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Analysis of Maneuver Time due to On-street Parking Near Signalized Intersections

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Abstract

The present study analyzes the variation in maneuver time of different vehicle types during on-street parking near signalized intersections with mixed traffic conditions. Traffic engineers frequently overlook this type of maneuver and their impact on a signalized intersection's performance while designing and assessing one. In this study, different type of vehicles, such as car, Two-Wheeler (TW), Autorickshaw (Auto), and Light Commercial Vehicles (LCV), are identified as parked vehicles near an intersection. Data on parking and maneuver time have been gathered from multiple Indian states. In this study, LCVs have the longest average maneuver time (MT) of 12.81 seconds (sec), followed by cars (10.25 sec), auto (7.58 sec), and TW (5.01 sec). According to these observations, maneuvering time (MT) for various types of vehicles operating in mixed traffic conditions vary considerably (5 to 13 sec). Further, the study analyzes vehicle MT among different vehicle classes and different intersections with parking maneuvers in the vicinity. The maneuver time (i.e., the time for which a parking vehicle blocks the traffic) observed in the present study is less than half of the benchmark values typically cited in capacity analysis guidelines. Notably, those conventional benchmarks are often applied uniformly, without differentiation across vehicle categories, approach volumes, or traffic composition. The outcomes of the current study will be useful for transportation planners to evaluate the performance of signalized intersections considering the effect of parking in the vicinity.

Keywords

signalized intersection, maneuvering time, parking, vehicle type

1 Introduction

It is necessary to locate a parking spot for a vehicle both at the outset and at the end of each and every trip. In recent years, there has been a tremendous increase in vehicle traffic, which has resulted in an increasing need for parking in metropolitan areas. Even though the majority of industrialized cities today have a greater number of dedicated parking places, these cities nonetheless frequently have to cope with traffic that is backed up during peak hours. Majority of drivers park their cars on the street, even though doing so is against the law (Kurek and Macioszek, 2022), because it is more convenient. On-street parking maneuvers commonly hinder traffic, and even if they only do so for a small amount of time, this obstruction can add to the delay experienced by approaching vehicles and therefore degrade the performance of the signalized intersections (Cao and Menendez, 2015; Gayah et al., 2016). The capacity of the facilities has decreased as a result of these parked vehicles. Understanding maneuver time patterns of parked vehicles is fundamental to improving urban mobility, optimizing parking systems, and enhancing traffic flow efficiency. These patterns influence road congestion, curbside activities, and parking turnover rates, directly affecting pedestrian safety and vehicular movement.

To account for the effects of on-street parking on the saturation flow estimation, Highway Capacity Manual provides an adjustment factor (Transportation Research Board, 2016). This adjustment factor takes into account the amount of parking maneuvers performed each hour, the total number of lanes, and the standard blockage duration or the maneuvering duration of parking vehicle of 18 sec. The duration required for vehicles to perform parking maneuvers in Transportation Research Board (2016) is based on a lane-based traffic with designated parking lanes. However, the application of this adjustment factor is not suitable in mixed traffic conditions. Especially in countries such as India, where the absence of

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dedicated parking lanes is typical. Consequently, there will be fluctuations in the width of lanes occupied by parked vehicles and a significant degree of variability in the time required for maneuvering. The objective of this study is to investigate the impact of non-lane-based traffic conditions on the maneuvering duration of parking vehicles. The study will explore the factors that influence MT, such as vehicle type, location, and vehicle composition.

The findings from this study will provide valuable insights into MT of vehicles in non-lane-based mixed traffic conditions. This would prove beneficial for traffic planners in properly evaluating the effectiveness of signalized intersections and optimizing signal timing accordingly. Researchers can use Markov chain models employed in this study to predict maneuver transitions and optimize space utilization for different vehicle classes. Moreover, integrating maneuver time analysis into microscopic traffic simulations enhances urban planning by forecasting congestion levels and designing effective parking layouts. Autonomous vehicles, powered by AI-driven maneuver strategies, rely on these insights for seamless parking, collision avoidance, and adaptive navigation. By leveraging these models, cities can reduce unnecessary circulation, minimize delays, and implement smart parking guidance systems, ultimately advancing sustainable urban development.

