# Towards a Personalized Multi-objective Vehicular Traffic Re-routing System

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***Abstract.*** *Vehicular traffic re-routing is the key to provide better vehicular mobility. However, considering just traffic-related information to recommend better routes for each vehicle is far from achieving the desired requirements of a good Traffic Management System (TMS), which intends to improve mobility, driving experience, and safety of drivers and passengers. In this scenario, context-aware and multi-objective re-routing approaches will play an important role in traffic management, considering different urban aspects that might affect path planning decisions such as mobility, distance, fuel consumption, scenery, and safety. There are at least three issues that need to be handled to provide an efficient TMS, including: (i) scalability; (ii) re-routing efficiency; and (iii) reliability. In this way, this thesis contributes to efficient and reliable solutions to meet future TMSs. The proposed solutions were widely compared with other related works on different performance evaluation metrics. The evaluation results show that the proposed solutions are efficient, scalable, and cost-effective, pushing forward state-of-the-art traffic management systems.*

## 1. Introduction

Urban mobility became an evident problem in large cities around the world due to the high number of vehicles on the roads and also by the traffic jams produced by them [de Souza 2021]. One effective way to deal with such problems is the implementation of vehicular traffic re-routing services [de Souza et al. 2020a], which aim to improve the overall traffic efficiency by recommending faster routes (e.g., paths that avoid traffic jams) to the vehicles. However, considering traffic-related information to recommend better routes for each vehicle is far from achieving the desired requirements of future Traffic Management Systems (TMS). Context-awareness and multi-objective re-routing will play an essential role in vehicular traffic re-routing, improving the vehicular experience and enabling a whole new set of services. Hence, improving traffic mobility and driving experience, the energy consumption of electric vehicles, as well as the safety of drivers and passengers [de Souza et al. 2017b]. This new vehicular experience will ultimately have a profound impact on society and the daily lives of billions of people worldwide, changing the way we live, work, and play.

Context-awareness in vehicular re-routing is essential since different drivers can have different preferences to perform their journey [de Souza 2021]. These preferences are related to urban factors, including travel time, distance, fuel consumption, scenery, and even safety, which can lead to different routes to reach the same location [de Souza et al. 2020a]. However, considering a single preference to re-route vehicles can directly lead to other significant concerns. For instance, CNN[1] showed a real example, where a couple got shot, and the woman died after taking the directions recommended by a vehicular navigation system (VNS), which guided them towards a dangerous neighborhood in Rio de Janeiro, Brazil, aimed to provide the fastest route. Another example shows a vehicle (which took the directions recommended by a VNS) passing through shooting in Boston[2]. These issues could have been possibly avoided using safe route recommendation systems [de Souza et al. 2018]. Navigation systems that focus on optimal safety can lead to stressful paths since the recommendation algorithm can include congested roads to provide the safest way, and these roads are more likely to be avoided in drivers' criteria during their route planning [Taha and AbuAli 2018]. Thus, multi-objective optimization of traffic efficiency and safety is desirable to increase the appeal and the effectiveness of the re-routing strategy.

Advances in wireless communication and processing such as the fifth-generation (5G) networks [Dong et al. 2017], vehicle-to-everything (V2X) [Wedel et al. 2009] communication and multi-access edge computing (MEC) [Liu et al. 2017] will enable TMSs to sense and act in the urban environment in different ways, interacting not only with vehicles, but also with intelligent devices, subsystems, and even people in order to provide better solutions [de Souza et al. 2020a, de Souza et al. 2020b, de Souza et al. 2019a]. In other words, TMSs will understand a set of different urban factors and build various pieces of knowledge to help traffic management decisions, including detecting areas with recurrent traffic congestion and limited safety, improve re-routing effectiveness, and avoid dangerous neighborhoods. Besides, with the help of machine learning techniques [Ye et al. 2018], TMSs can predict future urban dynamics and know in advance when some areas can become congested or dangerous to improve their effectiveness. However, how to predict these urban dynamics accurately and explore their spatiotemporal correlation is still an open issue. In this scenario, deep learning techniques such as recurrent neural networks (RNN) [Ye et al. 2018] can play an essential role by providing accurate predictions about urban dynamics such as traffic conditions and safety risks while exploring their spatial and temporal information.

