# Does limited on-street parking availability create safety issues? A case study of illegal parking in Toronto, Canada

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## Abstract

Promoting road safety in urban environments requires an understanding of the factors that create hazardous road conditions. Illegal parking can cause a wide range of safety concerns, from blocking driver sightlines at crosswalks to obstructing bike lanes causing cyclists to enter vehicle traffic. Some of the causes of illegal parking have been studied before but there appears to be a gap in the literature regarding the influence of different on-street parking occupancy levels on illegal parking activity.

The relationship between on-street parking location occupancy and illegal parking is examined in this paper using two data sources. First, on-street parking payment transaction data for locations managed by the Toronto Parking Authority is used to determine parking location occupancy. Second, parking infraction data from the City of Toronto is used to examine the prevalence of illegal parking activity. The study starts with identifying the five streets of each road type (arterial, collector, and local) within downtown Toronto that have the most parking infractions. The locations are selected only from downtown Toronto to help control for external factors (e.g., built environment). Next, parking infractions that occurred adjacent to paid on-street parking and that have potential safety implications are selected for further analysis. The parking infractions are then paired with the occupancy percentage of the adjacent paid on-street parking location at the time the infraction occurred. Finally, frequency distribution graphs are produced comparing the number of parking infractions to the adjacent parking location occupancy percentages. Some modifications are made to the frequency distribution graphs to control for certain factors (e.g., length of road). Linear and exponential regression models are produced to determine the trends within the frequency distribution graphs.

Overall, there is a positive relationship between parking location occupancy and illegal parking activity that may cause road safety concerns. For different times of the week, weekday mornings, afternoons, and evenings are analyzed but no weekend times were examined due to minimal data. All three times periods showed statistically significant relationships and parking location occupancy had a stronger effect on illegal parking activity in the morning. For the three types of road classification examined within the study (arterial, collector, and local), only local roads showed a statistically significant relationship. Finally, loading areas are shown to lower illegal parking activity.

The results show that there is a positive effect on road safety as on-street parking location occupancy decreases. This emphasizes the need for illegal parking to be managed through stringent enforcement and the creation of loading areas.

**Keywords:** On-street parking, illegal parking, road safety, parking availability, loading spaces

# 1.0 Introduction

Improving the safety of transportation facilities requires an understanding of the factors behind dangerous driving behaviour. In urban environments, developing this understanding can be particularly complicated due to the range of complex interactions between road users and other aspects of the built environment. One particularly important area of road safety is illegal parking due its potential safety implications for vulnerable road users (e.g., blocking sightlines for crosswalks) and the difficulty in managing it.

This study focuses on the potential causes of illegal vehicle parking within Toronto, Canada through examining the relationship between on-street parking occupancy and parking infractions. This paper explores whether an increase in on-street parking occupancy increases a driver's willingness to park in a manner which causes road safety issues. The analysis explores how this relationship varies throughout the day, for different road classifications, and for different types of active transportation infrastructure. The paper ends with examining the effect of loading areas on illegal parking and a discussion of the paper's results.

# 2.0 Background

This section will present a summary of the academic literature related to the relationship between on-street parking availability and illegal parking. Additionally, the academic literature regarding the safety implications of illegal parking will be discussed.

## 2.1 On-street Parking Availability and Illegal Parking

Studies have shown that people consider a range of factors when deciding to park illegally. A study out of Nanjing, China asked drivers about 19 different factors they may consider when deciding whether to park legally versus illegally. The aspects included driver related factors, traffic conditions, parking infrastructure, and the driver's awareness of the societal impacts of illegal parking. They found that the number of on-street spaces can be an important factor when drivers are considering to park illegally[1]. Further evidence from Greece found that the presence of a parking lane lowered the likelihood of four-wheeled vehicles parking illegally on the road while two-wheeled vehicles parked illegally on sidewalks[2]. The study also found that illegal parking behaviour increased when on-street parking was at capacity[2]. Finally, a psychological study on illegal parking behavior found that the primary reason for improper parking was the unavailability of parking near a driver's destinations[3]. These studies show that on-street parking availability, particularly near a driver's destination, is an important factor behind illegal parking behaviour.

