Train self-organisation for traffic management decisions

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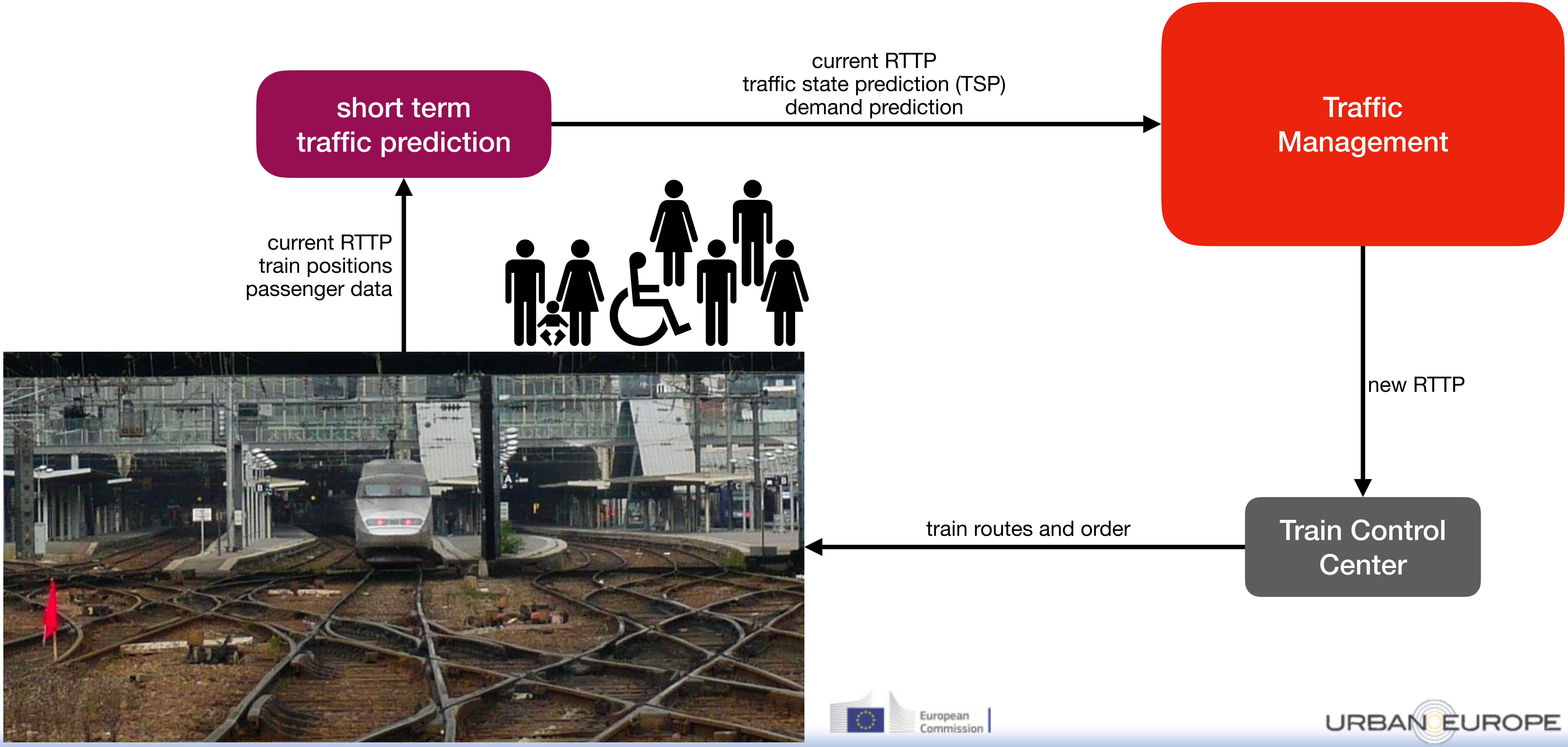
SORTEDMOBILITY Final Event
Paris, May the 13th, 2024

ERA-NET Cofund Urban Accessibility and Connectivity

Closed-Loop Traffic Management



European Commission

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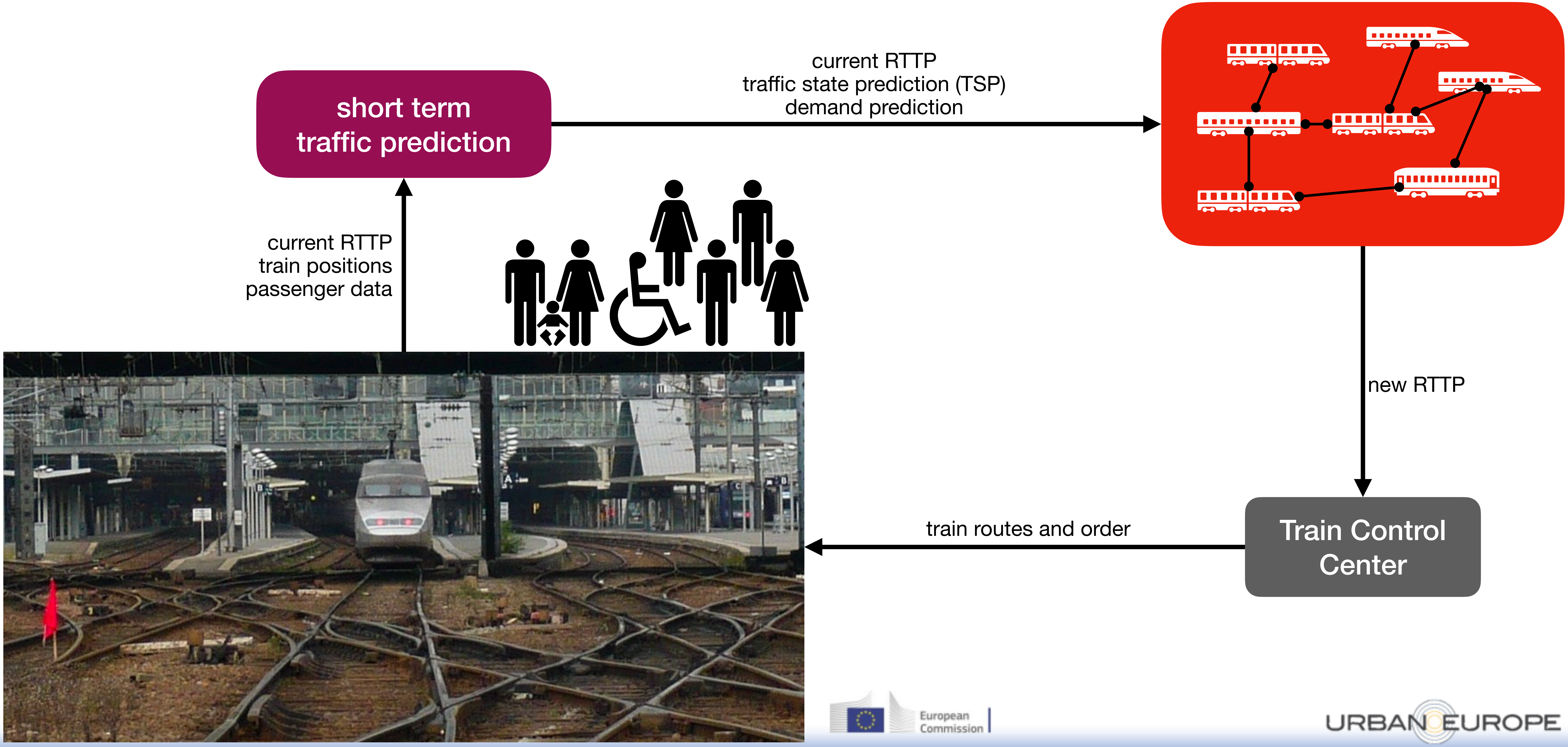
Closed-Loop Traffic Management



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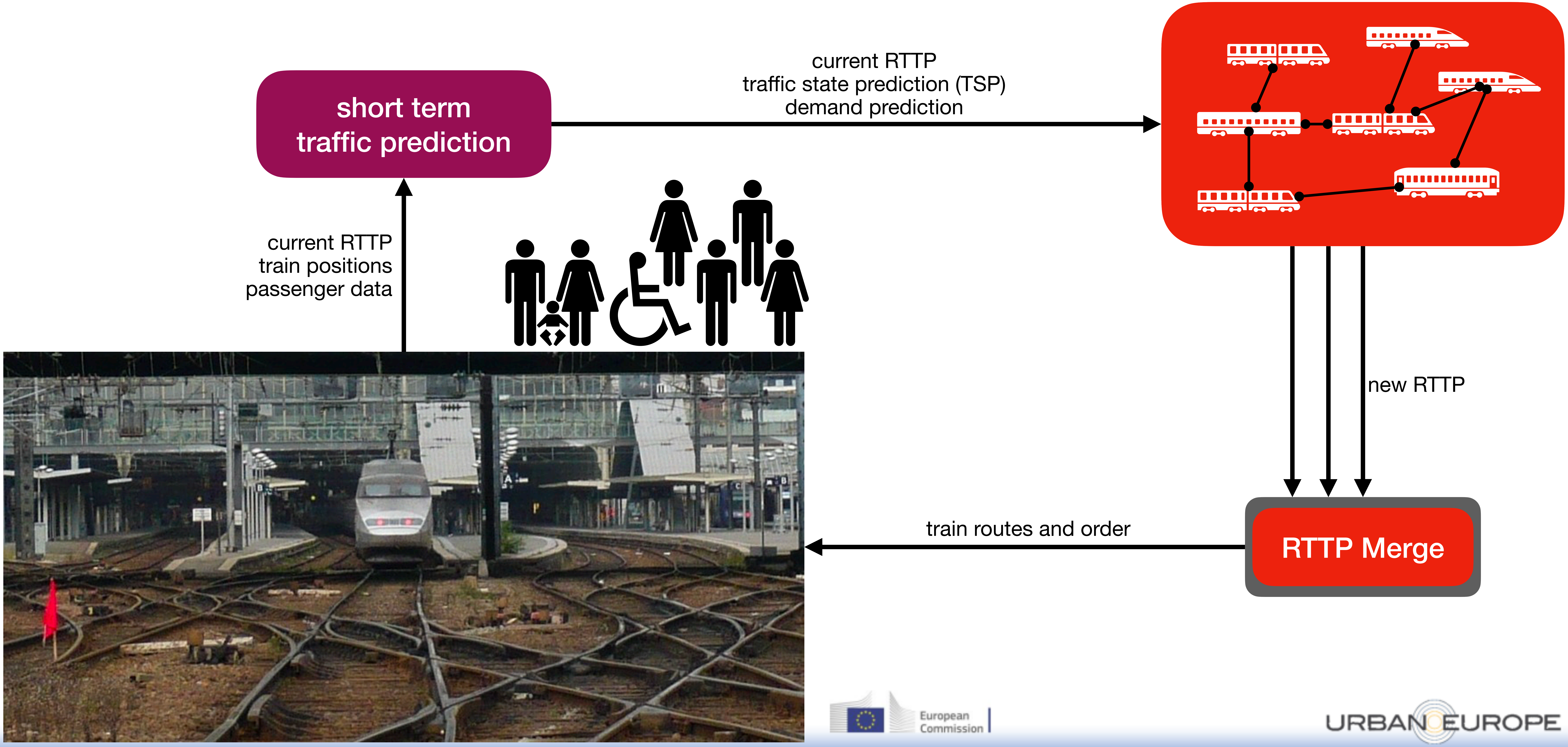

