TRANSALPINE RAIL NETWORK: A CAPACITY ASSESSMENT MODEL (CAPRES)

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Conference paper STRC 2001
Session Networks

STRC | 1st Swiss Transport Research Conference
Monte Verità / Ascona, March 1.-3. 2001

Transalpine rail network: a capacity assessment model (CAPRES)

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Abstract

The CAPRES model (Railway Network Capacity Assessment System) has been built to help planners to design timetables at the network level and to saturate them, making possible through the process to evaluate the capacity of the network. The model has been developed by ITEP-EPFL in partnership with the Swiss Federal Railways.

During the timetable saturation process, CAPRES takes into account infrastructure, rolling stock, and operations characteristics. It proceeds according to user-defined strategies that involve train succession rules and priorities allocation, especially concerning the use of available capacity, for the various train categories. The construction of the saturated timetable is carried out through a set of events (train departures and arrivals) that are subjected to a number of constraints, such as running and stop times, connections, headway, and so on. The problem is solved by an optimised branch-and-bound algorithm. Major stations' operations are modelled by a specific track assignment algorithm with constrains between events.

CAPRES has been used to analyse implementation alternatives for the North-South railway crossings through the Swiss Alps. Those applications have clearly showed the effect of integrating high-performance lines with the existing network. It has been possible to verify the feasibility of planned timetables, to pinpoint bottlenecks, and to assess effects on capacity of various infrastructure and service alternatives. As a result, the various scenarios for the development of services in the North-South rail corridor have been evaluated for the next 20 years. CAPRES methodology and results have been certified by the Swiss government and by the major Swiss railway companies. As a consequence, they have been instrumental in the political decision process that involves a 8.3 billion Euros investment for the AlpTransit project.

The paper presents a flexible methodology to assess rail capacity over an entire network, as well as a case study concerning the analysis of the capacity development for the North-South freight corridor through Switzerland.

Keywords

Rail Capacity – Network – Model – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Introduction

Deal with the use of existing network capacities becomes a central task for railway infrastructure managers, as it is important to react to operators' requests and to supply capacity at the right moment on the right place. Moreover, planning of investments for future capacity development must be done very carefully, because of the huge financial consequences. On the other hand, to correctly assess the capacity, one needs to take into account not only infrastructure, but also the required service quality passenger and freight trains, and the priority rules that apply to the use of capacity among different train categories [4].

To quantify a useful rail capacity indicator, planners must determine the maximum train traffic on the network over a given time period and under pre-defined operational objectives and constraints. For an existing network, whereas infrastructure and rolling stock characteristics are fixed, operational characteristics include:

- Line structure (origin and destination for each train service)
- Timetable structural data (cyclical or not, transfers to be guaranteed, succession order of train categories for each line...)
- Requirements for service quality (timetable stability, travel times...)

The paper presents a flexible methodology to assess rail capacity over an entire network, and also an application case involving the analysis of the progressive development of capacity for the North-South freight corridor through Switzerland.

2 Objectives for capacity assessment

Assessing the capacity of a network is useful when one needs to compare different states of the rail system (over time, or for different alternatives). The proposed methodology is equally adapted to major lines national networks, and to denser regional networks as well. It also makes it possible to evaluate options on rolling stock, on safety installations, on track layout for a particular link or in a station, etc.

Methodology, thus, aims to:

- integrate the various parameters that determine capacity, in the most simple way;
- quantify the capacity for the entire network, based on those parameters;
- pinpoint critical sections of the rail network;
- compare various states of the rail system, from a capacity point of view.

3 The CAPRES methodology

Compared to the case of a single section or station, assessing capacity over an entire network introduces additional complexity, due to common use of single sections or stations by several lines.

To take into account the additional complexity of a network over a line, planners must provide additional data on the strategy of common use for sections and stations. We need therefore to specify a train typology and a service strategy that defines for each pair of origin/destination over the network:

- the level-of-service requirements for each train category;
- the mix of trains belonging to different categories, over a time period;
- priority rules that apply to the use of available capacity.

The proposed methodology goes further than simple simulation. It is based on designing a "saturated" timetable, that is a timetable including a maximum number of trains. More precisely, starting with a basis-timetable, CAPRES builds a saturated one, using the maximum number of trains that still respect the whole set of constraints on infrastructure, on track assignment in stations, as well as other operational and service constraints.

