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# Measuring urban mobility: methodological aspects of vehicle counting applied to Argentine cities

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***Abstract*– Urban mobility is crucial for community life in cities, as it facilitates movement between work, educational, recreational and commercial spaces; considering all the necessary journeys that people make using different means of transport. As the urban population grows, it becomes a challenge to adapt the development of the city to meet new mobility needs in a sustainable, inclusive and economical way. In this sense, one of the great goals is to balance these three pillars of sustainability, which requires a holistic approach in its study. This work aims to promote sustainable mobility through the development of methodologies for the collection of key data, such as vehicular flow and its characterization. The acquisition of these data allows the analysis of congestion, vehicle use trends, and estimation of pollutant emissions, facilitating the design of public policies and evidence-based decision-making. This study focuses on describing the methodology used in Bahía Blanca, Argentina, to perform manual vehicular flow counts and segmentation, by direct observation of videos at strategic points of the city. Ten-minute videos recorded during peak hours are used, and the data are extrapolated to one hour. The methodology has been applied in the micro and macro center of the city, as well as on university campuses, adapted to the objective of each study. This kind of research is pioneering in Bahía Blanca, with the purpose of assisting in the decision-making process of authorities. Finally, the methodology can be replicated in other cities, as long as it is adapted to the specific context.***

***Keywords*— Manual counting, Vehicular flow, Urban mobility, Argentinian cities.**

## I. Introduction

Urban mobility refers to all the trips that people make around the city using the different means of transport available [1, 2]. As the population of urban centers grows, the challenge of adapting urban development and meeting new mobility needs arises, seeking alternatives that protect the environment, ensure social inclusion, and do not come at a high cost. Without a doubt, urban mobility is a vital social resource and an articulator of community life, since it is directly related to the movement of people between the different social spaces of the city, such as work, education, recreation, commerce, among others [3, 4].

The problems generated by urban mobility are increasingly relevant not only in Argentina, but in all Latin American countries, where there are many differences in transportation conditions [5]. People-centered transformation of public space, providing safety for pedestrians and cyclists, improving the quality of life, and prioritizing active mobility and public passenger transport, is a social, urban, political and economic challenge. As mentioned by [6], it is time to leave behind the traditional urban model and rethink urban mobility, the use of public space and city planning, aiming to generate public policies that promote the sustainability of transportation and urban development.

These aspects must be managed by local policies and the prevailing social awareness, involving all the actors in decision-making when planning the use of public space, designing public transport systems, organizing vehicular traffic, providing the necessary infrastructure and everything that defines the mobility of a city [3, 7]. Cities have the capacity to establish comprehensive policies to mitigate the negative effects of urban mobility and promote a more sustainable one, since they have the knowledge of local customs and their land borders are smaller than those of a province or a nation [8, 9].

One of the great challenges of future urban mobility is to find a balance between the three pillars of sustainability: economic, environmental and social, which requires studying it in depth and from a holistic approach [10]. Therefore, the study of urban mobility should be addressed from different approaches and using appropriate tools, such as surveys, direct observation, vehicle counting, vehicle fleet characterization, statistical analysis, transportation engineering, origin-destination matrices, among others.

On the other hand, it is known that changes in urban mobility can have a direct impact on the citizens' quality of life [11, 12]. Therefore, in redesigning mobility, it is necessary to study and characterize traffic, with the objective of understanding how the different means of transport move within the city. This makes it possible to detect congestion problems and optimize vehicular flow, achieving a more efficient movement of people and vehicles. As it is known, traffic varies from one place to another, differing in volume and type of vehicles circulating; for example, a downtown street may have a high volume of vehicles per day, being mostly cars while, a highway that leads to a port may have a high volume of traffic but with a predominance of heavy-duty trucks [13, 14].

The main purpose of this study is to support the development of sustainable and intelligent mobility in cities, for which the development of key methodological aspects for the collection of primary data such as vehicle flow and its characterization are essential. It should be taken into account that the data collection allows the analysis of congestion levels, trends in terms of type of vehicle used, as well as being an essential data for the estimation of emissions and their dispersion in the air, allowing local authorities to make decisions and generate public policies evidence-based. Therefore, the objective of this work focuses on the description of the methodology used in a medium-sized Latin American city (Bahía Blanca, Argentina) to manually count vehicles in strategic points of the city. It also presents viable alternatives to apply this methodology in other cities and details the challenges that could be encountered in such cases.

## II. Study area

The city of Bahía Blanca is an urban conglomerate located in the southwest of the province of Buenos Aires, Argentina. It is the head city of the district of the same name and has 336554 inhabitants according to the last census conducted in 2022 [15]. Bahía Blanca is considered a strategic logistic node in the country since it allows a close trade relationship with other regions, through multiple road, rail, air and sea connections, which are shown in Fig. 1. The local situation can be compared with the context of the following three Latin American cities, which also have a port and multiple connections by road and rail: La Plata (Argentina), Santa Marta (Colombia), and Antofagasta (Chile). In addition, one of the largest petrochemical poles in the country and a large industrial park are located around the Port of Bahía Blanca. This situation is favored by the existence of a technological link between the industry and the scientific sector of the city, since there are multiple public and private universities, as well as scientific research institutions.


