Digital Platform to promote sustainable mobility and COVID-19 infections reduction: a use case in the Guadalajara metropolitan area

Ramon A. Briseño
Ph.D. Student in Information Technology
CUCEA
University of Guadalajara
Guadalajara, México
alejandro.bmartinez@alumnos.udg.mx

Juan C. López
Ph.D. Student in Information Technology
CUCEA
University of Guadalajara
Guadalajara, México
juan.lopez6936@alumnos.udg.mx

Rocio Maciel Arellano
Smart Cities Innovation Center
CUCEA
University of Guadalajara
Guadalajara, México
rmaciel@cucea.udg.mx

Victor M. Larios
Smart Cities Innovation Center
CUCEA
University of Guadalajara
Guadalajara, Mexico
victor.m.lariosrosillo@ieee.org

Jesus Beltran Ramirez
Smart Cities Innovation Center
CUCEA
University of Guadalajara
Guadalajara, Mexico
raul.beltran@academicos.udg.mx

Carlos López-Zaragoza
Head of Sustainable Culture of Mobility & Liaison Office
Department of Mobility and Transport of the Municipality of Zapopan
Jalisco, Mexico
carlos.lopezz@zapopan.gob.mx

***Abstract*— This work proposes a digital platform based in a multi-agent system to plot the different mobility alternatives to counteract the agglomerations in public transport and therefore decrease COVID-19 infections in the GDL. Following the recommendations of the World Health Organization (WHO) in the face of the health emergency of COVID-19, mainly keeping a healthy distance, the GDL can integrate sustainable mobility as the public bicycle system and reduce the users in regular transport routes to safe levels. For that endeavor, we develop an analysis of the behavior of the trips in the public transport of Guadalajara to explore the possibility of substituting the short transfers of bus travel by bicycle travels using the existing public bicycle infrastructure. We introduce a multi-agent simulation to plot different scenarios of mobility moving bicycles and buses. In this preliminary work, we show possibilities of the simulation integrating as variables not only the risk of COVID-19 infection but also the impact on economy and traffic reduction, CO2 Footprint, and health achieved with this multimodal mobility simulation. Also, the simulation can help to incentivize safer and efficient mobility strategies in the public transport system to reduce the use of private vehicles.**

Keywords*— *Digital platform, sustainable mobility, Smart City, COVID-19 infection, Healthy lifestyle, Multi-Agent Simulation

I. INTRODUCTION

A Smart City, as a complex system, a problem has several dimensions of impact. Information Technologies can accelerate to reach solutions and plot different scenarios with given conditions. For example, COVID-19 has an impact on Healthcare. However, with the risk of infection to prevent the distancing strategies, the shutdown of non-essential businesses and services impacts the economy, mobility, and the environment. Such is the case of the Guadalajara (GDL) Metropolitan Area that has the specific infrastructure in mobility and weather conditions able to reduce COVID-19 infections. However, for the stakeholders of GDL (Citizens, Authorities, Industry, Academia) they need to understand the risks and conditions to take actions, and the best way to start is with digital simulations. Once the simulations can plot scenarios, the best strategies can be selected to adapt and mitigate as possible the impacts in related Key Performance Indicators of the City to keep a good quality of life level. Where GDL is the model for this work, but other cities in Latin America or other countries on continents with similar conditions can adapt it.

While the COVID-19 shutdown happens in GDL, the priority is to reduce the risks of infections to control de pandemic. GDL on its metropolitan area has a population near to 4.6 million, where 42.7% of them need to use the public transport system to develop its economic activity. Even with the campaign of staying at home for the home office, a small percentage impacted the use of public transport where those that can stay at home are the owners of private cars mainly. Another consideration for the public transport in GDL is that each bus unit, operated by a private owner under a license of the state government. Electronic tickets are not still in place because an agreement is not in place among bus owners, and to commute from one bus line to another requires a new ticket payment.

GDL citizens prefer the bus units as the principal medium of transport, with 42.7%. The private automobile holds 40.6%, the bike 4.1%, the motorcycle 1.5%, the taxi 3.0%, train 3.4, and the preference to walk 4.7% [6]. In figure 1, we can see that private transport offers an area of opportunity to improve the public transport offer.

