Dynamic Lane Reversal Review

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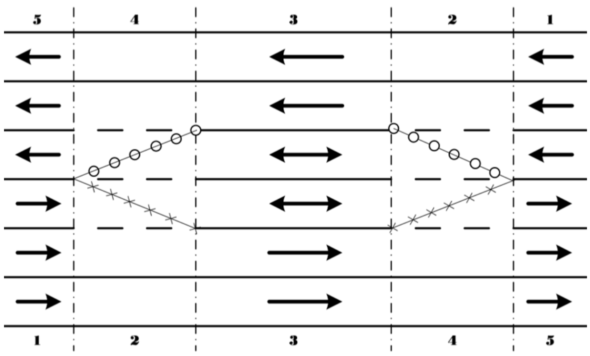
***Abstract**. Traditional traffic control methods based on fixed rules often fall short in addressing the variable nature of urban traffic patterns. Dynamic lane reversal systems, which enable reversible traffic lanes that change direction based on real-time conditions, have been implemented worldwide with varying levels of automation and technological integration. This review covers the evolution of lane reversal techniques over the past two decades, highlighting advancements in simulation modeling, artificial intelligence, and real-time control systems. By analyzing 35 relevant research papers published between 2005 and 2025, the paper identifies key simulation tools, methodologies, and use cases, including evacuation scenarios and autonomous vehicle integration. The findings reveal significant improvements in traffic efficiency and safety through dynamic lane reversal while underscoring the need for further research on AI-driven approaches and practical deployments in smart city environments. The review concludes by outlining research gaps and future directions for enhancing adaptive traffic management strategies through innovative technologies.*

Keywords. Lane Reversal, Tidal Flow, Reversible Traffic Lanes, Road traffic management, Artificial Intelligence, Road traffic simulation software

1 Introduction

A complex problem, such as road traffic control, has been studied for many decades. Traditional traffic control methods relied on fixed rules and algorithms, which are inflexible and inefficient due to changing traffic conditions. Traffic flow is affected by a variety of factors, including the number of vehicles on the road, the size and speed of vehicles, weather conditions, time of the day, day of the week etc.

In modern times, especially big and industrial cities experience the phenomenon of daily migration of the working population, which lives outside of these cities. During morning hours, a huge number of working people drive from suburban to the city center and cause very heavy traffic, and the situation is similar in the afternoon in opposite direction. Some cities have already found a solution for roads with more than two lanes. They've customized a system where a middle lane, or multiple lanes, can switch directions based on certain conditions. This allows the lanes to be used for traffic going in one direction at one time, and the opposite direction at another time. In his 1972 work, Lathrop (Lathrop, 1972) described this type of solution (Fig. 1).



1 Approach	2 Switch In	3 Reversible Lane	4 Switch Out	5 Depart

Figure 1. Traffic lane reversal (source: Lathrop 1972)

The Golden Gate, almost 3 km world famous bridge in San Francisco (USA) carries more than 110 000 vehicles per day in both directions over six lanes, according Goldan Gate Bridge Highway and Transportation District[1]. To improve traffic flow, a median barrier between the lanes is moved to make lane distribution by 4-2, 2-4 or 3-3 pattern: on weekday mornings southbound 4 lanes, northbound 2 lanes. Afternoons opposite – southbound 2 lanes, northbound 4 lanes. Weekends and during off-peak periods, each direction has 3 lanes. Until 2015, the median barrier was made by small plastic pylons. Because of inefficiency and uncertainty, in January 2015 it was replaced with the new system – moveable median barrier with a zipper truck.

The Sydney Harbour Bridge (Australia) has 8 lanes, where three lanes in the middle are reversible during peaks. The direction of reversible lanes is indicated by overhead gantries, showing green arrow pointing down to open lane in one direction on one side and static red

[1] www.goldengate.org/bridge/bridge-operations/

„X“ on the other side, indicating the lane is closed for other direction. Flashing red „X“ means the lane is closing but is not yet open for the traffic in opposite direction. This solution has been in use since 1986, when replaced manually moving lane markers operation.

The Lions Gate Bridge (Vancouver, Canada) has three lanes, where middle lane is reversal and controlled by traffic lights.

Around 1.6 km long section on the North Road in Cardiff (UK) has transformation from double two-lane to a three-lane section, where the middle lane is reversal, depending on the time of the date.

There are more use cases in the world, mostly in the USA, Canada, Australia and Europe, and there are implemented different management systems. In the USA they have been used since the 1920s. But most of these systems have one thing in common: they are mostly setup with a fixed time scheme, based on historical data, or controlled manually by control center.

Conventional road traffic management with fixed rules can combine just deterministic factors – time, weather conditions, day in the week – and adjust the working mode (Almeida, et al., 2023). These changes are also determined and fixed, only in some special cases, additionally equipped with car detectors embedded in the road or mounted on the roadside units (RSU) extend functionality based on the presence and number of the cars on the road.

Artificial intelligence (AI) offers a new approach to traffic control that can be more adaptable and responsive to changing conditions. By using AI to determine density of traffic, recognize number and types of vehicles, recognize or predict traffic and weather conditions, optimize traffic signal timing, reroute vehicles and inform drivers about conditions and changes on the route, it is possible to create a more efficient and safer transportation system. As AI technology develops continuously, it is expected to get even more innovative and effective ways to use AI to improve road transportation (Sharma, Liu, Honggang, & Shelley, 2017).

