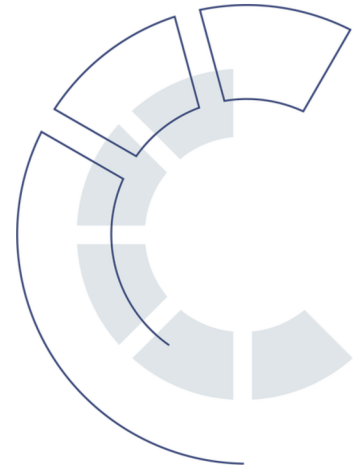




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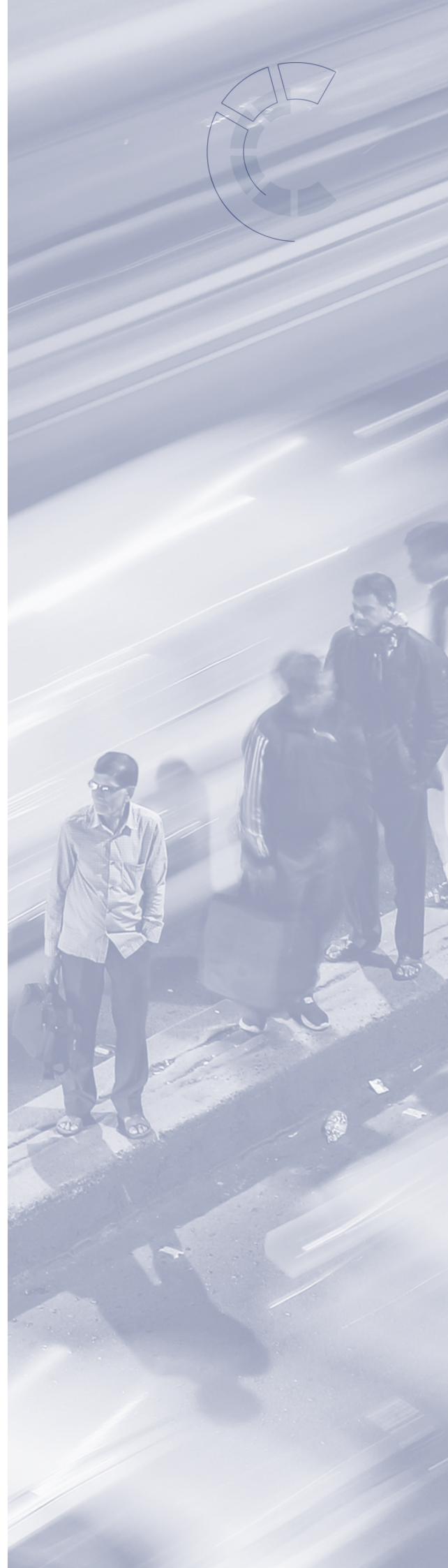
Klimawandel und Resilienz

Sonderausgabe zum 100-jährigen Jubiläum der ÖVG und
24. European Transport Congress in Wien



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Editorial

Klimawandel und Resilienz – zwei Begriffe, die längst nicht mehr nur in wissenschaftlichen Diskursen ihren Platz haben, sondern unsere Verkehrssysteme ganz konkret herausfordern. Ob Überschwemmungen, die Straßen und Schienen unpassierbar machen, Hitzewellen, die den Betrieb einschränken, oder Schadholzmengen, die Lieferketten unter Druck setzen: Die Frage, wie wir unsere Mobilität widerstandsfähiger gestalten können, ist aktueller denn je.

Die vorliegende Sonderausgabe entstand im Rahmen des 100-jährigen Jubiläums der ÖVG und des 24. European Transport Congress (ETC). Aus den zahlreichen Einreichungen zum Themenschwerpunkt Klimawandel und Resilienz haben wir die besten Beiträge für diese Ausgabe ausgewählt. Der internationale Charakter des Kongresses spiegelt sich auch in dieser Ausgabe wider: Die Beiträge sind deshalb sowohl auf Deutsch als auch auf Englisch verfasst und kommen aus zahlreichen europäischen Ländern.

Zwei der eingereichten Extended Abstracts überzeugten uns dabei so sehr, dass wir die Autorentteams eingeladen haben, sie zu vollständigen Leitartikeln auszuarbeiten: Milan Dedík und sein Team zeigen, welches Potenzial Nachtzugverbindungen in Mitteleuropa für eine klimafreundliche Langstreckenmobilität bieten, während Christoph Kogler und seine Co-Autoren beleuchten, wie die österreichische Holzlogistik durch digitale Entscheidungsunterstützung, GeoAI und Simulation resilienter werden kann.

Ergänzt werden die beiden Leitartikel durch sieben weitere Beiträge. Kosmas Anagnostopoulos und sein Team zeigen am Beispiel der Outta Climate Festivals in Griechenland, wie partizipative Mikro-Interventionen im Straßenraum gleichzeitig Verkehrssicherheit und Klimabewusstsein stärken können. Marianne Bügelmayer-Blaschek und ihre Co-Autor:innen stellen eine quantitative Methodik vor, mit der sich klimabedingte Risiken für Verkehrsinfrastruktur systematisch bewerten lassen. Andrea Faast und Isabel Heiß präsentieren mit „Nachhaltige Logistik 2030+“ ein Modellprojekt für die urbane Güterverkehrstransformation in Wien und Niederösterreich. Eva Michelaraki und George Yannis untersuchen anhand von Fahrsimulatoraten, wie Risikofaktoren die Sicherheitstoleranzzone von Fahrenden beeinflussen. Balázs Horváth und Viktor Nagy nutzen Verkehrssimulation, um die ökologische Irrationalität des Schnellfahrens auf Autobahnen offenzulegen. András Vágány und Tünde Hajnal berichten über Budapests Weg zu einem datenbasierten SUMP-Monitoring, und das Zagreber Team um Marko Šoštarić prognostiziert Kroatiens Straßenverkehrsemissionen bis 2050.

Was alle Beiträge verbindet, ist die Überzeugung, dass Resilienz kein Zustand ist, sondern ein Prozess – einer, der Daten, Zusammenarbeit und den Mut zu neuen Ansätzen erfordert. Ich wünsche Ihnen eine anregende Lektüre.



Marie-Luise Zwicker
Redaktion



Framework for Reintroducing and Expanding Night Railway Services in Central Europe: The Slovak Perspective

BY DEDÍK M., GAŠPARÍK J., BULKOVÁ Z. AND ZITRICKÝ V.

1. Introduction and objectives

In the context of the European Union's transport and environmental strategy, the transition toward climate-neutral and sustainable mobility systems strengthens the role of railway transport as a resilient, energy-efficient and socially inclusive mode (Kortekaas, 2024). Night railway passenger transport represents a specific segment that historically played an important role in long-distance mobility across Europe (Blainey & Hare, 2025; Kantelaar et al., 2022). Although night trains and sleeping cars were once a common and well-developed service, their importance declined at the end of the twentieth century due to competition from low-cost airlines, changes in travel behaviour, reduced public support and the closure of many international routes (Gerosa & Cellina, 2024). The COVID-19 pandemic further accelerated this decline by reducing demand for long-distance travel (Gašparík et al., 2024).

Recent years, however, have seen a renewed interest in night rail transport as a strategic element of sustainable mobility (Rickfeldwer & Schönberger, 2024). Its revival is driven by environmental objectives, growing demand for low-carbon travel alternatives and increasing political support at the EU level (Buh & Peer, 2024). Successful examples such as the ÖBB NightJet network illustrate that modern night services can be economically viable, operationally feasible and aligned with long-term climate goals (Tomeš & Pařil, 2026). Despite this renewed momentum, the availability of night services in Central Europe remains limited, and Slovakia currently offers only a small number of routes insufficient to meet potential demand or provide high-quality international connectivity.

The aim of this paper is to analyse the current state of night passenger railway transport in the Slovak Republic and in the broader Central European region, identify the main shortcomings of the existing network and propose a new concept for national and international night train services.

The analysis focuses on the strategic role of night mobility within the integrated transport system and examines its potential to shift demand away from air, bus and individual car transport, particularly on medium- and long-distance corridors. Attention is also given to the possibilities of strengthening cross-border night mobility between Slovakia and neighbouring countries such as the Czech Republic, Austria, Hungary and Poland.

The methodological approach combines several components. First, a review of technical, operational and organisational standards governing night services is carried out, including rolling stock requirements, interoperability aspects, timetable constraints and passenger comfort parameters.

Second, an assessment of infrastructure capacity is conducted, with a focus on bottlenecks affecting the feasibility of new night connections, such as single-track sections, planned maintenance windows, station capacity limitations or conflicts with freight traffic.

Third, current travel demand patterns, long-distance passenger flows and competing transport modes are analysed. Fourth, route-planning scenarios are developed to identify promising new connections linking major Central European urban regions.

Finally, a preliminary operational-economic assessment is conducted for a selected concept, including estimated operating costs and indicative fare levels. The results indicate that Slovakia has significant potential for developing a modern and competitive night railway offer. Promising opportunities include connections between Bratislava and major European cities such as Berlin, Warsaw, Krakow, Budapest, Prague, Vienna, Zurich or Milan. Such connections would strengthen Slovakia's integration into the European transport network, provide alternatives to congested airports and road corridors and enhance resilience by offering reliable low-carbon long-distance mobility during night-time hours.



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The paper further discusses the infrastructure implications associated with expanding night services. Increased night-time utilisation of key railway corridors may affect maintenance planning, freight operations and overall network capacity. Therefore, successful implementation requires balanced capacity allocation, improved traffic management systems and enhanced international coordination. Overall, the proposed concept demonstrates that night railway transport can become a key component of a resilient, low-carbon and competitive mobility system in Central Europe. The findings highlight the need for targeted investments, cross-border cooperation and innovative service models, supporting the integration of night rail planning into national and regional mobility strategies.

In the case of the proposed issue, the authors were inspired by several important professional articles, documents and studies, as well as scientific publications. There are mainly publications that deal with the issues of rail passenger transport and passenger transport flows, for example (Sun et al., 2019; Dedík et al., 2024; Gašparík et al., 2020). Other articles (Bulíček, 2018; Zhao et al., 2023; Bulková et al., 2022; Bartuška et al., 2023) for a change, deal with the issue of railway operations, train traffic diagram construction and timetabling. Therefore it is currently essential to follow up on the mentioned research in the context of the implementation and development of new night connections.

Currently, night transport in the Slovak Republic is not sufficiently developed, as only one line currently operates in domestic transport, namely from Bratislava via Žilina and Košice to Humenné, and in international transport, there are lines on the Košice - Žilina - Prague and Budapest - Bratislava - Prague - Berlin - (Warsaw). Figure 1 shows the current night connections of the state carrier Železničná spoločnosť Slovensko, which currently operate in the territory of the Slovak Republic.



▲ Fig 1 Current night railway lines in the Slovak republic (ZSSK, 2024)

2. Methodology and main results

In the case of proposals for connections, it is necessary to use universal scientific research methods, such as the brainstorming method, the analysis and synthesis method, as well as the Delphi method. It is also necessary to consider basic mathematical and statistical principles and other associated methods. When proposing new night train connections, it is important to focus on factors that will allow us to predict the intensity and direction of transport flows. The key is to analyse these factors:

- the number of inhabitants in individual settlements on the transport route,
- the population momentum in given regions and between settlements,
- the transport distance between individual settlements,
- the attractiveness of the given area (whether tourism potential, recreation, job opportunities, the presence of educational institutions, etc.).



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Based on the above factors, it is appropriate to consider whether it is possible to express their influence using mathematical relationships or models. It is important to focus on such variables that allow for exact expression, since not all aspects can be quantified. This work considers the use of a well-known formula from the field of geography, which is used to calculate population density. This formula can be suitably modified and applied to the needs of rail passenger transport, specifically to calculate population density within transport routes. Its shape is as follows:

$$H = \frac{A}{D} \tag{1}$$

where:

H – population density of the transport route (number of inhabitants/km),

A – number of inhabitants of individual settlements of the transport route (pcs),

D – length of the transport route (km).

The above calculation could be used to estimate the potential number of passengers, or to model traffic flows between individual settlements within the transport routes. Based on the analysis of the factors considered and the initial scientific and professional outputs of the above scientific task, it is possible to propose new routes for night train connections. These proposals also include transport routes where night connections are currently missing, while during the day there is relatively high-quality transport service and a higher number of transported passengers on these routes (Dedík et al., 2024).

Based on the above factors, as well as on the current passenger demand and current gaps and shortcomings in international night transport in the Slovak Republic, in the above contribution we will focus on the proposal of 4 main night lines. These are the following lines:

1. Budapest – Miskolc- Hidasnémeti – Košice – Muszyna – Krakow – Warsaw,

- Košice – Žilina – Bratislava – Vienna – Salzburg – Munich,
- Uzhorod – Košice – Žilina – Púchov – Brno – Prague,
- Humenné – Košice – Žilina – Bratislava – Vienna.

Tables 1 and 2 show the values adjacent to the individual proposed routes. These are the population numbers of the individual settlements where these connections will stop, then the total population, the length of the transport route in kilometres, and finally the resulting value according to the relationship $H=A/D$, which expresses the population density of the transport route (Vengrín, 2025).

▼ Table 1 The adjacent values of the first and second proposed railway connection (Eurostat, 2026)

City	Population	City	Population
	Number of inhabitants		Number of inhabitants
Budapest	1,685,000	Košice	230,000
Hatvan	20,000	Kysak	1,300
Mezőkövesd	16,000	Margecany	1,900
Miskolc	150,000	Spišská Nová Ves	37,000
Hidasnémeti	1,100	Poprad-Tatry	51,000
Košice	230,000	Liptovský Mikuláš	31,000
Kysak	1,300	Ružomberok	56,500
Prešov	82,300	Vrútky	7,500
Lipany	6,500	Žilina	80,000
Muszyna	4,500	Považská Bystrica	39,000
Nowy Sącz	80,500	Púchov	17,000
Tarnów	106,000	Trenčín	54,000
Krakow	804,000	Piešťany	26,000
Kielce	187,000	Trnava	63,000
Skar.-Kamienna	48,500	Bratislava	478,000
Radom	225,000	Vienna	1,920,000
Warsaw	1,862,000	St. Pölten	57,000
		Linz	212,000
		Salzburg	148,000
		Munich	1,512,000
A	5,514,700	A	5,022,200
D	913	D	979
H	6,040.2	H	5,129.93



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▼ Table 2 The adjacent values of the third and fourth proposed railway connection (Eurostat, 2026)

City	Population		City	Population	
	Number of inhabitants			Number of inhabitants	
Uzhorod	81,000		Humenné	29,000	
Chop	8,000		Strážske	4,000	
Košice	230,000		Michalovce	35,000	
Kysak	1,300		Trebišov	22,000	
Margecany	1,900		Košice	230,000	
Spišská Nová Ves	37,000		Kysak	1,300	
Poprad-Tatry	51,000		Margecany	1,900	
Liptovský Mikuláš	31,000		Spišská Nová Ves	37,000	
Ružomberok	56,500		Poprad-Tatry	51,000	
Vrútky	7,500		Liptovský Mikuláš	31,000	
Žilina	80,000		Ružomberok	56,500	
Považská Bystrica	36,000		Vrútky	7,500	
Púchov	16,000		Žilina	80,000	
Horní Lideč	1,000		Považská Bystrica	36,000	
Vsetín	25,000		Púchov	16,000	
Valašské Meziříčí	22,000		Trenčín	54,000	
Hranice na Moravě	18,000		Nové Mesto n/V	19,000	
Přerov	41,700		Piešťany	26,000	
Výškov na Moravě	21,400		Leopoldov	3,000	
Brno	400,000		Trnava	63,000	
Česká Třebová	15,000		Braťslava	478,000	
Pardubice	92,000		Vienna	1,920,000	
Kolín	33,000				
Prague	1,397,000				
A	2,703,300		A	3,201,200	
D	874		D	606	
H	3,093,02		H	5,282.51	

The following sub-chapters briefly describe the individual 4 proposals, including the proposed timetable for individual connections in both directions.

1. Railway connection Budapest – Košice – Warsaw and back

This route runs between two European capitals Budapest and Warsaw through the eastern part of Slovakia, while also serving other important cities, such as Miskolc in Hungary, Košice and Prešov in Slovakia and Kraków in Poland. However, the railway traffic on the railway line in Slovakia and southern Poland is not very fast, but in the context of night transport this will not be a problem and the transport potential for a night

connection is relatively high. When creating the timetable, which is shown in Table 3, particular attention was paid to ensuring optimal traffic service on individual line sections. For example, on the Budapest - Košice section, this connection is also the last daily connection on this route, on the Kraków - Warsaw section, it helps to supplement the strong morning peak on this route in the even-numbered direction. In the opposite direction, it is one of the last evening connections in the Warsaw - Kraków direction and the first morning connection on the Košice - Budapest route.

▼ Table 3 Train timetable on the route Budapest - Košice - Warsaw and back

Station	NighJet 180 Warszawa		NighJet 181 Warszawa	
	Arrival	Departure	Arrival	Departure
Budapest-Keleti pu		20:12	8:54	
Hatvan	20:56	20:59	8:08	8:10
Mezőkövesd	21:47	21:49	7:19	7:20
Miskolc-Tiszai	22:25	22:28	6:40	6:43
Hidasnémeti	23:18	23:29	5:48	6:00
Košice	23:51	23:55	5:22	5:26
Kysak	0:08	0:10	5:07	5:09
Prešov	0:29	0:31	4:46	4:48
Lipany	0:54	0:55	4:22	4:23
Plaveč	1:22	1:50	3:33	3:55
Muszyna	2:08	2:15	3:11	3:15
Nowy Sącz	3:04	3:06	2:20	2:22
Tarnów	4:29	4:31	0:57	0:59
Kraków Główny	5:23	5:38	23:56	0:05
Kielce Główny	6:58	7:01	22:36	22:38
Skarżysko-Kamienna	7:35	7:36	22:01	22:02
Radom Główny	8:02	8:04	21:33	21:35
Warszawa Zachodnia	8:52	8:54	20:43	20:45
Warszawa Centralna	8:58	9:01	20:36	20:39
Warszawa Wschodnia	9:07			20:30

The recommended potential train composition for the entire route in both directions is three seating cars - specifically 2 "Bpmz" series cars, 1 "Bmz" car, two "WLABmnouz" series sleeping cars, one "Bcz" series couchette car. However, in the Kraków - Warsaw section and back, it would be appropriate to add 2 second class "Bmnouz" series cars of the PKPIC company.