During the timetable saturation process, CAPRES takes into account infrastructure, rolling stock, and operations characteristics. It proceeds according to user-defined strategies that involve train succession rules and priorities allocation, especially concerning the use of available capacity, for the various train categories.

The construction of the saturated timetable is carried out through a set of events (train departures and arrivals) that are subjected to a number of constraints, such as running and stop times, connections, headway, and so on. The problem is solved by an optimised branch-and-bound algorithm.

Major stations' operations are modelled by a specific track assignment algorithm with constraints between events.

The saturated timetable does not provide fixed scheduling for the additional (saturating) trains. It rather assigns to them available time slots, defined as time intervals for departure and arrival in each station. Therefore, the saturated timetable includes upper and lower bounds for additional train traffic compatible with all the constraints that apply to the network, while it ensures that there is no other possible timetable for additional trains that still respect the constraints.

4 Modelling elements

CAPRES takes explicitly into account every rail system component that has an effect on capacity. Input data of CAPRES include:

- Infrastructure network, defined as a set of line sections and nodes
- Initial data necessary to design a basis-timetable (types and characteristics of trains, transfers to be enforced, service structure, periodicity…)
- Strategy for the saturation process, mainly as a ranked list of train types to be used during timetable saturation

4.1 Infrastructure

The way to model infrastructure, as a set of nodes and line sections that link them, gives the planner the possibility to set the detail level of modelling, as she/he remains in charge on how a given network will be modelled, depending on the objectives of each particular analysis she/he has to carry on.

A **node** is a peculiar point of the network; that may be a station, a line junction, or a crossing point including installations and tracks that are linked to it. For CAPRES, a node is actually a point of the network where train succession may be modified due to overtaking, crossing, or route splitting.

CAPRES provides three levels of specification for a node:

- ***Normal*** node, for which only the number of tracks should be specified
- ***Junction*** node, where two lines merge or split; in those cases, the model deals automatically with train conflicts
- ***Complex*** node, for which rules on platform assignment should be specified along with incompatibilities of train routes; in such case, the model takes into account incompatibilities between entry and exit routes

Track sections link network nodes. They are specified by:

- two nodes, one at each of both ends of the track section;
- the number of tracks and their use (mono- or bi-directional);

- the minimal time gap between two consecutive trains on the same track.

4.2 Trains

Although CAPRES has been designed specifically with cyclical timetables in mind, by using a time period long enough, one can almost rub out the effects of the periodicity on the fringes, and therefore be able to deal with non-periodical timetables.

Trains may be grouped in families. A train family has in common the train route (including the tracks to be used), the running and stop times, and the required time interval for departure or arrival. A given timetable may include several trains belonging to the same family, which differ only in the time at which they pass through the nodes.

CAPRES makes it possible to define which **transfers** should be enforced between each pair of train families. Moreover, trains of the same family may be required to run with a **fixed time interval**, allowing thus to define periodical service.

4.3 Saturation strategy

Saturation strategy sets the way to introduce additional (saturating) trains and the order among them, during the saturation process of the basis-timetable. It sets also priorities among trains or among group of trains.

5 CAPRES operational modes

CAPRES provides the following two principal functions:

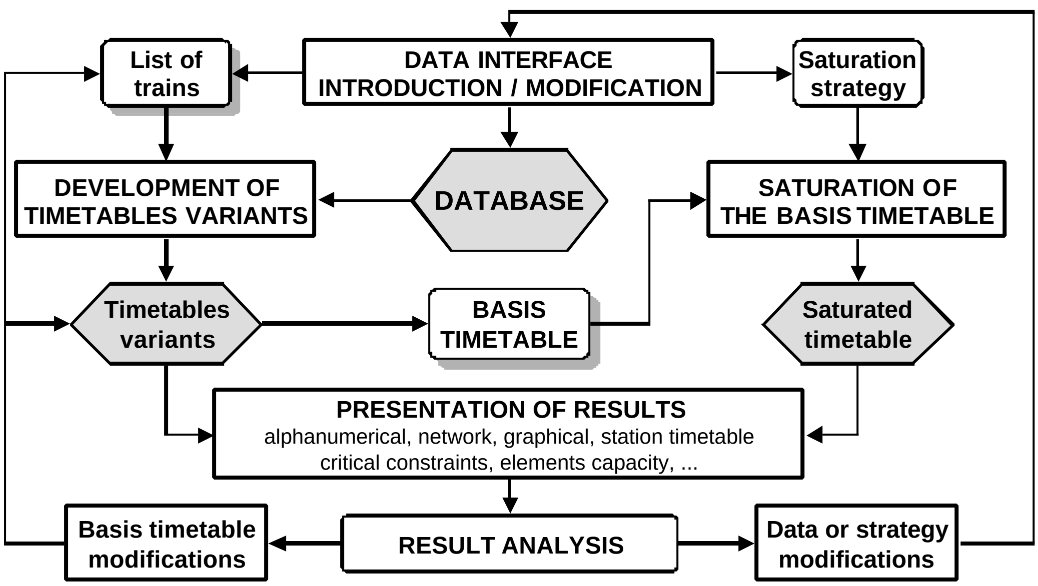
- **Design of timetable alternatives** that are compatible with a pre-defined set of objectives and constraints, and which include every train service that must be ensured. Those timetables are called **basis-timetables**.
- **Saturation of a basis-timetable** (which may be completely empty), using a list of saturating trains, and according to a given saturation strategy.

In the first case, CAPRES builds all possible timetable alternatives that are compatible with the constraints and for a given set of trains. In the second case, the model looks after a timetable alternative that allows the running of a maximum number of saturating trains, that is, a timetable that makes a maximum use of available capacity.

User intervention is crucial not only during network modelling, but also in:

- Defining the set of trains that have to be included in the basis-timetable
- Choosing among alternative basis-timetables the one that will be saturated
- Specifying the saturating train set, and the saturation strategy