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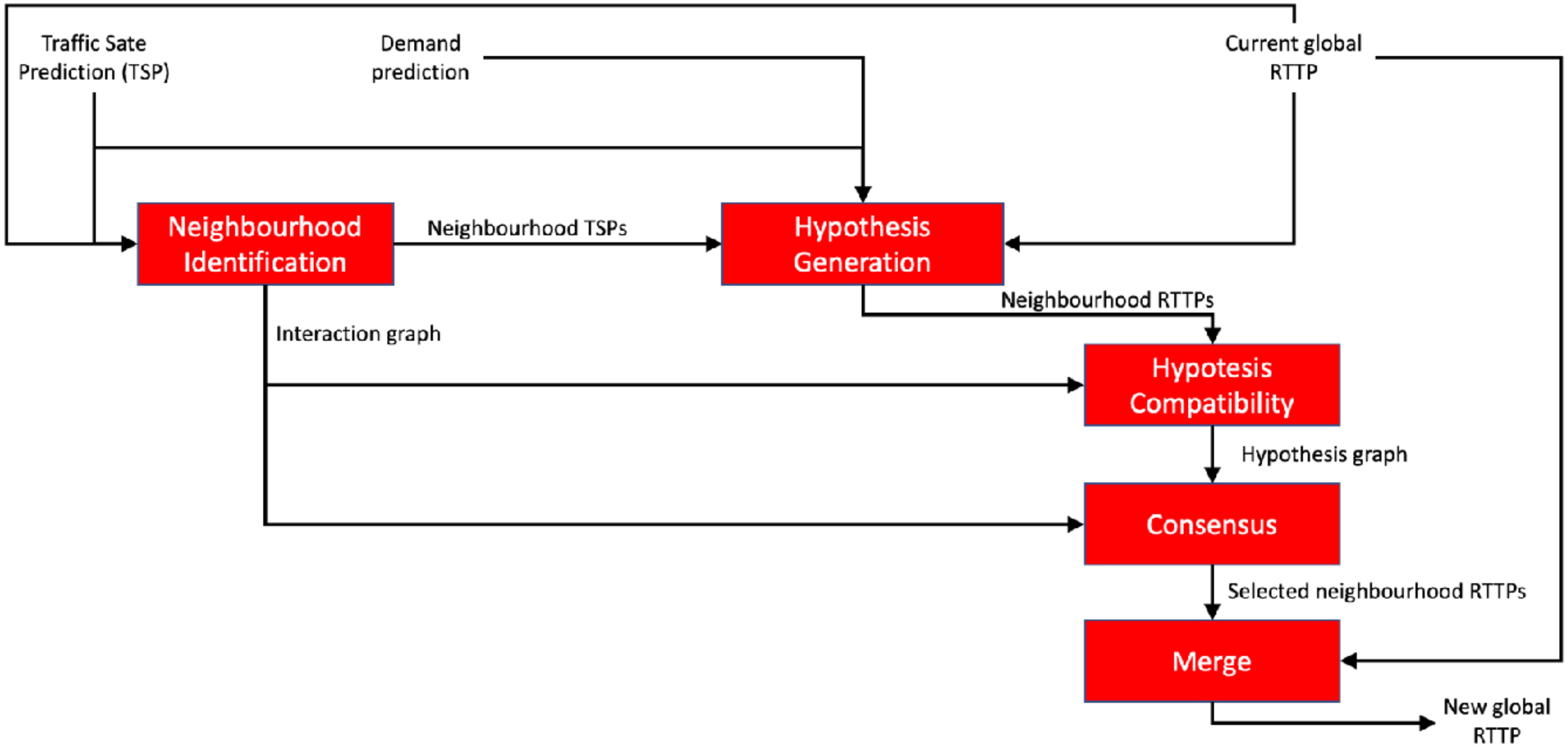

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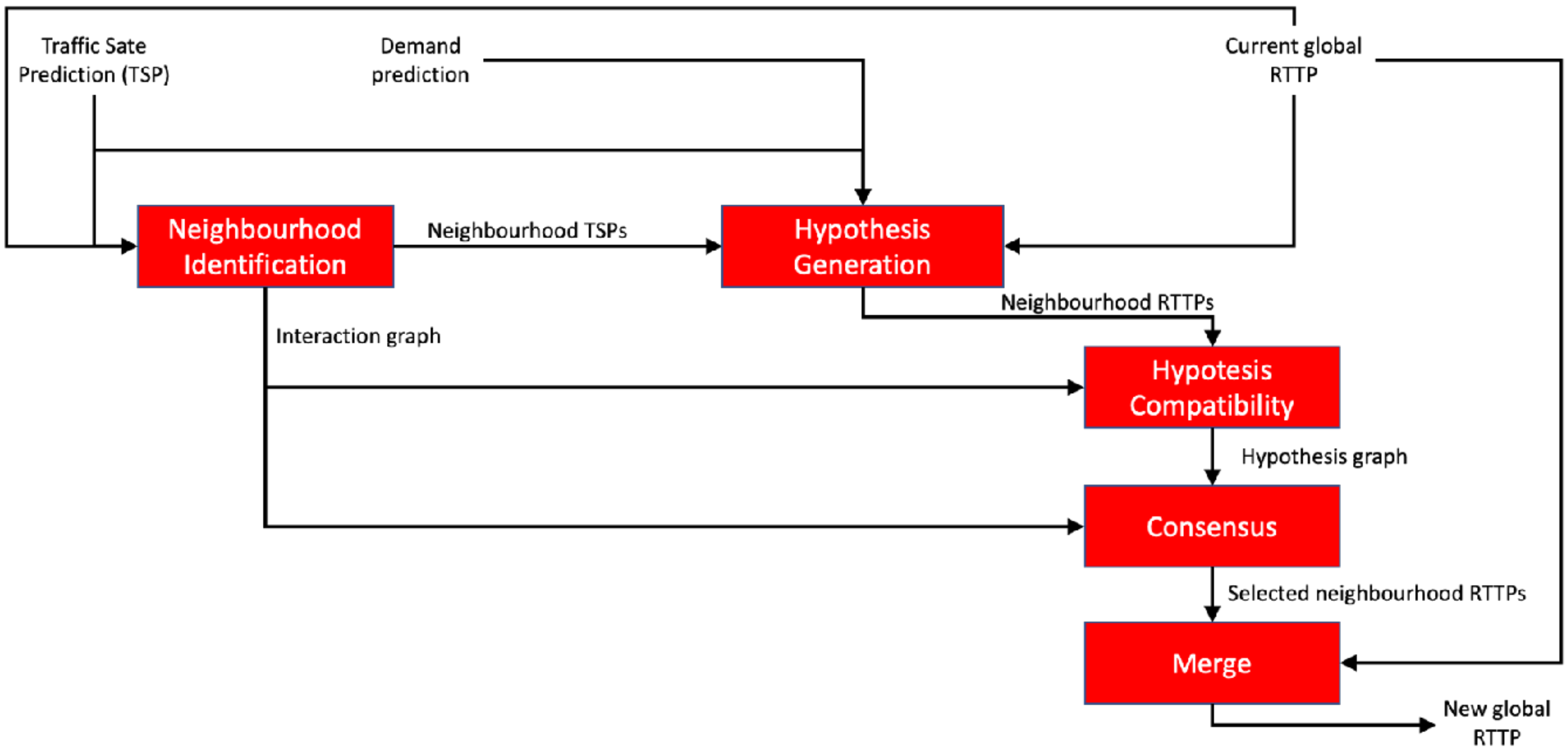

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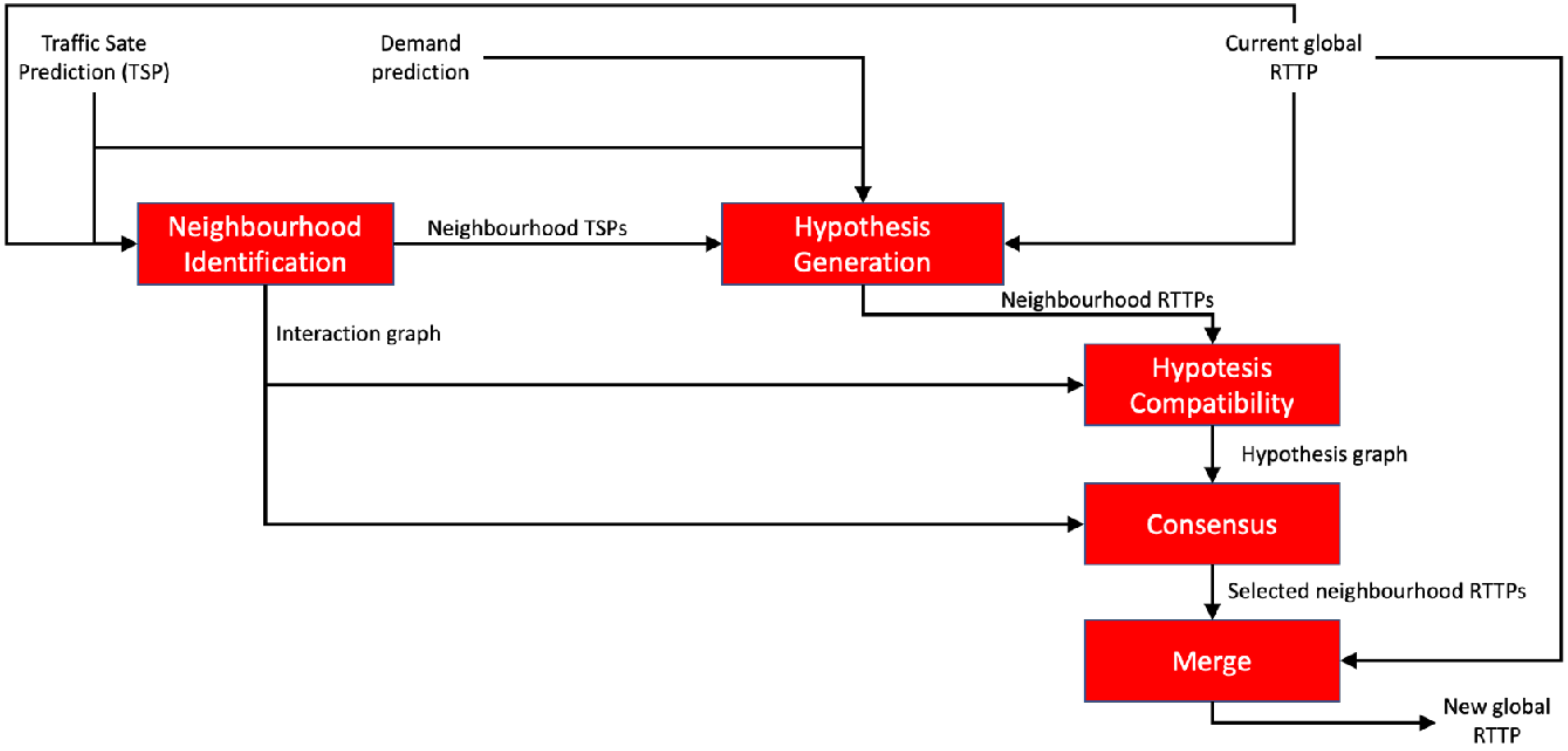