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2. Railway connection Košice – Žilina – Bratislava – Vienna – Munich

The route from Košice via Žilina, Bratislava, Vienna, Linz, Salzburg to Munich represents an important night rail connection between eastern Slovakia and southern Germany. It passes through important settlements that play a key role in supra-regional mobility, education and economy. The proposed timetable for the night train connection between Košice and Munich is shown in the table 4. It offers attractive travel times for different groups of passengers, considering logistical needs, comfort and the possibility of efficient use of time during the day and night.

However, in the section Vienna - Munich and back, it would be appropriate to add 3 second class cars of the „Bmpz“ series of the OBB company.

3. Uzhorod – Košice – Žilina – Púchov – Brno – Praha

The proposed night train route connects the western Ukrainian city of Uzhhorod with major centres of the Slovak Republic (Košice, Poprad, Žilina) and with two largest cities of the Czech Republic (Brno and Prague). Passenger flows between the Ukraine and the Czech Republic, or Slovakia, have recently increased significantly, so it is necessary to introduce new train connections. This is also the last night connection between eastern Slovakia and Prague, and the only direct night connection between eastern Slovakia and Brno. In the opposite direction, this is the first morning connection between the Czech Republic and Košice. The timetable is shown in the table 5. The arrival and departure times of trains at the Ukrainian stations Chop and Uzhhorod are given in brackets because they are expressed in Eastern European time.

▼ Table 4 Timetable on the route Košice – Žilina – Vienna – Munich and back

Station	NightJet 496		NightJet 497	
	Arrival	Departure	Arrival	Departure
Košice		22:20	6:47	
Kysak	22:32	22:34	6:33	6:35
Margecany	22:48	22:50	6:17	6:19
Spišská Nová Ves	23:16	23:18	5:49	5:51
Poprad-Tatry	23:42	23:45	5:21	5:25
Liptovský Mikuláš	0:22	0:24	4:42	4:44
Ružomberok	0:41	0:43	4:23	4:25
Vrútky	1:08	1:10	3:56	3:58
Žilina	1:26	1:40	3:10	3:40
Považská Bystrica	2:01	2:03	2:47	2:49
Púchov	2:11	2:13	2:37	2:39
Trenčín	2:30	2:32	2:15	2:20
Piešťany	2:55	2:57	1:52	1:54
Trnava	3:18	3:25	1:33	1:35
Bratislava - Vinohrady	3:47	3:48	1:11	1:12
Bratislava hl.st.	3:54	4:15	0:51	1:05
Wien Hbf	5:01	5:10	23:54	0:05
Wien Meidling	5:15	5:17	23:47	23:49
St. Pölten Hbf	5:43	5:45	23:19	23:21
Linz Hbf	6:40	6:42	22:22	22:24
Salzburg Hbf	7:54	8:05	21:00	21:10
München Hbf	9:45			19:20

The train connection is primarily intended for night transport between eastern Slovakia and Vienna, and possibly also Bratislava, where it arrives in the very early morning hours. It is also the first morning train connection between Vienna and Munich. In the opposite direction, it serves as the last connection on the mentioned route. The recommended potential train composition for the entire route in both directions is three sitting cars - specifically 2 cars of the „Bmpz“ series, 1 car of the „Bmz“ series, two sleeping cars of the „WLABmee“ series, one couchette car of the „Bcmz“ series.

▼ Table 5 Timetable on the route Uzhorod – Košice – Žilina – Púchov – Brno – Prague and back

Station	NightJet 444 Tisa		NightJet 445 Tisa	
	Arrival	Departure	Arrival	Departure
Uzhorod		(19:40)	(11:30)	
Chop	(20:10)	(21:25)	(9:40)	(11:00)
Košice	22:57	23:20	5:47	6:00
Kysak	23:32	23:34	5:33	5:35
Margecany	23:48	23:50	5:17	5:19
Spišská Nová Ves	0:16	0:18	4:49	4:51
Poprad-Tatry	0:42	0:45	4:21	4:25
Liptovský Mikuláš	1:22	1:24	3:42	3:44
Ružomberok	1:41	1:43	3:23	3:25
Vrútky	2:08	2:10	2:56	2:58
Žilina	2:26	2:55	2:13	2:40
Považská Bystrica	3:16	3:18	1:50	1:52
Púchov	3:26	3:28	1:40	1:42
Horní Lideč	3:51	3:55	1:13	1:17
Vsetín	4:11	4:13	0:55	0:57
Vaňoškovo Mezíříčí	4:30	4:32	0:36	0:38
Hranice na Moravě	4:52	4:54	0:14	0:16
Přerov	5:12	5:14	23:54	23:56
Výškov na Moravě	5:49	5:50	23:18	23:19
Brno hl. n.	6:32	6:37	22:31	22:36
Česká Třebová	7:37	7:39	21:29	21:31
Pardubice hl. n.	8:14	8:16	20:52	20:54
Kolín	8:35	8:37	20:31	20:33
Praha Libeň	9:10	9:11	19:57	19:58
Praha hl. n.	9:18			19:50



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The recommended potential train composition for the entire route in both directions is four seating cars - specifically 2 „Bpeer“ series cars, 2 „Bmz“ series cars, three „WLABmee“ series sleeping cars and 1 „Bcmz“ series couchette car.

4. Humenné – Košice – Žilina – Bratislava – Vienna

The last proposed connection is the extension of the current night connection R 681 / 680 Zemplín on the route Humenné – Košice – Žilina – Bratislava hl. st. up to the Wien Hbf station. This is another night connection between eastern Slovakia and Vienna. However, this connection is primarily aimed at connecting the area east of Košice with Bratislava and Vienna, while the second proposal was primarily aimed at connecting Košice with area west of Vienna. The proposed timetable in both directions is shown in Table 6.

▼ Table 6 Timetable on the route Humenné – Košice – Žilina – Bratislava - Vienna and back

Station	NightJet 680 Zemplín		↑	NightJet 681 Zemplín	
	Arrival	Departure		Arrival	Departure
Humenné		22:35		6:36	
Strážske	22:43	22:44		6:26	6:28
Michalovce	22:55	22:57		6:13	6:15
Trebišov	23:12	23:14		5:56	5:58
Košice	23:59	0:30		4:32	5:10
Kysak	0:42	0:44		4:18	4:20
Margecany	0:58	1:00		4:02	4:04
Spišská Nová Ves	1:26	1:28		3:34	3:36
Poprad-Tatry	1:52	1:55		3:06	3:10
Liptovský Mikuláš	2:32	2:34		2:27	2:29
Ružomberok	2:51	2:53		2:08	2:10
Vrútky	3:18	3:20		1:41	1:43
Žilina	3:36	3:55		1:02	1:25
Považská Bystrica	4:16	4:18		0:39	0:41
Púchov	4:26	4:28		0:29	0:31
Trenčín	4:49	4:51		0:06	0:08
Nové Mesto nV	5:07	5:09	23:48	23:50	
Piešťany	5:21	5:23	23:35	23:37	
Leopoldov	5:35	5:37	23:21	23:23	
Trnava	5:48	5:52	23:07	23:10	
Bratislava - Vinohrady	6:13	6:14	22:45	22:46	
Bratislava hl. st.	6:20	6:30	22:31	22:40	
Wien Hbf	7:16			21:45	

The recommended potential train composition for the entire route in both directions is 4 seating cars - specifically 2 „Bpeer“ cars, 2 „Bdteer“ cars, 3 „WLABmee“ sleeping cars and 2 „Bcmz“ couchette cars.

We also recommend seasonally or on selected days on the entire route to include another „WLABmee“ sleeping car and a „DDm“ wagon for transporting passenger cars.

3. Economic evaluation of proposals

The economic evaluation of the proposed connections includes a brief preliminary calculation of operating costs for traction vehicles, passenger cars, electricity consumption (if applicable), personnel management and fees for the use of the railway route. The calculations are carried out for a period of one calendar year (Vengrín, 2025).

Total annual costs for the chosen variant 2

Total costs represent the sum of the costs of the locomotives and their energy consumption, the costs of wagons, the costs of providing employees and the fees for the use of railways. The calculation of total costs is carried out for a period of one calendar year. Preliminary estimated values of the railway connection Košice – Žilina – Bratislava – Vienna – Munich are given in Table 7 (Vengrín, 2025).

▼ Table 7 Total annual costs for all variants (Vengrín, 2025)

Railway connection Košice – Žilina – Bratislava – Vienna – Munich		
Locomotive and consumption costs	1,984.48	thousand €/year
Wagon costs	5,442.19	thousand €/year
Employee costs	1,032.39	thousand €/year
Railway infrastructure usage costs	2,052.71	€/train
Direct costs	10,525.77	thousand €/year
Indirect costs	4,511.04	thousand €/year
Total costs	15,036.81	thousand €/year
Rate per 1 train km	21.23	€/train km

Example of fare estimate for option 2

Within the framework of the potential pricing proposal, the 2nd variant was selected, i.e. the Košice – Munich and back line. To set the ticket prices, the total annual costs of operating the train were first calculated, which amounted to €15,036,812.27. The capacity of the train set is 328 seats, with the following distribution: 60 beds, 54 couchettes and 214 seats.



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When proposing the prices, an average occupancy rate of 60% of the train capacity was considered. At this level of use, the train will transport approximately 196,800 passengers per year. To cover the annual costs, it was necessary to set the basic ticket price at €65.40 per passenger from Košice to Munich. To differentiate travel comfort, the following coefficients were applied:

- the price of a couchette is 40% higher than the price of a seat,
- the price of a bed is 110% higher than the price of a seat.
-

After calculations and rounding the prices up to the nearest €0.10, the following basic ticket prices were determined:

- Seat: €46.60,
- Couchette: €65.20,
- Bed: €97.70.

These prices will ensure the coverage of all operating costs while maintaining the expected occupancy of the trains and at the same time create a reserve for generating profit in the event of higher passenger interest (Vengrín, 2025).

4. Conclusion

The aim of the paper was to briefly analyse the current state of night passenger rail transport in Slovakia, including international connections, and subsequently propose new night train connections that could contribute to improve the quality and attractiveness of this transport form. Night train connections have declined in recent decades, with only a few lines operating today. This trend was driven by various factors, such as economic, technological and political circumstances, which affected the availability and competitiveness of these connections.

The second chapter was devoted to the proposal of new night train connections. Based on an analysis of transport needs and population density in the regions, four new routes were proposed:

1. Budapest – Miskolc- Hidasnémeti – Košice – Muszyna – Krakow – Warsaw,
2. Košice – Žilina – Bratislava – Vienna – Salzburg – Munich,
3. Uzhorod – Košice – Žilina – Púchov – Brno – Prague,
4. Humenné – Košice – Žilina – Bratislava – Vienna.

The proposal of the connections took into account factors such as distance, population density, importance of individual cities and potential for improving regional connectivity. Detailed timetables were created, including a recommended preliminary ordering of individual connections.

The third chapter briefly elaborated on the operational-economic evaluation of the proposed connections, where individual types of costs were calculated. These calculations showed that the proposed connections are economically sustainable, and based on these analyses, a proposal for setting ticket prices for model variant number 2 was created.

In conclusion, it can be stated that night rail transport represents a significant opportunity for the development of ecological and efficient transport in Central Europe. The proposed connections can improve accessibility for passengers on long routes and contribute to increasing the competitiveness of rail transport compared to other transport modes, such as air and bus connections. For the successful implementation of these proposals, it will be necessary to continue monitoring the market and adjusting prices and train capacity to current passenger needs. In the future, attention should also be paid to further developing the infrastructure, improving travel comfort and using modern technologies to optimise the operation of night trains.



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These steps can help make night rail transport a more attractive and efficient alternative to other forms of transport, especially in the context of the European Union's visions and strategies to make ecological and environmentally friendly modes of transport and public passenger transport more attractive and widespread.

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Declaration

The authors declare that they have no conflict of interest. Generative AI tools were employed solely for language refinement. The authors retain full responsibility for the accuracy and integrity of the content.

References

Bartuška, L., Stopka, O., Ľupták, V. & Mašek, J. (2023). Approach Draft to Evaluate the Transport System State—A Case Study Regarding the Estimation Ratio Model of Transport Supply and Demand. *Applied Sciences (Switzerland)*, 13(7), 4638. <https://doi.org/10.3390/app13074638>

Blainey, S. & Hare, B. (2025). An assessment of the potential contribution of overnight trains to sustainable long distance travel in Europe. *Case Studies on Transport Policy*, 22, 101599. <https://doi.org/10.1016/j.cstp.2025.101599>

Buh, B. & Peer, S. (2024). Environmental concern and the determinants of night train use: Evidence from Vienna (Austria). *Travel Behaviour and Society*, 36, 100802. <https://doi.org/10.1016/j.tbs.2024.100802>

Bulíček, J. (2018). Timetable synchronisation: Urban public transport in busy hubs of long-distance transport. In *Siberian Transport Forum – TransSiberia 2018*, 16-19 May 2018 (02001). Novosibirsk, Russia: MATEC Web of Conferences. <https://doi.org/10.1051/mateconf/201823902001>

Bulková, Z., Gašparík, J., Mašek, J. & Zitrický, V. (2022). Analytical Procedures for the Evaluation of Infrastructural Measures for Increasing the Capacity of Railway Lines. *Sustainability (Switzerland)*, 14(21), 14430. <https://doi.org/10.3390/su142114430>

Dedík M., Kampf R., Pečený, L. & Ľupták V. (2024). Determination of the Long-Haul Routes Attractiveness in Railway Passenger Transport in Europe. *Transportation Research Procedia*, 77, 179-186. <https://doi.org/10.1016/j.trpro.2024.01.024>

Eurostat. (2026). The statistical office of the European Union. Available online: <https://ec.europa.eu/eurostat>

Gašparík, J., Bulková, Z. & Dedík, M. (2024). Prediction of Transport Performance Development Due to the Impact of COVID-19 Measures in the Context of Sustainable Mobility in Railway Passenger Transport in the Slovak Republic. *Sustainability*, 16(13), 5283. <https://doi.org/10.3390/su16135283>

Gašparík, J., Dedík, M. & Čechovič, L. (2020). Estimation of Transport Potential in Regional Rail Passenger Transport by Using the Innovative Mathematical-Statistical Gravity Approach. *Sustainability*, 12(9), 3821. <https://doi.org/10.3390/su12093821>

Gerosa, T. & Cellina, F. (2024). Who uses night trains and why? A mixed-method study profiling night train users in Switzerland. *Travel Behaviour and Society*, 37, 100854. <https://doi.org/10.1016/j.tbs.2024.100854>



Framework for Reintroducing and Expanding Night Railway Services in Central Europe: The Slovak Perspective

Kantelaar, M.H., Molin, E., Cats, O., Donners, B. & Van Wee, B. (2022). Willingness to use night trains for long-distance travel. Travel Behaviour and Society, 29, 339-349. <https://doi.org/10.1016/j.tbs.2022.08.00>

Kortekaas, C.H. (2024). An Overview of Sustainability-Related Strengths and Weaknesses of Night Trains in Europe. Global Journal of Tourism, Leisure and Hospitality Management 1(1), 555555. <https://doi.org/10.19080/GJTLH.2024.01.555555>

Rickfelder, T. & Schönberger, J. (2024). Determining the potential of international passenger rail services with applications to the European night train market. Transportation 2024. <https://doi.org/10.1007/s11116-024-10565-7>

Sun, Q., Wang, X., Ma, F., Han, Y. & Cheng, Q. (2019). Synergetic Effect and Spatial-Temporal Evolution of Railway Transportation in Sustainable Development of Trade: An Empirical Study Based on the Belt and Road. Sustainability, 11(6), 1721. <https://doi.org/10.3390/su11061721>

Tomeš, Z. & Pařil, V. 2026. Night trains – Sustainable alternative or niche market? Research in Transportation Business & Management, 64, 101569. <https://doi.org/10.1016/j.rtbm.2025.101569>

Vengrín, M. (2025). Proposal for New Night Connections in Rail Passenger Transport in the Slovak Republic [Diploma thesis]. University of Žilina, Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, 111 p.

Železničná spoločnosť Slovensko, a. s. (2024). Night trains (in Slovak), National operator of Slovak Republic. Available online: <https://www.zssk.sk/nocny-vlak/>

Zhao, Y., Li, D., Yin, Y. & Zhao, X. (2023). Integrated optimization of demand-driven timetable, train formation plan and rolling stock circulation with variable running times and dwell times. Transportation Research Part E: Logistics and Transportation Review, 171(3), 103035. <https://doi.org/10.1016/j.tre.2023.103035>



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Wie wird Holztransport resilienter und nachhaltiger?

DAS FORSCHUNGSPROJEKT REGIOWOODTRAIN STELLT DIE WEICHEN FÜR DATENBASIERTE ENTSCHEIDUNGSGRUNDLAGEN DURCH DIGITALE SIMULATION UND GEOAI

VON KOGLER C., HACKER-ZAGLER J., KIENHOEFER F. S., HAHN J. UND SCHOLZ J.

