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Improving Fairness and Equity by Minimizing Community Vulnerability to Food Accessibility - A Computational Urbanism Approach

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Improving Fairness and Equity by Minimizing Community Vulnerability to Food Accessibility - A Computational Urbanism Approach

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***Keywords*—** spatial equity, computational urbanism, optimization, vulnerability; food accessibility.

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Abstract

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1 Introduction

Since the 1990ties, planning of services is being assessed in the context of spatial justice defined by Smith [45] as providing equal distribution of a resource or a service in relation to distance. Access to services in cities, especially in terms of walkable proximity, has been accepted as an integral component of a good urban practice [19, 35] and sustainable urban planning [7]. The evaluation of access is particularly significant considering vulnerable populations who depend on non-motorized transport to reach services, e.g., the elderly, children, permanently or temporarily disabled and the poor [46]. It has been argued that spatial equity or the consideration of vulnerable group´s proximity and access to a service, as well as the capacity of service in relation to demand, should be integrated in service location planning [48, 37]. The crucial difference between justice and equity lies in understanding the need of vulnerable groups to receive disproportionately more benefits, also known as ¨compensatory¨ equity [12]. Therefore, the term spatial equity is related to the spatial match between the facility´s location and service level and distribution of vulnerable population [51]. Yet, few studies discuss spatial equity of services and vulnerability even though these are key aspects of sustainable development [36]. Moreover, there is no clear or unified method to measure spatial equity in literature [49].

Computational urbanism defined herein as: the process of systematically classifying and quantifying data to develop computational techniques for the improvement of urban areas and the interaction of inhabitants with the built environment - can provide smart city planning and governance of services since it can process and analyze large amount of data available from different platforms [30]. A computational framework for location planning of services that links community vulnerability assessment with optimization could be a powerful tool to improve spatial equity in cities. One of the most challenging aspects however, is to incorporate the human and political aspect of data - the vulnerability measure - in the quantitative analysis [32]. To fill this gap, in this work we explore community vulnerability as a function of the access to a service by integrating the assessment into a location optimization problem that then allows to improve spatial equity. We collected the location of service as points of interest (POI) - a specific point location defined by geographical coordinates that is of potential interest for most citizens -, assessed the vulnerability of each area in walkable proximity to POIs and developed optimization for prospective planning of that service. We argue that this new computational framework can uncover social disparities within an urban area based on the distance to different points of interest as a proxy and provide an approach for 1) future equitable planning of service or 2) improving the current plan of a service. The main contribution of such a framework is to provide data-based decision support for sustainable urban planning by identifying new services-location based on vulnerability.

One of the most attractive POI in urban areas is the food market. Traditional food markets have been key development poles of our cities, in both economic and social sense [25]. They are not only a place for food retail but also a place of encounter, enjoyment and socio-cultural recreation that makes them the heart of a neighborhood [4]. The traditional street market is an open or partially open commercial complex with vending stalls (fixed or movable) organized in rows. They are a common retail space in neighborhoods from Latin America to southeast Asia that offers affordable access to local, fresh, and healthy foods [53]. They have been found to create ¨freshness through their sensoria, atmosphere, and trust between food vendors and consumers¨ [53] as a key attraction point that lacks in supermarkets. Even in large cities, such as Mexico City, Taipei, and Singapore, they are a common urban element. In the US, a comparison can be drawn to farmers' markets, although those markets have higher prices compared to supermarket food and are usually not present in under-served neighborhoods [28].

In Mexico, the tianguis – traditional produce markets on wheels – persisted from pre-Hispanic times until today [29]. They have resisted the global ¨retail revolution¨ that predicted the rapid decline of small-scale retail shops and traditional markets in favor of supermarket chains [53]. Since the tianguis are not fixed features - they can be installed almost anywhere in a short period of time - they have a significant adaptive and resilient value crucial for increasingly uncertain times. In Mexico, most urban residents, and especially lower and middle-classes, still acquire fresh foods from these street markets that pop-up once or twice a week. Therefore, in this study we use supermarkets and tianguis as our POIs to evaluate the fairness and equity in their spatial distribution and perform optimization of the location problem. In specific, we focused on the case of Atizapan de Zaragoza in the metropolitan periphery of Mexico City. The reason for choosing this peripheral municipality came from previous research that found structural disadvantages of periurban areas in Mexico in access to unprocessed foods [26]. Such disadvantages are linked with fewer outlets in periurban zones, long commuting distances and more pronounced socio-spatial fragmentation.

This paper has four additional sections. In section 2 we review previous research on food access in cities, vulnerability measures, and computational approaches to measure proximity and access, ending with a description of the case study we are focusing on in this work. Section 3 describes the methodology and data. Section 4 presents and discusses the results of the analysis of current conditions and the optimal location of tianguis based on suggested vulnerability metrics. Finally, section 5 provides concluding remarks and future work that should be explored.

2 Literature Review and Background

The global trend of increasing overweight and obesity in the population, resulting from an upsurge in processed food intake and the reduction of physical activities, has had a terrible impact on urban health [39]. Obesity and overweight are leading causes of several other preventable and non-communicable diseases, such as diabetes [14], hypertension [42], and depression [40]. In Mexico, the age-standardized mean for girls' body mass index (BMI) from 1975 to 2016 was almost four times higher than in other parts of the world [2]. A recent study by Jiménez-Aguilar et.al. [23] confirmed that the General Guidelines for Dispensing or Distribution of Foods and Beverages at School Food Establishments (SFEs) in Elementary Schools in Mexico enacted in 2010 did not fulfill the objective of stopping the epidemic of obesity. The percentage of vegetables, fruits, and plain water accounted for less than 7 percent of foods and drinks offered in schools.