2 Background

Side friction encompasses a comprehensive factor that sheds light upon the extent of interaction between the regular flow of traffic and the myriad of activities transpiring in its vicinity. Numerous studies conducted in developing nations have shed light on the abundant activities taking place alongside and occasionally even on the roadways, rendering urban road operation a challenging task (Bang, 1995; Chiguma, 2007). According to the insights of Bang, (1995), side friction entails from the proximity between the flow of traffic and the diverse activities occurring in close proximity, at times even across or within the very carriageway itself. This encompasses factors such as on-street parking (Biswas et al., 2017), pedestrian behavior (Bak and Kiec, 2012; Cao and Li-ying, 2021) pedestrian crossing, buses stopping at curbside bus stops, bus lanes (Cao et al., 2017), presence of vendors, access points, and the presence of non-motorized vehicles (NMVs) (Purohit et al., 2014). It is imperative to note that parking movements encompass both the longitudinal and lateral dimensions of the road, and they exert a significant influence on the efficiency of traffic flow. Several studies, including those conducted by Edquist et al. (2012), and Kladeftiras and Antoniou (2013) have adeptly examined the deceleration in traffic flow on urban roads attributed to parked vehicles, which contributes significantly to side friction.

In a study conducted by Behbahani et al. (2017), it was discerned that the time required for a parking maneuver is influenced by the width of the approach, with maneuver duration increasing as the width of the lane decreases. At intersections, taxis were found to possess an average maneuvering duration of 7.37 sec.

After conducting an extensive review of the available literature, our comprehensive investigation has uncovered a noteworthy finding: the temporal aspects associated with parking automobiles are essentially dynamic, influenced by a variety of factors as illustrated in Fig. 1. The allocation of time for maneuvering plays a crucial role in determining the correction variables for saturation flow calculation. Nevertheless, it is important to acknowledge that the existing body of research in this particular field has primarily concentrated on traffic scenarios that are identical in terms of lanes, with a specific emphasis on dedicated parking lanes. As a result, there is a significant lack of academic research regarding the variability of MT in the context of mixed traffic conditions. Fig. 1 gives many elements that have been observed to influence the duration of blockage in prior research investigations.

The literature highlights the importance of comprehensive planning, effective mitigation strategies, and careful consideration of the trade-offs between parking convenience and intersection efficiency. As urban areas continue to evolve, urban planners and transportation engineers must collaborate to strike a balance between accommodating on-street parking demand and maintaining optimal signalized intersection performance. To achieve this, an understanding of the MT (or even called blockage time) due to parking vehicles is crucial.

3 Methodology

The subsequent image (Fig. 2) illustrates the methodology framework utilized in this study. This study aims to examine the various elements that affect the time it takes for

