These were defined based on the general specifications of this tram system, developed by tl in collaboration with specialists in railway technology, safety systems and civil engineering, and validated by the FOT.

3.2 Calculation of the running time

The characteristics of the rolling stock, which are essential for the running time calculation, were provided by tl. The original specifications given to the manufacturers made it possible to establish a set of calculation assumptions, particularly in terms of passenger capacity. An assumption of 4 passengers per m² was made in the study to ensure a realistic representation of passenger load during operation.

Based on these elements, a minimum technical running time calculation was performed in Viriato. This time was then adjusted to include station dwell times and essential reserve times to account for operational uncertainties. Additional reserve time also had to be included to comply with planning rules (see below).

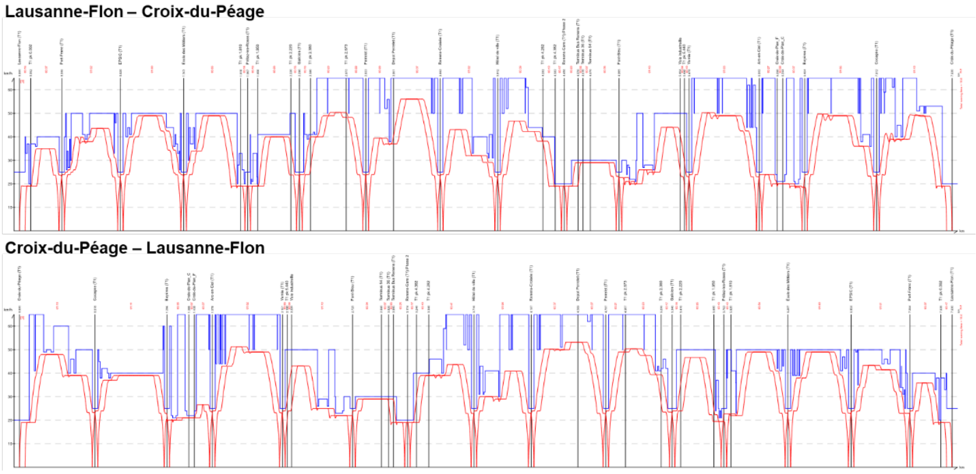


Figure3 : Running time calculation (output from Viriato)

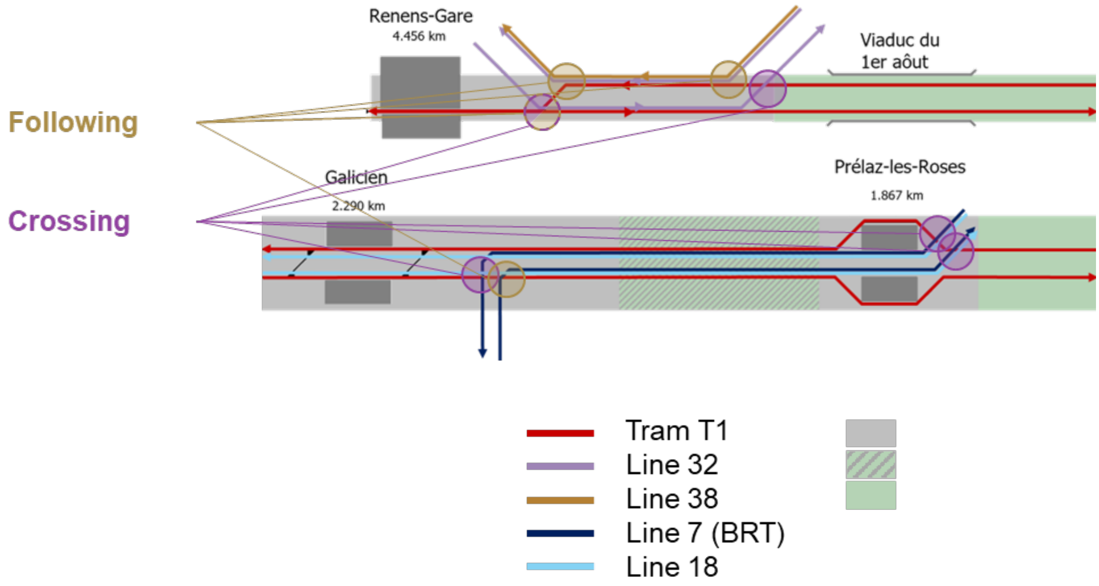
As Lausanne does not yet have a tram system in service, certain planning rules were defined based on the practices of other Swiss networks. The reserve time was therefore set according to the type of track used: dedicated tracks, tracks with mixed traffic, etc. The higher the risk of hazards or interference with other modes of transport, the greater the reserve time needed. This reserve time is expressed as a linear percentage of the minimum technical running time. Stopping times were also assessed for each individual station based on an analysis of estimated future passenger flows provided by tl.