To better understand road traffic problems in urban areas, and to evaluate developed solutions for these problems, it is necessary to use simulation models and simulation software tools. Road traffic simulation software is a powerful tool that can be used to study the behavior of traffic systems (Ejercito, Nebrija, Feria, & Lara-Figueroa, 2017). It can be used for next purposes:

- predict traffic flow under different conditions, such as different traffic volumes, weather conditions, and road construction projects, and this can be used to plan for future traffic demand and to identify potential bottlenecks;
- identify bottlenecks in the traffic network, what can be used to improve traffic flow by implementing some traffic management strategies;
- adding lanes, changing traffic signal timing, or installing traffic-calming devices;
- test the effectiveness of different traffic management strategies, to choose the most effective strategy for a particular situation.

While the issue has been examined extensively in professional and scientific circles for many decades (notably exemplified by Lathrop's 1972 study (Lathrop, 1972)), this paper offers an analysis of the field's progression over the past 20 years, specifically from 2005 to 2024. It will help to identify the most used road traffic simulation environments and technologies for dynamic lane reversal as well as research gaps in the field, which could be applied in the next research. Next section describes methodology used to get and analyze materials and data regarding selected topic – dynamic lane reversal. Section III shows detailed analysis of selected papers – use cases covered with these papers, methodologies and techniques used in these research papers and their results. Section IV discusses the state of the art in the field, research gaps and potential for next research. Section V is the conclusion of the paper. In the end of the paper, there is list of used sources for this research.

2 Methodology

Essential part of any research is a literature review. In this research was used scoping review (Peters, i dr., 2021) - a type of literature review that aims to map the existing literature on a particular topic, with the goal to provide historical content, summary findings and identify gaps. Detected research gaps open avenues for future research which consequently, if pursued, can contribute to advancing the field of study.

To carry out a literature review, Rowley et al. proposed a five-step methodology (Rowley & Slack, 2004). This methodology was adopted to 7-step procedure (Kamble, Gunasekaran, & Gawankar, 2018) (Astarita, Giofre, Guido, & Vitale, 2020). This methodology was frequently used in systematic literature reviews, and in this paper was improved into the 8-step procedure, as presented in Fig. 2.

2.1 Keyword candidates

For the first, there were selected few keywords as keyword candidates, which best cover topic “dynamically reversible traffic lanes” - “dynamic lane reversal” is commonly used word in American English, as well as “tidal flow” in British English. So, three basic keywords are “lane reversal”, “reversible lanes” and “tidal flow”.

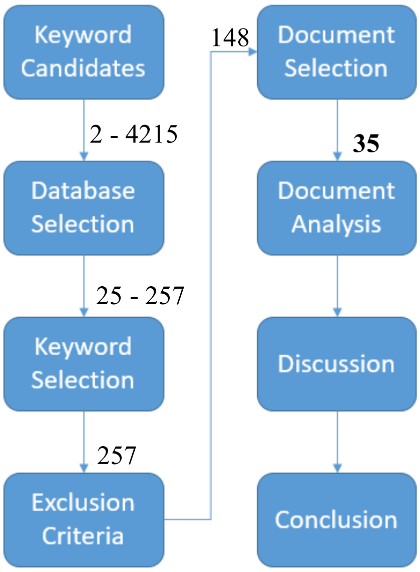


Figure 2. 8-steps procedure for the review

Primary scope of the paper is dynamic lane reversal, but the number of papers on this keyword is too low, then it was reduced to "lane reversal". Parallel, number of papers on synonym keyword, "tidal flow", was too big, because it refers not just to road traffic. On the contrary, keyword "tidal flow lanes" gives extremely low number of papers. Compromising solution is combined keyword "tidal flow" AND lanes". There are also keyword "reversible lanes". In the end, the list of keywords and keyword combinations was used for first step in the procedure:

1. "dynamic lane reversal"
2. "lane reversal"
3. "reversible lanes"
4. "tidal flow lanes"
5. "tidal flow"
6. "tidal flow" AND lanes
7. ("lane reversal" OR "dynamic lane reversal) OR "reversible lanes" OR ("tidal flow" AND lanes)

These queries were used for the search within article title, abstract and keywords in selected citation databases in few combinations, to get set of the data enough big to make further steps.

2.2 Database selection

The most used citation databases in the field of engineering and computer science, that includes peer-reviewed journals, are Scopus[2], Web of Science (WoS)[3] and IEEE Xplore[4], whereby most of journals indexed in IEEE Xplore are already covered with Scopus and WoS. The first step of the procedure was executed in Scopus and WoS, with results presented in Table 1.

Table 1. Results in the database on queries

Nr.	Keyword / Query	Scopus	WoS	I3E
1.	"dynamic lane reversal"	16	11	2
2.	"lane reversal"	58	29	11
3.	"reversible lanes"	180	32	7
4.	"tidal flow lanes"	6	2	2
5.	"tidal flow"	4215	860	111
6.	"tidal flow" AND lanes	24	7	10
7.	"lane reversal" OR "reversible lanes" OR ("tidal flow" AND lanes)	257	62	25

As shown in the Table 1, keyword Nr. 5 gives too high a number in all three databases, is not reliable, and it was excluded from the next analysis steps. The number of papers given for each keyword are significantly higher in Scopus than in WoS and much higher than in the IEEE Xplore database. Ration between given results for all 6 keywords, excluding keyword Nr. 5, is presented in Fig. 3.

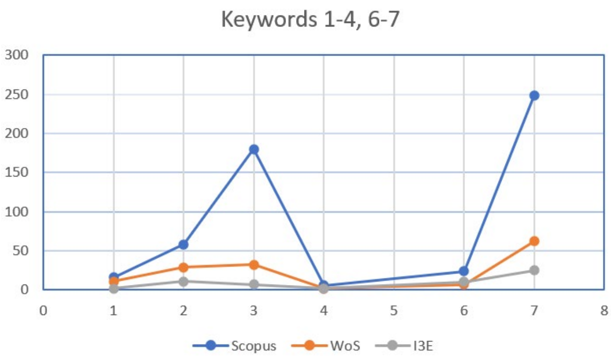


Figure 3. Result ration of results from Table 1

Regarding Astarita et al., WoS includes about 12.000 ISI indexed journals, while Scopus includes more than 25.000 peer-reviewed journals of the most important publishers (Astarita, Giofre, Guido, & Vitale, 2020) (Yong-Hak, n.d.), and for that reason, WoS and IEEE were excluded from further consideration, and Scopus was selected as source database for next steps in the procedure.