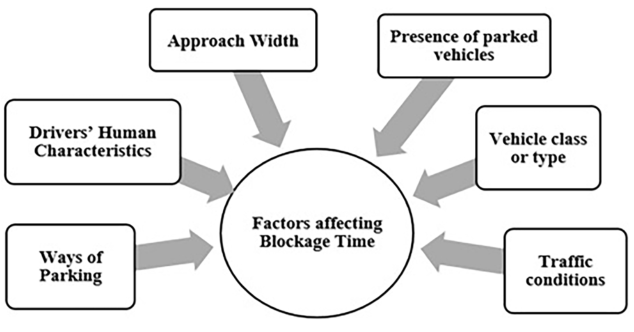

Fig. 1 Summary of literature review

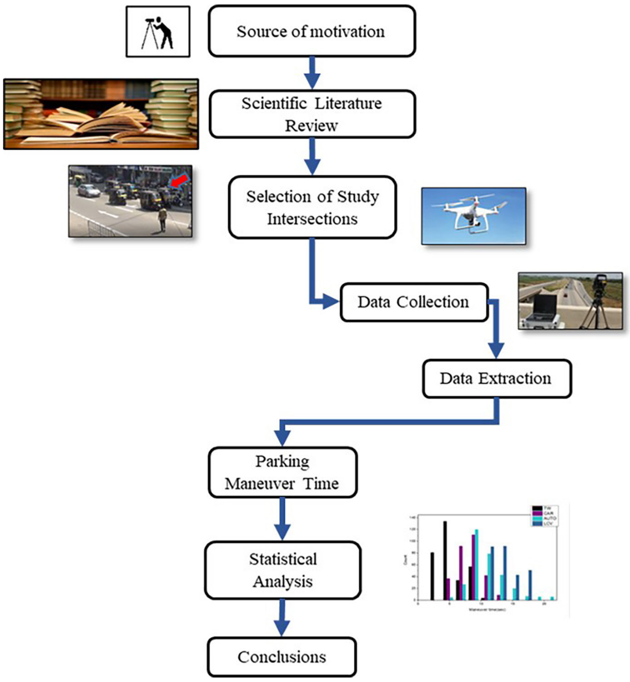

Fig. 2 Flowchart for proposed methodology

automobiles to park, in line with the overall goal of our research. In order to examine the variability in MT, a comprehensive videographic survey was undertaken at four unique locations. This survey methodically captured the intricate interaction between human behavior and environmental conditions.

At each of these sites, the method of extracting data involved carefully winding back the recording on a lab monitor. This allowed us to obtain useful information about the makeup of the traffic, the types of parked cars, and how long it took for them to move. UAVs were utilized for data collection instead of static cameras primarily due to the lack of a sufficiently elevated vantage point. They also enable a complete view of vehicle maneuvers that are often obscured in footage from fixed positions, such as the exact moment a vehicle blends into traffic or comes to a stop. These transitions are difficult to pinpoint from static angles.

Video data collection was conducted using the DJI Air 3 UAV, selected for its capability to capture orthogonal views in ultra-high-definition 4K resolution at 60 frames per second. Where necessary, fallback settings of 720p at 30 fps were employed to ensure uninterrupted recording. This setup effectively mitigated occlusion issues commonly caused by heavy commercial vehicles (HCVs) which often obstruct static camera views.

Recordings spanned a section extending 100 meters upstream and 40 meters downstream from the stop line of the intersection, providing a comprehensive view of vehicle maneuvers and intersection dynamics. All UAV flights were carefully monitored to maintain stable and consistent framing, proper orientation for capturing vehicle movement and intersection geometry, minimal external interference, such as weather conditions or bird activity. Due to UAV battery limitations, video was recorded in sets of 15-minutes over a total duration of 1 hour.

The time was measured with a precision of two decimal places. Details such the approach name, vehicle class, and the beginning and ending times of parking operations were noted down. The measurement of MT involves the computation of the time difference between the termination and initiation of parking activities of a vehicle at a designated approach to a signalized intersection. The time is measured from the precise moment the vehicle initiates the maneuver to the time when the vehicle resumes a stable trajectory or comes to a stop. The histograms, box plot, and cumulative distribution function (CDF) were displayed to analyze the variance in MT with respect to vehicle type, and location. To determine if there is a statistically significant difference in the variance of the computed MTs of the four types of vehicles at the four separate sites, the non-parametric Analysis of Variance (ANOVA) test was utilized.

4 Data collection and extraction

The present investigation included the collection of videographic field data at signalized intersections from four separate locations located in the middle and south western areas of India (Fig. 3). The selected locations, as shown in Fig. 3, are distributed across several regions of India, and thus offering a comprehensive geographical representation. The inclusion of a diverse range of traffic composition and driving patterns in various sections of the country was ensured through selection of intersections in three Indian cities, namely Nagpur, Surat

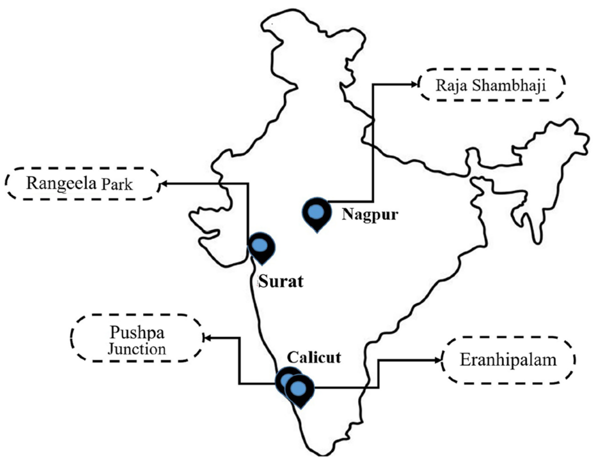

Fig. 3 Study sites

and Calicut (refer Fig. 3). Four types of vehicles, including cars, TW, auto, and LCV were observed as parked vehicles in the vicinity of the above selected intersections in Fig. 3.