A specific issue was identified at the Croix-de-Plan crossing, a critical point on the route. A planning rule was developed and added to schedule trams to cross at the intersection to optimise the management of traffic light sequences and limit the impact on private motorised traffic. This optimisation is particularly important during the rush hour peaks, however it is not considered necessary during off-peak hours.

3.3 Planning standards

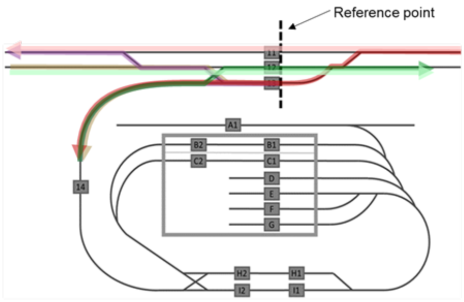
Specific planning standards were defined to capture the various operational situations expected. Standardised times were established for the main operating configurations, enabling timetable development and modelling to be undertaken. These standards are based on SMA's experience in similar studies conducted in Switzerland.

Minimum separation and headway times have been defined for crossings and tram movements in the same and opposite directions on lines and in stations. Interactions with bus lines have also been included, particularly in shared platform areas, such as at Galicien and Pont-Bleu. In addition, special attention was given to terminus stations in order to estimate required separation and turnaround times and to ensure smooth operations.



4 : Examples of bus and tram interactions during stage 1

A specific, more complex case was also studied at the Perrelet depot/maintenance facility. This depot is connected to the line by a single track, used to access the various working tracks within the depot. The separation times required between the various entry and exit movements were analysed and then defined as standard values. A route compatibility matrix was developed to detail all possible configurations and the associated constraints.



1er tram \ 2ème tram	Entrance from Lausanne-Flon	Exit to Lausanne-Flon	Passage to Renens-Gare	Passage to Lausanne-Flon	Exit to Renens-Gare	Entrance from Renens-Gare
Entrance from Lausanne-Flon	F	R	F	C	R	C
Exit to Lausanne-Flon	C	F		F	C	C
Passage to Renens-Gare	F		F		F	
Passage to Lausanne-Flon	C	F		F	R	F
Exit to Renens-Gare	C	C	F	C	F	C
Entrance from Renens-Gare	C	R		C	F	F

Track 13 can accommodate only one tram unit

Parallel movement
Impossible movement
C: Crossing
F: Following
R: Reuse of track in the opposite direction

Figure 5 : Compatibility matrix between traffic flows at the Perrelet depot/maintenance facility

3.4 Timetable development

Two operating scenarios were studied: one for peak hours and the other for off-peak hours towards the start and end of service. Each scenario had an appropriate set of parameters for the time period and complied with established standards and tl requirements for minimum turnaround time at the terminus. Analysis of these required peak and off-peak timetables showed where optimisation of the operations were required and the minimum fleet size:

– 6-minute frequency (peak hours): Applying the recommended parameters, combined with optimising the Croix-de-Plan junction, requires 11 vehicles.
– 10-minute frequency (off-peak hours): Without optimisation of the Croix-de-Plan intersection, 6 vehicles are required for operation. This arrangement ensures compliance with minimum operating requirements. A 7-vehicle variant is also possible, offering a more comfortable turnaround time at Lausanne-Flon.

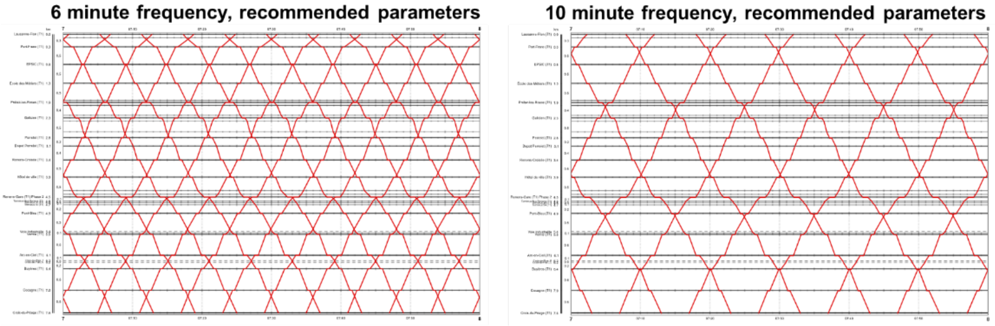


Figure 6 : Example timetables with 6- and 10-minute intervals

The average journey time for traversing the entire line is 26 minutes during peak hours.

