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Contribution to the performance evaluation of reversible lanes

Contribuição para a avaliação de performance de faixas reversíveis

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ABSTRACT
Recurrent congestion in urban centers requires traffic managers to adopt temporary or complementary strategies, such as implementing reversible lanes. Its principle comes from the temporary expansion of road capacity by taking advantage of the underutilized capacity of the road in the opposite direction. Despite being historically associated with a simple measure (compared to definitive interventions), there are technical guidelines for its implementation process, from initial stages (planning, previous studies, and design) to later stages (monitoring and performance evaluation), that, if not adequately considered, tend to impair the operation's benefits. On the other hand, national practice tends to rely on empirical knowledge and personal decisions. Considering the growing popularity of the technique in the country, the evaluation becomes essential not only in terms of measuring the benefits obtained in existing operations but also as a result of benchmarking in new operations. Thus, this research aims to contribute to the practice of reversible lanes, identifying, through a systematic literature review, the primary key information (approaches, indicators, data collection, and methods) used in reversible lane performance evaluation studies. Such information subsidized the development of flowcharts to guide the evaluation process in existing operations.

RESUMO
A ocorrência de congestionamentos recorrentes em centros urbanos demanda, aos gestores de tráfego, a adoção de estratégias de caráter temporário ou complementar, como a implantação de faixas reversíveis. O seu princípio advém da ampliação temporária da capacidade viária pelo aproveitamento da capacidade subutilizada da via no sentido oposto. Apesar de ser historicamente associada a uma medida simples (em comparação a intervenções definitivas), existem diretrizes técnicas que norteiam o seu processo de implantação, desde etapas iniciais (planejamento, estudos prévios e projeto), até etapas posteriores (monitoramento e avaliação de performance) e que caso não consideradas, de forma adequada, tendem a prejudicar os benefícios da operação. Por outro lado, a prática nacional tende a respaldar-se no conhecimento empírico e em decisões pessoais. Considerando a crescente popularização da técnica no país, o processo de avaliação torna-se essencial não apenas quanto à mensuração dos benefícios obtidos nas operações existentes, mas também como benchmarking em novas operações. Assim, a presente pesquisa tem o objetivo de contribuir com a prática de faixas reversíveis, identificando, através de uma revisão bibliográfica sistemática, as principais informações-chaves (abordagens, indicadores, forma de coleta de dados e métodos) utilizadas em estudos de avaliação de performance de reversíveis. Tais informações subsidiaram a elaboração de fluxograma para guiar o processo de avaliação em operações existentes.

1. INTRODUCTION

Traffic jams have become everyday occurrences in urban centers during peak hours. These result from the traffic volume varying considerably throughout the day, generating periods of temporary insufficiency of road capacity (Elvik et al., 2015).

The expansion of the road network is not always feasible or desirable. Thus, urban traffic management strategies that minimize congestion by optimizing existing infrastructure, such as implementing reversible lanes, emerge as an alternative (Guebert, 2010; Elvik et al., 2015). These are operations in which the direction of traffic flow is reversed to the opposite direction for a certain period, temporarily expanding road capacity in one direction. To do this, advantage is taken of the unused capacity in the direction of less traffic, incorporating it into the direction of greater traffic (Guebert, 2010).

Reversible lanes have been used in the United States since the 1920s. Between the 40s and 60s, its implementation in urban arterial roads increased significantly in the country. At the same time, in the following decade, its use was also observed in highways, bridges, tunnels, and other locations, such as Europe and Oceania (Fitzpatrick et al., 2016). In Wolshon and Lambert (2004), 47 active operations were reported in the United States, distributed among 16 states, totaling over 2.6 thousand kilometers, from urban operations of 800m in Baltimore to extensive road segments of approximately 300km in Florida. The strategy has spread around the world, with records of its implementation in several countries, such as Germany, China, England, and Norway (Waleczek et al., 2016; Wang, Wang and Zhang, 2015; Elvik et al., 2015).

In Brazil, there is an increase in the number of reversible lane operations as a strategy to address the frequent urban congestion that occurs in Brazilian municipalities. For example, in Rio de Janeiro, such a strategy has been used since the 80s, and in 2019, there were 13 regular operations (Machado, 2012). Queiroz (2016) reports the existence of urban operations in cities such as Blumenau (SC), Teresina (PI), and Recife (PE) and operations on highways, such as the DF-095 (DF) and the Anchieta-Imigrantes system (SP). At least two operations were recently implemented in the country's southern region (Porto Alegre, 2020, 2021). In Florianópolis (SC), in addition to the existing reversible lane on the SC-405 highway, four other operations were proposed in the Urban Mobility Plan in the south of Santa Catarina Island (Santa Catarina, 2014).

Studies indicate increased traffic flow, reduced travel time, and increased average speed among its benefits. For example, DeRose (1966) evaluated an operation in Michigan, noting an increase of up to 7.1% in traffic volume, a reduction in average travel time by 16.5%, and an increase in average speed by up to 21.5%. However, some studies report an increase in the number or severity of accidents after the implementation of the reversible (Elvik et al., 2015).