This document summarizes the goals and contributions of the thesis entitled: **Towards a Personalized Multi-objective Vehicular Traffic Re-routing System** [de Souza 2021], developed at University of Campinas, Brazil with joint-supervision at University of Bern, Switzerland. The results produced by this research pushed forward the state-of-the-art in traffic management systems by: *(i)* proposing a scalable and cooperative architecture for traffic re-routing systems; *(ii)* proposing a multi-objective non-deterministic re-routing algorithm that consider spatial and temporal correlation of urban aspects during the re-routing; *(iii)* proposing a reinforcement learning-based re-routing algorithm that adapts to future changes in urban dynamics to provide better routes considering users preferences.

The rest of the document is structured as follows: Section 2 summarizes the limitations of literature solutions for dealing with traffic re-routing. Section 3 details the main goal of the thesis and also present the research questions built to guide the research towards the goals. Section 4 lists the publications and achievements of the thesis. Finally,

[1] `https://tinyurl.com/wrong-directions-death`
[2] `https://tinyurl.com/gunfight-boston`

Section 5 concludes the document.

## 2. Related Work

Solutions have been proposed to enable context-awareness and multi-objective re-routing, such as Weighted-Sum (WS), Resource-Constrained Shortest Path (RCSP) and Evolutionary algorithms [de Souza et al. 2020a]. However, these solutions are deterministic and are not suitable for traffic management applications since many vehicles with the same origin and destination can take the same route, potentially degrading traffic efficiency [de Souza et al. 2020b]. Besides, most of the TMSs proposed to perform vehicular traffic re-routing have issues related to scalability as a result of the network overhead produced by them, and also due to computing efforts related to the complexity time of the re-routing algorithm and their architecture [de Souza et al. 2017b]. In this scenario, the major limitations presented by literature solutions to enable multi-objective vehicular traffic re-routing can be listed as follows:

**High network overhead**: To enable efficient vehicular traffic re-routing, the TMS needs to have accurate knowledge about traffic conditions on the roads. In this way, vehicles need to report their position and velocity to the system periodically to enable traffic condition estimation. However, if all cars communicate their traffic-related information, it potentially overloads the network in dense scenarios, consequently introducing an undesired latency, which might degrade the overall system performance [de Souza and Villas 2016].

**High computational efforts**: The vehicular re-routing task of a TMS consists of finding better paths connecting an origin and destination pair. Therefore, the complexity time of a personalized re-routing algorithm is directly related to its preferences (e.g., the number of additional urban factors that will be considered to plan the path) and the number of vehicles that need to be re-routed. Consequently, depending on the TMS architecture, such complexity can dramatically increase, especially under heavily congested scenarios [de Souza et al. 2019b].

**Lack of knowledge about future urban dynamics and their spatiotemporal correlation**: Different urban factors might have different conditions depending on the region, day, and time, which means that the same area can provide a set of different situations throughout the day for each urban factor (e.g., spatiotemporal correlation). For instance, some areas are more likely to present traffic congestion during rush hours than on business days. Also, some regions can provide different opportunities for criminal activities along the day, either increasing or decreasing the safety risk in that area. Therefore, the lack of knowledge about such a correlation can directly reduce the effectiveness and the reliability of the re-routing algorithm due to dynamic changes [de Souza et al. 2018a].

**Non-adaptable multi-objective re-routing**: The multi-objective re-routing algorithm itself is not enough to enable personalized re-routing since the TMS needs to be able to understand the relative preferences of each driver to provide methods to allow efficient and customized re-routing. For instance, considering safety risk as a preference, there are a set of events (e.g., criminal actives) that can provide different threats to the safety of drivers and passengers according to their relative preferences. In other words, different drivers can also have different relative choices to each type of crime (e.g., narcotics, assault, shooting, kidnapping, sexual attack, etc.) that can increase or decrease the risk to them. Those relative preferences can also vary according to age, gender, and social characteristics. Thus, enabling each driver its relative choices is essential to achieve trust and reliable TMS [de Souza et al. 2018b].

