Identification of cycle lane priorities based on observed and potential cyclist trips using GIS, the case of the Metropolitan Area of Mendoza, Argentina

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ABSTRACT
In Latin America and developing countries, urban planners often lack sufficient data on cyclists’ modal share and profile to establish effective cycling lane networks. Mendoza, Argentina, is such a city. This research aimed to identify adequate locations for new cycle lanes by speculating on potential cycle trips from observed patterns of existing cyclists for a coherent demand-based network. The study proposed a novel, simple, cost-effective Geographic Information Systems model that uses spatial and human data and presents results cartographically for policymakers. Statistical analysis of observed bicycle trips enabled constructing a local profile of cyclists, from which ‘potential trips’ were speculated: trips made by other modes, but which could have been biked given their distance, duration, purpose, and the traveler’s age. Geo-referencing observed and potential trips to their ‘sub-zones’ of origin and destination produced a migratory synthesis map highlighting general flows and densities. Superimposing this on the current cycling infrastructure exposed the critical gaps. As a broader aim, this geomatic method is readily transferable to other developing world settings. Actions for Mendoza and broader applications are proposed, significant limitations discussed, and further research suggested, noting issues of gender equity and safety.

Introduction
Latin American cities are undergoing territorial reordering as urban planners and transportation policymakers focus on solving the problems of rapid urban growth and rising motorization (CAF, 2010; Gwilliam, 2002). In recent decades, the paradigm of the car-centric city has lost validity due notably to its detrimental effects on safety, air quality, human health, and access equity. A transition and paradigm shift underway proposes intensive, widespread use of non-motorized transport (NMT) modes, mainly bicycles, for their multiple benefits (CAF, 2010; Estupiñán et al., 2018).

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The literature presents a broad consensus on the benefits of cycling for transportation purposes (beyond merely recreational exercise) in urban environments. These can summarize as economic benefits (in cost and time), environmental (greenhouse emissions reduction), health (physical activity), safety (traffic accident reduction), urban impact/public space revitalization (low urban space consumption; capillarity), and social integration/inclusion (Ortiz, 2018).

In the Metropolitan Area of Mendoza (MAM), Argentina, specific infrastructure for cycling as a mode of transport is being implemented. However, these isolated projects fail to provide cyclists with a continuous, coherent, safe network (Ortiz, 2018). Crucially, among significant obstacles to establishing an effective network is the lack of specific data on cyclists’ modal share, socio-economic demographics, and behavioral data.

This article contributes to research efforts undertaken by MAM policymakers to fill this data void (Ortiz, 2018). The study presents the results of using Geographic Information Systems (GIS) to model the priority areas to locate cycling infrastructure in MAM. The immediate objective was to identify these locations by a novel method using the observed patterns of existing cyclists to speculate on potential cycle trips (ones made by other modes, but which could have been biked), and propose how to link the existing cycle lanes into a coherent network. The larger research objective addressed a gap in the literature about rough methods to affordably and quickly model potential demand for cycleways. This simple and cost-effective GIS model synthesizes spatial and human data into a cartographic format suitable for policymakers. The main output is a synthesis map that displays the spatial dimension of the observed and potential trips for MAM. This model can be replicated in other cities with limited budgets and little or no relevant cycling data if they have mobility data from alternative transport modes such as Origin-Destination (OD) surveys. Among recommendations for the MAM, broader application of the model, and further implications, the study discusses gender equity, especially concerning real and perceived cyclist safety issues that are particularly salient in Latin America.

**Literature review**

Literature on cycling as a means of transportation has burgeoned in the last two decades. However, literature on planning for cycling, such as prioritizing locations for cycle lanes in countries with non-existing or scarce cycling data, is limited (CAF, 2010; Ortiz, 2018; Gwilliam, 2002).

Generally, the existing corpus comprises two categories. One focuses on the socio-cultural and economic determinants of cycling; the other, on the effects of different urban scales and configurations of infrastructure on cyclists’ travel behavior. Whereas the first category considers how individuals’ characteristics influence travel choices through a ‘bottom-up’ approach, the second examines how the built environment affects travel choices’ top-down.’ This study would fall in the first category. Concerning the influence of cycling-specific infrastructure on modal choices, when more and better cycling infrastructure is built, riders’ modal share increases (Dill & Carr, 2003; Moudon et al., 2005; Nelson & Allen, 1997). Moreover, cyclists often take significant detours to use segregated, high-quality cycling facilities (Cervero et al., 2009; Hull & O’Holleran, 2014; Larsen et al., 2013).
Also critical is how adding cycle lanes might persuade new riders to shift their modal choice (CAF, 2010; Ortiz, 2018). Several authors affirm that building new bicycle lanes in cities evokes new bicycle commuters (Dill & Carr, 2003), especially within a political strategy that seeks to discourage the use of private vehicles in urban environments.

