

Analysis, Evaluation, and Projection of the Operation of a University School Parking Lot, Chihuahua, Mexico

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Abstract

Vehicular transportation systems comprise three key components: vehicles, roads, and parking facilities. Parking lots' performance and operation must be continuously assessed to avoid saturation. Due to its current overcrowding, the student parking lot at the Autonomous University of Chihuahua's Engineering Department is the focus of this work. Tuesdays are the busiest day of the week, with 77% of students using their own cars, according to traffic volume data collected over a ten-day period. Additionally, a 3% annual growth rate for the student population was assumed. Based on these numbers, it was inferred that the current parking lot will soon be insufficient. To address this issue, a parking area expansion is deemed necessary, with the most feasible solution being the construction of a vertical parking structure to minimize the demand for additional horizontal space. The type of structure to be developed can be made of steel, concrete, or a hybrid combination of materials. In addition to expanding capacity, immediate attention is required to repave the existing lot and implement improved signaling to enhance traffic education and ensure the efficient operation of the facilities.

Keywords

Parking Lot, Mobility, Evaluation

1. Introduction

The automotive transportation system comprises three key components: vehicles, roads, and parking facilities [1]. This system, managed through road infrastructure, whether by a user with their own vehicle or public transportation, typically

requires a parking space when its purpose is fulfilled [2]. By analyzing the elements of vehicular flow, we can understand the traffic characteristics and behavior, basic requirements for the planning, design, and operation of roads, streets, and their complementary works within the transportation system, such as parking lots [3]-[6].

For parking lots, it is essential to understand the most critical points related to vehicle volume, including the mode of transportation based on costs, time, and comfort. These data allow the development of an optimal design for users, whether pedestrians or drivers [3]-[7]. Regardless of whether the user is a driver, pedestrian, cyclist, or passenger, parking must be considered a fundamental part of the road operational system, as it is necessary to avoid congestion and/or safety violations [8] [9].

Following the COVID-19 pandemic, vehicle use increased exponentially. This increase, in just three years, impacted the evaluation of existing infrastructure to ensure it meets the requirements for the new demand, or, where appropriate, to make necessary modifications.

The study area covers the student parking lot of the Engineering Department at the Autonomous University of Chihuahua (UACH, or Universidad Autónoma de Chihuahua in Spanish). On university campuses, increasing enrollment has led to a rise in both vehicular and pedestrian traffic [9]-[14]. However, infrastructure often lags, requiring the modernization of facilities to meet the demands of the university community. Therefore, improvements to the parking lot's accommodation and traffic management system were analyzed, evaluated, and planned. This led to the proposal to expand the current area to offer safe, comfortable, and efficient service to students.

The parking lot has only one entrance and exit, located in front of the bus station (Figure 1), so students use it to access their destination classrooms. This