# References

[1] Yan, J., Zhou, X., & Ji, Y. (2025). What Causes Curbside Illegal Parking Behavior: A Method Based on Structural Equation Model. *KSCE Journal of Civil Engineering*, *27*(8), 3581–3590. https://doi.org/10.1007/s12205-023-0048-6

[2] Zoika, S., Tzouras, P. G., Tsigdinos, S., & Kepaptsoglou, K. (2021). Causal analysis of illegal parking in urban roads: The case of Greece. *Case Studies on Transport Policy*, *9*(3), 1084–1096. https://doi.org/10.1016/j.cstp.2021.05.009

[3] Song, K.-W., Jeon, S.-M., Park, K.-J., & Shin, Y.-E. (2022). Study on the Psychology of Drivers Dealing with Illegal Parking Behavior. *Ksce Journal of Civil Engineering*, *26*(6), 2919–2925. https://doi.org/10.1007/s12205-022-1823-5

### 2.2 Safety Implications of Illegal Parking

Illegal parking has been shown to be an important factor contributing to vehicle-pedestrian and vehicle-vehicle collisions[4,5]. One study found illegal parking violations to be correlated with traffic collisions between vehicles and pedestrians[5]. Another study found that 1.2 percent of vehicle collisions resulted from parked vehicles obstructing driver sightlines[6]. This research shows that illegal parking can have a noticeable impact on the number of collisions within urban transportation systems.

In addition to collisions, two studies from New York City highlight the safety issue of illegal parking and bike infrastructure. One study examined the how cyclists reacted to obstructions within their bike lane and found that found that 88 percent of cyclists will ride into the vehicle traffic lane to pass the obstruction[7]. Furthermore, it was found that illegally parked vehicles can be a safety concern even for separated cycling infrastructure, with 19 percent of obstructions within cycle tracks being vehicles[8].

## 3.0 Methodology

This section will describe the data sources used for analysis, how the study area and street segments are selected, the filtering of the parking infraction dataset, the calculation of on-street parking occupancy, and the examination of the relationship between on-street parking occupancy and illegal parking.

### 3.1 Data Sources

The two datasets used for this paper's analysis are on-street parking payment transaction data and parking citations data, both from Toronto, Canada.

The on-street parking payment transaction dataset contains the transactions from May 2022 to July 2022 and is supplied by the Toronto Parking Authority (TPA). The dataset has information on the parking duration, cost, start time, end time, and the location number for each transaction. The geographical coordinates and location capacity for each parking location are also included in the dataset.

## References

[4] Li, X., Chengxiang Zhuge, & Yu, B. (2019). Analysis on the Impact of Illegal Driver Behaviors on Road Traffic Accidents Case Study on China. *2019 11th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC)*. https://doi.org/10.1109/ihmsc.2019.00065

[5] Wang, H., & Liang, G. (2025). Association Rules Between Urban Road Traffic Accidents and ViolationsConsidering Temporal and Spatial Constraints: A Case Study of Beijing. *Sustainability*, *17*(4), 1680–1680. https://doi.org/10.3390/su17041680

[6] Hendricks, D. L., Freedman, M., Fell, J. C., & Firm, V. (2001). The Relative Frequency of Unsafe Driving Acts in Serious Traffic Crashes [Final Report]. In *Bts.gov*. United States. National Highway Traffic Safety Administration. https://doi.org/10.21949/1525530

[7] Basch, C. H., Ethan, D., Fera, J., Kollia, B., & Basch, C. E. (2023). Micromobility Vehicles, Obstructions, and Rider Safety Behaviors in New York City Bike Lanes. *Journal of Community Health*, *48*(3). https://doi.org/10.1007/s10900-023-01197-6

[8] Basch, C. H., Ethan, D., & Basch, C. E. (2018). Bike Lane Obstructions in Manhattan, New York City: Implications for Bicyclist Safety. *Journal of Community Health*, *44*(2), 396–399. https://doi.org/10.1007/s10900-018-00596-4

The parking infraction dataset contains information about all parking citations issued within the City of Toronto for 2022 and is obtained from Toronto's Open Data Portal[9]. The dataset contains information related to the date, time, address, and type of parking infraction.

### 3.2 Study Area and Street Segment Selection

Downtown Toronto is selected as the study area due to research showing that illegal parking can be more prevalent in central business districts[10]. Preliminary analysis of the 2022 parking citation dataset confirms this, with majority of the top 20 streets measured by parking citation frequency being within downtown Toronto. In addition, only one area of Toronto is selected for analysis to minimize the potential effect of other built environmental factors. For example, outside of downtown there is a larger mixture of residential density while in downtown, most residential buildings are high-density.

The following street segment selection criteria is used for the analysis:

- Downtown Toronto is defined as Bloor Street to the north, Bathurst Street to the west, Parliament Street to the east, and Lake Ontario to the south
- Any street that had a portion of it within the boundaries defined above is classified as being within downtown Toronto
    - Only the segments of those streets within the boundaries are used for the analysis
- The five streets of each road classification (arterial, collector, and local) that recorded the highest amount of parking tickets are selected. The road classifications are from the City of Toronto Road Classification System map[11]. The streets selected for the analysis are shown in Figure 1.

