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Project report

Designing Effective Coordination Mechanisms for Combined Freight Transport

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1. Introduction

Switzerland's freight transport system is set for significant growth, with projections indicating a 31% increase in goods transport volume by 2050 (ARE Federal Office for Spatial Development, 2022). This surge presents challenges for existing road and rail infrastructures that are already operating near capacity. It also sets up the context for new entrants in the market, such as innovative freight solutions like Cargo Sous Terrain (CST), a logistics system designed to alleviate road traffic by transporting goods through underground tunnels. CST aims to connect Switzerland's key centres, relieving the load on rail and road at critical points, reducing environmental impact and ensuring fast delivery of goods.

In terms of expected freight volume, the Swiss Transport Outlook 2050 (ARE Federal Office for Spatial Development, 2022) outlines four scenarios for the future of passenger and freight transport, considering factors such as population growth, economic development, and technological advancements. These scenarios provide a framework for understanding potential demand shifts and are a basis for developing effective coordination mechanisms for combined (intermodal) freight transport.

This report examines the current state and future developments of Switzerland's freight transport system, emphasising intermodal transport. By analysing demand data from the Swiss Transport Outlook 2050, we derive four future demand scenarios and model three supply sources, namely road, rail, and Cargo Sous Terrain (CST), to assess their capacities and interactions using an agent-based simulation model. This approach provides a detailed examination of intermodal competition across the network, allowing freight entities to select modes, schedules, and routes, facilitating the analysis of spatial and transshipment influences.

Intermodal transport, involving combined road and rail use within the same journey, capitalises on each mode's strengths: the flexibility of the road network for first- and last-mile segments and the efficiency of rail for long-haul transit between terminals. In particular, we assess the effects of a new innovative logistics solution, the Cargo Sous Terrain network, which also relies on road transport for the first- and last-mile segments. For trips where origins or destinations lack direct rail or underground access, trucks are used for initial and final legs. By optimising variables such as trip distance, proximity to terminals, cargo schedules, and cost factors, intermodal transport can substantially reduce shipping costs compared to road-only options.

With CST joining road and rail to create a cohesive, multimodal network, this study's simulation enables a better understanding of Switzerland's evolving transport infrastructure, exploring how coordinated efforts and strategic investments can enhance the efficiency, reliability, and cost-effectiveness of intermodal freight transport.

2. Goals & approach

The primary objective of this research is to explore the integration of intermodal freight transport within Switzerland's logistics network, with a particular focus on the potential role of Cargo Sous Terrain (CST). By analysing future demand scenarios derived from the Swiss Transport Outlook 2050, the study aims to evaluate how various supply concepts—road, rail, and CST—can accommodate projected freight volumes. This involves conducting sensitivity analyses to understand the capacity and efficiency of different transport modes under varying conditions, thereby identifying opportunities for coordination and optimisation in the intermodal freight transport system. Some specific goals are:

1. **Assess Future Demand and Supply Dynamics:**

- Utilise Swiss Transport Outlook 2050 data to construct four distinct future demand scenarios for freight transport, emphasising intermodal solutions.
- Model the capacities and interactions of three primary supply modes/concepts (road, rail, and CST) to understand their potential contributions and limitations.

2. **Develop a Detailed Simulation Model:**

- Create an agent-based simulation framework that allows freight entities to autonomously select modes, schedules, and routes, facilitating a microscopic analysis of spatial influences and transshipment processes.

3. **Identify Opportunities and Challenges for Rail Freight:**

- Investigate how Swiss Federal Railways (SBB) can leverage combined and coordinated transport opportunities in planning and operational contexts.
- Analyse the potential for rail freight to remain competitive amidst emerging innovative logistics solutions, such as CST.

4. **Evaluate Coordination Mechanisms:**

- Examine the challenges associated with synchronisation and coordination in planning and operations, particularly concerning the integration of CST.

5. **Provide Strategic Recommendations:**

- Offer insights into how SBB and intermodal logistics services can prepare for and capitalise on future demand scenarios.
- Suggest capacity enhancements to support the sustainable growth of intermodal freight transport.

By achieving these goals, the research aims to contribute to the development of a more integrated, efficient, and sustainable freight transport system in Switzerland, capable of meeting future demands and adapting to emerging technological advancements.

3. Methodology

In this study, we employ MATSim, an open-source, activity-based, multi-agent travel demand simulator (Horni et al., 2016b). MATSim's modular design facilitates the simulation of large-scale scenarios, making it well-suited for our analysis of Switzerland's freight transport system.

Each agent in MATSim represents an individual entity (a standard Twenty-foot Equivalent Unit container TEU) with a daily activity plan that includes an origin, a destination and a departure time. The iterative simulation framework enables agents to optimise their plans based on a scoring function, balancing trade-offs in route choice, mode selection, and timing. The evaluation and optimisation of plans are based on utility functions that incorporate both generalised costs and

penalties. The methodological extensions to the previous cargo train setup, as described in Kaddoura et al. (2024), are publicly available on GitHub (https://github.com/matsim-scenarios/matsim-switzerland-freight/, release v1.0) and form the foundation for the simulation setup in this study, including the introduction of the innovative CST mode.

The iterative simulation framework comprises three key steps (Kaddoura et al., 2024):

- Mobility Simulation: Agents execute their daily plans simultaneously, interacting within the transport network. This includes modelling road traffic congestion and capacity constraints. MATSim utilises a time-step-based approach to simulate queuing dynamics, where road segments function as First-In-First-Out queues with defined outflow rates and storage capacities. For scheduled services, such as rail and CST, agents may experience boarding denials if vehicles reach capacity, requiring them to wait for subsequent services.
- Plan Evaluation: Post-execution, each agent assesses their plan using a generalised cost function that accounts for travel distance and time, monetary expenses, and adherence to departure and arrival time preferences.

Learning: In each iteration a subset of agents is allowed to modify their existing plans, exploring alternatives in route choice, mode selection, and departure times. These new plans are evaluated in subsequent iterations, while other agents select the highest-utility plan from their existing set for re-evaluation. This iterative refinement guides the system toward a user equilibrium.

To adapt MATSim for freight transport analysis, we introduced specific modifications:

- Customised Scoring Function: we replaced MATSIM's default plan evaluation with a scoring mechanism tailored to freight logistics (Kaddoura et al., 2024). This function rewards plans that achieve on-time deliveries within specified windows and penalises those with early departures or late arrivals, aligning with supply chain time constraints.
- Intermodal Terminal Integration: the simulation connects road, rail and CST networks via intermodal terminals (rail) and hubs (CST), facilitating transitions between transport modes.
- Freight-Specific Routing: MATSim's public transit routing module (SwissRailRaptor) was adapted for the freight context. Container agents are routed across networks, considering detailed network attributes such as distance, travel time, congestion, terminal/hub locations, and train/CST schedules.

The scoring functions reflect the operational costs of freight transport, including distance-based (s) monetary costs depending on the mode ($c_{s,<mode>}$), and time-dependent penalties for early departure (c_e) and late delivery (c_l), as well as rewards for on-time arrival (c_r). The utility functions, $V_{<mode>}$, combine these elements, where distance-based costs provide a baseline layer of evaluation, while penalties for timing deviations dominate the decision-making process. In the simulation, absolute costs for each transport mode are irrelevant; only the cost ratios matter, as entities make choices based on the relative percentage that one mode's cost represents compared to another. The time constraints are defined relative to a baseline road-only scenario, i.e. in the first iteration, all entities choose road-only, where the initial departure and arrival times establish the benchmark for succeeding iterations. A configurable tolerance enables minor deviations without incurring penalties. For instance, setting a three-hour tolerance ensures that deviations within this window are exempt from penalties, allowing distance-based costs to become the primary determinant in the scoring process. Equations (1)-(3) show the scoring functions applied in the simulation model. The index $road$ refers to the road only transport, $roadIM$ refers to the road leg of the intermodal transport trip (before and/or after a rail or CST main leg), and the indexes

$rail$ and cst refer to the rail and CST leg of the intermodal transport trip, respectively. Finally, d denotes a binary variable with index l for arriving later than the desired arrival time window, index e for departing earlier than the desired departure time window, and index r for arriving within the desired arrival time window.

$$V_{road} = -c_{s,road} \cdot s_{road} - d_l \cdot c_l - d_e \cdot c_e + d_r \cdot c_r \quad (1)$$

$$V_{IM_rail} = -c_{s,roadIM} \cdot s_{roadIM} - c_{s,rail} \cdot s_{rail} - d_l \cdot c_l - d_e \cdot c_e + d_r \cdot c_r \quad (2)$$

$$V_{IM_cst} = -c_{s,roadIM} \cdot s_{roadIM} - c_{s,cst} \cdot s_{cst} - d_l \cdot c_l - d_e \cdot c_e + d_r \cdot c_r \quad (3)$$

Routing decisions, modelled in MATSim's iterative process, use a simplified utility approximation for plan generation. This approximation excludes the arrival and departure time preferences/penalties. Instead, it only considers an expected travel time derived from past iterations (excluding delays). Additionally, a random factor is added to these routing utilities to increase or decrease the distance-based costs, guaranteeing a diverse set of transport routes for each agent. These routing options are evaluated against the scoring function, which accounts for individual preferences and system constraints, ensuring that only high-performing routes are retained in the agents' choice sets.

The simulation's sensitivity to changes in parameters such as tolerance levels, infrastructure capacities, and cost coefficients highlights the flexibility of the model. For example, enhancing terminals' capacities or increasing tolerance against delays impacts network performance and equilibrium outcomes, as will be explored in the sensitivity analysis. By incorporating the role and the time-distance conditions of the agents within each shipment, the model also captures the shipment requirements. This dynamic interaction between cost components, penalties, and operational constraints in an environment where entities have autonomy to choose mode, route and time make the model suitable to evaluate various freight transport scenarios.

To provide a clear structure for the paper, the following sections are organised as follows: Section 4 presents the development of the demand model, detailing the data sources, processing steps, and assumptions. Section 5 describes the supply-side elements, including network configurations and service definitions for road, rail, and the underground logistics system. Section 6 outlines the simulation experiments, focusing on the scenarios, parameters, and configurations used in MATSim. Finally, Section 7 discusses the results, providing insights into the impacts of intermodal freight transport and their implications for Switzerland's transport landscape.

4. Transport Demand

The transport demand for this study is based on the Swiss Transport Outlook 2050 for freight transport. This outlook provides projections for future freight flows in Switzerland, structured around four main scenarios:

- Basis Scenario: involves a set of transport policy measures that favour sustainability and resource-efficient mobility and includes a noticeable shift in freight traffic from road to rail, driven by political instruments such as the heavy goods vehicle charge (HGVC). Rail freight transport also benefits from a bundling of freight flows.
- Individualised Society (ITG): transport is strongly impacted by technical innovations, including widespread automation and digitalisation in freight logistics; road and rail operate at low cost with increased volume.

- Sustainable Society (NTG): transport is strongly impacted by technical innovations, but technologies are used for sustainability and resource conservation. The HGVC helps to shift a considerable proportion of freight traffic onto the railways (compared to ITG).
- Business-as-Usual (WWB): assumes a continuation of current trends in economic development and transport technology. No major technological breakthroughs or policy shifts are included.

These scenarios differ in terms of their assumptions about technology adoption, economic growth, and policy interventions, affecting the volume and nature of freight flows. Figure 1 shows the total expected freight volumes for road and rail for each scenario of the Swiss Transport Outlook.