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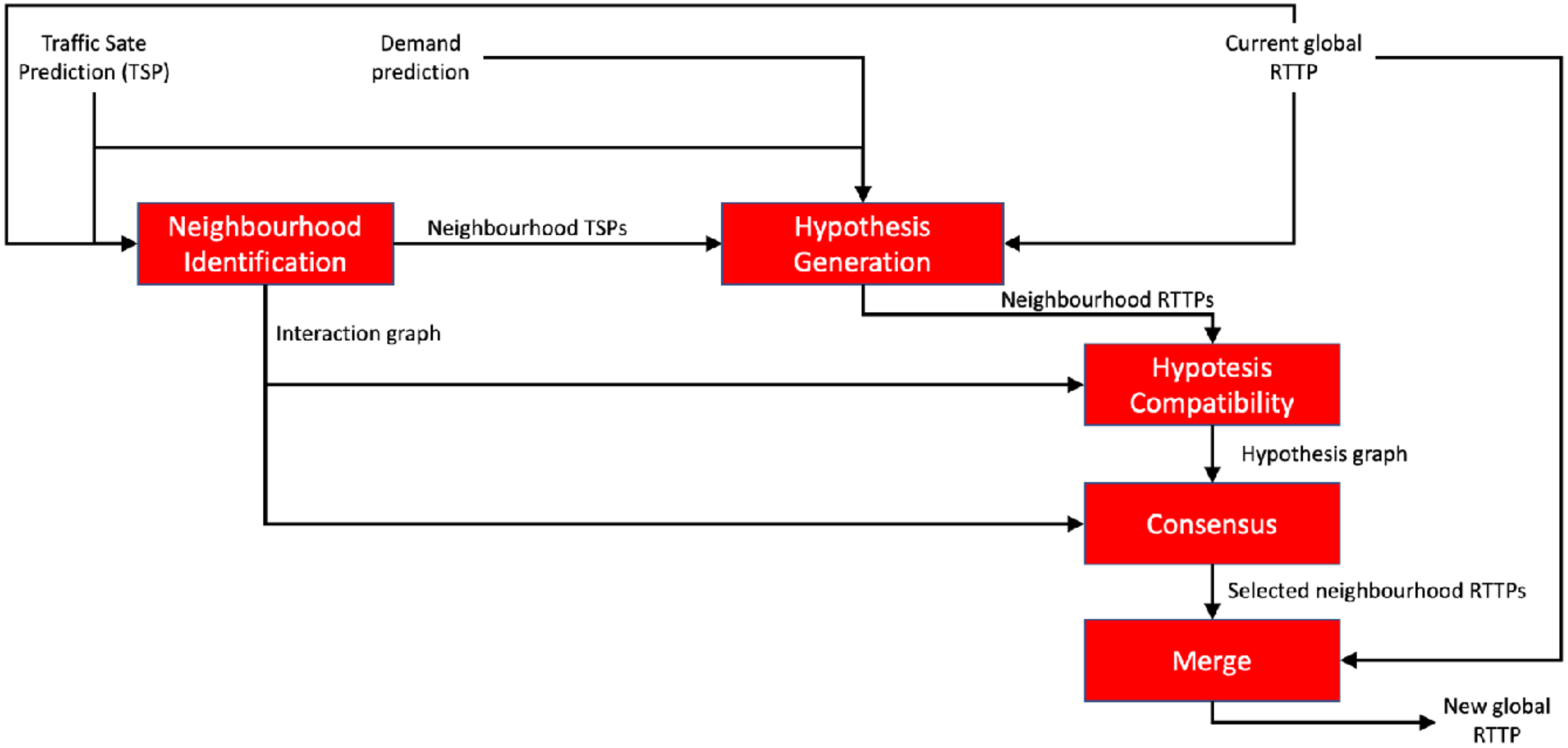

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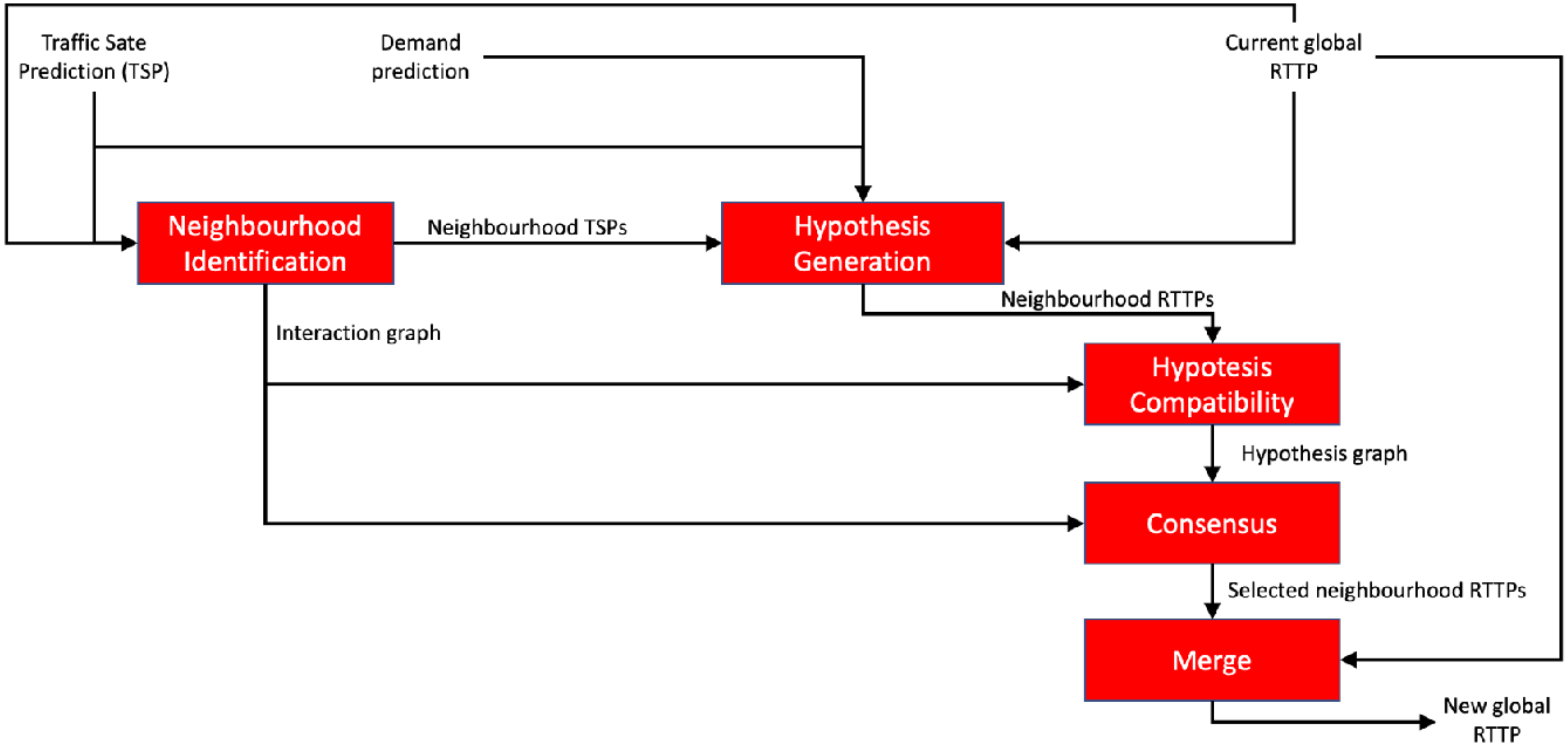
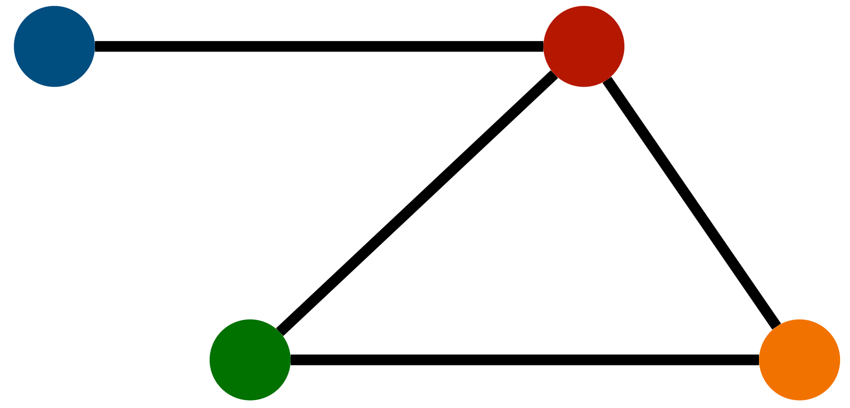


Interaction Graph



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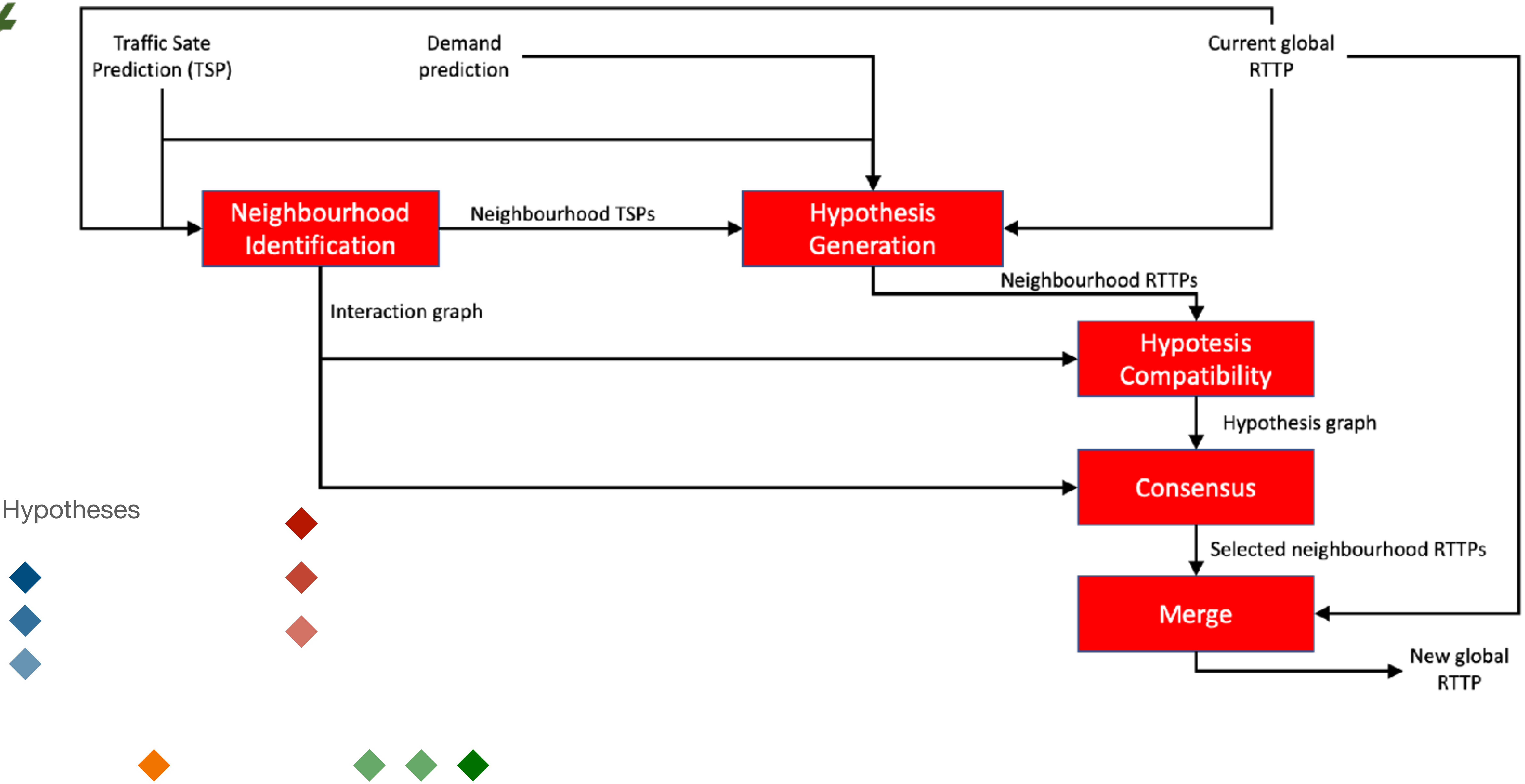