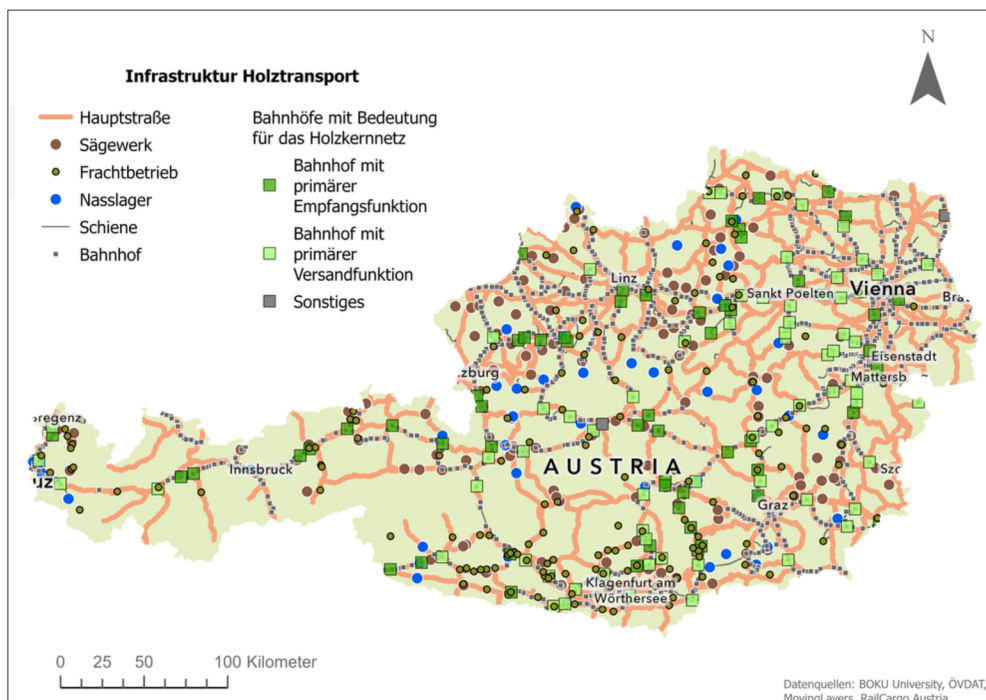
Österreichs nachhaltiger Schlüsselsektor

Der heute allgegenwärtige Begriff der Nachhaltigkeit hat seine Wurzeln in der Forstwirtschaft und stand ursprünglich für das Prinzip, nur so viele Bäume zu nutzen, wie nachwachsen können. Österreichs Wälder bedecken knapp die Hälfte der Staatsfläche und liegen damit sowohl über dem EU- als auch über dem globalen Durchschnitt. Die österreichische Waldlandschaft besteht zu rund vier Fünfteln aus Nadelbäumen, wobei die Fichte die Baumartenverteilung dominiert [1].

Diese Rohstoffbasis ist weit mehr als eine landschaftliche Besonderheit. Die Nutzfunktion des Waldes sichert entlang der österreichischen Holzlieferkette rund 300.000 Arbeitsplätze in etwa 172.000 Unternehmen.

Die Produktionsleistung liegt bei rund 12 Milliarden Euro und der Handelsüberschuss bei etwa 4,5 Milliarden Euro. Damit zählt Österreich beim Export seit Jahren konstant zu den Top 10 weltweit und liegt gemessen an der Bevölkerungszahl in den absoluten Spitzenrängen [2].

Ob der wirtschaftliche, ökologische und regionale Nutzen des Rohstoffs Holz unter zunehmend volatilen Bedingungen tatsächlich wirksam werden kann, hängt wesentlich von einer leistungsfähigen Holzlogistik ab. Zwischen Wald und Werk liegt heute nicht nur eine Transportstrecke, sondern ein strategischer Raum mit Trocken- und Nasslager sowie Umschlagterminals, in dem sich Versorgungssicherheit, Klimaschutz und Wettbewerbsfähigkeit konkret entscheiden (Abbildung 1).



▲ Abb. 1 Wichtige Infrastruktur für die Holzlogistik in Österreich (Auswahl)



Wie wird Holztransport resilienter und nachhaltiger?

Was nützt der Wald, wenn klimabedingte Störungen zur Normalität werden?

Wie groß der Anpassungsdruck inzwischen geworden ist, zeigen insbesondere die jährlichen Schadholzmengen. Im Zeitraum 2014 bis 2023 entfielen in Österreich durchschnittlich 42% des gesamten Holzeinschlags auf Schadholz [3].

Fast die Hälfte des Einschlags war damit in den vergangenen Jahren nicht Ergebnis regulärer Planung, sondern Ausdruck klimabedingter abiotischer (Sturm, Trockenheit, Eisbruch) oder biotischer Störungen (Borkenkäfer- oder Pilzbefall). Was früher als Ausnahme galt, prägt zunehmend die Holzlogistik und erfordert über operatives Notfallmanagement hinaus auch taktisches und strategisches Risikomanagement.

Denn die Folgen reichen weit über den Wald hinaus. Große Schadholzmengen müssen in kurzer Zeit geerntet, zwischengelagert, verladen, transportiert und verarbeitet werden. Fehlen Kapazitäten oder stocken Informationsflüsse, entstehen Engpässe entlang der Lieferkette. Verzögerungen erhöhen Lager- und Durchlaufzeiten sowie das Risiko von Qualitätsverlusten und Wertminderungen.

Neben der Nutzfunktion des Waldes geraten auch seine Schutz-, Erholungs- und Wohlfahrtsfunktionen unter Druck, etwa dort, wo Wälder vor Naturgefahren wie Erosion, Steinschlag, Lawinen oder Hochwasser schützen und zugleich zentrale Erholungs-, Klima- und Lebensraumfunktionen erfüllen. Damit wird deutlich, warum Holzlogistik zum neuralgischen Punkt der Lieferkette geworden ist, die sich an häufigere und heftigere Störungen anpassen muss, ohne dabei ihre wirtschaftliche Tragfähigkeit und ihren Nachhaltigkeitsanspruch zu verlieren.

Die Verwundbarkeit der Lieferkette zwischen Fachkräftemangel und Leistungsansprüchen

Schwankende Holzmengen, zunehmender Zeitdruck und steigende Anforderungen an Nachhaltigkeit, Effizienz und Transparenz setzen die Holzlogistik in Österreich zunehmend unter Druck.

Holz soll rasch, verlässlich und klimaverträglich transportiert werden. Gerade in Phasen hoher Auslastung zeigt sich, wo die Lieferkette besonders sensibel auf Engpässe, Abstimmungsprobleme und fehlende Informationen reagiert.

Das ist nicht nur eine logistische, sondern auch eine ökologische, soziale und wirtschaftliche Herausforderung. Wird Holz nach Schadereignissen nicht rechtzeitig abtransportiert, kann dies zu Qualitätsverlusten, Wertminderungen und zusätzlichen Belastungen für Lagerung, Umschlag und Verarbeitung führen. Zugleich wächst der Druck, Transporte emissionsärmer zu organisieren und bestehende Infrastrukturen besser zu nutzen. Vor allem der Schienentransport bietet hier wichtige Potenziale, die bislang jedoch nur teilweise ausgeschöpft werden.

Hinzu kommt, dass der Sektor in vielen Bereichen klein strukturiert organisiert ist und stark auf praktische Erfahrung, regionales Wissen und eingespielte Abläufe baut. Das kann in komplexeren Belastungssituationen aber eine rasche und übergreifend abgestimmte Reaktion erschweren. Besonders der Fachkräftemangel verengt die Spielräume in Transport, Disposition und Planung zusätzlich. Die Widerstandsfähigkeit der Lieferkette hängt damit nicht nur von Infrastruktur und Verkehrsträgern ab, sondern auch von qualifiziertem Personal, guten Arbeitsbedingungen und einer vorausschauenden Organisation.

Wo die Forschung ansetzt (wächst Neues)

Hier setzt das RegioWoodTrain Projekt an und untersucht, wie sich die regionale Holzlogistik in Österreich resilienter, nachhaltiger und digitaler gestalten lässt. Im Mittelpunkt steht die Frage, wie multimodale Transporte robuster und digital geplant werden können. Dabei wird kein rein technischer Ansatz verfolgt.



Wie wird Holztransport resilienter und nachhaltiger?

Vielmehr werden betriebliches Expert:innenwissen und qualitative Anforderungen aus der Praxis, lange Zeitreihen vielfältiger räumlicher Daten, GeoAI und simulationsgestützte Analysen so zusammengeführt, dass daraus tragfähige Entscheidungsgrundlagen für Akteur:innen entlang der Lieferkette entstehen.

Ziel ist es, Voraussetzungen dafür zu schaffen, dass robuste Handlungsoptionen im Alltag und im Krisenfall digital verglichen, bewertet und vorbereitet werden können. Gerade in einem Umfeld, in dem große Holzmassen zuverlässig bewegt werden müssen, gewinnt der Bahntransport an Bedeutung. Systematische Entscheidungsunterstützung macht komplexe Zusammenhänge sichtbar und hilft die Folgen unterschiedlicher Logistikstrategien frühzeitig abzuschätzen.

Dialog, Daten und digitale Modelle

Methodisch verfolgt RegioWoodTrain einen interdisziplinären und anwendungsorientierten Forschungsansatz, der qualitative Erhebungen, quantitative Datenanalysen, räumliche Modellierung und digitale Systementwicklung verbindet. Holzlogistik wird dabei als Koordinationsaufgabe einer regionalen Lieferkette verstanden, deren Engpässe meist nicht isoliert, sondern typischerweise an den Schnittstellen zwischen Waldbesitz, Ernte, Straßentransport, Zwischenlagerung, Verladung, Bahntransport und industrieller Übernahme entstehen [4].

Die empirische Grundlage von RegioWoodTrain ist breit und reicht von Interviews, Fallstudien, Stakeholderworkshops, Literaturrecherchen und Umfragen bis zu verknüpften Infrastruktur-, Standort-, Bahn- und Prozessdaten. Zentral ist dabei das Requirements Engineering, das konsequent an den Anforderungen der späteren Nutzer:innen ansetzt. Workshops, Interviews und Umfragen dienen dazu, Personas, Datenanforderungen, Simulationsparameter und Kernfunktionen einer webbasierten Plattform zu entwickeln.

Denn digitale Entscheidungsunterstützung kann in der Logistik nur dann Wirkung entfalten, wenn sie die Praxis nicht überformt, sondern an ihre Arbeitsrealität anschließt.

EINLADUNG

Juni

11

2026

Herzliche Einladung zum nächsten Stakeholderworkshop des RegioWoodTrain Projektes in **Fürnitz, Kärnten**.

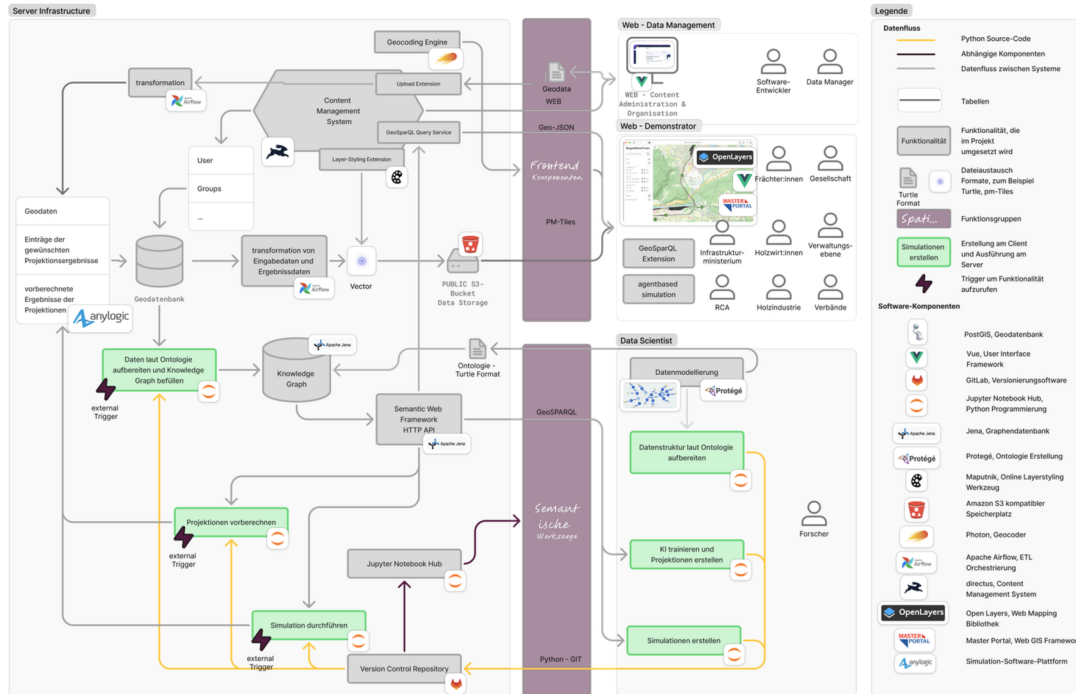
Weitere Information zum Ablauf und Veranstaltungsort gerne per E-Mail-Anfrage an christoph.kogler@boku.ac.at.

Die technische Architektur von RegioWoodTrain basiert auf einer modularen Systemlandschaft, die Softwarekomponenten, Datenbanken und Entwicklungsumgebungen miteinander verknüpft. Sie schafft eine integrierte, erweiterbare und nachvollziehbare Plattform für die gemeinsame Verarbeitung räumlicher, semantischer und statistischer Daten und deckt die gesamte Prozesskette von der Datenerfassung und -speicherung über die Verarbeitung und Simulation bis hin zur Visualisierung und Interaktion im Webportal ab (Abbildung 2).

Die Bedeutung dieser Architektur reicht über das Forschungsprojekt hinaus. Sie schafft nicht nur eine sektorspezifische Lösung für die Holzlogistik, sondern eine technologische Grundlage, die sich auf andere Lieferketten, Transportaufgaben und komplexe Planungsprozesse übertragen lässt, in denen räumliche Daten, unterschiedliche Akteur:innen-Logiken und dynamische Entscheidungen integriert werden.



Wie wird Holztransport resilienter und nachhaltiger?



▲ Abb. 2 Software-Architektur des RegioWoodTrain Projekts. Backend-Systeme wie Python, Apache Airflow, PostGIS und Jena bilden die Grundlage für Datenhaltung, Analyse und Automatisierung. Semantische Komponenten wie der Ontologie-Editor Protégé und die Python-Bibliothek RDFLib werden verwendet um Wissen im GeoKnowledge-Graph zu strukturieren. Frontend-Komponenten wie OpenLayers, Masterportal, Vue und Maputnik ermöglichen die interaktive Visualisierung von Geoinformationen. GitLab, Directus und Amazon S3 unterstützen Versionierung, Datenmanagement und den Austausch großer Datenmengen.

Wir geben Wissen einen Raum

Agentenbasierte und ereignisdiskrete Modellierung ermöglicht es, Zukunftsszenarien wie Kalamitätsereignisse, multimodale Transportkonzepte, Veränderungen in der Schienen- und Bahninfrastruktur oder alternative Verlade- und Lagerstrategien, systematisch zu simulieren und ihre Auswirkungen auf Transportleistung, Emissionen, Kosten und Robustheit vergleichbar zu machen. Simulation wird damit nicht nur zum Analyseinstrument, sondern auch zu einem Experimentier- und Integrationsraum, in dem verschiedene Datenquellen, Entscheidungslogiken und auch bislang nicht erfasste Daten für die Bewertung von Handlungsoptionen nutzbar werden.

Damit folgt das Projekt einem Forschungstrend, der Simulation als zentralen Baustein der nächsten Generation von Holzlogistikmodellierung versteht [5] und die Integration von Machine Learning vorantreibt [6].

Ein zentrales methodisches Element von RegioWoodTrain ist der Aufbau eines GeoKnowledge-Graphen, der Objekte (Knoten) und ihre Beziehungen (Kanten) so abbildet, dass Bedeutungen und Zusammenhänge in den Daten auch für Computermodelle und künstliche Intelligenz nutzbar werden.

Dieser Ansatz dient dazu, unterschiedliche Datenquellen und Formate zu harmonisieren und in eine einheitliche graphbasierte Struktur zu überführen. Dabei werden Objekte wie Wälder, Bahnhöfe oder Sägewerke als Knoten mit eindeutigen Bezeichnungen modelliert und über Kanten verknüpft, sofern Beziehungen zwischen ihnen bestehen. Auch diese Verbindungen tragen eine Bezeichnung, welche die Art der Beziehung beschreibt, etwa eine Straßen- oder Bahnverbindung. Knoten und Kanten können zusätzlich mit Attributen versehen werden, etwa zur geografischen Lage, Größe und Betriebszeit von Bahnhöfen oder zur Entfernung zwischen Wald und Sägewerk.



Wie wird Holztransport resilienter und nachhaltiger?

Dieser GeoKnowledge-Graph dient im Anschluss als Datengrundlage für das Training einer GeoAI, einer spezialisierten Form künstlicher Intelligenz, die geografisch verortete Daten analysieren und verstehen kann. Auf dieser Basis erkennt sie Muster und erstellt Prognosen über künftige Entwicklungen. Solche Prognosen unterstützen die kurzfristige Planung, etwa bei der Einschätzung der Auslastung sowie des Bedarfs an Waggons und Personal, ebenso wie langfristige Entscheidungen, beispielsweise zur Frage, wo zusätzliche Verlade- oder Empfangsbahnhöfe erforderlich sind.