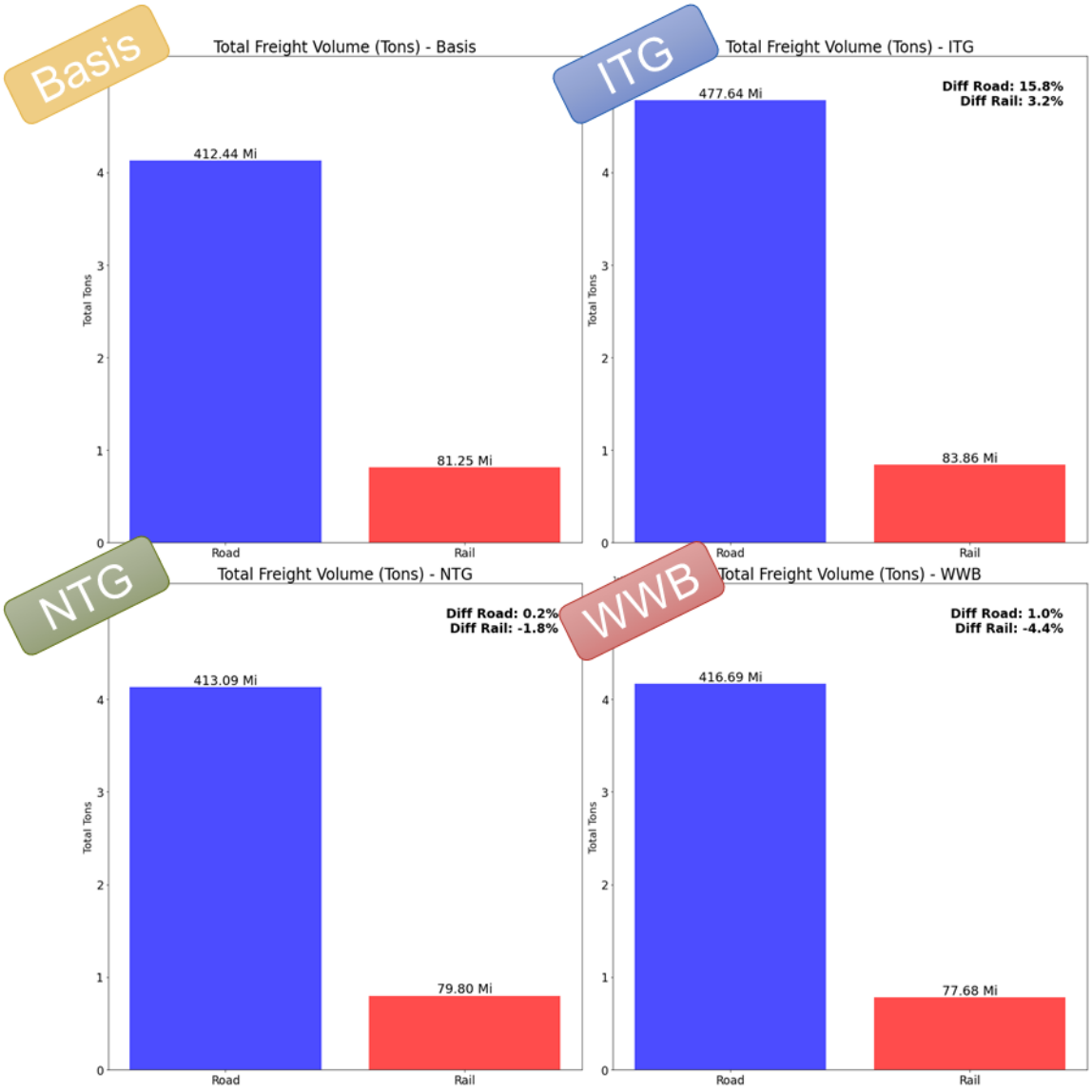

Figure 1 - Total Yearly Merchandise Volume by Road and Rail (Swiss Transport Outlook 2050)

The labels on top of the bars show the expected volume for that mode of transport over a year (all merchandise groups), and the annotations on the top right of the panels show the percentual difference to the volume in the Basis scenario. In terms of volume, the technological scenario ITG

has the highest projected total volume (561.5 Mio Tons), the highest relative share for road (about 85%) and an increase of 15.8% in road freight volume compared to the Basis scenario. The Basis scenario, which will be the baseline for this study, has a total of 493.69 Mio Tons, with rail corresponding to about 16.46% of the share and the lowest road freight volume numbers among all scenarios.

The *Aggregierte Methode Güterverkehr* (AMG) (ARE Federal Office for Spatial Development, 2019a, 2019b) was implemented to model and analyse the freight flows aggregated by spatial mobility (MS) regions, totalling 106 possible origin and destination regions. The differences in expected volume per MS region are shown in Figure 2, where purple colours correspond to the lowest volumes, and green-yellow colours represent the highest volumes. For each scenario, the left map represents origin points for freight, whereas the map on the right represents destination regions. The scale is the same across maps for better visualisation. In all scenarios, the regions of Aarau, Basel, Bern, Geneve, Luzern and St. Gallen are demand-intense, with varying volume depending on the scenario, as indicated by different colours. In the ITG scenario, the Aarau, Bern, Geneve and Basel regions appear all in yellow, indicating a high volume of flows into/from these regions.

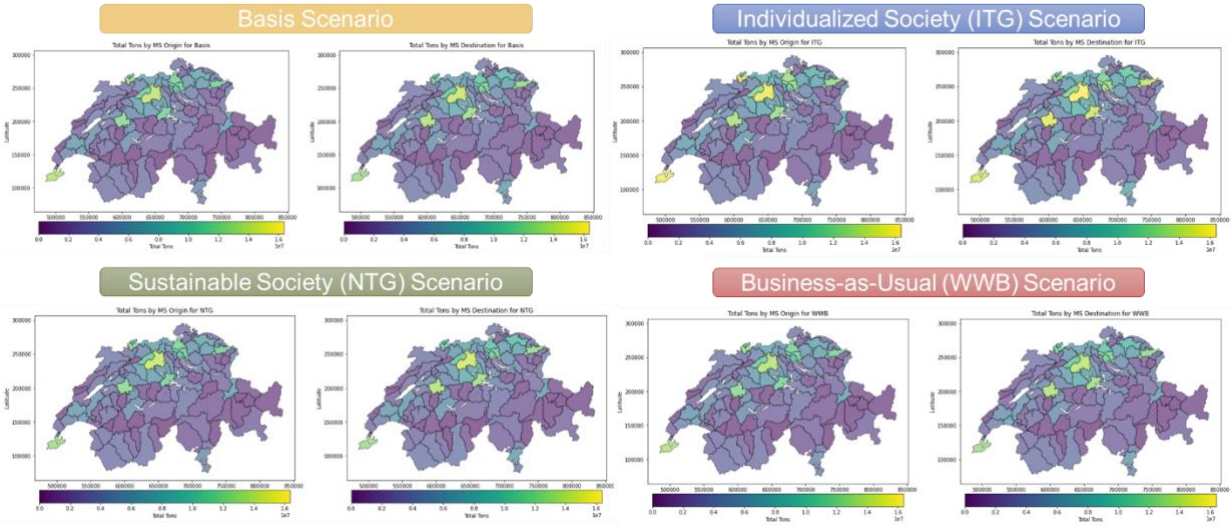

Figure 2 - Differences in volume (Mio Tons) per MS Region

The freight demand relevant to intermodal transport is based on the total projected merchandise quantity for the year 2050 for each of the four scenarios considered. The dataset brings the total quantity in tons for the origin and destination zone pair, the transport type (inland, import, export, transit), the merchandise group and the vehicle type (HGV, light vehicles, etc.). The data was generated by the AMG model with input parameters reflecting ARE's scenarios. The demand per year given by the AMG model is then divided by 250 to obtain the road freight transport demand for a single working day, with freight volumes expressed in Twenty-foot Equivalent Units (TEUs), i.e. each agent/container representing 1 TEU. Freight demand relevant to intermodal transport further narrows the data to (i) inland, import and export goods, (ii) road transport on HGVs only and (iii) exclusion of ores, stones, earth, and energy fuels from the relevant merchandise types. Additionally, a group of empty containers was included to balance flows, i.e. if the OD flow is unbalanced, the direction with fewer containers is supplemented with empty containers to achieve equilibrium. Finally, only OD relations with a minimum beeline distance of 100 km were included,

focusing on significant freight flows for intermodal transport where shorter distances are less relevant. Figure 3 shows the total containers for each simulated scenario (accumulated counts for 3 days) once the filters above are applied to the total annual volume in Figure 1.

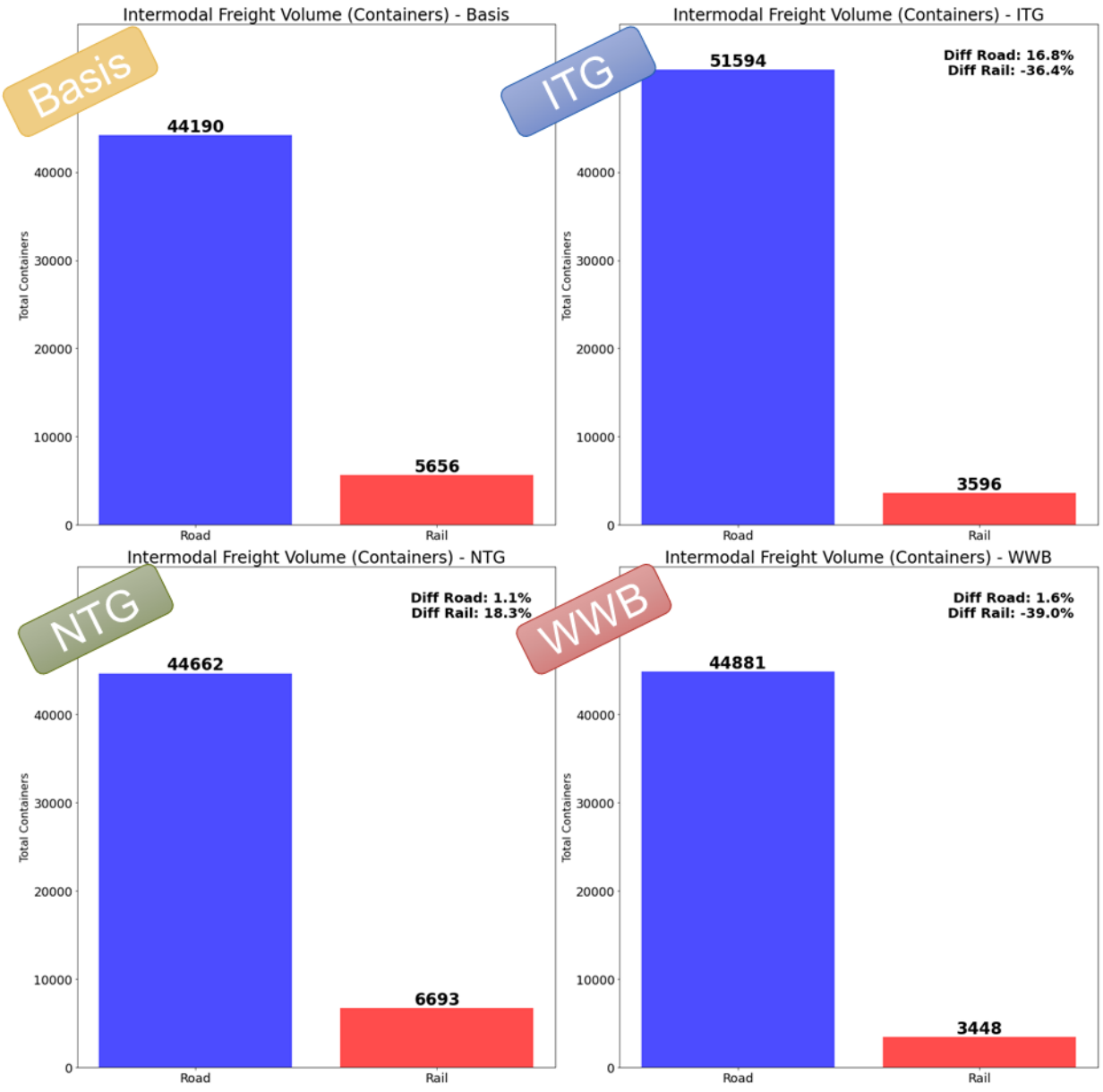

Figure 3 - 3-day Accumulated Containers Volumes for Intermodal Transport (Simulation Total)

5. Transport Supply

A comprehensive representation of transport supply is crucial for capturing the interactions and constraints of Switzerland's freight transport system within a large-scale, national-level network model. The road network includes all roads (links), characterised by detailed attributes such as speed limits, road classifications, and maximum capacity flows. The rail system is represented by a detailed cargo train schedule and train capacities. Intermodal rail terminals are represented by

capacity-constrained queues with predefined operation times. Finally, the underground logistics network introduces an innovative layer to the supply model. This network is represented by a detailed schedule for vehicles and intermodal hubs. The underground tunnel flows are modelled as conveyor belts, where vehicles travel at a constant speed while adhering to space constraints and maintaining a minimum distance between them. This setup ensures that the unique operational characteristics of the underground network are captured, including its efficiency and reliability as a transport mode. To reflect the expected development of this underground system, two supply scenarios are considered: initial and full development, aligning with the planned expansion phases of Cargo Sous Terrain [6]. The remainder of this section outlines the components and characteristics of the transport supply across the three different modes.