2.3 Keyword selection

In section 2.1 is shown list of 7 keyword candidates. Table 1 in section 2.2 shows results for each of three databases, and Scopus was selected as the relevant one. The keyword Nr. 5 was excluded, and in the Table 1 in red line. Keyword Nr. 2 comprehends the keyword Nr.

[2] Elsevier Scopus: www.scopus.com
[3] Clarivate Web of Science: www.webofscience.com
[4] IEEE Xplore: ieeexplore.ieee.org/Xplore/home.jsp

1, as well as keyword Nr. 6 comprehends keyword Nr. 4. Keyword Nr. 3 is also relevant. These 3 keywords are in the green line in the Table 1, and in the end, all together covered with the keyword Nr. 7 – yellow row in the Table 1.

2.4 Excluding criteria

Keyword Nr. 7 from Table 1 gave 257 results in the Scopus database. Limiting document type to article, conference paper and review, source type to journal and conference proceeding and language to English, result is decreased to 212 papers. There are a lot of very old papers, from the year before 2000, so the search was limited to papers published between the years 2005 and 2025, and result was decreased to 148.

The final query in the Scopus database is: TITLE-ABS-KEY ("lane reversal" OR "reversible lanes" OR ("tidal flow" AND lanes)) AND PUBYEAR > 2004 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p")) AND (LIMIT-TO (LANGUAGE , "English")).

2.5 Document selection

After database selection and keyword selection, search with selected keyword in Scopus database gave us result list of 257 papers. Next step was fine query tuning, after that we got the list of 148 papers. These steps are explained in topics 2.2, 2.3 and 2.4. The list of 130 papers was filtered based on their relevance to the topic, by manually reading the title and abstract. The final list contains 35 papers published from 2006 until 2025 and is presented in Table 2.

Fig. 4 shows a complete 5-step process of paper selection, where numbers present the number of papers given as a result after each step. The papers in the Table 2 are published in last 20 years, and all are related with the topic "lane reversal". The papers in the table are sorted by years ascending. Older papers present use cases with conventional management, new implementation of modern IT technology, and the newest also possibility of using artificial intelligence algorithms. Thus, it is possible to get an insight into the development of technologies used in the topic field through the timeline.

Some of these papers are used to describe particular use experience with road traffic simulation systems, some describe theoretical investigation of the problem (study) and some mathematical models of solution. These three groups are colored depending on purpose: urban traffic optimization – green, traffic management in case of evacuation – yellow, application of autonomous vehicles – orange, general purpose – gray. Papers presented the real implementation of lane reversal just for special occasions, such as sport or business happenings or in case of natural disasters, e.g. hurricanes, and on the table are colored yellow**.** Papers showing simulation, study or model description of real environment in some cities are colored green. Papers describing cases with autonomous vehicles are colored light orange, and papers describing general purpose are colored grey (s. Legend below). The third column is marked with the initials of the simulation tool used in the paper (s. Table 3).

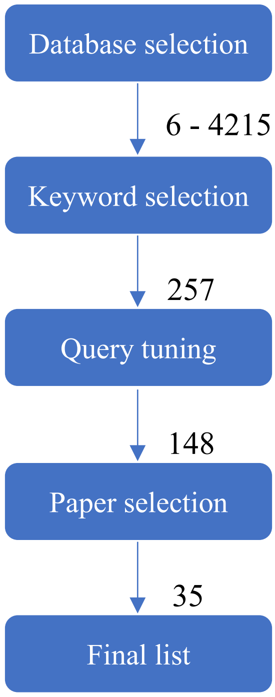


Figure 4. Document selection process

Table 2. Final list of selected papers

Nr.	Reference	Simul.	Study	Model
1	Handke2006 (Handke, 2006)	VS		
2	Logan2006 (Logan, McLeod, & Jordan, 2006)			
3	Wolshon2006 (Wolshon & Lambert, 2006)			
4	Shen2007 (Shen & Sokolowski, 2007)	VS		
5	Williams2007 (Williams, Tagliaferri, Meinhold, Hummer, & Rouphail, 2007)	CS		
6	Kim2008 (Kim, Shekhar, & Min, 2008)			
7	Brown2009 (Brown, White, Van Slyke, & Benson, 2009)			