There is mounting evidence that the neighborhood food environment, understood as "the interface that mediates one's food acquisition and consumption with the wider food system" [21], strongly influences dietary behavior and obesity [31][11][15]. Even though previous studies explore programmatic and policy measures to face the global obesity crisis [43][52][27], very few look at access to unprocessed foods in the neighborhood environment - such as vegetables, fruits, and seeds - as one of the essential factors that shape decisions about food acquisition and consumption [41]. Recently, two studies that looked at access to food in Mexico were published in the scientific literature. The study by Pineda et al (2021) associated the density of retail food environment and BMI in Mexico [38]. The study found that convenience stores that do not have a variety of unprocessed foods were the most accessible food outlets, especially in second lowest, middle, and second highest-income households. On the other hand, Reyes-Puente et al. [41] analyzed the physical and financial access to food in the Metropolitan Area of the Valley of Mexico (MAVM) between 2010 and 2020. In the study, physical access was calculated as a network distance to retail units and financial access through socioeconomic status at the block scale. The study found overall low access to food in the metropolitan area, especially in peripheral zones, related to the proliferation of convenience stores that have replaced grocery stores.

Previous studies mentioned above focus on the retail food environment composed of fixed markets, convenience stores, and grocery stores, not including the famous market-on-wheels or ¨tianguis¨ - a common source of fresh, unprocessed and often locally-grown and sourced food products for the residents of the country's urban areas. A possible explanation for not including the tianguis in assessing food access in previous studies is the lack of reliable and georeferenced databases on their locations. Nevertheless, the tianguis is such a common food outlet in Mexican cities that not including them in the assessment of food access can put in doubt the results of such studies. For example, in Mexico City - the only city in Mexico that has published a georeferenced database of tianguis in its territory - there are 1,367 tianguis (1 per 6,737 people), while in Guadalajara, there are 450 tianguis (1 per 3,079 people). Unlike supermarkets or convenience stores where the percent of unprocessed food offered can be from 6 to 10 percent of all products [17], in most Mexican cities (except Monterrey, to our knowledge), at least 40 percent of all the stalls in the tianguis offer unprocessed fresh food. Through a field survey with students in 2022, we found that in Guadalajara and Mexico City, up to 60 percent of the stalls offered fresh foods making a significant contribution to the community's access to nutrients not considered by previous studies.

The unfair and inequitable development of food environments in cities is not a natural phenomenon but the result of social action, planning, and public policies. The growing research focused on the relationship between food environments and health attests that urban and social environments, and the lifestyles they promote, generate differences in health outcomes. Long commutes and decreased walkable access to food outlets can encourage eating away from home and consuming processed and easy-to-prepare meals. Therefore, citizens who live in areas lacking walkable/safe/comfortable access to food outlets face inherent structural disadvantages that make them more vulnerable to consuming highly processed and easily prepared foods [24]. These dwellers are not always the poorest, but also older adults, children, and people with reduced mobility. Thus, there is a need for a data-driven approach to assess fairness and equity in food accessibility to formal and informal outlets and minimize vulnerability by optimization. The purpose of this approach is to set the base for planning and public policy aimed at improving the food security and nutritional health of the population in urban areas.

Another interesting point to address is the relevance of community resilience while facing any crisis. A community with social inequalities, such as an urban area with food accessibility dissimilarities, directly affects a reduction in social cohesion. Social cohesion is the glue that holds a society together [1] and it is considered a relevant factor in improving a community's capacity to face adversities, such as natural disasters [3]. Gongora-Svartzman et al. [16] explained how social cohesion improves the recovery time after a disaster by reducing the vulnerabilities within a community.

In this study, we focus on assessing accessibility to POI locations comprising supermarkets and tianguis. In recent years, POIs have been used increasingly in computational urbanism to evaluate urban functional areas [13][22][33][47], land use change [50] or accessibility to urban amenities [54]. However, no studies to our knowledge use the assessment of access to POIs for optimization of location planning to reduce vulnerability. The assessment of who is vulnerable in terms of proximity to a certain service can be performed by Euclidean straight line, Manhattan distance, or street network analysis [54][24]. The method for measuring the distance from individual houses or blocks to POIs today is commonly performed by using the shortest routes in a street network analysis. Mora-Garcia et al. [34], and Comber et al. [9] both argue that network analysis is better at measuring real distance since it accounts for actual access routes and barriers. Measuring distances between two points by walking is considered an accurate option for comparison since fewer factors could interfere. A similar case to our problem is presented by Bonnet et al. [6] who chose route-based walking distances to determine the nearest medical device available from demand points.

Once the measurement of distances has been addressed, the problem of choosing the optimal location for some type of facilities, such as fresh food suppliers, arises based on the minimum travel distance to demand centers, in this case blocks. The Uncapacited Facility Location Problem solves an NP-hard problem minimizing the overall distance by choosing a subset of facilities, not considering their service capacity, and assigning one to each demand center [44]. UFLP has been used in different studies to allocate various facilities under other circumstances, [18]. Hernandez et al. [20] used UFLP to understand system vulnerabilities with possible failures in a system with allocated facilities and not requiring failure probabilities.

2.1 Case Study

The municipality of Atizapán de Zaragoza is in the northern periphery of the Mexico City Metropolitan – some 23 km from the Mexico City´s historic center. The municipality started to consolidate in the late 1950s as an industrial center and high-income housing suburb. By the 1970s and 1980s, the urban growth of the municipality had increased significantly transforming some towns into new urban settlements. This situation generated a lack of urban structure to ensure the efficient functioning of the area. By 2000, the municipality already had a consolidated urban structure and, although there were inefficiencies, it contained homogeneous areas with housing, commerce, and services. In 2020, there were 523,674 people living in Atizapan, with an average urban density of 5,750 people/km^2. Even though the municipality is indexed to have low marginalization, the disaggregated data by neighborhoods show that there are significant pockets of medium and high marginalization in the northeast.