5.1. Road

The road network in this research is based on data from OpenStreetMap (OSM, www.osm.org), specifically filtered to include major road types relevant to freight transport, such as motorways, trunk roads, and primary and secondary roads. These road types are represented as links within the network, each with associated attributes such as speed limits, capacity, and the number of lanes. The network was generated using a customised MATSim process, ensuring scalability and precision in simulating freight movements. A schematic representation is provided in Figure 4.

The flow capacities of links are defined based on realistic assumptions of road capacities and traffic flow dynamics. These capacities determine the volume of traffic a link can handle per unit of time and are tailored to represent the functional characteristics of each road type.

Traffic conditions are not modelled explicitly but are dynamically controlled through network change events. These events adjust the flow capacity and number of lanes on specific links over time, simulating congestion or capacity reductions due to various factors, such as restrictions or infrastructure conditions. Finally, it was assumed that each vehicle (truck) could transport 1 TEU.

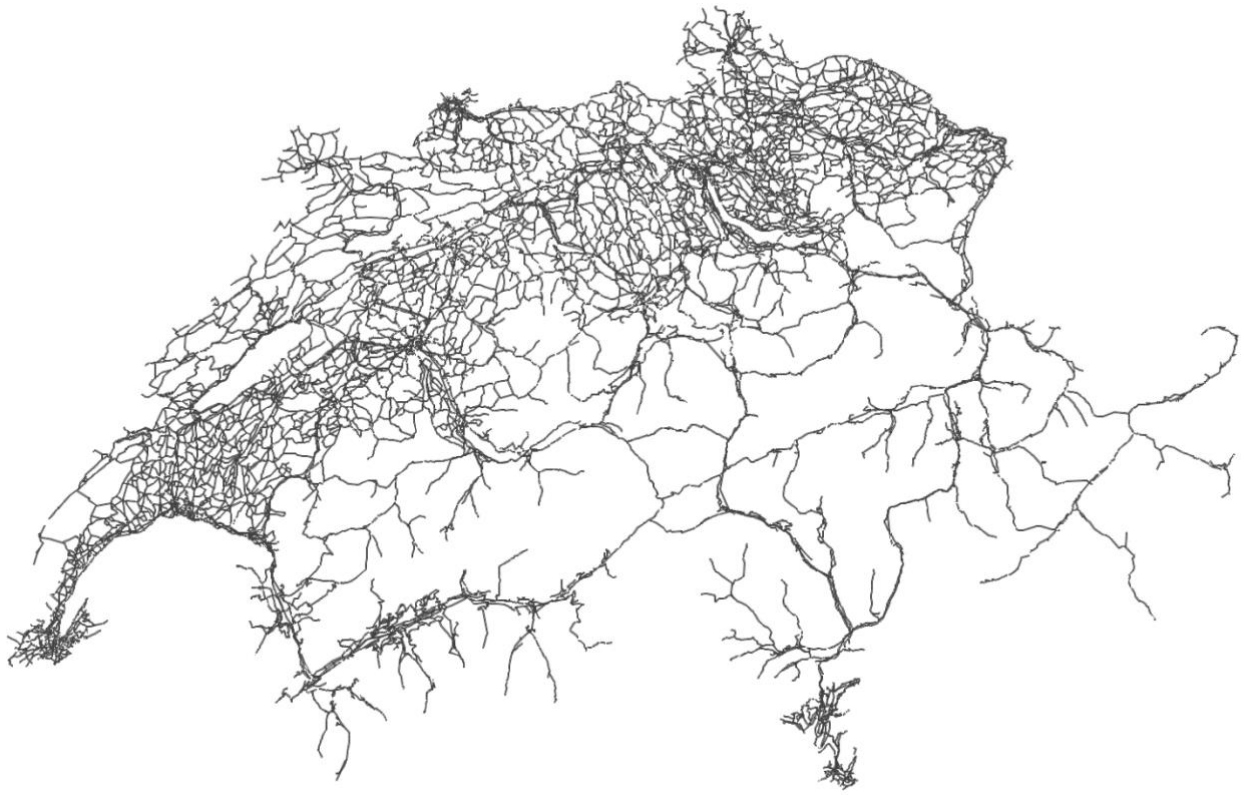

Figure 4 - Road Network based on OpenStreetMap (www.osm.org)

5.2. Rail

The rail supply in this simulation is designed to represent intermodal freight transport at a national scale, incorporating detailed train schedules, terminal operations, and intermodal connections. Cargo trains operate on fixed schedules with a standard capacity of 40 TEU containers (agents) per train. Terminals are modelled as capacity-constrained nodes, where crane operations and train handling times dictate flow rates. Crane links are simulated as First-In-First-Out queues, with their outflow determined by the terminal's crane capacity. For example, a crane requiring one minute to process a container handles 60 containers per hour. If a train reaches full capacity, containers remain queued until the next train arrives.

Terminals connect to the rail network via dedicated links for loading and unloading operations and are integrated with the road network through crane links. The rail and road systems interact dynamically at intermodal terminals. A schematic representation of this interaction is provided in Figure 5.

For a transfer from rail to road, the process begins at the 'Arrival Node – From Rail', where containers are unloaded from trains at designated stop links. These containers then enter the crane queue, where they are processed based on the terminal's crane capacity. Once the container is loaded onto a truck, it exits the terminal through the 'Exit Node – To Road', completing the transfer. Conversely, for a transition from road to rail, the container arrives at the 'Arrival Node – From Road', where it is processed through the crane queue. After handling, the container moves to the 'Exit Node – To Rail', where it waits until a suitable train arrives. For each terminal, the

number and type of cranes are specified, determining the total crane capacity of the terminal (i.e., the maximum number of containers that can be handled per hour). This crane capacity is shared between the train-stack queue and the truck-stack queue, with priority given to the train-stack queue. This structured flow ensures the effective utilisation of terminal infrastructure while accommodating the operational dynamics of both rail and road networks.

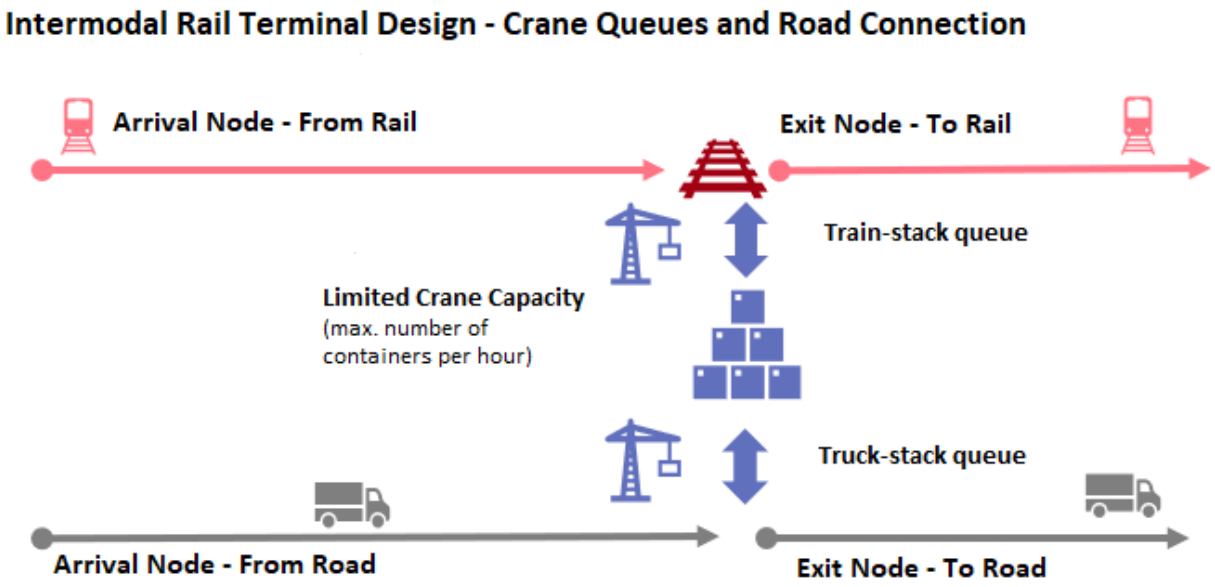

Figure 5 - Intermodal Rail Terminal Design

The supply includes seven large terminals (see Figure 6), which function 24 hours and cover routes from east (St. Gallen - Gossau) to west (Geneve - Genf) of Switzerland, and also routes connecting the most extreme south (Sottoceneri) and north (Basel) points. This design concept for the rail intermodal terminals is fictive, although it reflects some already existing operations and possible future expansions in critical connecting nodes for the network to support intermodal services. Each route operates in two lines (one direction each), with trains departing every two hours. Arrival and departure times at Gaeu and Dietikon (connecting terminals) were set in such a way as to allow for short connections from the main east-west corridor to the other ones.

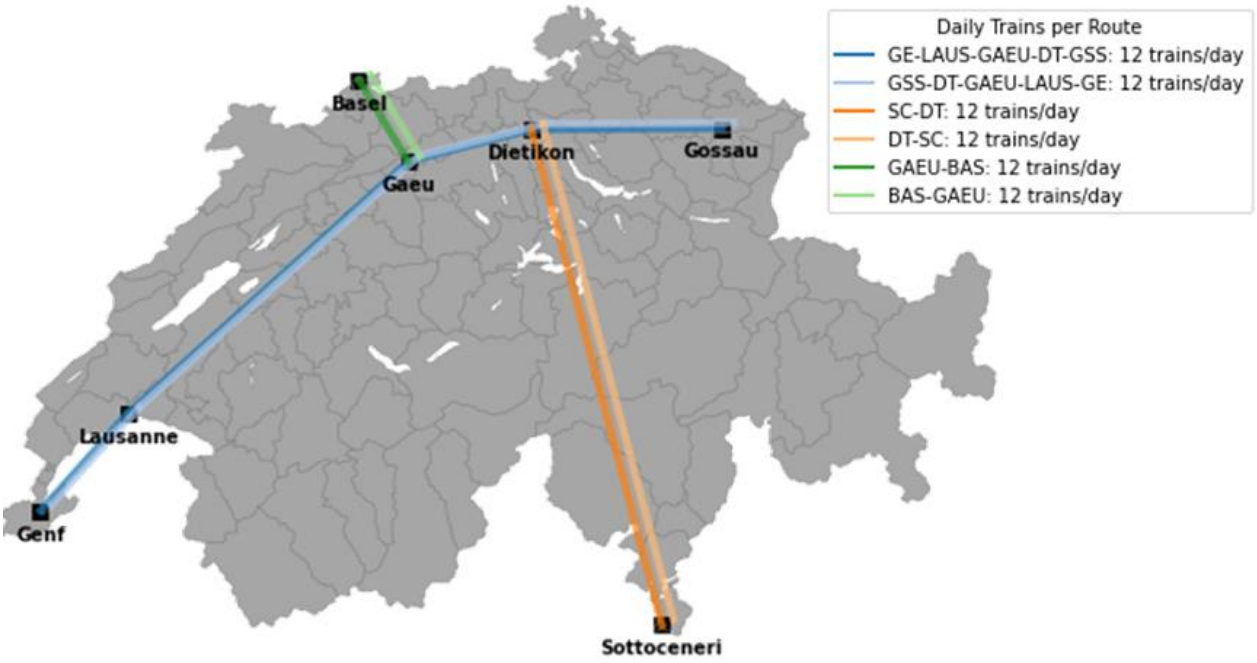

Figure 6 - Rail Supply: Terminals and Routes (illustrative and fictive case study)

Finally, dynamic network adjustments are implemented using network change events to account for real-time capacity variations at terminals. These events dynamically modify the flow capacity and lane availability of terminal links based on operational conditions, such as crane availability and train schedules. This detailed modelling ensures a realistic representation of the rail network, capturing the main components of intermodal rail freight transport and its dynamic interactions with other transport modes.

