Evaluation of The Recorded Trajectories in the Greater Munich Area Against Safety Specifications Using Signal Temporal Logic

Master's Thesis of Muhammad Ahmed

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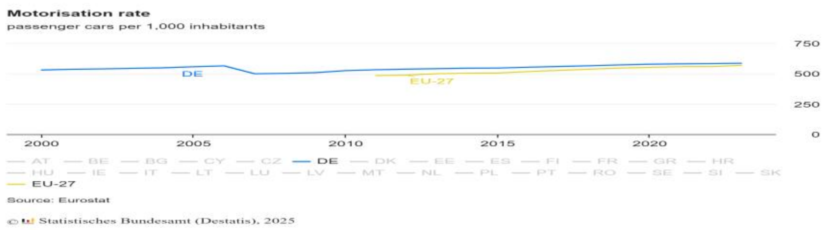

Year	Accidents reported to the police			Casualty		
	Total	of which		Total	of which	
		Accidents involving personal injury	Material damages		Persons killed[2]	Injured
2024[3]	2,507,790	289,334	2,218,456	365,868	2,759	363,109
2023	2,519,525	291,890	2,227,635	369,396	2,839	366,557
2022	2,406,465	289,672	2,116,793	363,922	2,788	361,134
2021	2,314,938	258,987	2,055,951	325,691	2,562	323,129
2020	2,245,245	264,499	1,980,746	330,269	2,719	327,550

Figure 1: Increasing Motorization rate & overview of accidents and resulting deaths

Motivation and Goals

This thesis addresses road safety concerns in Germany, where increasing car density and travel have led to higher dependence on private vehicles. Despite efforts like the Road Safety Pact 2021–2030, aimed at reducing traffic-related fatalities by 40%, the casualty rate has remained steady. While modern technologies like ADAS and automated driving systems have shown promise in reducing fatalities, traditional validation methods such as testing-by-driving have significant limitations, including high resource consumption and inability to address rare events or edge cases. The thesis proposes an approach using modern data sources, such as GPS and FCD, combined with Signal Temporal Logic (STL), to evaluate vehicle compliance with traffic regulations. The goal is to devise review safety regulations, translate them into STL and develop a framework to assess how much vehicles are complying with the stated regulations by robustness measurement.