For more details regarding the related work, please refer to Chapter 3 of the thesis [de Souza 2021], which provides the detailed analysis and classification for literature solutions. However, based on the limitations presented by related work it is possible to conclude that an efficient TMS for traffic management needs to have: *(i)* a scalable architecture to enable an efficient and real-time re-routing; *(ii)* a multi-objective non-deterministic re-routing algorithm to enable the personalization according to the preference of each user to improve the traffic management considering several urban aspects without degrading the efficiency of each other; and *(iii)* a re-routing algorithm that cares about future changes in urban dynamics to improve the reliability of the route computed by the system.

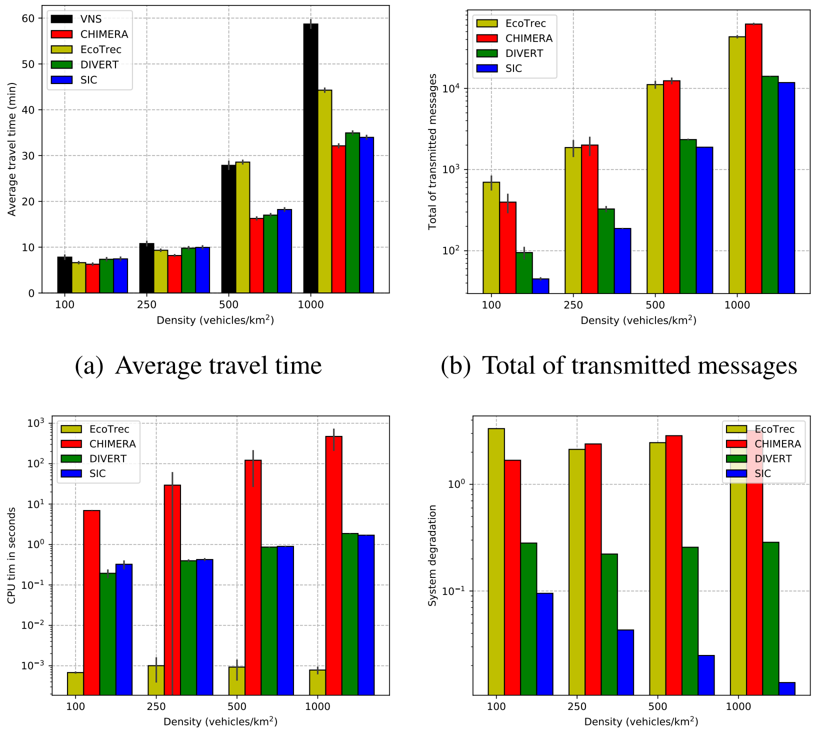
## 3. Goals and Contributions

Motivated by the limitations of literature solutions and the high safety risks to drivers and passengers produced by public safety issues, the thesis proposed a context-aware vehicular re-routing system to improve traffic efficiency and the safety of drivers and passengers. The system implements mechanisms to extract knowledge about traffic conditions and public safety issues. Thus, personalized path planning is applied, enabling the drivers themselves to choose which safety risk (e.g., criminal events) they want to avoid. Besides, to facilitate decision-making (e.g., compute an alternative route) in advance, the system exploits the spatiotemporal information of each criminal activity, consequently understanding the future safety dynamics of each area. In this context, the goals of the thesis were achieved by answering the following research questions:

**How to ensure system scalability with low overhead and reasonable traffic management?**

To enable a scalable system and efficient traffic management a distributed traffic-aware data sharing protocol is proposed, in which the vehicles estimate the traffic conditions on the roads locally within their communication range based on the traffic information shared by them. Thus, the best vehicles are chosen to report their local estimations to the TMS by employing a selection mechanism. To enable real-time traffic management (i.e, re-routing) an offloading mechanism is employed to distribute the re-routing task in several processing units. Therefore, by offloading the re-routing computation in each vehicle, the TMS will overcome the limitation of high latency produced by computational efforts related to the vehicles' density, consequently enabling real-time re-routing and improving system scalability. Finally, a cooperative re-routing approach is proposed to allow that the distributed approach achieves similar performance to the centralized one in terms of traffic balancing effectiveness. The detailed description of these solutions are presented in Chapter 4 of [de Souza 2021] which introduces a system named SIC (*Sharing is Caring*).

The results have shown that the SIC provides a suitable architecture for traffic re-routing, producing a low overhead, complexity and CPU time (which enables a real-time system), consequently enabling a highly scalable system cooperative re-routing algorithm. The main results are summarized in Figure 1 as it can be seen, SIC reduces the overhead and CPU time in up to $90\%$ and $99\%$ when compared to CHIMERA, which is a centralized approach. In addition, SIC also provides an efficient traffic management. It is worth noticing that when considering the CPU time, the EcoTrec solution achieves the lowest time, which is because it uses Dijkstra algorithm to compute the shortest path. On the other hand, SIC uses a cooperative providing a slight increasing in the CPU time, however the results achieve by SIC still are very low (i.e., approximately 1 second), thus not decreasing the system performance. When compared to DIVERT, SIC presents similar performance considering traffic management, network overhead, and CPU time, however when compared to the system degradation, which is a metric that express the scalability of the system, we can see that SIC outperforms DIVERT (see Figure 1(d))




(a) Average travel time (b) Total of transmitted messages

(c) CPU time (d) System degradation

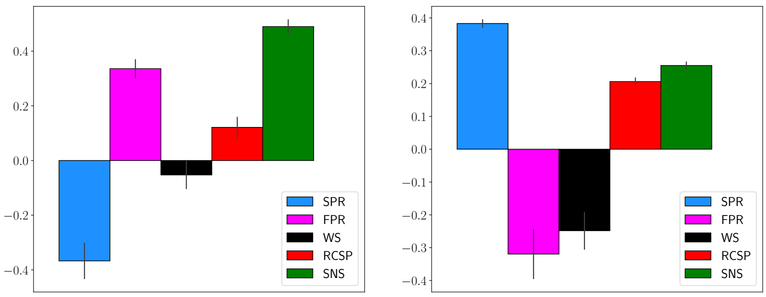
**Figure 1. System efficiency evaluation.**

**How to enable an efficient and personalized multi-objective re-routing without creating different congestion spots?**

To allow a personalized multi-objective re-routing, an architecture was designed that enables the estimation of different urban dynamics, such as, travel time, green house emissions, and safety considering their spatiotemporal correlation. Then, by extracting knowledge about city dynamics, the system can implement multi-objective re-routing. For instance, by extracting information about traffic conditions and safety risks, the system re-routes vehicles through the fastest and safest route. Also, supported by the offloading mechanism to enable real-time re-routing, vehicles can decide which information they want to re-route themselves considering the spatiotemporal correlation of the relevant urban aspects. Therefore, the system provides the vehicles the info they are interested in. However, to achieve the desired effect of traffic re-routing and avoid creating different congestion spots (due to many vehicles with the exact origin and destination take the same route), a non-deterministic re-routing algorithm is proposed to compute the set of paths that improve mobility of the vehicle and safety considering its preferences and then distribute the traffic flow over the collection of routes previously computed. In summary, the proposed algorithm uses a Pareto front to compute the route that improves the intended metrics (i.e., mobility and safety), then it uses an Entropy based mechanism to balance the traffic flow over the feasible routes considering the spatiotemporal correlation of these metrics. The detailed description of these solutions to deal with personalized multi-objective re-routing for TMS is presented in Chapter 5 of [de Souza 2021] which describes the system named as SNS *Safe and Sound*.

