Analysis of Coverage of Fire Stations in Manizales (Colombia) through Territorial Accessibility

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Abstract

The fire stations are fundamental since they are in charge of safeguarding the life and goods of the different natural disasters and emergencies that occurred in a city. Territorial accessibility is a model of transport supply that is responsible for quantifying the access that the inhabitants of a region have to the different facilities or opportunities within it, among which are jobs, hospitals, educational centers and fire stations, among others. In this research, the coverage of the fire stations for the city of Manizales will be measured through the road infrastructure network with the existing speed conditions and the areas that have shortcomings in their coverage will be measured with respect to the recommended minimum response times according to international standards and its relationship with social equity in the supply of transport and coverage of fire stations.

Keywords: Territorial Accessibility, Fire Stations, Emergency Coverage, Road Network

1 Introduction

The main mission of the fire departments of the different cities is to safeguard lives
and property from the different natural disasters and accidents that may occur [16]. Therefore, the coverage presented by the different stations in a city is very important to quantify the response time they have through the provided road network. Different methodologies have been used to quantify the area of coverage of each fire station in a city, in this case, territorial accessibility will be used, which has been applied to calculate the population covered by emergency systems such as ambulance centers [14]. The territorial accessibility allows to quantify the coverage of diverse equipment through the road network, evaluating the offer present in a city [6]. The term accessibility, which since its first definition as the potential for interaction opportunities given by Hansen (1959) [12], has taken different perspectives [10], approaches [11], types of measures [22] and analysis [15], making it a very important methodology in urban planning and transportation which currently has multiple challenges and applications [1, 9, 25]. In this research, a coverage analysis will be carried out for the fire stations in Manizales and their relationship with the population, their socio-economic level and the expected response time, obtaining an analysis related to social equity and coverage of emergency equipment [13].

Manizales (figure 1) is the capital of the department of Caldas, located in the center west of Colombia; accounts about 420 000 inhabitants in its urban area, which is taken next to the neighboring municipality of Villamaría because they form a metropolitan area given the continuous social dynamics among their inhabitants, although it is not legally constituted [5]. In addition, Manizales has an abrupt topography given its average elevation above sea level of 2 150 meters, this makes the expansion and urbanization processes to be complicated [23].

![Figure 1. Geographic Location of Study Zone.](image-url)
In spite of this, in terms of urban mobility, the mean of transport that has the highest preference is walking (29%), followed by public transport [18], although the latter has seen a significant decrease in transportation. during the recent years in the number of mobilized passengers [2], a trend that added to the growth of the private vehicle fleet, especially the motorcycle, generates a difficult panorama in terms of urban mobility in the coming years for the city [18].

In Manizales, several studies related to territorial accessibility have been made being used as a tool for urban planning for the evaluation of public transport systems [7], measuring the coverage of facilities such as the ambulance centers [13], shopping centers [27], eco-natural parks [6], universities[26], among others. These studies, in most cases, have had an evaluative component of social equity in access to transport due to their importance in closing inequality gaps around the world [17].

2 Materials and Methods

Figure 2 shows the flow diagram of the methodology applied in the investigation. In this, a preliminary stage is presented where the necessary data for the calculation are obtained, among which are the road network and the neighborhood polygon of the study area.

These data were updated for previous investigations so they meet the minimum requirements between the topology of the road network and its compliance with graph theory and the projection of the population of Manizales up to 2017 in the polygon of neighborhoods [2, 3]. It should be noted that the velocities arranged in the arcs of the road network correspond to real data obtained through global positioning systems (GPS) [26].
2.1 Fire Stations Georeferencing

On the first stage the equipment to be studied is georeferenced, in this case the operating fire stations in Manizales (3 stations) and Villamaría (1 station) with the help of the various tools of the geographic information systems (GIS), in this ArcGis software [6, 13]. Likewise, the node of the road network closest to each equipment studied must be related to which the calculations of territorial accessibility of the subsequent stage can be made.

2.2 Accessibility calculation

On this stage the calculation of territorial accessibility in the TRANSCAD software is carried out. To do this, the matrix of travel times must first be obtained from the fire stations to all the nodes of the road network. In this case, 4 fire stations were analyzed, so the matrix has a size of 10 088 X 4 [6]. Then, the analysis vectors are obtained, which in this case will be two coverage measures. Firstly, the average travel time of each node in the road network will be obtained, by means of the summation of the travel times of the four stations and dividing it by the number of facilities. This way you can get the coverage that the city has for an emergency which response must be met by all fire stations. Secondly, the minimum time from the fire stations to each node of the road network is analyzed, which indicates the fire station that can respond most rapidly in an emergency. This results in a coverage map with the minimum response times.