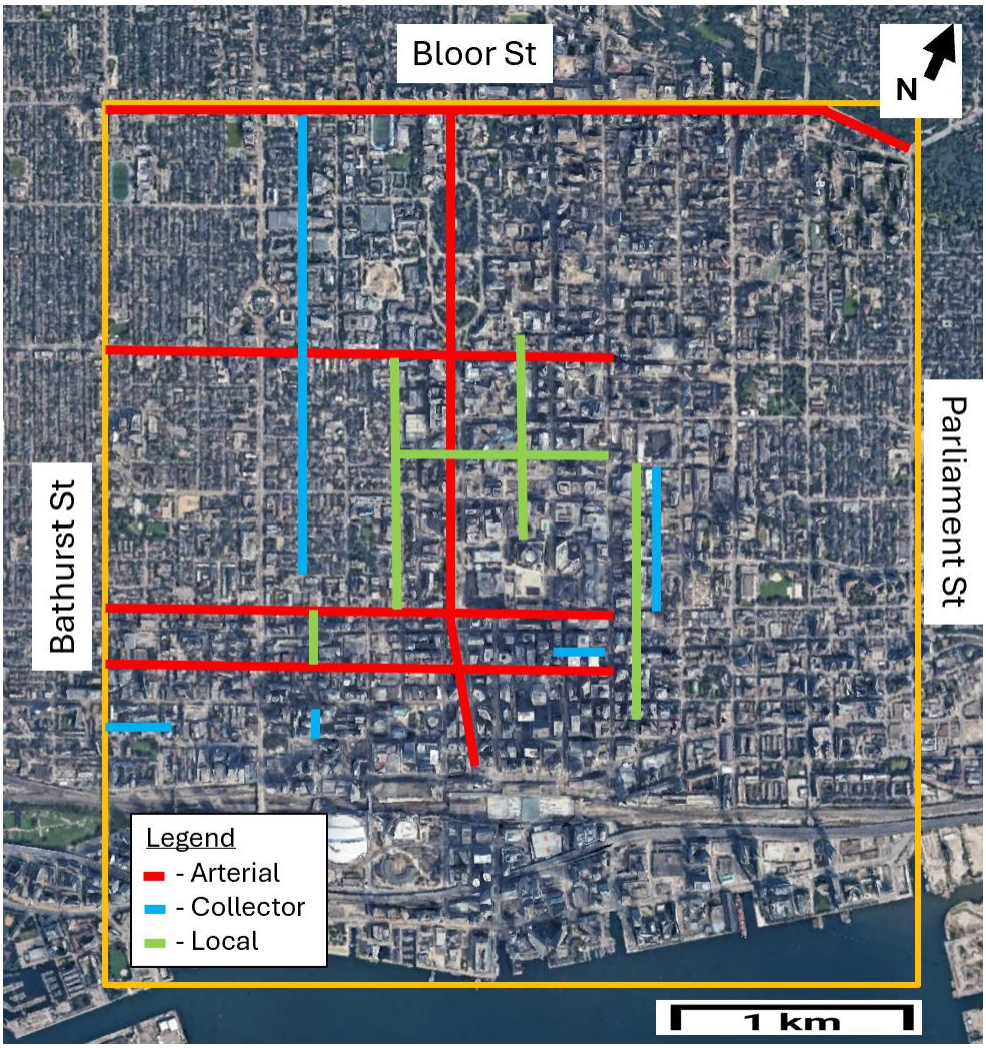
## References

[9] City of Toronto. (2025). *Open Data Dataset*. Toronto Open Data Portal. https://open.toronto.ca/dataset/parking-tickets/

[10] Jardim, B., Alpalhão, N., Sarmento, P., & de Castro Neto, M. (2022). The illegal parking score – Understanding and predicting the risk of parking illegalities in Lisbon based on spatiotemporal features. *Case Studies on Transport Policy*, *10*(3), 1816–1826. https://doi.org/10.1016/j.cstp.2022.07.011

[11] City of Toronto. (2019). *City of Toronto Road Classification System Map*. https://www.toronto.ca/wp-content/uploads/2019/09/9072-TS_RCS_2019-City-Wide.pdf

Figure 1. Study area and selected road segments




*Aerial Image Source: Google Maps*

After selecting the streets, the segments with paid parking are determined through historical Google Streetview images (cite). Segments without paid parking are removed due to not having data regarding their parking occupancy levels. Streets segments that are presumed to have issues with people accessing the paid parking areas are removed from the dataset (e.g., construction vehicles and equipment occupying paid on-street parking). Table 1 presents a summary of the selected street segments.

Table 1. Summary of the street segments selected for analysis

| Road Classification | Number of Paid On-street Parking Locations | Total length of selected segments (km) |
|---|---|---|
| Arterial | 14 | 8.019 |
| Collector | 11 | 2.129 |
| Local | 13 | 4.256 |

## 3.3 Parking Infraction Dataset Cleaning

After selecting the street segments, the parking infractions are filtered to include only citations issued along those specific segments. This is done through filtering the addresses within the parking infraction dataset. Parking citations that occurred at intersections are removed from the analysis due to uncertainty regarding their proximity to paid on-street parking locations.