8	Wu2009 (Wu, Sun, Gao, & Zhang, 2009)			
9	Xie2010 (Xie, Lin, & Travis Waller, 2010)	VT		
10	Lambert2010 (Lambert & Wolshon, 2010)			
11	Bede2010 (Bede, Szabó, & Péter, Optimalization of road traffic with the applied of reversible direction lanes, 2010)			
12	Edara2010 (Edara, Sharma, & McGhee, 2010)	VS		
13	Nassiri2010 (Nassiri, Edrissi, & Alibabai, 2010)	DS		
14	Delanoy2011 (Delanoy, Gaede, & Wong, 2011)			
15	Bede2011 (Bede & Péter, The mathematical modeling of reversible lane system, 2011)			
16	Cheng2011 (Cheng, Li, & Liu, 2011)	VS		
17	Liu2011 (Liu, Yang, Ke, & Wang, 2011)	VS		
18	Hausknecht2011 (Hausknecht, Au, Stone, Fajardo, & Waller, 2011)			
19	Dey2011 (Dey, Ma, & Aden, 2011)			
20	Zhao2014 (Zhao, Ma, Liu, & Yang, 2014)	VS		
21	Bede2014 (Bede & Torok, Theoretical investigation of traffic equilibrium on bridges, 2014)			
22	Frejo2016 (Frejo, Papamichail, Papageorgiou, & Camacho, 2016)	ML		
23	Ampountolas2018 (Ampountolas, Furtado, & Carlson, 2018)	AS		
24	Ding2017 (Ding, Zhang, Yuan, Zheng, & Guo, 2018)	VS		
25	Lobont2019 (Lobont & Pînzariu, 2019)	SY		
26	Kotagi2019 (Kotagi & Asaithambi, 2019)	ML		
27	Mao2020 (Mao, et al., 2020)	VS		
28	Chu2020 (Chu, Lam, & Li, 2020)	ML		
29	He2021 (He, Zhu, Zhang, & Ma, 2021)	VS		
30	Liu2022 (Liu, Ayng, Ke, & Wang, 2022)	VS		
31	Striewski2022 (Striewski, Thomsen, & Tomforde, 2022)	AS		
32	Wollenstein2022 (Wollenstein-Betech, Paschalidis, & Cassandras, 2022)			
33	Fu2022 (Fu, Tian, & Sun, 2022)	VS		
34	Katzilieris2023 (Katzilieris, Kampitakis, & Vlahogianni, 2023)	SM		
35	Li2023 (Li, Li, & Han, 2023)	CA		

Purpose:
- **City**
- **Evacuation**
- **Autonomous Vehicles**
- **General**

Table 3. Simulation tools used in papers

Initial	Tool name	Usage
VS	Vissim[5]	11
ML	MatLab[6]	3
AS	AimSum[7]	2
CA	Cellular Automaton[8]	1
CS	CorSim[9]	1
DS	DynaSmart-P[10]	1
SM	Sumo[11]	1
SY	Synchro[12]	1
VT	Vista[13]	1

Table 3 presents simulation tools used in 22 papers from the list of selected papers, with focus on traffic simulation. The column Usage shows representation of tool in research papers.

[5] https://www.ptvgroup.com/en/products/ptv-vissim
[6] https://www.mathworks.com/products/matlab.html
[7] https://www.aimsun.com
[8] https://udel.edu/~mm/traffic/ca.html
[9] https://mctrans.ce.ufl.edu/tsis-corsim/
[10] umventures.org/technologies/dynasmart-p
[11] https://eclipse.dev/sumo/
[12] www.cubic.com/transportation/products/intelligent-transportation-solutions/intelligent-systems/synchro-studio#
[13] https://vista.csail.mit.edu/

3 Documents analysis

In this section will be described scope of selected papers presented in the Table 2, and their relevance for the current research. Although the lane reversal (tidal flow) has been in use for a very long time, probably since beginning of the 20th century, for this review are relevant just paper published in last 20 years, after 2004.

Handke et al. (Handke, 2006) describe a simulation of a semi-automatic lane reversal traffic management system in Hannover (Germany), with about 1,000 dynamic components over a 16 km distance, operated by just six people. The use of the Path Flow Estimator for dynamic origin-destination matrix adjustment and mesoscopic simulation adds sophistication. The system's reliance on hardware integration and the complexity of interfacing subsystems highlights potential challenges in scalability and long-term maintenance. Furthermore, while initial results are promising, more extensive evaluation and comparative studies would strengthen confidence in the system's effectiveness and generalizability to other urban contexts.

Logan et al. (Logan, McLeod, & Jordan, 2006) described the successful implementation of a manual lane reversal system in the City of Calgary (Canada). Analysis of the implemented system showed improvements, decreasing and stopped delays, which is an excellent example of how existing infrastructure can be optimized. It provides a practical demonstration of how lane reversal can efficiently optimize urban traffic flow using existing infrastructure. However, the reliance on manual operations during the initial phase raises questions about long-term scalability and automation in comparable urban projects.

In the survey conducted in 2003 in the USA, Wolshon et al. (Wolshon & Lambert, 2006) identified a total of 45 discontinued reversible lane systems. The survey showed that lane reversal was mostly used for next purposes: congestion mitigation, planned special events, emergency management, roadway construction, transit and homeland security, where the first three were dominant. The survey also showed the most common types of roadways for the lane reversal: freeway, arterial roadway, bridge and tunnel. Despite the long history and varied applications of reversible lanes, there is a significant lack of established standards and guidelines for their planning, design, and operation.

Department of Transportation in the state Virginia (USA) performed an evaluation study of the Hampton Roads evacuation routes to determine which route would be the best choice in the case of evacuation (Shen & Sokolowski, 2007). They used the VISSIM microscopic simulation tool to model two-phase evacuation, ramp open-close, as well as a lane reversal scheme on six interstate routes in the region. The simulation results showed a mild impact on overall evacuation on one of the simulated routes.

Similar research was conducted in the USA state of Nord Carolina (Williams, Tagliaferri, Meinhold, Hummer, & Rouphail, 2007), concerning how efficiently would the beginning of the lane reversal operate, how would the open interchanges operate under contraflow conditions and how efficiently would the merge/crossover contraflow termination operate. The research successfully simulated a lane reversal plan for hurricane evacuation, demonstrating its effectiveness. However, a key finding and point of concern is the potential for extensive traffic queue formation at the end of the contraflow route.

Evacuation is a situation where residents in a dangerous area are removed to safe places as quickly as possible, and there are three models for the evacuation situation: microscopic simulation models traffic flow at the single-vehicle level, mesoscopic simulation models traffic by groups of entities, and macroscopic simulation describes traffic flow at a high level of aggregation (Kim, Shekhar, & Min, 2008). The key contribution is presenting what the authors believe to be the first macroscopic approaches for contraflow network reconfiguration, which incorporates key factors such as road capacity constraints and congestion. The study evaluates these approaches analytically and experimentally using real-world data, showing promising results.

