ETH zürich

Center for Sustainable Future Mobility (CSFM)

SMARTIES - Scheduling Methods for Automated Railway Timetabling Improving the Efficiency of Smart Rail

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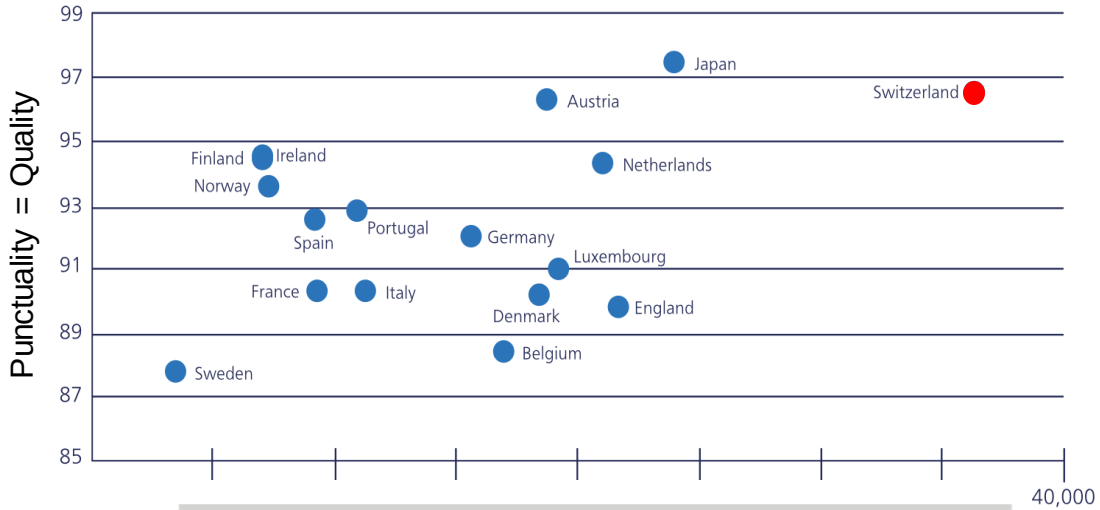
In mobility problems, Public Transport is part of the solution

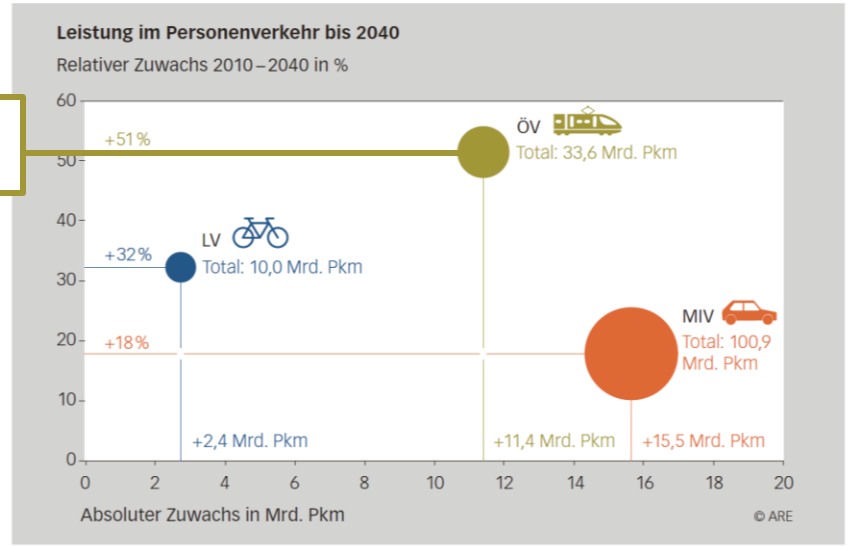
Extremely effective in terms of space, energy, costs
UN SDG 11:affordable and sustainable transport systems

Limited and slow to upgrade infrastructure capacity

Established societal relevance, large growth expected



Public Transport/Railway
51% growth 2010→2040



Referenzszenario: relativer und absoluter Zuwachs der Leistung im Personenverkehr in % und in Pkm, differenziert nach Modi, 2010 bis 2040. Die Grösse der Punkte entspricht der Leistung im Jahr 2040.

Bundesamt für Raumentwicklung ARE (2018) Verkehrsperspektiven 2040
RhB; Dutch Railways NS (2018) Yearly report; Bike citizens

Railway planning and control: running more traffic more on time

About 30% of transport capacity is now used in buffers against uncertainty, at multiple levels

Controlling traffic (interaction of vehicles) is much more effective than controlling vehicles (kinematics)

Plan carefully resource allocation to ensure smooth operations

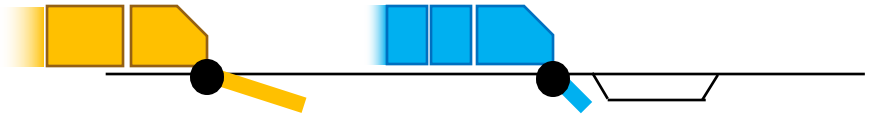
Control operations in realtime when deviations occur

Control replaces infrastructure.