5.3. Cargo Sous Terrain

The Cargo Sous Terrain (CST) logistics system is an underground network designed to streamline freight transport with minimal surface disruption. The system is modelled in two phases (see Figure 7): an initial phase encompassing a smaller network of approximately 70 km and ten hubs from Neuendorf to Zurich Airport, and a final phase covering around 500 km, expanding the network from Geneva to St. Gallen and Basel to Lucerne, with additional extensions to Thun, integrating 58 hubs.

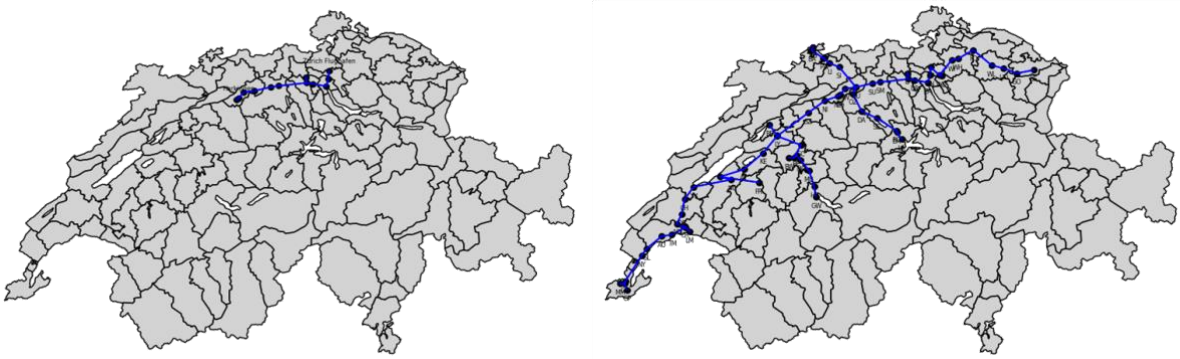

Figure 7 - Cargo Sous Terrain (a) Left Panel: first phase (small network); (b) Right panel: final phase (full network)

The model consists of a network of interconnected elements: hubs, elevators, tunnels, and roundabouts. Vehicles, pre-loaded with goods, operate on predefined schedules at fixed speeds of 40 km/h in tunnels and 8.5 km/h in roundabouts, maintaining safety distances under normal traffic conditions. Each autonomous vehicle has a capacity of 2 pallets, approximated to 0.2 TEU in the simulation, meaning five vehicles equate to one TEU (and this block configuration was enforced in the simulation to guarantee homogeneity of units across different modes). Hubs are connected to the underground network by four elevators (two in each direction), each capable of handling 450 vehicles per hour, operating on a First-In-First-Out (FIFO) queueing mechanism.

Hubs function as interface points for vehicles transitioning between the surface and the underground network. Surface vehicles queue at elevators, descend to the tunnels, and are dispatched directionally, while vehicles exiting the tunnels queue to ascend before merging with surface traffic. This interaction mirrors the crane queue logic of intermodal rail terminals, as illustrated in Figure 5, with adjustments to reflect the unique capacities and structures of the hubs and elevators. Considering the elevators' throughput and automated loading/unloading processes, each hub can manage up to 100 containers per hour.

Tunnels are dual-lane structures with an emergency central parking lane for bypassing stopped vehicles. For this study, the central lane is excluded from the model, assuming full system reliability with no failures. Tunnel movements are modelled using conveyor logic, simplifying simulation by enforcing uniform speeds, spacing, and sequential movement for all vehicles. Similarly, roundabouts are modelled as single-lane conveyors, operating counterclockwise with strict entry prioritisation and flow rules.

The CST system is designed for efficiency and scalability. Vehicle schedules are generated via Python scripts and integrated into the simulation. These schedules balance daily flows evenly across hubs and adjust to the system's primary bottlenecks, specifically roundabouts, ensuring congestion-free performance. Figure 8 illustrates hourly accumulated network flows, capturing vehicle inflows (arrival at delivery hubs) and outflows (departure from arrival hubs). The flows remain stable at about 4,300 vehicles after a gradual "outflow" warm-up period in the early hours, with minimal queues and traffic within the network.

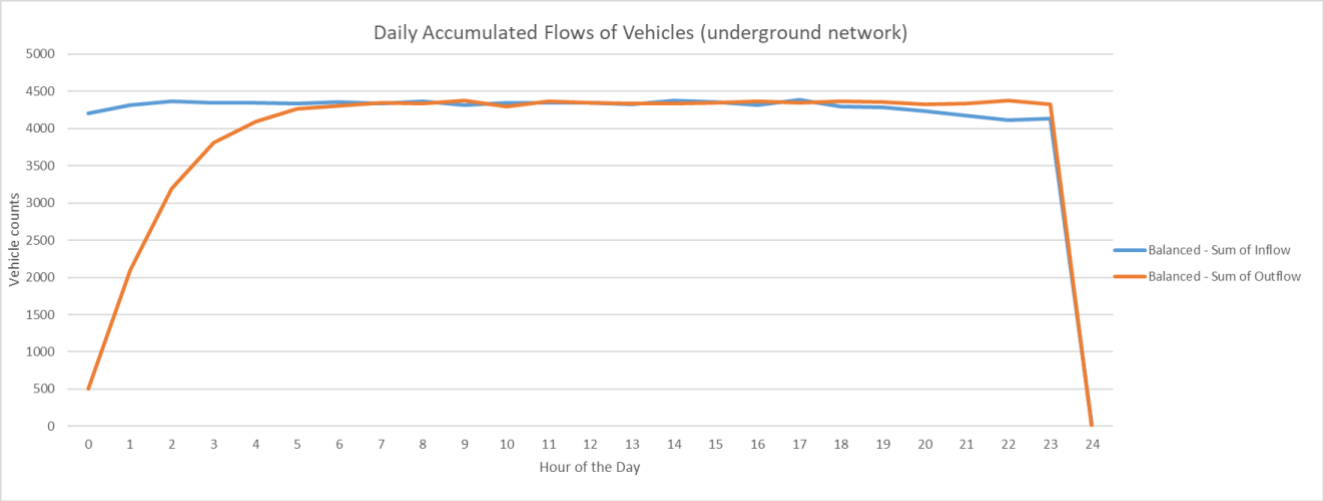

Figure 8 - Daily Adjusted Vehicle Flows for the Underground Network

Figure 9 provides a 3D representation of hourly flows through the busiest tunnels and roundabouts, ranked by traffic volume. The first four busiest structures are roundabouts (labelled as "Conveyor<Roundabout Acronym>"), operating near full capacity throughout the day. Utilisation is highest in critical areas—marked in yellow, grey, and orange—where top roundabouts operate at almost 100% capacity, while other segments handle significantly lower flows. The primary bottleneck, ConveyorRDS (a roundabout connecting the tunnels to Lucerne and Basel and the east-west tunnels), operates close to full capacity nearly 24 hours a day, underscoring its pivotal role in the network.

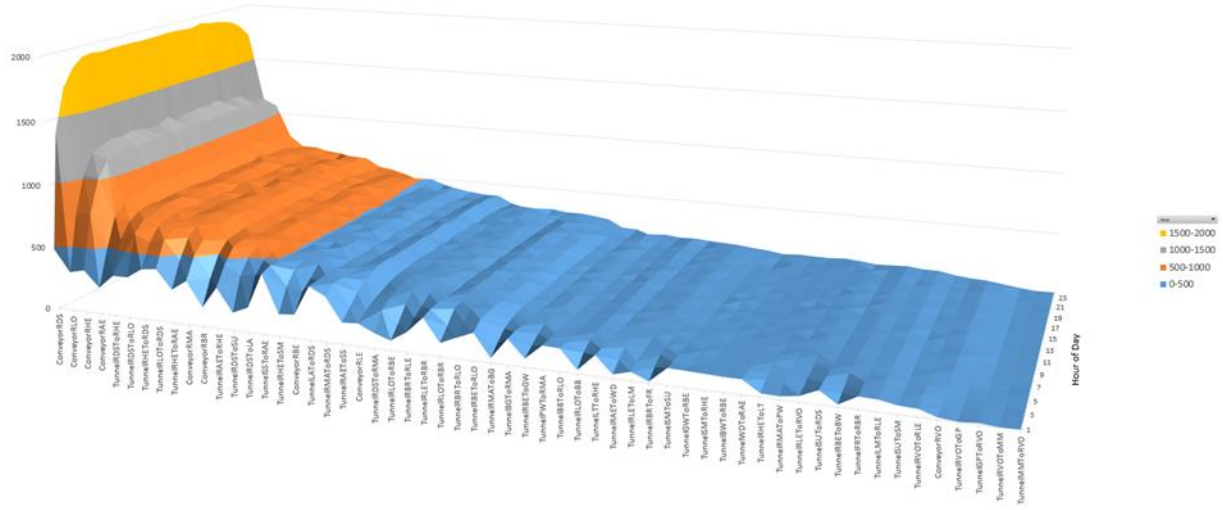

Figure 9 - Hourly Accumulated Vehicle Flows per Tunnels and Roundabouts, Ordered by Utilisation Rate

6. Simulation Experiments

The following sections present the most relevant simulation outcomes from a reference simulation run, focusing on the impact of integrating and expanding the Cargo Sous Terrain (CST) network within Switzerland's logistics infrastructure. Additionally, sensitivity analyses of various parameters are included to evaluate the robustness and reliability of the conclusions drawn from the study.

6.1. Reference simulation setup and assumptions

Given its significance as the most likely scenario, the remainder of this report focuses on the total projected merchandise quantities for the year 2050, as estimated under ARE's baseline socio-economic framework (i.e., Basis Scenario). A total of 49,846 loaded containers are simulated, corresponding to a 3-day volume. The simulation length is three days, and each scenario is replicated for 100 iterations to allow entities to change/optimise their plans until convergence. Figure 10 illustrates the spatial distribution of freight origin and destination points in this scenario, alongside the locations of rail intermodal terminals and CST intermodal hubs (full network). The plot reveals that both networks effectively cover the key regions of intermodal demand, particularly along the critical east-west corridor. While rail is the sole provider of connections to the southernmost area near Switzerland's border with Italy, the CST network extends its coverage to additional areas along the main corridor, enhancing accessibility and distribution potential.