The Houston-Galveston Area Council, together with other agencies responsible for safe and adequate transportation flow in the metropolitan area, identified the need for a tool to test policies and operational decisions for safe, secure, and efficient evacuations. Such a tool was developed using a dynamic traffic assignment model (Brown, White, Van Slyke, & Benson, 2009). A key critical point is that this model is a planning tool designed for system-wide performance evaluation and is not intended for real-time traffic management.

Wu et al (Wu, Sun, Gao, & Zhang, 2009) provide a valuable study on optimizing traffic flow models by integrating reversible lanes with an advanced traveler information system. A potential limitation, however, is that the findings are based on a theoretical model and simulation, not on a practical, real-world application. While the paper's findings are promising, it would be beneficial to see how the model performs in a real-world scenario with real-time data and driver behavior. This would provide more robust evidence of the model's effectiveness and feasibility.

Evacuation models may be categorized into two paradigms: simulation-based models and optimization-based models. Specific simulation software packages have been developed since 1980, but they were limited to evaluating a small set of pre-specified plans, mainly because of the high computational cost at that time. Optimization-based methods can identify optimal planning solutions for evacuation. Xie et al. presented an integrated approach combining both streams of research through a simulation-based dynamic traffic assignment (DTA) model, using lane reversal on road sections and crossing elimination at intersections (Xie, Lin, & Travis Waller, 2010). Its findings are based on a theoretical model and simulation, which raises questions about the practical feasibility and safety of implementing the proposed strategies in a real-world, dynamic traffic environment.

Lambert et al. (Lambert & Wolshon, 2010) analyzed traffic flow on reversible traffic roads. The goal of this research was to collect and analyze data on traffic flow characteristics and to determine the difference between normal and reversible segments under different conditions: roads, cities, and conditions (peak period, off-peak period, game day). Data (speed, volume) were collected at two locations with double lanes, using a pneumatic tube recording system. To determine the difference between speed and volume in corresponding time blocks, a mixed model analysis of variance (ANOVA Model III) was used. The analysis clearly showed better traffic conditions using reversible lanes. This research is crucial because the lack of reliable data has previously made it difficult to confidently model or gauge the true benefits of these systems.

The previous mentioned study was analyzed and compared with another similar study (City of Tucson, 2004) (Bede, Szabó, & Péter, 2010), which showed improvement in travel time, total delay, total stops, fuel consumption, and emissions of HC, CO, and NO. The study highlights a critical limitation, noting that this type of dynamic routing "changes the system's structure in an optimal direction" but raises many unresolved practical and safety questions.

Edara et al. (Edara, Sharma, & McGhee, 2010) conducted a literature review of traffic modeling studies regarding the evaluation of hurricane evacuation plans in the USA. Widely used tools are simulations: microscopic, for traffic operations at intersections, highways, and roadways, for time estimates, bottleneck identification, and disaggregate performance measures such as link speed, delay, or queue length; mesoscopic, for evaluating advanced traffic control strategies, evacuation time estimates, and bottleneck identification on large evacuation road networks; macroscopic, for evacuation model forecasts at state, county, and street resolutions. The paper identified three major tasks in simulation development: coding the simulation network and assigning traffic, establishing study scenarios and simulation setup and establishing additional simulation assumptions. It developed a large-scale traffic simulation model for hurricane evacuation, providing valuable insights into network performance and bottlenecks. However, as the findings are based solely on a simulation, their real-world applicability could be limited by unpredictable factors not accounted for in the model.

Contraflow is another term used for lane reversal in some studies (Nassiri, Edrissi, & Alibabai, 2010). This paper presents a simulation model tested for the network of the City of Fort Worth, Texas, especially for evacuation purposes in cases of natural or human-made disasters. The Logit choice model was used for contraflow prediction with online and offline scenarios. Contraflow is modeled through a bi-level programming approach. The results show an improvement of throughput by up to 16% using contraflow compared with the non-contraflow case. The paper addresses a gap in existing literature, noting that previous studies had not thoroughly addressed the online contraflow problem.

Delanoy et al. (Delanoy, Gaede, & Wong, 2011) conducted a study on an improved lane reversal system in Calgary, Canada - the same one already studied five years ago . The system was improved with video equipment, LED traffic signs, dual-state prism signs, and a traffic management operation center.

Bede and Peter (Bede & Péter, 2011) presented a descriptive mathematical network model of a reversible lane system - a positive non-linear dynamic system. The results of model examinations during morning and afternoon peaks show that improvement of vehicle density decreases peaks by activating reversible lanes. The paper describes techniques applied to be useful in working with very large dynamic network loading and a mesoscopic simulation model. Although a macroscopic model loses the properties of single-vehicle traffic flow, it effectively deals with road density and the capacity of a transportation network. While it highlights a significant reduction in travel time and waiting time, it also notes the necessity of further analyzing the risk factors associated with the application of such systems.

(Cheng, Li, & Liu, 2011) studied traffic and intersection organization methods for reversible lanes by simulating road networks of Kunming (China) with 11 intersections and proved improvement in total delay (8.5%), capacity (7.4%), and average delay (14.8%). The paper describes techniques applied to be useful in working with very large dynamic network loading and a mesoscopic simulation model. A critical point is that the paper's findings, while promising, are based on a simulation rather than a real-world implementation.

A similar case study and simulation showed positive effects of the reversible lane system, simulated on four intersections along a three-lane urban arterial: travel time was reduced by 38.73% and average vehicle delay decreased by 50.7% using the reversible lane system on congested roads (Liu, Yang, Ke, & Wang, 2011). The paper provides a strong theoretical framework for implementing reversible lanes in urban areas, including an optimization model and specific activation criteria. However, as the research is based on a conceptual model, it does not address the practical and safety concerns of a real-world application.