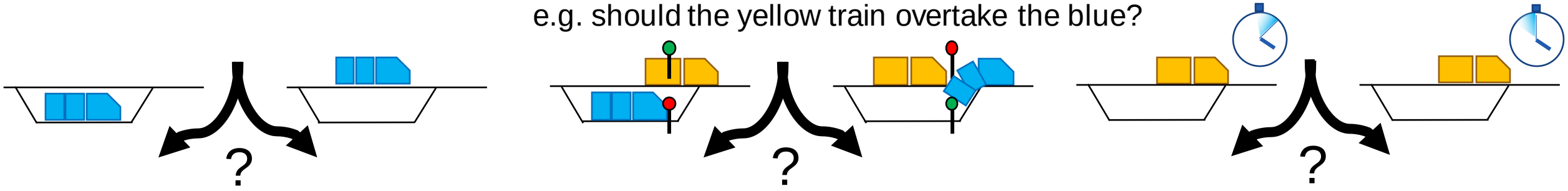
RhB; SmartRail4.0; Swissinfo.ch

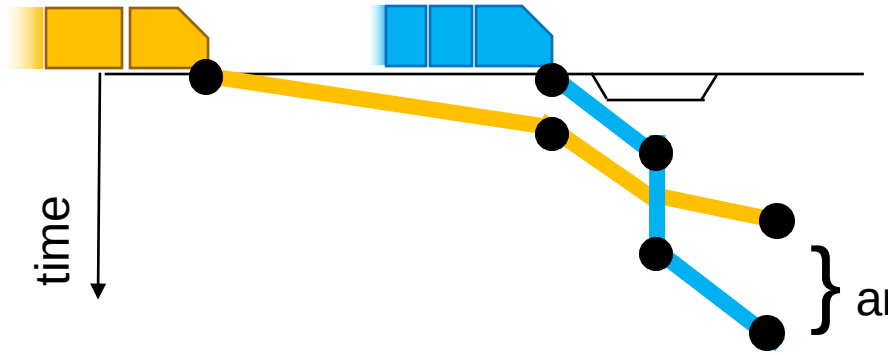
Planning Operations

Based on some **desired** traffic,



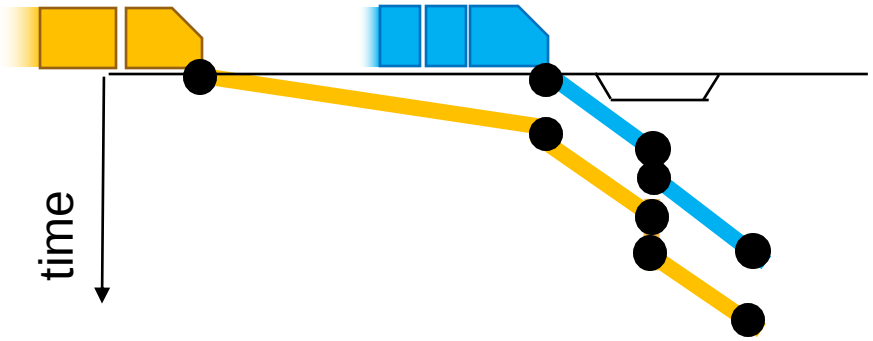
determine traffic **plan** (time; order**,** route, cancelling,…)
e.g. should the yellow train overtake the blue?





} arrival time

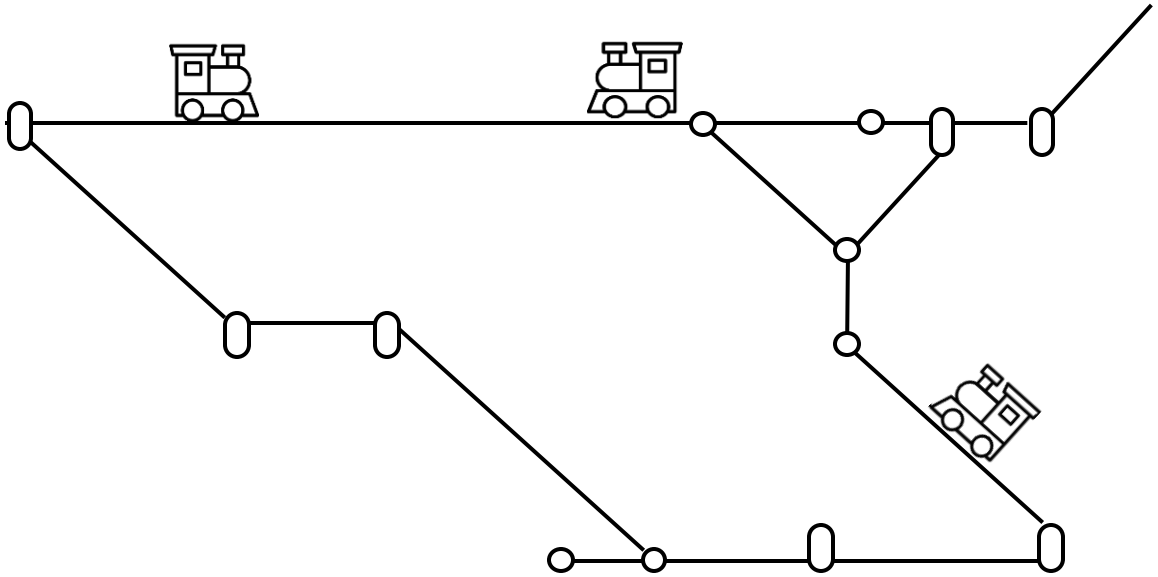
→ **performance**



which reduces travel time, runs as much trains as possible, avoids delays

Mathematics to optimize railway traffic control in real time

Strongly combinatorial problem; scales very badly with size



Mathematics to optimize railway traffic control in real time

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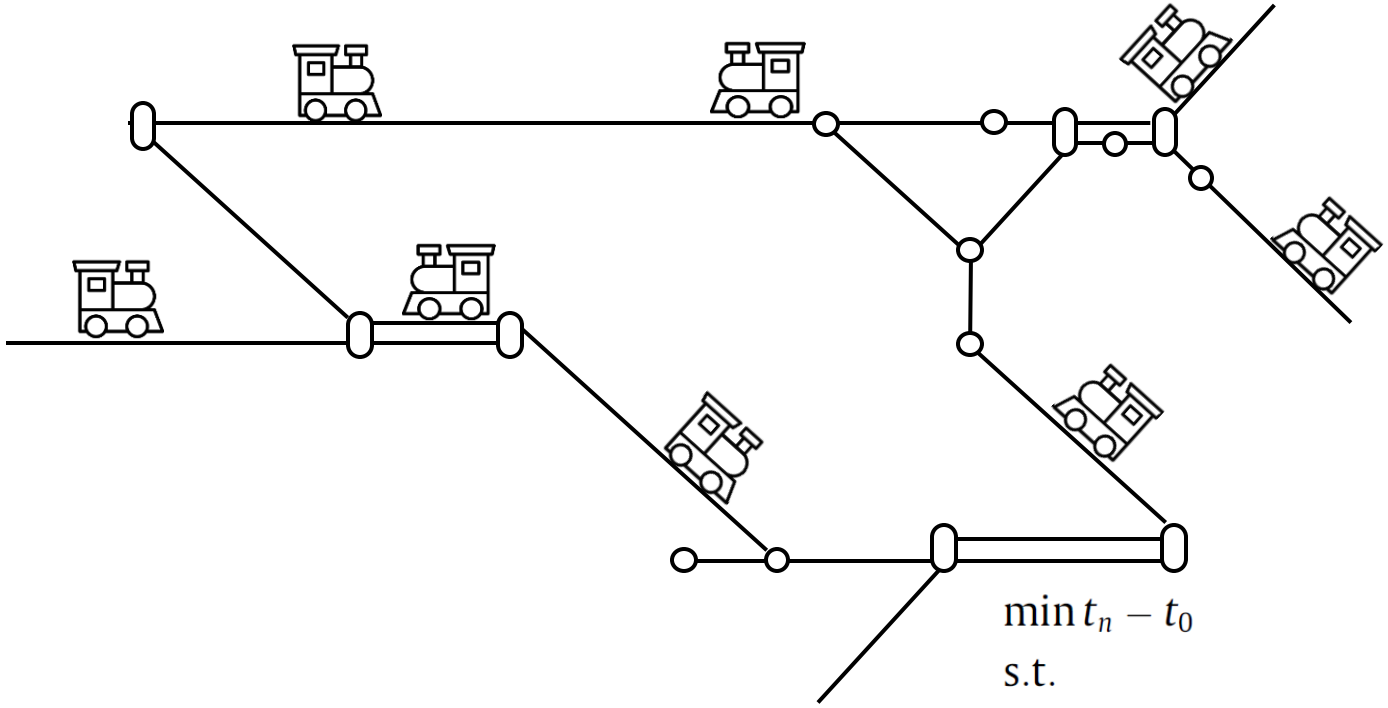
Fast solutions with **realistic** constraints require very sophisticated algorithms: scheduling



$$\min t_n - t_0$$

s.t.