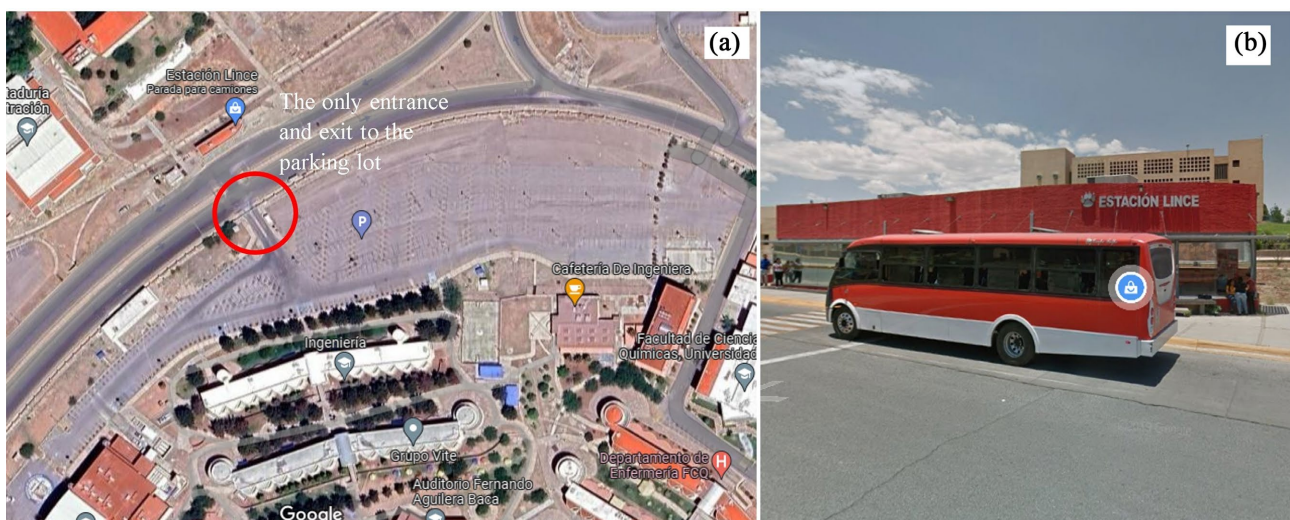


Figure 1. Location of the study area: (a) Engineering department parking lot marked with a “P” and the red circle indicates the bus station; (b) bus station in front of the parking lot.

becomes a hazardous route without clear signage, as it can lead to drivers injuring pedestrians. Having only one entrance and exit to the parking lot creates traffic congestion and reduces speeds during peak hours, causing congestion between buses, students, cars, and passenger platform vehicles. This leads to wasted time, inconvenience, and stress for drivers. The factors mentioned above encourage students to park illegally, spanning two spaces with one vehicle or impeding traffic flow within the parking lot.

This project proposes an expansion focused on future vertical growth to create a safe and comfortable environment for all users, optimizing travel time, distance traveled, and turnover within the facility. Currently, most of the population uses some form of transportation, and student growth is expected to continue to increase annually.

By analyzing the elements of vehicular flow, the traffic characteristics (flow, speed, and density) and behavior are examined. These are the basic requirements for planning, designing, and operating roads, streets, and their complementary structures within the transportation system. The infrastructure created must facilitate smooth traffic flow during peak hours, ensure stability without disrupting the user environment, and maintain stability [15] [16]. In areas where traffic volumes are relatively stable (e.g., no seasonal tourism, school breaks, or major construction), short-term counts can be extrapolated using adjustment factors (daily, weekly, or monthly) derived from long-term data or similar locations.

Parking

The most important characteristics of a parking lot can be summarized in three key aspects: accessibility, security, and convenience [6] [17]. Access to and from the parking lot must be spacious, with at least two entrances and exits that provide easy and convenient access to the facilities [17]. Drivers seek parking spaces that provide them with a secure, well-guarded location for their vehicles, allowing them to leave safely while carrying out their activities [12] [13] [17] [18].

2. Methodology

Conducting an operational and demand study enables the projection of a relationship between current and future needs, identifying the necessary upgrades to both its operation and infrastructure to meet the new specifications. This study involved vehicle traffic measurements of the parking lot for two weeks, and surveys were conducted with students who regularly use the facility, whether by car or on foot, regarding its infrastructure, operation, and signage.

First, an analysis was conducted to determine the current demand and service status of the parking lot, including the delimitation of parking spaces, slopes, medians, and various components. The number of parking spaces counted was 596 (Table 1). Damaged parking spaces are minimal compared to the number of currently open spaces, while the limited number of special spaces and green parking spaces require new signage and ramps (Figure 2(a)).

Table 1. The number of parking spaces at the engineering department parking lot, UACH.

Concept	Parking space	Special parking space (blue)	Green parking space
Parking spaces	586	8	2
Damaged parking spaces	18	0	0
Total number of open parking spaces	568	8	2
Total number of parking spaces			596
Total number of damaged parking spaces			18
Total number of open parking spaces			578

Within the general parking spaces, 18 of them are obstructed by electrical installations, which determines that a new design is needed where the spacing is distributed so that complementary installations do not disable any parking space (**Figure 2(b)**).