3 Methodology

To address the problem of spatial equity we have developed a framework consisting of three main components: data collection and cleaning; measurement of the actual distances between blocks and different food outlets; and finally, the analysis of the results, which was divided into two parts: the analysis of existing conditions, and the analysis of optimal locations for food outlets. Each phase is explained in detail in Figure 1 and in the following subsections. Briefly, the proposed framework generates a vulnerability assessment for a geographical area in a three phase process as follows: In the data collection phase the first step is to identify the POI within the geographical area of intent (in our case study: food distribution outlets in the municipality of Atizapan de Zaragoza). Once the POI have been included, the population of the location by block is obtained along with other potential socio-economic metrics for example marginalization. The data is then used in phase 2 to identify the minimum walking distance and route from the center of each block to the nearest POI. This phase allows to quantify the "status quo"' in the geographical distribution of POI. Also, in phase three, to identify vulnerabilities we implement a facility location optimization including each potential POI and compare optimal placement versus status quo in the form of two metrics.

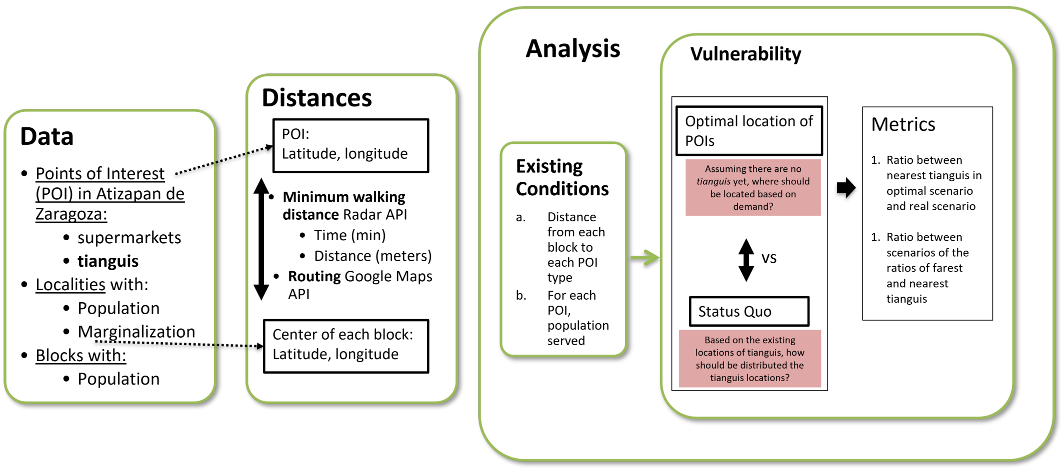

Figure 1: Framework proposed for the problem

3.1 Phase 1: Data Collection

The data required for the proposed framework are the location of points of interest, which in this case are food outlets (tianguis and supermarkets); information regarding the geographical boundaries and population for localities and blocks within the municipality of Atizapan de Zaragoza.

The geographical coordinates of the POI in this study were obtained partially from open government databases and partially by fieldwork. The locations of fixed markets were obtained from the National Statistical Directory of Economic Units (acronym in Spanish: DENUE from Directorio Estadístico Nacional de Unidades Económicas) available from the National Institute of Statistics and Geography of Mexico (INEGI). We found 26 supermarkets for our case study - the municipality of Atizapan de Zaragoza. The locations of street markets or tianguis for the municipality of Atizapan were obtained by students´ fieldwork. Even though the municipality has a directory of addresses of tianguis, they are not georeferenced. Thus, with the help of 4 students, each address was verified via fieldwork and Google Maps and then georeferenced. We discarded tianguis with less than 10 stalls since those markets do not provide sufficient variety of products to be considered POI. In total, we found 46 tianguis in the municipality of Atizapan.

The borders of each locality or Basic Geostatistical Area (AGEB in Spanish) were obtained as shapefiles from the National Institute of Statistics and Geography of Mexico (INEGI). INEGI conducted a census in 2020 which was used to acquire the population of each AGEB and each urban block. In fact, to calculate more accurately the demand on each tianguis or supermarket we used an aggregate population by blocks closest to that specific market. The data is open and accessible on INEGI´s webpage under the name Cartografía Geoestadística Urbana y Rural Amanzanada (CGURA).

Finally, data on marginalization was obtained from the National Population Council of Mexico or CONAPO (Consejo Nacional de Población). CONAPO calculates the index of marginalization as an integral measurement of 8 other indices: Percentage of population aged 15 or over that is illiterate, percentage of population aged 15 or over without elementary school, percentage of occupants in private homes without drainage or toilet, percentage of occupants in private homes without electricity, percentage of occupants in private homes without piped water, percentage of private homes with some level of overcrowding, percentage of occupants in private homes with dirt floor, and percentage of the employed population with incomes of up to two minimum wages. The data is available at the state, municipal and AGEB scale. For our research we used the marginalization at the AGEB scale calculated based on the 2020 census data.

Figure 2 shows two maps displaying the population considered for the problem by block and the marginalization exiting in each locality.