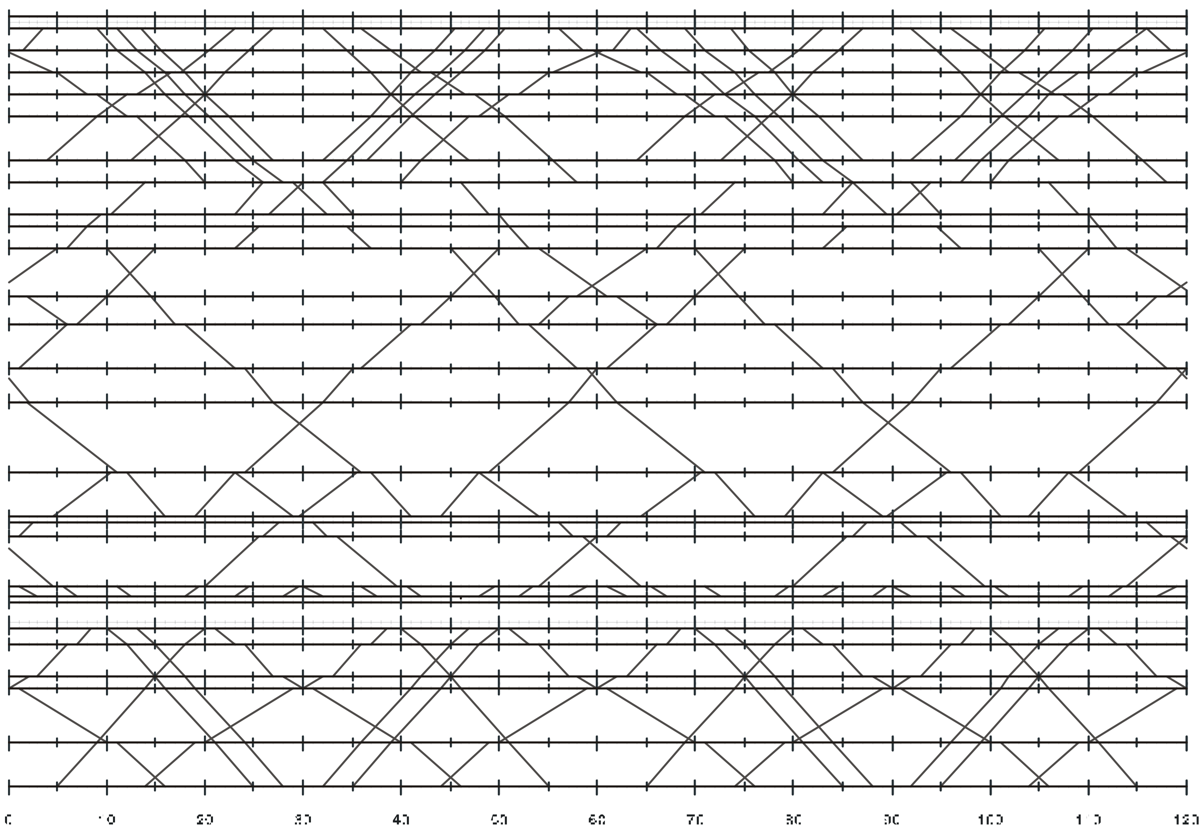
Figure 1 CAPRES operational modes



CAPRES does not provide a means to compute running of trains. Therefore, running times for each train and for each line section are input data, as are minimum and maximum stop times in stations. These data allow for some flexibility to saturating trains: running time may for instance include recover time, or allow optional stopping of a train in case of overtaking.

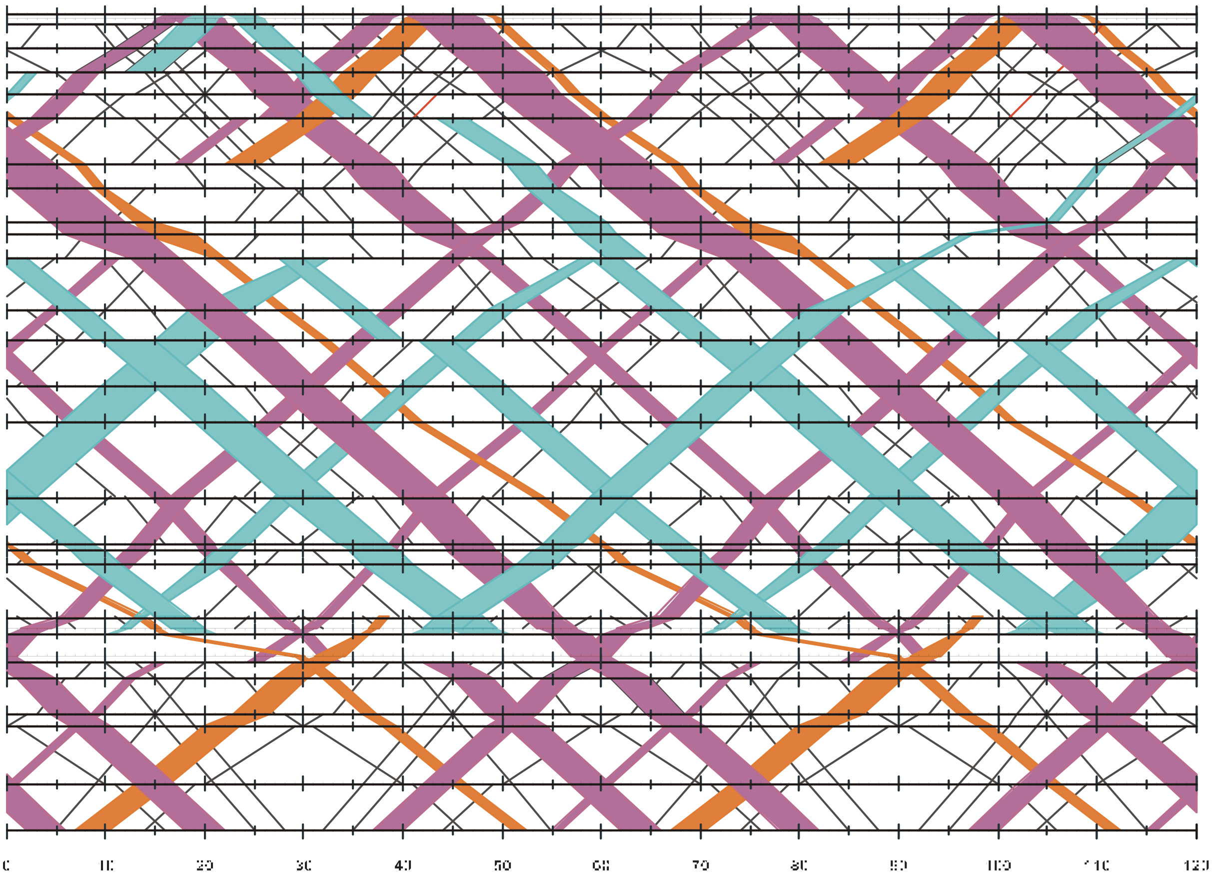
Figure 2 shows an example of a **basis-timetable**, for which all planned train-paths are fixed (with a 1-minute accuracy).