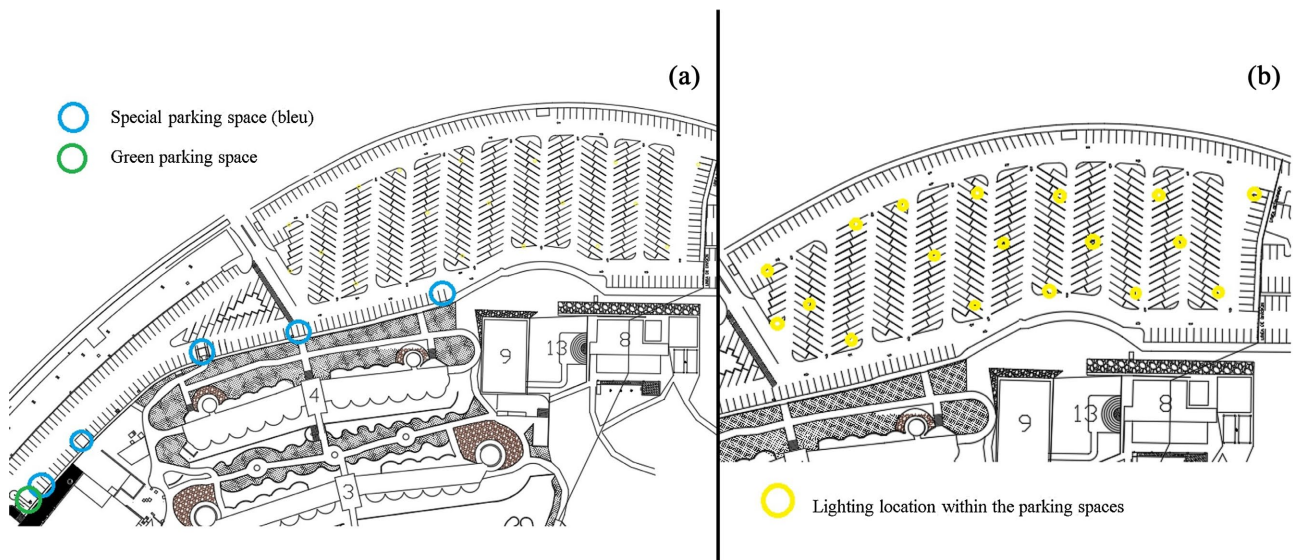


Figure 2. UACH Engineering department parking lot, (a) location of special parking spaces (blue and green spaces); (b) location of lighting, some of which obstruct parking spaces.

The increase in the student population was projected based on a growth rate aimed at anticipating future demand for higher education services and quality.

Table 2 shows the growth in the student population from 2019 to 2022.

Table 2. Student population at the UACH Engineering department from 2019 to 2022.

Year	Student number	Semester
2019	2347	January-June 2019
2020	2406	August-December 2020
2021	2695	January-June 2021
2022	2557	August-December 2022

The calculation to determine the future growth in student enrollment was carried out using the population estimation formula (Equation (1)) proposed by [19], where the population growth rate (i) is related to the final (p_2) and initial (p_1) population and the analysis period, in this case 2 years of the same semester were taken, those with the highest demand, August-December 2020 and 2022.

$$i = \left\{ \left[\sqrt[2]{p_2/p_1} \right] - 1 \right\} * 100\% \quad (1)$$

An online survey was also conducted among 552 out of 2557 students, representing 21.6% of the total population, to determine how they travel to the institution, whether by public transportation, their own vehicle, or walking. The Google forms survey was sent via e-mail to all the enrolled students. The result was that 77.4% of students travel to the university by car. If this percentage is applied to the entire student body, the result would be that 1979 students use the parking lot on different days of the week.

Subsequently, a vehicle counting study was conducted using the pneumatic tube traffic counters, also known as tube counters [20]. This method involves installing hoses (Figure 3(a)) in the lanes where the number of vehicles passing through the lane is to be counted at a given time. This is generally done at entrances and exits and is measured 24/7. The hoses expel air each time a vehicle compresses them, and these variations are recorded in the gauge's memory (Figure 3(b)). This method determines the current volume occupied during the days and hours of student attendance.

Measurements were made for 11 days, including weekdays and weekends, peak and off-peak days, and avoiding holidays or abnormal events. This ensures that the observed variation captures typical traffic patterns.

After the measurement period, the meter was uninstalled, and data was collected by transferring files from the meter. Data was extracted using a computer, and daily demand data were visualized and extracted using the Vehicle Identification and Analysis System (VIAS) software in a 24-hour record. If the daily variation across the 11 days is low (e.g., within $\pm 10\%$), it supports the fact that the dataset reflects normal operating conditions.