This initial study phase laid the foundations for a robust timetable that considers infrastructure constraints, rolling stock performance and operational requirements. The results obtained provided a clear picture of the rolling stock requirements and the adjustments needed to ensure optimal service frequencies.

A key result of this was the identification that the crossing at the Croix-de-Plan intersection was a bottleneck, and that the optimisation of tram movements here improves the flow of traffic and minimises the consequential effects of the trams on other motorised traffic.

The robustness of the peak and off-peak timetables were then evaluated for minor perturbations, i.e. small operational delays.

4 Robustness analysis

4.1 Definitions

The robustness of a timetable is defined as its ability to absorb operational uncertainties while maintaining a reliable level of service. A robust timetable limits the impact of perturbations and can return to normal (i.e. as planned) operations within a reasonable time frame.

In this study, the timetable robustness was assessed in Viriato by simulating the operation following the addition to the planned timetable of either a deterministic disruption or using the Monte Carlo method to analyse a series of stochastic disruptions taken from statistical distributions.

The robustness tests made it possible to evaluate several typical situations affecting operations, such as a bus occupying a platform and preventing the tram from departing, or random small delays which could occur on the line and at stations.

This simulation of operations and disruption recovery was based on the consumption of available reserve time along the line, at stops and during turnarounds. These reserve times were defined according to realistic assumptions based on the line configuration and were distributed between running, stopping and turnaround times.

Priority rules between buses and trams were established in consultation with tl. The simulations also considered the planning standards used in the design of the timetable. All analyses were performed using Viriato software.

Two levels of disruptions were tested:

– Basic delay level: realistic delay significant enough to disrupt operations
– Higher delay level: 150% of the basic delay level

4.2 Deterministic perturbations

This involves injecting one-off disruptions into the timetable. During these robustness tests, bus traffic in mixed traffic areas is considered in the simulation.

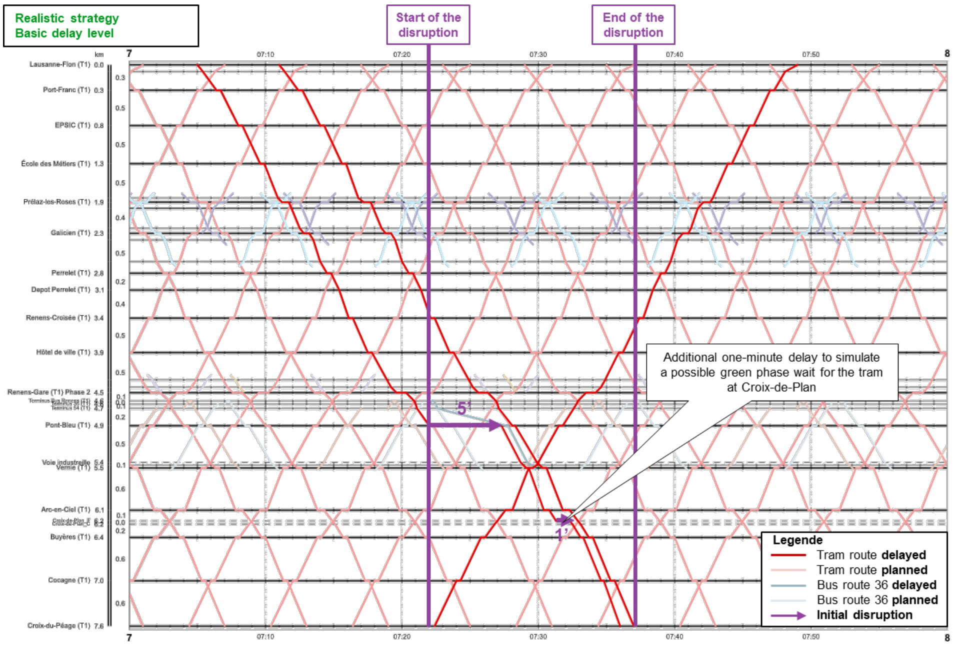


Figure 7 : Example of a deterministic robustness test

An example of a deterministic test is shown above. A 5-minute delay caused by a bus at the Pont-Bleu departure point was simulated. Only one bus was affected, but three trams were impacted, including one travelling in the opposite direction to the original disruption. The turnaround time available at Croix-du-Péage allows the concerned tram to make up for its delay and to depart on time for Lausanne-Flon. The impact of this type of delay is considered manageable, and the recovery time acceptable. The timetable is therefore considered robust in this configuration.