Fig. 1. Main road data of Bahía Blanca city. The location of the seaport, airport, and bus station are shown, as well as the main routes (blue) and the railway network (red). Source: Own elaboration

Given all the characteristics that the city of Bahía Blanca has, it can be classified as a medium-sized city because its population is between 200000 and 500000 inhabitants, according to the definition of the Organization for Economic Co-operation and Development [16].In addition, it can also be categorized as intermediate because it plays a strategic role in the interaction between the city and its surroundings [17].

In the last decade Bahía Blanca experienced a significant uncontrolled urban expansion or urban sprawl, which is the synonym for increased unplanned urban development [18, 19, 20]. As is well known, urban sprawl is related to increased mobility, which is known as the theory of induced traffic and, consequently, to complex problems, including the worsening of air quality and the deterioration of the citizens' quality of life [21, 22]. In addition, Bahía Blanca presents a lack of monitoring of both traffic and the emissions generated by it. For these reasons, it is essential to promote methodologies and data analysis oriented to know the reality of current urban mobility in order to act accordingly.

## III. Methodological aspects applied to vehicular counting in the study area (Bahía Blanca, Argentina)

Traffic engineering is a field within transportation engineering, which allows the study of traffic variables in cities. In the case of urban streets, it contemplates, for example, alternative traffic designs that lead to the creation of safer environments for all the actors involved in the city's mobility, as well as environmental and socioeconomic factors. This type of study focuses on the elements of traffic: driver, pedestrian, vehicle, street, signaling and control devices, and on the characterization and study of the behavior of traffic variables: vehicle volume, speed and density, as well as the relationship between elements and variables. From the study of these aspects, possible solutions to urban mobility problems such as congestion, pollution, travel times, the level of service of public passenger transport, and accidents can be found [23, 24].

The study of traffic circulating in a city provides essential information that allows the generation of policies and regulations to improve urban mobility [25]. In this sense, vehicle counting is a technique that produces basic data in the field of traffic engineering [24]. Counting the number of vehicles, bicycles or pedestrians is used to know the amount of each of these elements that pass-through a given point during a period of time, which can vary between a few minutes, 24 hours, a month or more, depending on the objectives of the study [24]. Furthermore, if the count is representative, and it is known that the flow is maintained over time for at least one hour, as occurs in the microcenter of Bahia Blanca, the measurement of about 10/15 minutes can be extrapolated to the number of vehicles per hour [26, 27]. This extrapolation is only possible if the area has been previously studied, and it is known for certain that during a peak hour the traffic flow remains relatively constant [24]. Considering all this, it would be possible to know the average daily or hourly traffic in a given street segment, identify when the highest traffic volume occurs, among other aspects. In addition, periodic counts allow detecting current or future problems to take preventive measures in time, such as on the level of congestion, among others. Likewise, categorization by vehicle type makes it possible to evaluate the predominant segment and its fluctuations at each point, time and month evaluated. Fig. 2 shows a general scheme of the essential steps to count and characterize vehicle traffic.

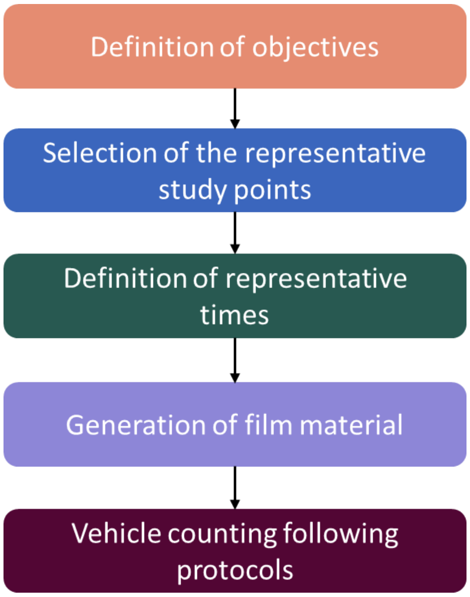


Fig. 2. Main steps for a local traffic count and characterization. Source: Own elaboration.

The two basic methods of traffic counting are manual counting (trained observer) and automatic counting (video, radar, infrared or laser technology, pneumatic tubes, piezoelectric strips, among others). Manual counting consists of a person identifying and counting the number of vehicles or pedestrians or cyclists during a stipulated time either by direct observations in the field or from recordings [28]. Whereas, automatic counting uses software technology to perform the count, requiring the video to be obtained from a fixed, high-resolution camera that is properly focused on the study intersection. The main advantage of manual counting is that it reduces the necessary equipment costs and preparation time. In addition, it is accurate and reliable if properly planned, i.e., the objectives of the count must be established to be able to collect all the necessary data for the subsequent analysis, as well as to prepare a data loading sheet according to the situation to be analyzed [24]. However, they tend to be inefficient as the counting time increases due to the fatigue that can be caused in the analyst, however well trained he or she may be. In this case, it is automatic counting that has the advantage, allowing the collection of large amounts of data with a reasonable expense of time and resources, although it does not always achieve the level of detail in identification that a human can. As mentioned by Zheng and McDonad [29], they managed to establish that manual counting, performed by direct observation of short videos, has a very low margin of error (1%). On the other hand, the work of De Meio Reggiani and Viego [30] presents the specific case of automated vehicle counting on videos obtained from the security cameras of the Bahía Blanca Municipality, in which they conclude that the particularities of these recordings, such as micro cuts, change of focus and glare, generate significant biases in the results. It should be noted that, in the presence of the aforementioned faults in the security camera recordings, a human can make decisions that a computer might not be able to solve, such as choosing another day to perform the count or selecting another video fragment in order to correct these faults. Although the use of artificial intelligence and machine learning is currently being used to perform vehicle counts, it must be considered that these tools must be trained to obtain the data correctly and as accurately as possible. This situation requires time and constant improvement of the algorithms, since, as previously mentioned, videos are not perfect.

