Abstract

The simulation program "Tramatik" allows quantifying in advance the effects of planned changes to infrastructure or timetables for tramways. It can simulate any tramway or light rail system. The simulated operation is displayed in a diagram of the network and as graphic timetables.

Why Simulate Tramway Operation?

The use of simulation for railway operation is a proven method when the following questions arise:

• Is it possible to modify the operational concept (e.g. with a denser timetable) while retaining an existing infrastructure?

• What are the effects of planned changes to the infrastructure on operation?

• What changes to the infrastructure are necessary to improve operation? What operating costs can be saved by improving the infrastructure?

For tramway networks the questions to be solved are often identical. This is the field where "Tramatik", a simulation program for tramway operation can be used. In addition it serves the following purposes:

• Determining the effects of traffic lights.

• Training the staff of control centres.

In addition to traditional tramway operation as part of road traffic, Tramatik can also be used for light rail systems with their own right of ways controlled by railway signalling, as well as for mixed solutions.
Properties of the Simulation Program

The simulation program "Tramatik" was developed as part of a research project by the Swiss Federal Institute of Technology (ETH), Zurich [1]. At present it is being implemented for Apple Macintosh computers. The program simulates tram operation exactly. The input data have to be provided by the user in the form of an ASCII file. The results are displayed graphically as a schematic network showing the positions of vehicles and as distance/time diagrams.

![Distance/time diagram](image)

Figure 1: Tramatik output in the form of a Distance/time diagram

In order to simulate tram operation in detail, a precise model of the whole system with all internal interactions and external influences is needed. The heart of the simulation program is a data structure which describes the simulated tramway network in the computer. The data structure contains all information about the infrastructure and operational rules of the simulated network: track topology, length of tracks, information on points, vehicle positions, stopping points, priority rules, etc. This information has to be provided by the user in the form of a dedicated programming language. The acquisition and conditioning of the input data involves quite a considerable effort. For instance, the case study presented below required 32'000 lines of input data.

Driving on sight, keeping distance: The main difference between a tram simulation program and the programs for simulation of railways [2, 3] is the method of keeping distance between one vehicle and the next. Whereas on railways the distance is governed by interlocking systems, trams have to be driven on sight. That means, it is the responsibility of each tram-driver to maintain a sufficient distance from the vehicle in front of him. This minimum distance includes at least the minimum braking distance. In Tramatik driving on sight is implemented by each vehicle reserving in advance a section of track, which includes the braking distance. No other vehicle may occupy this reserved section. If a vehicle is unable to reserve a section of the necessary length, its speed has to be reduced so that the braking distance actually available is sufficient. At prescribed halts, for example at stops or when approaching signals, the track can be reserved only until the stopping point. While approaching the stopping point, the speed and braking distance are progressively reduced, until
both are zero and the vehicle stops. As soon as the reason for stopping ends
(because the stopping time has expired or the signal turns to green) the
reservation may be extended beyond the stopping point. To avoid collisions on
track crossings and short single track sections, special precautions are
implemented.

Figure 2: Vehicle with reserved section.

**Traffic lights and road traffic:** Traffic lights have a considerable influence
on tram operation. Inexpediently controlled traffic signals have a negative effect
on the stability of the timetable, causing longer travelling times and increasing
running costs. The simulation of all kinds of traffic signals is feasible, no matter
whether they are rigidly phased or traffic-controlled. Tramatik enables us to exa-
mine the influence of different traffic control strategies on tram operation. It is
also necessary to simulate the effect of other traffic on tram operation. The simu-
lation of this other traffic, especially cars, is essential for networks or parts of
networks where the tram tracks are not separated from road traffic. Cars are
simulated by treating them as "special kinds of trams" with adapted characteris-
tics (mass, length, acceleration, etc). This procedure yields exact results, but
involves a lot of effort in data acquisition and calibration. Simulation of areas
with mixed traffic also requires a lot of computing time and storage capacity.

Figure 3: Including car traffic in tramway simulation.

**Driving dynamics and calculation of running time:** The exact position,
speed and acceleration of every vehicle is calculated in steps of one second. For
each type of vehicle the user specifies a tractive effort/speed diagram and other
important data, such as the length, mass, maximum acceleration, adhesion and
braking parameters. Each type of vehicle describes a train. It may be a single
unit or a composition of several units. Whenever the actual speed of a vehicle is
lower than the permissible value, it accelerates, thereby taking into account the
adhesion and resistance. The program continuously calculates what deceleration
is necessary in order to stop within the reserved section or to slow down to a
prescribed lower speed. If the deceleration exceeds a set value, a braking
operation is initiated. The program also checks whether the available maximum
braking force is sufficient for the deceleration required.