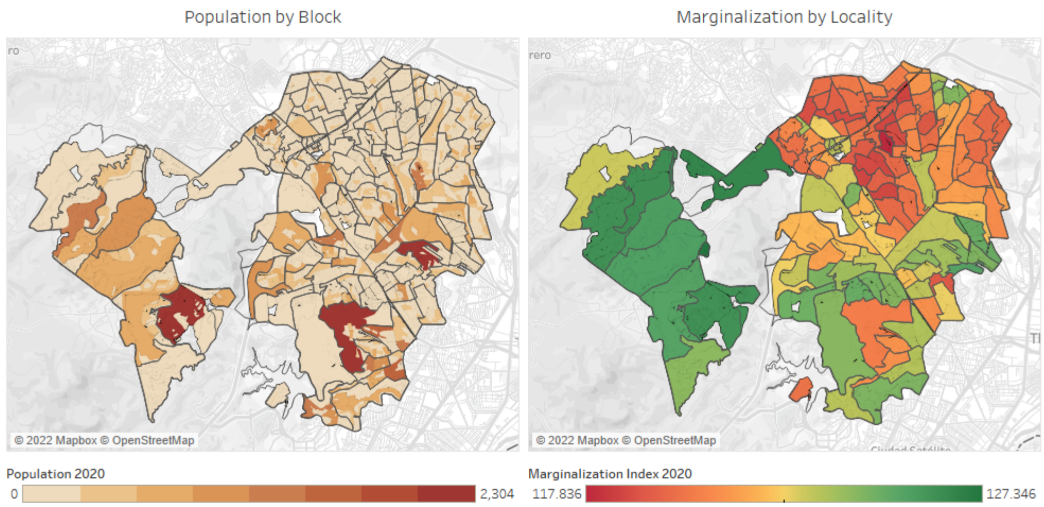

Figure 2: Population by urban block and marginalization by locality (AGEB), INEGI 2020

3.2 Phase 2: Distance Measurements

To address the stated problem, the distances from each block to each POI are required. The distances are necessary to identify the nearest POI to each of the blocks in Atizapan. The considered blocks for this study are those with a population on the INEGI data of 2020. The most accessible approach for measurement is using linear and geodesic distances, but these are not realistic measures. Therefore, a better approach is to consider a routing API that provides information regarding walking distance between two points, considering the real street network. Specifically, we used walking distance instead of any other transportation mode since vulnerability is related to mobility (as explained in section 2) and to avoid considerations such as traffic.

Different application programming interfaces provide information related to accurate distances between two geographical points, such as Places API from Google Maps and Radar Places API; in our framework, Radar was chosen because of the large number of requests allowed.

The input data consists of two geographical coordinates required to calculate a distance and a travel mode, which is "foot" for walking distances. Then, the output consists of distances in meters and travel times in minutes. Given 4,134 blocks, 46 tianguis, and 26 supermarkets, we needed to compute a total of 297,648 requests. The results were sorted from small to large, giving each block a list of the nearest POI. Figure 3 displays an example of the shortest route between two locations in Atizapan which has a walking distance of 9,191 meters or 7,029 seconds (almost two hours).

3.3 Phase 3: Analysis

The last phase of the framework consist of two parts:

1. An analysis of the existing conditions based on the distances from each block to the nearest food supplier (POI) and the total population served by each POI based on the proximity.
2. A vulnerability analysis implementing the Uncapacitated Facility Location Problem (UFLP) to identify the optimal location of a fresh food supplier.

3.3.1 Uncapacitated Facility Location Problem

The Uncapacitated Facility Location Problem finds an optimal subset of facility locations by minimizing the total distance and demand from population centers to demand centers. In this case, the demand centers are the blocks, and the facility locations are the tianguis or another fresh food supplier. The original formulation also

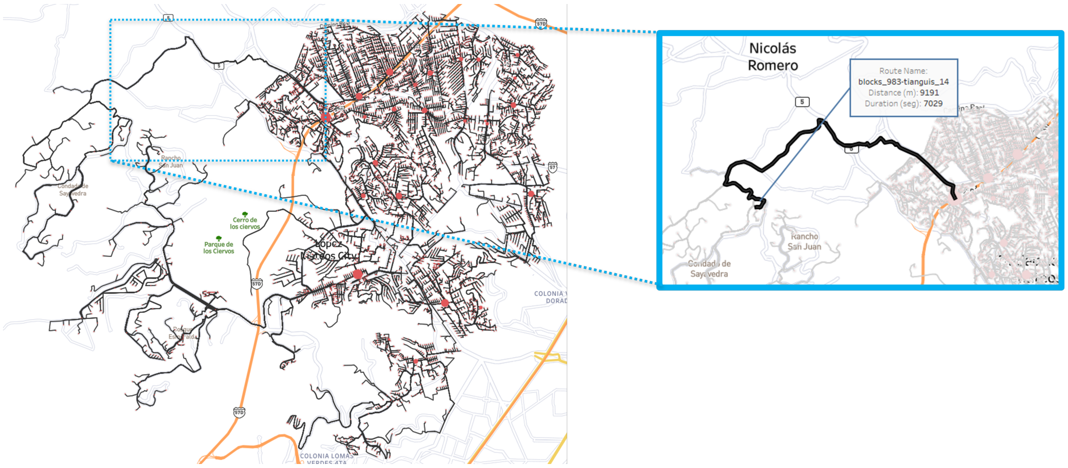

Figure 3: Routing example with Radar and Google Maps data

considers the cost of building a facility, which is unnecessary for this study since the tianguis are temporary fixtures that can be set in almost any street.

The original formualation of UFLP is [44]:

$$
\begin{aligned}
\underset{yx}{\text{minimize}} \quad & \sum_{i \in F} f_i y_i + \sum_{i \in F} \sum_{j \in D} d_j c_{ij} x_{ij} \\
\text{subject to} \quad & \sum_{i \in F} x_{ij} = 1, for\ each\ j \in D \\
& x_{ij} \leq y_i, \quad for\ each\ j \in D \\
& x_{ij} \in \{0,1\}, \quad for\ each\ i \in F,\ j \in D \\
& y_i \in \{0,1\}, \quad for\ each\ i \in F
\end{aligned}
$$

Our framework considers two data sets which are F the candidate tianguis and D the demand centers which in this case are the blocks. The objective function has the sum of set up cost and the assignment cost. The set up cost, f_{i} y_{i}, consists of the cost of building f_{i} which in this case is 1, and the binary decision variable that indicates if a tianguis is open or not y_{i}. The assignment cost, d_{j} c_{ij} x_{ij}, consists of the population in each block j, the distance from tianguis$i$ to block j, and the binary decision variable that indicates if block j is assigned to tianguis i or not. The constraints limit the decision variable x_{ij} to have one assigned tianguis to each block, to assigned only open tianguis, and the last two constraints are related to the binary nature of decision variables. Considering the assumption that a tianguis can be set in any place, the set of candidate tianguis F was chosen to be 1 per each of the 135 localities in Atizapán resulting in a total of 135 candidate locations. To determine the exact location of a tianguis within a locality there were two rules followed for each locality:

1. If there is already a tianguis in that locality, that tianguis is set as location. In cases of having more than one tianguis by locality, it is chosen the most central tianguis.
2. If there is no existing tianguis in a locality, the location is established at the center of the most populated block.