Table 1 provides information about the selected intersections as well as the schedule for conducting the traffic surveys.

The data that have been extracted provide insights on the mix of traffic at each specific site. Figs. 4(a) to (d) display the distribution of vehicle classes based on their respective percentage shares.

The traffic seen in the field mostly comprises TW, followed by three-wheelers (Auto), and subsequently cars. These intersections exhibit a relatively low presence of LCVs, heavy commercial vehicles (HCV), and buses. A limited proportion of cycle rickshaws are also found.

Table 1 Study areas and details of survey

Sl No. (Study site)	Name of intersection	City	Date and duration of data collection		Approach width (m)
I01	Pushpa Junction	Calicut	27/10/2022 Thursday	9.30 AM to 10.30 AM and 4.30 PM to 5.30 PM	7.0
I02	Rangeela Park	Surat	15/11/2022 Tuesday		7.5
I03	Raja Shambhaji	Nagpur	11/01/2023 Wednesday		10.5
I04	Eranhipalam	Calicut	09/11/2022 Wednesday		12.5

5 Analysis of maneuvering time

The duration of the maneuvering process was quantified by measuring the elapsed time from the moment of diverging from the traffic till reaching a parked position, as well as the time from the parked position to the point of merging back into the traffic flow. The study examined the variability in MT across different vehicle classes and locations.

5.1 Variation between vehicle classes

The MT is a measure of how long it takes for a vehicle to either diverge and park or merge into the traffic flow.