Based on the above, to collect traffic data in the city of Bahía Blanca, it was decided to carry out manual counts by direct observation of 10-minute videos during peak hours, considering the low level of error reported by Zheng and McDonad [29]. Then, the number of vehicles counted in ten minutes can be extrapolated to one hour, after studying the area. At this point, it is worth mentioning that the area selected for the study, as well as the timetable, must be representative of the objective to be achieved; for which it is necessary to carry out a previous analysis of the area before the count, to know its activity and critical moments. In the particular case of Bahía Blanca, the count is done on working weekdays, ideally Tuesdays or Wednesdays, representative of a normal vehicular flow, which should not be the eve of official holidays or specific activities, nor days where there are meteorological phenomena that affect the normal flow, such as rainy days. The observed videos can be collected at the place of interest or, if there are security cameras at the site, by direct observation of these recordings. It is worth mentioning that the research group has agreements with the municipality, which allow access to this material. For confidentiality reasons, the videos can only be viewed at the Centro Único de Monitoreo (CeUM), respecting the indications of the local authorities. The recordings allow for multiple views, when necessary, for example, when counting vehicles traveling on two-way streets. It should be noted that in the studies carried out in Bahía Blanca, the largest streets have a maximum of four lanes, which does not generate a major difficulty for the trained eye of the person performing the count.

Furthermore, although Zheng and McDonad [29] established that a high margin of error is generated in the classification of vehicles, it refers to a segmentation by dimensions and not by type of vehicle, which is easier for humans to perform and even more so when the criteria are always applied by the same observer. In this case, the circulating fleet is mainly classified into: bicycles, motorcycles, cars, pick-up trucks, buses, and light commercial vehicles. In some cases, pedestrians and electric micro-vehicles have also been considered, as well as discriminating whether cyclists use exclusive lanes, among other particularities.

It may also be of interest to know the age of the vehicles, as well as the type of fuel. In such cases, statistical data generated by recognized entities can be used, or surveys can be carried out to estimate the age of the vehicles by means of particular observable characteristics of the vehicles and the license plates. Over the years, Argentina's license plate system has evolved (see Fig. 3). From 1995 to 2016, a new format using three letters followed by three numbers (AAA-000 to PZZ-999) was introduced. At this moment, vehicles before 1995 were re-registered with plates ranging from RAA-000 to ZZZ-999. In 2016, a Mercosur-wide license plate format (AA-000-AA) was implemented for new vehicles, featuring a white background and a blue stripe. These changes facilitate the estimation of vehicle fleet ages and emissions while enabling comparisons with national fleets.


Fig. 3. Different license plates of Argentine vehicles over the years. Source: Own elaboration.

The categorization by type of license plate also allows associating each vehicle with the type of emission control technology it has (EURO) [31]. Thus, vehicles older than 1995 (license plates from *RAA-000* to *ZZZ-999*) are considered as those that do not follow any EURO standard. Vehicles that are within some of the EURO standards: I-II-III-IV, are registered with the 1995 patent format *AAA-000* up to *PZZ-999*. Finally, newer vehicles with the 2016 patent can be associated with the EURO V standard.

Once the count has been carried out, the raw data must be processed in an appropriate manner using standardized spreadsheets that allow the data to be analyzed and the relevant calculations to be made. It is also necessary to record the observations of the video and important data of the day taken, such as weather, important events in the city, among others.

The following is a brief description of the methodology applied in each area of the city of Bahía Blanca according to the objective to be achieved in each study. Fig. 4 shows the location of the different points monitored in Bahía Blanca considering all the work carried out so far. Points 1, 2 and 3 are located within the city microcenter and do not have bicycle lanes, but some of them do have exclusive lanes for buses, being interesting places to analyze vehicular congestion. Points 4 and 5 are intersections that are within the city's bicycle lane network and are of interest to evaluate the use of bicycle lanes. Points 6 and 7 are the locations of the two campuses of the Universidad Nacional del Sur where mobility studies have been carried out. Finally, point 8 is a strategic location where traffic is monitored in order to validate the air quality modeling due to mobile sources, since a continuous air quality monitoring station of the municipality is located there.