In this regard, Guebert (2010) highlights that the lack of uniformity of operations impacted the systems' performance over time. In addition, it states that no standard was established for the applicable indicators and benchmarks at any of the stages of its development, which may have contributed to reduced efficiency in operations.

Since then, foreign publications, such as Wolshon and Lambert (2004), Guebert (2010), and Fitzpatrick et al. (2016), aim to guide the systematic implementation of this type of operation. In Brazil, Machado (2012) establishes a procedure for implementing urban reversible lanes.

In general, the process for implementing reversible lanes can be separated between previous stages (previous studies, planning, design) and after their implementation (monitoring, evaluation) (Wolshon and Lambert, 2004; Guebert, 2010). In contrast, the synthesis of national practice tends to be based on empirical knowledge and personal experiences of decision-makers, which may undermine the potential benefits of these operations (Machado, 2012). Especially in this context, it becomes crucial to evaluate operation performance, enabling the measurement of its performance and benefits and providing benchmarks for further operations.

Thus, a systematic literature review was performed to raise the primary information that makes up a reversible lane performance evaluation study (hereinafter referred to as "key information").

Based on the summary of the results, two flowcharts were prepared to assist the performance evaluation process for existing reversible lanes and operations under planning.

2. SYSTEMATIC LITERATURE REVIEW

This review was based on Bueno (2020) containing three stages: planning, execution, and selection, as shown in Figure 1:

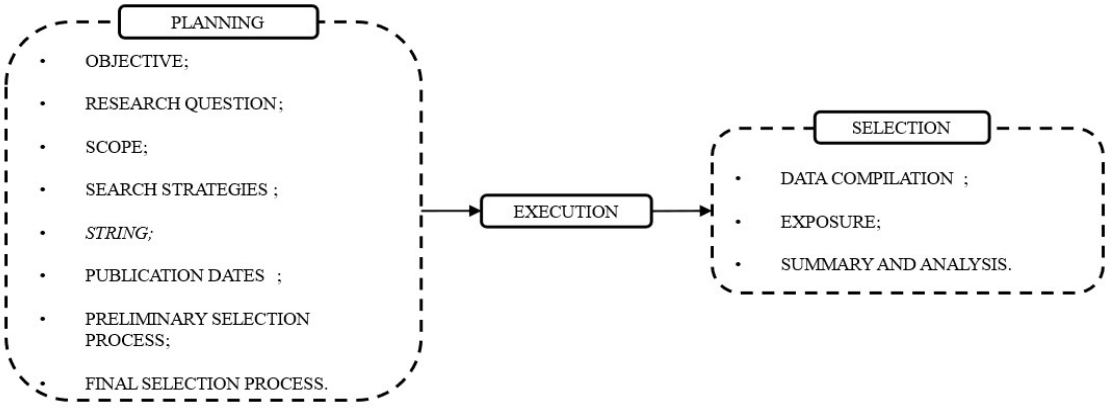

Figure 1. Stages of the systematic literature review.

The stipulated objective was to gather the evaluation studies of reversible lanes and other urban traffic management strategies contemplated in the concept of *managed lanes*, such as exclusive lanes for vehicles with high occupancy (High-Occupancy Vehicle Lane), toll lanes (High-Occupancy Toll Lane), and special use of the shoulder (Hard Shoulder Running) in academy and grey literature, aimed at identifying the key information used.

2.1. Planning

At this stage, the analysis categories were defined, corresponding to the key information to be identified and extracted from the publications:

- Approach: the aspect under which the evaluation is carried out, such as traffic, safety, and environment. The approach should reflect the motivation that originated the operation.
- Method: methodology used to perform the evaluation, such as questionnaires and comparative analyses, among others. It must include the calculation, formulas used and any necessary tools.
- Indicators: variables used during the evaluation to measure operational performance, such as traffic volume and the number of accidents.
- Data collection: how the authors collected the necessary data for the evaluation, such as traffic counts and accident databases, among others.

For the search, publication portals were used (CAPES Journals, Scopus, Science Direct, Web of Science, Biblioteca Brasileira de Teses e Dissertações, Network Digital Library of Theses and Dissertations, Open Access Theses and Dissertations, and Transportation Research International Documentation), and consultation with the agencies responsible for reversible operations in Brazil (Companhia de Engenharia de Tráfego "CET" of São Paulo and Rio de Janeiro, Empresa Pública

de Transportes e Circulação "EPTC" of Porto Alegre, Secretaria de Estado de Infraestrutura e Mobilidade "SIE" of Santa Catarina, Prefeitura Municipal of Blumenau and Natal).

No time restriction was stipulated, given the review's objective to map the existing evaluation studies. The search was conducted in English, Portuguese, and Spanish and included the term "managed lanes", which contemplates several traffic management strategies aiming to increase the scope of the research. Thus, the terms and combinations used are as follows:

- Keywords: reversible lanes; convertible lanes; tidal lanes; managed lanes; evaluation; *faixas reversíveis*; *carriles reversibles*;
- Combination of terms: (reversible lanes OR convertible lanes OR tidal lanes OR managed lanes AND evaluation); (*faixas reversíveis*); (*carriles reversibles*).