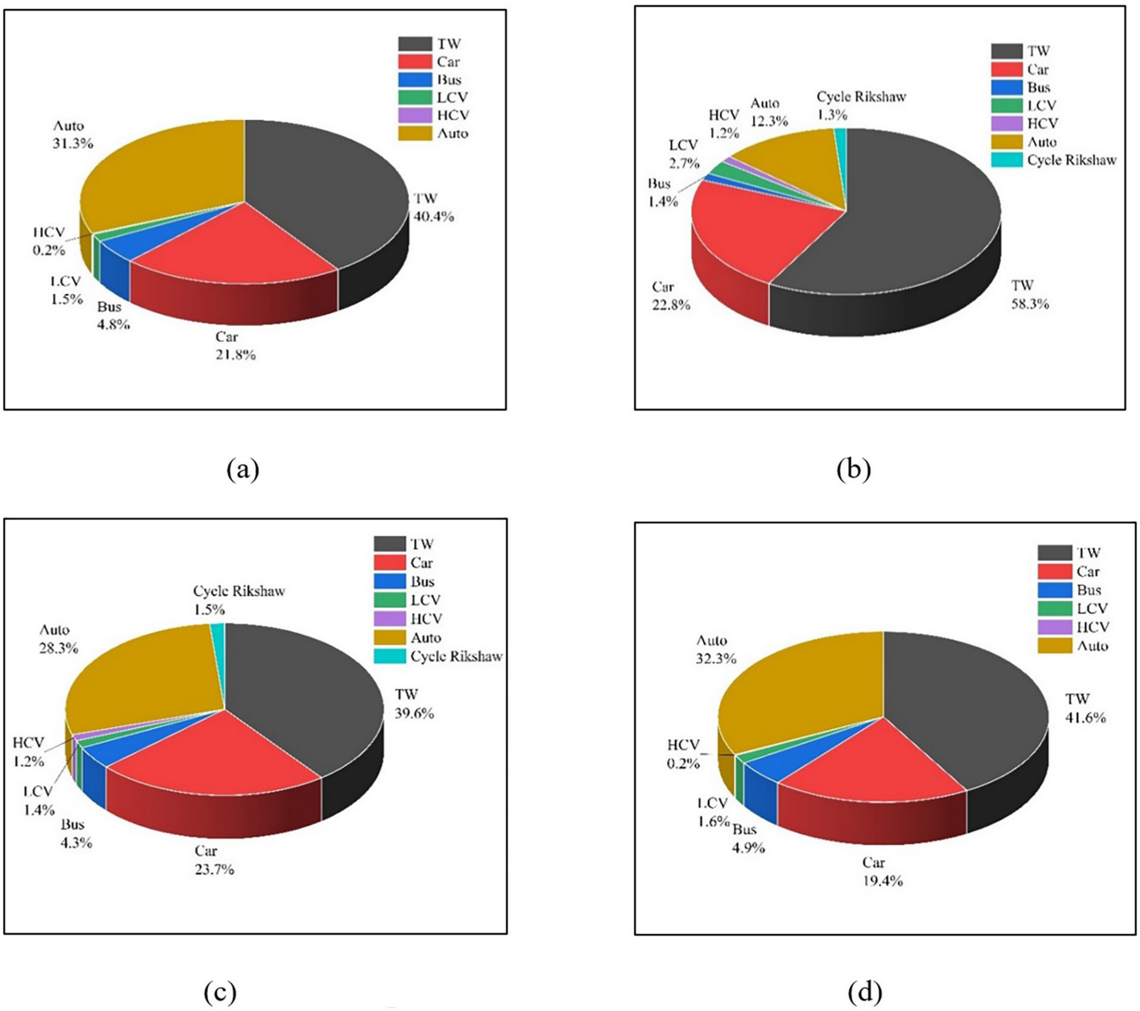

Fig. 4 Location wise traffic composition: (a) Traffic composition at I01; (b) Traffic composition at I02; (c) Traffic composition at I03; (d) Traffic composition at I04.

Data have been collected from four distinct geographical sites and subjected to analysis in order to determine the duration of maneuvers for different vehicle types namely, cars, TWs, autos, and LCVs.

Table 2 summarizes the descriptive statistics of the MT for each vehicle class. It was found that the MT for cars ranged from 4.00 to 20.00 sec, while for TWs it ranged from 2.00 to 11.00 sec. In addition, it was noted that the mean duration of maneuvers for autos was 26.04% less than that of cars, however for LCVs, it was 24.97% greater than that of cars. The average value for TWs is around 50% less than that of cars. These results suggest that the MT depends on the size and maneuverability of the vehicle, as well as the traffic conditions and parking availability at each location. For all the vehicle classes the MT is positively skewed while positive kurtosis is observed only for cars.

Fig. 5 depicts the distribution of MT for different vehicle classes using a box plot. The plot reveals that autos and LCVs exhibit a wider distribution of MT than cars and TWs, with more variability in the data. The frequency histogram plot for maneuver time, also shown in Fig. 5, indicates that the most frequent value of MT for TWs is 4.00 sec, while for cars and autos it is near to 8.00 sec, and for LCVs it is more than 10.00 sec. This observation suggests that TWs are more agile than cars and autos, while LCVs are less agile than other vehicle classes due to their size of the vehicle and engine configuration.

Table 2 Descriptive statistics of MT across vehicle classes

	TW	AUTO	CAR	LCV
Mean MT (sec)	5.01	7.58	10.25	12.81
Standard error	0.11	0.11	0.17	0.14
Standard deviation	2.01	1.96	2.98	2.30
Sample variance	4.05	3.84	8.86	5.28
Kurtosis	−0.37	−0.55	1.59	−1.13
Skewness	0.89	0.01	1.12	0.36
Minimum	2.00	4.00	4.00	10.00
Maximum	11.00	12.00	20.00	17.00
Count	310	291	313	277