Cyclist safety is another subject of considerable research within cycling as a means of transportation because risk or danger (whether real or perceived) is a principal barrier to cycling (Jensen, 2007; Lusk et al., 2011; Teschke et al., 2012; Transport for London, 2010). Cyclist safety is a two-dimensional variable comprising traffic safety and personal safety. Traffic safety has been extensively researched through Level of Service methodologies. First, the concept of Level of Stress (LOS), where stress is like an obverse or flipside of service, measures cyclists' willingness to travel in different road conditions. It refers to tolerance of the stress generated by surrounding traffic, which combines perceived danger and factors such as noise and toxic fumes. Under this concept, researchers have developed different schemes to classify roadways. Switching the label back from stress to service, the most typical classification is the Bicycle Level of Service (BLOS; Landis et al., 1997), measuring on-road comfort as a function of the road’s traffic conditions and geometry. This methodology has been criticized for not establishing a correspondence between the service levels and user tolerance of stress and because the data to calculate it are sometimes unavailable (e.g. traffic volume). An attempted improvement measures the Level of Traffic Stress (LTS), which does establish a relationship between stress levels (on given roadways) and tolerances of population groups (Mekuria et al, 2012).

Similarly, the Bicycle Compatibility Index (BCI) measures Level of Service as developed by the US Federal Highway Administration (1998). The BCI is used to evaluate the ability to accommodate motorists and cyclists on the same road. Albeit data on their availability could likewise be hard to assemble, BCI variables include elements such as the presence of large trucks on the same street, speed of surrounding vehicles, road width, and parking of vehicles on the roadway. At the same time, and at the confluence of safety and equity, it is crucial to analyze the transportation modes of travelers who cause accidents and those who suffer them. Some studies show that users of active modes (cycling, walking) suffer the most (Guittink & Flora, 1995) – particularly in crashes with motorized modes. In general, the debate centers on the fact that the most equitable and mass modes are the least harmful to other modes (certainly cycling and walking, the most equitable, cause less harm on impact) and that the minority of travelers who can access private motorized modes produce the most victims (CAF, 2010).

However, in Latin American countries, traffic or road safety is very much just one of the two dimensions of cyclist safety noted above. Personal safety is also a salient limiting factor in adopting sustainable modes of transport such as cycling (CAF, 2010). Personal safety means vulnerability to be criminal or anti-social acts such as bag-snatching and sexual harassment rather than traffic accidents (Gwilliam, 2002). Latin America has an exceptionally high rate of attacks on the public during non-motorized transport (Gwilliam, 2002). Argentina is no exception (Allen et al., 2015).

Collecting cycling-specific data on personal safety is problematic since the documentation of accidents or crimes involving cyclists is rare, poorly organized, and not geo-referenced. In general, cities correctly document motor vehicle accidents, but only an estimated 35% to 88% of cyclist incidents are officially reported (Hook, 2005). This is because the victims fear being arrested or fined, and few authorities are trained to collect such data. Further, cyclists’
personal safety is a complex social problem. It not only affects active transportation but also determines access to education and work for specific demographics, disproportionately low-income women and girls (Allen et al., 2015; Gwilliam, 2002).

Since their popularization, GIS have been a major tool for spatial planning of road networks (Castro & De Santos-Berbel, 2015; Zou et al., 2012). With widespread use in both the developed and developing world of smartphones, including GPS, copious rich data ('big data') has become available for more accurately profiled spatial analysis. GIS models can be calibrated with detailed spatiotemporal data from individual trips through data mining (Endo et al., 2016; Wu et al., 2016; Zheng, 2015). Data are obtainable, for instance, on one’s specific trajectory, speed, acceleration, and change of direction (Ashqar et al., 2019; Biljecki et al., 2013).