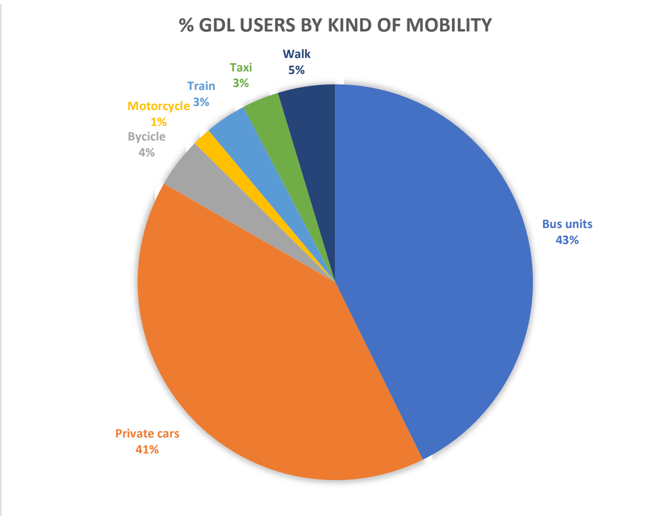

Figure 1. Distribution of GDL citizens on mobility options

Even if the use of bicycles is small in GDL, the cities promote and develop their public infrastructure because of numerous benefits to reducing cost generated by traffic congestion, traffic accidents, low air quality, noise pollution, among others [12]. Using the bicycle as a means of transportation is beneficial for physical and mental health. Studies have shown that cycling groups are the happiest travelers due to factors such as well-being produced by moderate exercise and control of arrival time at their destination [10]. Also, using the bicycle instead of a motorized vehicle as a means of transportation improves the cardio-vascular state of the citizen without requiring extra time to exercise.

During the time of COVID-19, when cities are the reopening the economic activities, mobility alternatives to avoid agglomerations in the public transport system is critical. We need to decrease the possibility of infections, and one of the viable alternatives is bicycle mobility.

During the pandemic, cities such as Vienna, Boston, Oakland, Philadelphia, Minneapolis, Bogota, and Mexico City have enabled emerging spaces for the transfer of cyclists and pedestrians to avoid conglomerations in the public transport system [3]. GDL is not the exception; in the city, 15.3 kilometers of new bicycle infrastructure is in the build [4]. The city of GDL has so far more than 100 km of bicycle lanes with security infrastructure [13].

According to the recommendation of the World Health Organization (WHO), distancing is one of the necessary measures to protect versus the new coronavirus [2]. The bike can offer a reasonable distance compared with transport systems like the bus units and the train wherein combination as multimodal mobility can prevent infections of COVID-19.

This work presents a simulation to plot situations to maintain the distancing recommended by the WHO in the public transport system, switching a percent of citizens that use the bus units, train, or particular vehicles and commuting to the bicycle mobility in GDL. Besides, the work describes the impacts of bicycle mobility in the environment, the economy, and mobility in GDL.

II. GDL PUBLIC BICYCLE INFRASTRUCTURE

The MiBici program is a public transportation system based on a network of automatic stations in the Guadalajara Metropolitan Area; bicycles are available for rent per day, week, or year depending on the acquired membership. Figure 2 illustrates the bike-sharing system stations. With 4,658,208 trips achieved in 2019 included 85,143 users registered in the program until May 2020. The MiBici program posts open data on trips made per day, per month, or year on its website [8]. MiBici program is our reference to analyze the behavior of citizens who use the bicycle as a means of transportation due to their available open data.

Figure 2. GDL public bike-sharing system mibici.

We can see in figure 3 all the deployed stations over the GDL Metropolitan area and the cycle lines in the blue lines where bicycles can safely circulate. This infrastructure is growing in the next years as a sustainable mobility solution for the city.

There are digital platforms for public transportation travel planning that provide data to understand the mobility of cities. Moovit is a mobile application and digital platform present in 102 countries around the world, including GDL. We used open data from the Moovit digital platform for our simulation purposes with the aim that other cities can replicate and reuse our development.