**Points:** Special treatment is necessary for the points operated from the vehicle
itself. The most common methods of actuating points, – by hand, with overhead
wire contact, with a manually emitted radio signal or automatic –, can all be
simulated. All cases that occur in practice, such as actuating points still occupied
by another vehicle, can be simulated in a realistic manner.

**Stops, disturbance buildup:** Important data for mass transit operation are
the times spent at stops. These times are simulated specifically for each stop. If
required, disturbance buildup can be simulated. Disturbance buildup is observed
when trams follow in short intervals and there is a continuous flow of passen-
gers to the stops. If a tram arrives late at a stop, more passengers will board it,
with the result of an extended stopping time. Thus the already late tram gets a
greater delay. Tramatik simulates this effect by assigning stopping times depend-
dent on the actual intervals between successive trams. The user specifies a mini-
imum and a maximum stopping time. Between these two limits an appropriate
function may be chosen.

![Figure 4: Stopping time as a function of the interval between trams: The
minimum and maximum stopping times and the gradient of the
function in between are user definable.](image)

**Safety facilities:** Safety facilities, typical for railways, can also be simulated
with Tramatik. This is necessary for the simulation of mixed networks with part-
ly driving on sight and partly according to signals. The program superposes dri-
viving according to signals onto driving on sight, the former - being more restricti-
ve - is decisive. The user formulates the functions and dependences of the safety
facilities in a dedicated programming language. Tramatik does not check the cor-
rectness and completeness of the specification for the safety facilities. The me-
chanisms of the safety facilities may also be utilized to simulate complex priori-
ties at junctions.
So far a number of simulation studies have been carried out on tramway networks in Switzerland. The results of a study on the tram network of the city of Berne (Switzerland) will now be presented.

Case Study

The tramway network of the City of Berne consists of 3 diametral lines (lines 3, 5 and 9). In the city centre these three lines share a common section, also used by bus line 12. The shared section is located in the pedestrian zone. The suburban line G of the privately owned railway company RBS (Regional Transport Berne-Solothurn) runs on the tracks of lines 3 and 5 from the city boundary to its terminal at "Helvetiaplatz". At peak hours lines 3, 5 and 12 run at intervals of 6 minutes, line 9 at 4-minute intervals. On line G the interval is 10 minutes.

![Diagram of the tramway network of the City of Berne](image)

Figure 5: Tramway network of the City of Berne, with line G and the proposed extension.
The terminal of line G at Helvetiaplatz is at the edge of the city centre. Most of the passengers change there to either line 3 or 5 as their destination is the main railway station or somewhere in the centre of the city. The extension of line G to the main station is an obvious solution to shorten travelling times and reduce the number of unattractive changes.

The effects of extending line G on tramway operation were examined with Tramatik. In the study the entire tramway network of the City of Berne was simulated, including bus line 12 on the common section. The results prove that the extension of line G has no negative effects on the operation quality of the tramway network. Contrary to expectations, the vehicles of line G do not obstruct the other trams on the common section or at main station. Since the common section is located in the pedestrian zone, it has sufficient free capacity. At the main station stop line G can turn without difficulty as there are enough tracks and a turning loop.

The following diagrams illustrate tramway operation with and without extension of line G between 4 and 5 p.m. (evening peak, line G shown in bold type).

Figure 6: Simulation of line G with actual terminal at Helvetiaplatz, 1991 timetable.
During the morning peak the stability of the timetable for lines 3 and 5 is improved by extending line G. Today, from Helvetiaplatz onwards, some trams of lines 3 and 5 are overloaded, owing to passengers changing from line G, and consequently delayed. This effect is eliminated with the proposed extension of line G.

**Concluding Remarks**

The quality of the service offered by light-rail and tramway systems depends on their interactions with road traffic and traffic lights. Where possible, it is preferable for trams to run on a private right of way. Nevertheless bottlenecks often affect the operation of an entire light-railway network. In such cases the use of the Tramatik simulation model provides valuable indications and figures for an optimal planning of future service during the initial projects.

**References**

3. COMPRAIL 87, Computers in Railway Management: A Data Concept for Simulation of Railway Networks, P. Giger.