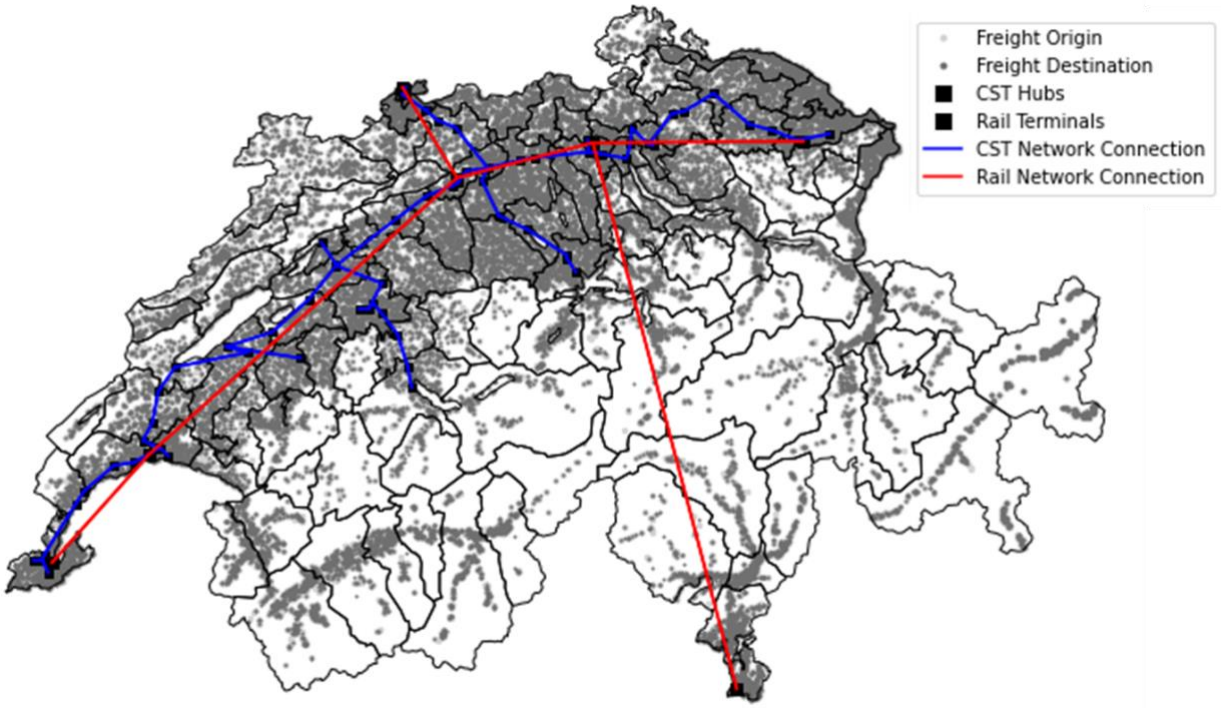

Figure 10 - Spatial distribution of demand points (origin and destination) according to ARE's Basis Scenario

The reference simulation scenario assumes the following cost ratios: the cost per container-kilometre for car-only transport relative to rail transport is set at 4.3, reflecting the assumption that rail offers significantly lower costs compared to road. The cost ratio of road-only to rail-intermodal (i.e. road leg of rail intermodal) transport is 0.8, accounting for higher fixed costs, such as planning and dispatching, associated with intermodal transport. The cost ratio of road-only to CST transport is set at 2.2, illustrating the relative cost efficiency of CST while the ratio of road-only to CST-intermodal transport is set at 1, representing comparable cost efficiency for these two modes under the assumed conditions. Under these configurations, rail stands out as the most cost-effective mode, while road-only transport remains the most expensive. CST positions itself as a mid-range option, reflecting its intended role in the cost structure. This setup aligns with the aspirations of the underground network to compete effectively with road transport by leveraging advanced infrastructure, efficient local distribution in urban agglomerations, and integrated digital logistics. These elements enable fully automated operations, positioning CST as a strong competitor to road transport (Bachman et al., 2022).

Additional assumptions include a delay tolerance of 8 hours for container arrivals, enabling the assessment of the current cost structure without excess penalties for delays or early departures. Different tolerance levels are assessed later in the sensitivity analyses. Though restricted by terminal capacities, high-frequency rail services are modelled, reflecting realistic operational constraints. A late-night (22:00-05:00) penalty for heavy goods vehicles (HGVs) is applied to discourage road freight movement during nighttime hours, reflecting the current regulative framework in Switzerland. Rail and CST networks would be able to operate during those hours.

6.2. Impacts of CST expansion

The following experiments consider both the initial (small) and full CST networks and evaluate their performance against a scenario without CST. This setup allows for a comprehensive analysis of the CST system's impacts on Switzerland's logistics network, focusing on its effects on rail intermodal transport. Sensitivity analyses and additional experiments are planned to further assess the robustness and variability of the outcomes.

6.2.1. Mode share analysis

We first evaluate the impact of the insertion and development of the underground network in terms of the mode share. Figure 11 compares the three scenarios following the configurations of demand, costs and rail/road supply stated in section 6.1.

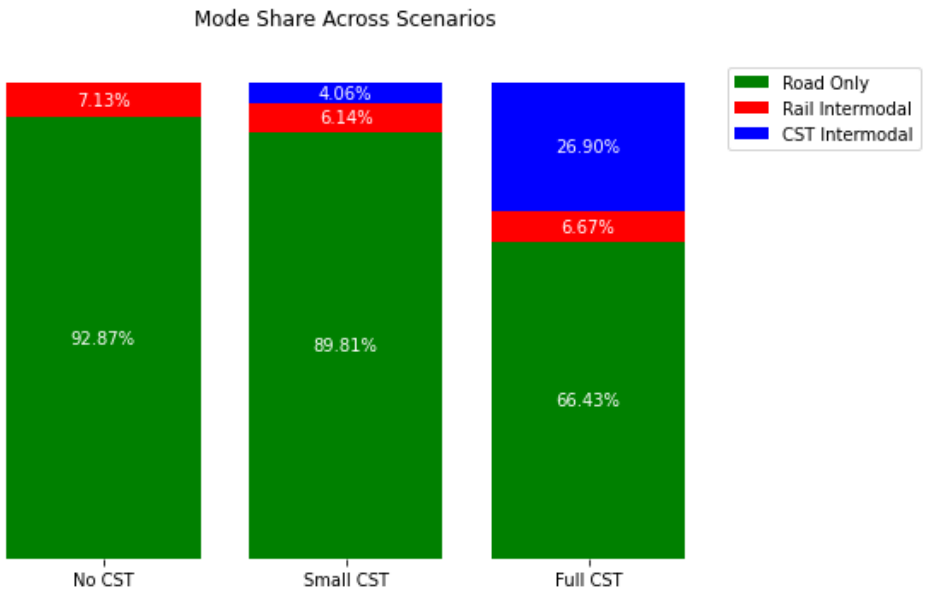

Figure 11 - Intermodal Share Across Scenarios: No CST, Small CST, and Full CST

In the scenario without CST, the Intermodal Rail share is 7.13%. Introducing a small CST network slightly decreases this share to 6.14%, while the full CST network raises it marginally to 6.67%. These minimal variations suggest that the presence of CST has a limited effect on Intermodal Rail demand under the given configurations.

However, the CST network's influence becomes evident when evaluating the share of freight demand relevant to intermodal transport. The small CST network achieves only about 4% of this share, whereas the full CST network captures a significantly higher share of 26.90%. This substantial increase highlights the full CST network's potential to attract intermodal freight, emphasising the competitive advantage it gains when operating at full scale.

It is important to note that the intermodal demand considers a minimum distance of 100 km for freight, while the small CST network covers only 70 km. Consequently, in this scenario, only cargo transported by CST that includes a road leg of at least 30 km qualifies as possibly CST intermodal freight. This limitation significantly constrains the small CST network's ability to capture intermodal demand, also partially explaining its relatively modest share compared to the full CST network.

6.2.2. Costs

The cost structure across modes reveals notable differences between the small and full CST scenarios. When transitioning from the small to the full CST network, Intermodal CST costs decrease substantially by 75.1%, and Intermodal Rail costs experience a modest reduction of 4.4%. These percentage changes highlight the significant impact of network configuration on cost dynamics. The sharp decline in intermodal CST costs with the full CST network reflects improved efficiency, likely due to the extended underground coverage, which reduces reliance on the expensive road leg. The slight reduction in Intermodal Rail costs also suggests better integration of rail infrastructure with the expanded CST network. A critical factor influencing these costs remains the road leg of intermodal transport, which is the most expensive segment for both Intermodal Rail and CST. Investigating how road leg distances vary across scenarios will be pivotal to understanding these cost patterns, a topic that will be explored in the next subsection.

6.2.3. Travel times and distances

The average distances and travel times for the small and full CST scenarios reveal key patterns in the performance and integration of transport modes. Table 1 below summarises these results:

Table 1 - Comparison of Average Distance and Travel Time Across Modes for Small and Full CST Scenarios

Mode	Road-Only		Intermodal Rail		Intermodal CST	
Scenario	**Small CST**	**Full CST**	**Small CST**	**Full CST**	**Small CST**	**Full CST**
Average Distance (km)	156.34	161.39	286.52	267.01	124.91	158.58
Average Time (hours)	2.12	2.27	13.83	10.89	11.11	7.76

The shifts reported in **Error! Reference source not found.** highlight how the expanded CST coverage influences modal characteristics. The table reveals notable shifts in travel characteristics between the small and full CST scenarios. For road-only transport, the average distance increases from 156.34 km to 161.39 km (a 3.2% rise), accompanied by a rise in average travel time from 2.12 hours to 2.27 hours (a 7.1% increase). Intermodal rail shows a significant improvement in efficiency, with the average distance decreasing from 286.52 km to 267.01 km (a 6.8% reduction) and average travel time dropping from 13.83 hours to 10.89 hours (a 21.3% reduction), reflecting better integration with the CST network. The expanded CST network makes intermodal CST increase its average distance from 124.91 km to 158.58 km (a 26.9% increase), while average travel time decreases sharply from 11.11 hours to 7.76 hours (a 30.2% reduction). Combined with the cost analysis, which shows a significant decrease in costs for intermodal trips, it can be inferred that the expansion of CST increases the efficiency and integration of the transport network.

A closer examination of the road leg distances of those intermodal modes provides further insight into these dynamics. In the small CST scenario, Intermodal Rail features an average road leg of 71 km. In the full CST scenario, road leg distances are significantly reduced to an average of 59 km (a 16.9% decrease). Figure 12 illustrates the traffic volume per road link for the road legs of Intermodal Rail. In the left plot, representing the small CST scenario, road legs often span longer distances to capture demand located farther from terminals. This likely corresponds to specialised freight needs that require long-distance transport, where rail serves as the primary mode despite the substantial road leg distances involved. Conversely, the right plot, depicting the full CST

scenario, shows a noticeable reduction in heavy traffic on links far from terminals. This suggests that terminals become increasingly focused on servicing neighbouring demand, with shorter road legs contributing to more efficient, localised, and cheaper operations.

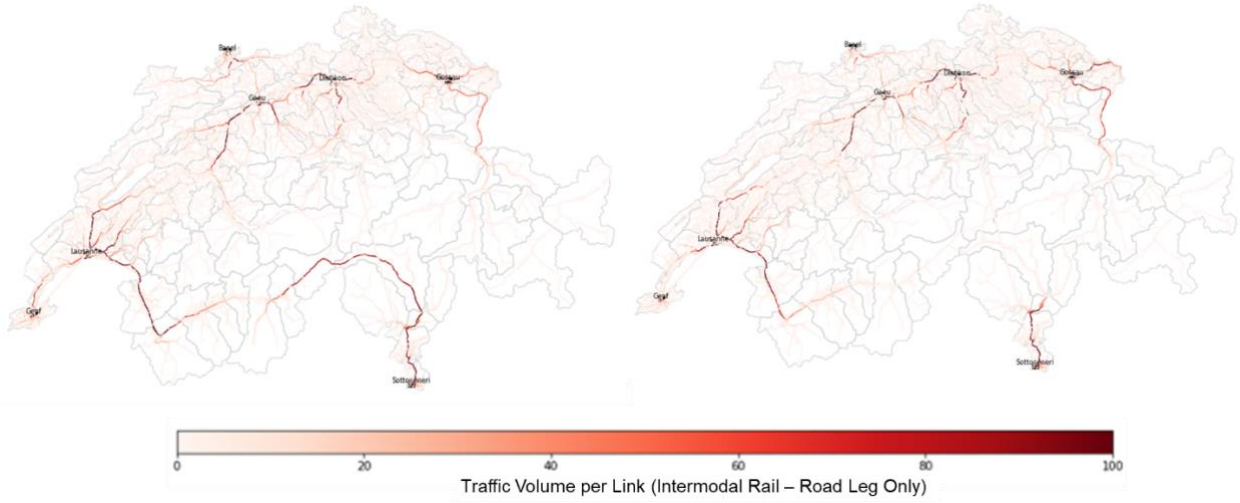

Figure 12 - Traffic Volume per Road Link - Intermodal Rail (left : small CST scenario, right: full CST scenario)

For Intermodal CST, the reduction in road leg distances is even more pronounced with the expansion of the network. In the small CST scenario, road legs average 100 km, while in the full CST scenario, they drop significantly to 61 km (a 29.12% decrease). The long road segments in the small CST scenario reflect the limited underground network coverage, necessitating substantial road-based transport to access terminals or CST hubs. This is evident in the left panel of Figure 13, which shows extensive road usage to connect demand to the CST system. In contrast, the right panel of Figure 13, representing the full CST scenario, demonstrates a much broader network coverage, even extending to areas in southern Switzerland. This enhanced coverage likely shifts the balance in favour of CST for many freight decisions. The presence of multiple hubs, offering convenient pick-up and drop-off locations, combined with the typically faster transport times of CST, makes it a more attractive option compared to the cheapest alternative, rail.