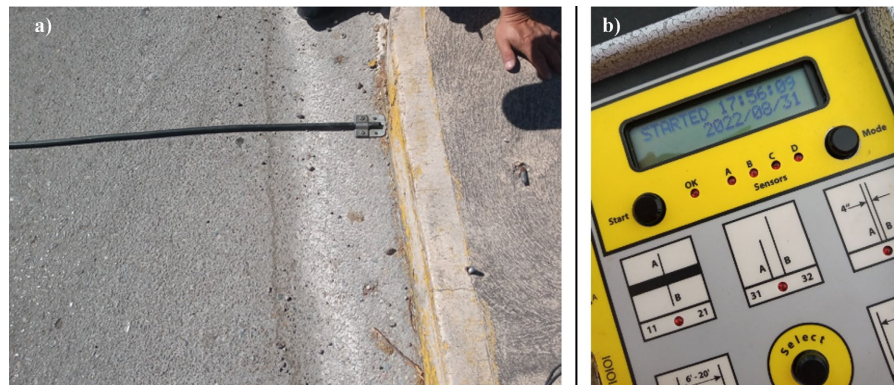


Figure 3. Vehicle counting study: (a) Installation of pneumatic tubes or hoses; (b) A gauge that counts the number of vehicles passing through the pneumatic tubes.

Finally, two software programs were used: AutoCAD for the parking lot drawing, and STAAD Pro V8, which enabled structural design and generated designs for concrete, steel, or hybrid buildings, used to design the proposed parking infrastructure.

3. Results

The results obtained from the various activities are listed below:

The survey (Figure 4) on students' means of transportation to the Faculty of Engineering indicated that 77% of students use their own vehicle to get to the institution, while 12% use public transportation, and the remaining 11% walk.

The future projection of student population growth predicted a 3% annual growth (using Equation (1)), suggesting that, within 20 years, student enrollment will reach 4700 in the College of Engineering alone.

Vehicle counting studies conducted from September 12 to 22, 2022, showed the highest demand on Tuesdays (Figure 5) and the lowest on Fridays, due to scheduled field practices and other off-campus activities. The peak hours for vehicle traffic are between 8:15 a.m. and 9:45 a.m., considering entry hours, while

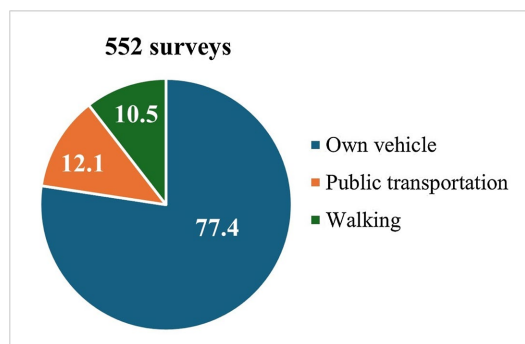


Figure 4. Pie chart results for the survey on the type of transfer to the institution by students.

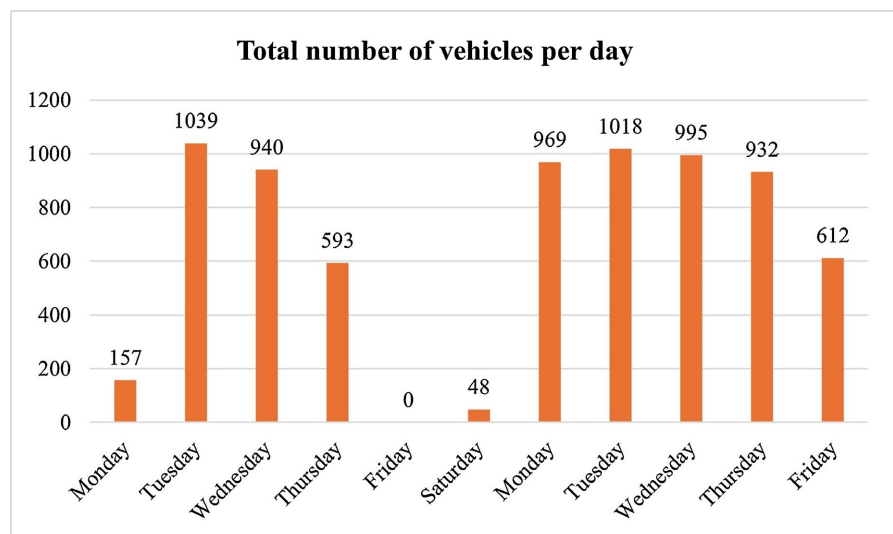


Figure 5. Vehicle capacity data of the parking lot.

