Assessing Road Network Resilience in Vehicles (Belgium

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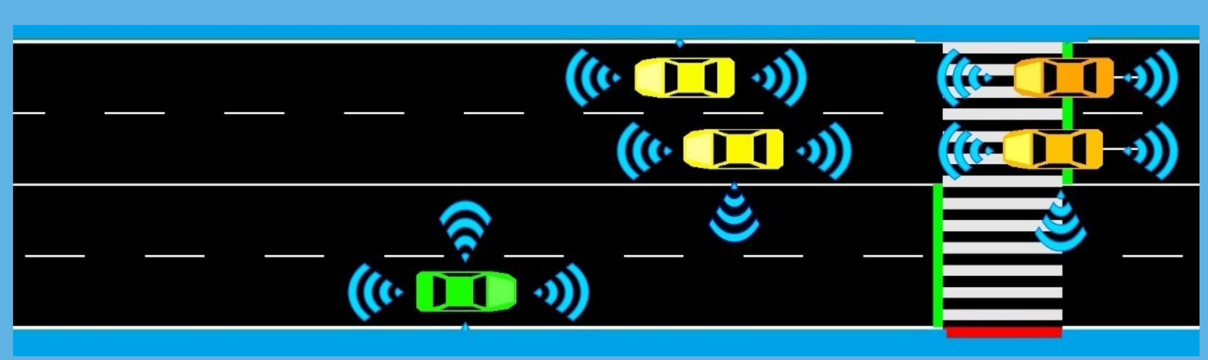
Abstract

The emergence of Connected and Automated Vehicles (CAVs) has brought about significant transformations in the transportation industry, leading to noteworthy effects on various aspects, including the resilience of road networks. CAVs have the ability to receive and transmit real-time information about road conditions, enabling them to avoid congestion caused by disruptions and optimize their routes to enhance the network's resilience through rerouting. Moreover, these vehicles also have a considerable impact on road capacity, which contributes to strengthening the overall resilience of the network. Therefore, this study aims to evaluate the impact of CAVs on the resilience of a large-scale road network in Belgium. The study contributes to the existing literature by employing a simulation-based method to quantify the resilience triangle of the network. The results of this study demonstrate that the presence of CAVs can significantly enhance network resilience in various scenarios, varying in a range of 4.4% for a 10% penetration rate to 59.9% for a 100% penetration rate.

Highlights

1. This study provides a simulation-based framework for evaluating the resilience of road networks
2. The proposed solution framework can capture various dimensions of road network resilience (including robustness, redundancy, and recovery)
3. The proposed methodology is tested on a large-scale road network (Belgium) using Mesoscopic Simulation



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RESILIENCE CONCEPT

The resilience of road network includes 4 dimensions:

- **Robustness:** The ability to withstand or absorb disturbances and remain intact.
- **Redundancy:** the ability to take over the functions of failed components.
- **Resourcefulness:** Availability of materials, supplies, crews to restore functionality.
- **Rapidity:** A hidden meaning of recovery, with more emphasis on speed to recover.