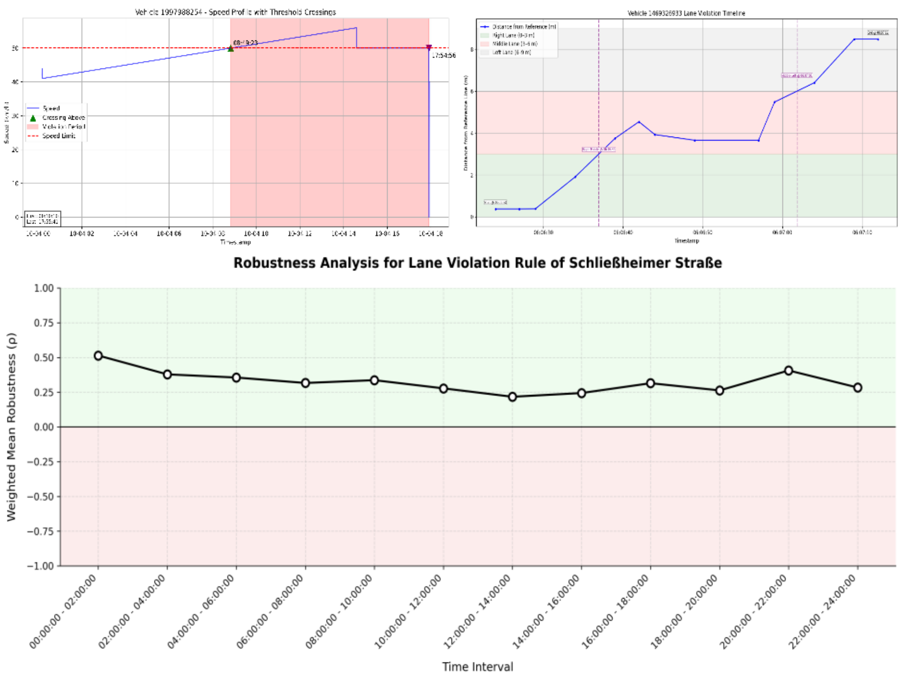

Figure 3: An example of the visualizations of the results

Methodology

This study analyses Floating Car Data (FCD) from ADAC collected in the Greater Munich area to evaluate vehicle compliance with traffic regulations using Signal Temporal Logic (STL). Two rules were formalized for analysis: the maximum speed limit (50 km/hr for more than 300 seconds) and road use (staying in the right lane for at least 30 seconds). The primary tool for analysis was Python, where STL formulas were implemented to evaluate vehicle trajectories. The data, organized by vehicle ID and timestamp, was processed to calculate robustness values, indicating how closely vehicles adhered to the rules. The analysis focused on two road sections, Ungererstraße and Schleißheimer Straße, considering lane widths and road geometries in the robustness calculations. Results were visualized to highlight variations in vehicle behavior across different time intervals and road sections, providing a clear assessment of rule compliance and violations.

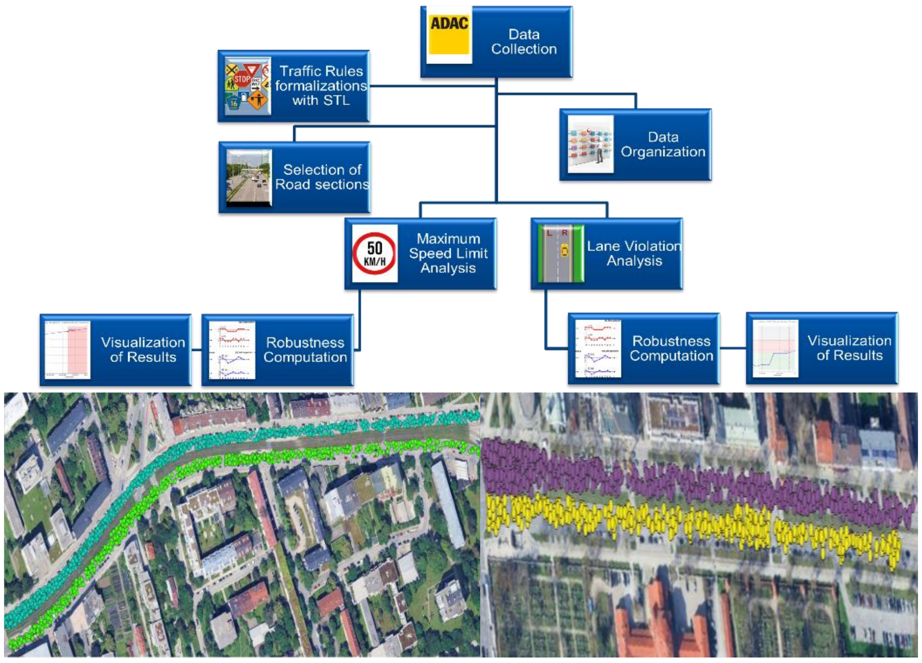

Figure 2: Overview of Methodology and road sections with highlighted dataset

Results and Conclusion

This thesis provides valuable insights into vehicle compliance with traffic safety regulations using FCD, STL and robustness measurement. The analysis focused on speed limit and lane usage violations across two major road sections in Munich: Ungererstraße and Schleißheimer Straße. The results revealed specific instances of speed violations, with some vehicles exceeding the speed limit for extended periods, and lane violations, where vehicles deviated from the right lane for more than 30 seconds. The weighted mean robustness (WMR) analysis showed that overall, vehicles on Ungererstraße exhibited good compliance with the speed limit and lane usage, while Schleißheimer Straße displayed more variation due to factors like high traffic volume and the presence of tramlines. The results suggest that traffic behavior is influenced by factors such as time of day, traffic congestion, and visibility. This detailed understanding of how vehicles conform to or deviate from safety rules can inform future traffic management strategies, improve road safety, and support the development of more efficient traffic safety enforcement policies.