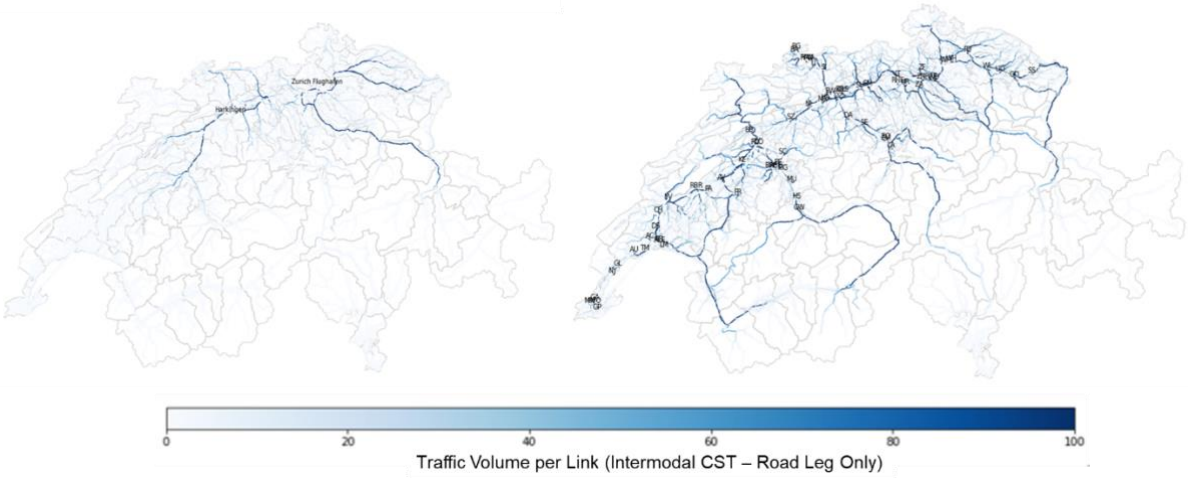

Figure 13 - Traffic Volume per Road Link - Intermodal CST (left : small CST scenario; right: full CST scenario)

A detailed analysis of road leg distances for boarding rail terminals reinforces the argument for terminal specialisation. Table 2 summarises the share of containers and average road leg distances for each rail terminal in both the small and full CST scenarios.

Table 2 - Rail Terminal Share and Average Road Leg Distance (Boarding Terminals)

Terminal	Small CST: Share (%)	Small CST: Avg. Road Leg (km)	Full CST: Share (%)	Full CST: Avg. Road Leg (km)
Basel	9.3	49.5	9.9	37.8
Dietikon	15.9	67.3	15.7	61.3
Gaeu	14.5	82.2	12.9	64.2
Genf	11.4	51.4	8.6	50.0
Gossau	8.0	74.4	15.4	67.7
Lausanne	23.6	76.6	19.6	66.4
Sottoceneri	17.4	79.8	17.9	55.5

The data reveal a general reduction in road leg distances across all terminals in the full CST scenario, indicating improved accessibility and terminal specialisation. Lausanne and Sottoceneri remain pivotal, maintaining the largest shares of containers while seeing notable reductions in average road leg distances. Lausanne drops from 76.6 km to 66.4 km (13.3% reduction), and Sottoceneri decreases from 79.8 km to 55.5 km (30.4% reduction).

Gossau emerges as a key beneficiary of the network expansion, nearly doubling its share from 8.0% to 15.4% while reducing its average road leg from 74.4 km to 67.7 km. Basel also shows significant improvements, with a 23.6% reduction in road leg distances (from 49.5 km to 37.8 km) and a modest increase in share from 9.3% to 9.9%. In contrast, Genf and Gaeu see declining shares (from 11.4% to 8.6% and 14.5% to 12.9%, respectively) but shorter road legs, particularly at Gaeu, where distances drop from 82.2 km to 64.2 km (21.9% reduction). These shifts indicate a redistribution of demand, reflecting the improved accessibility and expanded coverage of the CST network. The following analysis of terminal utilisation and average processing times explores potential bottlenecks, highlighting areas for adjustments and optimised demand allocation.

Overall, the full CST scenario demonstrates increased terminal specialisation, with terminals like Gossau, Sottoceneri, and Basel gaining prominence while focusing on more localised demand. The expanded network reduces reliance on long road legs, leading to cost-effective and time-efficient operations. Shorter road legs, combined with adequate terminal and train capacities, enhance the efficiency of intermodal rail. Likewise, intermodal CST benefits from better integration with the underground network, enabling faster, more competitive operations.

6.2.4. Utilisation rates at intermodal terminals and hubs

To assess the utilisation rates of rail terminals and CST hubs, Figure 14 and Figure 15 depict the queues of containers switching from road to rail and road to CST, respectively, over a typical day. These analyses compare the small CST scenario (top panel) and the full CST scenario (bottom panel). The plots depict cumulative loading from road to rail (Figure 14) and road to CST (Figure 15). Containers entering the crane or hub queue within a 1-hour time bin are represented in grey

bars, while those successfully processed within the same time bin are shown in blue bars. A dashed line marks the cumulative hourly capacity for all rail terminals, which remains constant since no adjustments to the supply are made. For CST, capacity values are omitted from the plots to maintain scaling clarity; however, they are proportional to the number of hubs in each scenario, equating to 1,000 containers per hour for the small CST scenario (10 hubs) and 5,800 containers per hour for the full scenario (58 hubs).

For rail terminals (Figure 14), utilisation peaks between 05:00–06:00 and just before 22:00, reflecting intense container loading and unloading activity. These peaks are primarily driven by the night ban on HGV circulation (22:00–05:00), leading to container accumulation for intermodal transfers during non-restricted hours. After 06:00, loading activity stabilises with a steady throughput of approximately 300–400 containers per hour until around 20:00. In the full CST scenario, utilisation patterns are similar but exhibit slightly higher absolute numbers due to increased rail modal share, as previously discussed. Generally, the cumulative number of containers remains well below the cumulative capacity for terminals. However, an exception occurs in the full CST scenario between 05:00–06:00, when the number of containers unloading to rail reaches the total capacity of all terminals. Discrepancies between grey bars (containers waiting on road) and blue bars (containers unloading to rail) suggest minor bottlenecks.

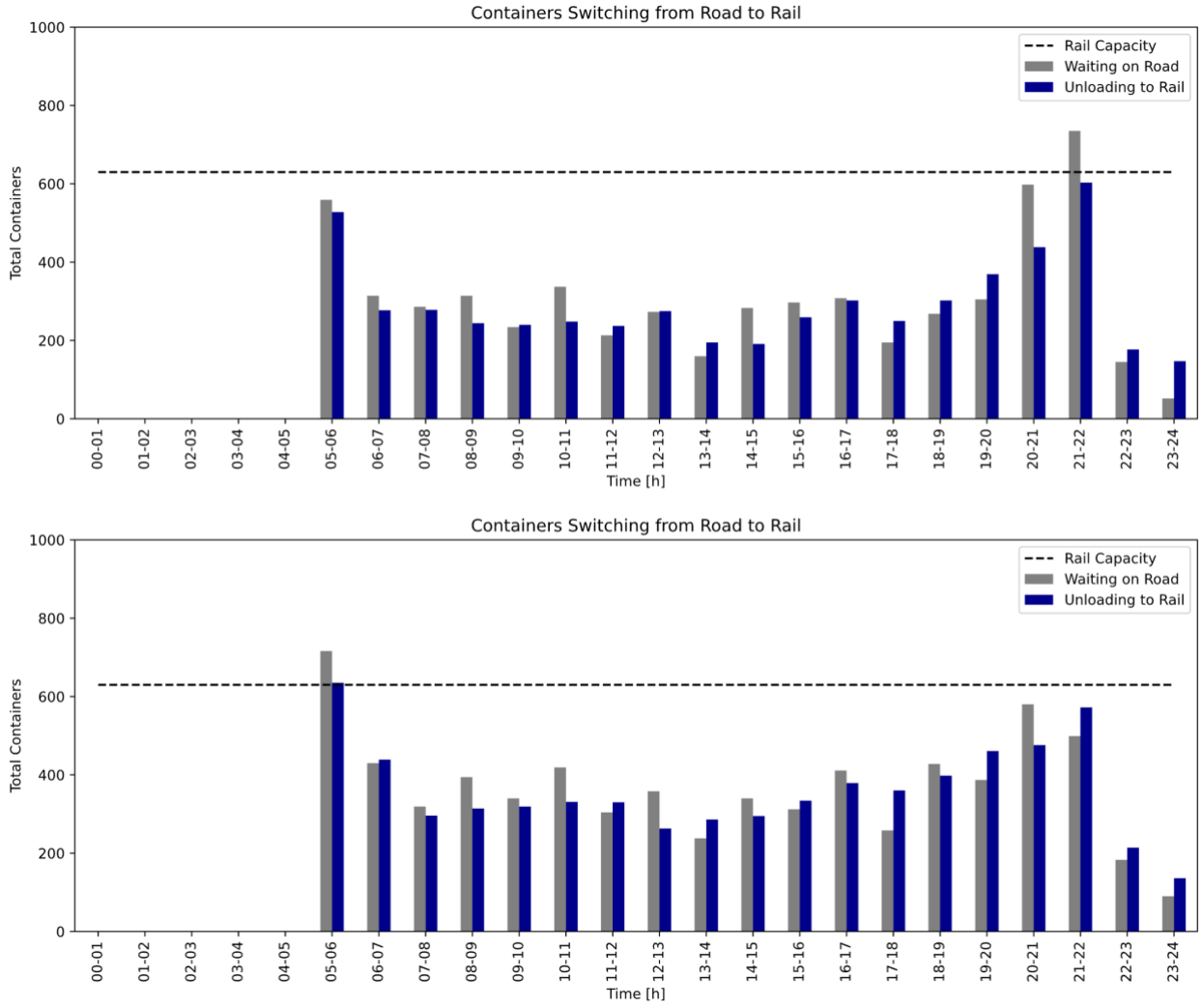

Figure 14 - Queues at Rail Terminals. Top panel: Small CST Scenario, Bottom panel: Full CST Scenario

The queues for CST hubs (Figure 15) exhibit distinct behaviour compared to those at rail terminals. In the small CST scenario (top panel), peaks occur between 05:00–07:00 and 21:00–22:00. However, the cumulative unloading capacity of 1,000 containers is never reached, and the uniform height of the bars suggests that most containers entering the system are processed within the hour. In contrast, the full CST scenario displays a different utilisation pattern, characterised by a linear increase in containers transitioning from road to CST between 05:00 and 10:00. This reflects improved throughput and reduced bottlenecks, with higher absolute numbers, as the expanded network accommodates more containers. Although the maximum cumulative capacity of 5,800 containers per hour is not reached, the extensive size of the network calls for a more granular analysis of potential bottlenecks by examining average waiting times at each individual hub, which is addressed next.