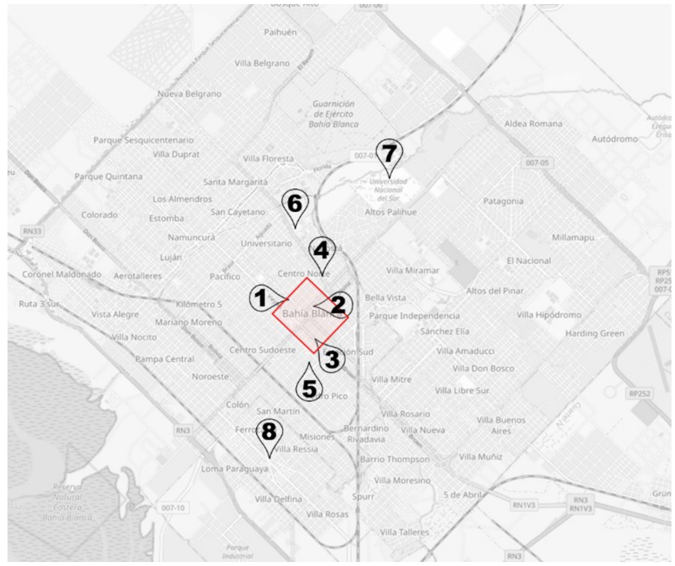

Fig. 4. Location of the strategic points studied in Bahía Blanca considering all the vehicular counting works carried out. Shaded in red is the area of the city's microcenter. Source: Own elaboration.

### A. *Microcenter of the city without bicycle lanes*

The microcenter area of the city has been studied since 2020 by our research line. Initially, it began to be analyzed by videos generated in situ, but due to the pandemic, permission was requested for access to film material from the city's security cameras (July 2020). From that time to the present, data on the level of vehicular flow and its segmentation are collected at three strategic points in the city's downtown area (points 1, 2 and 3 in Fig. 4), at three peak hours (8:00, 12:00 and 17:00). In this area, the fleet was classified according to whether they were bicycles, motorcycles, cars, pick-up trucks, buses, light commercial vehicles and vans, as well as whether there were electric micro-vehicles. Heavy duty vehicles are not considered in this study area because they are prohibited from entering the central area of the city during the daytime hours studied according to municipal regulations, No. 5631 and No. 7136 [32].

In the first period of the study, carried out by means of on-site video, data were obtained on the age of the fleet, as well as on the emission control technology of the vehicles. Also, using national statistics, the type of fuel used by the circulating fleet was estimated [33], which was already used in the development of the emissions inventory of the city's vehicle fleet in 2018 [34]. This area and period of study made it possible to determine changes in the form of mobility, mainly in the pandemic period; to detect new means of transportation (such as the use of electric micromobility since October 2021) [35, 36]; s well as to employ these data in air quality modeling [36, 37], generating not only data of a scientific nature, but also transferring the results obtained to local authorities through technical reports.

*B. Macrocenter of the city with bicycle lanes*

The analysis of the flow in streets with bicycle lanes allows us to know the level of use of these lanes, as well as to evaluate whether it is necessary to build more infrastructure that favors and facilitates the use of bicycles as a means of transportation. The study was developed in two strategic points of the bicycle lane network of the city of Bahía Blanca (points 4 and 5 in Fig. 4) during the period October 2022 to October 2023, presenting in [38] the main findings. At the selected points, videos were filmed on a weekday, only during the midday peak hour. In this case, vehicular flow was categorized into: people on foot, bicycles (pedal and electric), motorcycles (combustion and electric), electric scooters, cars, pick-up trucks, buses, cabs, and light-duty vehicles. In addition, the use of the bicycle lane was analyzed by evaluating where cyclists ride, as well as considering the direction in which they ride. It should be taken into account that the current network of bicycle lanes in the city (24 km) is entirely two-way, allowing cyclists to circulate in both directions. In this study, no characterization of the flow by age or fuel type has been made because it was not considered necessary for the purpose of the work.

*C. University campuses in the city*

As has been mentioned, there are several institutions of higher education in the city of Bahía Blanca. In particular, in our work we have studied the campuses of the Universidad Nacional del Sur (UNS). First, we will present the study of the Alem Campus (point 6 in Fig. 4) and then, the work carried out on the Palihue Campus (point 7 in Fig. 4).

The vehicle flow characterization study of the UNS Alem Campus was conducted during the period from August 2023 to March 2024 [39]. To perform this work, on-site videos were recorded at the intersections adjacent to the campus during the midday peak hour. Fifteen-minute video segments were filmed on a working day, without rain and preferably not consecutive to a holiday or public holiday. Then, a manual vehicle count was carried out by direct observation of the videos generated, classifying the flow into six categories: bicycles, motorcycles, cars, pick-up trucks, light commercial vehicles and buses. It should be noted that there are no heavy-duty vehicles, and that electric micro-vehicles were counted but their presence was very low. Pedestrians were also counted, although they were taken as estimated data due to the difficulty in counting them and the variability in the values obtained. One of the main objectives of the analysis carried out in this area was to generate primary data to be compared with new information when a new bicycle lane is built in the area, which would allow us to analyze the impact of this intervention, as well as to analyze the current situation of where most cyclists ride. In addition, as in the case of the city's downtown area, the data generated were used to model the dispersion of pollutant emissions from these mobile sources.