Abundant GIS application literature focuses on distance, travel time, and spatial accessibility of public transportation modes (Broach, 2019; Horner & Grubesic, 2001; Li et al., 2020; Milakis & Athanasopoulos, 2014; Skov-Petersen et al., 2018). These data let researchers draw behavioral conclusions regarding modal and route preferences to optimize networks and better inform mobility policy. Whereas official reporting rates in Latin America have weaknesses, another valuable use of GIS is to analyze traffic accidents concerning the built environment. Many authors have investigated the use of GIS to identify accident-prone areas for pedestrians and cyclists (Austin et al., 1997; Kim & Levine, 1996, 1996; Levine et al., 1995; Pulugurtha et al., 2007; Steenbergen et al., 2004). To determine accident hotspots using GIS, values are assigned by accident ratio (accidents per km traveled), frequency (accidents per km of roadway), Kernel Density, or Spatial correlation (Anderson, 2007; Jang et al., 2013; Ziari & Khabiri, 2005).

**Methods and tools**

This research aimed to identify the main locations to build new cycle lanes in MAM based on potential cycling trips at a local, immediate level. To determine potential trips, the researcher first analyzed observed cyclist trips from the most comprehensive database was available, the 2010 Origin-Destination survey of Mendoza (ODSM), which had recorded only 544 bicycle trips (2.16% of total trips surveyed), being ill-suited to gather quality data on NMT modes (PTUMA, 2011). By statistical analysis of the observed bicycle trips, the researcher constructed a regional profile of cyclists for Mendoza. Potential trips were defined as trips that were actually made by other modes but, according to that profile, could have been biked given their distance, duration, purpose, and the age of the traveler. Observed and potential trips were then geo-referenced in relation to their 'sub-zones' (geographic departments) of origin and destination. Open source QGIS software and base maps from OpenStreetMap were used as it is free and thus accessible to developing countries, where public entities rarely have funding for paid versions (Quinn, 2020). Finally, the model yielded a synthesis map of trip flows by existing and potential users against existing cycling lane infrastructure and public bike stations. Figure 1 illustrates the methodological steps followed.
The Metropolitan Area of Mendoza, MAM, was chosen because it exemplifies a medium-sized Latin American city endeavoring to encourage cycling but lacks much data directly on local cycling mobility. The city is not unusually inhospitable to cycling in topography or climate. MAM comprises six administrative districts or departments (Figure 2) and lies in the Northern Oasis of Mendoza, Argentina, a province of which it is the Capital. Greater Mendoza occupies over 14,712 km². However, only 370 km² are considered urbanized areas (MAM), with a population density of 2,900 inhabitants per km² across perpendicular axes running 30 km north-to-south and 15 km east-to-west, occupying only 168 km² of those 370 km² (Ministry of Transport of Mendoza, 2010).

Although the MAM had an intercensal growth of 100,000 inhabitants in the last census (2000–2010), this growth has been uneven, continuing a longer trend of settling in the peripheral departments of Mendoza Capital. The departments of Maipú, Luján, Las Heras and Guaymallén tripled their population from 1960 to 2010. Luján stands above the rest with a 19% increase (Ministry of Transport of Mendoza, 2010).

**Observed bicycle trips from the Origin-Destination survey**

The ODSM is a household mobility survey conducted in 2010 in the Metropolitan Area of Mendoza by the Ministry of Transportation as a tool for transportation planning that allows policymakers to determine how and why the population that regularly resides in the study area moves (PTUMA, 2011). To date, this OD survey constitutes the most comprehensive mobility survey carried out for the study area. The survey identified 544 trips made by bicycle, comprising 2.16% of the total trips surveyed. Fully 81.3% of the people reporting bicycle trips were male, whereas males were only 48.3% of survey respondents. Most cycling trips (33.6%) were made by young adults (31–50 years), youth (19–30 years) with 29.2%, and adults (51 – 65 years) with 19.9%, followed by older adults (more than 66 years) with 8.6%, adolescents (13–18 years) with 6.9%, and
children (4–12 years) with 1.8%. This age pattern coincided with that of total trips, except for children and adolescents, who travel mainly on foot, by bus, or as companions in private vehicles. Cycling trips originated primarily in Guaymallén and Maipú, followed closely by the other departments (see far right Totals column of Table 1), with Luján having the fewest. Most trips had their origin and destination within the same department, as shown by the diagonal cells in Table 1 (PTUMA, 2011).