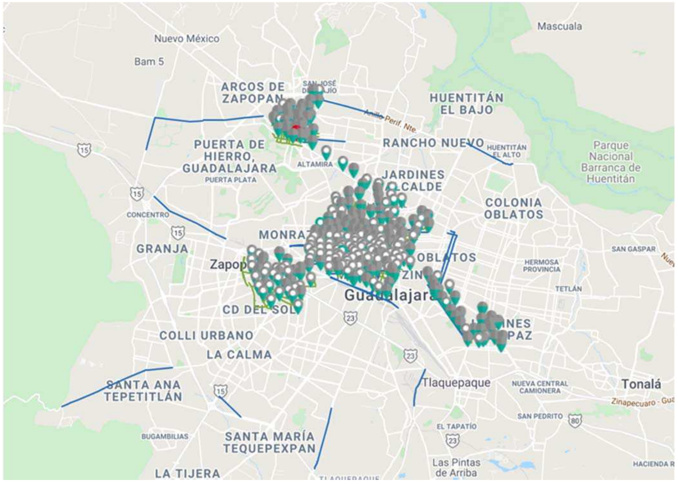

Figure 3. Deployed stations of MiBici over GDL Metropolitan Area

III. Problem Statement

GDL, as discussed before, has areas of opportunity to improve the trips on public transport to reduce transport time in routes and the cost of transfers. Nevertheless, it happens when users are limited to use the bus units and do not combine with the public bicycle system. In rush hours, GDL has agglomerations on public transport, creating risk situations for the spread of COVID-19. However, the analyzed data reflects that GDL has the right amount of cycling infrastructure with a few use. Then it can provide an opportunity to promote and incentivize its use to reduce COVID-19 infections.

We create an analysis from the mobility data in GDL, and then we simulate bicycle use increased. Our objective is to find a balance between the use of bike paths, public transport, and private vehicles. With these conditions, we will look as possible to provide an increase in the healthy distance for public transport passengers. The above, without increasing the cost of the trip or increasing its duration. Also, we estimate the traffic flow and the carbon footprint to highlight the benefits of this mobility scenario in our multi-agent simulation.

IV. Methodology

According to the Moovit app statistics, the travels in public transport of Guadalajara have an average time of 56 (includes walking, waiting, and traveling) minutes and a distance average of 8.52 kilometers. With such mobility data, the average wait time is 15 minutes approximately [5]. Also, Table 1 shows more characteristics of travel in public transport.

TABLE I. Characteristics of travels in public transport

TRAVELS	
Long travels	***Percentage***
1 to 2 hours	29.49%
2 hours or more	3.45%
Time of travel	***Percentage***
More than 30 minutes	***80.36%***
Less than 30 minutes	***19.64***
Number of means of transport	***Percentage***
Two means of transport	***60%***
Three or more means of transport	***9%***
One means of transport	***31%***
Distance traveled	***Percentage***
More than 12 km	***20%***
Less than 12 km	***80%***

In the statistics of travels from the Mibici program, we found that citizens use the bike for short travels. The time of the average travel is 11 minutes, with 26 seconds, and the distance average per travel is 1467 meters. Also, organizing the travel distance values from minor to mayor, the distance corresponding to the median is approximately 3400 meters [7].

The data in table 1 show that in the 69% of the travels, citizens use two or more medium of transport to travel an average of 8.52 kilometers. Such a travel pattern may be an indicator that of this 69% of trips, citizens take at least one form of transport that transports them a short distance.

Therefore, and considering that the climate of the GDL is considered temperate, with an average temperature of 19.2 degrees Celsius [16] (conducive to riding a bicycle), it is possible to substitute some short transfers in public transport and cars Private for bicycle transfers.

The simulation contemplates three different scenarios. The first scenario shows the current situation of mobility in the city. The second scenario shows how city mobility behaves, moving 25% of citizens who use the bus towards mobility by bicycle. Furthermore, the third scenario is moving 25% of citizens who use the bus and 10% of citizens who use particular vehicles towards mobility by bicycle.

A. Simulation

A deployed simulation on the NETLOGO platform used a multi-agent system in its version 6.1 [14]. We extended the "traffic 2 Lanes" model for the development of the simulation [15]. New agents, a bike path, and new properties to monitor in the simulation were added, such as the carbon footprint emission of each vehicle.

In the simulation, we represent a two-lane street and a bike path where cyclists and vehicles transit in the same direction (from left to right in the graphic interface). Despite the platform was adapted to can simulate streets of 1 to 4 lines, this work focuses on representing two-lines street being the most common infrastructure in GDL. Cyclists and vehicles are moving in a cyclic space and always are visible in the graphic interface of the simulation.

Agents will represent the bus, private vehicles, and cyclists. In the simulation, the agents will have the behavior of traveling on the avenue for the bus and private vehicles. The behavior of cyclists will be to travel on the bike path. Motorcycles were represented as a private vehicle since, for the simulation, they require the same space as a car. The following are the types of agents that the simulation has:

1. The bus unit agent can transport from 1 to 40 passengers.
2. The black car agent can transport one passenger. This agent represents a particular vehicle, including cars and motorcycles.
3. The yellow car agent can transport one passenger. This agent represents taxi mobility in the city.
4. The blue car agent can transport two passengers.
5. The cyclist agent can transport one passenger.