3.3.2 Vulnerability Metrics

Since this work aims to improve access to fresh food with a redistribution of tianguis, a metric must be created and used to compare the optimal scenario we developed with the current scenario (the status quo).

For each block i, the metrics used are described as:

$$
\begin{aligned}
&\qquad \textbf{Vulnerability1}_{\mathrm{i}} = ratio_{a,i} - ratio_{b,i} \\
&\qquad \textbf{Vulnerability2}_{\mathrm{i}} = n_{a,i} - n_{b,i} \\
&Where: \\
&\qquad ratio_{k,i} = \frac{n_i}{f_i} \\
&\qquad a = optimal\ scenario \\
&\qquad b = real\ scenario \\
&\qquad n_i = Travel\ time\ to\ \textbf{nearest}\ tianguis \\
&\qquad f_i = Travel\ time\ to\ \textbf{farthest}\ tianguis
\end{aligned}
$$

The first metric, *Vulnerability1*, uses the difference of the ratio between the travel time to the nearest tianguis by the travel time to the farthest tianguis of each block. The second metric, *Vulnerability2*, is the difference between the travel time to the nearest tianguis in the optimal scenario minus the travel time to the nearest tianguis in the real scenario.

4 Results

4.1 Existing Conditions

Before analyzing and proposing an optimal location for tianguis, it is necessary to understand the current tianguis scenario in Atizapan to determine the possible inefficiencies in their locations that require improvement. As mentioned before, tianguis is a convenient and accessible fresh food outlet in Mexico that can easily move to almost any street. However, larger food markets are the first choice for many families as well. Therefore, to analyze the existing conditions, the location supermarkets was also considered for the analysis.

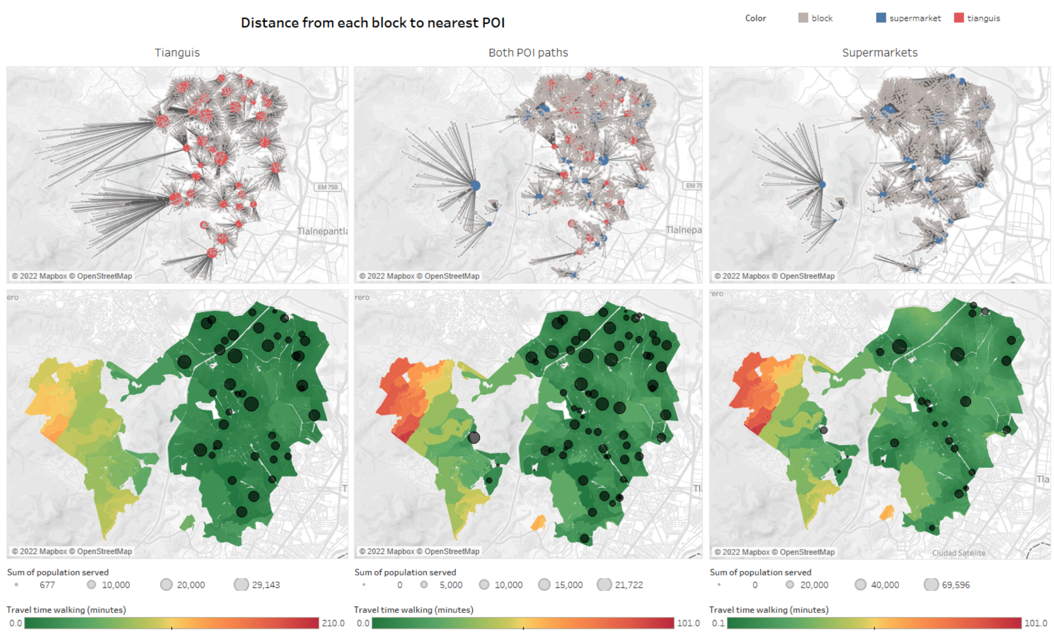

Figure 4: Distances comparison considering tianguis and supermarkets

Figure 4 shows each block's nearest option to a food retailer. The left-hand-side maps display the location of tianguis only; the right-hand-side maps consider the location of supermarkets only, and the central maps consider both food outlets (tianguis and supermarkets). For all these graphs, the size of the circles represents the total population served based on the food outlet assigned to each block. The top maps show which food outlet is assigned to each block while the bottom maps show the travel distance by each block to the nearest POI based on a color scale. For example, based on the maximum travel distance, it can be noticed that supermarkets are more accessible since the maximum travel time is 101 min while for the tianguis is 210 min.

Given that the distance from blocks to all POIs was calculated, Figure 5 shows the travel time distribution by considering disruptions to the first nearest food outlet and then to the second, third, and fourth closest

POI, which is distinguished with colors on the left charts. This is a valid consideration as it can identify food deserts in different point of a geographical area. So for example, failure of the closest tianguis would double the traveling time for almost all blocks. It can be seen that the changes in distance for the tianguis are similar but not for the supermarkets; by the fifth experiment, the distribution drastically changes showing some peaks on the right. On the right charts, it is easier to notice the differences from the experiment of the third nearest POI, which instead of having a right skew, tends to a no skew distribution.