In the ILP (Integer Linear Program) experiment based on macroscopic ILP traffic model, Hausknecht et al. (Hausknecht, Au, Stone, Fajardo, & Waller, 2011) analyzed the effectiveness of dynamic lane reversal and proposed a framework for lane reversal optimization using a linear programming formulation and a bi-level programming formulation. Analysis of experiment results showed an increase in network efficiency by 72% with active contraflow. The paper provides a strong theoretical framework for implementing reversible lanes in urban areas, including an optimization model and specific activation criteria.

Although reversible lanes help optimize traffic capacity, a study conducted in Washington, D.C., on 10 roadway segments with reversible lanes, with a total length of about 17 km, suggested that more crashes are associated with reversible lane operations compared to non-reversible lane segments (Dey, Ma, & Aden, 2011). Reversible lanes can be confusing if the turning operations are not clearly signed, especially for tourists and untrained drivers, according to the authors. However, a key limitation is that the findings are based on a single, specific urban environment and only draw "preliminary conclusions," which may not be universally applicable to other cities.

Zhao et al. (Zhao, Ma, Liu, & Yang, 2014) proposed a mathematical model for a road traffic section with three four-arm intersections and two internal segments. The paper presented a simulation experiment with six different study patterns, with cycle lengths between 60 and 120 seconds, and a clearance time of 5 seconds. Analysis of experiment results suggests that the lane reversion strategy has very limited success when intersections are well optimized and is not recommended in similar cases. The simulation validation using only VISSIM with deterministic scenarios is insufficient to demonstrate real-world effectiveness, particularly regarding driver confusion and safety concerns during lane reversals that are only briefly acknowledged but not quantitatively addressed.

Bede and Peter (Bede & Torok, 2014) provided a mathematical model of traffic flows with reversible lanes from an economic point of view. In the paper, the authors presented results of an investigation of price as a traffic controlling parameter, but they also discussed vehicle dynamics, fuel consumption, and environmental impact. The numerical experiment was conducted on a simple bridge model with four lanes and bridge tolling. Theoretical analysis showed that reversible lanes could lead to decreased prices if it is possible to change lane direction while keeping road safety in mind. Mathematical modeling is superficial, lacking empirical validation, and the authors fail to demonstrate how their theoretical economic equilibrium model would translate into practical traffic management solutions for real bridge operations.

Frejo et al. (Frejo, Papamichail, Papageorgiou, & Camacho, 2016) proposed a modified macroscopic second-order traffic flow model, METANET, for reversible lanes on freeways and tested the proposed MPC (Model Predictive Control) strategy with the MATLAB simulation environment. The model was validated with real data over the Centenario Bridge in Seville, Spain, and results confirmed that the model can reproduce traffic congestion with an error between 4% and 14% for flow and speed. The proposed model and algorithms are validated solely through simulation, which may not fully capture the complexities and unpredictable nature of real-world traffic.

Ampountolas et al. (Ampountolas, Furtado, & Carlson, 2018) proposed a simple strategy for reversal lane operations, based on a triangular FD (Fundamental Diagram) policy. In the paper, they use the term “tidal flow” for reversal lane. The proposed algorithm for the FD-based switching policy was evaluated with a microsimulation study of a road segment of Aston Expressway in Birmingham, UK. For this purpose, the microscopic simulation framework AIMSUN was used. Simulation outputs were compared with real data on the road, and the results showed an increase in motorway throughput and decreased total travel time by 48.4%. This simple and practical real-time control strategy for road lane reversal, validated through simulation, should be yet tested in real-world performance.

Regarding Ding et al. (Ding, Zhang, Yuan, Zheng, & Guo, 2018), the lane reversal strategy can be widely used on city road segments with intersections, but with some constraints: the intersection signal control should have multiphase control with three phases and special dedicated left-turn and right-turn lanes; considering safety factors, the number of road crossings should not be less than three; a reversible lane segment should have enough time and space conditions to set up direction change. This study presented the VISSIM simulation of a road segment with an intersection between two roads in Xuancheng city in China, using simulation data before and after setting the reversible lane strategy. The result comparison showed queue length improvement of 17.7% and travel time reduction by 20.3%. But this solution suffers from limited scope: analyzing only a single intersection without addressing scalability, real-world validation, or potential safety concerns that are critical for such traffic management interventions.

Lobont and Pinzariu (Lobont & Pînzariu, 2019) analyzed a road segment between two intersections, on one of the main transit arteries in the city of Sibiu, Romania. Real data were collected from actual traffic conditions and implemented with the Synchro simulation framework. Observation of traffic flow without lane reversal showed daily congestion between the two intersections. Implementation of lane reversal solutions in the simulation environment showed only partly satisfactory results, as the improvement was significant only at intersection B, while the value at intersection A was worse. However, inconclusive results and lack of alternative solutions undermine the paper's practical contribution to traffic engineering.

Kotagi and Asaithambi (Kotagi & Asaithambi, 2019) conducted an extensive study with microscopic simulation of lane reversal implementation in two Indian cities: Bangalore and Kollam. The simulation environment was developed with MATLAB, using Object-Oriented Programming (OOP) concepts. The objectives of the study were: to identify and model movements of different kinds of vehicles on urban roads; to develop a simulation model for bi-directional mixed traffic; and to evaluate lane reversal operation using the developed model. Real traffic data were collected using video-graphic technique, on a road segment without the effect of intersections, bus-stops, parked vehicles, and pedestrians, during morning and afternoon peak hours in both directions. The simulated road segment had six lanes, with ratios 3:3 (without lane reversal) and 4:2 (with lane reversal). The simulation model was validated using collected datasets, and it was proven that the simulation model can be used for simulation. Comparison of simulation output showed improvement by 20.5% in the morning direction and 19.2% in the opposite direction using lane reversal. There was also an increase of 568 veh/h in the morning peak and 396 veh/h during the evening peak. These results showed promise in reducing traffic congestion on urban roads in Indian cities. However, the model's validation is limited to two particular cities, and the reversible lane evaluation lacks critical safety analysis and practical implementation considerations such as signaling, enforcement mechanisms, and transition zones that would be essential for real-world deployment.