The simulation contains 90 passengers. They represent 90% of the mobility in the GDL because this simulation does not contemplate the other preferred mobilities, as shown in figure1.

Both the agents representing the vehicles and those representing the cyclists have a series of properties and behaviors in stock but with different parameters. For example, both cyclists and vehicles can advance, accelerate, and brake. However, the maximum speed that a vehicle can take for the simulation is 50 km per hour, while that for cyclists is 20 km per hour. We integrated a function for Co2 production in vehicles in order to monitor air quality (2.3 kg of co2 per liter of gasoline [17]).

For each scenario, in the setup, we randomly create both vehicles and cyclists in the available space of the avenue and the bike path. Also, each vehicle and cyclist starts with an aleatory velocity. When a cyclist or a vehicle has a free space in the line, it tries to get its maxima velocity. On the other hand, when a cyclist or a vehicle has another agent in front, it brakes. The only extra capacity that vehicles have over cyclists is that cars can change lanes if they detect a space where they can increase their speed in another lane of the avenue.

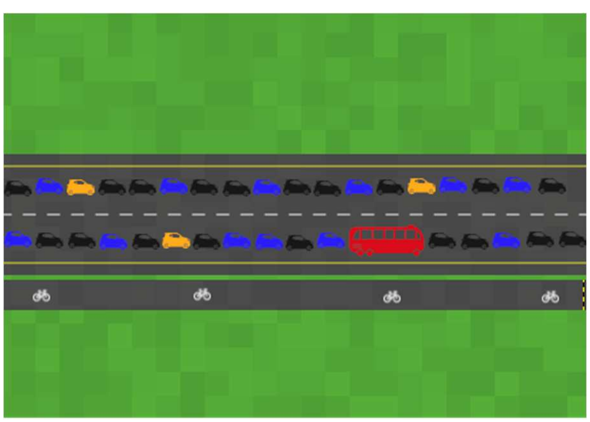

Figure 4. First scenarios, the actual state of GDL

The dynamics of the simulation add and remove cyclists from the bike path. Also, the platform adds and removes different types of vehicles to the avenue and adds and removes the number of passengers from the buses. The simulation tries to reach a balance between passengers and vehicles. The simulation always has to have 90 passengers in different scenarios.

In the initial state (first scenario), the simulation contains four cyclists, one bus unit with 40 passengers, three yellow cars, 12 blue cars and, 19 black cars (90 passengers).

In this first scenario, there is a 0% healthy distance to avoid COVID-19 infections in public transport.

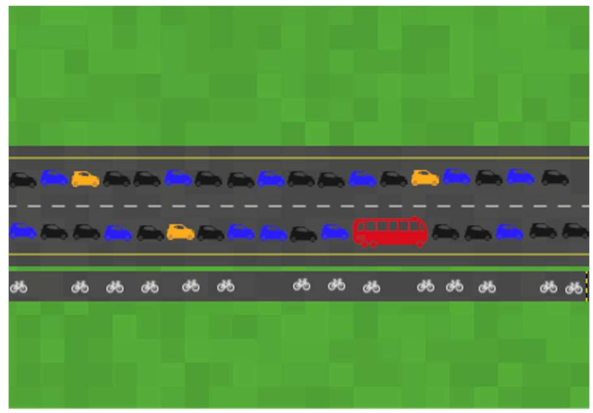

Figure 5. Second scenario, moving the 25% of passengers from the bus to the bike path.

In the second scenario, the simulation contains 14 cyclists, one bus unit with 30 passengers, three yellow cars, 12 blue cars, and 19 black cars (90 passengers).

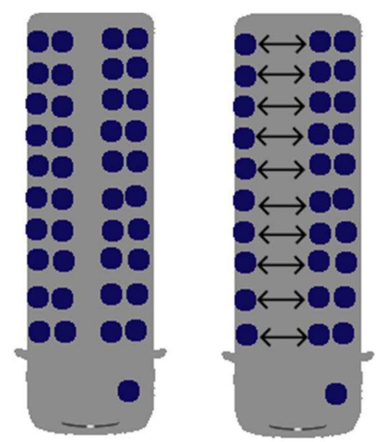

Figure 6. Simulation after moving the 25% of passengers from the bus unit to the bike path.

If we shift 25% of the passengers riding a bus with 100% of seat capacity to the bike path, the number of cyclists increases by 10%. In this way, we ensure the correct distance of 10 passengers from the bus unit (see in figure 6) and the ten passengers who changed from the bus unit to the bike path. These 20 passengers assured with proper distance represent approximately 47% of the people who travel by public transport.