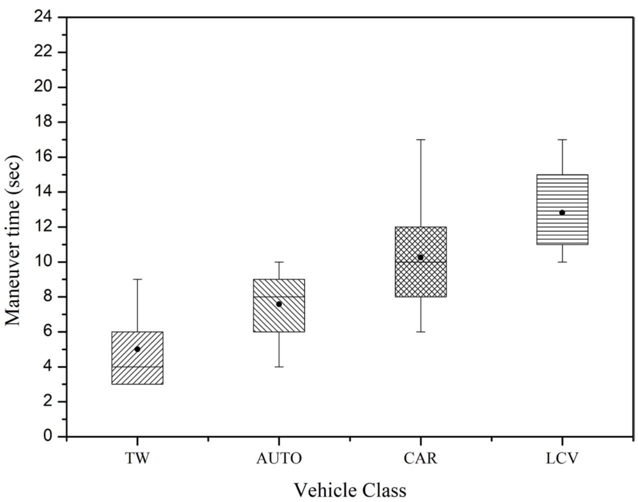

Fig. 5 Box plot representing the duration of maneuver time

Further it is evident [vide Fig. 6(a)], TWs and autos have a higher cumulative frequency at lower maneuver times, whereas cars and LCVs have a lower cumulative frequency for lower MT.

This difference in cumulative frequency of MT can be seen across the vehicle types which is presented in the CDF [refer to Fig. 6(b)]. For instance, the cumulative frequency of TWs is around 80 % for an operation that lasts for 6 sec, while the frequency of autos is approximately 70% over the same maneuver. On the other hand, the cumulative frequencies of cars and LCVs are around 20% and less than 5%, respectively, of all occurrences.

All vehicle types significantly deviate from normality ($p < 0.05$), justifying the use of non-parametric tests. Kruskal-Wallis analysis of variance (KW ANOVA) and Friedmans test is performed to examine the differences in variation among vehicle classes. Table 3 shows the results of the non-parametric tests. The analysis was performed at a 95% level of confidence, and the resulting p-value was found to be 2.14E-167. The statistical analysis indicates that, at a significance level of 0.05, there is a significant difference between the populations.

5.2 Variation between intersections

A detailed analysis was conducted to assess the geographical variation in MT. Table 4 presents the descriptive statistics of MT at different sites, categorized by various vehicle classes.

The analysis of descriptive statistics reveals that the average MT of different vehicle classes exhibits variation across distinct locations. The trend that was observed may have been caused by a combination of factors, including variations in the behavior of drivers and the geometric qualities of intersections in varying geographic regions.

Fig. 7 shows the location wise variability of average MT values across different vehicle classes. The MT for the vehicle classes auto, car, and LCV has a varying relationship with the width of the approach, characterized by an increase of MT with approach width followed by a subsequent decrease. This effect can be attributed to the modification in driving behaviors. When the approach width increases, drivers have a tendency to shift towards the lane adjacent to the

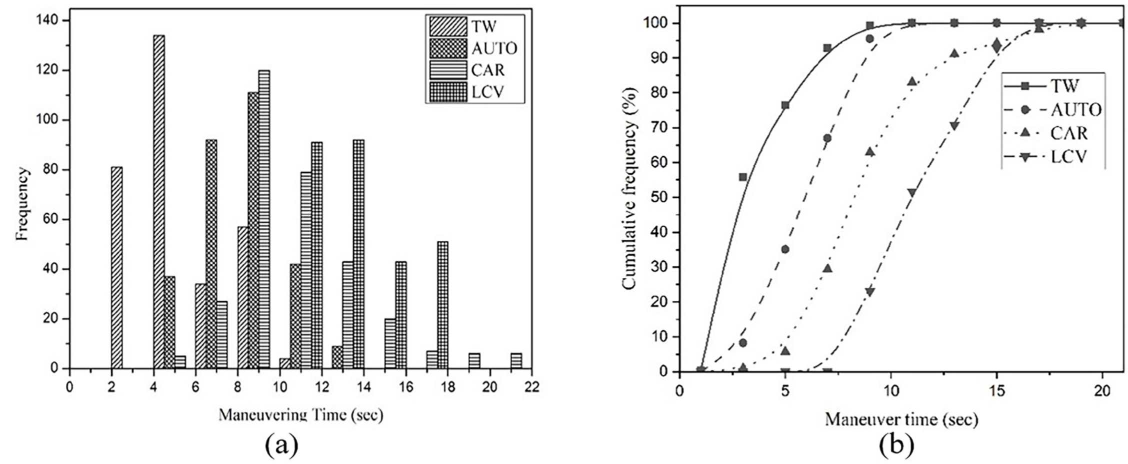

Fig. 6 MT variation across vehicle classes: (a) Frequency histogram of MT; (b) CDF of MT.