Figure 2 shows the simulation results, which revealed that when compared to state-of-the-art approaches, which includes: *(i)* Safest Path Re-routing (SPR); *(ii)* Fastest Path Re-routing (FPR); *(iii)* Weighted-Sum (WS); and *(iv)* Resource Constrained Shortest Path (RCSP). SNS decreases the average safety risk (which is a metric defined to estimate the overall safety risk over the vehicles route) for drivers and passengers in at least $30\%$ while keeping efficient traffic mobility.

To evaluate the personalization considering the spatiotemporal correlation of the urban aspects (in this analysis the urban aspects refer to criminal events types i.e., assault, robbery, narcotics, etc), SNS was compared against EBPOP [de Souza et al. 2018b], which is an early version of SNS that is centralized and that does not consider either the preferences of each uses nor the spatiotemporal correlation of the urban aspects that the drivers are interested in. Table 1 shows how SNS can achieve better performance considering the drivers interested to avoid safety issues related to assault with spatiotemporal of such criminal event. The spatiotemporal correlation used by SNS considers the different dynamics in business days and weekends, and also four different periods of the day, *(i)* Dawn, from $00{:}00$ to $05{:}59$; *(ii)* Morning, from $06{:}00$ to $11{:}59$; *(iii)* Afternoon, from $12{:}00$ to $17{:}59$; and *(iv)* Night, from $18{:}00$ to $23{:}59$.




(a) Average percentage of improvement in relative travel time

(b) Average percentage of improvement in relative safety

**Figure 2. Results of the trade-off analysis between mobility and safety.**

The results were based on the Chicago open dataset, which provides data for traffic conditions and also for criminal events over the city. Therefore, the traffic conditions and the safety risk estimation with personalization considered routes planned for all solutions using the conditions provided by such dataset. The complete description of the dataset and simulation setup is described in the thesis.

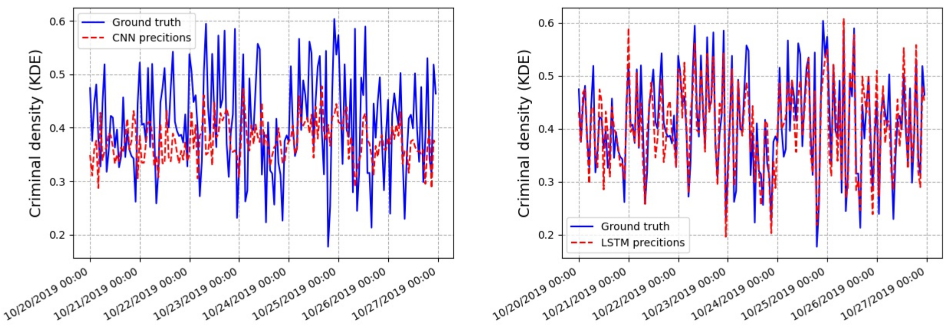
**How to consider future changes in urban dynamics during re-routing to plan more**

**Table 1. Average route safety risk for assault-related crimes on business days and weekend considering different periods of the day.**

| | Business days | | | | Weekend | | | |
|---|---|---|---|---|---|---|---|---|
| | Dawn | Morning | Afternoon | Night | Dawn | Morning | Afternoon | Night |
| No Re-routing | 16.07 | 14.02 | 17.03 | 16.65 | 11.62 | 3.55 | 16.54 | 18.61 |
| EBPOP | 11.04 | 9.55 | 13.67 | 12.87 | 10.15 | 3.00 | 15.07 | 17.98 |
| SNS | 10.76 | 8.54 | 10.72 | 11.00 | 8.87 | 2.25 | 10.52 | 15.07 |

**efficient and reliable routes?**

To pave the way for a more efficient and reliable traffic re-routing a prediction model is proposed, which predicts future changes in the urban dynamics to understand the environment and to know when and where some changes will happen. Thus, a recurrent neural network has been implemented to predict the future dynamics (considering a time window) based on past events and historical data. Figure 3 shows the criminal density prediction for one week in the downtown of Chicago, using the Open Data Chicago dataset, the criminal density was estimated using a KDE, then this data was used to compare the prediction of different models. Due to space constraints we are presenting only the performance of CNN and LSTM models, however the entire comparison can be seen in Section 6.4 of [de Souza 2021]. As it can be seen, LSTM achieved better performance due to its ability to handle with temporal correlation. In other words, the better performance of the LSTM enables a more efficient decision making.