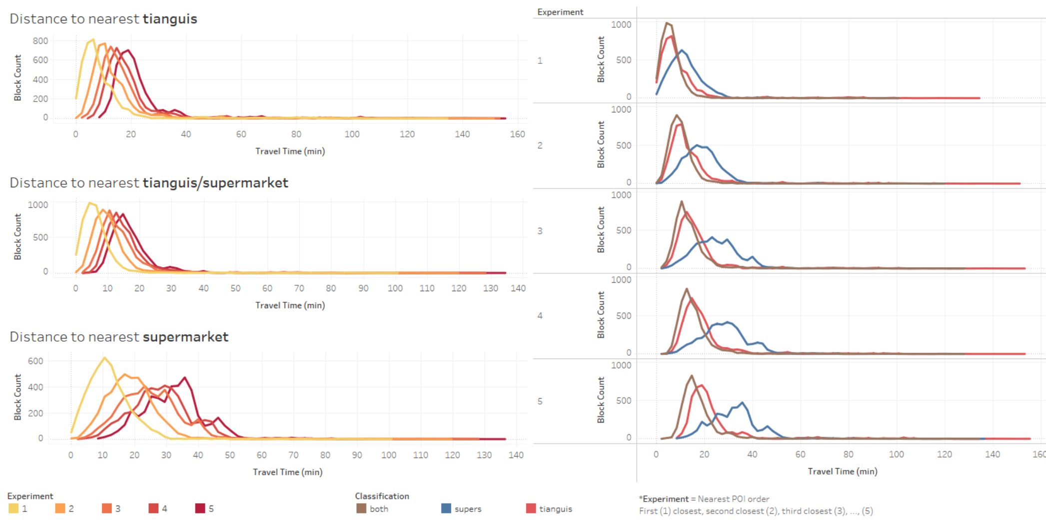

Figure 5: Distances to the five nearest food retailers for each block

4.2 Optimal Location of Tianguis against Status Quo

The first scenario analyzed with the results from UFLP is under the assumption of not having the location of any tianguis, so it determines where a tianguis should be located. For that, a constraint was added to the UFLP formulation limiting the number of facilities and is executed in 25 scenarios starting with 5 tianguis and incrementing by five units up to 125 tianguis as shown in Figure 6. In these charts, the size of the locations is the total population served by each tianguis, and the color blue shows if that location is associated with a pre-existing tianguis (already located in that location as per the status quo scenario), while the color orange is a new tianguis identified for that location. It can be observed that while the number of POIs is incremented, the size of the points keeps on the relatively same size, for which it can be inferred that there is a point at which incrementing the number of tianguis is irrelevant.

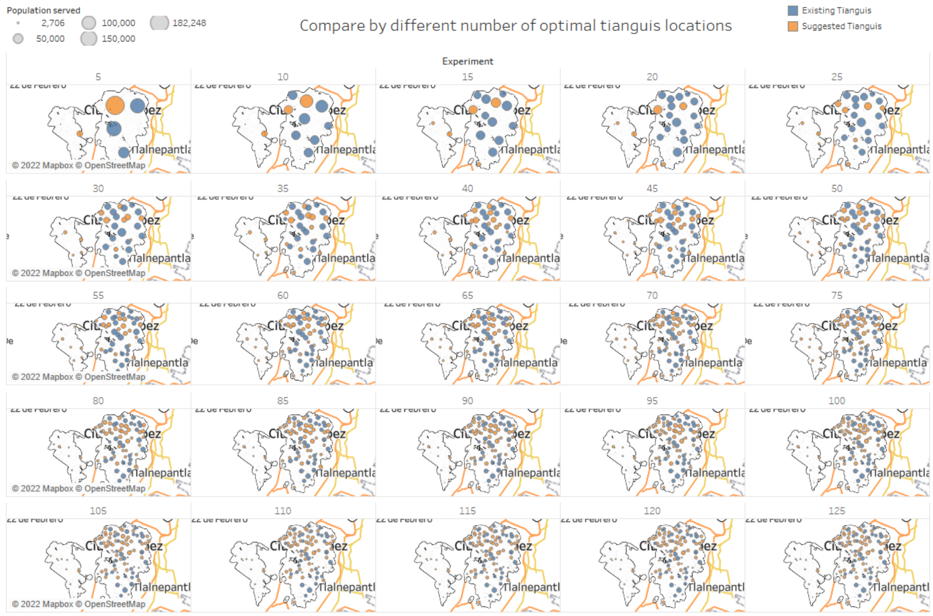

Figure 6: Comparison of the number of optimal tianguis locations

Figure 7 compares the travel time distribution by blocks in the status quo tianguis scenario against the optimal scenario of 45 tianguis. In the status quo scenario, the maximum time travel by a block is 134 min for one block, while in the scheme of 45, tianguis is 56% less with a maximum time of 59 min. The most frequent travel time in the status quo scenario is 7 min for 395 blocks, while 480 blocks have the same travel time in the optimal scenario. Even the experiment with five optimal tianguis locations also has a maximum travel time of 99 min, identifying inefficiencies in the existing locations of tianguis in Atizapan.