The parking infractions are then filtered to include citations related to road safety. This required removing a range of parking citations, including not paying for parking in a paid parking location, parking improperly (e.g., parking too far from the curb), or exceeding the permitted parking duration. There is a total of 200 parking infractions included within the analysis and Table 2 summarizes the frequency of each type of road safety related parking citation.

Table 2. Frequency of each type of road safety infraction

| Parking Infraction | Frequency |
|---|---|
| Stopping Vehicle Other than a Bicycle in a Bike Lane | 90 |
| Stopping on or over a sidewalk/footpath | 32 |
| Park within 9.0 meters of the intersection road | 26 |
| Stop non-bicycle in cycle track | 14 |
| Park within3 30.5 meters of a signalized intersection | 13 |
| Stop within 15.0 of the approach of a pedestrian crossing | 10 |
| Park on the boulevard | 9 |
| Stop within 9.0 meter beyond a pedestrian crossing | 4 |
| Park between road and sidewalk | 1 |
| Parking in a fire route | 1 |

## 3.4 Parking Location Occupancy Calculation

The parking location occupancy for the street segments selected on Section 3.2 is calculated using the on-street parking payment transaction dataset. This is done through determining the number of vehicles parked in a location using the start and end times of payment transactions. After, the number of parked vehicles is divided by the parking location's capacity to determine the parking location's occupancy percentage. This is done for 15-minute intervals from 8:00am to 8:00pm for weekdays and weekends. The analysis is restricted to this time period due to irregularities within the payment dataset beyond these hours. These irregularities are likely from paid parking not being required for most locations between 8:00pm and 8:00am. Table 3 presents a summary of the parking location occupancies observed within the selected street segments.

Table 3. Parking location occupancies observed within selected street segments

| Parking Occupancy Percentage Quantile | Frequency of Observation | Proportion of Overall Parking Location Occupancies that Occur Within Each Quantile |
|---|---|---|
| 0% - 5% | 28299 | 33.4% |
| 5% - 10% | 17345 | 20.4% |
| 10%-15% | 11232 | 13.3% |
| 15%-20% | 7023 | 8.4% |
| 20%-25% | 5177 | 6.0% |
| 25%-30% | 3532 | 4.1% |
| 30%-35% | 2408 | 2.8% |
| 35%-40% | 1605 | 1.9% |
| 40%-45% | 892 | 1.0% |
| 45%-50% | 454 | 0.5% |
| 50%-55% | 290 | 0.3% |
| 55%-60% | 171 | 0.2% |
| 60%-65% | 114 | 0.1% |
| 65%-70% | 68 | 0.08% |
| 70%-75% | 55 | 0.06% |
| 75%-80% | 34 | 0.04% |
| 80%-85% | 26 | 0.03% |
| 85%-90% | 20 | 0.02% |
| 90%-95% | 12 | 0.01% |

## 3.5 Parking Infraction Versus Parking Location Occupancy Analysis

The final aspect of the paper's analysis is combining the parking infractions selected within Section 3.3 with the calculated parking location occupancies in Section 3.4 to examine if there is any potential relationship. The data from Section 3.3 and 3.4 are combined using pandas commands in Python.

After combining the dataset, a frequency distribution chart is made (Figure 2) through plotting the amount of parking infractions on the y-axis and the parking location occupancy percentage on the x-axis. The parking location occupancies were grouped in five percent intervals (0%-5%, 5%-10%, etc.). A few adjustments were made to the parking infractions values to account for certain variables (e.g., length of road segment). The adjustments are the following:

- The total hours over which the analysis is conducted is accounted for through dividing the parking ticket frequency by the number of paid-parking requirement hours: 92 days x 12 hours per day, resulting in 1,104 hours.
- After, the total length of the road segments examined is accounted for by dividing the parking tickets/hour by: 8.02km (arterials) + 2.13km (locals) + 4.26km (collector), totaling 14.40 km.
- Studies have shown that only about 0 to 6 percent of illegal parking act are caught by parking enforcement [12,2]. To account for this underreporting, it is assumed that the recorded parking tickets represent approximately three percent of the actual illegal parking acts. Therefore, the parking tickets/(hour *kilometer) are adjusted by the following factor: 100% / 3% = 33.33.
- Even with the adjustment above, the y-axis values are relatively low, making it difficult to create exponential models. To resolve this, the y-axis values are scaled by 10,000. The unit of the y-axis is still parking acts/(hours*km) but now the results of the model predict the amount of parking acts every 10,000 hours.
- Finally, the amount of 15-minute parking location occupancies observed within the on-street parking payment transaction dataset (Table 3) varies between the five percent quantiles. For example, the dataset from Section 3.4 shows that 8.4 percent of the 15-minute parking occupancies fall within the 15%-20% quantile and 2.8 percent fall within the 30%-35% quantile. This makes parking infractions more likely to occur adjacent to parking location occupancies between 15% to 20% than compared to parking location occupancies between 30% and 35%. Ideally, there would be an equal number of observations for each parking occupancy quantile in Table 3. To account for this, an adjustment factor is applied to the y-axis values to account for the difference in parking occupancy frequency. Table 4 presents the adjustment factors applied to the overall combined dataset:

## References

[12] Cullinane, K., & Polak, J. (1992). Illegal parking and the enforcement of parking regulations: causes, effects and interactions. *Transport Reviews*, *12*(1), 49–75. https://doi.org/10.1080/01441649208716803

[2] Zoika, S., Tzouras, P. G., Tsigdinos, S., & Kepaptsoglou, K. (2021). Causal analysis of illegal parking in urban roads: The case of Greece. *Case Studies on Transport Policy*, *9*(3), 1084–1096. https://doi.org/10.1016/j.cstp.2021.05.009

Table 4. Adjustment factors for parking location occupancy percentage mismatch

| Parking Occupancy Percentage | Proportion of Parking Location Occupancies From Table 3 that Occur Within Each Quantile | Ideal proportion within each quantile | Adjustment Factor |
|---|---|---|---|
| 0% - 5% | 33.4% | 5% | 0.150 |
| 5% - 10% | 20.4% | 5% | 0.245 |
| 10%-15% | 13.3% | 5% | 0.377 |
| 15%-20% | 8.4% | 5% | 0.596 |
| 20%-25% | 6.0% | 5% | 0.829 |
| 25%-30% | 4.1% | 5% | 1.217 |
| 30%-35% | 2.8% | 5% | 1.790 |
| 35%-40% | 1.9% | 5% | 2.660 |
| 40%-45% | 1.0% | 5% | 4.817 |
| 45%-50% | 0.5% | 5% | 9.342 |
| 50%-55% | 0.3% | 5% | 15.262 |
| 55%-60% | 0.2% | 5% | 24.599 |
| 60%-65% | 0.1% | 5% | 37.000 |
| 65%-70% | 0.1% | 5% | 62.493 |
| 70%-75% | 0.1% | 5% | 77.075 |

The analysis is stopped at the 70%-75% parking quantile due to the adjustment factors significantly increasing. Restraining the analysis to the quantiles between 0% and 75% balances the need to develop the models for a range of parking occupancy levels and concerns regarding the size of the adjustment factors. The frequency of each parking infraction type within the combined dataset after restricting the analysis to parking location occupancies less than 75% is shown in Table 5. There is now a total of 191 parking infractions included within the analysis.

Table 5. Frequency of each parking infraction after restricting parking occupancy at 75%

| Parking Infraction | Frequency |
|---|---|
| Stopping Vehicle Other than a Bicycle in a Bike Lane | 88 |
| Stopping on or over a sidewalk/footpath | 32 |
| Park within 9.0 meters of the intersection road | 25 |
| Stop non-bicycle in cycle track | 13 |
| Park within3 30.5 meters of a signalized intersection | 13 |
| Stop within 15.0 meters of the approach of a pedestrian crossing | 10 |
| Park on the boulevard | 5 |
| Stop within 9.0 meter beyond a pedestrian crossing | 4 |
| Park between road and sidewalk | 1 |

After the adjustments, the relationship between on-street parking occupancy and illegal parking is explored using linear and exponential regression models. Linear modelling was initially tested, but after getting negative intercepts, it was determined another model may be more realistic. Exponential modeling is used because y-axis values increase sharply at higher parking occupancy quantiles. The modelling examines the relationship for the overall combined dataset but also for the following situations:

- Different times of day
    - Weekdays, 8:00am-12:00pm
    - Weekdays, 12:00pm-4:00pm
    - Weekdays, 4:00pm-8:00pm
- Different road classifications
    - Arterial
    - Collector
    - Local
- Active transportation infrastructure
    - Blocking bike lanes for the street segment with the highest amount of infractions
    - Parking on sidewalks for the street segment with the highest amount of infractions
    - Parking within 15 meters on the approach of a crosswalk or 9 meters beyond a crosswalk for the street segment with the highest amount of infractions
- The effect of loading spaces on illegal parking
    - The criteria for this scenario is that a road segment needs to have a no-parking, no-standing zone, or short-term parking area (i.e., 15 minutes or less)

The analysis does not examine the relationship on weekends due to limited data in the combined dataset. The three active transportation infrastructure issues related to illegal parking are selected because they represent the most frequent road safety concerns within the parking infraction dataset. The effect of nearby loading spaces is explored due to illegal parking typically occurring for short durations[13]. The number of parking infractions for each scenario is shown in Table 6.