$$t_j - t_i \geqslant w_{ij} \qquad (i,j) \in F$$

$$(t_j - t_k \geqslant w_{kj}) \vee (t_i - t_h \geqslant w_{hi}) \qquad ((k,j),(h,i)) \in A$$

Corman F., D'Ariano A., Pacciarelli D., Pranzo M. (2010) M. A tabu search algorithm for rerouting trains during rail operations. Transportation Research Part B 44 (1), 175-192

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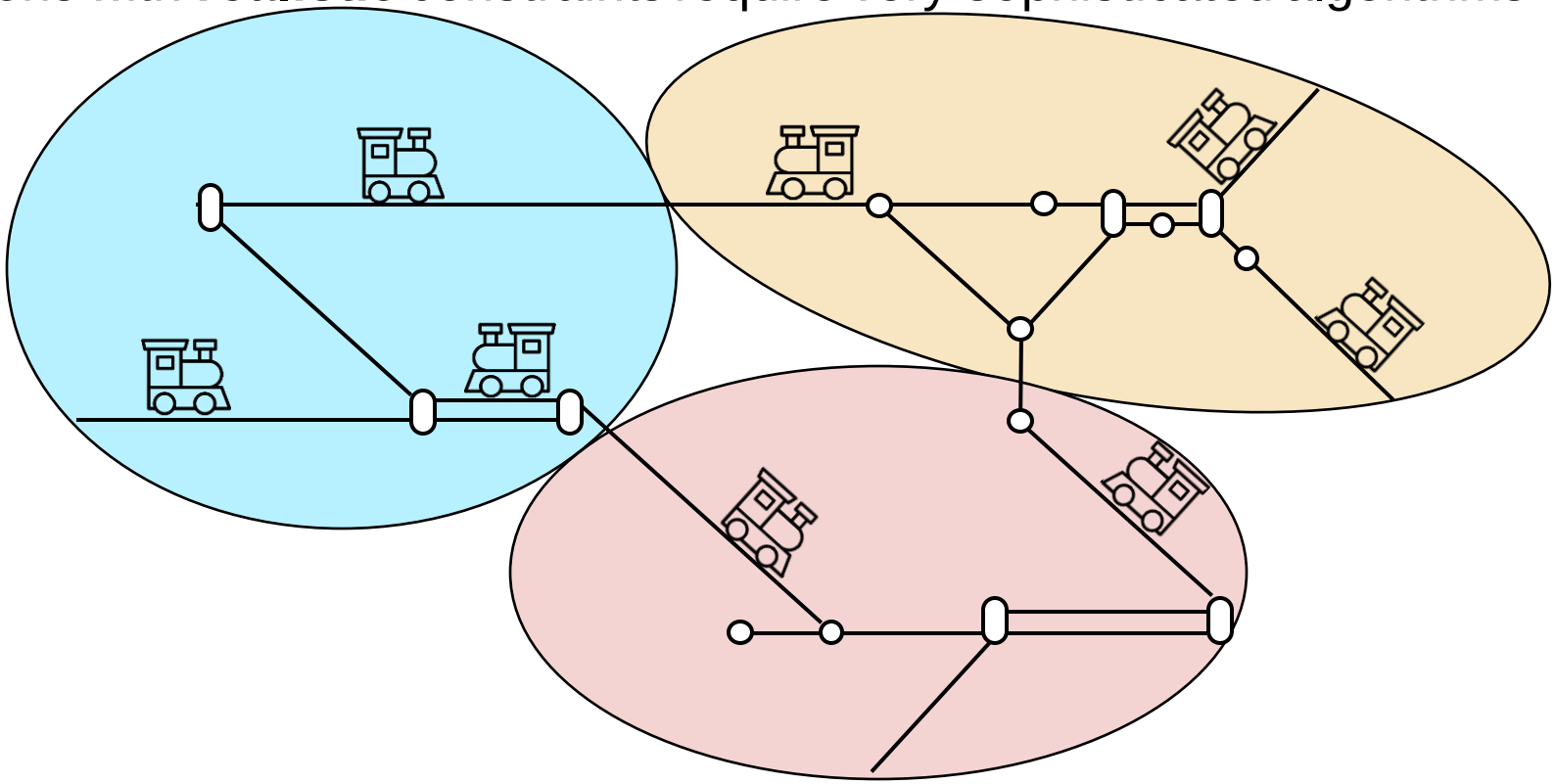