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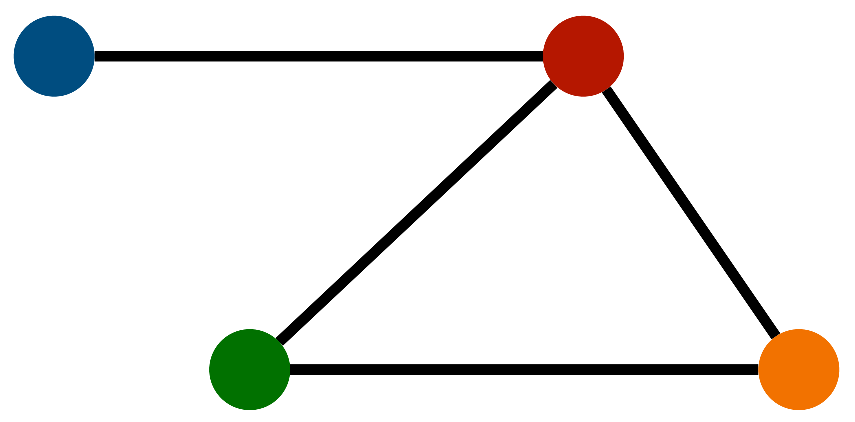

RTTP Hypotheses

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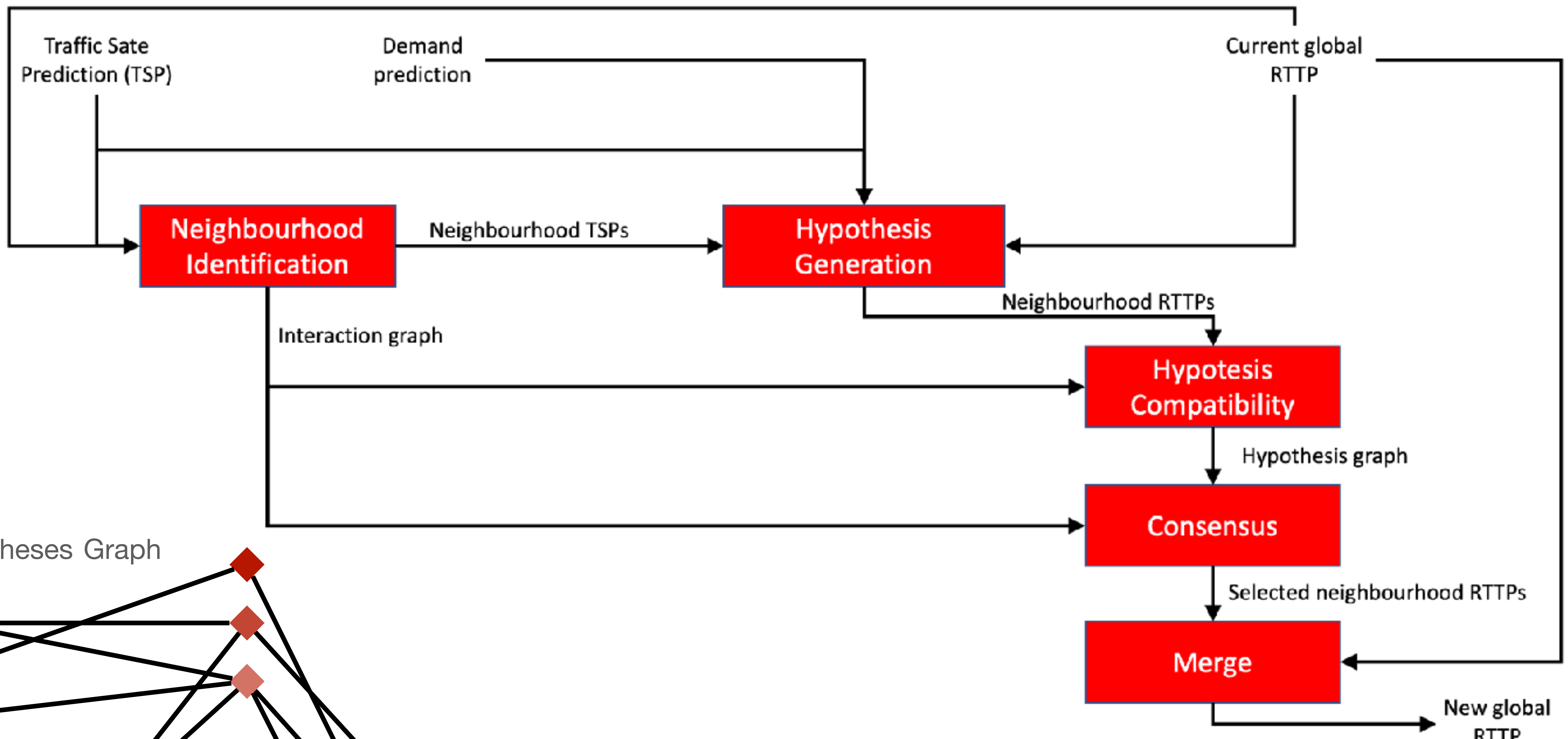

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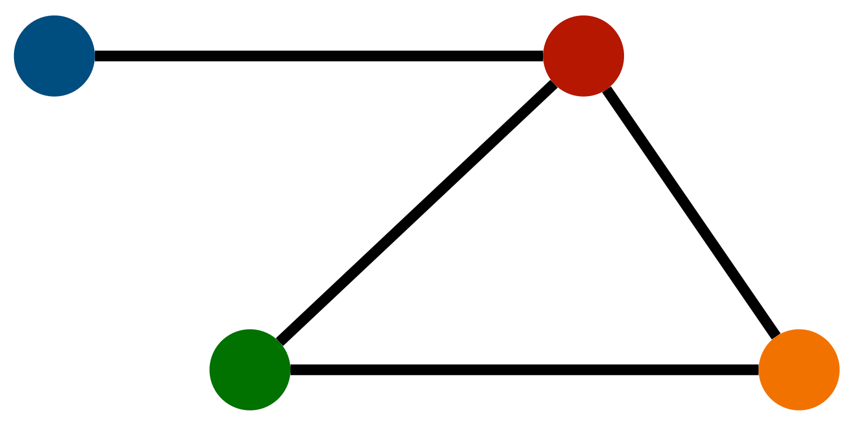

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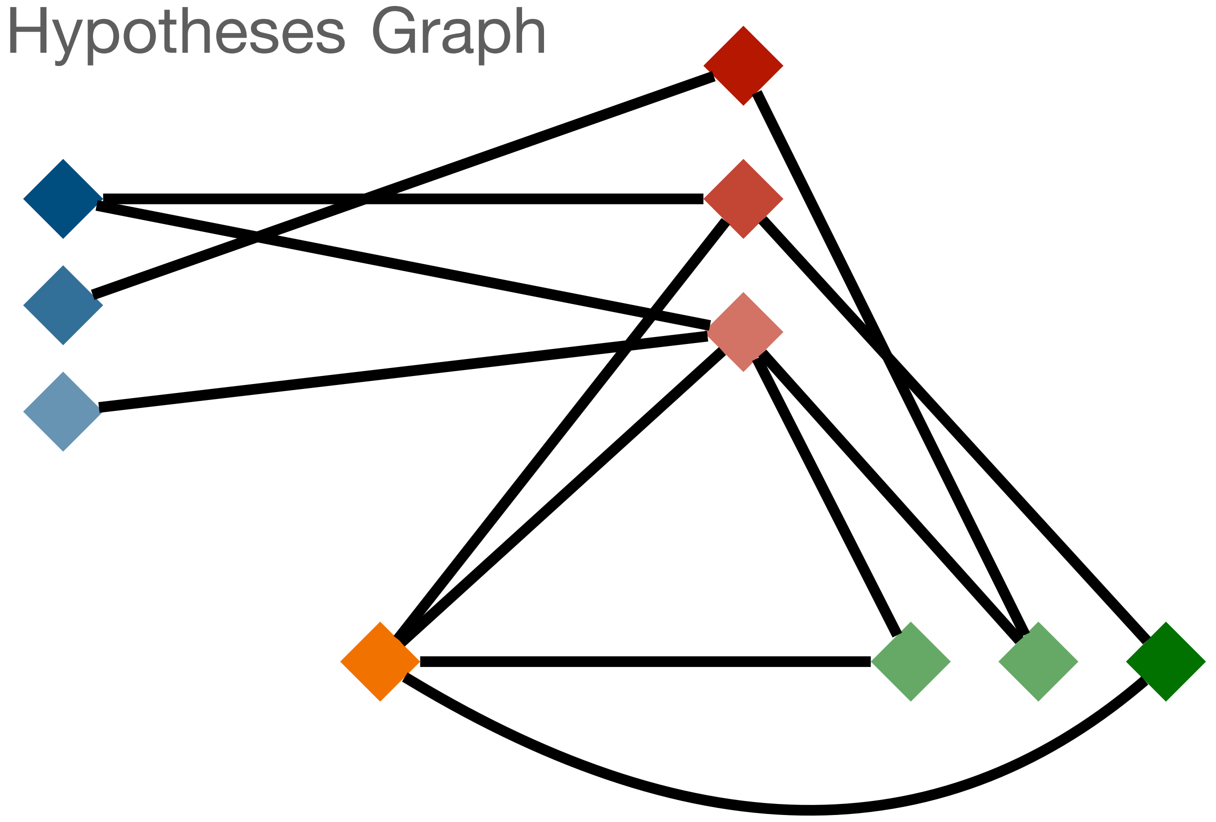

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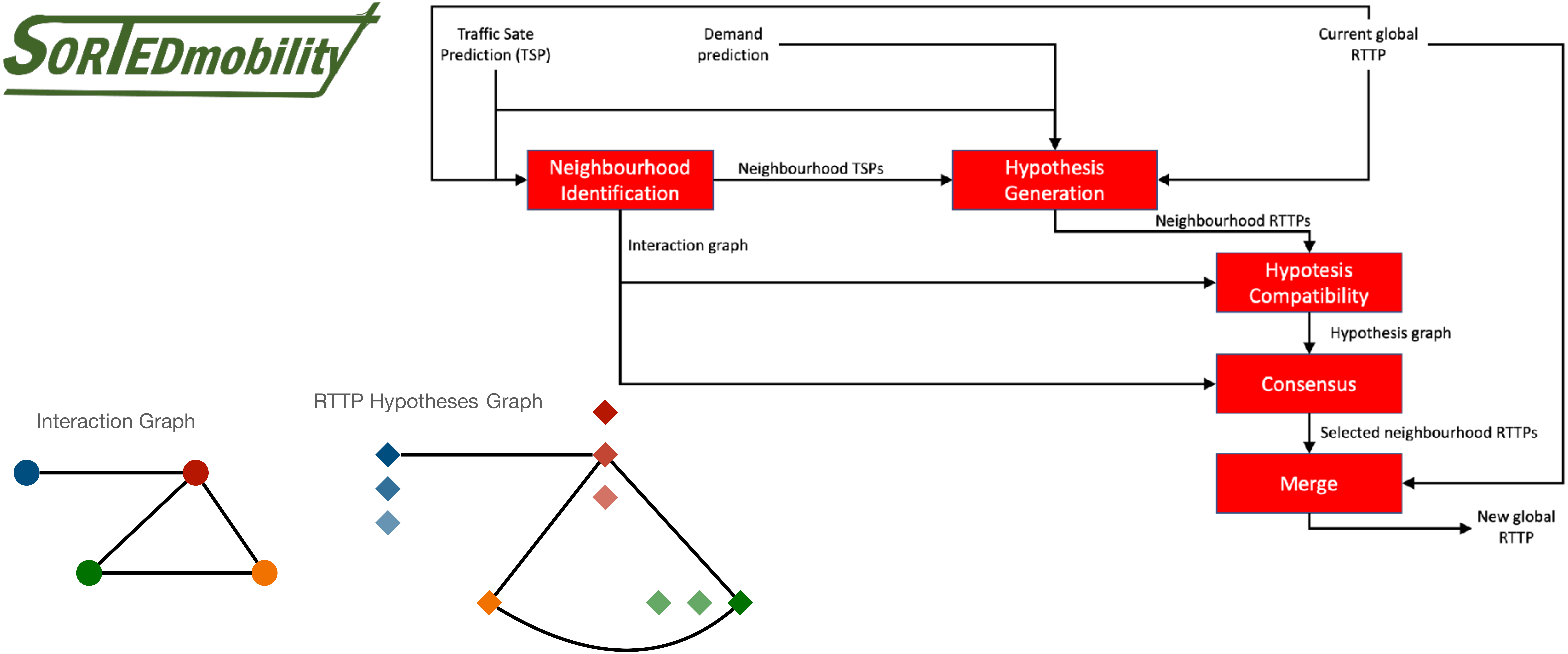