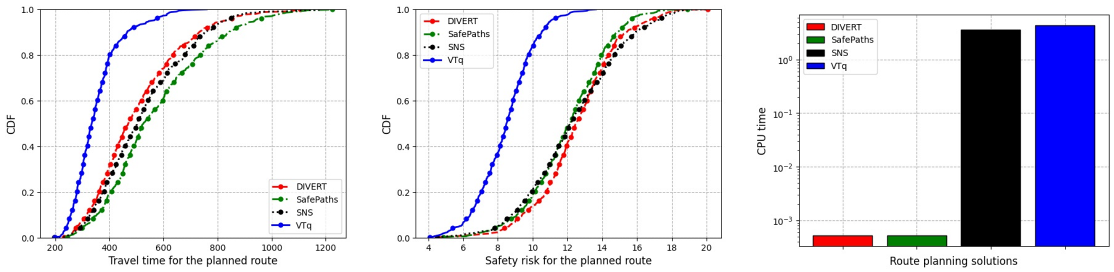



(a) CNN (b) LSTM

**Figure 3. Results of the comparison of the predicted dynamics in respect to the real dynamics of the scenario**

Hereafter, a routing algorithm that considers the predicted dynamics during the route planning is proposed. In summary, the algorithm learns the most efficient path by iterating with the environment considering the future changes using a trial-and-error approach, which is suitable for reinforcement learning-based solutions. In other words, a reinforcement learning-based route planning algorithm is proposed. The detailed description of the prediction model and the reinforcement learning-based algorithm are presented in Chapter 6 of [de Souza 2021] which introduces the system named VTq (*Vehicular Traffic re-routing with Q-learning*).

The results have shown substantial improvements for the planned routes provided by VTq when compared to state-of-the-art solutions for traffic management considering




(a) Travel time (b) Safety risk (c) CPU time

**Figure 4. Result of the comparison of the route planning of VTq against literature solutions.**

mobility and safety, which is consequence of the efficient predictions provided by the LSTM that are used to a better decision making in advance by the reinforcement learning algorithm. In other words, the reinforcement learning knows the future changes in urban dynamics and uses that information to plan more efficient and reliable routes.

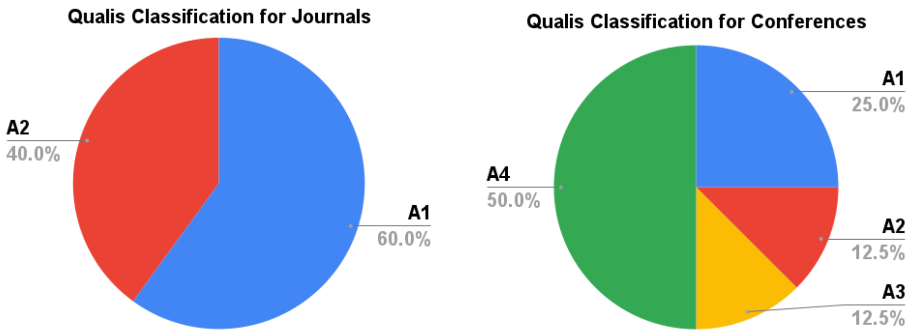
Figure 4 summarizes the results of three different literature solutions for traffic management in comparison with VTq, including: *(i)* SafePaths, which is a bi-objective solution based on safety risks and traveled distance; *(ii)* DIVERT, which is a distributed solution for traffic management which considers just mobility to recommend better routes; and *(iii)* SNS, which is a solution described in this thesis that considers both metrics to compute the most efficient path, however does not consider the future changes in the urban dynamics.