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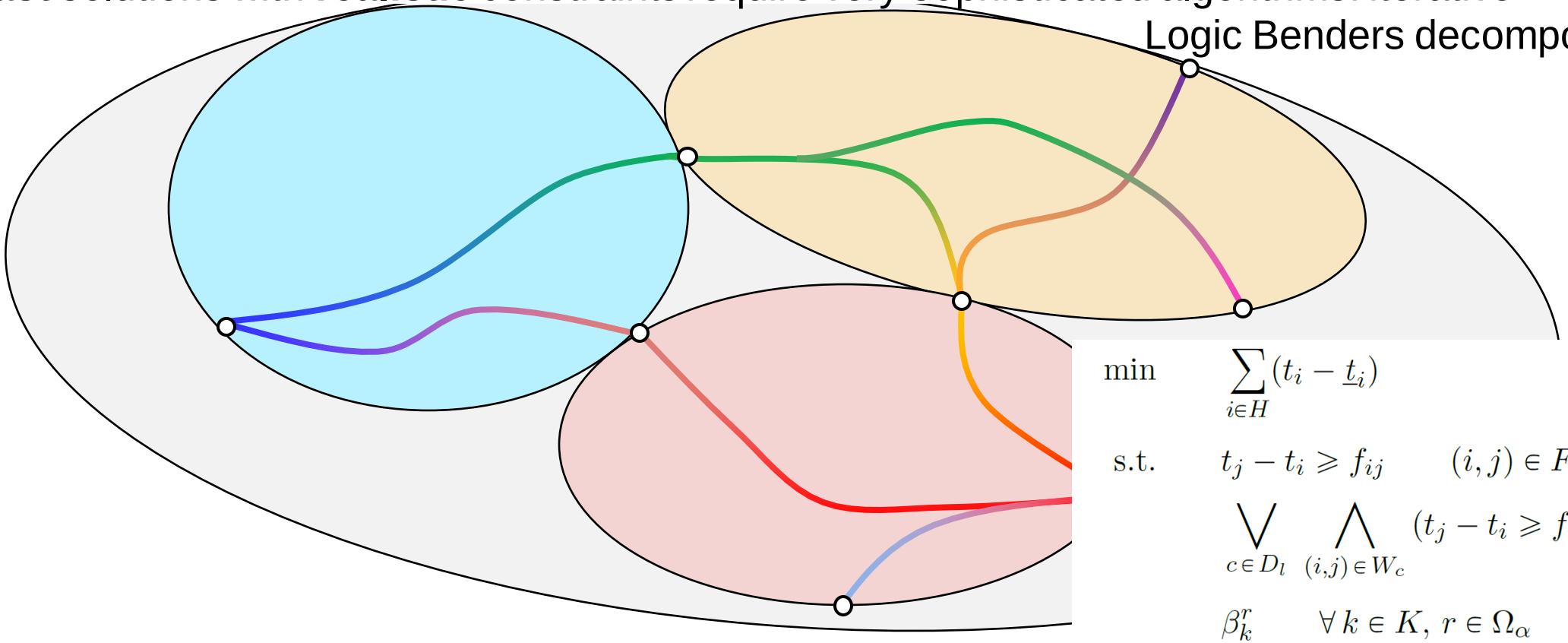
Fast solutions with **realistic** constraints require very sophisticated algorithms: iterative Logic Benders decomposition



$$
\begin{aligned}
\min \quad & \sum_{i \in H} (t_i - \underline{t}_i) \\
\text{s.t.} \quad & t_j - t_i \geqslant f_{ij} \qquad (i,j) \in F_M \\
& \bigvee_{c \in D_l} \bigwedge_{(i,j) \in W_c} (t_j - t_i \geqslant f_{ij}) \quad l \in L_M. \\
& \beta_k^r \qquad \forall\, k \in K,\ r \in \Omega_\alpha \\
& t_i \in \mathbb{R}_+ \ \forall t_i \in M
\end{aligned}
$$

Leutwiler F., Corman F. (2022) A logic-based Benders decomposition for microscopic railway timetable planning. European Journal of Operational Research https://doi.org/10.1016/j.ejor.2022.02.043

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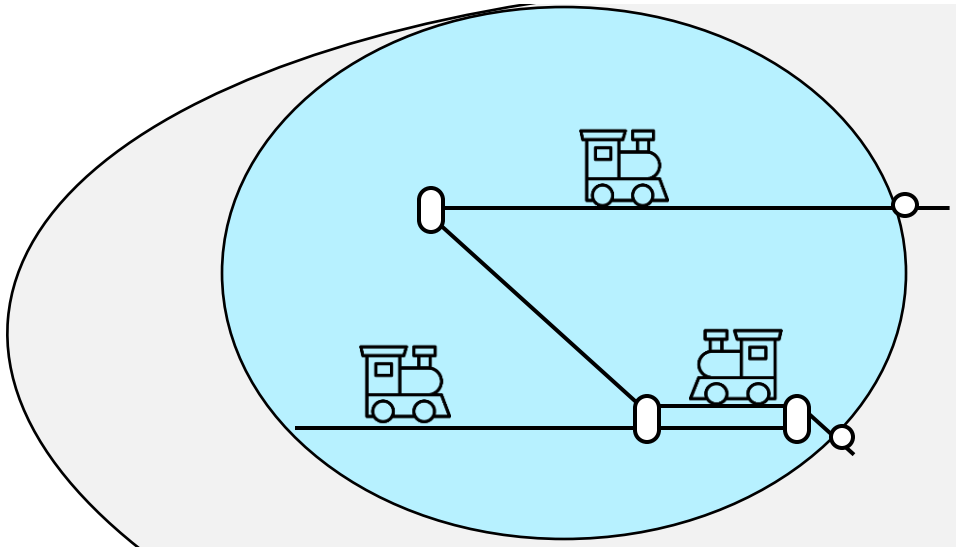

$$
\begin{aligned}
\min \quad & 0 \\
\text{s.t.} \quad & t_j - t_i \geqslant f_{ij} && (i,j) \in F_k^{\alpha} \\
& \bigvee_{c \in D_l} \bigwedge_{(i,j) \in W_c} (t_j - t_i \geqslant f_{ij}) && l \in L_k \\
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\end{aligned}
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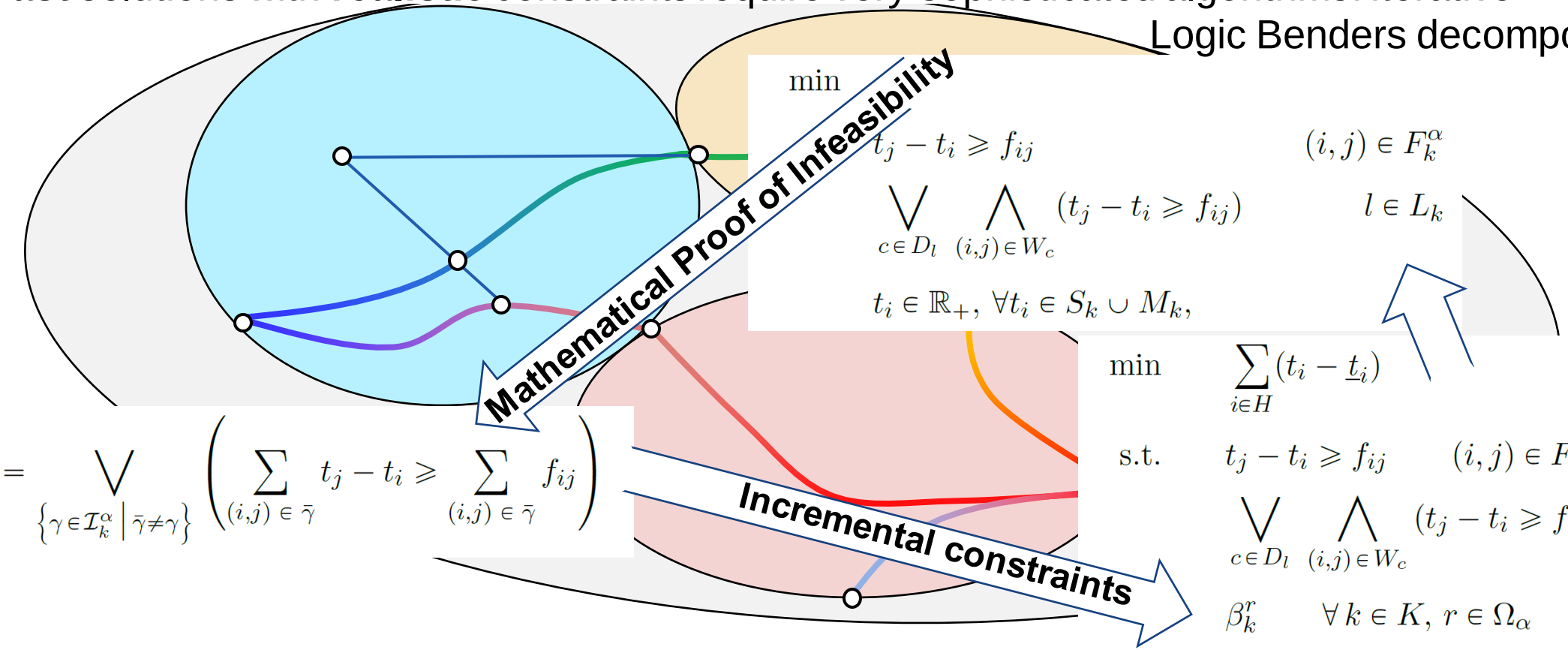