Für diese Prognosen ist eine ganzheitliche Betrachtung der Infrastruktur erforderlich, da entsprechende Entscheidungen nur selten isoliert getroffen werden können. Vielmehr müssen infrastrukturelle Abhängigkeiten systematisch verstanden und in die Analyse einbezogen werden, was zu den besonderen Stärken GeoAI-gestützter Ansätze zählt. Gerade in Kalamitäts-szenarien wie Windwurf, Borkenkäferbefall oder Waldbränden kann die GeoAI wertvolle Einblicke liefern, da solche Ereignisse häufig größere Teile der Infrastruktur betreffen und den Bedarf an Personal und Waggons kurzfristig stark verändern können.

Damit eignet sie sich besonders für die Analyse der österreichischen Holzlieferkette sowie der zugehörigen Straßen- und Schienennetzinfrastruktur.

Die Kombination aus GeoKnowledge-Graph und GeoAI, die in dieser Form erstmals auf die österreichische Holzlieferkette angewendet wird, begründet einen innovativen Ansatz, um historisch gewachsene Datenbestände systematisch nutzbar zu machen. Das ist besonders wertvoll, weil diese Informationen bislang oft als getrennte Dateninseln in nicht kompatiblen Formaten vorlagen. Dadurch konnten relevante Informationen kaum in Planungsprozesse integriert werden, sodass Entscheidungen vielfach auf implizitem Wissen beruhten. Künftig kann die GeoAI solche Entscheidungen datengetrieben unterstützen

und damit insbesondere in fragmentierten Lieferketten zu mehr Transparenz und Nachvollziehbarkeit beitragen. Der in RegioWoodTrain entwickelte technologische Ansatz ist zudem auf viele weitere Anwendungsfelder übertragbar, in denen Lieferketten analysiert und komplexe Entscheidungssituationen fundiert unterstützt werden müssen.

Was sich bisher mit Blick auf Österreich abzeichnet

Die Herausforderungen in der Holzlogistik sind nicht nur technischer Natur. Engpässe entstehen nicht allein deshalb, weil irgendwo ein Terminal fehlt oder zu wenige Waggons bereitstehen. Vielmehr verdichten sich die Probleme an den Schnittstellen von Infrastruktur, Organisation, Daten, Wirtschaftlichkeit und Personal. Dies entspricht auch den Ergebnissen einer empirischen Studie zur Resilienz von Holztransport in Österreich, wonach zusätzliche Lagerkapazitäten, eine stärkere Kooperation, ein verbesserter Datenaustausch und multimodale Transportlösungen zu den wichtigsten Hebeln für mehr Resilienz zählen [3].

Besonders anschaulich zeigt sich dies bei der Frage nach geeigneten Verlade- und Lagerstandorten. Ein Standort ist nicht schon deshalb ein relevanter Ladepunkt, weil dort ein Gleis vorhanden ist. Fallstudien zeigen vielmehr, dass konkrete Voraussetzungen wie Gleislänge, Erreichbarkeit, Lagerfläche, Befestigung, Beleuchtung, Umschlagtechnik, rechtliche Absicherung und betriebliche Einbettung ausschlaggebend sind. Potenziale für zusätzliche oder reaktivierbare Bahnverladeplätze sind vorhanden und können benannt werden, doch ohne vorbereitete Prozesse und klare Zuständigkeiten bleiben sie im Krisenfall vielfach ungenutzt. Genau hier kann datenbasierte Entscheidungsunterstützung einen wichtigen Beitrag leisten, indem sie Standortinformationen, Nutzungsanforderungen und Szenarien systematisch zusammenführt.



Wie wird Holztransport resilienter und nachhaltiger?

Ebenso relevant ist die Abstimmung zwischen den beteiligten Akteuren. In der Praxis entstehen Reibungsverluste überall dort, wo Waggonbereitstellung, Beladung, Zwischenlagerung, Abtransport und Informationsflüsse nicht ausreichend koordiniert sind. In der empirischen Analyse berichteten die befragten Unternehmen von hoher Zusatzbelastung in Kalamitätsphasen, wachsendem Organisationsaufwand und deutlich steigender Nachfrage nach Transportkapazität.

Besonders aufschlussreich ist dabei, dass Transportkosten, Emissionen und Zuverlässigkeit als wichtigste Einflussfaktoren auf Transportentscheidungen genannt werden, während auch der organisatorische Aufwand erheblich ins Gewicht fällt.

Hinzu kommen Wartezeiten und mangelnde Transparenz an den Schnittstellen zur Industrie, wie bereits eine empirische Erhebung zur Schadholzlogistik in Österreich gezeigt hat [4]. Verzögerungen bei der Be- und Entladung von LKWs und Waggons verringern die effektiv nutzbare Transportkapazität erheblich, sodass wertvolles Potenzial für zusätzlich transportierbare Kubikmeter Holz ungenutzt verpufft. Resilienz entsteht damit nicht allein durch zusätzliche Transportkapazitäten, sondern ebenso durch bessere Informationsflüsse, verlässlichere Zeitfenster und koordinierte Prozesse.

Die Perspektive von europäischen Holzfrachtunternehmen

Eine in der ersten Projektphase durchgeführte internationale Unternehmensbefragung gibt vergleichende Einblicke in die Perspektiven von Holztransportunternehmen in Österreich, Deutschland, Italien, Tschechien, Polen, Finnland, Lettland und Portugal. Insgesamt nahmen 308 Unternehmen aus acht europäischen Ländern an der Studie teil, wodurch erstmals eine repräsentative internationale Datenbasis für den Holztransport geschaffen wurde. Die aus-

gewählten Länder bilden eine bewusst heterogene Stichprobe, die unterschiedliche Eigentumsstrukturen, Arbeitskräfteprofile, Klimazonen, Verkehrsinfrastrukturen, Modal Splits und Krisenerfahrungen in Europas Holztransportsektor widerspiegelt.

Der standardisierte Onlinefragebogen umfasste 64 Fragen zu Unternehmensstruktur, Marktbedingungen, Arbeitskräften, Infrastruktur, Digitalisierung sowie zu Risiken, Lösungsstrategien und aktuellen regulatorischen Rahmenbedingungen, einschließlich EU-bezogener Umwelt- und Transportvorgaben. Der Fragebogen wurde iterativ in englischer Sprache entwickelt, in drei Review- und Testphasen mit insgesamt 20 Forschungs- und Praxisexpert:innen aus acht Ländern weiterentwickelt, in die jeweiligen Landessprachen übersetzt und durch nationale Vorabtests auf sprachliche Eignung, Verständlichkeit und inhaltliche Vergleichbarkeit geprüft.

Die Ergebnisse zeichnen über Ländergrenzen hinweg ein konsistentes Bild. Holztransportunternehmen agieren in einem wirtschaftlich angespannten Umfeld, das von geringen Margen, steigenden Betriebskosten und wachsendem Wettbewerbsdruck geprägt ist. Zugleich wird der Fachkräftemangel als eines der größten strukturellen Probleme des Sektors genannt. Ein Großteil der Unternehmen berichtet von Schwierigkeiten bei der Rekrutierung neuer Fahrer:innen, während zugleich viele erfahrene Beschäftigte kurz vor dem Ruhestand stehen.

Die Arbeit im Holztransport gilt als physisch anspruchsvoll und zeitlich belastend, was die Attraktivität des Berufs zusätzlich mindert. Vor diesem Hintergrund wird deutlich, dass die Leistungsfähigkeit der gesamten Holzlieferkette nicht nur von Infrastruktur oder Technologie, sondern auch von der langfristigen Sicherung qualifizierter Arbeitskräfte abhängt.



Wie wird Holztransport resilienter und nachhaltiger?

Ein weiterer zentraler Befund betrifft die organisatorische und digitale Struktur des Sektors. Zwar verfügen viele Unternehmen über ein ausgeprägtes Problembewusstsein hinsichtlich Klimarisiken, Kalamitäten und zunehmender Unsicherheit, strategische Risiko- oder Krisenmanagementansätze sind jedoch bislang nur begrenzt verbreitet.

Gleichzeitig sehen die befragten Unternehmen großes Potenzial in einer besseren Koordination entlang der Lieferkette, insbesondere beim Umschlag auf die Bahn, sowie in der Entwicklung digitaler Werkzeuge für Planung und Informationsaustausch.

Besonders häufig genannt wurden verbesserte Datenplattformen, digitale Entscheidungsunterstützung sowie zusätzliche Lager- und Umschlagkapazitäten als Maßnahmen zur Stärkung der Resilienz. Insgesamt zeigt die Umfrage damit, dass technologische Innovationen, multimodale Transportstrategien und eine intensivere Zusammenarbeit zwischen Forstwirtschaft, Trans-

port und Industrie entscheidende Hebel für eine robustere Holzlogistik darstellen.

Die vollständigen Ergebnisse sind bereits in einem wissenschaftlichen Journalbeitrag gebündelt, der sich derzeit im Begutachtungsprozess befindet. Im September werden die daraus gewonnenen Schlussfolgerungen auf der FORMEC-Konferenz in Prag erstmals international vorgestellt und diskutiert, bevor sie durch begleitende populärwissenschaftliche Publikationen, Workshops und Vorträge gezielt an die Praxis und breitere Öffentlichkeit vermittelt werden.

Die Bahn als Chance, nicht als Selbstläufer

Ein entscheidender Zwischenbefund betrifft die Rolle des Schienentransports. Die durchgeführte SWOT-Analyse (Abbildung 3) zeigt deutlich, dass die Bahn im Holztransport vor allem dort ihre Stärken ausspielen kann, wo größere Mengen gebündelt, längere Distanzen überwunden und gut angebundene Standardrouten bedient werden können.



▲ Abb. 3 SWOT-Analyse (S=Strength, W=Weakness, O=Opportunity, T=Threat) des Holztransportes per Bahn in Österreich



Wie wird Holztransport resilienter und nachhaltiger?

Hohe Transportkapazitäten pro Einheit, ein geringerer ökologischer Fußabdruck, die Entlastung des Straßennetzes sowie die Sicherung regionaler Infrastruktur und Wertschöpfung sprechen dafür, der Bahn in resilienten Holzlieferketten eine deutlich aktivere Rolle zuzuweisen. Gerade in Kalamitätssituationen kann sie zusätzliche Kapazitäten bereitstellen und dazu beitragen, Versorgungssicherheit, Emissionsminderung und regionale Stabilität zugleich zu stärken. Gleichzeitig macht die SWOT-Analyse deutlich, dass die Bahn ihr Potenzial nicht automatisch entfaltet. Begrenzte Waggonverfügbarkeit, aufwendige Umschlag- und Verschubprozesse, Informationsdefizite sowie unzureichend ausgestattete Ladepunkte bremsen ihre Nutzung im Alltag und erst recht unter Krisenbedingungen.

Hinzu kommt, dass das Einzelwagensystem seine logistischen Vorteile vielfach nur dann voll entfalten kann, wenn Förderungen bestehen oder regulatorische Rahmenbedingungen zu mehr Risiko- und Kostenwahrheit im Wettbewerb mit dem Straßentransport beitragen. Daraus folgt, dass die Bahn gezielter in multimodale Konzepte eingebettet werden muss. Zielführend ist kein schlichtes Entweder-Oder zwischen Straße und Schiene, sondern ein abgestimmtes Zusammenspiel unterschiedlicher Verkehrsträger.

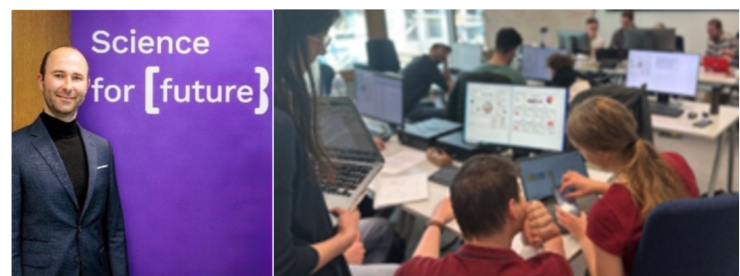
In diesem Zusammenhang erscheint auch der Umschlag auf Sattel als sinnvoller Teil der Lösung. Mehrstufige unimodale Konzepte mit Satteltransporten bieten zusätzliche Flexibilität, höhere Nutzlasten als Kran-LKWs und können gerade auf kürzeren Vor- und Nachläufen oder bei fehlender direkter Bahnanbindung wertvolle Funktionen übernehmen. Ebenso sollten spezialisierte Elektro-LKW im Holztransport mitgedacht werden, vor allem dort, wo kurze Distanzen, regionale Bündelung, effizientes Laden, Energierückgewinnung durch Talfahrten und klimafreundliche Vorläufe im Vordergrund stehen. Eine zukunftsfähige Holzlogistik wird daher nicht von einem einzelnen Verkehrsmittel geprägt sein, sondern von der klugen Kombination elektrifizierter Straßensegmente mit einer strategisch gestärkten Bahn als Rückgrat klimafreundlicher Transporte.

Forschungsgeleitete Lehre und Serious Game-based Learning

An der Universität für Bodenkultur Wien fließen relevante Projektergebnisse laufend in die Lehrveranstaltung Unternehmensführung des Masterstudiengangs Holztechnologie und Management ein. Zentrale Erkenntnisse werden zudem an der Paris Lodron Universität Salzburg in die Studienprogramme Digitalisierung-Innovation-Gesellschaft sowie Applied Geoinformatics eingebracht. An beiden Universitäten werden thematisch eng mit dem Projekt verbundene Masterarbeiten betreut, wobei zwei Studentinnen und zwei Studenten aktiv in die Forschungspraxis eingebunden sind. RegioWoodTrain stärkt damit nicht nur Forschung und Praxis, sondern auch Ausbildung, Nachwuchsförderung und langfristigen Kompetenzaufbau.

Gemeinsam mit Kolleg:innen aus den USA und Großbritannien wurde auf Grundlage dieser forschungsgeleiteten Lehre ein internationales Rahmenwerk für die Simulationsdidaktik entwickelt, das im vergangenen Jahr erstmals auf der Winter Simulation Conference in Seattle vorgestellt wurde und kürzlich im Journal of the Operational Research Society erschienen ist [7].

Dieses Rahmenwerk basiert auf Constructive Alignment und strukturiert Simulationskurse entlang klar aufeinander abgestimmter Lernziele, Lernaktivitäten und Prüfungsformen. Inhaltlich umfasst es modulare Bausteine zu Simulationstheorie, Simulationslebenszyklus, konzeptueller Modellierung sowie erfahrungsbasierten Formaten wie Fallstudien, Serious Games und KI-gestützter Lernbegleitung. Zudem erscheint noch in diesem Jahr ein mitherausgegebener Springer-Band zu Forest Logistics and Supply Chain Management,



▲ Abb. 4 International Wood Supply Game Competition



Wie wird Holztransport resilienter und nachhaltiger?

in dem mehr als 50 renommierte internationale Autor:innen zentrale Forschungsergebnisse der vergangenen zwanzig Jahre bündeln und damit ein künftiges Referenzwerk für die universitäre Lehre und unternehmerische Praxis schaffen.

Ein besonderer Mehrwert des Projekts liegt darin, dass die gewonnenen Erkenntnisse frühzeitig in internationale Ausbildungsformate einfließen. Besonders sichtbar wird dies durch die Mitorganisation der International Wood Supply Game Competition [8]. Grundlage ist ein ausgezeichnetes simulationsbasiertes Planspiel, das komplexe finanzielle, materielle und informationelle Flüsse in Holzlieferketten erfahrbar macht. Studierende erleben dort unter Zeitdruck und Unsicherheit unmittelbar, wie Zielkonflikte zwischen Effizienz, Nachhaltigkeit und Resilienz entstehen und wie stark funktionierende Koordination über den Erfolg ganzer Lieferketten entscheidet. Im Jahr 2025 nahmen 21 Teams von zwölf Universitäten aus neun Ländern teil. Das Format stärkt damit nicht nur analytische und kommunikative Kompetenzen, sondern auch internationales Lernen und interdisziplinäre Zusammenarbeit.

Wie sich ein solches Serious Game-based Learning didaktisch in die universitäre Lehre integrieren lässt, behandelt zudem ein auf Einladung eingereichter Konferenzbeitrag, der in Kooperation mit Kollegen aus Frankreich und Kanada auf der diesjährigen Winter Simulation Conference vorgestellt wird.

Teamwork

Getragen wird das Forschungsprojekt RegioWoodTrain von einem Konsortium, das die fachlichen, methodischen und praktischen Voraussetzungen für das Thema in stimmiger Weise zusammenführt.

Auf Seiten der Universität für Bodenkultur Wien bringen Projektleiter Dr. Christoph Kogler und Prof. Manfred Gronalt ihre Expertise in Holzlogistik, Lieferkettenmanagement, empirischer Forschung und Simulationsmethoden ein und werden dabei von Studierenden der Studiengänge Holztechnologie und Management sowie Forstwissenschaften unterstützt. Die Paris Lodron Universität Salzburg stärkt das Projekt unter der Leitung von Prof. Johannes Scholz gemeinsam mit Florian Sebastian Kienhoefer, Franz Welscher, Thomas Schneidergruber und Susanna Spindler in den Bereichen Geoinformatik und GeoAI. Auf Unternehmensseite verantworten Dr. Jürgen Hahn und Julia Hacker-Zagler gemeinsam mit dem Team von MovingLayers das Requirements Engineering sowie die nutzerorientierte Entwicklung der webbasierten Plattform. Durch Peter Sorian, André Fattome, Evelin Jank und Bernd Koglbauer bringt die Rail Cargo Austria zudem wertvolles Praxiswissen zu Bahnprozessen, Infrastruktur und operativen Abläufen. Gerade diese interdisziplinäre Zusammenarbeit schafft eine sehr gute Grundlage, um RegioWoodTrain erfolgreich umzusetzen und die Kooperation auch in künftigen Forschungs- und Umsetzungsprojekten fortzuführen.