Figure 2 Passenger trains (Basis-timetable)



After saturation of the basis-timetable, the time slots show the possibilities to introduce additional trains (**figure 3**). As train-paths for additional trains are not fixed, but defined inside time slots (the large strips in figure 3), it is possible to generate a large number of fixed timetables for this saturated network, by varying the exact time of each additional train.

Figure 3 **Saturating the timetable** with additional freight trains



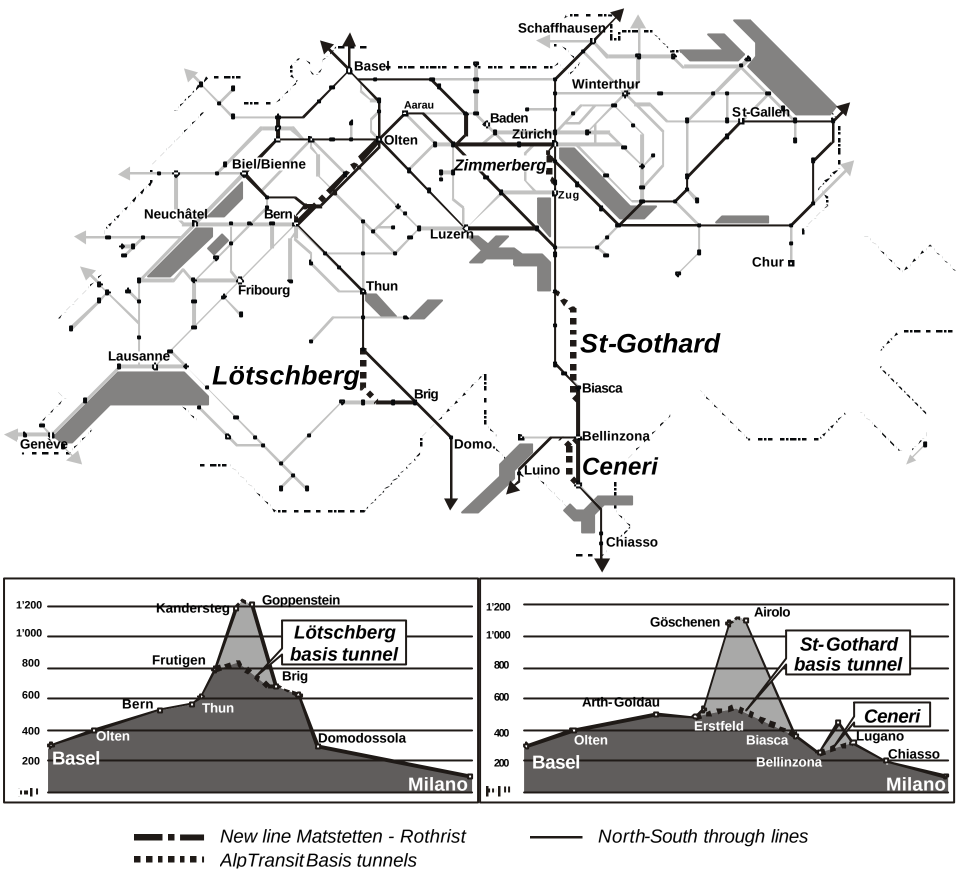
To reduce number of alternatives, CAPRES admits that two alternative timetables are different only if the succession order of any two trains is different on at least one line section. Consequently, a saturated timetable is only defined using time slots, and not exact train paths for the additional trains.

6. A CAPRES application: Developing the capacity of the Swiss rail network

Freight train traffic through the Swiss Alps is expected to increase substantially due, on one hand to the agreement between European Union and Switzerland on the through traffic, and on the other hand, due to a Swiss constitutional provision that mandates a huge modal transfer on rail (Alp initiative). Through trains will be distributed over the 2 major axes, Lötschberg and Gothard, that link Southern of Germany to Northern Italy.