$$\min \quad t_j - t_i \geqslant f_{ij} \qquad (i,j) \in F_k^\alpha$$

$$\bigvee_{c \in D_l} \bigwedge_{(i,j) \in W_c} (t_j - t_i \geqslant f_{ij}) \qquad l \in L_k$$

$$t_i \in \mathbb{R}_+, \ \forall t_i \in S_k \cup M_k,$$

$$\beta_k^\alpha = \bigvee_{\left\{\gamma \in \mathcal{I}_k^\alpha \,\middle|\, \bar{\gamma} \neq \gamma\right\}} \left(\sum_{(i,j) \in \bar{\gamma}} t_j - t_i \geqslant \sum_{(i,j) \in \bar{\gamma}} f_{ij} \right)$$

$$\begin{aligned} \min \quad & \sum_{i \in H} (t_i - \underline{t}_i) \\ \text{s.t.} \quad & t_j - t_i \geqslant f_{ij} \qquad (i,j) \in F_M \\ & \bigvee_{c \in D_l} \bigwedge_{(i,j) \in W_c} (t_j - t_i \geqslant f_{ij}) \qquad l \in L_M. \\ & \beta_k^r \qquad \forall\, k \in K,\ r \in \Omega_\alpha \\ & t_i \in \mathbb{R}_+ \ \forall t_i \in M \end{aligned}$$

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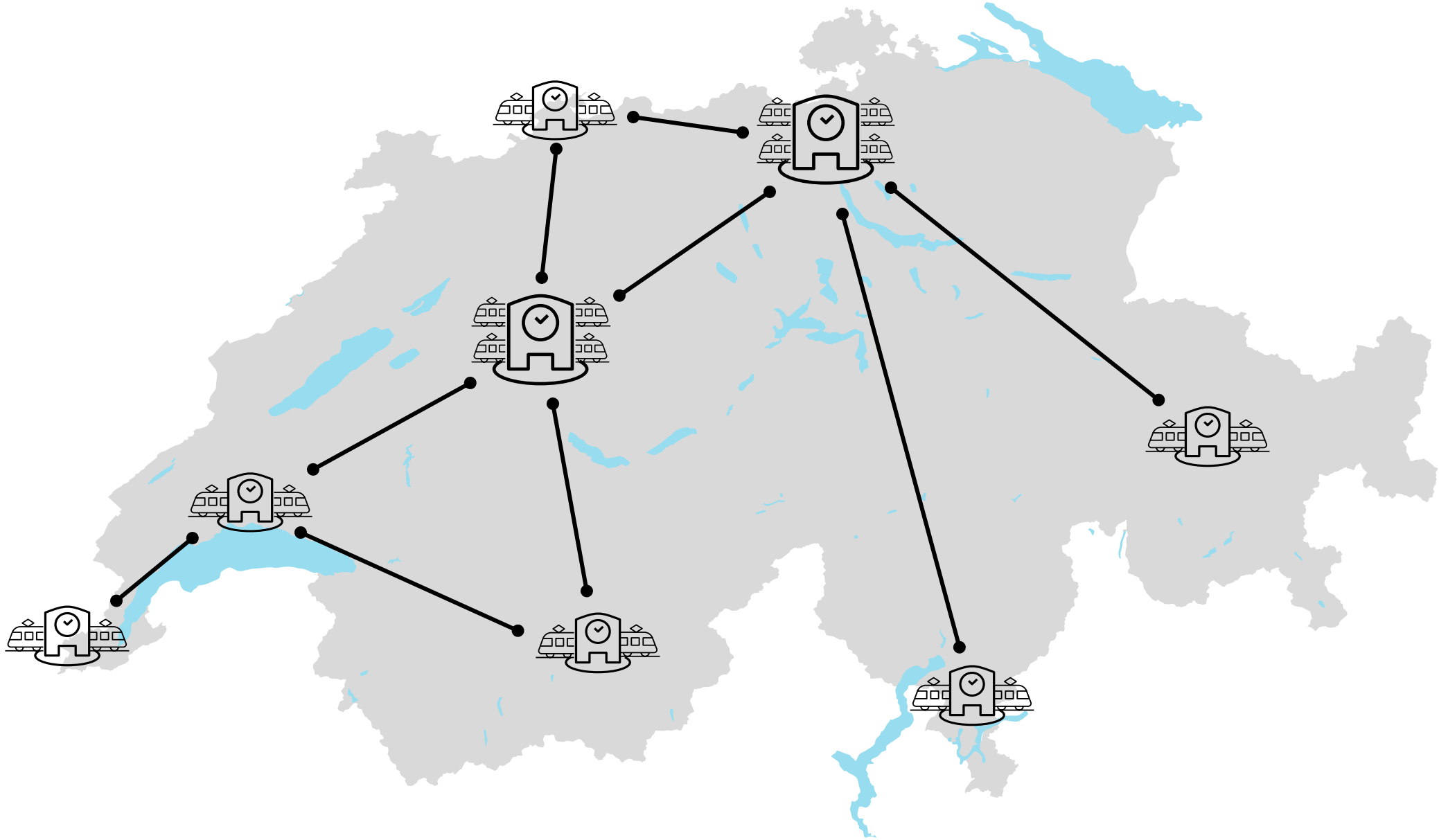
Decomposition – Lines & Stations