## References

[13] Gao, J., Zuo, F., Ozbay, K., Hammami, O., & Barlas, M. L. (2022). A new curb lane monitoring and illegal parking impact estimation approach based on queueing theory and computer vision for cameras with low resolution and

Table 6. Number of parking infractions for each scenario

| Scenario | Number of Parking Infractions |
|---|---|
| All Times and Locations | 191 |
| Weekday Mornings | 50 |
| Weekdays Afternoons | 107 |
| Weekday Evenings | 34 |
| Arterial Roads | 98 |
| Collector Roads | 49 |
| Local Roads | 36 |
| Bike Lanes | 63 |
| Sidewalk | 25 |
| Crosswalk | 13 |
| Loading Spaces | 90 |

low frame rate. *Transportation Research Part A: Policy and Practice*, *162*, 137–154. https://doi.org/10.1016/j.tra.2022.05.024

## 4.0 Results

This section presents a summary of the results from modelling the different scenarios. Table 7 shows the model equations, R-squared ($R^2$) values, and p-values for the independent variables.

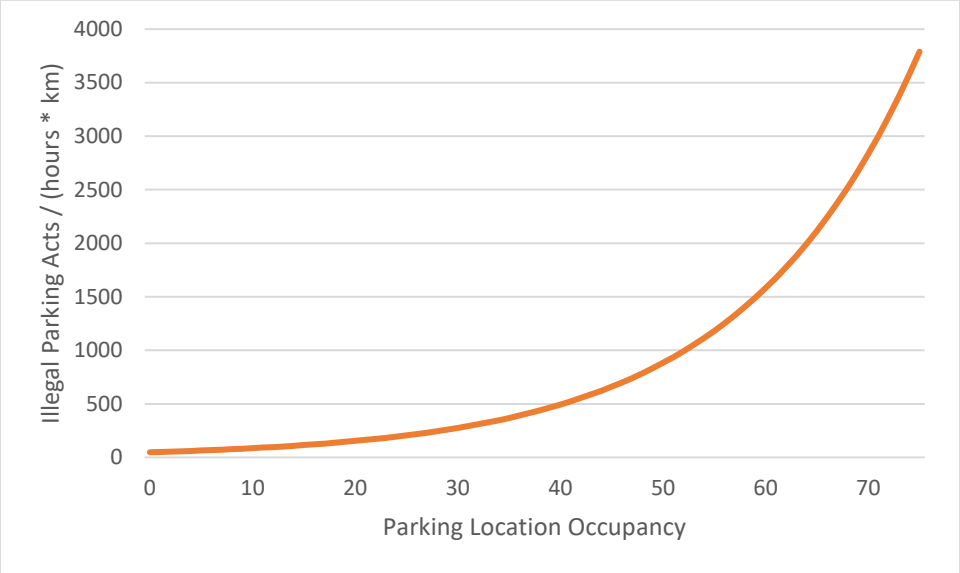
Table 7. Linear and exponential models for every scenario

| Scenario | Linear Model | Exponential Model |
|---|---|---|
| All Times and Locations | y= -215.453+30.605*x<br>R^2 = 0.469*** | y=e^(0.058*x+3.870)<br>R^2 = 0.713*** |
| Weekday Mornings | y= -562.866+31.428*x<br>R^2 = 0.658*** | y=e^(0.059*x+3.468)<br>R^2 = 0.637*** |
| Weekdays Afternoons | y= -32.0468+17.999*x<br>R^2 = 0.233* | y=e^(0.059*x+3.545)<br>R^2 = 0.575*** |
| Weekday Evenings | y= -244.329+18.713*x<br>R^2 = 0.714*** | y=e^(0.049*x+3.805)<br>R^2 = 0.765*** |
| Arterial Roads | y = - 141.4 -6.691*x<br>R^2 = 0.003 | y=e^(0.008*x+4.712)<br>R^2 = 0.390* |
| Collector Roads | y=46.91+1.987*x<br>R^2 = 0.089 | y=e^(0.013*x+4.126)<br>R^2 = 0.037 |
| Local Roads | y= -461.8+36.17*x<br>R^2 = 0.699*** | y=e^(0.082*x+3.134)<br>R^2 = 0.751*** |
| Bike Lanes | y = 2.207 + 9.818*x<br>R^2 = 0.145 | y=e^(0.057*x+3.433)<br>R^2 = 0.279 |
| Sidewalk | y= -4463+169.4*x<br>R^2 = 0.562 | y=e^*(0.099*x+3.462)<br>R^2 = 0.5452 |
| Crosswalk | Not enough data points to create a model | Not enough data points to create a model |
| Loading Spaces | y= -39.239+4.834*x<br>R^2 = 0.429** | y=e^(0.033*x+383)<br>R^2 = 0.480*** |

***p-value < 0.01
**p-value < 0.05
*p-value < 0.2

The first scenario, covering all times and sites, shows that there is a statistically significant correlation between on-street parking location occupancy and illegal parking. Within this scenario, the exponential model is a better predictor of illegal parking, with a higher $R^2$ value than the linear model. Furthermore, the exponential model is more realistic due to the linear model having a negative intercept, which implies a negative number of illegal parking acts. The exponential model predicts that when an on-street parking location has no vehicles parked, that there will approximately 48 illegal parking acts for every 10,000 hours for every kilometer of road. The exponential model also estimates that the amount of illegal parking acts for every 10,000 hours will increase to 871 illegal acts per kilometer of road when the adjacent parking lane is at 50 percent occupancy. Figure 2 shows the first scenario plotted for parking occupancies up to 75 percent.