Of the cyclists surveyed, 52.6% stated they do not own a car or a motorcycle, while the rest own one or both, whereas in the total population studied, 35.5% did not own a car. The peak departure times coincide with the peaks of mobility of all modes in MAM, with the highest peak from 7 to 8 am where 21% of the trips occur, followed by a peak from 12 to 1 pm, with 16.6% of the trips. For bicycle trips, a third peak is observed from 5:30 pm to 7:30 pm, with 15.5% of trips, whereas this peak is less pronounced in the other modes. Trip duration (see, Table 2) ranges from 5 minutes to two hours, with an average of 21.4 minutes and a 75th percentile of 30 minutes (PTUMA, 2011).

Figure 2. Composition of the study area covered by the study. Source: ODSM 2010 (PTUMA, 2011) Mendoza.
Concerning trip purpose, 58.1% of the cyclist respondents answered that it was ‘work’-related, while only 9.9% of the trips made were for ‘study’ purposes. Next were ‘social’ purposes, then ‘dropping off or picking up children from school’, while ‘shopping’ came last. The low percentage of ‘study’-related trips was striking, as it differs considerably from the rest of the modes, where the rate was 25.2% (PTUMA, 2011).

**Potential trips based on the regional cyclist profile**

From the statistical analysis of the observed bicycle trips, a profile of the Mendoza cyclist was constructed, which served as a basis for identifying potential trips by non-cycling commuters. In the total amount of trips surveyed by the ODSM, there is a preponderance of trips made by bus or tram with 44.74%, followed by car with 31.6%, and by foot (walking) with 16.19% of total trips (See, Figure 3). To estimate potential bicycle trips, we decided to analyze the characteristics of these trips (made by modes other than cycling) and identify those with similar characteristics.

As has been foreshadowed, potential trips are actually made by other modes but could have been made by bicycle due to the traveler’s distance, duration, purpose of the trip, and age. The criteria used to identify potential trips have been summarised in Table 3 and respond to the following assumptions.

All trips made by alternative modes to cycling (including walking), with a trip duration equal to or less than 30 min, were considered, representing the 75th percentile of trip durations made by cyclists. The researcher estimated that at an average speed of 20 km/h (Puliafito & Castesana, 2010), the 75th percentile of cycling trips would be 10 km in distance.

Within MAM, private cars, taxis, motorcycles, and hired transport modes travel at an average speed of 30 km/h (Puliafito & Castesana, 2010). Therefore, the potential trips identified were both under 30 min in duration and under 10 km in distance. Buses and trams average 20 km/h (Puliafito & Castesana, 2010), the same as bicycles. Because waiting times and trip stages should be counted, trips were selected for their duration (up to 30 min), and as a result, all trips considered were less than 10 km in distance. In

| Department of Origin | Department of Destination | Total |
|----------------------|---------------------------|-------|
| Capital              | Capital                   | 29    |
|                      | Godoy Cruz                | 5     |
|                      | Guaymallén                | 18    |
|                      | Las Heras                 | 19    |
|                      | Luján                     | 0     |
|                      | Maipú                     | 1     |
|                      | Total                     | 70    |
| Godoy Cruz           | Capital                   | 5     |
|                      | Godoy Cruz                | 59    |
|                      | Guaymallén                | 7     |
|                      | Las Heras                 | 0     |
|                      | Luján                     | 6     |
|                      | Maipú                     | 5     |
|                      | Total                     | 84    |
| Guaymallén           | Capital                   | 16    |
|                      | Godoy Cruz                | 8     |
|                      | Guaymallén                | 77    |
|                      | Las Heras                 | 7     |
|                      | Luján                     | 0     |
|                      | Maipú                     | 6     |
|                      | Total                     | 112   |
| Las Heras            | Capital                   | 19    |
|                      | Godoy Cruz                | 0     |
|                      | Guaymallén                | 5     |
|                      | Las Heras                 | 75    |
|                      | Luján                     | 1     |
|                      | Maipú                     | 0     |
|                      | Total                     | 102   |
| Luján                | Capital                   | 0     |
|                      | Godoy Cruz                | 6     |
|                      | Guaymallén                | 0     |
|                      | Las Heras                 | 1     |
|                      | Luján                     | 62    |
|                      | Maipú                     | 5     |
|                      | Total                     | 102   |
| Maipú                | Capital                   | 1     |
|                      | Godoy Cruz                | 6     |
|                      | Guaymallén                | 5     |
|                      | Las Heras                 | 0     |
|                      | Luján                     | 1     |
|                      | Maipú                     | 93    |
|                      | Total                     | 93    |
|                      |                         | 106   |

Table 1. Observed Origin-Destination bicycle trips by department of MAM.
contrast, walking trips have an average speed of 5 km/h (Puliafito & Castesana, 2010). Hence walking trips of up to 120 mins duration were considered, since, if made by bicycle, they would take 30 min or less. From these trips, those made by children (4 to 12 years of age) were discarded because only trips for transport and not recreational purposes were relevant to this study and because it is unlikely for children under 12 to travel unaccompanied. Similarly, to be conservative, trips made by those aged 65 years or older in case of physical limitations.