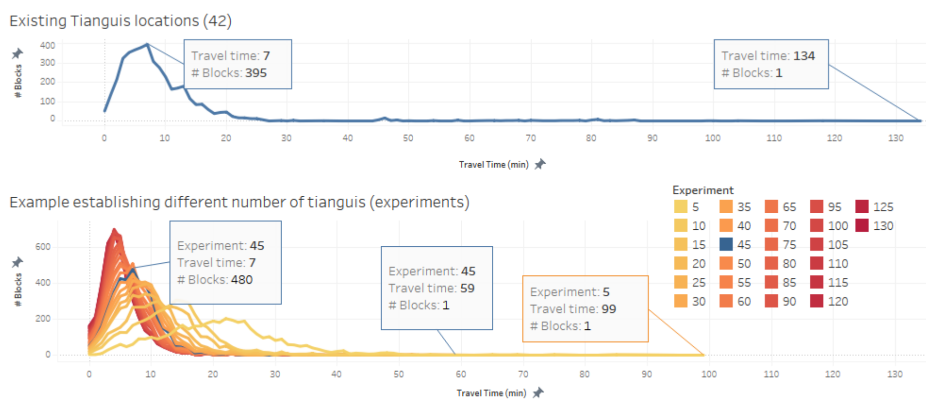

Figure 7: Comparing the travel time distributions between real and optimal scenarios

4.3 Vulnerability Metrics

By implementing the vulnerability metrics described in section 3, an analysis was made using as the optimal scenario of 45 tianguis. The results can be observed in Figure 8 Based on the formulation of the metrics, a value below zero represents an improvement, and the chart shows clearly how there are blocks with a substantial favorable difference on the left bottom side. The figure shows some examples, such as the block_507 with a value of -0.5232 in Vulnerability1 and -84.2 for Vulnerability2 because the travel distance in the optimal scenario is 4 min while in the present, the travel time to the nearest tianguis is 88 minutes walking. An opposite example is block_470 with a vulnerability1 of 0.0878 and 12.9 for vulnerability2 because of the difference between 15 minutes and 2 minutes on the optimal against the real. Even in cases like the second, the time difference is not as relevant as the other favorable cases.

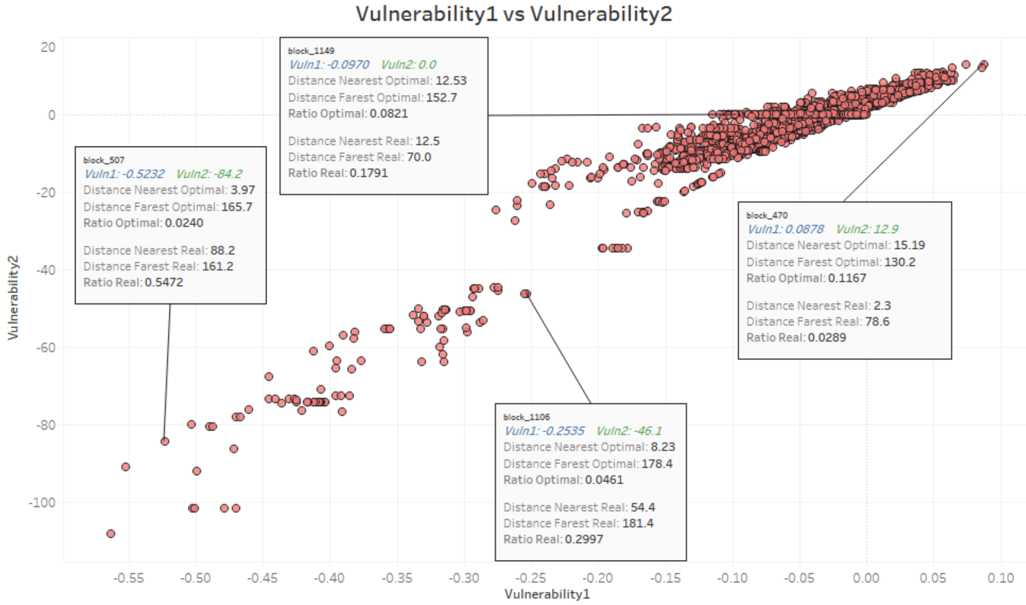

Figure 8: Analysis of the vulnerability metrics

Another relevant factor to consider for these changes is shown in the right side of Figure 9, where it shows on the top the distribution of values for the Vulneraibility1, proving that there are more favorable cases than negative. The right bottom chart shows how the most populated blocks are located on the left side of the graph, which means that more population is served. On the left side is illustrated with more details the comparison between existing and optimal scenarios by comparing with colors the travel distance to the nearest tianguis in each block, and the points' size is the sum of the population served by each tianguis. The maps use the same color and size scale to show how the actual conditions can be optimized with a redistribution of tianguis since there is no red color in the optimal scenario compared with the real one. In the actual scenario, the maximum population served by a tianguis is 29,143, while in the scheme of 45 tianguis is 15,000.