Initially, we removed duplicate publications, those unavailable in the digital medium or languages other than those defined. Subsequently, the preliminary selection phase of the publications was concluded by reading their abstracts, with its adherence to the research objective depending on the author's discretion. After the preliminary selection, the final selection phase was conducted based on the full reading of the publications. The premise adopted was that the publication should effectively contain some kind of reversible lane or other traffic management strategy evaluation.

2.2. Execution

The systematic review was performed between September 2022 and February 2023, when the primary term (reversible lanes and its variants) was searched in the primary fields (title, abstract, or keywords*)* and the term referring to the evaluation stage in any fields. Considering the small number of publications, the searches in Portuguese and Spanish were performed only with the primary terms and without restrictions on their position in the publication. The recovered bibliography was incorporated into the Mendeley® publication management program for the organization of the bibliographic body and its analysis and verification regarding adherence to the research.

2.3 Selection

The selection of publications was guided by the premises defined during the research planning stage, resulting in the recovery of 162 publications. After the preliminary selection (removal of duplicates, not available digitally, languages beyond the pre-established ones, and adherence analysis by the abstract), 99 publications were obtained. After the final selection (adherence analysis by the integral reading of the publication), the final bibliographic body perfected 13 publications (approximately 8% of the initial search).

It was found that the use of the term evaluation was also associated with the evaluation in the context of feasibility for the planning stage (pre-implementation). However, in previous tests, the greater use of the term assessment had been observed in such cases. In addition, despite addressing the stage of evaluating operations in the desired context, some studies did not contemplate its application in a real case study, therefore, not meeting the review's objective.

2.3.1. Result presentation

In Agent and Clark (1980), the evaluation process included traffic variables (distribution by direction, traffic volume, travel time and stopping time, speed, and impact on the surroundings), safety (accidents, severity, and traffic conflicts), environment (fuel consumption, noise, and air pollution), and economic (cost/benefit analysis), segregated by direction and in each peak period. Data collection relied on the use of a tachograph coupled to a test vehicle, which traveled the road several times before and after the implementation of the reversible lane, in addition to traffic and conflict counts, accident database, recordings to measure noise pollution, and parametric data (reference costs and vehicle emission rates).

Dey, Ma and Aden (2011) addressed aspects of traffic (road capacity) and safety (accidents, invasions, and signaling effectiveness), while Waleczek et al. (2016) included a study of the operation's effects on traffic flow, using data from video recordings, radars, and inductive loops, and on road safety, using accident data recorded before and during operation. Also, an economic evaluation through referential costs was conducted.

In DeRose (1966), the evaluation was restricted to the reversible lane's operational period (peak hours) and contemplated, among other specific aspects, the following indicators: traffic volume, travel time, speed, and accidents. Vehicle counts were performed (24 hours, every 15 minutes) on three different dates at the five defined counting points to subsidize the traffic assessment.

In Wang et al. (2015), traffic counts were performed and established the peak-hour factors in the existing operation in both directions of the road during the morning (between 8h and 9h) and afternoon (18h to 19h). Such data were used to calculate the directional imbalance of traffic (percentage between the directions at each peak time) and to model the existing operation in a given traffic simulation software.

In Brazil, CET-SP (1997) evaluated three indicators (travel time, traffic volume, and queue length), conducting two types of comparison of the "before and after" type, contemplating the average of the data collected in both periods and the comparison of the same day of the week before and after implementing the operation. The period before and after implantation was four and two days, respectively.

CET-SP (1995) interviewed users (drivers and pedestrians) in another study. Drivers were interviewed on five reversible lanes, while pedestrians were randomly approached near crossing points. The information was collected through structured and pre-tested forms, distinguishing between frequent or sporadic users, covering 625 drivers and 382 pedestrians. The questions in the forms included the frequency of trips on the road, opinion on traffic after implementation of the reversible lane, opinion on the opening hours of the operation, and opinion on the implementation in other places for drivers and the frequency of crossing on the road, opinion on crossing on the road, and space for suggestions for pedestrians.

Finally, the work developed by Machado (2012) was applied to create a procedure for implementing urban reversible lanes in a case study of a reversible lane in Rio de Janeiro. In the evaluation stage, the author uses the travel time data before and after the operation's implementation. The evaluation stage evaluated the operation in the direction of the route favored by the reversal and in two other groups (disadvantaged direction and in a parallel route).

Among the managed lanes, McCasland (1981) presents the evaluation of a contraflow lane operation (specific type of reversible lane, where physical elements segregate highway flow). The evaluation is based on monitoring the operation's data throughout its first 12 months and

comparing "before and after" periods of its implementation, contemplating traffic, economic, environmental, and safety approaches.

Buckeye (2012) rated a High-Occupancy Toll (HOT) Lane that had been converted from a High-Occupancy Vehicle (HOV) Lane. The evaluation was performed using three primary approaches: the road's performance (speed reliability, travel time, and traffic volume), the toll operation (number of transactions, parking facilities and tags, and income generation), and user satisfaction (value attributed by users to the operation and identification of problems).