▲ Abb. 5 Projektteam



Wie wird Holztransport resilienter und nachhaltiger?

Wo Zusammenarbeit entlang der Lieferkette gelingt, entstehen die Voraussetzungen für eine resilientere und nachhaltigere Holzlogistik. Resilienz zeigt sich dabei nicht nur im Umgang mit akuten Störungen, sondern auch in der Fähigkeit, Schienen- und Straßentransporte, Infrastruktur und Schnittstellen vorausschauend und abgestimmt zu organisieren. In diesem Zusammenspiel entfaltet die Bahn ihr volles Potenzial für eine nachhaltige Holzlogistik.

Quellen

- [1] Kogler (2023): Neues Waldsterben – Wie durch nachhaltiges und resilientes Holzlieferkettenmanagement eine Risikoreduktion gelingt, Interesse, bit.ly/Interesse2023.
- [2] Kogler (2024): Innovative transport simulation for sustainable and resilient wood logistics, Simulation Notes Europe, doi.org/10.11128/sne.34.tn.10681.
- [3] Kogler, Beiglböck, Rauch (2025): An empirical study of the resilience in Austrian wood transport, Transportation Research Part A: Policy and Practice, doi.org/10.1016/j.tra.2024.104303.
- [4] Kogler, Beiglböck, Rauch (2024): Empirical insights into salvage wood logistics, Croatian Journal of Forest Engineering, doi.org/10.5552/crojfe.2024.2272.
- [5] Zamora-Cristales, Kogler, Sessions et al. (2026): Simulation in forest engineering: planning the next generation of forest operations and logistics for the challenges of the XXI century, Current Forestry Reports, doi.org/10.1007/s40725-026-00268-w.
- [6] Kogler, Maxera (2026): A literature review of supply chain analyses integrating discrete simulation modelling and machine learning, Journal of Simulation, doi.org/10.1080/17477778.2025.2500393.
- [7] Kogler, Roeder, Tako, Anagnostou (2026): An international educational framework for teaching simulation, Journal of the Operational Research Society, doi.org/10.1080/01605682.2026.2656354
- [8] Kogler (2022): Zukünftige Führungskräfte kultivieren Kompetenzen – Wie durch forschungsgeleitete Unternehmensführungslehre internationale Spitzenleistungen gelingen, BOKU Magazin, bit.ly/3rgs0T7.

Förderhinweis

Das Projekt Sustainable Regional Wood Transport through Cooperative Supply Chain Management Integrating Simulation and AI Technology (RegioWoodTrain) wird von der Österreichischen Forschungsförderungsgesellschaft (FFG) aus Mitteln der Ausschreibung Mobilität – Regionen und Digitalisierung des Bundesministeriums für Innovation, Mobilität und Infrastruktur gefördert. Der internationale Austausch im Rahmen des Kooperationsprojekts Serious Game-based and Agent-based Modeling Education for the Forest Value Chain (GAME) wird durch das EPICUR Seed Funding finanziell unterstützt.



Wie wird Holztransport resilienter und nachhaltiger?



Christoph Kogler leitet das Forschungsprojekt RegioWoodTrain als Postdoc am Institut für Produktionswirtschaft und Logistik der Universität für Bodenkultur Wien. Mit zehn Jahren Forschungserfahrung in der Holzlogistik verfügt er über ausgewiesene Expertise im resilienten und nachhaltigen Lieferkettenmanagement, Bioökonomie und Simulation. Durch Forschungsaufenthalte an der UC Berkeley, Universität Freiburg und TU Brno sowie seine wissenschaftliche Tätigkeit als Autor, Editor, Reviewer, Vortragender und preisgekrönter Lehrender verfügt er über ein breites internationales Netzwerk. Im Projekt koordiniert er das Konsortium mittels agilen Projektmanagements und verbindet qualitative Erhebungen, quantitative Datenanalysen und simulationsgestützte Modellierung zur Entwicklung praxisnaher Entscheidungsunterstützung für nachhaltigen Holztransport.



Jürgen Hahn ist Gründer und Geschäftsführer von MovingLayers GmbH. Er promovierte an der TU Wien und sammelte in verschiedenen Rollen Erfahrung in Softwareentwicklung und Geoinformation. Sein Team teilt mit ihm die Vision, Geodaten zum Sprechen zu bringen. Genau das verfolgt er auch im Projekt RegioWoodTrain, in dem Technologien aus der Forschung praktische Anwendung finden, um sprechende Entscheidungsvorlagen für nachhaltigen Holztransport zu erstellen.



Julia Hacker-Zagler ist zertifizierte Requirements-Engineerin (IREB CPRE) und spezialisiert auf die Entwicklung nutzerzentrierter digitaler Lösungen. Als Geoinformatikerin mit einem Masterabschluss in Raumplanung verfügt sie über fundierte Kenntnisse in Verkehrsplanung und Logistik sowie in der Analyse und Verarbeitung von Geodaten. Im Projekt RegioWoodTrain nutzt sie diese Kompetenzen, um Anforderungen systematisch zu erfassen und in praxistaugliche Anwendungen für den Holztransport zu überführen.



Johannes Scholz ist Full Professor für Geoinformatik am Department of Geoinformatics (Z_GIS) der Universität Salzburg. Er leitet die Forschungsgruppen GeoAI, GeoKG und GeoSemantics und beschäftigt sich mit GeoAI, geospatialen Wissensgraphen, semantischer Interoperabilität sowie spatio-temporaler Modellierung und Simulation. Zuvor war er an der TU Wien, TU Graz, den Research Studios Austria und der UC Santa Barbara tätig. Seine Arbeiten finden Anwendung in den Bereichen Energiewende, Mobilität, Logistik, digitaler Tourismus und räumliche Entscheidungsunterstützung. Im Projekt koordiniert er die GeoAI-Methodik und den Aufbau einer digitalen Entscheidungsunterstützung für die Logistikkette Holz.



Florian Sebastian Kienhoefer ist wissenschaftlicher Mitarbeiter und Doktorand in angewandter Geoinformatik an der Universität Salzburg und verfügt über einen Master in Data Science. Seine aktuelle Forschung konzentriert sich auf die Optimierung von Lieferketten mit besonderem Fokus auf graphbasierte KI-Modelle. Im Projekt RegioWoodTrain gestaltet er die Konzeption und Implementierung des GeoKnowledge-Graphen und der GeoAI und kombiniert dafür Data Science mit räumlichen Analysen, um komplexe Infrastrukturen zu modellieren und datenbasierte Entscheidungen zu ermöglichen.



Schlaglicht Europa

PARTICIPATORY MICRO-INTERVENTIONS FOR URBAN RESILIENCE: THE CASE OF THE OUTTA CLIMATE FESTIVALS IN GREECE

BY ANAGNOSTOPOULOS K., NIKOLOPOULOU K. AND LIAKOU H.

1. Introduction

Cities worldwide face growing challenges in ensuring the safety, resilience, and inclusivity of their transport infrastructure amid accelerating climate change and increasing urbanisation. While large-scale infrastructure projects remain essential, the need for small-scale, community-led interventions has become equally critical in fostering adaptable, people-centred mobility systems.

The Outta Climate Festival series, launched in 2023 by CIVINET Greece-Cyprus with funding from the Ministry of Environment and Energy, represents an innovative model of participatory urban change that integrates art, sustainability, and road safety. Inspired by the New European Bauhaus principles, it aims to reimagine public space through creative, rapid, and low-cost interventions that enhance safety, promote active mobility, and cultivate local ownership, while simultaneously raising awareness about climate action and sustainable urban design.

The initiative takes place in the context of a recent national reform in Greece reducing the speed limit in residential areas to 30km/h, a measure that few countries worldwide have implemented. This change offers a unique opportunity to link micro-scale interventions with formal traffic-calming policies.

2. Objectives

- Enhance urban resilience and road safety through participatory interventions in public space.
- Engage young people, schools, and local communities in co-creating safer, climate-conscious urban environments.
- Demonstrate how art-based, small-scale urban design actions can serve as effective, replicable tools for sustainable mobility and behavioural change.
- Develop a collaborative governance model that links municipalities, schools, artists, and civil society in transforming mobility culture and public space use.

- Integrate micro-interventions with broader sustainable mobility frameworks, aligning with both local SUMP and European climate and mobility targets.

3. Methodology

The initiative has been implemented in five Greek municipalities — Agios Dimitrios (September 2023), Vari-Voula-Vouliagmeni (February 2024), Heraklion, Crete (March 2024), Heraklion, Attica (October 2024), and Karpenisi (May 2025) — each adapted to local needs and urban contexts.

The selection of streets and intervention zones outside schools is based on the strategic frameworks of the respective Sustainable Urban Mobility Plans (SUMPs), where these interventions are considered quick-win measures. In SUMPs, the main measure, “Soft Mobility and Urban Regeneration Network”, designates schools as key nodes for initiating and densifying interventions to enhance road safety and sustainable mobility.

Each intervention combines asphalt art murals, participatory workshops, and public cultural performances to reclaim urban space. Under the guidance of professional visual artists such as Soteur and b., students and residents co-design and paint large-scale murals directly on the street surface. These interventions act as visual traffic-calming measures, drawing drivers’ attention to pedestrian zones and improving safety for vulnerable users.

Asphalt art is primarily an awareness and educational tool, with long-term retention depending on pedestrianisation, a strategy proposed for nearly all interventions but not yet widely implemented. The festivals thus function as catalysts for the activation of legislated but unimplemented pedestrian streets. The murals represent only one element of a broader palette of pop-up interventions.

Complementary cultural activities (music, dance, and participatory performances) are organised with the Jazz Solidarity Network, creating an inclusive, intergenerational experience and strengthening social cohesion.



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The methodology is supported by international evidence, such as the Bloomberg Philanthropies' Asphalt Art Initiative, which confirms that such visual interventions can reduce crashes and promote a sense of belonging.

International evidence from a multi-site before-after study of 17 projects found a 50% decrease in crashes involving pedestrians and cyclists, a 37% decrease in injury crashes, and a 17% decrease in total crashes after asphalt-art treatments; observed behaviour also improved, with 27% more drivers yielding and 25% fewer pedestrian-vehicle conflicts.

The approach emphasises cross-sector collaboration, uniting municipalities, schools, artists, media, and NGOs under a shared climate and mobility vision.

Finally, these interventions take place within the context of Greece's recent 30 km/h limit in residential areas, providing a significant opportunity to align micro-scale, community-led actions with nationwide traffic regulations.

4. Observations and Impact

Initial observations indicate a measurable impact in the participating municipalities:

- **Traffic behaviour:** Local authorities reported lower vehicle speeds and increased driver awareness near the decorated zones. These findings are consistent with the Asphalt Art Safety Study's documented reductions in vulnerable-user crashes and conflict behaviours across varied contexts (signalised/unsignalised intersections and painted plaza/pedestrian crossing treatments).
- **Public space quality:** Residents and school communities expressed improved perceptions of safety and ownership of their streets.
- **Social cohesion:** The participatory process strengthened community bonds and intergenerational cooperation.
- **Policy influence:** Several municipalities expressed interest in scaling similar participatory interventions as part of their Sustainable Urban Mobility Plans (SUMP).

Beyond immediate safety outcomes, the Outta Climate Festival serves as a communication bridge between mobility, climate, and educational policy, demonstrating that low-cost, participatory actions can complement formal traffic management strategies and encourage sustainable urban mobility. Future steps include integrating pavement extensions, raised intersections, safe pedestrian crossings, pop-up cycle lanes, green parklets, and smart devices for environmental and traffic monitoring, into broader urban resilience frameworks.

5. Conclusions

The Outta Climate Festival demonstrates that micro-scale, community-driven interventions can meaningfully contribute to transport resilience, behavioural change, and climate awareness. By merging art, mobility, and sustainability, the initiative promotes adaptable, low-cost solutions that enhance safety, accessibility, and liveability.

By combining educational engagement, visual traffic-calming, and alignment with SUMP, these interventions provide a replicable model for cities aiming to strengthen local ownership of transport spaces, align with European climate and mobility goals, and foster public participation in infrastructure adaptation strategies.

Acknowledgement

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Declaration

The authors declare that they have no conflict of interest. Generative AI tools were employed solely for language refinement. The authors retain full responsibility for the accuracy and integrity of the content.



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PARTICIPATORY MICRO-INTERVENTIONS FOR URBAN RESILIENCE: THE CASE OF THE OUTTA CLIMATE FESTIVALS IN GREECE

References

Bloomberg Philanthropies. (2023). Asphalt Art Initiative: Improving Street Safety & Vibrancy through Art. Bloomberg Philanthropies, New York, USA.

European Commission. (2021). The New European Bauhaus: Beautiful, Sustainable, Together. Communication COM (2021) 573. Publications Office of the European Union, Luxembourg.

Hellenic Republic. (2025). Road Traffic Code. Law No. 5209/2025. Official Government Gazette, Issue A, 13 June 2025.

Hellenic Republic. (2020). Law No. 4712/2020: Sustainable Urban Mobility Plans in Greece. Government Gazette, Issue A, 147/8-8-2020.

European Commission. (n.d.). Sustainable Urban Mobility Planning and Monitoring. Retrieved October 2025, from https://transport.ec.europa.eu/transport-themes/urban-transport/sustainable-urban-mobility-planning-and-monitoring_en

CIVINET Greece-Cyprus. (2023-2025) Climate Festival – Project Documentation Videos. YouTube playlist: <https://www.youtube.com/playlist?list=PL4oM6vCmmz-XRWhOk2dGg55B-2FqjBCV>

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Katerina Nikolopoulou is Director of Operations and Head of Proposals at CIVINET Greece–Cyprus. With a background in political science and project management, her work focuses on the design and coordination of European projects at the intersection of sustainable mobility, participatory urban interventions, and social innovation. She explores how small-scale, community-driven actions can contribute to urban resilience and behavioural change.



Hara Liakou is a Political Scientist and International Relations expert with postgraduate studies in Environmental Policy (MSc, UNIWA). She has solid experience in environmental policy, sustainability strategies, and project management. She currently works as Cities Network Manager and Project Manager within CIVINET Greece–Cyprus, coordinating actions that promote sustainable mobility, environmental innovation, and stakeholder engagement.

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ANALYSIS OF RISK FACTORS AFFECTING THE DRIVER SAFETY TOLERANCE ZONE USING DRIVING SIMULATOR DATA FOR ENHANCED MOBILITY RESILIENCE

BY MICHELARAKI E. AND YANNIS G.



1. Introduction

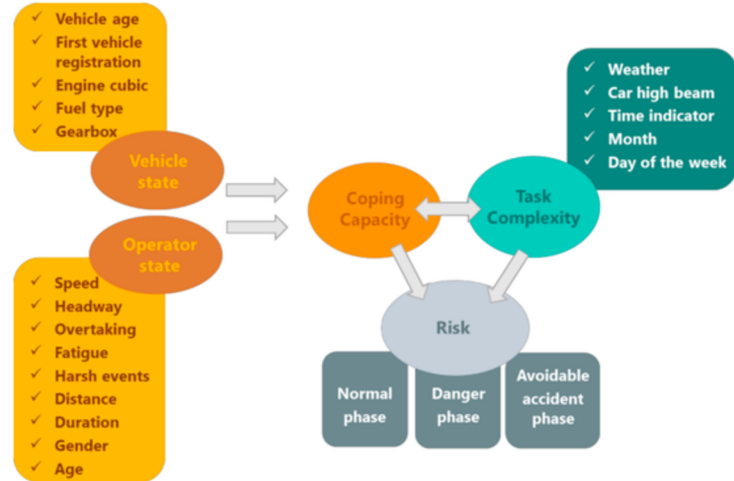
Insufficient headway, the gap between two vehicles, is a major contributor to traffic collisions, as a gap that is too small limits a driver’s ability to react to sudden braking (Fu et al., 2024). Headway can be expressed in time or distance (Risto & Martens, 2013) and maintaining an adequate gap helps drivers manage both physical and cognitive demands by providing time to respond to changing traffic. This reduces stress, cognitive load and supports situational awareness.

The aim of this work is to develop a context-aware Safety Tolerance Zone (STZ), which defines the point at which self-regulated driving remains safe (Michelaraki et al., 2021). The STZ reflects the balance between driving task demands (task complexity) and the driver’s ability to cope with them (coping capacity). It includes three phases: normal driving, where crash risk is low and the driver adapts effectively; danger, where changing conditions increase crash risk but a collision is not yet inevitable; and avoidable accident, where a crash is unfolding but corrective action can still prevent it.

Within the above framework, this study aims to improve driver STZ through the analysis of road, vehicle and behavioural risk factors. The objective of this work was to determine the interactions among road, vehicle and driver risk factors for the STZ identification. More specifically, the impact of task complexity and coping capacity on crash risk was investigated. For that purpose, a large dataset spanning four months from simulator driving experiment was exploited.

2. Data Overview

To fulfill the objective of this work, a simulator experiment was conducted with 55 participants and data from 165 trips were collected and analyzed. Key explanatory variables related to risk and the most reliable indicators of task complexity (e.g. weather, time of the day) and coping capacity (e.g. headway, speed, harsh brakings) were evaluated. Figure 1 presents the conceptual framework used for risk prediction, focusing on task complexity and coping capacity.



▲ Fig 1 Conceptual framework for risk prediction of task complexity and coping capacity

3. Methodology

Structural Equation Modelling (SEM), or path analysis, is a multivariate technique used to test hypotheses about relationships among observed and latent variables (Harrison & Friston, 2007). Observed variables are directly measurable, while latent variables represent underlying constructs. SEM consists of two components: the measurement model, which assesses how well observed variables capture latent constructs and the structural model, which examines causal relationships, including direct and indirect effects (Stein et al., 2011). This combined framework allows SEM to evaluate complex variable interactions beyond what standard regression can capture.