The results of the deterministic robustness tests demonstrated that disruptions added to a single tram are resolved without generating a major impact on other traffic, for the two sets of parameters tested and according to the assumptions defined with tl.

4.3 Stochastic perturbations

This involves the stochastic addition of delays to trams according to the methodology described below.

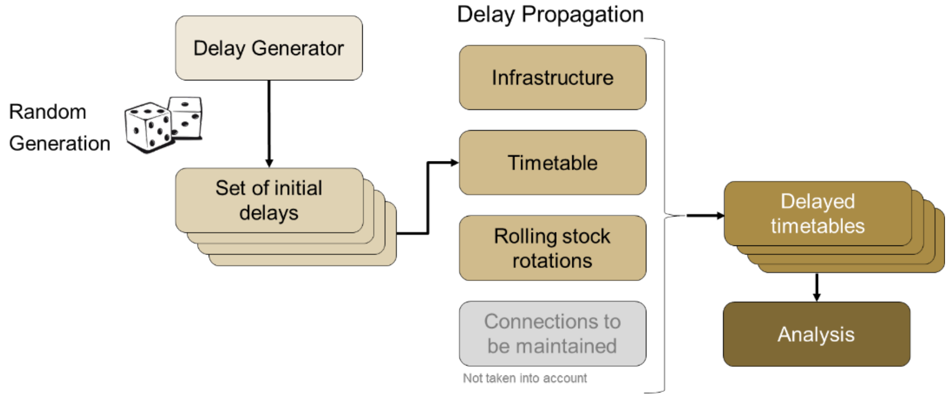


Figure 8 : Principle of stochastic perturbations

Delays based on a statistical distribution were added to trams according to a probability p. For each affected tram, the level of delay followed a geometric distribution with a mean of μ (between 0.3 and 0.8 minutes of average delay for each stop depending on ridership), bounded by a maximum delay value (5 minutes). The number of points at which delays could occur was also defined according to a geometric distribution, and the value of the delays followed a homogeneous distribution. In this case, bus traffic in mixed zones is not explicitly simulated, as it was considered to be sufficiently covered by the applied delay distributions.

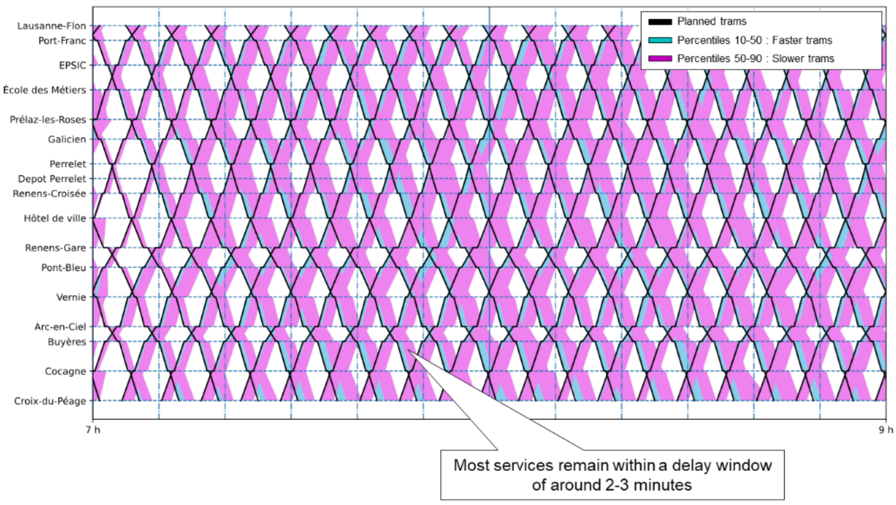


Figure 9 : Example of a robustness test with random delays

To analyse the stochastic perturbation simulations, the results were grouped by percentiles.