Table 3 Non-parametric test results

Test	Statistic	*df*	*p*-value	Effect size (η^2)
Kruskal-Wallis	734.09	3	0.0000	0.6631
Friedman	615.46	3	0.0000	0.5575

Table 4 Descriptive statistics for MT at different study locations

	Vehicle class	Mean MT (sec)	Standard deviation	Sample variance	Skewness
I01	TW	4.08	1.24	1.54	1.27
	AUTO	5.91	1.81	3.27	0.83
	CAR	9.65	2.61	6.84	0.58
	LCV	13.45	2.51	6.31	−0.06
I02	TW	4.37	1.24	1.54	1.31
	AUTO	8.60	1.64	2.69	0.04
	CAR	11.67	3.03	9.18	0.82
	LCV	13.66	1.78	3.16	0.27
I03	TW	5.24	2.20	4.82	0.69
	AUTO	8.52	0.98	0.96	0.04
	CAR	10.35	3.67	13.44	1.17
	LCV	12.59	2.58	6.63	0.41
I04	TW	6.13	2.31	5.33	0.02
	AUTO	7.63	1.83	3.35	0.87
	CAR	9.28	1.78	3.17	1.25
	LCV	11.81	1.73	3.00	1.14

shoulder and then eventually park. This behavior may be caused by factors such as traffic conditions, parking availability, and driver preferences. While MT of TWs increases with the width of approach, this tendency can be attributed to the relative ease with which the TW driver can perform the turning maneuver, often initiating the parking activity from a lane situated farther from the edge of the carriage way.

The results of the Kolmogorov–Smirnov (KS) test across vehicle types and intersections reveal consistent deviations from normality, justifying the use of non-parametric tests (Table 5). Two classes exhibited borderline normal behavior:

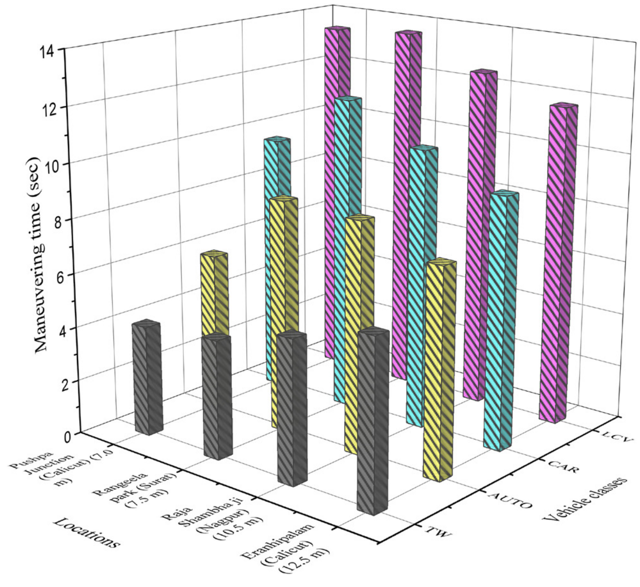

Fig. 7 Mean MT of vehicle classes at different locations

Table 5 Normality test results

Vehicle	Intersection	KS statistic	*p*-value
TW	I01	0.2383	0.0016
	I02	0.2363	0.0018
	I03	0.2741	0.0002
	I04	0.1880	0.0232
AUTO	I01	0.2177	0.0051
	I02	0.2651	0.0003
	I03	0.2098	0.0078
	I04	0.1444	0.1425
CAR	I01	0.1402	0.1651
	I02	0.1889	0.0222
	I03	0.1735	0.0447
	I04	0.1813	0.0317
LCV	I01	0.1447	0.1408
	I02	0.2014	0.0121
	I03	0.1908	0.0203
	I04	0.2100	0.0077

AUTO at I04 (p = 0.1425) and LCV at I01 (p = 0.1408). While both p-values exceed the conventional 0.05 threshold, indicating failure to reject the null hypothesis of normality, they remain close enough to suggest non-normality.