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Neighbourhood Selection

detecting interactions among trains

- Two trains interact if they may use the same track within a given time horizon
  - Consider all trains that will be in the area within the time horizon
  - Consider all possible routes of these trains, limited to the time horizon
  - Check for trains that may pass through the same track
- Choosing the best time horizon is crucial

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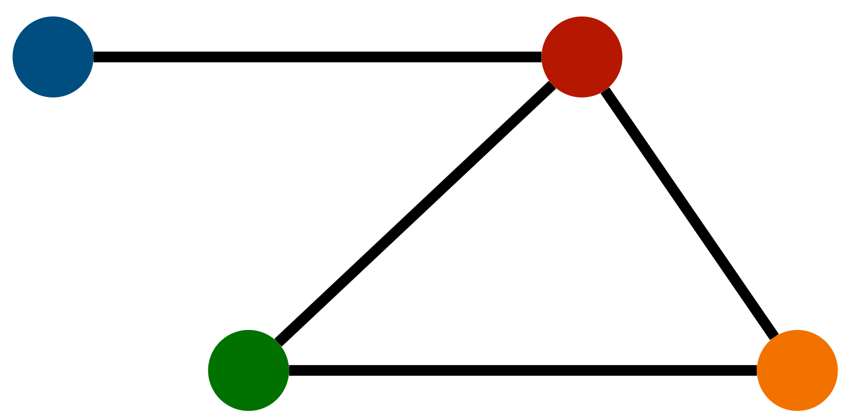

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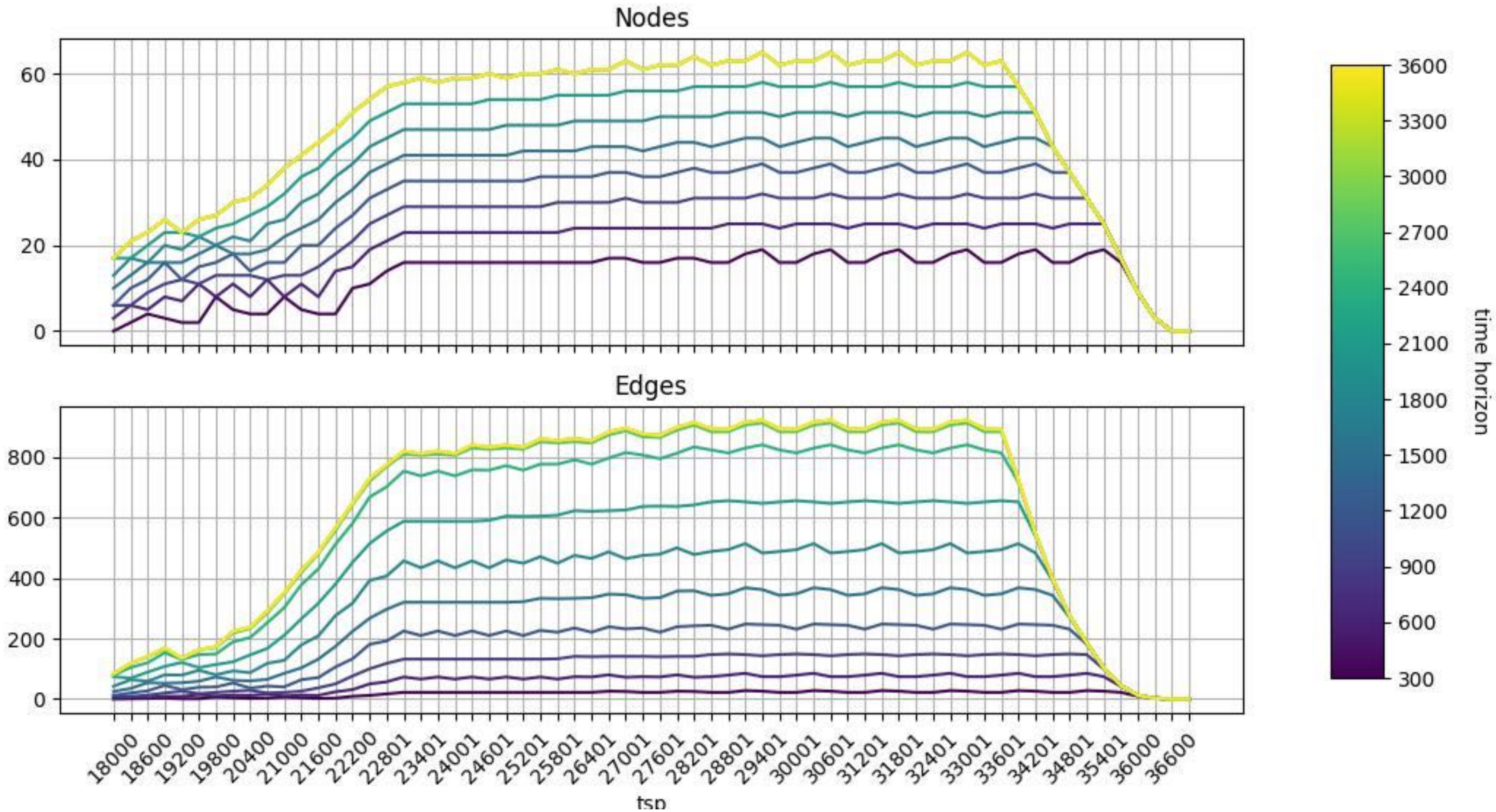
Effects of varying time horizon



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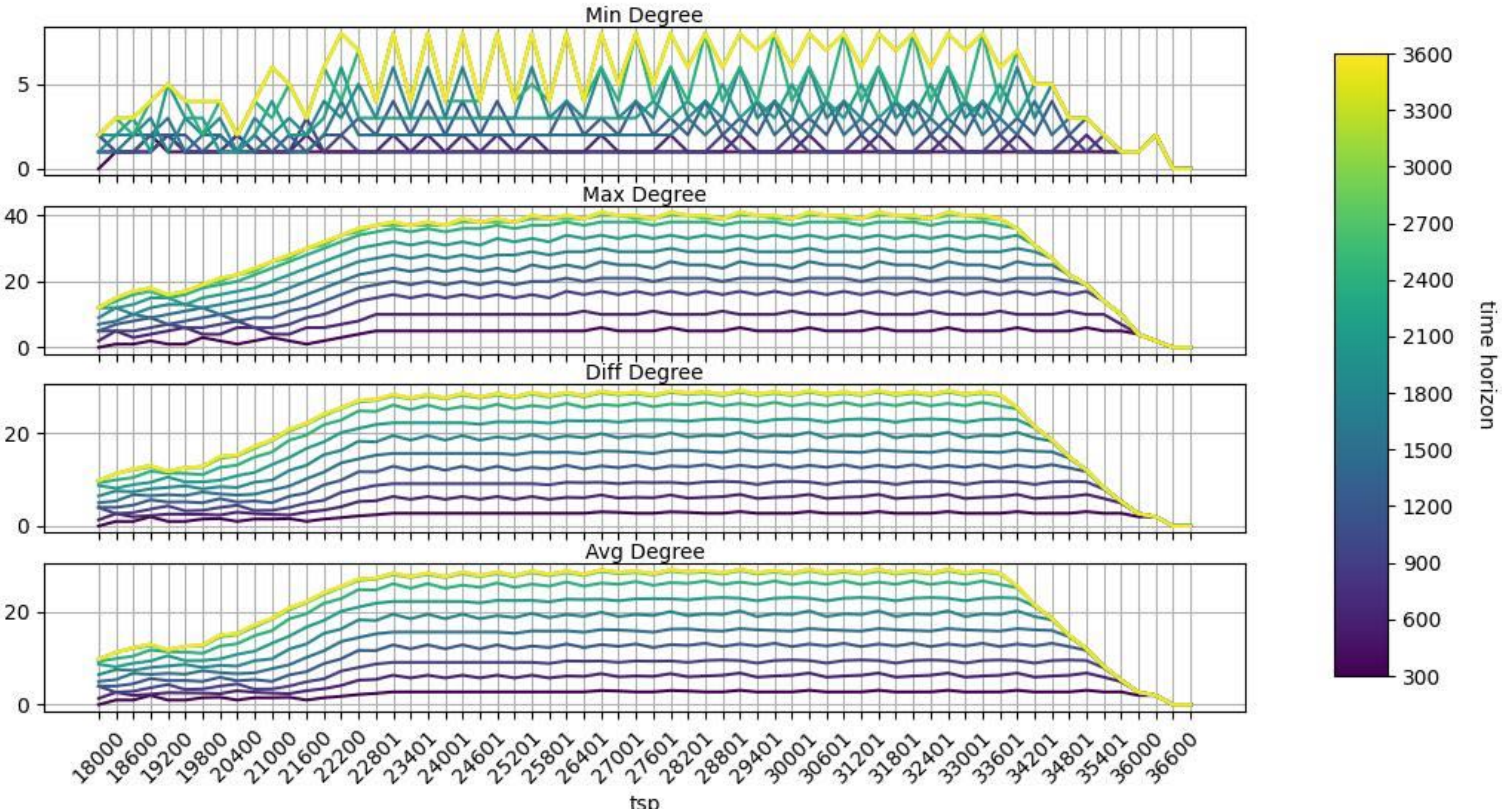