The ODSM has cataloged trip purposes under the following criteria: ‘does not know/does not answer’, ‘home’, ‘workplace’, ‘work-related’, ‘study’, ‘study-related’, ‘health’, ‘shopping’, ‘sports’, ‘recreation’, ‘gastronomy’ (as eating outside your home), ‘social visits’, ‘associative activities’ (e.g. religion, cooperatives, etc.), ‘personal errand’, ‘drop/pick up children’, ‘drop/pick up somebody else’, ‘accompany somebody’, and ‘others’. Of these categories, trips made for medical purposes (e.g. trips to the hospital) were discarded due to their likely incompatibility with cycling. It was decided to include trips cataloged by the ODSM as being for ‘other’ purposes after analyzing the modes of travel observed and concluding that the bicycle would not be a limiting factor. Other interesting categories were the ‘drop/pick up children’, ‘drop/pick up somebody else’, and ‘accompany...
Table 3. Summary of potential trip selection criteria for each transportation mode.

| Trip selection criteria | Assumption | Distance (km/h) | Duration (minutes) | Age of traveler | Purpose of trip |
|-------------------------|------------|-----------------|-------------------|-----------------|-----------------|
| Observed mode           |            |                 |                   |                 |                 |
| Private car/ taxi/      | Average    | Maximum distance| 75th percentile   | Children under  | All trip        |
| hired car with driver   | speed (in  | achieved by     | of observed      | 12 and adults   | purposes        |
|                         | urban       | cycling 30 min  | cycling trip      | over 65 were    | except ‘health’ |
|                         | context of  | at an average   | durations at an   | discarded       | except ‘health’ |
|                         | MAM)        | speed of 20 km/h.| average speed of  | based on physical| except ‘health’ |
|                         |             | ≤10 km          | 20 km/h.          | limitation/      | except ‘health’ |
|                         |             | ≤30 min         |                   | autonomy.        | except ‘health’ |
| Bus/tram/special        | 20 km/h    | ≤30 min         | 13–65 yr.         |                 |                 |
| transport (e.g.         |            |                 |                   |                 |                 |
| school bus)             |            |                 |                   |                 |                 |
| Motorcycle               | 30 km/h    | ≤10 km          | 13–65 yr.         |                 | All trip        |
| Walking                 | 5 km/h     | ≤120 min        | 13–65 yr.         | All trip        |

somebody’ that would require two or more people sharing one bicycle or cycling together. We decided to keep these categories as bicycle trips have been observed for these purposes. A summary of the selection criteria for each mode is presented in Table 3.

The result after this filtering process yielded data from 12,036 potential trips, equivalent to almost 50% the number of 24,344 total trips surveyed by the ODSM (PTUMA, 2011). Figure 4 presents the percentage of potential cycling trips in relation to observed modes. Though speculative and simplistic, this larger sample could reflect the general mobility patterns of the Mendoza cyclist as relevant to MAM’s project for expanding cycling infrastructure by revealing not only current cycling trips, but also understanding the trips that could have technically been made by bicycle, because of their duration, distance, trip purpose and age of the traveler. Please note that many other variables influence cycling as a transport mode, as stated in the discussion chapter. However, some cities have achieved such a high modal share (Goel et al., 2022), such as Copenhagen (Denmark), which reported a 49% cycling modal share (Haustein et al., 2019), and Groningen (Netherlands) with 40%+ of transport trips (since the 2010 report) are
Table 4. Most frequent ten sub-areas as points of origin or destination for observed and potential trips, respectively.