The work carried out at the Palihue Campus of the UNS was part of a research project that aimed to diagnose the mobility of the university community [40, 41]. For this study, videos were recorded in situ in the two accesses of the campus, considering the characteristics of each one to evaluate how it affected the means of transport chosen by people. In particular, the videos were taken in the month of September 2022 (month of high educational activity), in five time slots considered to have a high vehicular flow, according to previous surveys. The classification made in this study was into bicycles, electric bicycles, electric scooters, combustion motorcycles, electric motorcycles, private cars, private pick-up trucks, buses, cabs, light commercial vehicles, as well as people on foot, those getting on/off the bus or car/taxi, whose vehicle does not enter the campus. In addition, the number of passengers coming in each of the detected vehicles was counted. This work also analyzed the age of the vehicle fleet, associated with the type of emission control technology, through the study of the license plate, as well as surveyed the type of fuel of the vehicles through particular observable characteristics. All this work was carried out through a survey in the campus parking lots by direct observation of the parked vehicles. The data obtained not only contributed to generate an initial diagnosis of mobility on the university campus, but also to propose sustainable mobility alternatives and estimate the emissions generated by mobility [42].

*D. Strategic area of the city where a continuous air quality monitoring station is located*

It is well known that when air quality modeling is performed, it must be validated. In this sense, we worked in an area seven kilometers from the city center (point 8 in Fig. 4), where a continuous air quality monitoring station is located, with the objective of modeling the air quality due to nitrogen oxides generated by traffic in the area and comparing it with the station's records [43]. For this purpose, it was necessary to carry out a survey of the vehicular flow in the area and its characterization. For this purpose, during the period from November 2022 to December 2023, the area was analyzed. First, by means of direct observation counts of videos generated in situ, and then by recordings from the municipality's new security camera at the study location. In this study, only the morning peak hours were analyzed and the flow was segmented into bicycles, motorcycles, cars, pick-up trucks, light commercial vehicles, buses and heavy-duty trucks, since in this area they can transit and it is common to see them. Electric micro-vehicles were also considered, but their incidence in the area is almost nil. Currently, since November 2024, the area is being monitored again following the methodology proposed, but considering three peak hours (morning, midday and afternoon), to analyze the impact that vehicles have on the level of particulate matter recorded by the station.

### E. *Main findings at each point studied*

Although this paper focuses on the methodological aspects used to carry out the vehicle count in different parts of Bahía Blanca, the most important findings detected in the cases analyzed are briefly presented. One of the main findings of the studies carried out in different parts of the city is the predominance of private cars. This type of vehicle represents between 60% and 70% of the vehicle fleets studied. As for vehicle flow, it is difficult to compare the results obtained at each point since they were taken specifically for a given study.

In the city's microcenter area, Brown and Estomba streets stand out as main arteries, with average flows of motorized vehicles of 1314 and 1055, respectively, in 2024. Thanks to the analysis of the macrocenter streets that have bicycle lanes, we have been able to detect that those streets with bicycle lanes favor cyclists' circulation compared to those that do not have them [38]. Likewise, it has been detected that the flow of bicycles, during midday hours, is greater in the area of the Alem campus of the UNS with respect to the Palihue campus, but in the latter a greater number of electric micro-vehicles is detected [44].

## IV. Methodology aspects applicable to vehicular counting in other Argentine cities

Considering that the methodological aspects previously mentioned for the city of Bahía Blanca have been used in different strategic points of the city and with different objectives, it could be inferred that this type of methodology could easily be transferred to other cities with similar characteristics.

La Plata is a slightly larger city than Bahía Blanca, since it has 768547 inhabitants [15], but it is also similar because it is considered a university city, and has multiple road connections to its port and an industrial center nearby. However, despite the similarities, there will always be aspects to consider, such as the fact that La Plata's public transport fleet is newer than Bahía Blanca's, using stricter emission control technologies such as EURO 5 (see Fig. 5).


Fig. 5. La Plata city (Argentina) bus indicating the EURO 5 emission control technology standard. Source: Own elaboration

Another city that could be assimilated to Bahía Blanca is Viedma (capital of the province of Río Negro, Argentina), Although it should be considered that this city is smaller than Bahía Blanca since it has 60903 inhabitants [15]. This is a university city with a road infrastructure similar to that of our city. Fig. 6 shows part of the two-way bicycle lane network, as in Bahía Blanca, and low-speed streets (maximum 10 km/h). Viedma, like La Plata, has a difference in public transport compared to Bahía Blanca, but in this case, it is related to a poorer quality service in terms of frequency, since buses usually run every 25/30 minutes.

Fig. 6. Section of the bicycle lane network and calm streets in the city of Viedma, Argentina. Source: Own elaboration

On the other hand, it is interesting to analyze what methodological aspects could be applied in cities that are not similar, such as those that do not have a flat geography like Bahía Blanca, or that are touristic. In this case it will be essential to work with interdisciplinary teams that have a wide knowledge of the new study area. Likewise, it is essential to establish the objective(s) to be achieved before carrying out a characterization of the vehicular flow.

At present, Tandil has 145575 inhabitants [15]; this city, considered a tourist destination, can also be considered a university one (see Fig. 7). This city, not only differs from Bahía Blanca in terms of its function, but also has a more complex geography due to being located in a mountain range (Sistema Serrano de Tandilia). In particular, we consider that the main methodological aspects to be adapted in this situation are to determine the days and times of data collection, since it is influenced by tourist fluctuations. In Bahía Blanca, the frequency is normal on working days and decreases on weekends. However, in the city of Tandil, this does not necessarily occur in this way; there may even be a greater flow of vehicles on weekends due to the incidence of tourism. Also, the non-flat geography makes it necessary for vehicles to have more power, in some cases consuming more fuel than usual, which should be surveyed if we want to work on the air pollution aspect.