Extension of rail infrastructure will be undertaken progressively, to match the implementation of the service increases planned with Rail 2000 and AlpTransit projects. That will result in conflicts between the development of passenger services and freight traffic; both will compete to use the same residual capacity.

Figure 4 The 2 axes of **Alptransit** project



The case study aimed to define the progressive development of capacity for North-South freight traffic, given the passenger traffic structure for the following planning milestones:

- Implementation of the new timetable concept for the year 2001, which is the reference scenario
- Start of operation of the new line Matstetten-Rothrist, and simultaneous implementation of a new timetable concept for the year 2005
- Start of operation of the new Lötschberg basis tunnel in years 2006/7
- Start of operation of the new Monte Ceneri basis tunnel in year 2017 (at which time, new Zimmerberg and Gothard basis tunnels will already be in operation)

6.1 Objectives

Objectives for each one of the above-mentioned planning scenarios were:

- To estimate the maximum number of available freight train slots over the North-South corridor
- To guarantee train paths for a set of domestic freight trains that link the major marshalling yards
- To estimate the residual available capacity provided for other domestic freight trains
- To show up bottlenecks, in order to assess the need of additional investment on infrastructure

6.2 Approach

For each planning scenario, first step was to design a basis-timetable including mandatory passenger trains and domestic freight traffic between major marshalling yards. Basis-timetable, then, has been saturated step-by-step, using freight trains selected among 4 categories [5]; their number and mix were defined according to demand forecasts for the freight through traffic.

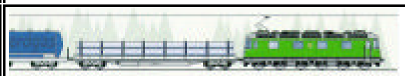
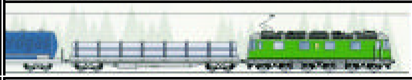
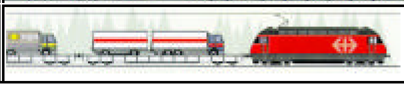
Category	Train make-up	V max [km/h]	Weight [t]	Length [m]
High Performance		160	1200	450
Specialised		110	2000	750
Conventional		90	2000	750
Heavy		90	3200	750
Roll-on roll-off		110	4000	1500

Figure 5: Categories for additional (saturating) freight trains

Several saturation strategies have been used (combined with train route alternatives, involving for instance partial use of the older ridge tunnels) in order to assess also the efficiency of concepts for operations.

6.3 Results

CAPRES software has been effective to show the progressive evolution of capacity for North-South train traffic through Switzerland and for the year 2001 up to year 2017 period. The study clearly demonstrated that the projected new lines would bring not only additional capacity, by providing substantial increase of available train slots for freight traffic, but also significant time gains for passenger and freight traffic. Example given, passenger travel time between major Swiss cities and Mainland (Italy) will be shortened for more than 1 hour.

More specifically on freight traffic, the study reached the following conclusions [6]:

- Operation of basis tunnels combined to the projected new lines will result in substantial increase of transportation capacity, increasing both the number of available slots and the permissible overall trainload. Projected investments are expected to ensure sufficient freight capacity over several decades.
- In year 2017, with all the projected lines in operation, both freight traffic volume and level of service will significantly improve. It will be thus possible to let pass daily more than 300 freight trains through Switzerland. The most efficient among them will cross Swiss territory in about 3 hours, which is a 40% improvement over current running times.

- Keeping in operation the older ridge tunnels is paramount. They are essential in order not only to fully use the capacity of the access lines, but also to allow network operation during maintenance on basis tunnels.

- With that in mind, when the full project will be operational, capacity limit will be set by the capacity of access lines.

7 Conclusions

Four years of theoretical and applied research in partnership with the Swiss Federal Railways led to design a methodology and to develop an efficient tool to assess capacity of complex rail networks that sustain mixed traffic.

Experience shows that CAPRES remains very flexible, with a large application field. Moreover, it has vastly contributed to the political decision process, making it possible to validate the relevance and the utility of the projected investments. CAPRES is currently in use at SBB/CFF, SNCF, and at consulting offices.

To conclude, CAPRES makes it possible to assess rail capacity following an iterative and structured approach. Its algorithmic component is flexible enough to allow use over networks of very different sizes, and with various detail levels, which adds most-wanted use flexibility to a high user-friendliness.

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