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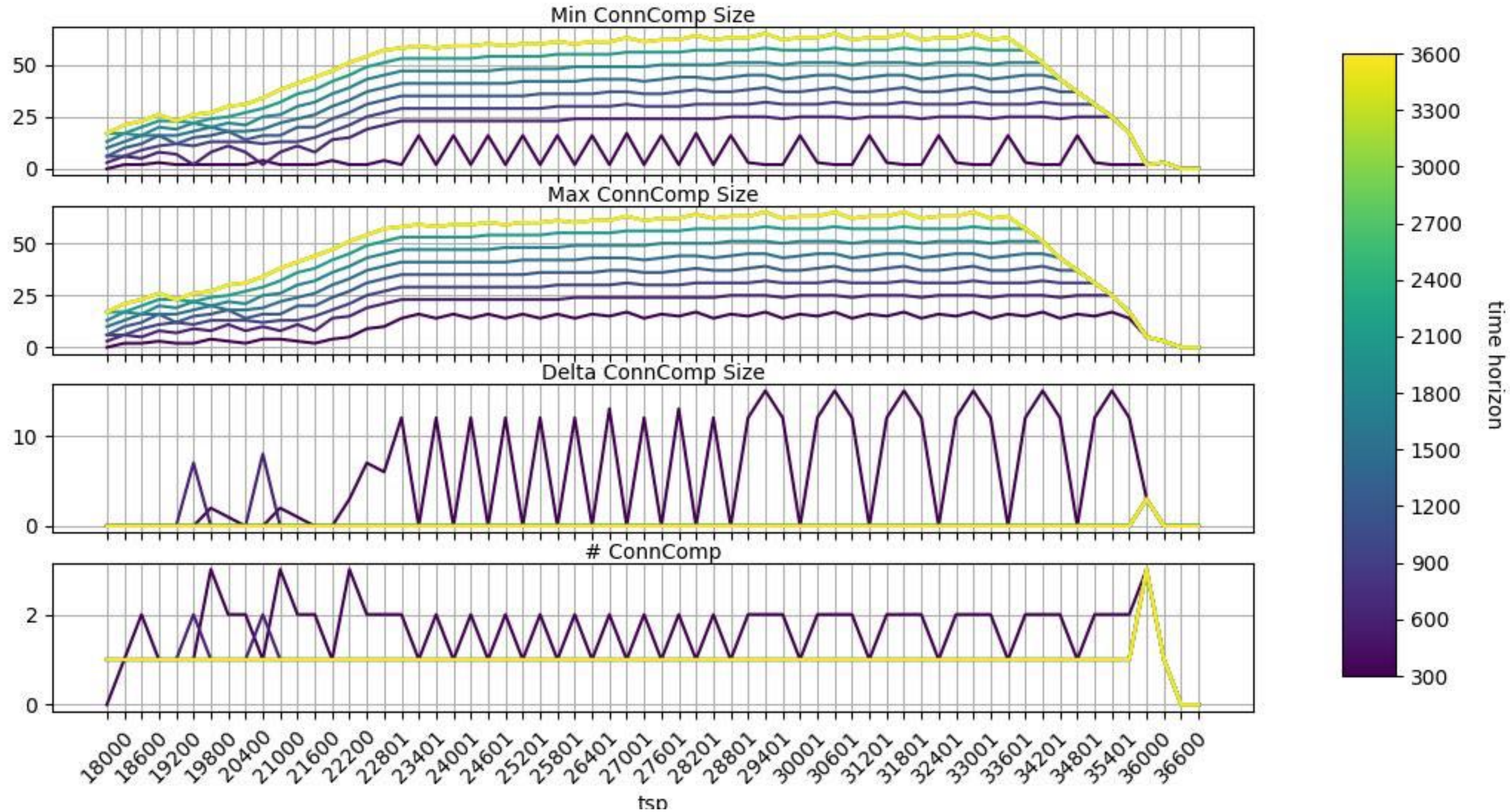
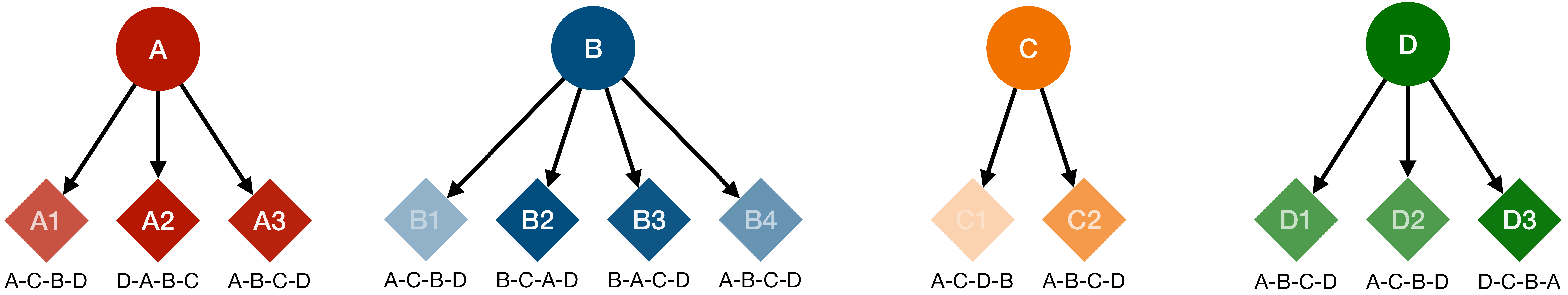


Hypothesis Generation

producing alternative solutions

- Each train independently solves a local traffic management problem exploiting a custom version of RECIFE-MILP
  - The focal train may weight differently from other trains in the objective function
  - Passenger demand is considered at this stage
  - Only trains belonging to the neighbourhood are optimised



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- One or more different solution hypotheses are produced
  - Retain only solutions within a certain margin from the optimal one
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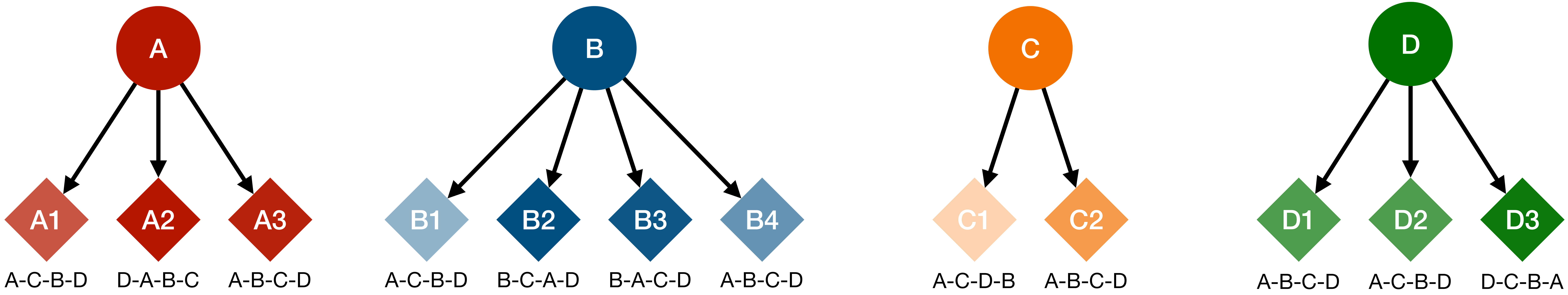

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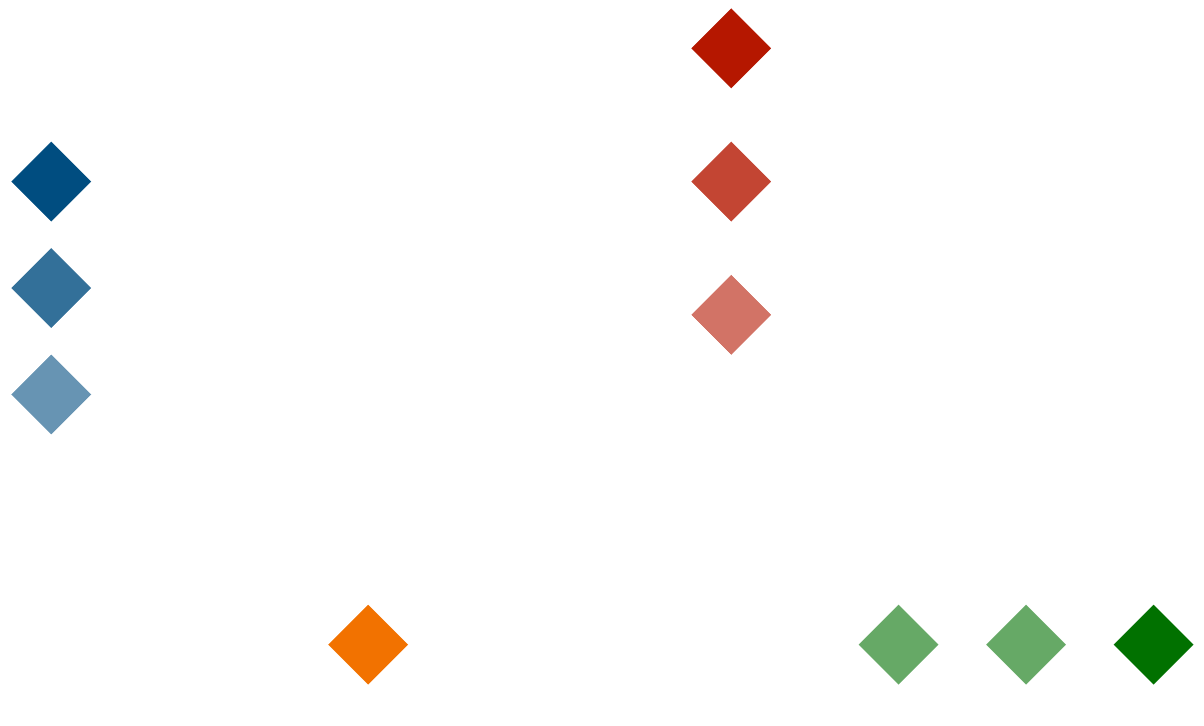
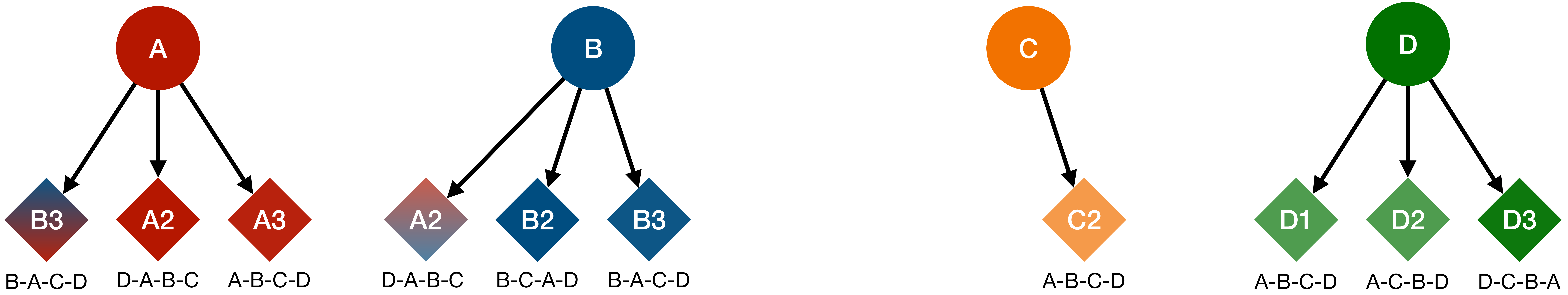
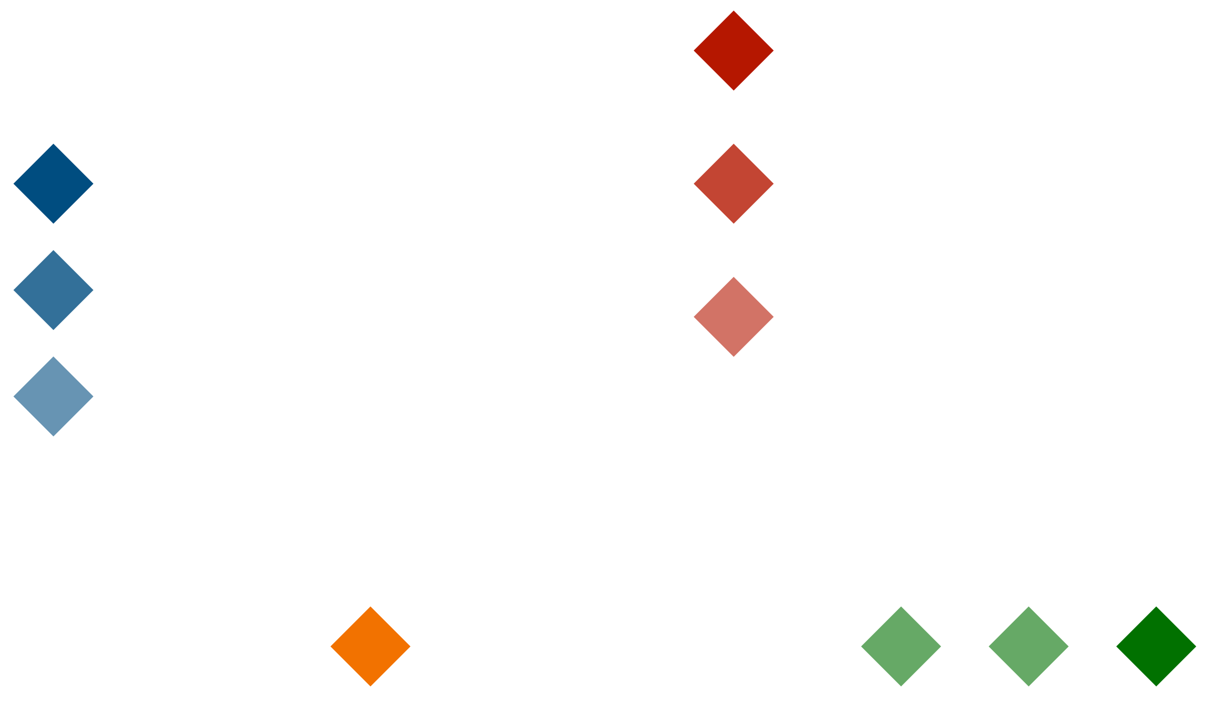




Hypothesis Compatibility

can different get merged without conflicts?