In the third scenario, by moving 25% of passengers riding a bus with the 100% passenger capacity to the bike path and 10% of passengers from particular vehicles to the bike path, the number of cyclists increases by 14%. The simulation leaves a total of 18% of cyclist mobility in the third scenario.

In the same way, as in scenario two, we guarantee a healthy distance of 47% of people traveling by public transport. However, the change of only 10% of passengers from private vehicles to the bike path caused changes in speed average in which vehicles move and in air quality. Table 2 shows the characteristics of average vehicle speed, the average speed of cyclists, and the carbon footprint in each of the scenarios after 1000 ticks of time in the simulations.

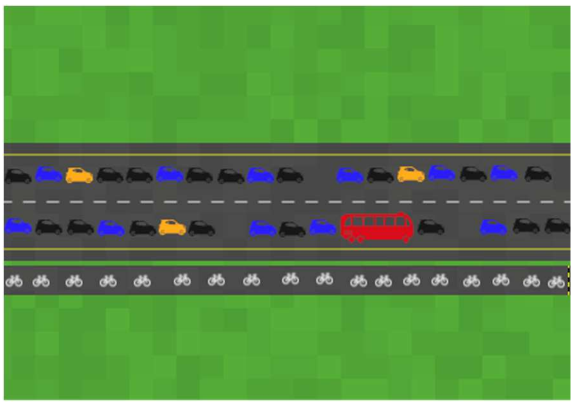

Figure 4. Simulation after moving the 25% of passengers from the bus unit and, 10% of passengers from particular vehicles to the bike path (third scenario).

TABLE II. METRICS OF THE THREE SCENARIOS

SCENARIOS OF SIMULATION			
characteristic	***Scenario 1***	***Scenario 2***	***Scenario 3***
Average vehicle speed	8-23 k/h	8-23 k/h	13-28 k/h
Average Cyclist speed	20 k/h	20 k/h	20k/h
Carbon footprint per liter of gasoline	80.5 kg	80.5 kg	73.6 kg
Healthy distance	0%	47%	47%

V. RESULTS ANALYSIS

In the proposal, switching 25% of people who travel by bus unit to a bicycle route only ensures a correct distance to 47% of citizens who travel by public transport. However, if we play with the frequency of bus units to move fewer passengers, the percentage of risk infection may decrease. For example, under the second and third scenarios, if the frequency of public transport were increased by 30%, the correct distance would be ensured for approximately 94% of the people who use public transport.

For each passenger that we move from the bus to the bike path, this simulation ensures the correct distancing for two passengers (the passenger moved to the bike path and one passenger on the bus). Moving 20 or more passengers from the bus to the bike path, we ensure the correct distancing of the total number of the passenger capacity of the bus can transport in the simulation.

In the simulation, when moving passengers from private vehicles to the bike path, the number of cars decreases, the avenue gains space, and the traffic flow decreases. Table 2 shows that the range of average speed with which vehicles move increases by 5 kilometers per hour approximately. Figures 8, 9, and 10 show the comparison of the average speed of the vehicles between the second and third scenarios. At the same time, by decreasing the number of vehicles, the air quality improves.

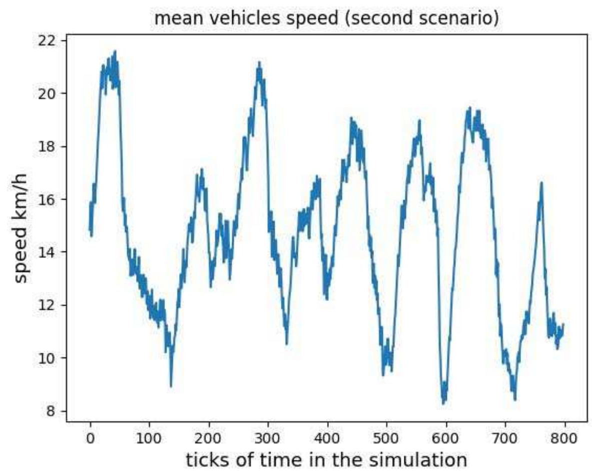

Figure 8. Mean vehicles speed (second scenario).