In order to evaluate the model, several goodness-of-fit measures were used. These include GFI and AGFI, which assess how well the model matches the observed covariance matrix and RMSEA, where values ≤ 0.05 indicate a close fit. Comparative indices such as CFI and TLI compare the hypothesised model against an independence model, with values above 0.90 considered indicative of good fit. Lastly, AIC and BIC were examined to balance model fit with model complexity, with lower values reflecting better models.



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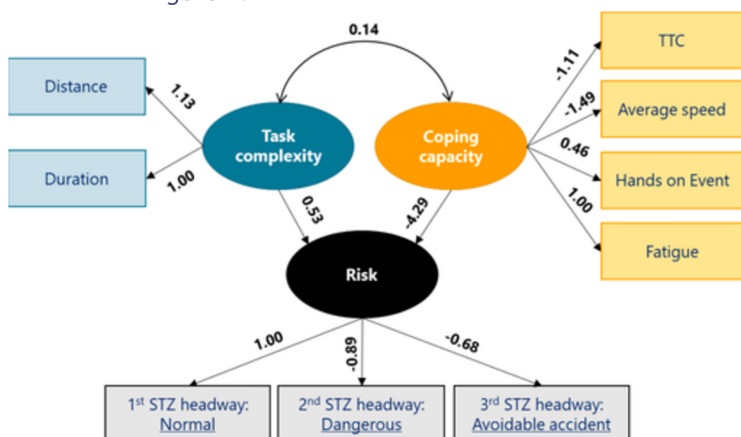
ANALYSIS OF RISK FACTORS AFFECTING THE DRIVER SAFETY TOLERANCE ZONE USING DRIVING SIMULATOR DATA FOR ENHANCED MOBILITY RESILIENCE

4. Results

Risk was assessed using the three STZ headway levels (normal driving, dangerous driving and avoidable accident). Task complexity was represented by trip duration and distance travelled, while coping capacity was measured through driver state indicators such as TTC, average speed, hands-on events and fatigue.

Results showed that distance and duration were positively correlated with task complexity. Hands-on events and fatigue were positively associated with coping capacity, suggesting that fatigued drivers may adopt more cautious behaviours. In contrast, TTC and average speed were negatively correlated with coping capacity, indicating reduced ability to manage driving demands at longer TTC and higher speeds.

SEM findings revealed a positive relationship between task complexity and coping capacity (coefficient = 0.14), implying that drivers tend to increase their engagement as task demands rise. Task complexity showed a strong positive association with risk (0.53), whereas coping capacity showed a strong negative association with risk (-4.29), indicating that higher coping ability reduces crash likelihood. The corresponding SEM path diagram is shown in Figure 2.



▲ Fig 2 SEM results of task complexity and coping capacity on risk (STZ headway)

The resulting GFI was 0.973 and AGFI was 0.952, both exceeding the conventional threshold of 0.90, indicating a very good model fit. Additional indices, including the CFI = 0.966, TLI = 0.944 and RMSEA = 0.079, further support the adequacy of the model and confirm the robustness of the latent structure. Table 1 summarizes the model fit of SEM applied for headway, while residual variances details are presented in Table 2.

▼ Table 1 Model Fit Summary for STZ headway per driving experiment

Model Fit measures	Values
CFI	0.966
TLI	0.944
RMSEA	0.079
GFI	0.973
AGFI	0.952
Hoelter's critical N ($\alpha = .05$)	247.93
Hoelter's critical N ($\alpha = .01$)	300.04
AIC	65281.04
BIC	65445.96

▼ Table 2 Residual variances STZ headway per driving experiment Variable Estimate Std. Error z-value

Variable	Estimate	Std. Error	z-value	P(> z)
Distance	0.108	0.024	4.576	< .001
Duration	0.107	0.023	4.542	< .001
Fatigue	0.950	0.024	39.002	< .001
TTC	0.939	0.025	38.280	< .001
Average speed	0.890	0.026	33.990	< .001
HandsOnEvent	0.989	0.024	40.565	< .001
Headway_STZ_level_0	-0.242	0.059	-4.082	< .001
Headway_STZ_level_1	0.177	0.049	3.652	< .001
Headway_STZ_level_2	0.422	0.029	14.344	< .001

5. Conclusions

This study aimed to improve the Driver Safety Tolerance Zone (STZ) by analysing road, vehicle and behavioural risk factors using driving simulator data. Towards that end, data from a simulator experiment were collected and analysed. SEM revealed that task complexity significantly increased crash risk, especially under demanding conditions such as adverse weather, night-time driving or complex environment.



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ANALYSIS OF RISK FACTORS AFFECTING THE DRIVER SAFETY TOLERANCE ZONE USING DRIVING SIMULATOR DATA FOR ENHANCED MOBILITY RESILIENCE

In contrast, coping capacity showed a strong negative relationship with crash risk, indicating that drivers with higher coping ability are better equipped to manage challenging situations. The analysis also showed a positive relationship between task complexity and coping capacity, suggesting that drivers tend to become more engaged and adaptive when confronted with complex driving tasks. Although coping capacity helps reduce crash likelihood, task complexity exerted a stronger overall influence on risk. A positive association between risk and STZ indicators was also observed, with the highest values appearing during normal driving, highlighting the dynamic nature of risk perception even in seemingly safe conditions.

Overall, the study offers a holistic view of driver safety by integrating driver, vehicle and environmental factors within a unified mobility resilience framework. The STZ proved effective for understanding how drivers respond to changing task demands and coping requirements. Future work with larger, more diverse datasets could improve the generalisability and applicability of this approach.

Acknowledgement

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Declaration

The authors declare that they have no conflict of interest.

References

Fu, C., Lu, Z., Ding, N., & Bai, W. (2024). Distance headway-based safety evaluation of emerging mixed traffic flow under snowy weather. *Physica A: Statistical Mechanics and its Applications*, 642, 129792.

Harrison, L., & Friston, K. J. (2007). Effective connectivity. *Statistical parametric mapping: the analysis of functional brain images*, 508-521.

Michelaraki, E., Katrakazas, C., Brijs, T., & Yannis, G. (2021). Modelling the safety tolerance zone: Recommendations from the i-DREAMS project. In 10th International congress on transportation research.

Risto, M., & Martens, M. H. (2013). Time and space: The difference between following time headway and distance headway instructions. *Transportation research part F: traffic psychology and behaviour*, 17, 45-51.

Stein, C. M., Morris, N. J., & Nock, N. L. (2011). Structural equation modeling. In *Statistical human genetics: Methods and protocols* (pp. 495-512). Totowa, NJ: Humana Press.



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BETWEEN HEAT, FLOODS, AND STORMS: HOW TO ASSESS CLIMATE RESILIENCE FOR TRANSPORT INFRASTRUCTURE

BY BÜGELMAYER-BLASCHEK M., TÖTZER T., GAZZANEO P., HASEL K., HOCHBNER A., KOZLOWSKA A. AND PÖCHERSDORFER P.

1. Introduction

Evidence from recent years indicates that climate change is already driving more frequent and more intense extreme events in Austria, throughout the European Union, and worldwide. The latest assessments by the European Environment Agency (EEA 2025) have shown that the costs of extreme events such as heat waves, floods and storms were higher in the last four years than in all previous years (since 1980).

For instance, the flooding caused by Storm Boris alone resulted in billions of Euros worth of damage to urban areas, industry and infrastructure (Friesenbichler et al. 2024). In order to keep the transport infrastructure functional, existing and future requirements resulting from the consequences of climate change must be taken into account in construction, maintenance and operation today.

The need to prepare for potential climate risks at an early stage has also been recognised by the European Commission and the Austrian government through the revised reporting requirements (CSRD, EU taxonomy) and the Critical Infrastructure Resilience Act. This also requires research efforts to lay the foundations for resilient planning and adaptation of existing and new infrastructure; to enhance cross-system infrastructure resilience through the interaction of research, technology and innovative solutions; and to increasing strategic intelligence within and across infrastructure systems (Dinges et al. 2024).

Various aspects are necessary to ensure resilience, but the basis is knowledge about possible future conditions and impacts. Climate models and climate impact calculations provide an important basis for strategic planning and cost-effective measures.

In this paper, we present a quantitative risk assessment methodology embedded within a resilience framework to comprehensively display (i) the risk assessment procedure applicable to infrastructure and (ii) the potential points of action for infrastructure operators.

2. Methodology

Within the European funded project ICARIA (Russo et al., 2023) the impact of climate risks on critical infrastructure as well as potential cascading effects was assessed for a region in the Austrian province Salzburg. This was done in order to support infrastructure operators in preparing for future conditions. Therefore, all components of risk (hazard, exposure, vulnerability) were analysed with additional focus on multi-hazard events. For example, we investigated the compound occurrence of windstorm and extreme precipitation events, considering events occurring simultaneously in time or space (i.e., within the same day), as well as consecutive events occurring within a defined time window (e.g., one week).

Multi-hazard assessment is particularly important because the occurrence of one event, together with its associated impacts, can alter infrastructure vulnerability and thus increase the risk posed by subsequent events. A well-known example is a windstorm that causes trees to fall and roads to become blocked. If such an event coincides with or is followed by extreme precipitation leading to flooding, emergency services may be unable to access affected areas due to the blocked roads. Hazard data are based on state-of-the-art global climate models (CMIP6, Eyring et al., 2016) driven regional climate model simulations (Bügelmayer et al., 2025), covering Austria at 1km² spatial resolution to account for the most recent global climate models. This dataset includes, among others, the temperature and precipitation projections. Road exposure is assessed using Open Street Map data together with data from federal data sources. The vulnerability of affected traffic is based on cars counted on specific streets.

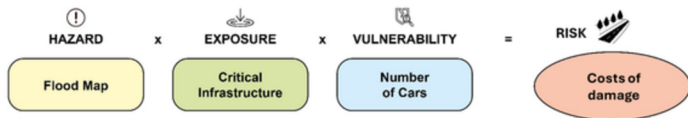
To derive flood maps, a flood model is applied using observed and simulated precipitation data to compute flood depth. Vulnerability is presented in a simplified approach as it encompasses state of the infrastructure (age, maintenance cycle, etc.) which is difficult to collect and quantify.



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One exemplary risk assessment is on affected roads and consequently cars during a flood event (Figure 1).

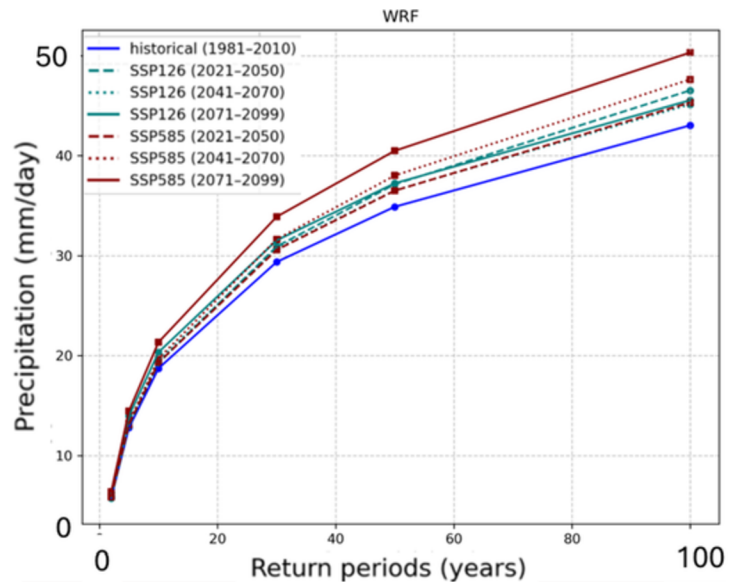


▲ Fig 1 Risk computation workflow – the flood depth computed is combined with the available infrastructure (e.g. roads, railway networks) and in this example with the average number of cars travelling on the roads.

After assessing the risk, indicators relevant for improving the resilience of the region were defined in order to stakeholders to assess and monitor their progress towards resilience. Resilience is defined as "The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. (IPCC, AR2, 2022). To estimate the overall resilience of infrastructure, different indicators can be developed and monitored. Thus, they need to be chosen to support providers in ensuring that the infrastructure fulfills these conditions (anticipate, absorb, recover). Within the European funded project CLIMEMPOWER we investigated in detail various sources of resilience indicators and selected most suitable ones for infrastructure.

3. Results

The analysis of climate data displays an increase in intensity of extreme precipitation events and consequently the flood depth and area. Based on the altered precipitation values (Figure 2), the flooded area and depth are computed within a hydrological model which is combined with the information on available infrastructure to assess risk (see Figure 1).



▲ Fig 2 precipitation intensity (maximum rainfall in mm/day) for the different return periods, climate periods, emission scenarios and climate model (WRF)

To support infrastructure operators, the risk analysis presents a first piece of information but as stated above, the impact varies according to the prevailing vulnerability. This aspect is reflected within resilience indicators and the following were chosen to be the most relevant for infrastructure:

- Number of alternative transport routes to enter / exit the area
- Average age of infrastructure e.g. the water supply network, road network, electrical grid
- Percentage of emergency responders in the city equipped with specialized communication technologies able to operate reliably during a disaster event
- Percentage of critical facilities served by off-grid energy services
- Annual expenditure on upgrades and maintenance of infrastructure as a percentage of total city/regional budget

¹https://www.salzburg.gv.at/fileadmin/Dateien/Verkehr/20606_Stra%C3%9Fenbau/Jahresbericht_Salzburg_2024_250519.pdf



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4. Conclusion

Climate impact maps illustrate the current and projected effects of climate change on transport infrastructure and indicate the degree of resilience of this critical system. The R&D roadmap on climate adaptation for infrastructure (Dinges et al, 2024), which was drawn up on behalf of the Climate and Energy Fund, lists further research and technological development that is required to enable Austria's transport infrastructure to adapt effectively to climate-related challenges. Key topics include forecasting and modeling, sensor technologies and climate-adapted maintenance, green infrastructure, enhanced disaster management, and climate-resilient materials and road design (Dinges et al, 2024).

Significant work therefore remains, and substantial costs will continue to be incurred to make Austria's transport infrastructure fit for a changing climate. In times of constrained public budgets, it is essential to preserve existing infrastructure and enhance its resilience. Developing a strategic roadmap requires robust analyses and a solid evidence base. Climate impact and risk maps can help identify route segments that require prioritization and highlight areas where future interventions are necessary. They also support the assessment of the effectiveness of proposed measures. Risk assessments and simulations can ensure that urgent investments are both climate-resilient and cost-efficient.

Acknowledgement

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Declaration

The authors declare that they have no conflict of interest. The authors retain full responsibility for the accuracy and integrity of the content.

References

- Bügelmayer-Blaschek, M., Hasel, K., Redolat, D., Paradinas, C., & Monjo, R. (2025). Future climate projections for South Aegean and Salzburg region based on statistical and dynamical downscaling-similarities and discrepancies. *Environmental Research Communications*, 7(6), 065003.
- Dinges, M., Brodnik, C., Gasser, M., Tötzer, T., Jung, M., Kupzog, F., Ponweiser, W., Kinner, P., Kollmitzer, C., Latzenhofer, M., Leitner, M., Balas, M., Offenzeller, M., & Wolf-Ott, F. (2024). Klimawandelanpassung Infrastruktur. Energie, Wasser, Verkehr & Kommunikationsnetze. Klima- und Energiefonds der österreichischen Bundesregierung (Hrsg.). https://www.klimafonds.gv.at/wp-content/uploads/2024/03/FE-Fahrplan_KlimaWandel-Anpassung2024-RZ_BF_ISBN.pdf
- EEA, 2025, Economic losses and fatalities from weather- and climate-related extremes (<https://www.eea.europa.eu/en/analysis/publications/economic-losses-from-climate-extremes>) accessed 5 October 2025.
- Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development*, 9(5), 1937-1958.
- Friesenbichler, K., Ialongo, L., Klimek, P., Renhart, A., & Sinabell, F. (2024). A Rapid Assessment of the Economic Impact of the Central European Flood 2024 on Austria. WIFO Research Brief, 14/2024.



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IPCC, 2022: Annex II: Glossary [Möller, V., R. van Diemen, J.B.R. Matthews, C. Méndez, S. Semenov, J.S. Fuglestedt, A. Reisinger (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2897–2930, doi:10.1017/9781009325844.029.

Russo, B., de la Cruz Coronas, À., Leone, M., Evans, B., Brito, R. S., Havlik, D., ... & Sfetsos, A. (2023). Improving climate resilience of critical assets: the ICARIA project. Sustainability, 15(19), 14090.



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SUSTAINABLE LOGISTICS 2030+: A MODEL FOR URBAN LOGISTICS TRANSFORMATION IN VIENNA AND LOWER

AUSTRIA

BY FAAST A. AND HEISS I.

The “Sustainable Logistics 2030+” project is a groundbreaking partnership between the Vienna Economic Chamber, Lower Austria Economic Chamber, and their federal states. Its mission is to organize logistics in the Vienna metropolitan region in a sustainable, efficient, and future-proof manner, creating the right framework for economic, social, and environmental balance.

1. Initial Situation and Challenges

Vienna and its region are experiencing rapid growth, with the population expected to surpass three million by 2030. This growth brings increased traffic, emissions, and land-use conflicts. Logistics must adapt to technological innovation, stricter regulations, and the relocation of logistics areas. The project’s goal is to reduce emissions, optimize traffic, and ensure reliable supply, presenting a joint strategy for sustainable logistics that benefits both society and the economy.