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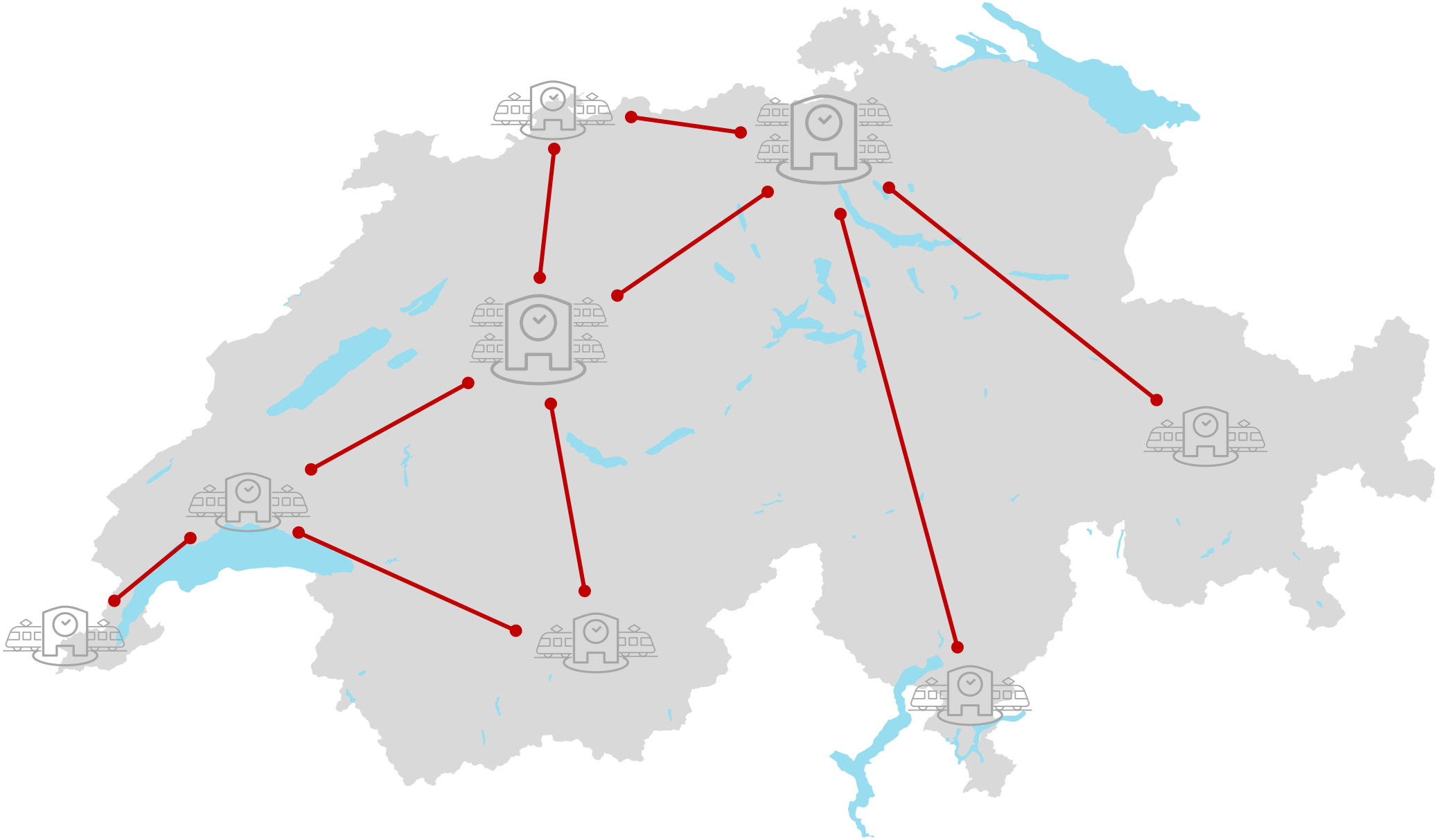
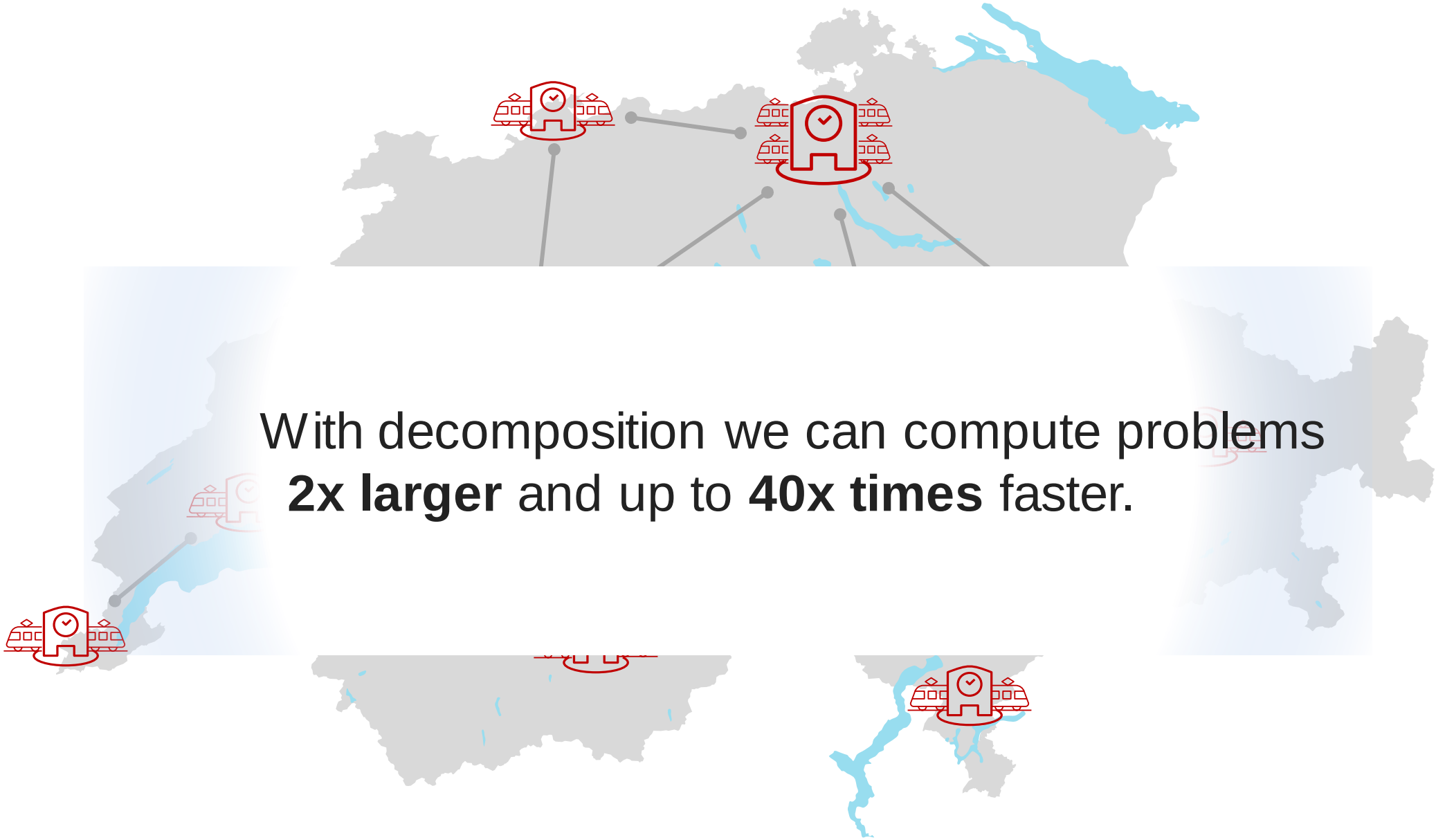