Jang et al. (2009) compared two types of HOV Lanes (continuous and limited access operations). To this end, data were collected from a California Highway Agency system in the United States between 1999 and 2003 in eight road corridors, totaling approximately 1320 kilometers of this type of operation.

In Goodin et al. (2013), the evaluated object consisted of the operation evolution presented in McCasland (1981), a publication that also integrated the final bibliographic body. This new evaluation addressed from conventional aspects, such as traffic and safety, to specific aspects of this type of operation (collection and charging) and other aspects (use of human resources, regulation, maintenance, among others). From the traffic perspective, the indicators evaluated were traffic volume, travel time, and transport use, while in safety, the number of total accidents, accidents by type, and their severity were mainly considered.

2.3.2. Result summary and analysis

The distribution of the bibliographic body in terms of year of publication, source database, and type of publication is shown in Table 1. It was observed that the database with the highest number of publications incorporated into the final bibliography was the Transportation Research International Documentation (TRID), with approximately 38.5%. This is explained by the predominance of reports, type of publication traditionally developed by highway departments, indicating an important percentage of the so-called grey literature compared to strictly academic publications.

Table 1: Distribution of the bibliographic body according to year, origin, and publication type.

Year of publication	BDTD	CAPES		Science Direct	Scopus	TRID		WOS	CET-SP Library
	Thesis	Annals	Journal	Annals	Journal	Journal	Report	Annals	Report
1966	0	0	0	0	0	1	0	0	0
1980	0	0	0	0	0	0	1	0	0
1981	0	0	0	0	0	0	1	0	0
1995	0	0	0	0	0	0	0	0	1
1997	0	0	0	0	0	0	0	0	1
2009	0	1	0	0	0	0	0	0	0
2011	0	0	1	0	0	1	0	0	0
2012	1	0	0	1	0	0	0	0	0
2013	0	0	0	0	0	0	1	0	0
2015	0	0	0	0	0	0	0	1	0
2016	0	0	0	0	1	0	0	0	0
Total n (%)	1 (7.7%)	2 (15.4%)		1 (7.7%)	1 (7.7%)	5 (38.5%)		1 (7.7%)	2 (15.3%)

Regarding the period, the year of the publications contemplated in the research varied between 1966 and 2016, with the decade between 2011 and 2020 presenting the highest number of publications (53.8%). In addition, considering the inclusion of the term managed lane in the searches, the publications were segregated according to the object studied (reversible lanes or other strategies of managed lanes), as well as their country of origin, resulting in the distribution expressed in Table 2.

Table 2: Distribution of the bibliography regarding the object studied and country of origin.

Country of Origin	Reversible Lane	Managed Lane			
		Total	HOV Lane	HOT Lane	HSR
Germany	1	0	0	0	0
Brazil	3	0	0	0	0
China	1	0	0	0	0
United States	3	4	2	2	0
France	0	1	0	0	1
Total n (%)	8 (61.5%)	5 (38.5%)	2	2	1

The number of publications referring to reversible lane operations comprised 61.5%. Among the other strategies of managed lanes, those identified most frequently were HOV and HOT lanes. As expected, the United States had the highest number of publications in both cases (reversible lanes and other types of managed lanes) due to the pioneering adoption of these types of traffic strategies.

In terms of key information, performance evaluation studies predominate in traffic and road safety approaches. Except for Jang et al. (2009), all other publications contemplated some type of traffic evaluation (92.3%), adhering to what tends to be the primary objective of these types of operations: congestion reduction.

A significant number of publications addressing road safety assessment were observed (61.5%). Although the increase of safety is hardly listed as a primary objective in this type of strategy, this is explained by some operations (such as reversible lanes) having a historical reputation of increasing accidents severity. Finally, some studies also included economic, environmental, and other approaches (such as customer satisfaction, operational issues, and specifics of the type of operation evaluated). These approaches corresponded to evaluations in a complementary character, and no publication was observed contemplating such approaches exclusively.

The summary of the evaluations carried out in the recovered bibliography regarding the approach is expressed in Figure 2:

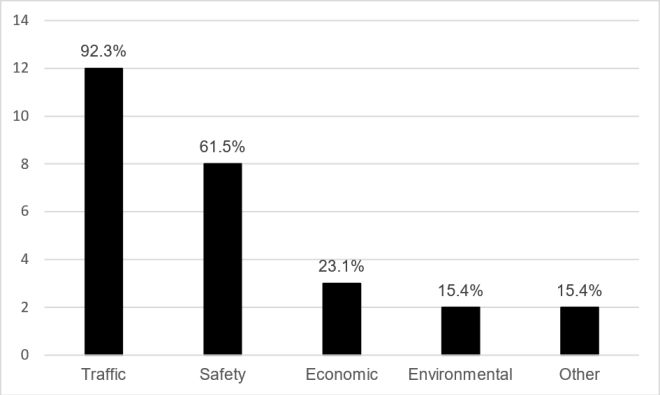

Figure 2. Summary of the approaches identified in the literature.