2. Origin and Development

The initiative began in 2015, driven by new climate targets and business needs for planning security. Four main partners—Vienna and Lower Austria Economic Chambers, the City of Vienna, and the federal state of Lower Austria—led the process. Around 300 stakeholders from business, administration, and science participated in workshops and interviews, ensuring diverse perspectives. The process included:

- Identifying key issues and development needs.
- Developing future scenarios for post-2030 logistics.
- Creating the Logistics 2030+ Action Plan, with 35 packages and 133 actions.

3. Objectives

As part of the action plan jointly developed by the four project partners, Logistics 2030+ is therefore pursuing several key objectives:

- Improve the interaction between moving and stationary freight transport and individual transport

- Increase efficiency in logistics and freight transport
- Initiate, support, and accompany cooperation projects
- Sustainably reduce emissions in the federal states of Lower Austria and Vienna
- Develop and support consensus-based logistics and transport concepts

4. The Action Plan – Topic Clusters and Measures

The action plan, developed through stakeholder participation, has been divided into eight fields:

1. Securing logistics areas: Early identification of locations to minimize conflicts.
2. Bundling goods & multimodal concepts: Micro-hubs and multimodal solutions to reduce traffic and pollution.
3. Sustainable parcel delivery: Cargo bikes and alternative delivery times.
4. Low-emission vehicle fleets: Incentives and innovations for climate-friendly transport.
5. Digitalization: Real-time tracking, AI route optimization, and smart logistics.
6. Legal framework improvement: Policy adjustments to support sustainable logistics.
7. Awareness & communication: Campaigns to promote sustainable logistics.
8. Monitoring & evaluation: Regular review and adjustment of measures.

At the end of the last project period in 2024, all topic areas were reviewed. As a result, by the end of the year 2024, 97% of actions were in progress, with an overall implementation rate of 85%.

5. From the Action Plan to the Strategic Agenda

Building on the strong implementation success of the Action Plan, the Logistics 2030+ initiative entered a new project phase in 2025. In order to remain effective under changing conditions and emerging challenges, the Action Plan was further developed into a Strategic Agenda.



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This transition reflects the need for a more compact, flexible, and strategically oriented framework. The Strategic Agenda consolidates the previous eight thematic fields into five overarching topic clusters, allowing for clearer prioritization, greater adaptability, and stronger strategic focus:

- **Freight Flows and Locations:** this cluster aims to strengthen modern logistics through the targeted development and use of suitable locations and the efficient organization of freight volumes and flows. A shared understanding of logistics areas and clear criteria for suitable and unsuitable locations supports informed location decisions and development.
- **Last Mile (R)Evolution:** this cluster focuses on developing innovative, low-emission solutions for last-mile delivery across all logistics segments, key milestones include the further development of city hubs and micro-hubs, the introduction of time-shifted delivery concepts, and the use of intelligent systems and IT solutions.
- **Modal Shift:** Incentives are created to strengthen rail-based freight transport and multimodal transport chains, supporting a shift toward more environmentally friendly transport modes.
- **New Logistics Concepts:** economically and ecologically efficient, resilient logistics solutions for urban and regional freight distribution, focuses on optimizing distribution and delivery systems by building on existing structures, avoiding redundancies, and strengthening bundling and consolidation.
- **Zero Emission:** focuses on advancing low- and zero-emission freight transport and supporting the transition away from fossil fuels. It promotes future-proof solutions that reduce emissions and noise, leverage innovative vehicle concepts, and enable climate-friendly freight mobility

6. Impact

On Society and the Mobility system

The project aims to reduce freight transport volumes, emissions, and noise, while maintaining supply quality. Continuous feedback and pilot projects ensure practical solutions. The interdisciplinary approach integrates urbanization, climate crisis, and digitalization into strategy.

On Business location and Value Creation

The region's competitiveness is supported by efficient logistics, digitalization, and cross-border cooperation. Measures are evaluated for feasibility, cost, and risk, and categorized by implementation horizon.

The significance of the project was also recognized with the awarding of the VCO Mobility Award 2020. This prestigious award highlights innovative and sustainable mobility solutions, underscoring the project's contribution to environmentally friendly and future-oriented transportation.

7. Cooperation Projects – Milestones for Practical Implementation

Cooperation projects for L2030+ are one of the greatest added values as they ensure a systematic approach and high transparency in communication and implementation. They deliver concrete physical results, creating tangible value. Notably, 70% of the projects have scaling potential, allowing successful approaches to be sustainably transferred to larger structures.

These projects specifically focus on new technologies, intelligent control systems and sustainable mobility concepts all aimed at enhancing efficiency and minimizing environmental impact.



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Below some of these promising initiatives are listed in more detail:

- Central LogPOINT: A city hub in Vienna for CO₂-free parcel delivery using cargo bikes and e-vehicles.
- WienBox/NextBox: An open network of parcel lockers, reducing congestion and integrating local retailers.
- LOGSTEP: Zero-emission delivery for field technicians, decoupling technician journeys from material deliveries.
- CO₂-Free Construction Site: Pilot sites to test climate-neutral construction logistics.
- Zero Emission Transport: Over 40 companies committed to emission-free transport in Vienna's central districts.

8. Education – A Building Block for the Future

From 2025/26, Vienna Business School will offer LogistikHAK, a logistics management program developed with the Vienna Chamber of Commerce. The curriculum emphasizes digitalization, sustainability, and practical experience, preparing students for careers in logistics.

9. Conclusion, Opportunities, and Connectivity

Sustainable Logistics 2030+ is a model for future-proof, resilient, and efficient urban logistics. Its holistic approach, strong partnerships, and openness to adaptation make it transferable to other regions. The project demonstrates tangible benefits—CO₂ reduction, minimized conflicts, and improved quality of life—and offers a blueprint for sustainable logistics worldwide.

References

Homepage: <https://www.logistik2030.at/>

All cooperation Projects: Kooperationsprojekte – Logistik 2030+

Media Reports: Medienberichte – Logistik 2030+



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Institution

Vienna Economic Chamber



Schlaglicht Europa

SIMULATION TO DISCOVER THE ENVIRONMENTAL COST OF HIGHWAY SPEEDING

BY HORVÁTH B. AND NAGY V.

1. Introduction

Today, the traffic load on high-capacity roads that also handle international transit traffic has reached a critical level, making the operation of these network elements highly sensitive to disturbances. Even the smallest disruption can cause prolonged operational failures. Under these circumstances, the traffic flow is rather inhomogeneous with a lot of acceleration and deceleration, which causes greater environmental impact.

These data clearly show that these high traffic volumes on the Hungary's "M1" highway (7,000 PCU/h/direction) combined with an extremely inhomogeneous traffic flow result in a dangerous flow with rather high emission.

2. Literature Review

Earlier studies on this topic have not focused extensively on the question of travel-time loss but not on emissions.

Peer [1] approached the topic by comparing the perceived time savings of drivers with their actual time savings in an urban environment. Fuller et al. [2] investigated how changes in speed influence the estimated travel time. Wiklund et al.'s [3] studies are somewhat closer to the focus of the present investigation but only examined the relationship between speed choice and travel time on single-lane roads.

Recarte and Nunes [4] studied the relationships between speed, estimated arrival time, and actual arrival time. Based on earlier work by Peer and Rosenbloom [5], they identified the combination of significantly overestimated time savings and the psychological "thrill of speed" as the primary drivers of speeding behaviour. Similarly, Ruimin et al. [6] compared the estimated and actual time savings in the context of speed choice.

Kim et al. [7] started from an assumption close to our study that there is a systematic difference between perceived and actual speed, and this difference can be measured.

Eriksson et al. [8] analysed whether time-saving estimations of drivers were realistic when increasing speed. Zhang [9] reached the same conclusion as Eriksson et al., Ruimin et al., Kim et al., and Peer, again using Kim's spot-speed measurement approach.

The reviewed literature discusses in detail the issues of estimated versus actual time savings and travel time. However, they did not pay too much attention to the environmental impact of speeding only the real- and perceived-time savings.

3. Methodology

In our research, we used the SUMO [10] microscopic traffic simulation system. This is an open-access, open-source simulation tool that can be programmed during runtime, even using a general-purpose language such as Python.

The simulation model represents the section of the M1 motorway between Győr and Budapest. In the study, we simulate traffic on the main highway that leads to Budapest.

The simulation was based on the average traffic volumes for 2019 on the motorway, which ranged between 1600 and 2,000 PCU/h depending on the cross section. This traffic volume was used as the base load in the simulation. In addition to this base load, a series of test vehicles was introduced. Here, test vehicles refer to vehicles that were added to the measured traffic with predefined speeds (110-150 km/h in steps of 5 km/h). These vehicles represent the measuring cars whose speeds were fixed for each free-flow section of the highway. In total, we examined nine speed categories, each measured eight times, distributed over time.

Vehicles in base traffic were assigned random speeds according to realistic speed distributions.

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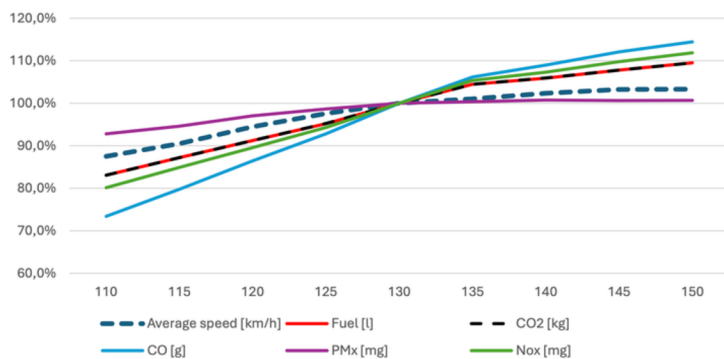


The simulations were executed using the combined base and measuring traffic. Each simulation run lasted 10 hours to ensure the proper loading and stabilisation of the network. The movements of the test vehicles were recorded on each ramp, resulting in intermediate measurement sections and allowing the entire route to be recorded.

For model validation, verification trips were made along the investigated section of the motorway at a target speed of 125 km/h. The average difference between the observed travel times and those obtained in the simulation was 35 seconds (1.4%), which indicates that the simulation can be considered reliable.

4. Results

The objective of the simulation runs was to determine the emission of the different speed classes. The results show that speed and, therefore, time savings are increasing slower than emission values, as shown in Figure 1.



▲ Fig 1 Results of simulation runs.

Even this highly simplified calculation clearly shows that the time savings from speeding are far from sufficient to offset the additional emission costs. This does not yet consider the effects of risk, increased stress, or additional wear and tear on the vehicle. Based on these findings, it can be concluded that for drivers who exceed the speed limit, the assumed risk does not generate benefits but rather results in unnecessary expenses.

5. Conclusions

Based on simulation runs performed in this study, it can be concluded that compared to travelling at legal speed (used as the target speed), the risks and environmental costs associated with speeding far exceed any potential gains. Consequently, speeding is not only illegal and dangerous, but also ecologically irrational.

Declaration

The authors declare that they have no conflict of interest. Generative AI tools were employed solely for language refinement. The authors retain full responsibility for the accuracy and integrity of the content.

References

- [1] Eyal Peer: Speeding and the time-saving bias: How drivers' estimations of time saved in higher speed affects their choice of speed, *Accident Analysis & Prevention*, Vol 42/6, 2010, pp 1978-1982, ISSN 0001-4575, DOI: 10.1016/j.aap.2010.06.003.
- [2] R. Fuller, M. Gormley, S. Stradling, P. Broughton, N. Kinnear, C. O'Dolan, B. Hannigan: Impact of speed change on estimated journey time: Failure of drivers to appreciate relevance of initial speed, *Accident Analysis & Prevention*, Vol 41/ 1, 2009, pp 10-14, ISSN 0001-4575, DOI: 10.1016/j.aap.2008.07.013.
- [3] Mats Wiklund, Arne Carlsson, Olle Eriksson, Johan Olstam, Andreas Tapani: Effects of desired speeds for queuing and delay on single-lane road segments, *Transportmetrica A Transport Science*, Vol 11/8, 2015, pp 716-728, ISSN 2324-9935, DOI: 10.1080/23249935.2015.1066462.
- [4] Miguel Angel Recarte, Luis M. Nunes: Effects of distance and speed on time to arrival estimation in an automobile: two classes of time?" *Engineering*, 1998.

Schlaglicht Europa

SIMULATION TO DISCOVER THE ENVIRONMENTAL COST OF HIGHWAY SPEEDING



[5] Eyal Peer, Tove Rosenbloom: When two motivations race: The effects of time-saving bias and sensation-seeking on driving speed choices, *Accident Analysis & Prevention*, Vol 50, 2013, pp 1135-1139, ISSN 0001-4575, DOI: 10.1016/j.aap.2012.09.002.

[6] Ruimin Li, Geoffrey Rose, Majid Sarvi: Evaluation of Speed-Based Travel Time Estimation Models. *Journal of Transportation Engineering*, Vol 132/7, 2016, DOI: 10.1061/(ASCE)0733-947X(2006)132:7(540)

[7] Hyungjoo Kim, Youngho Kim, Kitae Jang: Systematic Relation of Estimated Travel Speed and Actual Travel Speed. *IEEE Transactions on Intelligent Transportation Systems*. 18. pp 2780-2789. 2017, DOI: 10.1109/TITS.2017.2713983.

[8] G. Eriksson, C. J. D. Patten, O. Svenson, L. Eriksson: Estimated time of arrival and debiasing the time saving bias. *Ergonomics*, 58(12), pp 1939–1946. 2015, DOI: 10.1080/00140139.2015.1051592

[9] Wang Zhang: Freeway Travel Time Estimation Based on Spot Speed Measurements, PhD dissertation, Virginia Tech, 2006

[10] Pablo Alvarez Lopez - Michael Behrisch - Laura Bieker-Walz - Jakob Erdmann - Yun-Pang Flötteröd - Robert Hilbrich - Leonhard Lücken - Johannes Rummel - Peter Wagner - Evamarie Wiessner: Microscopic Traffic Simulation using SUMO, 2018 21st International Conference on Intelligent Transportation Systems (ITSC), 2575-2582, 2018



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INTEGRATING MOBILITY STRATEGY MONITORING TASKS INTO THE SUMP PROCESS IN BUDAPEST

BY ANDRÁS V. AND TÜNDE H.



1. Introduction

Sustainable urban mobility planning has a decades-long history in Budapest, with the Budapest Mobility Plan (BMT) [1] serving as its foundational document. Since the adoption of the capital's first SUMP, the Balázs Mór Plan [2], in 2015, the Budapest General Assembly has adopted revised mobility plans twice, in 2019 and 2023, with increasingly detailed content. Thanks to the developing SUMP methodological framework of the European Union, the results of the cyclical planning phases, which are repeated every 4-5 years, are increasingly detailed, with a transport development strategy embedded in urban development plans.

A general requirement for the planning of urban development strategies is that the monitoring of the agreed objectives should also be developed and adopted, and that a strategic, data-based assessment of the impact of the plans should be carried out. In the case of Budapest, the City Report [3] is used to monitor the At home in Budapest – Integrated Urban Development Strategy (ITS) [4], while the Sustainable Energy and Climate Action Plan of Budapest (SECAP) [5] and the Budapest Environmental Protection Program [6] is provided by the Budapest Environmental Status Assessment [7], which has been published annually since 2011.

The framework for monitoring the strategic objectives of the BMT is provided by the BMT Monitoring and Evaluation System [8], on the basis of which the BKK Centre for Budapest Transport published its first SUMP-based monitoring report for Budapest on March 20, 2025, presenting and analyzing the strategic indicators [9]. This report is described in detail in our article.

2. How was the BMT monitoring system created?

Since 2013, the City of Budapest has been using the SUMP (Sustainable Urban Mobility Plan) methodological framework to develop its transport strategy, which was initiated by the European Commission in its White Paper adopted in 2011. Following a process of institutional and

social consultation, the Balázs Mór Plan [2], adopted in 2015, was Budapest's first SUMP-based transport strategy, followed by the 2019 and 2023 Budapest Mobility Plans [1].

SUMP planning is a people-centered planning approach in which proposals for the development of different modes of transport are coordinated and integrated into urban development plans. The main goal of the Budapest SUMP is that by 2030, 8 out of 10 trips in the capital will be made in a sustainable manner—on foot, by bicycle, or by public transport—and that greenhouse gas emissions from transport will be significantly reduced. The SUMP emphasizes making public transport more attractive, encouraging walking and cycling, improving conditions for these modes of transport, and improving transport connections within the agglomeration. The SUMP's target system, adopted in 2023, is presented in Figure 1.



▲ Fig 1 The target system of the Budapest Mobility Plan, operational targets aligned with strategic goals and areas of intervention.



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It is characteristic of SUMP planning that the approved plan sets long-term goals based on data, to which measurable indicators are assigned. The systematic planning of transport development impact monitoring was first undertaken in 2019 during the preparation of the Budapest Mobility Plan (BMT) [10], but the planned monitoring process has not yet been launched in the following years. This can be attributed to methodological shortcomings in the EU monitoring system, the excessive detail of the set of indicators, but above all to a lack of data and resources. During the 2023 review of the BMT, the monitoring system was also reviewed [11] and, based on the results of the SUMI (Sustainable Urban Mobility Indicators) research and development project [12] available at that time and EU legislation, the range of indicators to be calculated and the method of calculation were defined in much more concrete terms. The process of preparing the Budapest Mobility Plan and thus the application of the monitoring system is also facilitated by the fact that the municipality of the capital has established the institutional background necessary for planning within the Budapest Transport Centre. This process coincided fortunately with the institutional strengthening of data-based decision-making, the establishment of strategic data management, and the creation of a data warehouse.

3. Legal background

In December 2023, the European Parliament adopted the Regulation on the Trans-European Transport Network (TEN-T) concerning Union guidelines for the development of the trans-European transport network [13]. The regulation stipulates that all nodes of the TEN-T network, including Budapest, must have a SUMP-based transport development plan. The legislation defines a uniform set of topics for all TEN-T hubs across the EU, for which indicators must be used to measure urban transport impacts.