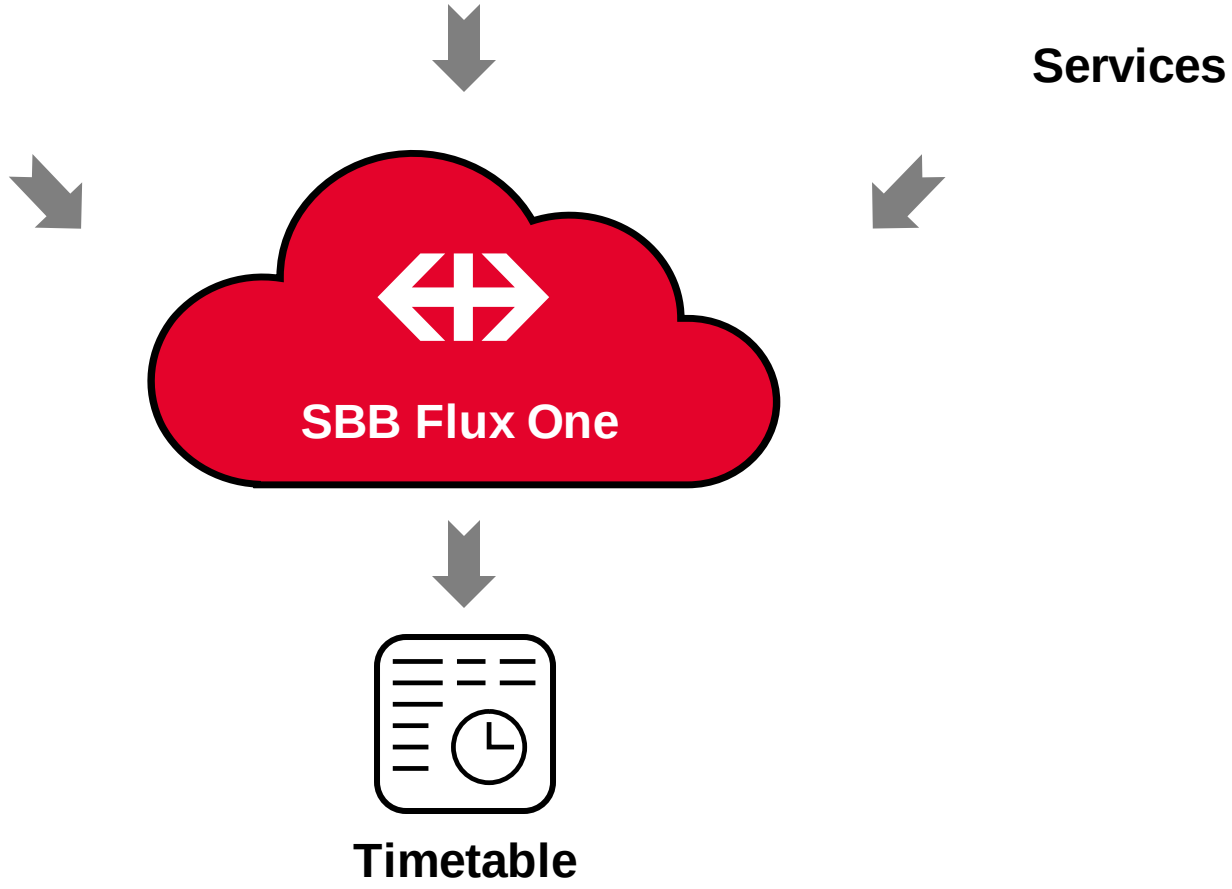
Decomposition – Lines & **Stations**



With decomposition we can compute problems **2x larger** and up to **40x times** faster.