2.3 Construction of the isochronic coverage curves

With the vectors of average travel times and minimum travel times it is possible to construct the isochronous coverage curves by means of a geo-statistical analysis, which is a branch of geography that analyzes a set of data on the surface, in our case the vectors mentioned above [19]. These methods are responsible for predicting values in space by entering data; time vectors in the case of territorial accessibility. The method used in various investigations given its good results is the Ordinary Kriging with linear semivariogram [4, 20, 24]. This model allows us to obtain the isochronous coverage curves for the two analyzed scenarios.

2.4 Relationship between isochronic curves and population urban area

Lastly, a comparison is made between the neighborhood polygon and the isochronous coverage curves of both scenarios. This allows us to calculate the relationship among population, urban area, socioeconomic strata and coverage of fire stations [21, 26].

3 Results and Discussion

3.1 Fire Stations, Road Network and Neighborhoods Polygon, Georeferencing

Figure 3 shows the four (4) fire stations of Manizales and Villamaría, duly geore-
ferenced with their respective coordinates; this information was obtained thanks to a search in various data sources and corroborated by calling the different stations in order to confirm their location. In addition, the polygon of neighborhoods, which has 150 in total, including Villamaria corresponding to the urban area of the city reaches 5,868 hectares and a population of 419,944. In addition, the road network is observed, which is composed of 12,714 arcs and 10,088 nodes.

![Figure 3. Fire Stations, Road Network and Neighborhoods polygon.](image)

### 3.2 Minimum Travel Time Coverage of Fire Stations

Figure 4 shows the result of the coverage analysis of the fire stations in their minimum response time, taking into account the most node of the road network to each fire station in the study area. In these, you can see how there is a minimum response time of 0.59 min and a maximum time of 45 minutes. This last data corresponds to areas of the polygon studied where there are no population records so that actually 100% of the population is covered for less than 30 minutes, which can be seen in Figure 5, which corresponds to the percentage ogives cumulative population and area for this scenario.
Figure 4. Isochronous curves of coverage for minimum travel time from fire stations.

In figure 5, you can also see how 10% of the population is within the response time of 5 minutes or less, a percentage that grows up to 48% for a response time of 10 minutes or less. Likewise, for each isochronous curve of coverage, the percentage...
of the population is higher than that of the urban area because a large amount of population is concentrated in the central areas of the city. Figure 6 shows the analysis of population coverage relating the different socioeconomic strata. As it is a population analysis, the maximum coverage times reach 30 minutes. There it can be seen how the strata of higher socio-economic level, stratum 5 and 6, have a better coverage of the fire stations in the city of Manizales, while the lower strata, stratum 1 and 2, have poor coverage by which is why the response times to these places and to this population is longer.

![Figure 6. Relationship between population and socioeconomic strata and the isochronous curves of coverage for minimum time from fire stations.](image)

### 3.3 Average Travel Time Coverage of Fire Stations

In this analysis, the sum of the travel times of all stations to each node was taken into account and then divided by the number of fire stations analyzed. This will serve as an indication of the coverage before a presumed emergency that requires the action of all the fire stations of the city. Figure 7 shows how the average response time for the 4 fire stations is 15 minutes and the maximum time is 53.67 minutes, which occurs in areas of the city where there are no population records. The maximum response time for neighborhoods with population records is 40 minutes, although Figure 8 shows that 99% of the population is covered by average travel times of 30 minutes or less. For average times between 15 and 20 minutes, there is a broad population coverage that reaches 49%. In the analysis that corresponds to socio-economic strata of the population (see figure 9), the trend generated in the previous scenario is followed where the strata with the best level have better time coverage with respect to the socioeconomic strata with fewer economical resources.

### 4 Conclusions

Regarding the coverage of the fire stations in Manizales and Villamaria, there is a
failure in the minimum response times, which are 6 minutes according to the "National Fire Protection Association" (1 minute for the confirmation of the event, 1 minute for preparation and 4 minutes for displacement) [8], so that only 10% of the population would be covered by the fire stations in their minimum response time through the existing road infrastructure and with the average speeds of the current roads.

Figure 7. Isochronous curves of coverage for average travel time from fire stations.

Figure 8. Relationship between population, area, and the isochronous curves of coverage for average time from fire stations.
Therefore, to comply with the international standards, new fire stations should be adapted throughout the city in order to increase population coverage in the minimum response time. Given the conditions of inequity in the coverage, it is recommended to locate them in neighborhoods with low socio-economic strata, (strata 1 and 2).

Figure 9. Relationship between population and socio economic strata, and the isochronous curves of coverage for average time from fire stations.

On the other hand, in the average time of coverage, for the events that require attention of all the fire stations there is also a social disparity although 50% of the population is covered by less than 20 minutes.

For future investigations, it is recommended to review the coverage using the maximum speeds given by the control entities given that these organisms can reach them in the road network in order to attend emergencies as quickly as possible.

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References


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