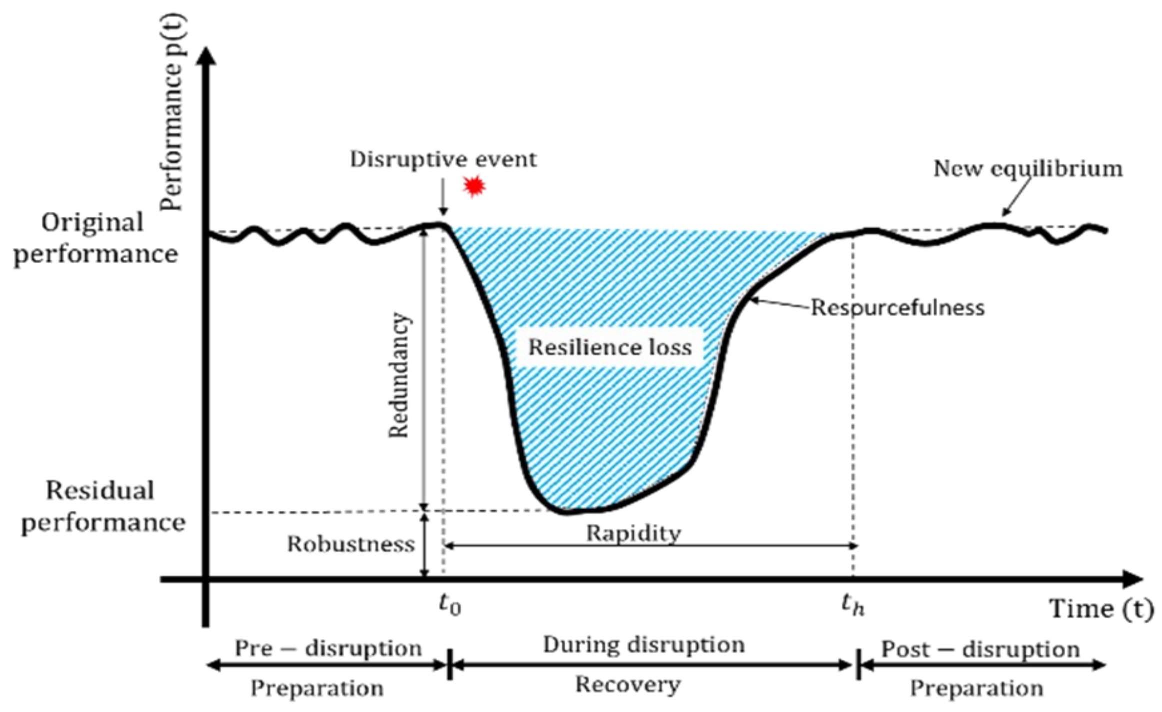
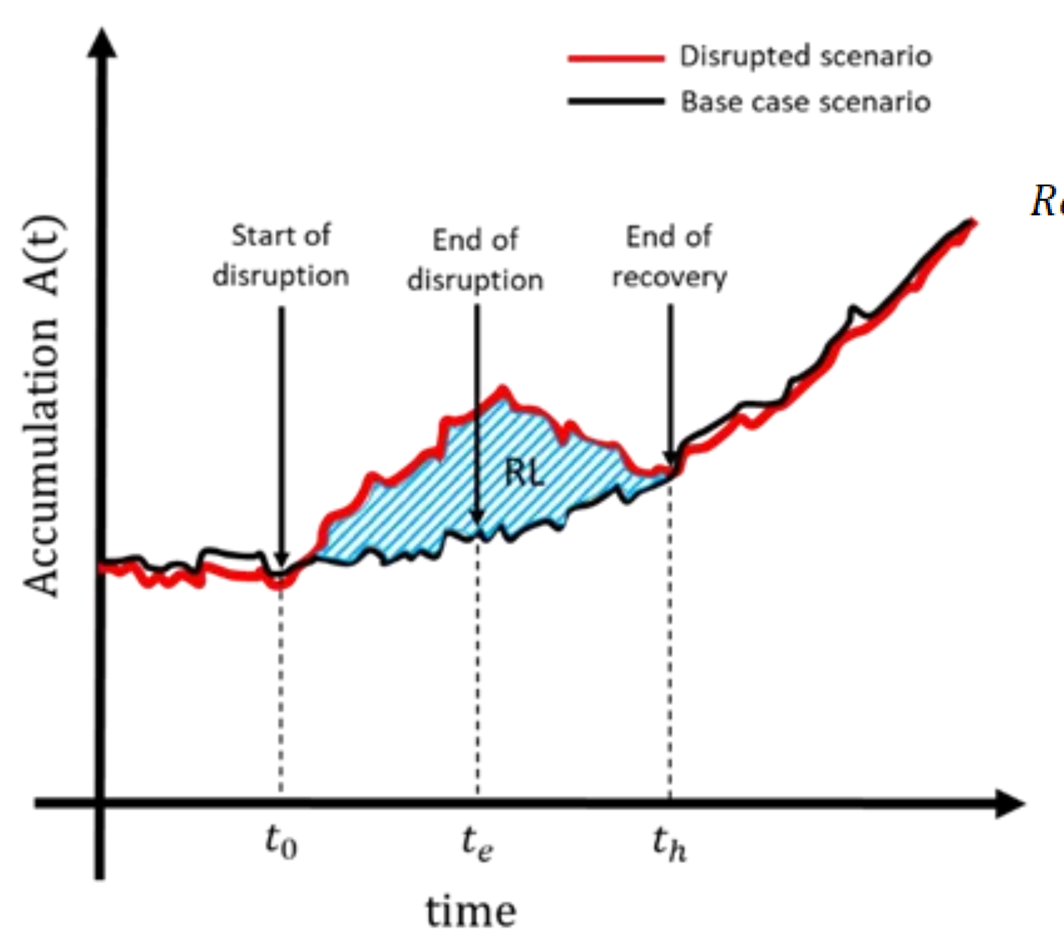