3:00 p.m. is the peak time in the evening.

Supposing an average of 6 hours per student vehicle within the parking lot per day, the calculations will be 3576 hours of parking-time per space during peak hours (mostly Tuesday's mornings, see **Figure 5**). Assuming that the parking lot efficiency is 80% (100% is nearly impossible to acquire), the number of rotating parking spaces will be 149, this should allow us to have 447 available parking spaces (2682 hours unattended). The total demand is 6258 hours of parking-time per space. The equation (Equation (2)) for parking peak-hour demand (S) from [20], where the number of the parking opening hours ($N = 15$, it is open from 7:00 am to 10:00 pm), parking lot efficiency (80%), and the hours demanded, are accounted for calculating the number of extra parking spaces needed. The results show that about 522 extra parking spaces are needed.

$$S = f \sum_{i=1}^N (t_i) \quad (2)$$

The parking lot drawings and proposals for the new building were created in AutoCAD. In STAAD Pro, the structure model was created based on the measurements from the AutoCAD drawing. Since it is a university parking lot, the cost is the main variable to consider. The construction time is not essential because it can be scheduled for the vacation period, so it does not have an impact. The environmental impact was considered, but since the parking area already exists, it is just a modification.

If the existing design must be used, improvements to visualization and signage are recommended, given that the pavement markings for the proposed layout are unclear. Another objective to be met is to resurface the asphalt, re-align, and reorganize the parking spaces.

Considering that parking will soon be insufficient, two proposals are made for the construction of a new multi-story building: Based on a regular geometry that occupies half of the area to be optimized. This proposal leaves empty spaces that will not be accessible, resulting in wasted space. The geometry is rearranged to make it more user-friendly (**Figure 6(a)**); it fully occupies the main parking area, creating two distinct geometries to meet the new demand. In addition to increasing open spaces between the proposed buildings, the geometry distribution is

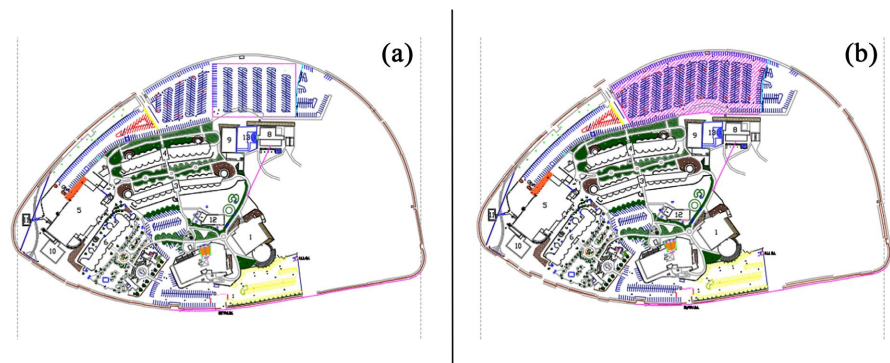


Figure 6. Projected geometry for the parking lot; (a) Occupying only half the area; (b) Occupying the entire area.

similar, with varying dimensions (Figure 6(b)).

4. Conclusions and Recommendations

This study is based on a relatively short data collection period (11 days), which may not fully capture seasonal or semiannual variations in traffic volume. Furthermore, a constant 77% share of car trips was assumed over 20 years, which represents a simplification, as modal preferences can change depending on mobility policies, infrastructure, or social behavior.

Although the current design is functional, it is advisable to plan for a parking facility in the future, as the population is expected to grow, and in the not-too-distant future, the existing parking lot may become insufficient. The most viable option is to create a vertical infrastructure, avoiding the problem of increased demand for horizontal space.

It is also recommended to analyze the type of structure to be developed. The use of steel in construction allows for faster assembly; however, concrete or hybrid buildings may also be viable options, the design will depend on the budget assigned to the project. Procedures such as mill and inlays in pavement are necessary with or without vertical expansion. Current road signs are not functional, and new signage must be implemented.

For future construction, an analysis of the structure must be conducted to ensure that the conditions for which it was designed will be met at the time of implementation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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