Mao et al. (Mao, et al., 2020) proposed real-time dynamic lane reversal in CVIS (Intelligent Cooperative Vehicle Infrastructure System), simulated with VISSIM microscopic simulation software. Simulation was conducted on an eight-lane road example, with two inner reversible lanes, and three phases of lane direction change: opening, entering, and closing. The dataset was collected on a road segment in the Chinese city of Huai'an during afternoon peak hours. Comparison of simulation outputs for traditional time-controlled lane change mode and proposed real-time lane reversal showed improvement of 13.5% in traffic flow and reduction of average delay by 27.4% using real-time lane reversal. The practical feasibility of the proposed "light curtain wall" technology and its integration with existing infrastructure remains unproven, and the study relies heavily on simulation without extensive real-world validation.

A dynamic lane reversal strategy, combined with a distributed algorithm, can significantly improve the travel time of connected and autonomous vehicles (CAV), as shown by MATLAB simulation of the proposed model (Chu, Lam, & Li, 2020). The study's reliance on simulations with idealized assumptions, such as constant vehicle speeds, no traffic lights, and a fully CAV-dominated environment limits its immediate real-world applicability, especially in mixed-traffic scenarios.

He et al. (He, Zhu, Zhang, & Ma, 2021) presented a simulation of a lane reversal control system at intersections based on VISSIM simulation software extended with a Python interface. The simulation environment was tested with real traffic flow data on a two-way 10-lane road segment. The result of the analysis showed a decrease in average queue length at intersections by 38.6%, average delay time by 20.07%, and average carbon emission by 17.3% compared with the system without a variable lane reversal system. The approach relies on simplified traffic scenarios and does not address the challenges of real-time implementation, such as driver compliance, infrastructure costs, or integration with adaptive signal control systems.

Liu et al. (Liu, Ayng, Ke, & Wang, 2022) presented the Predictive Empowered Assignment scheme for Reversible Lane (PEARL) - an advanced traffic flow prediction module with a bi-level optimization model. The model was tested with a simulation experiment using the VISSIM simulator. The test data were collected on a 16.8 km long segment of Guangfo Express Road in China. The results of the experiment showed total throughput improvement by 5.76% in one direction, 2.04% in the other direction, and a total increase in both directions by 4.47%. The paper assumes idealized conditions, such as perfect driver compliance and homogeneous lane properties and its performance gains, while promising, are modest given the heavy traffic loads, raising questions about scalability and robustness in more complex or mixed-traffic environments.

Striewski et al. (Striewski, Thomsen, & Tomforde, 2022) used the road traffic simulation software Aimsun Next to develop and evaluate four tidal-flow-management algorithms: ratio, speed, density, and occupancy. A 1 km road segment with 6 lanes in both directions served as the experimental setup. Three models were tested: without intersections, with one intersection and with two intersections. The occupancy algorithm performed best, reducing total travel time to 81% (no intersections), 71% (one intersection), and 68% (two intersections) of baseline values. The study is based on simulations, which may not fully address the complex, real-world implementation challenges and safety considerations.

Wollenstein-Betech et al. (Wollenstein-Betech, Paschalidis, & Cassandras, 2022) proposed multiple lane-reversal solutions and validated them on Eastern Massachusetts' transportation network. Their case study demonstrated a 4.7% travel time improvement. The paper makes a significant contribution by proposing a global optimization approach to the joint lane reversal and traffic routing problem, which has been shown to be NP-hard. The effectiveness of the proposed methods is demonstrated through a mathematical model and not validated in a large-scale real-world or simulated dynamic environment.

Fu et al. (Fu, Tian, & Sun, 2022) identified priority roads for dynamic lane reversal in CAV (connected and autonomous vehicles) environments by developing a multi-objective optimization model (Cell Transmission Model), integrating NSGA-II genetic algorithm with VISSIM simulations and conducting regression analysis. Results showed lane reversal performs best on multilane roads with high traffic flow and balanced bidirectional demand (small flow discrepancies). The reliance on idealized assumptions such 100% CAV penetration and simplified lane-changing behaviors, limits the immediate real-world applicability, and the safety implications of high-frequency lane reversals remain underaddressed.

Katzilieris et al. (Katzilieris, Kampitakis, & Vlahogianni, 2023) presented microscopic simulation model for dynamic lane reversal built within SUMO (Simulation of Urban Mobility) road traffic simulator. The model was built within imaginary 4-way intersection – 500 m long 2-lane artery with one reversible lane in the middle, and secondary streets with static 2 lanes. Simulation used reinforcement learning (LR) algorithm to optimize direction change in the middle lane. Results of such model showed average travel time improvement up to 19.9% and average decreasing of CO_2 emissions on the intersections up to 15.1%. A critical limitation is that the model's effectiveness is demonstrated on an "artificial intersection" in a simulated environment, raising questions about its practical application in real-world, large-scale urban networks.