A percentile is a statistical measure that indicates the position of a data point relative to the set of observed values. It divides a distribution into 100 equal parts, each representing 1% of the data. The 50th percentile corresponds to the median.

For the analysis of simulations, extreme percentiles (the fastest 10% and slowest 10%) were excluded to avoid interpretation bias from outliers. This method identified that 50% of trams are usually on time (In Figure 9 this is the blue region following the black planned trains, unfortunately this can be hard to see in this diagram because of superimposed results). This basic level of perturbation can be absorbed without causing major disruptions, and the operations remain stable and under control.

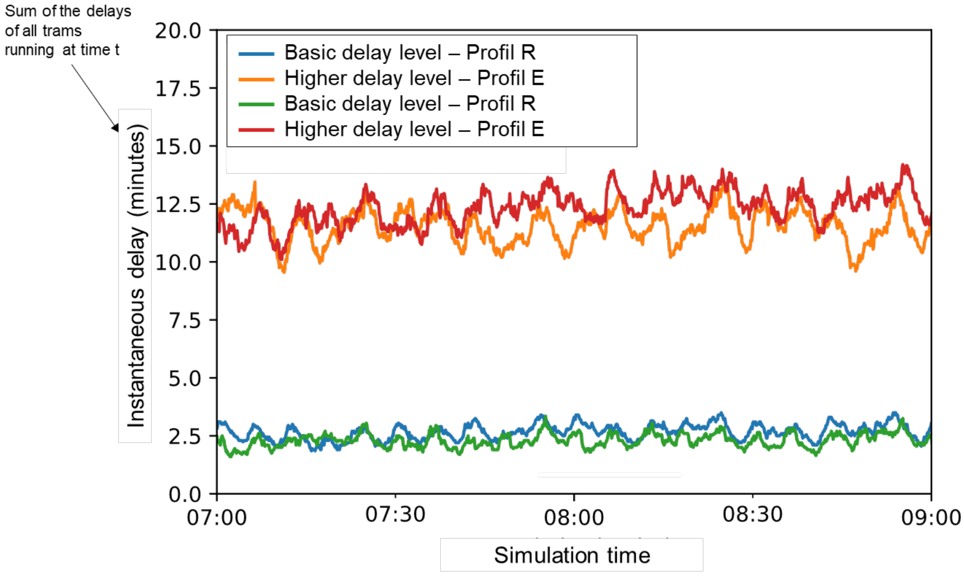


Figure 10 : Propagation of delays over time for two speed profiles and two delay levels

Figure 10 shows the current total instantaneous delay at each time step in the simulation. Four situations were tested, combining two delay levels (basic and higher, see section 4.1) with the Recommended and Exception speed profiles (see section 3.1).

This result shows that none of the simulations diverged, even with increased input delays. Both the basic and higher delays levels were stable without increasing over time for both speed profiles tested.

Ultimately, stochastic robustness tests confirm that the overall punctuality remained broadly similar between the two sets of parameters. Despite the injection of multiple delays for both the basic and higher-level disruption cases, they were effectively absorbed. The timetable can therefore be considered robust under the simulated operating conditions.

5 Conclusion and outlook

Establishing the timetable for this line was a major challenge because of several complex factors. It involved creating a new tram network from scratch in Switzerland, it is the first standard-gauge tram line in the country and will be operated with new rolling stock, and it is the first time tl must manage a tram line in addition to buses trolleybuses and the metro.

In this context, numerous assumptions had to be made, and reserve times were incorporated to ensure operational feasibility from the moment the line enters service. Calculating running times was a key challenge, as this directly determines the timetable and therefore the size of the vehicle fleet required.

As the line is being built in two stages, it will be essential to compare the theoretical assumptions made during this first stage with the reality on the ground. This comparison will enable the timetable for the second stage of the project to be adjusted and optimised if necessary.

The timetable has a robust structure. The buffer times incorporated into journey times should make it possible to absorb any operational uncertainties, ensuring a regular service. However, the completed line will undergo an initial operating phase, which will be used to gradually refine the settings and confirm the choices made during the planning stage.

The approach, methods and tools applied in this study demonstrate the importance of planning the timetable in advance based on solid data and parameters and of verifying the robustness of the timetable for a wide range of possible disruptions to ensure the operational feasibility and the quality of the service offered. In this sense, despite the specificities of this project, this study demonstrates the value of this approach for any type of tram system development project.