A sustainable urban mobility plan must include:

- greenhouse gas emissions,
- traffic congestion,
- accidents and injuries,
- the modal share of mobility services, and
- accessibility,
- objectives, targets and indicators underpinning the current and future performance of the urban transport system,
- data on air and noise pollution in cities.

Budapest intends to comply with the legal requirements by adopting the BMT, reviewing it regularly, and publishing an annual Budapest mobility report. In addition to EU legislation, Resolution 859/2023. (X. 25.) of the Budapest General Assembly [14] also provides for the regular monitoring of the BMT. By the time our paper is published, in 2026, the recommendations adopted by the European Commission are expected to be available, containing the set of indicators to be defined uniformly for SUMP and the detailed methodology for their calculation.

4. Principles for preparing the Budapest Mobility Report, frequency of reporting

When preparing the SUMP report, it is important to ensure that the summary strategic information is presented in a way that is easy to understand and accessible not only to experts but also to the general public. Our goal is to provide objective and transparent information – primarily in quantitative terms, the results should be placed in context, the causes and background processes should be identified, and conclusions, whether positive or negative (e.g., identifying corrective needs), should be drawn and general recommendations should be formulated in a way that is easy to understand. To this end, we have developed a uniform data sheet layout to present all indicators in a clear manner. The indicator data sheet uniformly displays the indicator code number, title, topic specified in the TEN-T Regulation and its code, infographics illustrating the indicator, and the evaluation and analysis of the indicator.



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For each indicator, we uniformly display its unit of measurement, base value, calculated actual value, and target value set for 2030. The definition of the indicator, the calculation methodology, and additional information to help understand the application of the methodology are presented on a separate page.

The BMT monitoring system provides for the calculation of more than 40 strategic indicators and 44 progress indices, but the annual reports will contain 20-30 of these indicators. The detailed assessment prepared for the BMT review, which is planned every five years, will be more comprehensive than the annual reports and will present the progress of all indicators in the monitoring system.

5. Conclusion

Budapest's mobility planning reached a new milestone in March 2025 with the publication of its first SUMP report. In addition to basic data on general transport, the Budapest Mobility Report for 2023 calculated and evaluated 14 core indicators, 6 complementary indicators, and 44 progress indices based on the BMT Monitoring System. The evaluation of the indicators provided a comprehensive strategic overview of the progress made towards the goals set out in the Budapest Mobility Plan. Unfortunately, only a small proportion of the projects envisaged in the BMT investment program could be implemented in the last planning cycle, primarily due to a lack of funds, and the financial background for the implementation of the projects therefore, the achievement of the BMT's goals is also fraught with uncertainty. At the same time, BKK is working intensively to identify the most cost-effective developments that will enable us to approach the goals set out in the BMT by 2030, even in an environment of limited resources. The Budapest Mobility Report is an important tool for defining development priorities and preparing data-driven decisions.

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References

- [1] Budapest Mobility Plan – Budapest Mobility Plan - BKK.hu (2025.09.29.)
- [2] Balázs Mór Plan 2015 - bkk.hu/downloads/6416/ (2025.09.29.)
- [3] City Report (Városjelentés) 2022–2023 OTTHON BUDAPESTEN PROGRAM MONITORINGJA: https://budapest.hu/api/file/doc/Varosjelentes_2022_2023.pdf (2025.09.29.)
- [4] At home in Budapest – Integrated Urban Development Strategy -ITS_2027_III_STRATEGIA_EN_20211001.pdf (2025.09.29.)
- [5] Sustainable Energy and Climate Action Plan of Budapest SECAP –(BP_klimastrategia_SECAP_EN_final.pdf) (2025.09.29.)
- [6] Budapest Environmental Protection Program (Budapest Főváros Környezetvédelmi Programja) - BKP_2021-2026.pdf (2025.09.29.)
- [7] Budapest Environmental Status Assessment (Budapest környezeti állapotértékelése): https://budapest.hu/api/file/doc/BK%C3%83%C2%81%C3%83%C2%89_2023.pdf (2025.09.29.)
- [8] BMT Monitoring- és értékelési rendszer 2023: <https://bkk.hu/rolunk/strategiank/budapesti-mobilitasi-terv/elfogadott-budapesti-mobilitasi-tervek/2023/> (2025.09.29.)
- [9] Budapesti mobilitási riport 2023– Budapest Mobility Report (2025.09.29.)

Schlaglicht Europa

INTEGRATING MOBILITY STRATEGY MONITORING TASKS INTO THE SUMP PROCESS IN BUDAPEST



[10] Hajnal T. – Kerényi L. S. – dr. Juhász M.: A fenntartható mobilitástervezés monitoring és értékelési rendszerének kialakítása Budapesten. <https://bkk.hu/downloads/5522/> (2025.09.29.)

[11] Kimmer D. – Hajnal T.: Revision of the Budapest Mobility plan, and the alignment of urban and transport strategies in Budapest © The Authors, under exclusive license to Springer Nature Switzerland AG 2023 E. G. Nathanail et al. (Eds.): CSUM 2022, 2023. https://doi.org/10.1007/978-3-031-23721-8_132 (2023.04.19)

[12] Technical support related to sustainable urban mobility indicators (SUMI): https://transport.ec.europa.eu/system/files/2020-09/sumi_wp1_harmonisation_guidelines.pdf (2025.09.29.)

[13] Sustainable urban mobility planning and monitoring are key for the trans-European transport network - Sustainable urban mobility planning and monitoring - European Commission (2025.09.29.)

[14] Fővárosi Közgyűlés 859/2023. (X. 25.) határozata - E-Információszabadság oldalak (2025.09.29.)



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From the very beginning, she has been involved in the technical supervision of the development of the Budapest Mobility Plan, as well as in organizing the institutional framework for the planning process. Her responsibilities include developing the strategic monitoring system and preparing the annual monitoring report.

Institution

BKK Centre for Budapest Transport



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THE IMPACT OF ROAD TRAFFIC ON AIR POLLUTION AND CLIMATE CHANGE: EMISSIONS TRENDS AND FORECASTING USING COPERT

BY ŠOŠTARIĆ M., JAKOVLJEVIĆ M., ŠVAJDA M., GRUHONJIĆ D. AND MANJARIĆ J.

1. Introduction

Road transport is the dominant global mode for passengers and freight but also the largest source of transport-related pollution. It contributes to about 25% of global GHG emissions and 73% of transport-sector emissions in the EU, or 20% of total EU GHGs.

Although rail and maritime emit less, their limited reach sustains road dependence [1].

Vehicle emissions, mainly CO₂, NO_x, PM_{2.5}, PM₁₀, VOCs, and CO, cause millions of premature deaths yearly. The EU's Green Deal, Fit for 55, and Euro standards aim for climate neutrality by 2050. In Croatia, road transport dominates due to weak rail and public transport. The aging fleet (14.6 years vs. EU's 12.3) raises emissions [2]. The National Energy and Climate Plan targets a 16.7% GHG cut by 2050, but progress and Investment remain limited [3]. This study forecasts Croatia's road transport emissions to 2050 using the COPERT model, assessing CO₂, NO_x, CH₄, CO, PM_{2.5}, and PM₁₀, and potential mitigation strategies.

2. Literature Review

Transport contributes about 15% of global greenhouse gas (GHG) emissions, ranking fourth after energy, industry, and agriculture. In the U.S., it is the top emitter, while in the EU, passenger cars produce 61% of road emissions, followed by trucks (27%) and light commercial vehicles (11%) [4]. This reflects strong car dependence and limited public transport. Road transport emits pollutants such as CO, hydrocarbons, NO_x, PM_{2.5}, PM₁₀, and SO₂, contributing to respiratory and cardiovascular diseases, smog, and acid rain. CO₂, CH₄, and N₂O are key GHGs, with CO₂ dominant and CH₄ and N₂O having higher warming potential.

In Croatia, road transport is a major pollution source, especially in urban areas. Pollution exposure causes over 3,000 premature deaths annually. Although total emissions fell 35% since 2005, transport still accounts for 27%.

The NECP targets a 13.2% renewable energy share in transport and 3.5% of trips by low- or zero-emission vehicles by 2030, but progress is slow due to an aging fleet and limited modal options [5].

The EU, responsible for about 6% of global GHGs, advances reductions through the Green Deal and Fit for 55. Models such as MOVES, TREMOD, PHEM, and COPERT support emission estimation [6]. In Croatia, COPERT has been used for past analyses, but national projections are limited [7]. This study fills that gap by providing the first forward-looking forecast, offering insights for Croatia and similar car-dependent countries.

3. Methodology

The Computer Programme to calculate Emissions from Road Transport (COPERT), developed by the European Environment Agency, is a key tool for estimating air pollutants and greenhouse gas emissions from road transport. Widely used in Europe, it supports various vehicle types and relies on detailed input data such as fleet composition, fuel properties, and meteorological conditions. Its strengths include a solid scientific basis, frequent updates, and flexibility for national and local analyses.

COPERT estimates exhaust (CO₂, NO_x, PM, HC, CO), non-exhaust, and evaporative emissions, using inputs like vehicle counts, activity data, and temperature or humidity [6]. This study applied COPERT to Croatia using 1990-2022 data on registered vehicles, fuel sales, and climate parameters. The Timeseries mode was used to analyze long-term trends, while the Tier 3 method ensured high accuracy through detailed segmentation. The process involved defining the project setup, inputting environmental and fuel data, specifying vehicle activity and speeds, and performing a fuel balance check. Emissions for CH₄, CO, CO₂, NO_x, PM_{2.5}, and PM₁₀ were then calculated and exported. Using COPERT in Timeseries and Tier 3 modes enabled robust multi-decade estimates of Croatia's transport emissions, supporting policy evaluation and EU climate compliance.

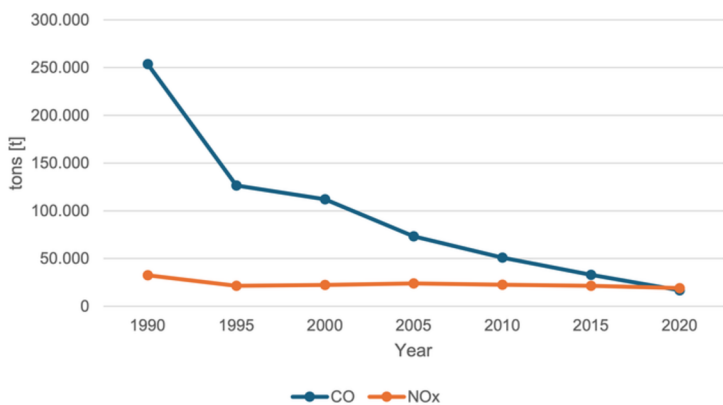


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THE IMPACT OF ROAD TRAFFIC ON AIR POLLUTION AND CLIMATE CHANGE: EMISSIONS TRENDS AND FORECASTING USING COPERT

4. Results and Discussion

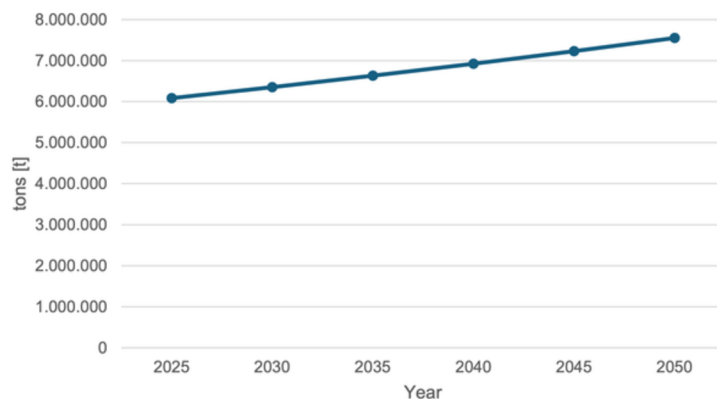
Using the methodology described, national-level estimates of past and future pollutant emissions were produced. Figure 1 shows CO and NO_x trends from 1990 to 2020, revealing decreases of 93.2% and 41.3%, respectively.



▲ Fig. 1 CO and NO_x trends from 1990 to 2020

When it comes to CO₂ emissions, they have increased by 39.5% in the same period. Also, CH₄ emissions have dropped by 77.2%, PM_{2.5} emissions have dropped by 16% and PM₁₀ emissions by only 1%. Throughout the analyzed period, CO₂ accounted for 97.5% of total emissions. The forecast covers CH₄, CO, CO₂, NO_x, PM_{2.5}, and PM₁₀ from 2025 to 2050 in five-year intervals, using average percentage changes from the past 15 years to project future trends. The emissions of CO and NO_x are predicted to fall by 91% and 31.3% respectively. Figure 2 shows CO₂ emissions projected to rise steadily, with a total increase of 19.5% over the analyzed period.

Also, CH₄, PM_{2.5}, and PM₁₀ emissions are all projected to decline, by 76%, 56.5%, and 46.4%, respectively. In the forecast period, CO₂ remains dominant with 99.7% of total emissions. This study highlights major trends in Croatia's road transport emissions.



▲ Fig 2 CO₂ predicted trends from 2025 to 2050

While pollutants such as CO, NO_x, CH₄, PM_{2.5}, and PM₁₀ declined due to cleaner technologies and policies, CO₂ is projected to rise by 19.5%, challenging EU climate goals. The increase reflects reliance on fossil fuels, an aging fleet, and slow adoption of low-emission vehicles. Accelerated electrification, renewable energy use, and investment in public and active transport could reverse this trend.

The persistence of CO₂ growth shows the gap between air quality gains and climate mitigation. While controls reduced toxic pollutants, cutting CO₂ requires systemic changes in energy use and travel behavior. Experiences from the UK, Norway, and the Netherlands show that strong EV incentives and urban planning can achieve sustained reductions.

Croatia and many EU states still face rising CO₂ emissions, exposing gaps in implementation. Fleet renewal, carbon pricing, and better EV infrastructure are key. Future work should evaluate transport interventions, fleet structure, and barriers to decarbonization, and compare tools like COPERT and HBEFA. Despite limitations, COPERT remains valuable for national assessments.



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THE IMPACT OF ROAD TRAFFIC ON AIR POLLUTION AND CLIMATE CHANGE: EMISSIONS TRENDS AND FORECASTING USING COPERT

5. Conclusion

This paper analyzed Croatia's road transport emissions from 1990 to 2050 using the COPERT model. Results show major declines in CO, NO_x, CH₄, PM_{2.5}, and PM₁₀ but a 19.5% rise in CO₂, highlighting the challenge of decarbonizing transport. While cleaner technologies reduce toxic pollutants, cutting CO₂ requires systemic changes in behavior, energy, and infrastructure.

Croatia's car dependence, aging fleet, and weak public transport hinder progress. Without faster electrification and stronger support for public and active transport, national and EU climate goals may be missed. The study confirms COPERT's value for transparent, EU-aligned emission estimation despite data limits. Continued use of COPERT or similar tools can improve policy evaluation. Future work should assess the real impact of mitigation measures and integrate behavioral and economic data to support sustainable mobility.

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Study conception and design: Marko Šoštarić; data collection: David Gruhonjić; analysis and interpretation of results: Marko Švajda; draft manuscript preparation: Marijan Jakovljević

Declaration

The authors declare that they have no conflict of interest. Generative AI tools were employed solely for language refinement. The authors retain full responsibility for the accuracy and integrity of the content.

References

- [1] European Environment Agency. Greenhouse Gas Emissions from Transport in Europe. Published Oct. 31, 2024. Accessed Nov. 11, 2025.
- [2] Centar za vozila Hrvatske. Prosječna starost vozila po vrstama vozila 2007–2024. Published circa early 2025 (covering data for years 2007 through 2024). Nov. 11, 2025.
- [3] Directorate-General for Communication. Croatia – Final Updated NECP 2021–2030 (Submitted in 2025). European Commission, April 1, 2025. Accessed Nov. 11, 2025.
- [4] U.S. Environmental Protection Agency. Fast Facts on Transportation Greenhouse Gas Emissions. Accessed Nov. 11, 2025.
- [5] Hrvatska agencija za okoliš i prirodu. Utjecaj kvalitete zraka na zdravlje stanovništva. Published December 9, 2021. Accessed Nov. 11, 2025.
- [6] EMISIA. COPERT Documentation. Accessed Nov. 11, 2025.
- [7] Pejić, G. Model za brzo predviđanje emisija iz cestovnog transporta A Model for Rapid Prediction of Road Transport Emissions. Doctoral dissertation, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, 2019. urn:nbn:hr:235:786903. Accessed Nov. 11, 2025.

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THE IMPACT OF ROAD TRAFFIC ON AIR POLLUTION AND CLIMATE CHANGE: EMISSIONS TRENDS AND FORECASTING USING COPERT



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Vorausschau



Wann	Was	Wo
7. & 8. Mai	100 Jahre ÖVG European Transport Congress	Wien
28. Mai	Exkursion LINSINGER	Steyermühl
18. Juni	Transformation durch Verbindung	Graz & Klagenfurt
22. Juni	Exkursion Klima-Wind-Kanal	Wien
24. Juni	Exkursion Herzogenburg	Herzogenburg
3. September	Exkursion Bergbahnen Mitterbach	Gemeindealpe Mitterbach
8. & 9. Oktober	DACH Tagung	München
14. Oktober	6. Busforum	Wien
20. Oktober	RAILCONNECT: Innovation & Einstieg	Graz
3. & 4. November	Weichentagung	St. Pölten
10. November	Karrieretag der Jungen ÖVG	Wien
12. November	Kritische Infrastruktur	Wien
3. & 4. Dezember	8. Kongress Fahrstromanlagen	Wien

Alle Events





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