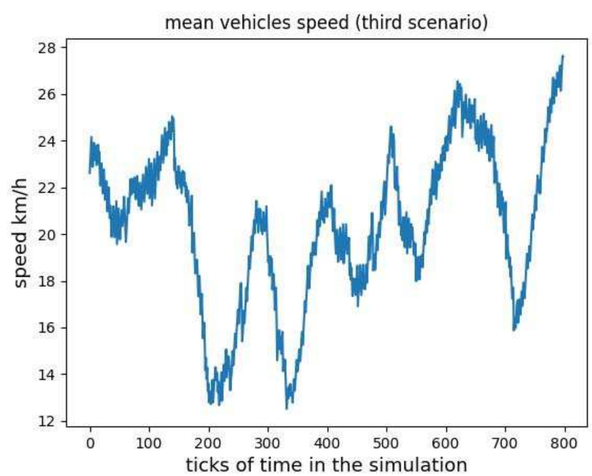

Figure 9. Mean vehicles speed (third scenario).

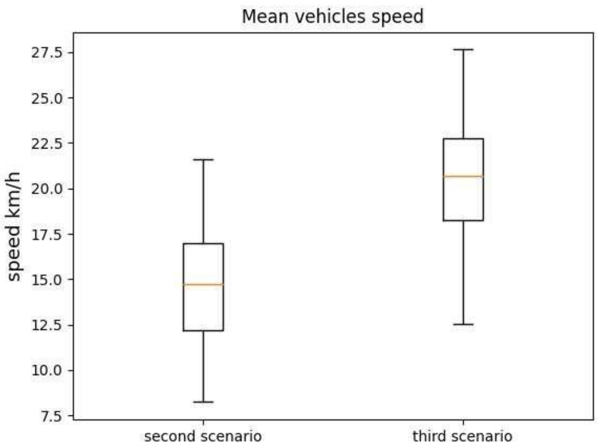

Figure 10. Box plot of mean vehicle speed (second and third scenarios).

The bicycle mobility strategy presented in this article focuses on switching the short transfers that are carried out both in public transport and in private vehicles to bicycle mobility. In addition to helping to maintain the WHO recommended distance to avoid COVID-19 infections and decrease traffic on avenues, we find three more benefits in the statistics of the sources consulted. Traveling by bus is approximately one minute faster per kilometer than traveling by bicycle. However, the bike does not have a waiting time, so in short transfers, bicycle mobility is faster. Besides, citizens obtain a tremendous economic benefit by using bicycle mobility for short trips—a bus ticket in the GDL costs around 9.50 Mexican pesos.

In comparison, an annual subscription to the "MiBici" bicycle mobility program costs 416 Mexican pesos a year, a subscription that has unlimited trips of up to 30 minutes (ideal for short trips) [9]. This trip behavior means that one trip per day has a cost of 1.13 Mexican pesos in the MiBici program. A difference of more than 8 Mexican pesos per trip. In Mexico, public transportation belongs to the private industry. In public bus transport, citizens have to pay a ticket for each transfer, unlike bicycle transport, where citizens can make an unlimited number of trips of up to 30 minutes.

The simulation shows that decreasing the number of vehicles, air quality improves.

The analysis shows that the MiBici program can, by replacing short transfers between means of transport, become a "smart bike-sharing systems," where the system "provides the missing link between existing points of public transportation and desired destinations, offering a new form of mobility that complements the existing public transport systems" [11]

An incentive system is supporting this proposal with a mobile application based on the Internet of the People (IoP). The application detects when a citizen is traveling by bicycle and gives the citizen electronic money. This electronic currency is valid in exchange for products or services in the local economy. Hence, the use of bicycles is encouraged with a positive impact on the local economy of GDL.

On the other hand, the mobile application informs citizens of the good it produces for the environment by traveling by bicycle, by reducing the pollution produced by the carbon footprint released by vehicles powered by fossil fuels. Also, the mobile platform allows people with related interests to interact face to face and provides advice to local businesses.

VI. LIMITATIONS FOR THE SIMULATION AND SCALING THE PROJECT

In the simulation presented, it was possible to observe the opportunity to change the short trips from bus unit or private car to mobility in a bicycle. However, the simulation works with percentages and estimates without having the exact figures. Although GDL has cycling infrastructure, not all of its neighborhoods have a bike path. For this reason, the immediate future work is to transfer this simulation to a polygon in GDL. The Polygon of the city that has cycling infrastructure and an essential flow of public transport (bus, train), is located in the municipality of Zapopan near our University Campus. Also, in this future simulation, we will apply the model simulation of Montecarlo to get more exact results. Figure 11 illustrates a heat map of users from a shared urban study from the mobility direction.

The "NetLogo" platform used gives us the possibility to scale the simulation to a polygon in GDL without requiring supercomputing capabilities.