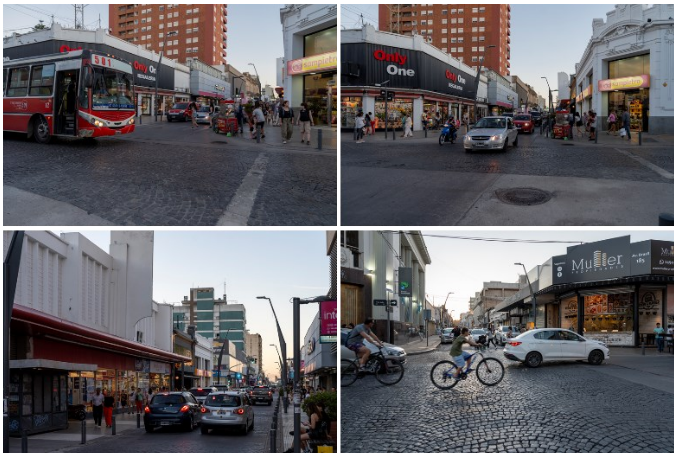

Fig. 7. City of Tandil (Argentina). Different intersections showing the different actors of local urban mobility. Source: Own elaboration

Another city that could be mentioned is Mar del Plata, which has 667082 inhabitants [15]. Although this city is known as a tourist city, it has a large urban area where the city functions as one that is not. In addition, it can be considered a university city, as well as a port city. It should be noted that the city's strong tourism, which triples the number of inhabitants, occurs between the months of December and February. Therefore, it would be interesting to analyze the impact of tourism on the city's mobility. It would also be interesting to work with the different zones of the city to evaluate similarities and differences. Fig. 8 shows how the parking spaces are full on the seafront street in the middle of summer 2025.

Fig. 8. Vehicles parked in all available spaces in Mar del Plata's seafront street in January 2025 (Argentina). Source: Own elaboration

## V. Conclusions

This paper shows the methodological aspects used to perform the manual counting of vehicular flow and its segmentation in the city of Bahía Blanca, Argentina. In particular, it was presented how the methodology is adapted to the different objectives of each study carried out in strategic points of the city.

The proposed methodology can be applied not only to Bahía Blanca city, but it is considered adaptable to cities with similar characteristics, as well as to others that are not. In this sense, it is important to work together with experts from the new cities who have specific knowledge of the new study area, as well as well-defined objectives, which will allow adapting the methodology to the requirements

It is worth noting that this research line is a pioneer in the study of urban mobility in Bahía Blanca. Although manual counting methodologies are still being applied at present, work is being done on the development of a computational tool, with AI assistance based on pattern recognition, to generate vehicle counts and their characterization, with the necessary level of detail and minimum margin of error. Given that the videos that could be used correspond to city security cameras, special permits must be obtained to access them, and strict confidentiality protocols must be followed.


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## References


[1] Ministerio de Transporte de Argentina, "Guía Para la Planificación de la Movilidad Urbana Sostenible (PMUS) en Argentina", 2023, retrieved on January 15, 2025, from https://www.argentina.gob.ar/sites/default/files/guia_para_la_planificacion_de_la_movilidad_urbana_sosostenible.pdf.

[2] Y. Grassi, "Estudio de la movilidad urbana y el modelado de la contaminación atmosférica asociada en la ciudad de Bahía Blanca, Argentina", Doctoral Thesis in Chemical Engineering, Universidad Nacional del Sur, March 2024, retrieved on January 15, 2025, from https://repositoriodigital.uns.edu.ar/handle/123456789/6749.

[3] A. Nikolaeva, P. Adey, T. Cresswell, J. Lee, A. Nóvoa, and C. Temenos, "Commoning mobility: Towards a new politics of mobility transitions", *Transactions of the Institute of British Geographers*, vol. 44, no 2, pp. 346-360, February 2019. https://doi.org/10.1111/tran.12287.

[4] P. Costa, G. Neto, and A. Bertolde, "Urban mobility indexes: A brief review of the literature", *Transportation Research Procedia*, vol. 25, pp. 3645-3655, 2017. https://doi.org/10.1016/j.trpro.2017.05.330.

[5] E. Vasconcellos, "Transporte urbano y movilidad: reflexiones y propuestas para países en desarrollo", UNSAM Edita. San Martín (Bs. As.), Argentina, 2015.

[6] D. Zunino Singh, V. Pérez, C. Hernández, and M. Velázquez, "Movilidad pública, activa y segura. Reflexiones sobre la movilidad urbana en tiempos de COVID-19", *Prácticas de Oficio, Investigación y Reflexión en Ciencias Sociales*, vol. 1, no. 25, pp. 67-84, December 2020, retrieved on January 15, 2025, from http://revistas.ungs.edu.ar/index.php/po/article/view/34

[7] F. Núñez, E. Albornoz, J. León, and A. Zumelzu, "Socially sustainable mobility: Strategic analysis to identify accessibility barriers", *Sustainable Cities and Society*, vol. 76, pp. 103420, January 2022. https://doi.org/10.1016/j.scs.2021.103420.