- Pairwise evaluation of hypothesis of different trains
- Compatibility strength: how strict is the evaluation?
  - **Strong compatibility**: require that all trains have compatible paths
  - **Weak compatibility**: require that focal trains have compatible paths
- Compatibility outcome: how to create the hypothesis graph?
  - **Binary compatibility**: graph edges exists or not
  - **Continuous compatibility**: weighted edges in the graph
- Current solution: **weak** and **binary**

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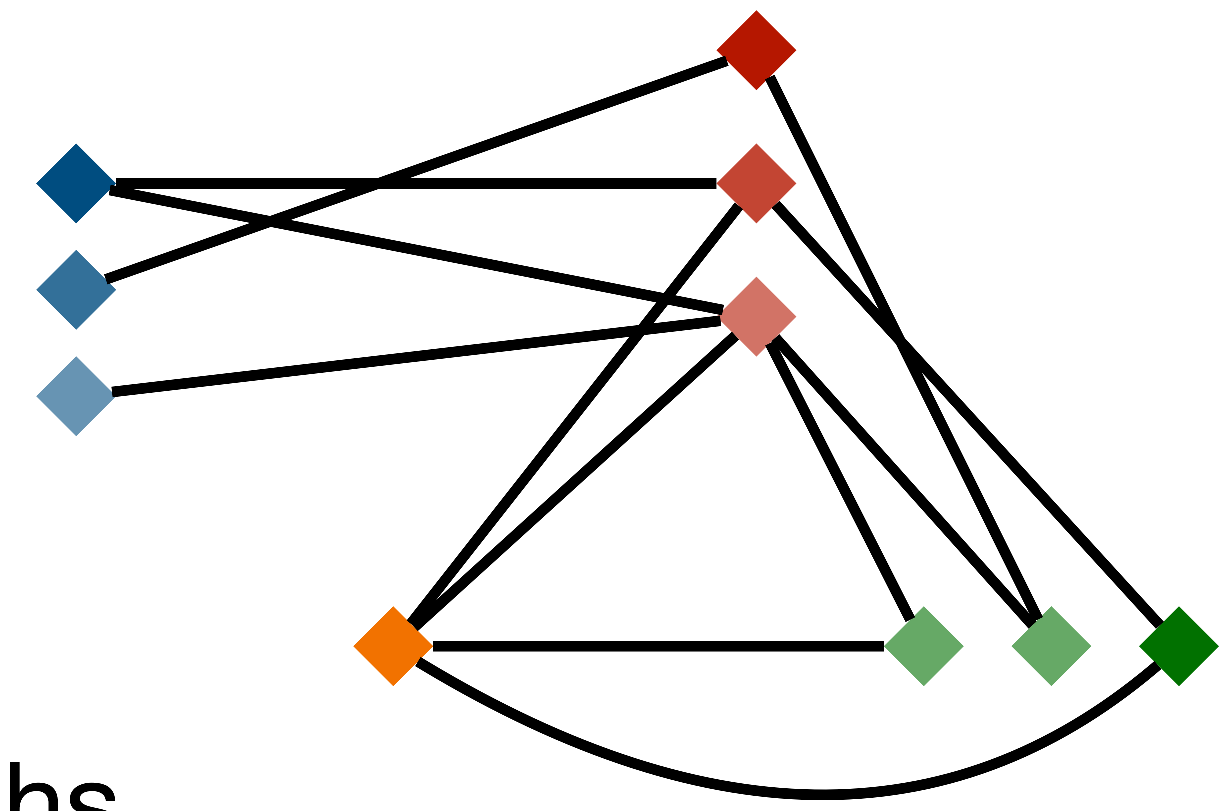

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Consensus
how to select the best set of hypotheses?

- Given knowledge about hypothesis compatibility, find a global solution
  - each train selects an hypothesis compatible with the one of the neighbours
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- A solution is a subgraph of the hypothesis graph
- SORTEDMOBILITY:
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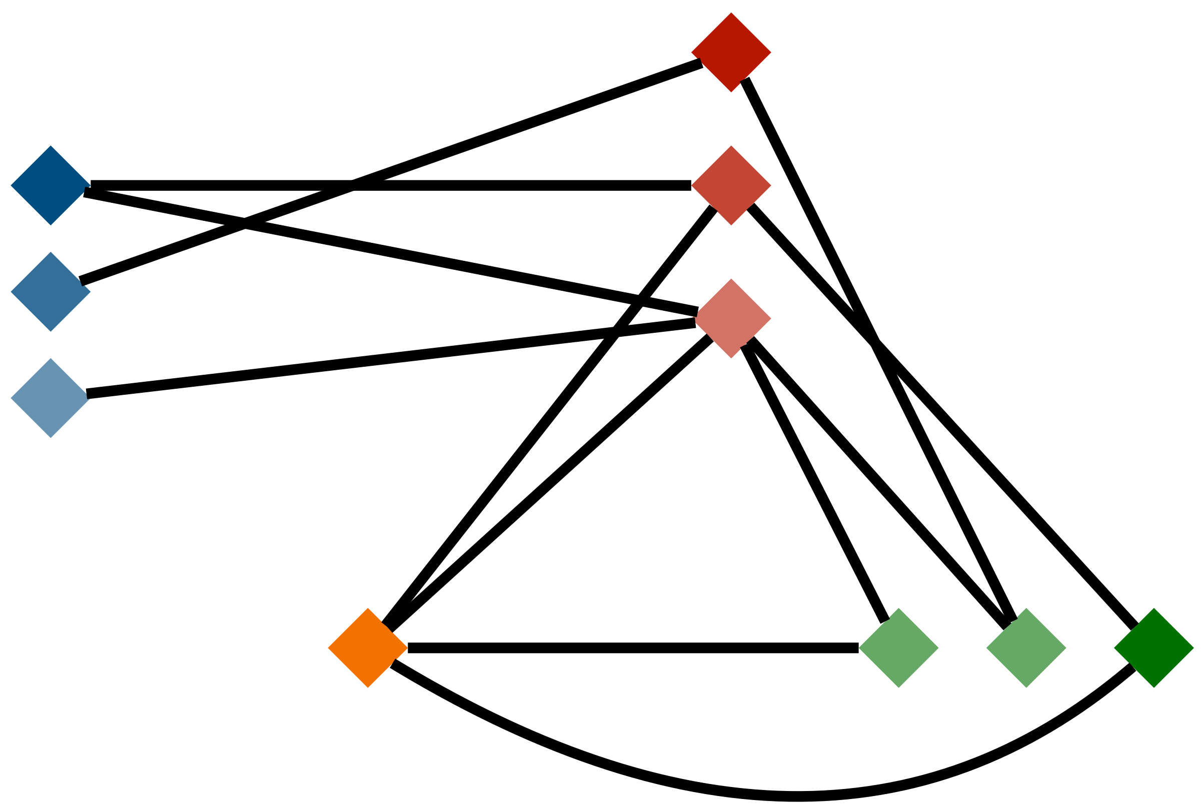

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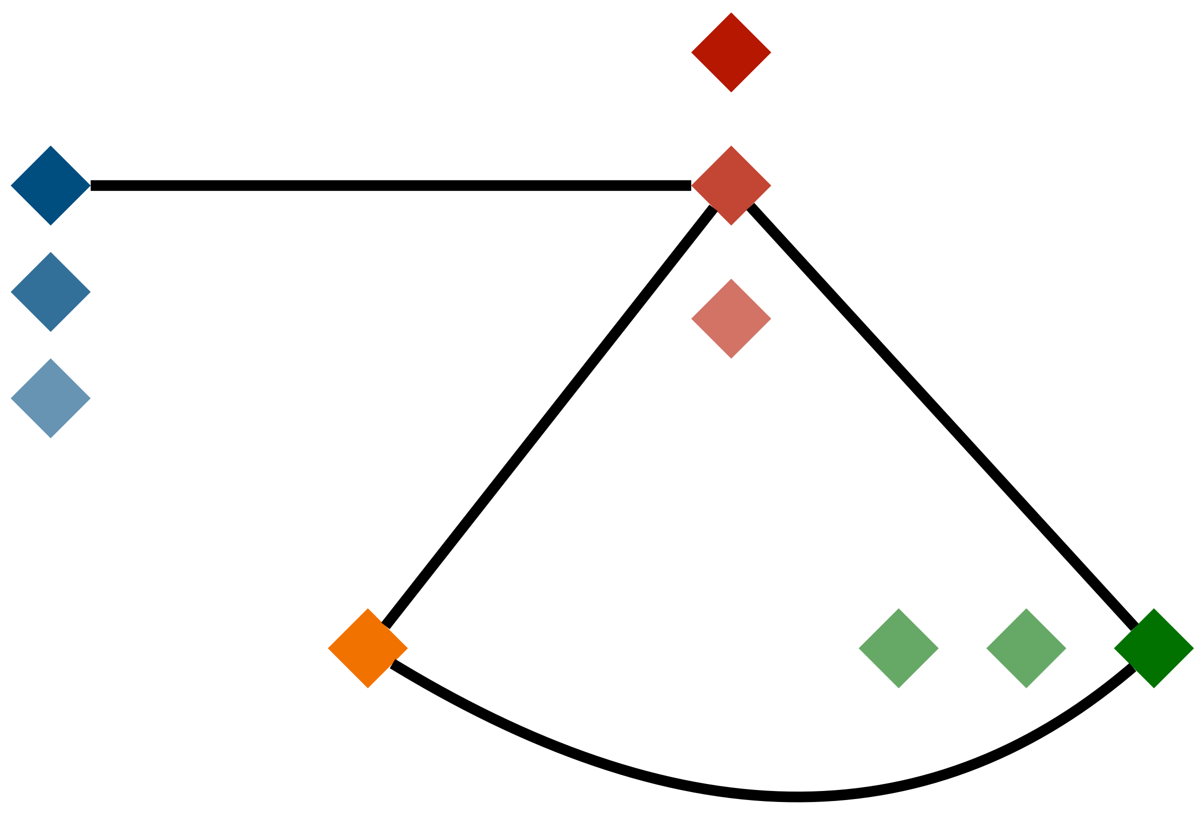