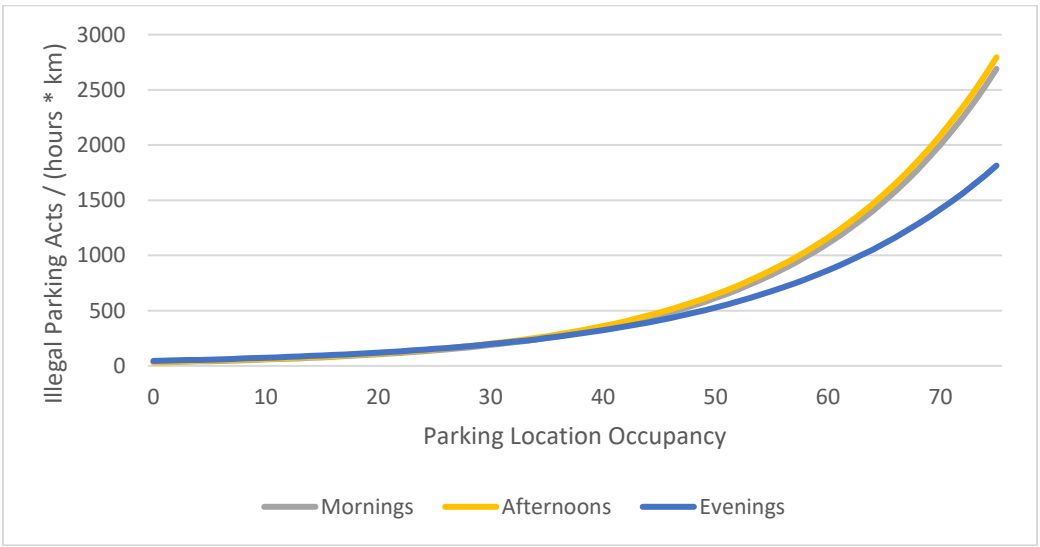
Figure 2. Illegal parking acts versus parking location occupancy




For the different times of the day during weekdays, the exponential and linear models show that parking location occupancy has a statistically significant effect on illegal parking. The only exception is the linear model for weekday afternoons, where the p-value, ranging from 0.05 to 0.2, indicates that there is only a weak correlation. Even though the $R^2$ for the weekday morning linear model is slightly higher than the $R^2$ value for the weekday morning exponential model, the exponential models for all times of the day will be examined further due to their intercepts not being negative.

Figure 3 shows the exponential models for different times of the day during weekdays. Parking location occupancy has a stronger influence on illegal parking earlier in the mornings and afternoons. This indicates that parking enforcement during weekday mornings and afternoons can potentially reduce illegal parking more than parking enforcement during weekday evenings.

Figure 3. Parking location occupancy versus illegal parking acts for different weekday time periods



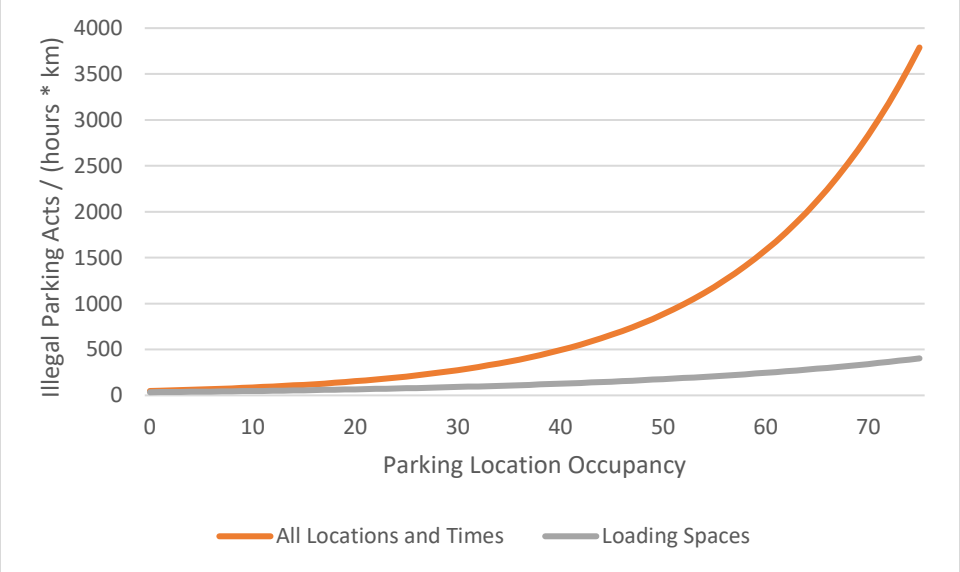
For the different road classification models, only the linear and exponential models for the local road classifications show statistically significant correlation between parking location occupancy and illegal parking. In addition, the slopes for the linear and exponential models decrease from local to collector and then to arterial roads. Even though the collector and arterial models are not statistically significant, this could suggest that as road classification changes from low volume to high volume, drivers are less willing to park illegally. This would be logical due to drivers being more willing to block vehicle travel lanes on roads with less traffic. Further data collection and analysis are needed to confirm any potential effects of road classification on illegal parking.