Regarding the indicators used, it was possible to identify some general indicators and variants according to the availability of the data used by the authors or the desired focus of the investigation. Thus, the main indicators identified in the evaluation studies, according to their associated approach, were:

- Traffic: traffic volume, travel time, speed, service level, delay time, queue length, percentage of reversible lane use, and impact of operation on parallel routes or adjacent lanes.
- Safety: total number of accidents, number of specific types of accidents, severity of accidents, number of conflicts or violations, and spatial location of accidents.
- Economic: operation cost, deployment cost, average hourly cost (lost hours), accident cost, and fuel cost.
- Environmental: fuel consumption, emission of vehicle pollutants (hydrocarbons, CO2, NOx), and noise pollution.

It should be noted that the list above is not exhaustive, and several of these indicators are subdivided into specific variants. Examples are temporal delimitations (volume of vehicles during the counting period, number of accidents during the operation, and percentage of use of the reversible lane during peak hours, among others) and descriptive statistical measures (average travel time, 85° percentile of operating speed, and average number of accidents weighted by traffic volume).

In addition, evaluation studies involving qualitative variables were identified, corresponding to the user's perception of the overall performance of the operation under the traffic and safety approach (reduction of travel time and improvement for pedestrian crossing, for example).

Considering that it is common that data availability acts as a limiting factor to the development of research, especially in academic studies, the authors sought to identify how the data used in the evaluations were collected. Figure 3 illustrates the most frequently identified sources of data collection associated with their respective collected data:

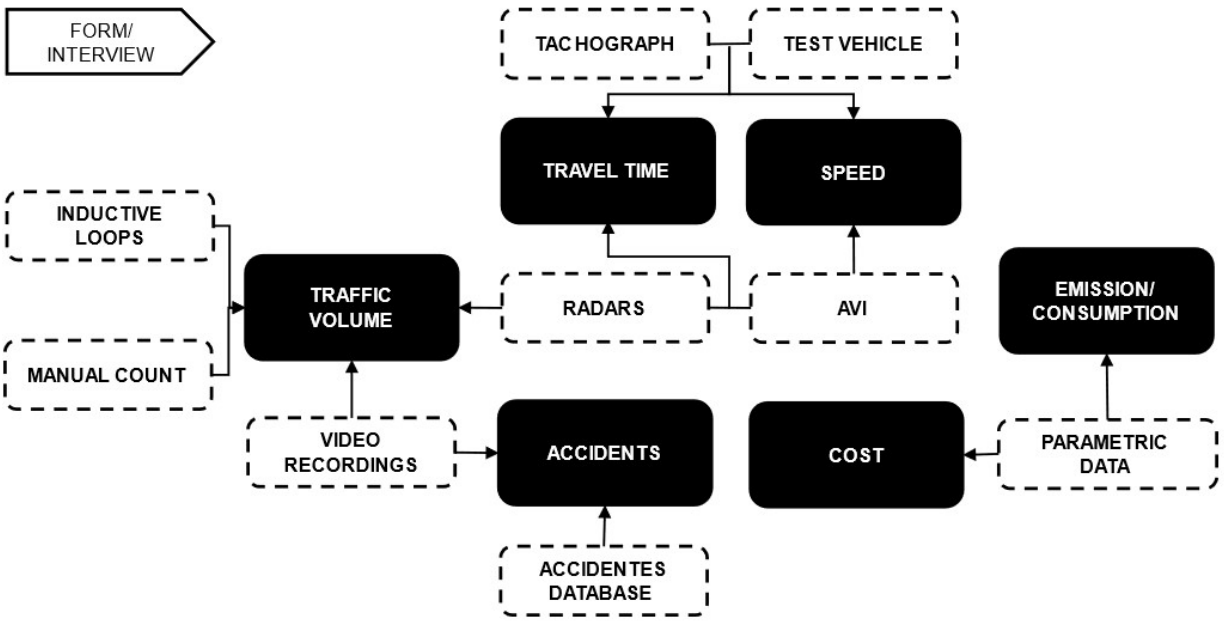

Figure 3. Summary of the sources of data collection identified in the literature.

Given the long period between publications, the diversity in terms of technology and complexity in the data collection sources can be noted. Traffic data were identified from mechanical tachographs and manual counts to electronic systems equipped with software, such as AVI (Automatic Vehicle Identification) technology, which made it possible to provide a large amount of data in real time. On the other hand, accident data collection was generally summarized in accident databases. Naturally, it has moved from physical records and files with a smaller variety of data to digital databases with more specific and accurate information. Finally, for data on costs and environmental issues, a trend in the use of reference values found in the literature (for example, average cost per accident and average fuel consumption of a given vehicle, among others) can be seen.

Finally, the predominance of quantitative evaluations over qualitative ones was identified regarding the evaluation method used. The only study developed with an exclusively qualitative evaluation through interviews with drivers and pedestrians was CET-SP (1995). Among the quantitative methods, the vast majority (approximately 77%) used some variation of the observational study of the "before and after" type. These methods were found in the format called naive (simple) and with the comparison group, comparing indicators of the traffic, safety, and environmental approaches between before the implementation of the evaluated operation and a subsequent one.