## 4. Publications

The solutions presented in the thesis were published in $8$ relevant conferences and $5$ prestigious journals on computer networks and communication. The conferences in which the solutions were published include *IEEE International Conference on Communications (ICC, Qualis A1), ACM International Conference on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWIM, Qualis A4), IEEE Vehicular Technology Conference (VTC, QUalis A1), IEEE Intelligent Transportation System Conference (ITSC, Qualis A2), IEEE Distributed Computing in Sensor Systems (DCOSS, Qualis A3), and* $3$ *Brazilian Symposium on Computer Networks and Distributed Systems (SBRC, Qualis A4)*. On the other hand, the published journals: *IEEE Transactions on Intelligent Transportation Systems (T-ITS, Qualis A1, IF 6.49), IEEE Intelligent Transportation System Magazine (ITSM, Qualis A1, IF 3.41), Springer Journal of Internet Applications and Services (JISA, Qualis A2, IF 1.88), MDPI Sensors (Qualis A1, IF 3.73), and International Journal of Distributed Sensor Networks (DSN, Qualis A2, IF 1.664)*. In addition, the solutions produced by this thesis contributed to several papers that are shown in the publication list. The complete list of publications, citations, and milestones achieved by the thesis is presented in the document that describes the byproducts of the thesis.

It is worth noticing the quality of the venues in which the papers were published according to the Qualis system. Figure 5 shows the scientific production published in journals (Figure 5(a)) and papers published in conferences (Figure 5(b)). As can be seen, all papers were published in journals and conferences classified in the top levels of the

CAPES systems (i.e., Qualis A1, A2, A3 and A4). In addition, the journals were published in high impact factor venues, in which $60\%$ of them have impact factor higher than $3$.




(a) Journals (b) Conferences

**Figure 5. Percentage of scientific production published in journals and conferences according to the Qualis classification.**

Finally, the achievements received by research presented in thesis [de Souza 2021] includes: a best thesis award in the computer institute of the University of Bern in 2021 (university where the *"Cotutela"* agreement of this thesis was established). Two honorable mentions awards in previous editions of SBRC (e.g., SBRC 2017 [de Souza et al. 2017a] and SBRC 2018 [de Souza et al. 2018]), which is the greatest conference of computer networks and distributed systems in Latin-America, and several citations ($\approx$ 350 citations according to *Google Scholar*[3]) in top-tier venues in the area of traffic management, computer networks and distributed systems.

## 5. Conclusion

This document sums up the contributions of the thesis in [de Souza 2021] which addresses the issues to provide an efficient TMS, including: *(i)* scalability; *(ii)* re-routing efficiency; and *(iii)* reliability, which paved the way for development of efficient and reliable traffic management solutions. The main contributions of the thesis includes: the proposal of a scalable and cooperative architecture for traffic re-routing systems; a multi-objective non-deterministic re-routing algorithm considering spatial and temporal correlation of urban aspects; and a reinforcement learning-based re-routing algorithm that adapts to future changes in urban dynamics to provide better routes considering users preferences. Finally, the knowledge produced during research has been featured in several top-tier venues in the area, in terms of scientific publications or in short course.

## References

[de Souza 2021] de Souza, A. M. (2021). *Towards a Personalized Multi-objective Vehicular Traffic Re-routing System*. PhD thesis, University of Campinas with joint-supervision at University of Bern.

[de Souza et al. 2018] de Souza, A. M., Botega, L. C., Garcia, I. C., and Villas, L. A. (2018). Por aqui é mais seguro: Melhorando a mobilidade e a segurança nas vias urbanas. *Anais do Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos (SBRC)*, 36.

[3] `https://scholar.google.com/citations?hl=en&user=Y4lKgtgAAAAJ`

[de Souza et al. 2017a] de Souza, A. M., Botega, L. C., and Villas, L. A. (2017a). Gte: Um sistema para gerenciamento de trânsito escalável baseado em compartilhamento oportunista. In *Anais do XXXV Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos*, Porto Alegre, RS, Brasil. SBC.