Li et al. (Li, Li, & Han, 2023) proposed dynamic lane reversal strategy which dynamically changes direction on reversible lane depending on current traffic density. A two way 6-lane road segment is divided 3:3 without lane reversal, and 4:2 or 2:4 with the lane reversal strategy. Two crucial questions were in focus of the research: how to establish the criteria to trigger entering lane reversal mode; and how to determine optimal duration for the contraflow. The simulation based on cellular automaton (CA) model showed optimal direction change when density reaches 0.37 and goes back to normal direction when density falls to 0.22. The study relies on a simplified cellular automaton model and does not address practical challenges such as driver compliance, infrastructure costs, or the integration of real-world traffic variability and connected vehicle technologies.

4 Discussion

The previous chapter gives a short overview of each paper from the list presented in Table 2, altogether 35 papers. Upon analyzing the papers, it was found that individual studies commonly employed one of three approaches: simulation models, mathematical models, or observational studies. Consequently, the papers were categorized accordingly. From the perspective of their research objectives, themes such as urban traffic optimization, traffic management during evacuations, application of autonomous vehicles, and general traffic control purposes were identified (s. Table 2).

From this list of 35 papers, 22 papers (62,86%) use some kind of simulation as a research tool to reach research objectives. Other papers have a goal to make a study of the topic or make a description of the strategy using mathematic model.

From another point of view, use case of some specific cities were described in 16 papers (45.71%) – almost a half of the papers, and mostly with simulation as a research tool (10 papers). Complete distribution is presented by Fig. 5.

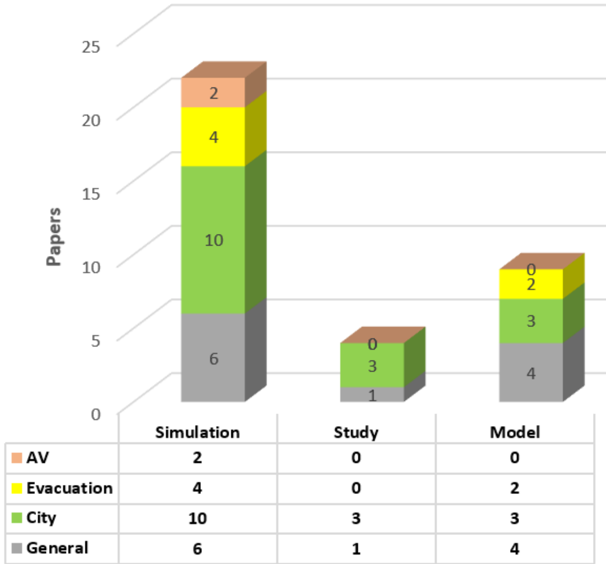


Figure 5. Selected paper distribution

Traffic simulation software tools are the best solutions to evaluate models of specific road segment and to optimize control strategy on it. They have been widely used for more than 30 years. As presented in Table 2 and Table 3, 50% of simulation focused papers from the list are using VISSIM simulation tool. 3 papers are using MATLAB, 2 papers AIMSUM, and other tools (Sumo, Corsim etc.) are used in 1 paper each.

Until 2010, they were widely used to model lane reversal strategy for evacuation purposes in cases of natural disasters, and later research was more focused to model and evaluate automatic control strategy of existing, manually controlled lane reversal segments, or to model and evaluate some new segments with huge congestion.

The review of dynamic lane reversal systems over the past two decades reveals significant progress in both the conceptual understanding and practical implementation of reversible lanes as a traffic management strategy. Traditional reversible lane systems, managed manually or by fixed schedules, have demonstrated measurable benefits, such as reductions in travel time, stops, delays, fuel consumption, and vehicle emissions. However, these conventional approaches are limited by their inflexibility and inability to respond dynamically to real-time traffic fluctuations.

Recent advancements in information technology, particularly the integration of artificial intelligence (AI), machine learning (ML), and sophisticated traffic simulation tools, have opened new avenues for optimizing lane reversal operations. Modern simulation platforms enable accurate modeling of complex, multimodal urban traffic networks and facilitate the evaluation of innovative, adaptive control strategies. This transition from static to dynamic, data-driven management holds the promise of even greater improvements in efficiency, safety, and sustainability.

Despite these advancements, the literature review highlights several research gaps. There is a need for more real-world deployments of AI-driven dynamic lane reversal systems and comprehensive studies evaluating their long-term impacts on urban mobility. Additionally, the integration of connected and autonomous vehicles into these systems presents both challenges and opportunities that warrant further investigation.

In summary, dynamic lane reversal remains a vital and evolving tool in the quest for smarter, more responsive urban transportation systems. Continued research, especially leveraging AI and real-time data, will be crucial in realizing the full potential of reversible lanes, ultimately contributing to more sustainable and efficient cities.

5 Conclusion

Dynamic Lane Reversal (DLR) control is one of the most cost-effective strategies to increase capacity of road traffic, improve traffic flow, decrease congestion, delay time and travel time on existing road infrastructure, without physical interventions. Well optimized DLR can enhance traffic flow by up to 40% compared to conventional reversible lanes control systems. It can significantly decrease total queuing delays, especially on multilane road segments with balanced directional flows. It effectively reduces road congestion and improves overall system performance through optimal control strategies.

This strategy has been in use since the late 1920s, first using physical barriers and ramps, then traffic signals and time-based regulation, and with recent advancement of information and automotive technologies, focus shifts to artificial intelligence as well as to autonomous driving.

Based on these findings, the suggested next steps are to create a prototype for intelligent lane management that leverages both real-time and historical data from smart cameras, traffic sensors, and weather sensors, enhanced by artificial intelligence algorithms. Initially, this system should be tested within a simulation platform that accurately replicates the chosen real-world setting as a digital twin. Demonstrating success in simulation, while adhering to traffic safety standards, will be essential before proceeding to trials in an actual environment, which should involve collaboration with municipal and government agencies. Identifying effective ways to optimize road traffic management through artificial intelligence will present a challenge for future research.

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