Consensus

iterative stochastic decentralised algorithm

- Train t selects hypothesis $h_t \in H_t$
  at start, select its best hypothesis h_t^*
- Train t selects a subset $\mathcal{N}'_t$ of k neighbours
  $(|\mathcal{N}'| = k)$
- Train t ranks its hypotheses in H_t for compatibility with $\mathcal{N}'$
- If h_t is a top-ranked hypothesis, keep it
- Otherwise, chose a top-ranked hypothesis proportionally to its utility $u(h_t)$

Consensus

results on abstract problem instances

- We test three different implementations
  - $k = 1$: only choose a single neighbour at a time
  - $k = \infty$: always choose all neighbours
  - k adaptive: start with ∞ and slowly decrease to 1
- Convergence when a global solution is found (absorbing state)
- Goals:
  1. Select the best global solution
  2. Minimise the time to convergence

Consensus

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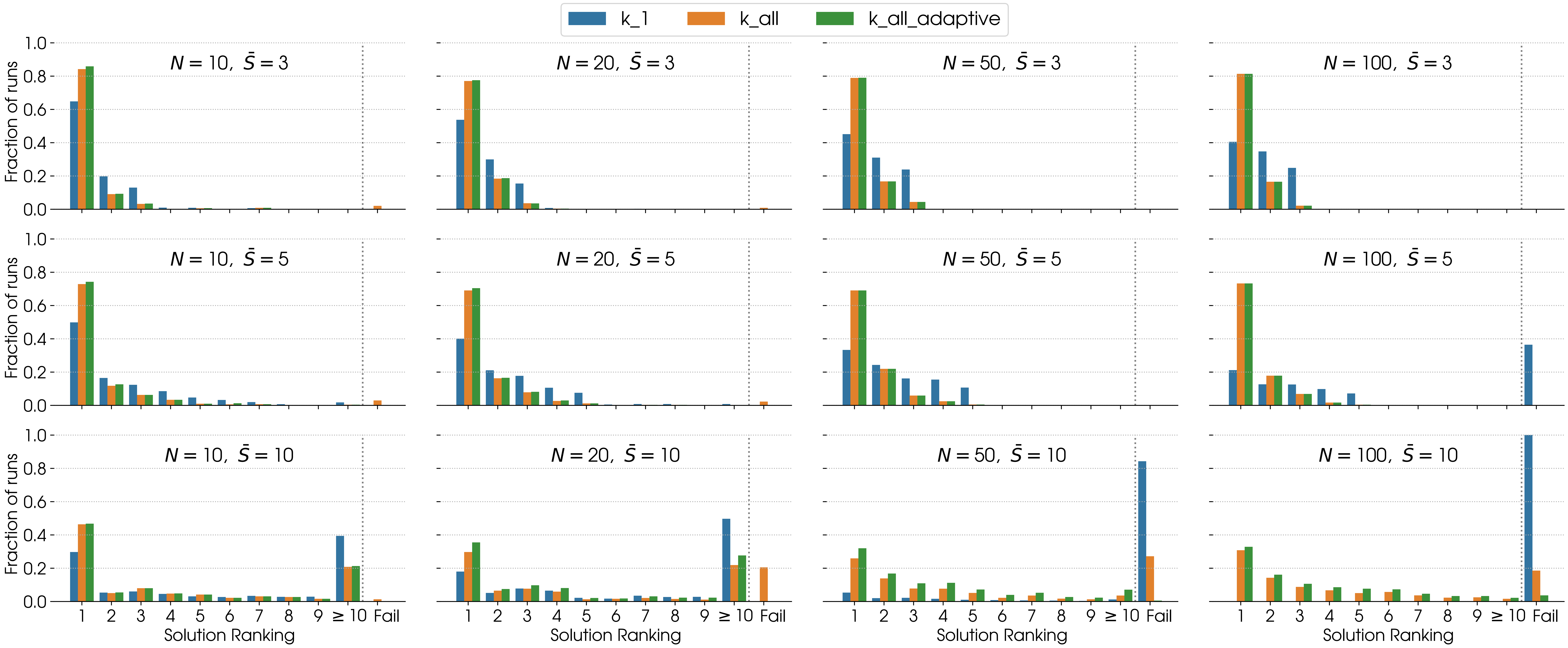

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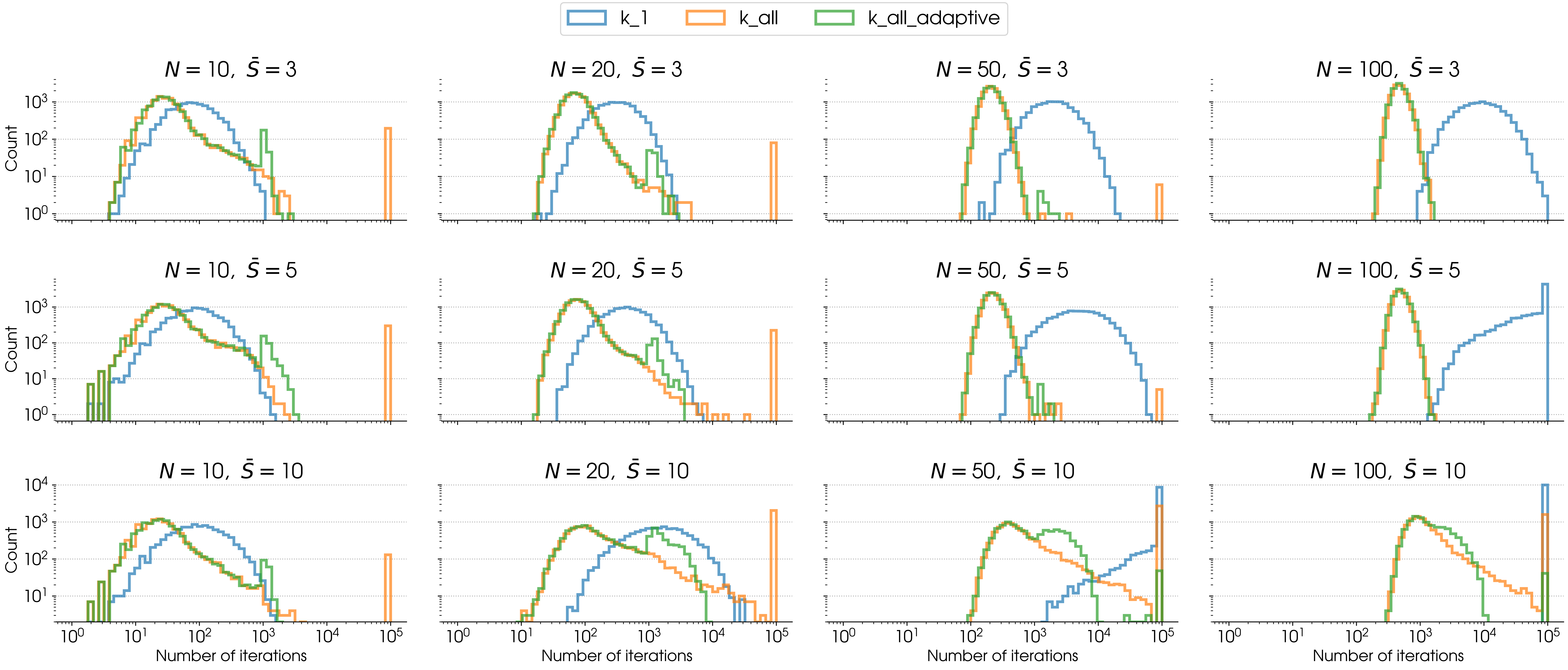
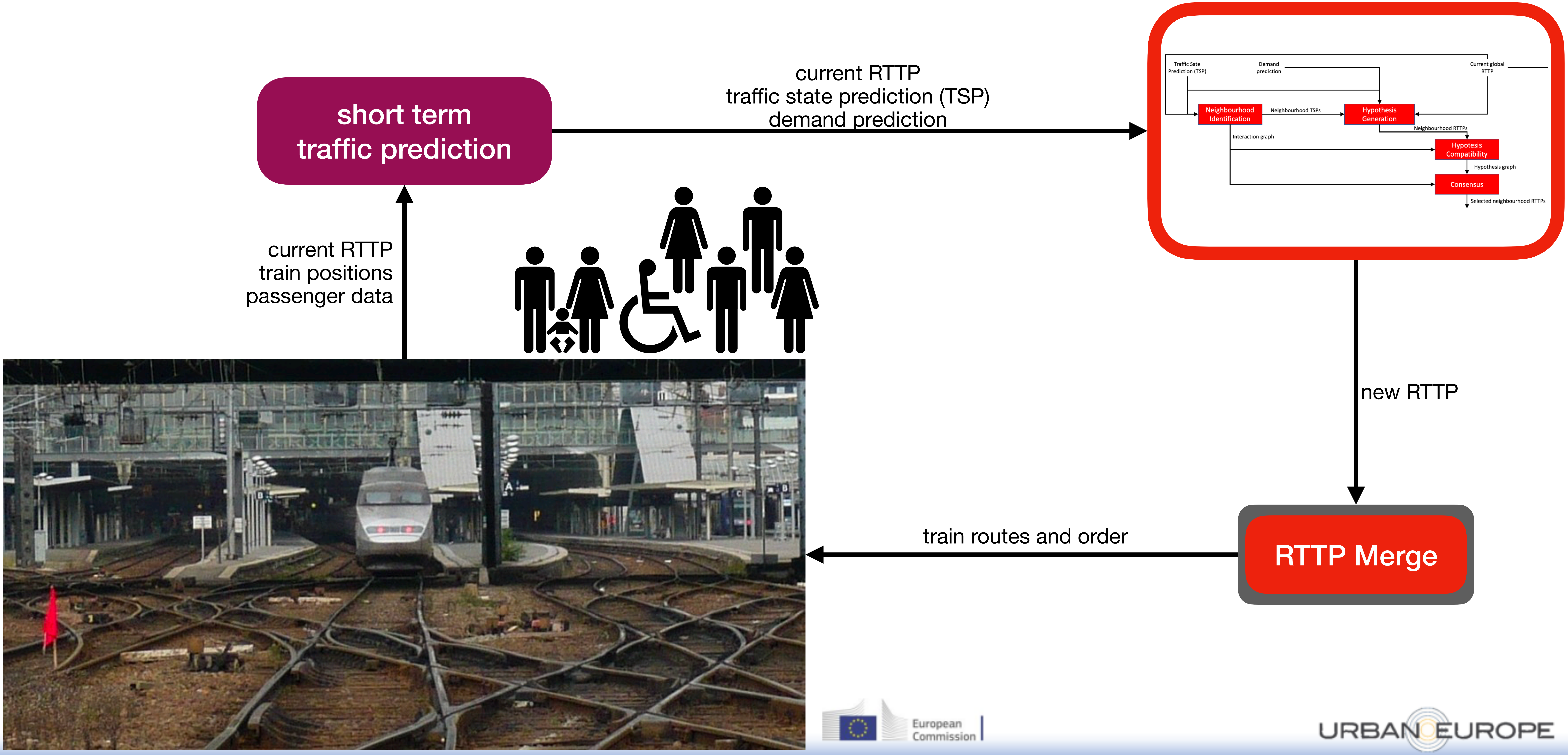


Merge

how to generate a global RTTP

- After consensus, each train proposes an hypothesis (RTTP)
- All hypotheses are merged to create a new, well-formed, RTTP
- The merge process is centralised at the train control center
  - The path of each train t is extracted from the selected hypothesis h_t
  - All previous paths are replaced by the new one into the RTTP
  - If consensus is not achieved (or partially achieved), the previous paths remain valid
- In the unlikely case that the merge process produces incompatibilities in the long term, these are repaired centrally

Closed-Loop Traffic Management



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Thanks for your attention!

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