[de Souza et al. 2018a] de Souza, A. M., Botega, L. C., and Villas, L. A. (2018a). Fns: Enhancing traffic mobility and public safety based on a hybrid transportation system. In *2018 14th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, pages 77–84.

[de Souza et al. 2019a] de Souza, A. M., Braun, T., Botega, L. C., Cabral, R., Garcia, I. C., and Villas, L. A. (2019a). Better safe than sorry: a vehicular traffic re-routing based on traffic conditions and public safety issues transportation systems. *Springer Journal of Internet Services and Applications*, 10(1).

[de Souza et al. 2020a] de Souza, A. M., Braun, T., Botega, L. C., Villas, L. A., and Loureiro, A. A. F. (2020a). Safe and sound: Driver safety-aware vehicle re-routing based on spatiotemporal information. *IEEE Transactions on Intelligent Transportation Systems*, 21(9):3973–3989.

[de Souza et al. 2018b] de Souza, A. M., Braun, T., and Villas, L. (2018b). Efficient context-aware vehicular traffic re-routing based on pareto-optimality: A safe-fast use case. In *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, pages 2905–2910.

[de Souza et al. 2017b] de Souza, A. M., Brennand, C. A., Yokoyama, R. S., Donato, E. A., Madeira, E. R., and Villas, L. A. (2017b). Traffic management systems: A classification, review, challenges, and future perspectives. *International Journal of Distributed Sensor Networks*, 13(4):1550147716683612.

[de Souza et al. 2019b] de Souza, A. M., Maia, G., Braun, T., and Villas, L. A. (2019b). An interest-based approach for reducing network contentions in vehicular transportation systems. *Sensors*, 19(10).

[de Souza et al. 2020b] de Souza, A. M., Oliveira, H. F., Zhao, Z., Braun, T., Villas, L., and Loureiro, A. A. F. (2020b). Enhancing sensing and decision-making of automated driving systems with multi-access edge computing and machine learning. *IEEE Intelligent Transportation Systems Magazine*, pages 0–0.

[de Souza et al. 2018] de Souza, A. M., Pedrosa, L. L. C., Botega, L. C., and Villas, L. (2018). Itssafe: An intelligent transportation system for improving safety and traffic efficiency. In *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)*, pages 1–7.

[de Souza and Villas 2016] de Souza, A. M. and Villas, L. A. (2016). A Fully-distributed Traffic Management System to Improve the Overall Traffic Efficiency. In *Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, MSWiM '16, pages 19–26, New York, NY, USA. ACM.

[Dong et al. 2017] Dong, P., Zheng, T., Yu, S., Zhang, H., and Yan, X. (2017). Enhancing vehicular communication using 5g-enabled smart collaborative networking. *IEEE Wireless Communications*, 24(6):72–79.

[Liu et al. 2017] Liu, J., Wan, J., Jia, D., Zeng, B., Li, D., Hsu, C., and Chen, H. (2017). High-efficiency urban traffic management in context-aware computing and 5g communication. *IEEE Communications Magazine*, 55(1):34–40.

[Taha and AbuAli 2018] Taha, A. and AbuAli, N. (2018). Route planning considerations for autonomous vehicles. *IEEE Communications Magazine*, 56(10):78–84.

[Wedel et al. 2009] Wedel, J., Schunemann, B., and Radusch, I. (2009). V2x-based traffic congestion recognition and avoidance. In *Pervasive Systems, Algorithms, and Networks (ISPAN), 2009 10th International Symposium on*, pages 637–641.

[Ye et al. 2018] Ye, H., Liang, L., Li, G. Y., Kim, J., Lu, L., and Wu, M. (2018). Machine learning for vehicular networks: Recent advances and application examples. *IEEE Vehicular Technology Magazine*, 13(2):94–101.