[8] S. Sultana, D. Salon, and M. Kuby, "Transportation sustainability in the urban context: a comprehensive review", *Urban Geography*, vol. 40, no. 3, pp. 279-308, October 2017. https://doi.org/10.1080/02723638.2017.1395635.

[9] D. Hoornweg, L. Sugar, and C. Trejos Gómez, "Cities and greenhouse gas emissions: moving forward", *Environment & Urbanization*, vol. 23, no. 1, pp. 207-227, January 2011. https://doi.org/10.1177/0956247810392270.

[10]M. Miskolczi, D. Földes, A. Munkácsy, and M. Jászberényi, "Urban mobility scenarios until the 2030s", *Sustainable Cities and Society*, vol. 72, pp. 103029, September 2021. https://doi.org/10.1016/j.scs.2021.103029.

[11]M. Sánchez-Sepulveda, J. Navarro-Martin, D. Fonseca-Escudero, D. Amo-Filva, and F. Antunez-Anea, "Exploiting urban data to address real-world challenges: Enhancing urban mobility for environmental and social well-being", *Cities*, vol. *153*, pp. 105275, October 2024. https://doi.org/10.1016/j.cities.2024.105275.

[12]A. Ceder, "Urban mobility and public transport: future perspectives and review", *International Journal of Urban Sciences*, vol. 25, no. 4, pp. 455-479, July 2020. https://doi.org/10.1080/12265934.2020.1799846.

[13]C. Benevolo, R. Dameri, and B. D'Auria, "Smart Mobility in Smart City", in *Empowering Organizations,* pp. 13-28, January 2015. https://doi.org/10.1007/978-3-319-23784-8_2.

[14]C. Bachechi, and L. Po, "Traffic analysis in a smart city", in *IEEE/WIC/ACM International Conference on Web Intelligence-Companion,* pp. 275-282, October 2019. https://doi.org/10.1145/3358695.3361842.

[15]Instituto Nacional de Estadística y Censos, "Censo nacional de población, hogares y viviendas 2022", retrieved on January 14, 2025, from https://censo.gob.ar/.

[16]Organisation for Economic Co-operation and Development, "Urban population by city size (indicator)", retrieved on May 14, 2021, from https://data.oecd.org/popregion/urban-population-by-city-size.htm. https://doi.org/10.1787/b4332f92-en.

[17]J. Bolay, and A. Rabinovich, "Intermediate cities in Latin America risk and opportunities of coherent urban development", *Cities,* vol. 21, no. 5, pp. 407-421, October 2004. https://doi.org/10.1016/j.cities.2004.07.007.

[18]F. Dieleman, and M. Wegener, "Compact city and urban sprawl", *Built Environment*, vol. 30, no. 4, pp. 308-323, December 2004. https://doi.org/10.2148/benv.30.4.308.57151.

[19]F. Ferrelli, M. Bustos, and M., Piccolo, "La expansión urbana y sus impactos sobre el clima y la sociedad de la ciudad de Bahía Blanca, Argentina", *Estudios Geográficos*, vol. 77, no. 281, pp. 469-489, December 2016. https://doi.org/10.3989/estgeogr.201615.

[20]G. Lanfranchi, C. Cordara, J. Duarte, T. Gimenez Hutton, S. Rodriguez, and F. Ferlicca, "¿Cómo crecen las ciudades argentinas? Estudio de la expansión urbana de los 33 grandes aglomerados", Centro de Implementación de Políticas Públicas para la Equidad y el Crecimiento (CIPECC), Buenos Aires, Argentina, 2018, retrieved on January 16, 2025, from https://www.cippec.org/wp-content/uploads/2018/11/C%C3%B3mo-crecen-las-ciudades-argentinas-CIPPEC.pdf.

[21]R. Fontanilla Andong, and E. Sajor, "Urban sprawl, public transport, and increasing $CO_2$ emissions: the case of Metro Manila, Philippines", *Environment, Development and Sustainability*, vol. 19, no. 1, pp. 99-123, November 2015. https://doi.org/10.1007/s10668-015-9729-8.

[22]M. Young, G. Tanguay, and U. Lachapelle, "Transportation costs and urban sprawl in Canadian metropolitan areas", *Research in Transportation Economics*, vol. 60, pp. 25-34, December 2016. https://doi.org/10.1016/j.retrec.2016.05.011.

[23]J. Quintero-González, "Del concepto de ingeniería de tránsito al de movilidad urbana sostenible", *Ambiente y Desarrollo*, vol. 21, no. 40, pp. 57-72, June 2017. https://doi.org/10.11144/Javeriana.ayd21-40.citm.

[24]B. Wolshon, and A. Pande, "Traffic engineering handbook", John Wiley & Sons, Inc: New Jersey, Estados Unidos, 2016. https://doi.org/10.1002/9781119174738.

[25]J. Pérez, J. de Andrés, R. Borge, D. de la Paz, J. Lumbreras, and E. Rodríguez, "Vehicle fleet characterization study in the city of Madrid and its application as a support tool in urban transport and air quality policy development", *Transport Policy*, vol. 74, pp. 114-126, February 2019. https://doi.org/10.1016/j.tranpol.2018.12.002.