In some publications, as in Dey, Ma and Aden (2011), comparisons were made only with data after implantation, while in Jang et al. (2009), the comparison aimed exclusively at differentiating between two types of HOV lanes, therefore not requiring data before implementation.

Specifically in safety evaluations, Goodin et al. (2013), Waleczek et al. (2016), and Jang et al. (2009) taking advantage of the incorporation of the information on the geographical coordinates of the accident site in the databases, carried out a spatial evaluation of the location of the accidents throughout the operation to identify any critical points. Finally, Agent and Clark (1980) performed a cost/benefit economic evaluation, listing the costs necessary for the implementation and maintenance operation and comparing them with the benefits obtained.

The summary of the methods used can be seen in Figure 4:

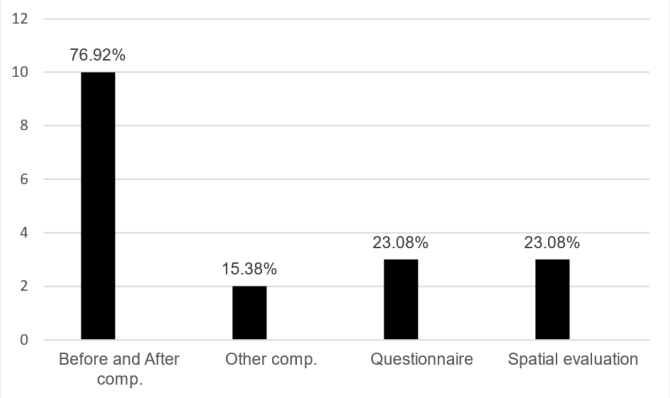

Figure 4. Summary of the evaluation methods identified in the literature.

3. FLOWCHART FOR EVALUATION OF REVERSIBLE LANES

3.1. Approach

A common consensus among several authors is that the approach used for the operation's evaluation should be directly linked to the objective for which it was implemented (Guebert, 2010; Wolshon and

Lambert, 2004; Fitzpatrick et al., 2016). However, in practice, this objective is not always explicitly defined. However, despite other approaches identified in the literature, such as road safety, environmental, or economic issues, it has been clear that the origin of reversible lanes is associated with traffic aspects.

In some cases, reversible lanes were responsible for the increased quantity or severity of accidents. Therefore, the presence of the road safety approach in evaluation studies is fundamental. Environmental and economic approaches play a relevant role and should also be considered throughout the implementation of reversible lanes, especially in the planning stage. However, in the performance evaluation stage, it was verified that the studies contemplating such approaches measured the benefits from reference values, which is a consequence of the operation's success from the traffic or safety perspectives. Therefore, associated benefits can be measured under the environmental and economic approaches if the operation has, in fact, improved traffic or safety performance.

Thus, the evaluation of the traffic and safety approaches is understood as a priority.

3.2. Indicators

In general, in terms of indicators under the traffic approach, the literature identifies the predominance of two indicators: traffic volume, which, in a survey conducted by Wolshon and Lambert (2004), had been identified as the indicator most used by road agencies in the country; and travel time, mentioned in publications such as Bhouri, Aron and Kauppila (2012) as the indicator that best represents the impact felt by users.

Another very important indicator from the management perspective is the percentage of use of the operation since it consists of fundamental information to justify a performance below expectations. For example, one can verify the increase in travel time after the implementation of the operation, even though the volume of traffic has remained the same, caused by the low adherence of users to the operation.

As for the safety approach, it is logical to choose performance measurement from indicators associated with the number of accidents. The variation of the indicators used is associated with the characteristics of accidents, such as the consideration of specific types, severity, spatial distribution, and other delimitations. In the environmental approach, indicators related to fuel consumption, vehicle emissions of pollutants, and traffic noise pollution were identified. The evaluation under the economic approach contemplated costs linked to reversible lanes (implementation and maintenance) and any benefits obtained with the operation (reduction of accident costs and time lost by users, among others).

Thus, in operations with conventional objectives, such as congestion mitigation, it is understood that the evaluation contemplating indicators, such as traffic volume, travel time, percentage of use, and the number of accidents, could subsidize decisions based on performance evaluation.

3.3. Source of data collection

However, in addition to the objective, a practical factor that can limit the selection of the indicator to be used is data availability. Authors such as Kuhn *et al.* (2005) and Fitzpatrick et al. (2016) highlight the need for indicators to be reduced in quantity and easily collected so as not to overload the resources of the operations managers.

The literature review shows that some data, such as traffic volume and the number of accidents, tend to be more easily collected than others, such as travel time. Manual counts can be used to obtain the traffic volume in simple studies, while automatic counters can be used in more robust studies.

There is also the possibility of counting vehicles remotely from video recordings. On the other hand, measuring travel time requires more resources, such as using a test vehicle or Intelligent Transport Systems (ITS*)*. A trend of accident data collection through consultation with the database of existing road accidents was noted. It is uncommon to generate these data specifically for the study.