| Ranking | Sub-area | Origin | Destination | Total | Sub-area | Origin | Destination | Total |
|---------|----------|--------|-------------|-------|----------|--------|-------------|-------|
| 1       | sz_00_1  | 33     | 26          | 59    | sz_00_1  | 742    | 764         | 1506  |
| 2       | sz_00_2  | 18     | 22          | 40    | sz_00_2  | 388    | 379         | 767   |
| 3       | sz_03_4  | 15     | 20          | 35    | sz_10_4  | 258    | 253         | 511   |
| 4       | sz_05_4  | 17     | 17          | 34    | sz_00_3  | 232    | 238         | 470   |
| 5       | sz_10_4  | 15     | 18          | 33    | sz_00_4  | 228    | 220         | 448   |
| 6       | sz_00_6  | 13     | 14          | 27    | sz_10_3  | 228    | 200         | 428   |
| 7       | sz_01_3  | 14     | 10          | 24    | sz_08_2  | 206    | 198         | 404   |
| 8       | sz_10_3  | 11     | 12          | 23    | sz_00_6  | 204    | 199         | 403   |
| 9       | sz_06_3  | 12     | 10          | 22    | sz_23_5  | 183    | 188         | 371   |
| 10      | sz_10_2  | 10     | 10          | 20    | sz_29_3  | 182    | 175         | 357   |

made by cycling (Pucher et al., 2010). The differences between Mendoza (Argentina) and these two cities are many and varied; however, aiming for a 50% cycling modal share in a city like Mendoza may be ambitious but is still an aspirational goal.

Territorial model of observed and potential trips

After collating data on the origin and destination of observed and potential cycling trips (see, Table 4), the researcher created a series of cartographic visualizations of these data. Given the need for affordable, serviceable, easy-to-apply models for resource-strapped communities, these representations aimed to show the general spatial movement pattern to give a rough idea on where to prioritize the building of cycling lanes. Since information about each trip’s routes (road network traces) was not known, but rather only the sub-areas of origin and destination, the sub-areas considered were the census subdivisions currently used by the ODSM.

The methodology for mapping bicycle trips then selected the ten census sub-areas with the highest number of bicycle trips. Subsequently, the ten longest trips were represented for each designated sub-area, yielding the top ten trip’ migration paths’ (rows in Table 3) for each category: observed and potential. For instance, in row 1 of the observed column sz_00_1 designates the most frequent sub-area (’sub-zone) of origin/destination overall since its occurrence as a sub-area of either origin or destination in observed trips totaled 59, whereas sz_10_2 ranked 10th because it totaled only 20 – see row 10. By contrast, while the most frequent potential trip origin/destination also happened to be sz_00_1, the 10th-most frequent was sz_29_3. Finally, all the top ten origin/destination points for each category were compiled into a single ‘synthesis’ map. Still, only the most noteworthy patterns of each one are represented in the visualization below, which was superimposed on existing cycle lanes. A migratory representation without arrowheads was employed since cycling trips occur in both directions. In addition, oval loops represented trips starting and ending within the same sub-area. In both cases, thicker lines mean denser flows. The observed, potential, and highlighted synthesis maps are presented in the Results section below.
Results

In both Figure 5 and Figure 6, the researcher has collated the ten migration patterns that represented the most significant frequencies from our statistical analysis. In both maps, the sub-areas involving the highest number of observed trips (Origin + Destination) from Table 2 are shaded in gradations of green, darker indicating higher frequencies. The thickness of the migration lines is a function of the number of trips, as per the map legend. Note that the lines consist of spliced segments in many cases, where journeys did not necessarily run the whole length but overlapped in the same direction.

In Figure 5, we see a high density of trips in the central area of the Capital and Las Heras departments describing a pattern like the upper handle and the prongs of a trident. These two business centers are both the main trip attractors (points of destination) and generators (points of origin) of MAM. Three critical flows or prongs fork northwards. One runs north-east, fed by cyclists from the areas of 4° Section, B° UJEMVI (B° standing for barrio, suburb) from las Heras, Aeropuerto El Plumerillo (an airport), sectors adjacent to Hospital Carrillo, and B° Independencia, in addition to a large volume of internal cycling trips (shown by a loop at the top of that prong around Control 60 Las Heras). The second prong/flow goes north transversally, concentrating the trips of sub-zones of San Martín Street to the west and Lisandro Moyano Road to the east, ending in the area of B° Estación Espejo and surroundings (marked as Estación General Espejo Las Heras), where there is also a loop of internal movement. The third flow runs north-west, crossing sectors of the 6° Sección (6th Section), B° Cano, B° Reconquista and Cementista (being the most outstanding with internal movement), B° San Martín, B° Infanta, and ending in B° Municipal de Las Heras. The last flow of less statistically relevant trips takes a southerly direction, below CASA DE GOBIERNO (Government House), ending in the department of Godoy Cruz, as can be seen by the point Barraquero-Club Andes Talleres Godoy Cruz.