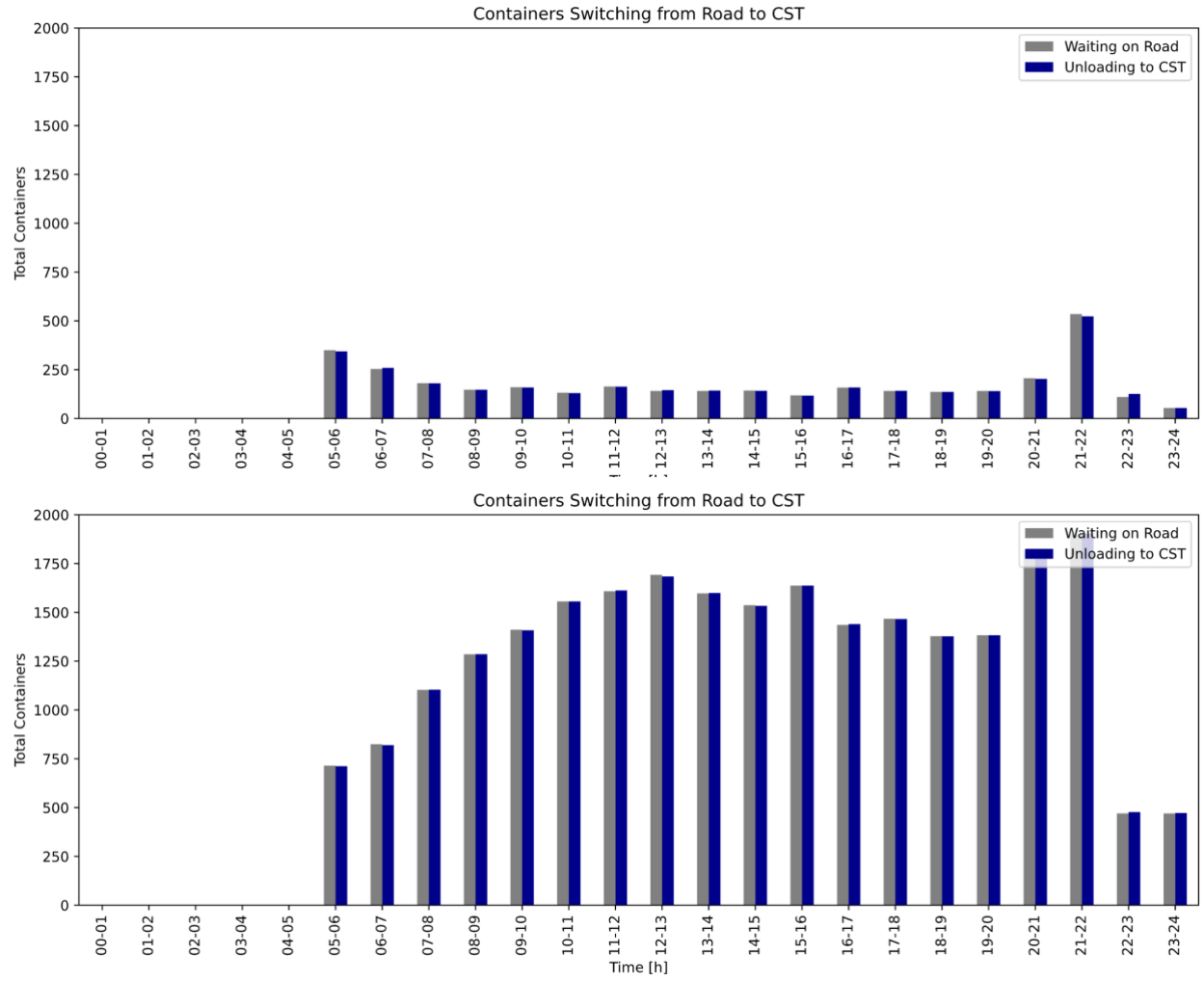

Figure 15 - Queues at CST Hubs. Top panel: Small CST Scenario, Bottom panel: Full CST Scenario

Figure 16 summarises the average waiting times in minutes for rail terminals and CST hubs under the small CST (left) and full CST (right) network scenarios. These waiting times encompass loading/unloading processes, vehicle availability delays, and waiting periods for mode switching (e.g., when the rail/CST leg ends during the HGV ban period, preventing immediate access to the

road leg). The plot highlights the operational differences between the two scenarios, emphasising the impact of network expansion on reducing waiting times and improving efficiency at CST hubs. Waiting times are presented in minutes and categorised by transit type (rail or CST). For the small CST network (the blue triangles on the left), average waiting times are between 40-150min, whereas in the full network, average times drop significantly from close to 0 to a maximum of 110min, although most terminals exhibit average waiting times of less than 10min (which can be inspected by the light blue colours in the right panel of Figure 16).

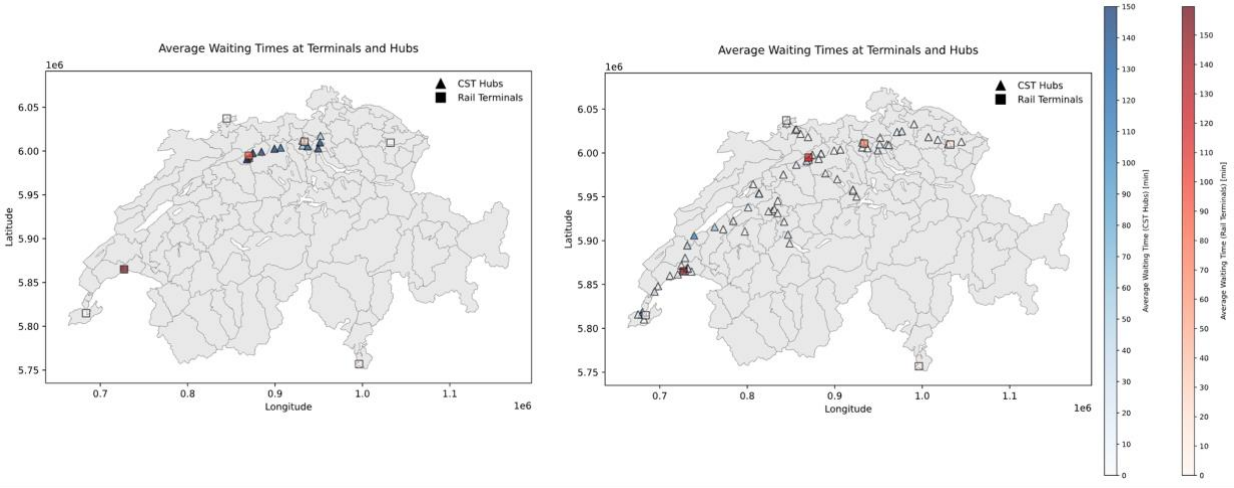

Figure 16 - Average Waiting Times (min) per Terminal and Hub. Left panel: Small CST; Right Panel: Full CST

The comparison demonstrates a significant reduction in waiting times at CST hubs and rail terminals in the full CST scenario, reflecting the enhanced capacity and efficiency of the expanded network, where CST operates in synergy with rail. In the small CST scenario, many overnight trips favour CST, as it remains operational during the HGV night ban and spans an area of interest for deliveries around the greater Zurich area. However, containers destined for their egress hubs often face delays until the ban ends, leading to penalties for late delivery. This occurs for 39.7% of CST trips, compared to 21.2% of rail trips, highlighting the greater impact on CST. As a result, average waiting times for hubs are, on average, higher than those of terminals.

For rail, this effect is particularly noticeable, although less pronounced than those of CST network, at three key rail terminals—Lausanne, Gaeu, and Dietikon—which span the busiest areas for container arrivals and departures. In the full CST scenario, the proportion of trips penalised for late delivery drops dramatically to 1.2% for CST and 7.7% for rail. The expanded network allows containers to optimise their routes effectively, with those covering greater distances better utilising available capacity, leaving less room for suboptimal trips with long delays.

This demonstrates the critical role of network capacity in mitigating bottlenecks and optimising intermodal transfers. Improvements are evident in both utilisation patterns and average waiting times. For instance, as shown in Table 3, the waiting times for the two terminals located in the east-west corridor are significantly reduced: Lausanne decreases by 48.9% (from 159.73 to 81.51 minutes), and Gaeu decreases by 29.9% (from 83.69 to 58.66 minutes). These findings highlight the operational advantages of the full CST network in enhancing efficiency and reducing delays across both transit modes.

Table 3 - Comparison of Average Waiting Times (min) at Rail Terminals: small and full CST scenarios

Terminal	Scenario	Average Waiting Time (min)	Scenario	Average Waiting Time (min)
Lausanne	Small CST	159.73	Full CST	81.51
Gaeu	Small CST	83.69	Full CST	58.66
Dietikon	Small CST	27.73	Full CST	33.01
Sottoceneri	Small CST	2.57	Full CST	1.88
Basel	Small CST	0.48	Full CST	0.03
Gossau	Small CST	0.02	Full CST	5.82
Genf	Small CST	0.02	Full CST	0.02

6.3. Sensitivity analysis

To further investigate the factors influencing intermodal shares, 90 additional simulation experiments were carried out, varying key parameters such as delay tolerance, cost ratios, rail terminal capacities, and CST network configurations. The two panels in Figure 17 summarise the findings for the Rail Intermodal Share (left panel in red) and the CST Intermodal Share (right panel in blue). The x-axis represents delay tolerance values (4, 6, or 8 hours), while the colour scale reflects the cost ratio between road and intermodal road legs (darker colours represent higher cost ratios). Marker size indicates whether rail terminal capacity was limited (60 containers/hour) or unrestricted, and their shape differentiates between those without CST (square markers, only shown for the rail-only scenario, left panel) and with CST (circle markers). For both scenarios, shaded circles represent the results of the small CST network, and circles above the shaded area represent the results of the full CST network.