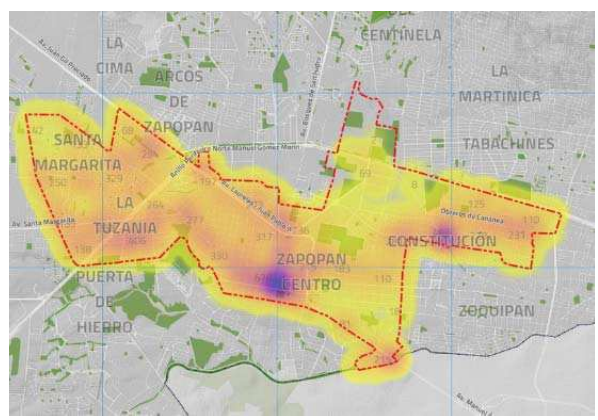

Figure 11. Polygon of the Guadalajara metropolitan area to expand the simulation where the heat map represents potential bicycle demand and dashed lines means existent bicycle lanes as infrastructure.

A. How to use the simulation model of this work in other cities?

With the analysis of the mobility of one city or avenue, the detailed understanding of how the citizens use the system public transport, and the existence of the bike path infrastructure, it is possible to replicate this work using the model developed. The model able to run in the NetLogo platform is in a GitHub repository, and interested cities can under request contact any of the authors of this article to have access. Make sure to change the typical characteristics of the region, like the velocity of the vehicles and cyclists, the number of passengers per bus, number of vehicles from 1 and 2 passengers, number of taxis, and number of cyclists, among other things. Figures 12 shows the steps to follow to use the model simulation in other cities.

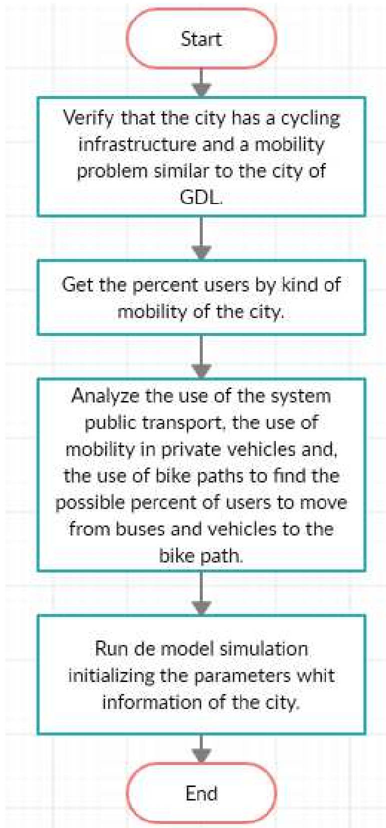

Figure 12. Steps to follow to use the model simulation with other cities.

VII. Concluding Remarks and Works in Progress

In the simulation, switching the 25% of citizens who travel by public transport to a bicycle route achieves 47% effectiveness in the corresponding distance recommended by the WHO to avoid COVID-19 infections. This metric improves if we combine this proposal is with others, such as the increase in the frequency of public transport. The information shows that this 25% destined to migrate from public transport to a bicycle route is eligible from the number of short transfers that citizens of GDL make during a trip because 69% of citizens take two or more means of transport to move 8.52 km.

Switching short trips by bus or private car can be the premise to start with clean mobility in GDL. On top of that, short transfers proved to be faster and much cheaper than transfers made on a bus, in addition to offering other benefits, such as reducing the carbon footprint and physical strengthening. Not least, the simulation showed that using the bicycle instead of the private car as a means of transportation reduces the flow of traffic on the avenues. As ongoing works, we are doing a collaborative project with international partners (DOMILA LTD) to develop the concept of the Internet of People integrating a social coin earned when the people use public transport. Where this project is deployment, the social coin earned will help local commerce and business to get visible and local citizens to have a healthy lifestyle if they decide to move using the bicycle infrastructure. The "IoP Jalisco platform," as is named, can provide the data of trips of users every minute, helping to grow the possibilities of the digital simulation we present in this work. The platform allows creating polygons or specific cycle lanes to incentivize with the social coin and to fix the rewardable to be exchanged by products and services in GDL. Figure 13 shows an example of moving and earning with the IoP Jalisco Mobile App and the digital platform for setting the polygons of mobility.

Figure 13. Incentive system of the IoP Jalisco mobile app and digital platform to reward citizens with a social coin every kilometer they use the bicycle in specific polygons of the city.