Figure 6 represents potential trips that could have been made by bicycle. As for the observed trips, the most significant flow (thickest portion) is found in the sub-zones that comprise the business center of the Capital department (sitting above CASA DE GOBIERNO), making it the main generator and attractor of bicycle trips. Relative to Figure 5, this thick portion sits much higher up towards the north end of Figure 6 because the latter must also accommodate the potential migratory routes lying south of it but not present among observed routes.

In second place, above the thick chunk, are the flows located in the northern department of Las Heras, where two streams bifurcate. The more prominent one comprises sub-areas west of San Martín Street across the 6th Section, B° Reconquista and Cementista (being the most notable), then B° San Martín and Infanta. The other flow is east of San Martín Street in which the sectors of B° UJEMVI, B° Aeronautico, B° Independencia, San Miguel, and Carrillo hospital, among others, stand out. Another bifurcation occurs south of CASA DE GOBIERNO. The south-easterly fork links the business centre with Maipú department (note for instance, B° Galiño Maipú, Plaza Maipú and B° las Torcasitas Maipú), crossing areas of Guaymallén department. From B° las Torcasitas Maipú another important flow then arcs southwest, running ultimately through B° las Parras-B° Huentota.
Figure 5. Spatial distribution of observed trips. Darker shades of green = sub-areas with higher observed density of origin/destination. Base map by OpenStreetMap.
Figure 6. Spatial distribution of potential trips (that could be made by bicycle). Base map by OpenStreetMap.
Finally, the south-westerly fork below CASA DE GOBIERNO starts in the business center and runs towards the center of Godoy Cruz department, crossing sectors around San Martin Street [(not shown)], the most notable area being Plaza Godoy Cruz (Godoy Cruz Square). This flow (with offshoots) continues more finely towards the southwest corner of Figure 6, crossing into Luján de Cuyo department.

The synthesis map (Figure 7) shows the most noteworthy trends in the spatial distribution of both observed and potential cycling trips in the study area. Observed and potential trips share a similar profile, with observed trips north of CASA DE GOBIERNO being slightly shifted towards the west but absent in the more southerly parts of the figure. Because the figure superimposes this model of observed and potential trips on the existing cycling infrastructure (bicycle lanes and public bicycle stations), it is possible to analyze the gaps and redundancies in the cycle lane network. The most notable gaps are shown from Capital towards the north, going through Las Heras in three streams, where only the north-east stream could use cycle lanes (Lateral Acceso Norte). Further, a west-to-east axis that crosses the Capital business center, connecting the regional university, Universidad Nacional de Cuyo or UNCuyo (in the west) with the Regional Bus Station (in the east; not shown) lacks any cycling-specific infrastructure. The south-eastern stream of potential trips that connect Capital’s business center with several neighborhoods of Maipú likewise lacks cycle lanes. The westerly shift of observed trips could indicate that observed cyclists take detours to use the cycleways there.

Discussion

This research yields two contributions. The immediate, local and main contribution is the series of maps in the Results section above that present original spatial data for decision-making by urban planners and policymakers in Mendoza regarding the location of bicycle lanes. The synthesis map of results superimposed on existing infrastructure already notes main gaps, which become priorities in extending and linking up the cycle lane network. Granted, the migratory lanes show only general direction axes. But these can be complemented with case-by-case refinements (such as selecting segregated or non-segregated lanes based on the urban space available), allowing for flexibility when deciding the specific network path typology. MAM cycling policy would also benefit from noting departmental population trends, cycling safety enhancement (such as lighting), and a systematic approach integrated into its overall mobility offering (public transport through trams is also being extended (Ministry of Transport of Mendoza, 2010) instead of the ad hoc cycle lane initiatives so far, and further general recommendations below as to method (bullet-pointed).

Besides the development of MAM, this paper also contributes to the broader literature on transportation policymaking and urban planning. Its methodology could be duplicated elsewhere in Latin America and the developing world, where cycling data are scarce and resources for research limited to equip decision-makers with a more complete picture of cycling patterns.
Figure 7. Synthesis map: spatial distribution of trips in relation to existing bicycle lanes. Base map by OpenStreetMap.
Because this model only shows general migratory paths, decision-makers should use it cautiously and as a first step for planning, and then define each network path considering the characteristics of existing transportation infrastructure, and decide where segregated or non-segregated bike lanes are more appropriate. Similarly, this GIS model should not be the sole information source when planning a cycling network. If affordable, it should be accompanied by a spatial analysis of:

- Demographic potential of origin and destination centers
- Road safety parameters in the case of shared lanes (such as vehicle speed, size, and quantity).
- Location of high crash-risk areas.
- Location of socio-economically disadvantaged areas (people who, for want of resource equity, lack safer mobility alternatives).
- Existing and potential user journey preferences.