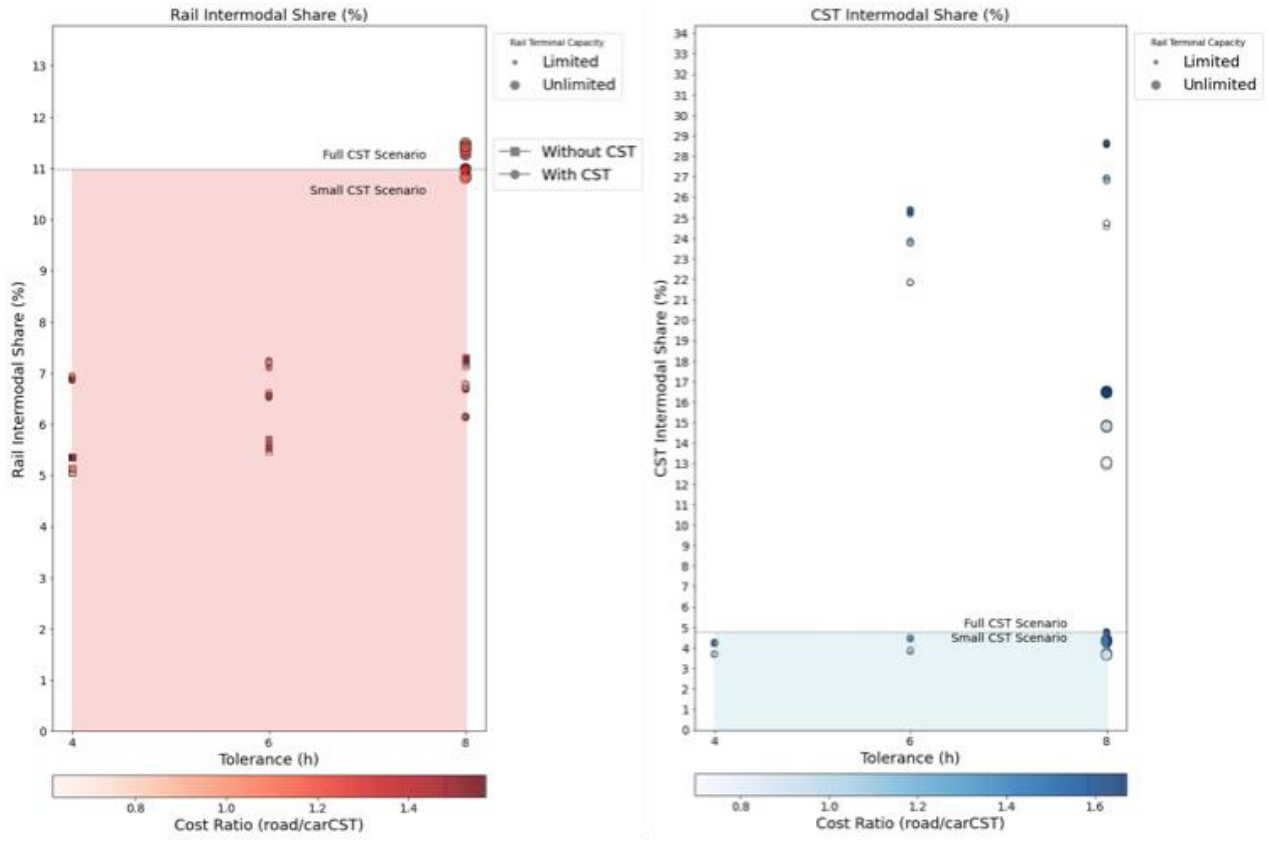

Figure 17 - Impacts on Rail Share (left panel) and CST Share (right panel) of different simulation parameters' values

In the Rail Intermodal Share (left panel), the scenario without CST (square markers on the lower part) reveals that tolerance and cost ratio effects are distinguishable. Rail share grows linearly from 5% to about 7% as delay tolerance and road costs increase, with a more pronounced effect of delay tolerance. For the CST scenarios (circle markers), a key distinction arises between the small and full CST networks. In the small CST network (markers within the red-shaded area), tolerance and cost ratio effects appear less prominent. Instead, the determining factor is rail capacity, represented by the marker size. Unrestricted rail capacity (large circles) results in a significant share increase, where rail captures 4–6% more share when compared to restricted capacity. This effect holds independently of the CST network size, as the rail intermodal share consistently jumps from 5–7% to over 10% when rail terminal capacity is unconstrained.

The primary factor in the CST Intermodal Share (right panel) is network size. The small CST network appears to saturate at around 4% modal share, indicated by the smaller circles within the blue-shaded area. In these cases, CST cannot absorb additional share even with restricted rail capacity, and the outcomes for restricted and unrestricted rail capacity remain largely the same. However, in the full CST scenario (markers outside the shaded area), rail terminal capacity emerges as the dominant factor. When rail terminal capacity is restricted (small circles), the CST share jumps to 22–29%. In contrast, with unrestricted rail capacity (large circles), CST share stabilises around 13–17%. Beyond terminal capacity, cost ratio and delay tolerance play secondary roles, with higher (road) cost ratios and greater delay tolerance favouring CST share over road transport.

Additionally, the importance of key features influencing the Rail Intermodal and CST Intermodal shares was quantified using Permutation Feature Importance (Figure 18). The CST network size is not contemplated since it dominates the other factors for the CST share. This method measures the impact of each variable on the model's predictive accuracy by randomly shuffling its values and observing the resulting decrease in performance. The Mean Importance Value reflects how influential a feature is, while the 95% confidence interval (CI) accounts for uncertainty in the estimation. Larger standard deviation (the black bars crossing each coloured bar) indicate higher variability in importance, while smaller bars reflect consistent importance across the data.

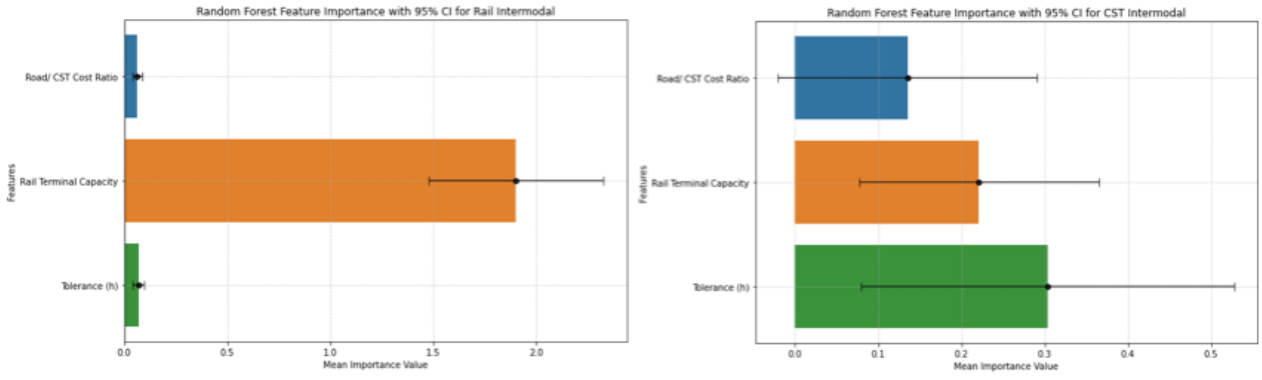

Figure 18 - Random Forest Feature Importance Results for Rail Intermodal (left) and CST Intermodal (right)

The main results for Figure 17 and Figure 18 can be summarised for rail and CST shares. For the Rail Intermodal Share (in the full CST scenario), rail terminal capacity dominates the results:

- Terminal capacity has a Mean Importance Value of 1.9020 (95% CI: [1.4790, 2.3250]), highlighting its overwhelming influence on rail share outcomes.
- Tolerance and cost ratio are negligible, with Mean Importance Values of 0.0686 (95% CI: [0.0407, 0.0965]) and 0.0627 (95% CI: [0.0389, 0.0865]), respectively. These results align with the sensitivity analysis, where rail share increases are almost entirely driven by terminal capacity constraints, while other factors have minimal influence.

For the CST Intermodal Share (in the full CST scenario), the results indicate a more balanced interplay among the features:

- Tolerance emerges as the most impactful factor, with a Mean Importance Value of 0.3034 (95% CI: [0.0791, 0.5277]).
- Rail terminal capacity is the second most influential feature, with a Mean Importance Value of 0.2211 (95% CI: [0.0772, 0.3650]).
- Cost ratio contributes to a lesser extent, with a Mean Importance Value of 0.1352 (95% CI: [-0.0202,0.2905]). The larger confidence intervals for tolerance and rail terminal capacity suggest variability in their importance across the simulation experiments, particularly for the CST share. This variability reflects the interaction between network size, rail capacity, and cost conditions.

Overall, the sensitivity analysis and feature importance results collectively highlight the factors driving intermodal modal shares. For Rail Intermodal share, rail terminal capacity is a determinant of significant share growth, with tolerance and cost ratios playing a negligible role. In contrast, the CST Intermodal share is primarily driven by network size and further modulated by rail terminal capacity, delay tolerance and cost ratios. These findings highlight the importance of infrastructure capacity and network coverage in optimising intermodal transport performance.

7. Conclusions and Future Research

This study examined the current state and potential future developments of Switzerland's freight transport system, with a focus on intermodal transport and the introduction of Cargo Sous Terrain (CST) as an innovative logistics solution. Using demand projections from the Swiss Transport Outlook 2050, we modelled a future demand scenario and assessed the capacities and interactions of three supply modes (road, rail, and CST) through an agent-based simulation framework. This microscopic modelling approach enabled freight entities to select transport modes, schedules, and routes autonomously, facilitating a detailed analysis of intermodal competition, spatial dynamics, and transshipment processes.

The results highlight the importance of road transport for its flexibility for first- and last-mile delivery, while rail remains the most efficient option for long-haul freight under adequate terminal capacities. CST introduces a new dimension to the freight system, competing directly with road transport and creating opportunities for coordinated multimodal solutions. The findings show that CST expansion plays a key role in reducing transport distances and costs. By optimising container routing, long-haul shipments make better use of rail capacity, easing congestion and reducing inefficient trips with excessive delays. Additionally, the faster loading process at CST hubs absorbs containers that might otherwise strain rail terminals, especially for long-distance freight that is too costly by

road alone. Therefore, CST plays a key role in reducing transport distances while improving rail terminal specialisation, easing pressure on both road and rail systems.

Through sensitivity analysis and feature importance methods, we explored the system's capacity limitations, the factors driving intermodal competition, and the spatial effects of freight flows. Rail terminal capacity emerges as the most critical driver of rail performance, directly boosting rail modal share by 4–6% when constraints are lifted. In contrast, CST's performance is primarily determined by its network size, with an expanded network enabling CST to achieve substantial modal share gains of up to 29% while also reducing road-leg distances for rail intermodal operations. The results further demonstrate that rail freight will continue to operate almost unaffected by CST's introduction. In contrast, cost ratios, delay tolerance, and rail capacity constraints shape CST's ability to take over road freight.

As key takeaways, we highlight:

- **Intermodal Rail remains stable and independent**: Increasing train frequency improves rail share, regardless of CST's presence.
- **Rail terminal capacity is critical**: Expanding capacity significantly improves rail's competitiveness, keeping it viable even in a fully developed CST scenario.
- **CST's full network reshapes freight flows**: The full CST network captures a large share of shipments, shortens road-leg distances for intermodal rail, and encourages rail terminal specialisation.
- **Cost ratios and delay tolerance refine CST share**: While secondary to network size and capacity, optimising these factors helps CST compete more effectively with road transport.

Further studies should focus on real-world validation of CST's cost structures, freight handling processes, and network conditions to understand its long-term role in Swiss logistics. On the rail side, optimising transit schedules and pinpointing cost-effective terminal locations will be essential to keeping intermodal transport competitive.

While this study assumes ideal CST operations, such as fully automated loading/unloading and unrestricted vehicle availability, testing these assumptions with real data will offer a more grounded assessment of CST's potential. Additionally, the findings align with synchromodal principles, where real-time flexibility and infrastructure coordination improve freight flows. Future research could expand on this by exploring dynamic coordination mechanisms that enhance intermodal operations.

Ultimately, CST's ability to transform freight transport will depend on network design, infrastructure capacity, and operational efficiency. Nevertheless, the findings highlight CST's transformative potential and the critical importance of infrastructure capacity and network design in shaping future intermodal freight performance.

References

ARE Federal Office for Spatial Development, 2019a. Aktualisierung der Aggregierten Methode Güterverkehr (AMG) auf den Basiszustand 2016.

ARE Federal Office for Spatial Development, 2019b. Aggregierte Methode Güterverkehr (AMG)— Benutzeranleitung und technische Dokumentation.

ARE Federal Office for Spatial Development, 2022. Schweizerische Verkehrsperspektiven 2050 (Transport Outlook 2050).

Bachman, C. (CST), Schmid, T. (Rapp T.A., Buschor, O. (Rapp T.A., Hegi, P. (Rapp T.A., Graf, J. (CSD), Zaugg, A. (CSD), Amet, N. (CSD), 2022. Cargo Sous Terrain Bericht Machbarkeit St. Gallen.

Horni, A., Nagel, K., Axhausen, K.W., 2016a. The Multi-Agent Transport Simulation Title of Book : The Multi-Agent Transport Simulation MATSim.

Horni, A., Nagel, K., Axhausen, K.W., 2016b. The Multi-Agent Transport Simulation Title of Book : The Multi-Agent Transport Simulation MATSim.

Kaddoura, I., Masson, D., Hettinger, T., Unterfinger, M., 2024. An agent-based simulation approach to investigate the shift of Switzerland’s inland freight transport from road to rail. Transportation 51, 1701–1722.