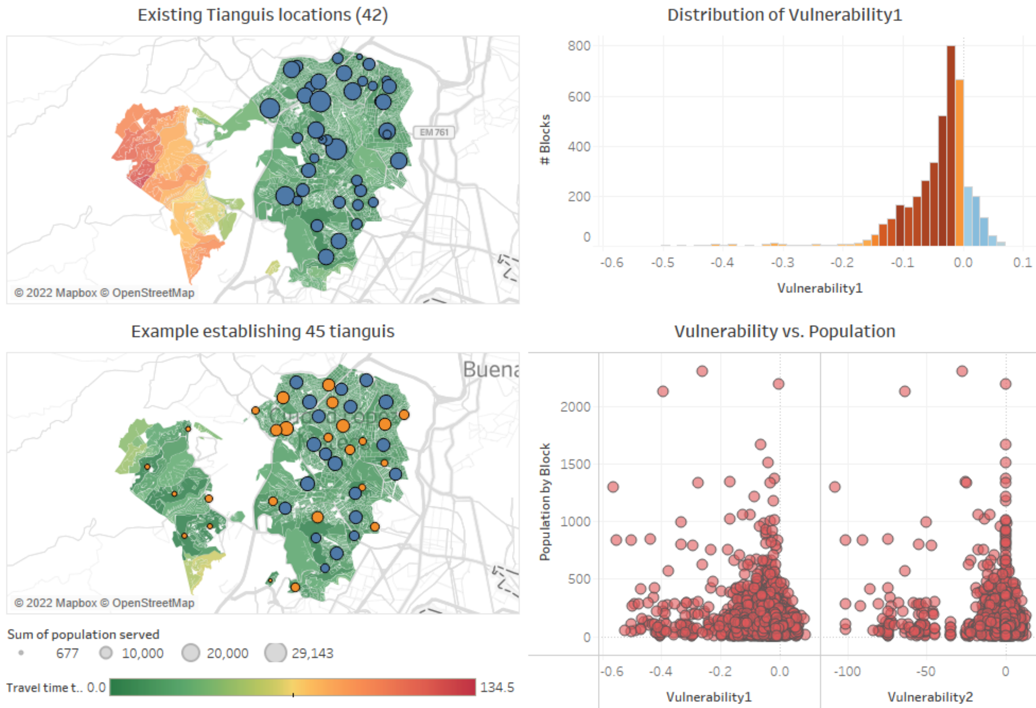

Figure 9: Comparison between optimal scenario with existing scenario with vulnerability metrics

4.4 Discussion

The results of vulnerability and optimization presented above have several implications. First, they show undoubtedly the important role that the tianguis hold in access to healthy food in this periurban zone. This is clearly shown in the analysis of travel distances comparing supermarkets and tianguis in figure 4. The number of formal fixed markets is insufficient to cover demand and their distribution is not equitable, especially in the red zones on the northwest that are located more than 90 minutes walking distance from the nearest supermarket. The northwest is also poorly served by the tianguis, although the situation in terms of travel time is slightly better, as shown in figure 5. To understand this result we have to consider the socio-economic context presented in figure 2. The west zone of this municipality is significantly more affluent, where strict zoning laws do not allow for informal vending. On the other side, the northeast side houses more informal neighborhoods with higher marginalization index. The tianguis in the northeast are more common and they significantly increase access to fresh food by reducing travel times to supermarkets. This has a significant impact on reducing vulnerability to food access and improving fairness and equity in food outlet spatial distribution. Even though the northeast can be considered more vulnerable in socio-economic aspects, the vulnerability in walkable access to fresh food is much more pronounced in the affluent west area. Thus, vulnerability is not only a product of socio-economic conditions but is also a result of how we plan (or not plan) our urban services, as shown recently in Berke et.al. [5]. The informal adaptation in cities, such as the tianguis in our case study, can have a significant impact on reducing vulnerability and improving fairness and equity in spatial distribution of service. Nevertheless, we point out that this benefit of reduced vulnerability has not been the result of formal planning. We stress out the urgent need for official and reliable planning tools to reduce the food access vulnerability.

Secondly, the results show that even though informal tianguis reduce food access vulnerability in the zone their distribution is inefficient. The results show that the optimal number of tianguis is 45, which is close to the real number of 42. However, the optimization of spatial distribution depending on served population and proximity was able to reduce the medium travel time from 134 to 59 minutes (Figure 7). This shows that there is a need for optimization in spatial planning of these services to improve fairness and equity. The proposed optimal spatial distribution reduced significantly the access vulnerability as shown in figure 8 and doubled the served population.

Finally, we stress the importance of taking advantage of new computational methods for the interdisciplinary research on cities and vulnerability. Computational urbanism as a new growing field can bring advantages in allowing faster evaluation and optimization of planning solutions. The computational approach demonstrated in this study was able to evaluate vulnerability in access to food in short period of time and develop a new optimal solution for improving spatial equity and fairness in distribution of this essential urban service. However, this approach has to be complemented with the soft-planning or a turn to ¨computational humanities in data-driven urbanism¨ [32] to bridge the gap between the technical data-based solutions and the socio-cultural context of vulnerability. Since vulnerability is a complex and multilayered phenomenon, we used a qualitative approach to our study to contextualize the results. The benefit of this approach is shedding light on the real condition of vulnerability in the complex urban context and setting the base for informed decision making.

5 Future Work

The work presented in this paper on assessing vulnerability with computational approach possesses substantial potential for augmenting the understanding of processes affecting at-risk individuals. For example, a possible future research work could be oriented towards further investigating possible scenarios in case of failure of certain service points that can serve as a base for preparing preparedness plans. The value of having such redundant plan B, or even plan C, in case of major failure of a food outlet was clearly visible when the only supermarket Tops on the east side of Buffalo closed because of a mass shooting in May 2022 [8]. This prompted a large volunteer campaign to deliver fresh groceries, fruits and vegetables to residents who were left without the only accessible fresh food outlet in the zone. For this purpose, the optimization approach demonstrated in this study can be developed further to provide data for preparedness plans.

Another topic of research can be focused on the effectiveness of interventions that intend to improve access to fresh food outlets. There is clear evidence that people who live in low-access areas have poorer diets. However, despite the initiative led by Michelle Obama that promised to eliminate food deserts in 7 years and the 2014 passing of the Healthy Food Financing Initiative, which allocated $125 million for expanding food resources in underserved communities across the US, people continue to live in low-income, low-access areas. In Mexico, the situation is similar and despite government efforts to put in place policies that reduce food-related diseases, the problem persists [23]. In this context, there is an urgent need to re-evaluate the effectiveness of policies, plans and interventions to improve access since this evidence base is incomplete.

Evidence also shows that people prefer places that they are familiar with and where they feel secure or comfortable when doing grocery shopping [10]. This points out that only improving access to fresh food is not sufficient to combat food vulnerability. Future research should also look at the route experience related to mobility in cities, as well as food affordability. In terms of route quality, future interesting research would be focused on defining not only the shortest route, but also the most pleasant or safe route. This research will enrich the socio-cultural context of the computational approach and better the understanding of travel preferences.

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