3.4. Methodology

Another way to obtain information concerning the operation performance is to conduct questionnaires and/or interviews with users (qualitative information). The literature included face-to-face interviews, and digital forms. Conducting interviews becomes a viable method to measure the operation's performance considering the scenario of national practice described in Machado (2012), whose operations tended to be based on empirical knowledge and daily practice. After all, in such cases, where the planning stage was hardly carried out, there is no history of data collection before the operation, which makes it impossible to conduct before-and-after studies. However, these were the methods identified most frequently in the literature.

Although this method can include the traffic and safety approach, it tends to become less accurate with increasing time elapsed since the implementation of the operation due to the difficulty of capturing confounding variables (confounding factors), which correspond to the extra effects (other than the variable in question) that influence the behavior of the studied object. Studies have presented the simple/naive versions and with comparison groups. They were used in virtually all approaches (traffic, safety, environmental, and economic), involving several indicators. Thus, it is necessary to collect the data evaluated before the implementation of the operation and in subsequent periods.

Finally, another method used specifically in studies with a safety approach was the spatial evaluation of accidents. Using the location of the accidents (geographical coordinates), it is possible to identify any critical segments that present a greater number of accidents throughout the operation's extension. However, it should be noted that this method demands high-accuracy location information.

3.5. Flowchart conception

In an ideal context, the conception of new reversible lane operations would include a procedure contemplating pre-implementation stages (associated with studies, planning, and design), implementation, and post-implementation stages (involving monitoring and performance evaluation). However, the literature shows that this situation was not observed in practice for a long time. Thus, two performance evaluation hypotheses are observed: when designing new operations or in existing operations.

In the first, considering the pre-implementation stages, the objectives and goals of the operation are defined with a natural direction of the performance evaluation to be performed after its implementation. After all, the performance evaluation of the operation is precisely the measurement of its performance against the expectation (stipulated goals), attesting to its success against the previously defined objectives. Thus, it is possible to define the approach, indicators, and method used during the performance evaluation in advance. In possession of this information, one should verify the existence of the necessary data and, if not, draw up a plan for collecting or generating such data.

However, there are cases of existing operations that, as observed in the literature, do not tend to be preceded by robust pre-implantation stages. Despite that, every operation was implemented for some reason. This should be the basis for the evaluation, guiding the procedure sequence. If the objective previously defined is clear, this will be the starting point of the evaluation.

In general, the process begins with the definition of the approach and the selection of the indicators that will be used based on the motivations or objectives of the operation, as well as the previous mapping of existing data. The difference between both hypotheses is due to the inversion of the order between two key pieces of information: the evaluation method used and the form of collection of the necessary data. After all, unlike planned operations, where the desired data can be generated more easily, the studies of existing operations can be limited to the availability of existing data, especially concerning data referring to the situation before the implementation of the operation.

In this sense, the proposed flowchart incorporates questions about the existence and possibility of obtaining the data that will subsidize the evaluation, directing the study to two basic proposals:

- Possibility of data collection in both reference periods: quantitative assessment by the "before and after" study method. It is suggested to incorporate a comparison group in cases where there are comparable groups available.
- Impossibility of data collection in both reference periods: qualitative evaluation through interviews. Adopting a diagnostic bias during evaluation in cases where the operation was implemented for a significant time, to the detriment of a comparative bias, is suggested. This bias can even help identify the motivations of the operation, feeding back the process.

Specifically, data collection only after implementation may involve consulting pre-established goals or benchmarks. However, no such references have been identified in the literature for most indicators.

Thus, Figures 5 and 6 present the flowcharts proposed for existing operations and new operations, respectively:

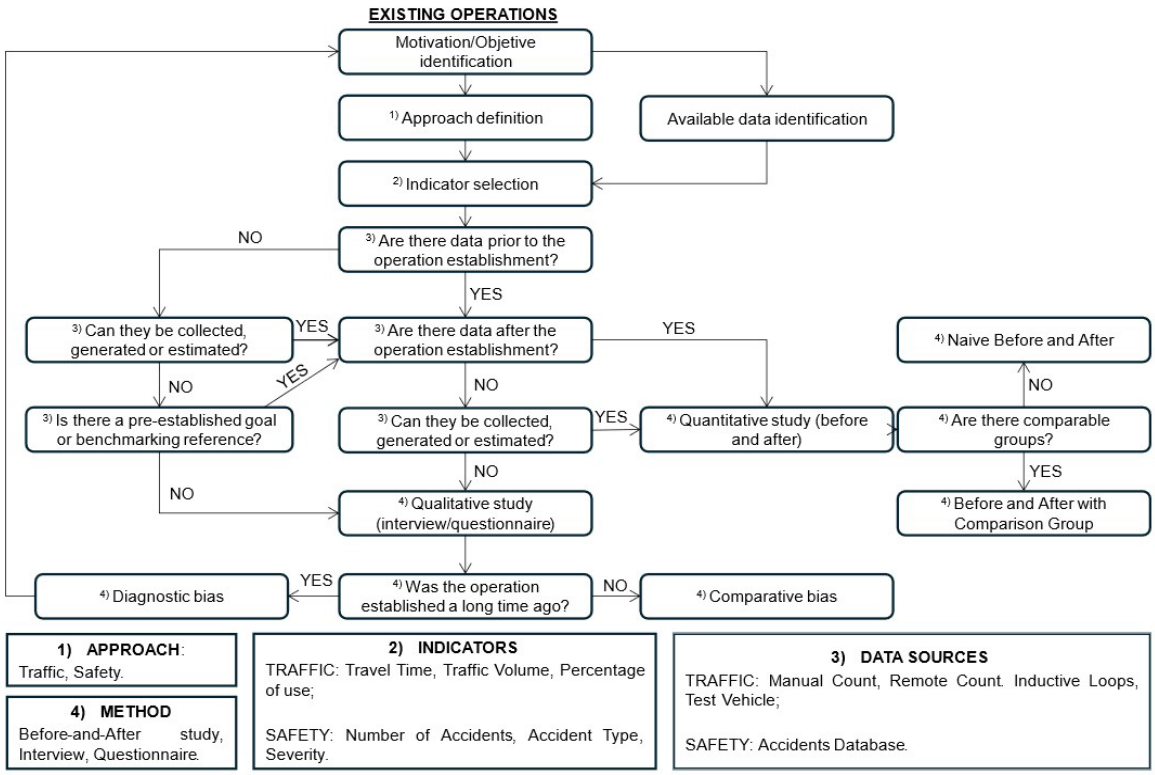

Figure 5. Flowchart of the performance evaluation of existing reversible lanes.

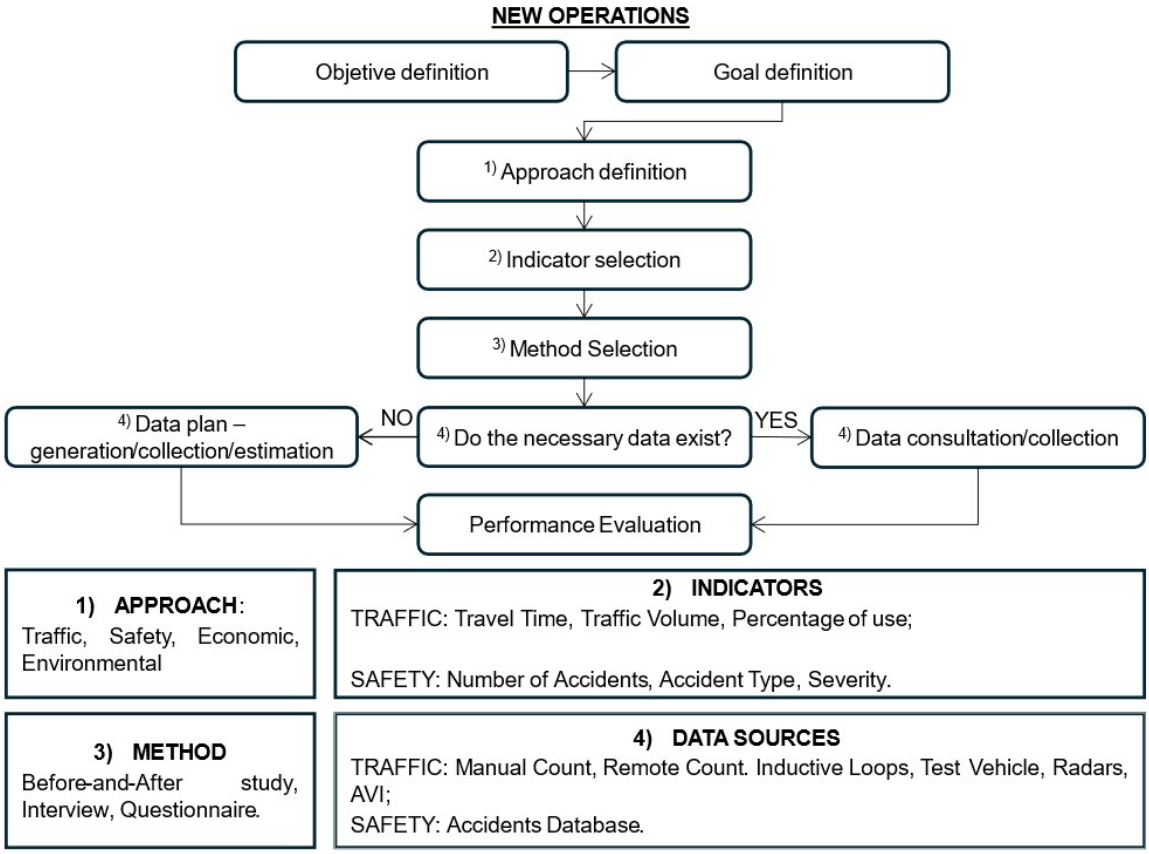

Figure 6. Flowchart of performance evaluation in new operations.

The objective of these flowcharts was to simply and objectively help define some key information for the performance evaluation studies in reversible lanes: approach, indicators, data collection source, and method.

In addition, the primary key information identified in the literature was listed and numerically correlated with its corresponding flowchart activity.

Other complementary information should be raised, such as considering confounding factors, criteria used to define the comparison group, and structuring of the interview forms, among others, to develop complete performance evaluation studies.

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