Alongside environmental imperatives, urban cycling is fundamentally one of the most equitable means of transportation. The dynamics of equity work differently between gender and economic factors, though. Economically, the high cost-effectiveness of buying and operating a bicycle lets low-income communities to access education and work opportunities. Unaffordability is likely why 52.6% of the cyclists who made the 544 trips observed owned neither a car nor a motorcycle. In contrast, only 35.5% of the surveyed population lacked a vehicle. Given that in Latin American households that own one car (or motorcycle), this is generally used by a male (Foundation, F.I.A., 2017), cycling is, or should be, especially accessible for girls and women who might otherwise be somewhat confined to their homes. That accessibility would lead us to expect that females would dominate among cyclists, effectively relegated to that mode. However, the fact that 81.3% of observed cyclists in the ODSM were male (PTUMA, 2011) indicates gender inequity against females through a different cause: safety perceptions. While a similar gender disparity appears in first-world countries, such as Australia (Bell et al., 2006; Merom et al., 2003), the opposite case has also been observed where utilitarian cycling rates are high (Garrard, 2003). Mobility studies from Latin America agree that cycling feels, and can be, very dangerous to women given high rates of crime and sexual harassment, making fear a significant barrier to uptake (Gomez, 2000; Canavire-Bacarreza et al., 2016; Allen et al., 2015; Vasconcellos et al., 2019). Concerning traffic safety, several authors agree that women are more risk-averse than men (Byrnes et al., 1999; Garrard et al., 2008; Goldsmith, 1993).

Finally, and stepping back, efficient and equitable mobility networks require systemic approaches. These should integrate cycling infrastructure into the whole mobility offering, so users can combine modes to satisfy their travel purpose. Urban citizens should consider the entire road network, except primary arteries (e.g. motorways), a space to be shared with cyclists (Forrester, 2001; Montezuma, 2015; Ortiz, 2018), whether routes are shared or segregated. Some authors state that segregating bicycles from other vehicles will increase automobile traffic volumes and speeds, negatively impacting other community goals such as environmental sustainability, air quality, and automobile-on-automobile accident rates. However, whether real or perceived dangers, potential cyclists may be
discouraged from riding if not offered segregated lanes (Garrard et al., 2008; Jensen, 2007; Landis et al., 1997; Lusk et al., 2011). In any case, new cycling facilities should not be an isolated measure but be complemented with transport education, transportation law reform, and the promotion of a cycling culture (Parkin et al., 2007, Handy & Xing, 2011; Ortiz, 2018).

Conclusions
Investing in adequate road infrastructure that favors sustainable, non-motorized forms of mobility generates benefits beyond mobility, including all-important carbon reduction, improved air quality, healthy physical exercise, revitalized public spaces, stronger social cohesion, and consequent improvements in citizens’ safety and quality of life.

The bicycle is the most efficient means of urban mobility for short distances (5 to 10kms) when no significant topographical constraints exist, as in Mendoza, Argentina. As policymakers from resource-strapped developing countries turn increasingly to cycling for short-distance trips, the literature needs to offer simple, cost-effective empirical methods and reliable geomatic tools to plan new infrastructure. Crucially, modeling cycling mobility purely from observed trips underestimates potential demand as it ignores trips that could theoretically be made by bicycle. For cities without reliable datasets on cycling preferences and needs, a model of possible cycling trips can be obtained from data on alternative modes of transportation (private vehicles, hired vehicles, walking, and public transportation).

This research has conducted a technical estimation of potential bicycle trips based on the statistical characteristics of observed bicycle trips and located both types of trips geographically. A set of three cartographic visualizations are presented, collating data on the origin and destination of observed and potential cycling trips, showing the general spatial movement pattern to give a rough idea on where to prioritize the building of cycling lanes. A final ‘synthesis’ map shows the most noteworthy patterns of these two categories superimposed on existing cycle lanes as a visual way to inform policymakers. Additionally, actions for application are proposed, significant limitations discussed, and further research suggested, noting issues of gender equity and safety.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Data and codes availability statement
The data and codes that support the findings of this study are openly available at the private link bit.ly/3HHYCMcE

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