Integration – SBB Cloud Service

Embedding:
Researcher on the same desk of the users



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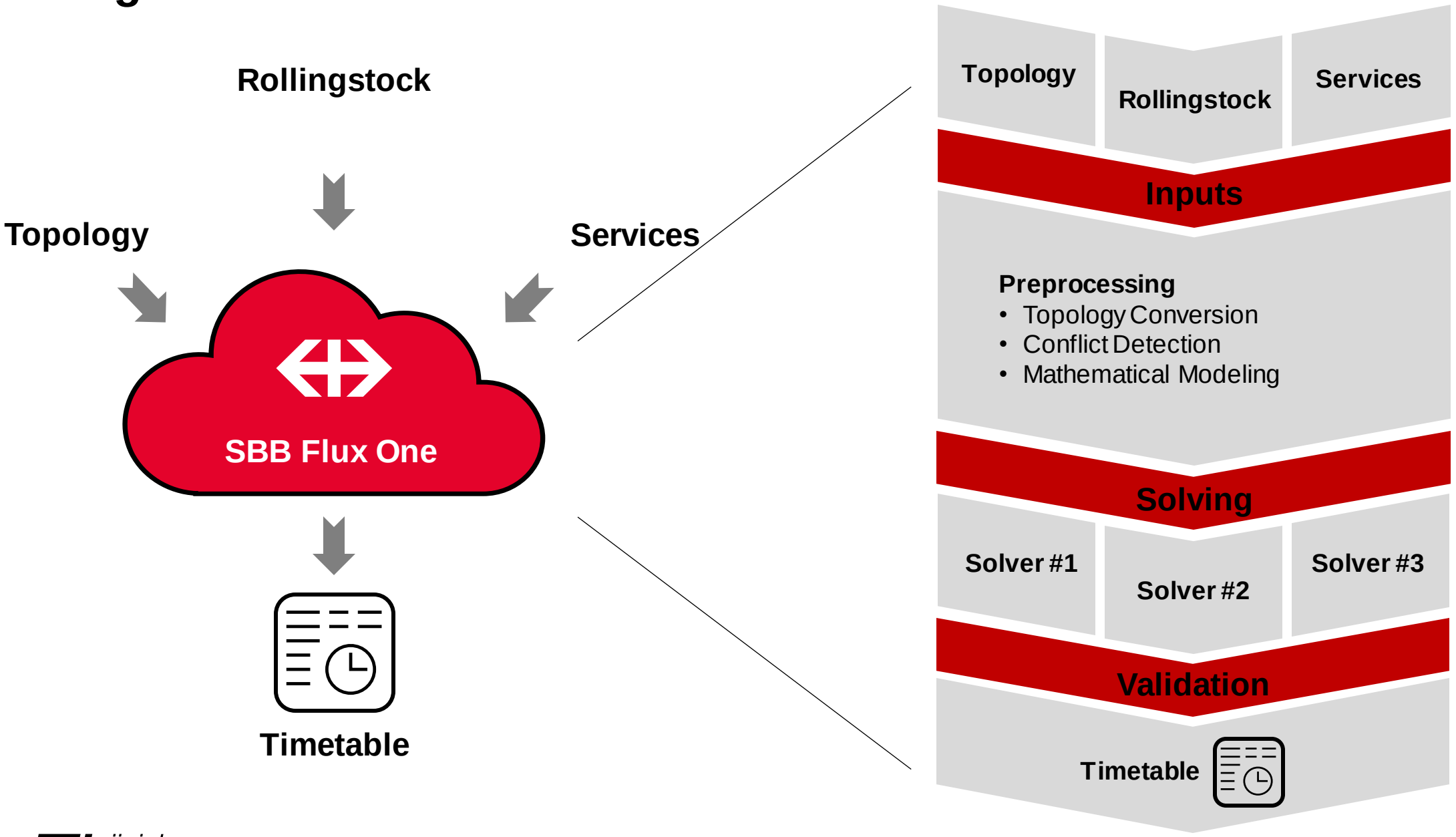

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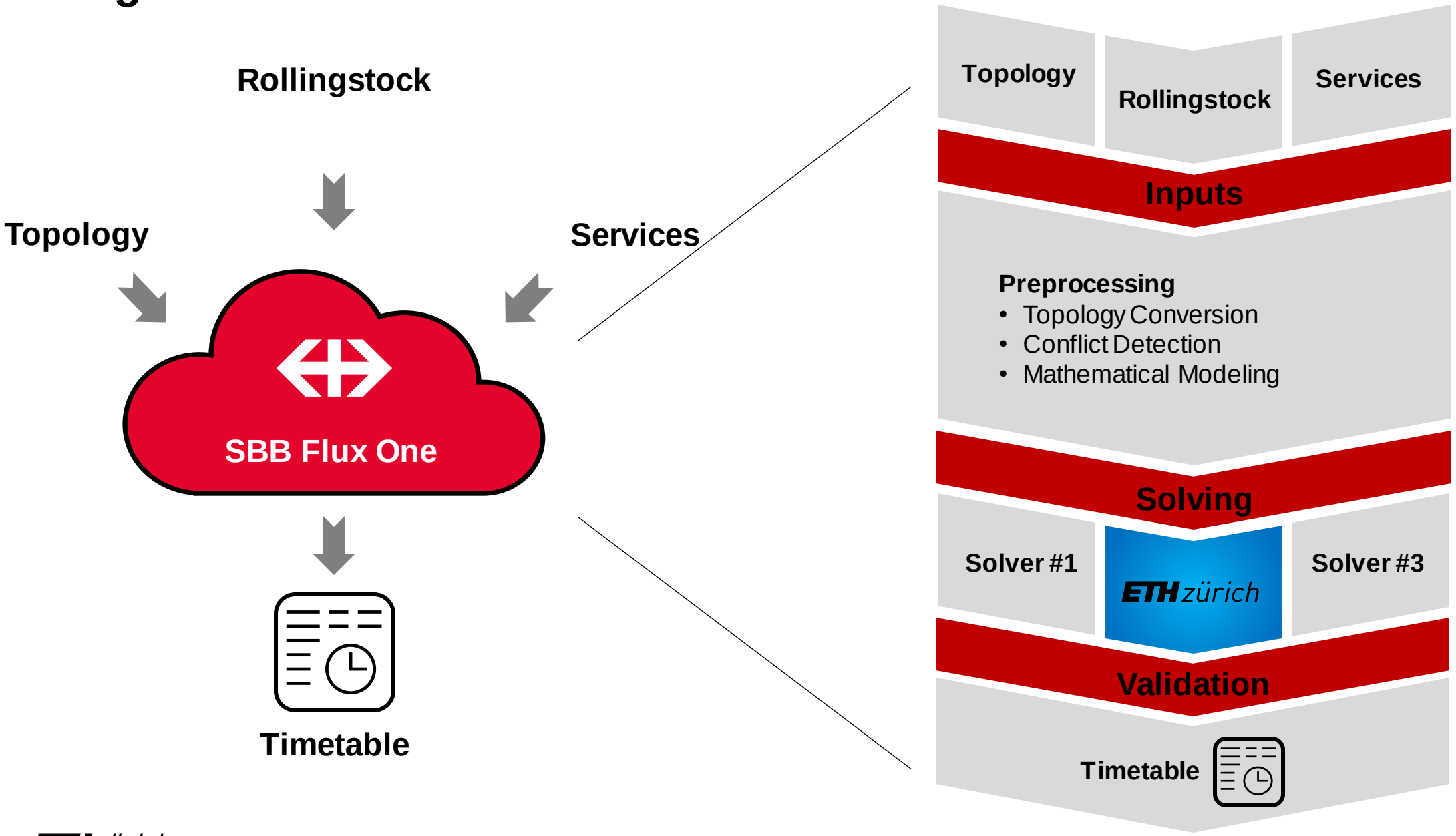

Embedding in current research, Future Research

Enabler and synergy with other projects:

- multiple objectives & Passenger delay (SBB Forschungfonds, NWO, NCCR Automation)
- energy saving (SCCER)
- data driven approaches (SNF Eccellenza)

- Automated Decomposition, balancing global and local computation efforts
- Focus on real time Rescheduling (exploiting delays statistics)
- Heuristic solving for faster solution
- Inclusions of line planning; resilience; demand changes

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