Figure 1: Schematic of performance of a resilient system

RESILIENCE EVALUATION FRAMEWORK

- Performance of a road network can be quantified as the number of completed trips.
- Performance of the network is closely related to its production.
- Network production refers to the internal flows in the network.
- Network production is dependent on its accumulation.
- Accumulation refers to the number of vehicles in the network.
- The network accumulation can be easily measured in practice.
- The impact of incidents on accumulations can be detected very fast.
- This study considers accumulation as performance indicator for resilience triangle.

Calculation of Resilience Loss



$$\text{Resilience Loss} = \int_{t_0}^{t_h} A_t^d(t)dt - \int_{t_0}^{t_h} A_t^b(t)dt$$

$$A_t = V_t^i + V_t^o \quad (3)$$

V_t^i : number of vehicles in the network at time t

V_t^o : number of vehicles waiting for insertion to the network at time t

Figure 2: Road network resilience triangle using accumulation

the Era of Connected and Autonomous Road Network)

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Case Study

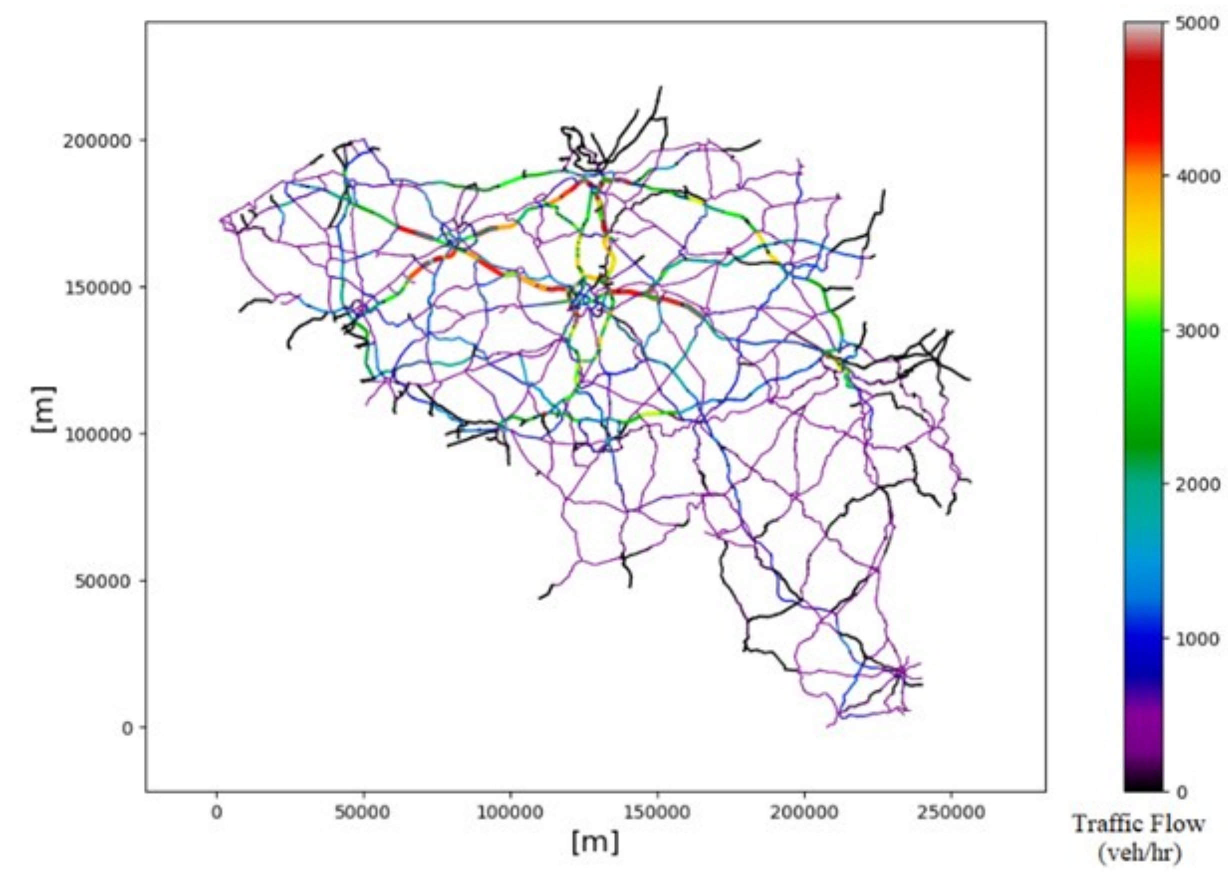

Figure 3: Simulated traffic flow of the Belgium road network

Simulation Setting

- The SUMO traffic simulation software is used at the mesoscopic scale.
- The simulation includes two types of vehicles: HDVs and CAVs.
- It is assumed that CAVs has safer and faster driving behavior