Acknowledgments

We appreciate the support of the municipality of Zapopan in GDL for the urban study developed by Miriam Y. Lejeune under the direction of Carlos Lopez-Zaragoza and its mobility staff. We also acknowledge the Smart Cities Innovation Center and the Ph.D. in Information Technologies for their support at the University of Guadalajara as well as the Mexican national research council CONACYT for the Scholarships of the Ph.D. Students involved in this work.

References

[1] WHO. HealthyAtHome - Physical activity. https://www.who.int/news-room/campaigns/connecting-the-world-to-combat-coronavirus/healthyathome/healthyathome---physical-activity. Accessed May 30, 2020.

[2] WHO. Coronavirus disease (COVID-19) advice for the public. https://www.who.int/es/emergencies/diseases/novel-coronavirus-2019/advice-for-public. Accedido el 30 mayo 2020

[3] HONEY-ROSES, Jordi, et al. The impact of COVID-19 on public space: a review of the emerging questions. 2020.

[4] Gobienno de Zapopan. Presenta Pablo Lemus estrategia de ciclovías emergentes en sesión de Junta de Coordinación Metropolitana. https://www.Guadalajara.gob.mx/v3/noticias/presenta-pablo-lemus-estrategia-de-ciclovias-emergentes-en-sesion-de-junta-de-coordinacion. Accessed May 30, 2020.

[5] Moovit. Facts and usage statistics about public transport in Guadalajara, México.

https://moovitapp.com/insights/es/Moovit_Insights_%C3%8Dndice_de_Transporte_P%C3%BAblico_M%C3%A9xico_Guadalajara-2900. Accessed May 30, 2020.

[6] Jalisco Cómo Vamos. Sexta encuesta de percepción ciudadana sobre la calidad de vida 2018 . (2019). https://drive.google.com/file/d/1MOChrisac4jzw97tzK44ZIFrEWLC1-6R/view. Accessed May 30, 2020

[7] Instituto de Información Estadística y Geográfica de Jalisco.Uso del medio de transporte MiBici, enero a octubre del 2019. (2019). https://iieg.gob.mx/ns/wp-content/uploads/2019/11/MiBici19_1_rev.pdf. Accessed May 30, 2020.

[8] MiBici. Datos abiertos. Explora, experimenta y comparte los datos de uso de MIBICI. https://www.mibici.net/es/datos-abiertos/. Accesed May 30, 2020

[9] Mibici. Tarifas. Conoce las diferentes opciones para acceder a MIBICI y elige la que más te convenga. https://www.mibici.net/es/tarifas/ . Accessed May 30, 2020

[10] WILD, Kirsty; WOODWARD, Alistair. Why are cyclists the happiest commuters? Health, pleasure, and the e-bike. Journal of Transport & Health, 2019, vol. 14, p. 100569. MIDGLEY, Peter. The role of smart bike-sharing systems in urban mobility. Journeys, 2009, vol. 2, no, 1, p. 23-31.

[11] MITTON, Nathalie; RIVANO, Hervé. On the use of city bikes to make the city even smarter. 2014 International Conference on Smart Computing Workshops. IEEE, 2014. p. 3-8.

[12] TOMLINSON, David. The Bicycle and Urban Sustainability. 2001.

[13] UDGTV. Más de 100 km de ciclovías en Guadalajara, motivo para "celebrar" en el Día Mundial de la Bicicleta. http://udgtv.com/noticias/mas-100-km-ciclovias-guadalajara-celebrar-dia-mundial-bicicleta/#:~:text=Guadalajara%2C%20Jalisco.,del%20colectivo%20GDL%20en%20Bici. Accessed on may 30, 2020.

[14] Wilensky, U. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. 1999.

[15] Wilensky, U. & Payette, N. NetLogo Traffic 2 Lanes model. http://ccl.northwestern.edu/netlogo/models/Traffic2Lanes. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. 1998.

[16] Cordinación de Internacionalizacion. Universidad de Guadalajara. Vivir en Guadalajara. http://www.cgci.udg.mx/es/estudiantes/externos/llegada_mx/vivir. accessed May 30, 2020.

[17] Microsiervos. ¿Qué es la emisión de CO2 por kilómetro recorrido? (gCO2/km). https://www.microsiervos.com/archivo/ecologia/que-es-emision-co2-kilometro-recorrido.html. Accessed May 30, 2020.

[18] Mobility Department Zapopan, Urban Mobility Study of Zapopan Polygon for IoP Bicycle Riding and Attraction Zones, February 2020, Internal Report, February 2020