[26]R. Roess, E. Prassas, and W. McShane, "Traffic Engineering", (4th ed.), Pearson Higher Education, Inc, Upper Saddle River, NJ, 2011.

[27]M. Slinn, P. Matthews, and P. Guest, "Traffic Engineering Design Principles and Practice", (2nd ed.), Elsevier: Butterworth-Heinemann, 2005.

[28]J. Paľo, J. Caban, M. Kiktová, and Ľ. Černický, "The comparison of automatic traffic counting and manual traffic counting", in *IOP conference series: materials science and engineering*, vol. 710, no. 1, pp. 012041, December 2019. https://doi.org/10.1088/1757-899X/710/1/012041.

[29]P. Zheng, and M. McDonad, "An investigation on the manual traffic count accuracy", *Procedia - Social and Behavioral Sciences,* vol. 43, pp. 226-231, 2012. https://doi.org/10.1016/j.sbspro.2012.04.095.

[30]M. De Meio Reggiani, and V. Viego, "Conteo automatizado de tráfico en Bahía Blanca basado en videos", in *Simposio Argentino de Ciencia de Datos y Grandes Datos*, pp. 25-28, 2021, retrieved on January 16, 2025, from https://50jaiio.sadio.org.ar/pdfs/agranda/AGRANDA-06.pdf.

[31]J. Vasallo, "Status of emission control science and technology in Argentina", *Emission Control Science and Technology*, vol. 4, no. 2, pp. 73-77, June 2018. https://doi.org/10.1007/s40825-018-0091-9.

[32]Municipalidad de Bahía Blanca, "Digesto Municipal - Ordenanzas, Decretos y Resoluciones", retrieved on January 16, 2025, from https://www.bahia.gob.ar/digestomunicipal/.

[33]Asociación de Fábricas Argentinas de Componentes, "Estadísticas Sectoriales, Argentina", retrieved on August 16, 2019, from http://www.afac.org.ar/.

[34]Y. Grassi, N. Brignole, and M. Díaz, "Vehicular fleet characterisation and assessment of the on-road mobile source emission inventory of a Latin American intermediate city", *Science of the Total Environment*, vol. 762, pp. 148255, October 2021. https://doi.org/10.1016/j.scitotenv.2021.148255.

[35]Y. Grassi, and M. Díaz, "Post-pandemic urban mobility in a medium-sized Latin American city. Is sustainable micro-mobility gaining ground?", *International Journal of Environmental Studies*, vol. 81, no. 4, pp. 1579-1595, March 2023. https://doi.org/10.1080/00207233.2023.2195327.

[36]Y. Grassi, N. Brignole, and M. Díaz, "Pandemic impact on urban air pollution and mobility in a Latin American medium-size city", *International Journal of Environmental Studies*, vol. 79, no. 4, pp. 624-650, August 2021. https://doi.org/10.1080/00207233.2021.1941662.

[37]Y. Grassi, and M. Díaz, "Urban air pollution evaluation in downtown streets of a medium-sized Latin American city using AERMOD dispersion model", *Environmental Monitoring and Assessment*, vol. 196, pp. 521, May 2024. https://doi.org/10.1007/s10661-024-12699-8.

[38]Y. Grassi, J. González Martínez, and M. Díaz, "Evaluation of traffic flow on streets with bicycle lanes in a medium-sized Latin American city. Are we moving towards more active urban mobility?", *Case Studies on Transport Policy*, under review since February 2025.

[39]F. Carrizo, "Movilidad urbana y contaminación atmosférica en bahía blanca: caso de estudio en zona universitaria de Alem y Córdoba", Bachelor's Thesis in Environmental Sciences, Universidad Nacional del Sur, May 2024.

[40]Y. Grassi, M. Díaz, G. Pesce, F. Pedroni, M. Rivero, and H. Chiacchiarini, "Motorized mobility on a Latin American university campus: a preliminary study focused on sustainability", in *Sustainable Smart Cities and Territories International Conference*, pp. 3-14, June 2023. https://doi.org/10.1007/978-3-031-36957-5_1.

[41]G. Pesce, F. Pedroni, M. Rivero, H. Chiacchiarini, Y. Grassi, and M. Díaz, "Understanding urban mobility habits and their influencing factors on a university campus in Argentina", in *Sustainable Smart Cities and Territories International Conference*, pp. 111-123, June 2023. https://doi.org/10.1007/978-3-031-36957-5_10.

[42]Y. Grassi, G. Pesce, and M. Díaz, "Promoting sustainable mobility patterns on a Latin American university campus: Focus on air quality", *International Journal of Environmental Studies*, under review since March 2025.

[43]Y. Grassi, and M. Díaz, "Initial validation regarding the use of AERMOD to model air pollutant dispersion in medium-sized Latin American city streets", in *Sustainable Smart Cities and Territories International Conference*, pp. 266-276, June 2023. https://doi.org/10.1007/978-3-031-36957-5_23.

[44]Y. Grassi, M. Díaz and D. Rossit, "Sustainable urban mobility: comparison of two university campuses using multi-criteria analysis", work accepted in *Latin American and Caribbean Consortium of Engineering Institutions (LACCEI, 2025)*.