- CAVs follow a lower headway parameter
- It is assumed that CAVs follow the system optimal principle
- HDVs adhere to the user equilibrium principle
- CAVs have the ability of rerouting en-route and before insertion
- HDVs have the ability of rerouting only before insertion
- This study simulate accident scenarios to assess the network's resilience.
- Accidents at critical links in the network are considered as the disruption scenarios.
- The simulation covers a 3-hour, during rush hours.
- The accidents happen one hour after the start of the simulation.
- The accident last for 30 minutes.

Simulation Scenario

Table 1: Malfunction scenarios

Scenario	CAV percentage	HDV percentage	Disrupted links	Scenario	CAV percentage	HDV percentage	Disrupted links
1	0	100	0 (base case)	29	0	100	Top 4 critical link
2	10	90		30	10	90	
3	20	80		31	20	80	
4	40	60		32	40	60	
5	60	40		33	60	40	
6	80	20		34	80	20	
7	100	0		35	100	0	
8	0	100	Top 1 critical link	36	0	100	Top 5 critical link
9	10	90		37	10	90	
10	20	80		38	20	80	
11	40	60		39	40	60	
12	60	40		40	60	40	
13	80	20		41	80	20	
14	100	0		42	100	0	
15	0	100	Top 2 critical link	43	0	100	Top 10 critical link
16	10	90		44	10	90	
17	20	80		45	20	80	
18	40	60		46	40	60	
19	60	40		47	60	40	
20	80	20		48	80	20	
21	100	0		49	100	0	
22	0	100	Top 3 critical link				
23	10	90					
24	20	80					
25	40	60					
26	60	40					
27	80	20					
28	100	0					
Duration of Simulation : 3-hr; Duration of Incident: 30 Min							