For the three different types of active transportation road safety issues, the bike lane and sidewalk models show no statistically significant correlation between parking location occupancy and illegal parking. This could indicate that high parking location occupancy does not make drivers more likely to park illegally within bike lanes or sidewalks compared to any other type of transportation infrastructure. There were not enough data points to create a linear or exponential model for the crosswalk scenario.

A potential solution to illegal parking explored through modelling is having loading zones nearby on-street parking areas. The modelling shows statistically significant correlations and moderate R^2 values for the linear and exponential models. The exponential model is explored further due to it having a lower p-value and a higher R^2 value.

Figure 4 compares the exponential models for the All Locations and Times scenario versus the Loading Spaces scenario. Parking location occupancy has a significantly lower effect on illegal parking for the Loading Spaces scenario compared to the All Locations and Times scenario. This could indicate that loading spaces nearby on-street parking locations lowers the frequency of illegal parking.

Figure 4. Parking location occupancy versus illegal parking acts comparing the all sites and times scenario to the loading spaces scenario



## 5.0 Discussion

The results show a clear correlation between parking location occupancy and illegal parking behaviour. For the overall condition, the exponential model was able to explain 71.3 percent of the variability within the illegal parking dataset, showing that parking location occupancy is an important factor but other aspects affect illegal parking. These results are consistent with the prior research presented in Section 2.1 and provide a quantitative model for predicting how illegal parking activity increases with parking location occupancy. This paper has focused on illegal parking that causes road safety issues but this methodology could be expanded to other forms of illegal parking.

The willingness for people to park illegally due to high parking location occupancy could be explained by the psychology of drivers. One study found that drivers may chose to park on sidewalks because they consider the safety of pedestrians the responsibility of others[14]. Another study found that the purpose of a driver's trip purpose and the driver's awareness of parking regulations are important factors for a driver's willingness to park illegally[15]. Furthermore, when the time driver's have to find on-street parking decreases, they are more willing to park illegally[5].

There are multiple strategies that can be implemented to reduce road safety issues related to driver parking illegally. One shown through the results of this paper and through other papers could be to create temporary loading or short-term parking zones nearby locations with large amounts of illegal parking activity. The results in Figure 4 show that loading spaces nearby parking locations lowers the likelihood of someone committing an illegal parking action. Another study from Toronto, Canada found that the availability of loading areas was negatively correlated with commercial vehicle parking infractions[16]. One potential reason for this relationship between loading areas and illegal parking could be due to loading areas accommodating the short-term nature of illegal parking. One study showed that most illegal parking actions last fewer than four minutes, regardless of the amount of illegal parking activity in the area[13].

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Another strategy could be to increase the enforcement of illegal parking in problematic areas. One study showed that 95 percent of drivers were willing to follow parking regulations when significant fines and strict enforcement were in place[17]. Stringent parking enforcement could be completed through video surveillance, which has been shown to be effective, but that can be costly and there could be visibility issues[10]. An alternative is to use data driven approaches to predict illegal parking behaviour to more effectively use enforcement resources[10].

## 6.0 Conclusion

The exponential relationship between parking location occupancy and illegal parking shows that managing on-street parking is critical to improving road safety. While maximizing occupancy in paid on-street parking areas provides revenue, in certain areas nearby popular destinations or with vulnerable road users (e.g., bike lanes), an evaluation of the trade-off between revenue and road safety should be conducted. Through analyzing parking infractions, areas with high illegal parking activity may be identified. Parking enforcement and loading areas are two potential ways of decreasing illegal parking activity and improving the safety of vulnerable road users.

The linear and exponential models provide insight into how an important factor, on-street parking availability, contributes to illegal parking. Through the modeling focusing on the potential causes of illegal parking related to road safety issues, this paper explores a topic that has not been extensively researched. Further data collection and analysis could provide additional information regarding any potential influence that road classification and active transportation infrastructure has on illegal parking activity.

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