Results

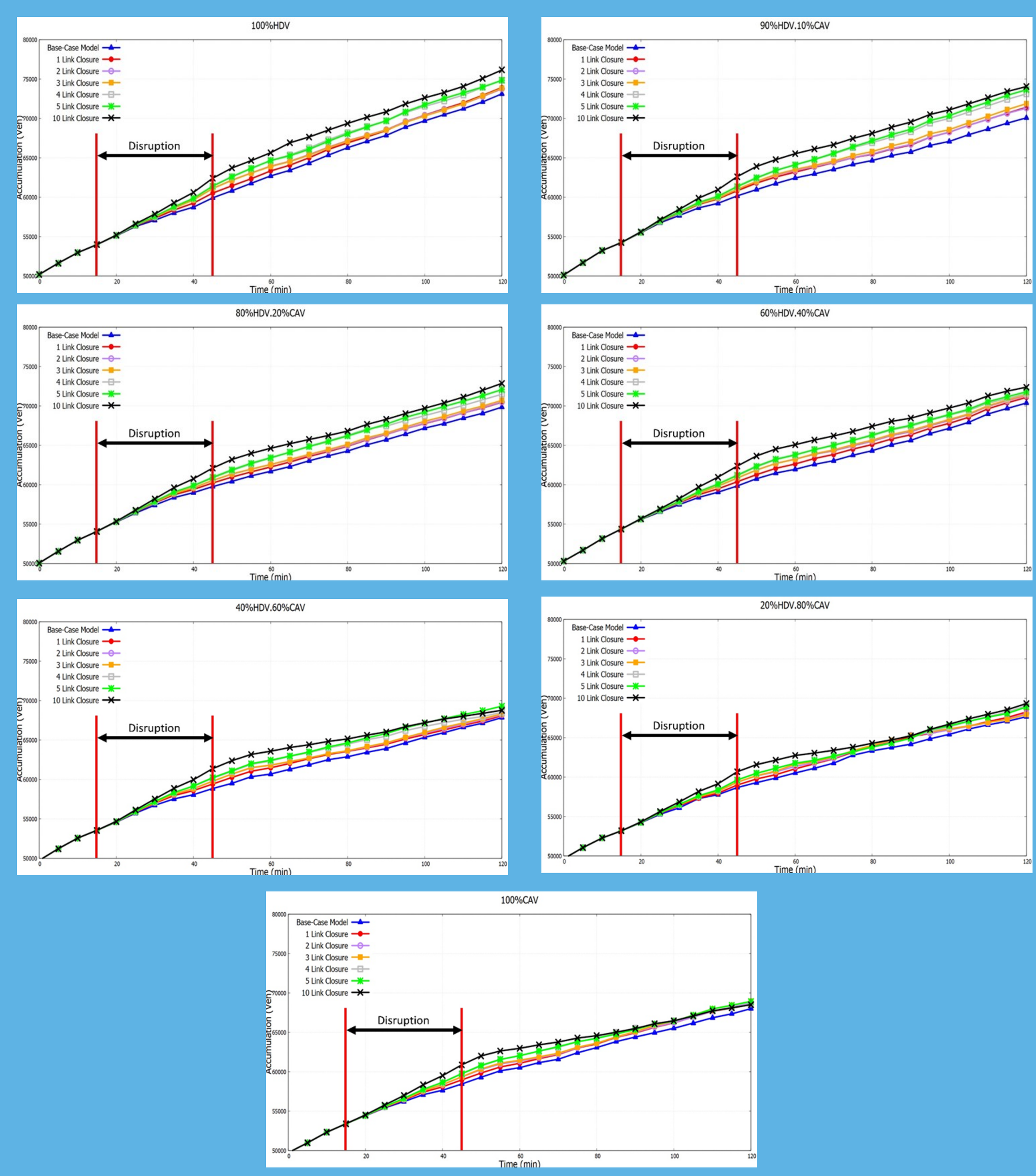

Figure 4: Resilience triangle for all scenarios

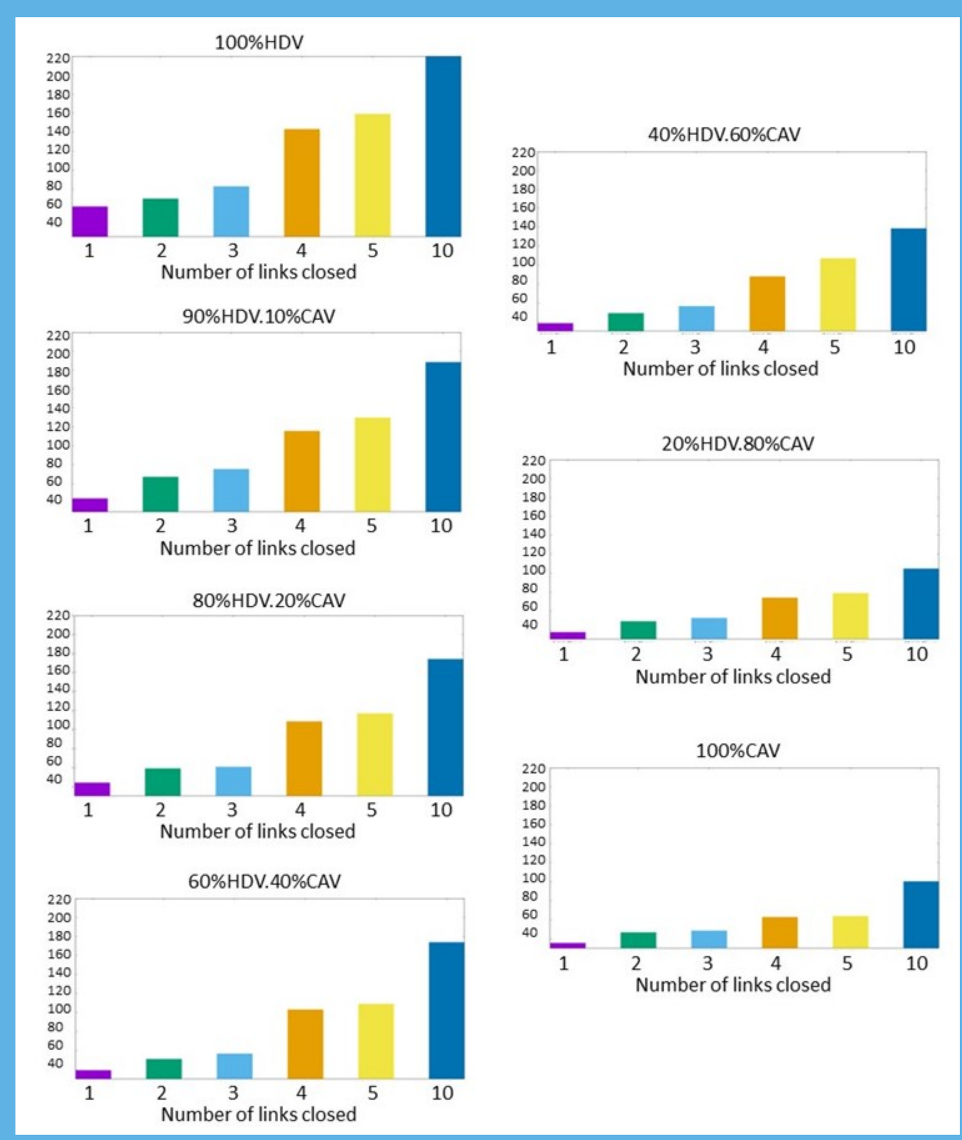

Figure 5: Resilience Loss for all scenarios

Findings

Table 2: Percentage of improvement in resilience in different PR of CAVs

	10%CAV	20%CAV	40%CAV	60%CAV	80%CAV	100%CAV
1 link Closure	28.5	28.9	36.6	37.8	39.6	42.5
2 Link Closure	4.4	15.9	27.3	30.1	30.3	33.4
3 Link Closure	9.4	27.0	31.8	32.1	36.9	41.6
4 link Closure	19.3	24.3	28.1	38.6	48.4	56.2
5 Link Closure	18.5	26.6	31.6	32.6	50.6	59.9
10 Link Closure	14.2	20.7	20.8	36.9	52.4	54.3

- The study provides a comprehensive analysis of the impact of CAVs on network resilience.
- Depending on the penetration rate of CAVs the resilience can be improved by more than a factor 2.

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