A Friedman's analysis of variance (ANOVA) and Kruskal-Wallis test was conducted to assess the statistical variation in MT values across multiple sites. Table 6 shows non-parametric Test results of the intersections.

The Kruskal-Wallis test revealed significant differences in vehicle counts across intersections for all vehicle types, indicating that traffic volumes vary significantly by location. Two-wheelers (TW) show a moderate intersection-level effect and a moderate repeated-measure effect. Autos showed the strongest intersection-level variation with a large effect size, while cars exhibited the mildest differences, suggesting more uniform distribution across sites. These findings highlight the need for intersection-specific traffic management strategies, especially for highly variable modes like autos and LCVs.

6 Markov Chain-based approach to analyzing MT shifts

Standard probabilistic models assume independent observations, but maneuver time transitions are sequentially dependent. Markov models adapt to changing probabilities over time, making them more suitable for dynamic urban environments. Fixed probabilistic models require predefined parameters, limiting adaptability. Markov chains dynamically adjust transition probabilities based on real-time data.

Markov Chain modelling is employed to assess the probabilistic behavior of MT for different vehicle types. Transition probability matrices are used to analyze long-term behavior and state dependencies within maneuvering processes. The stationary distribution of the Markov Chain is computed to evaluate long-term behavior, indicating the equilibrium probability of a vehicle remaining in a given maneuver state. This helps to determine whether certain maneuver times are dominant. Modeling vehicle movement using a Markov chain framework provides insights into maneuver time transitions across different vehicle classes. Each vehicle category (TW, AUTO, CAR, and LCV) is represented as a stochastic system, where maneuver time intervals serve as discrete states in the transition process.

Table 6 Non-parametric test results of the intersections

Vehicle	Test	Statistic (H / χ^2)	df	p-value	Effect size (η^2)
TW	Kruskal-Wallis	37.67	3	< 0.0001	0.1550
	Friedman	38.46	3	< 0.0001	0.1603
AUTO	Kruskal-Wallis	86.55	3	< 0.0001	0.3562
	Friedman	71.41	3	< 0.0001	0.2975
CAR	Kruskal-Wallis	13.68	3	0.0034	0.0563
	Friedman	12.67	3	0.0054	0.0528
LCV	Kruskal-Wallis	24.18	3	< 0.0001	0.0995
	Friedman	24.16	3	< 0.0001	0.1007

A Markov process describes transitions between states where future probabilities depend only on the present state (memoryless property). By constructing transition matrices, the probability of a vehicle remaining in its current maneuver duration or shifting to another category is quantified.

Here, maneuver time intervals act as system states:

- State 1: Maneuver time between 1–5 seconds;
- State 2: Maneuver time between 5–10 seconds;
- State 3: Maneuver time between 10–15 seconds;
- State 4: Maneuver time between 15–20 seconds.

Each vehicle class is modeled using a transition probability matrix, capturing how often a vehicle moves from one MT state to another.

General formulation of a transition matrix:

$$\boldsymbol{P} = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}, \quad (1)$$

where P_{ij} represents the probability of transitioning from State ii to State jj.

The transition probabilities reflect the likelihood of a vehicle's maneuver duration falling within each time interval.

The concept of equilibrium is interpreted as the steady-state distribution derived from the normalized frequencies. This distribution represents the long-run expected proportion of vehicles in each time bin.

Each heatmap (Fig. 8) serves as a visual representation of the likelihood of transition between different MT categories, allowing for an intuitive interpretation of maneuvering dynamics. The color bar positioned on the right-side acts as a probability scale, where varying color intensities correspond to different levels of transition likelihood. Darker shades indicate higher likelihoods of transition. These heatmaps provide critical insights into how different vehicle classes adjust their maneuver behavior over time. For instance, vehicles with shorter MTs may exhibit concentrated high-probability zones in early time intervals, while those with

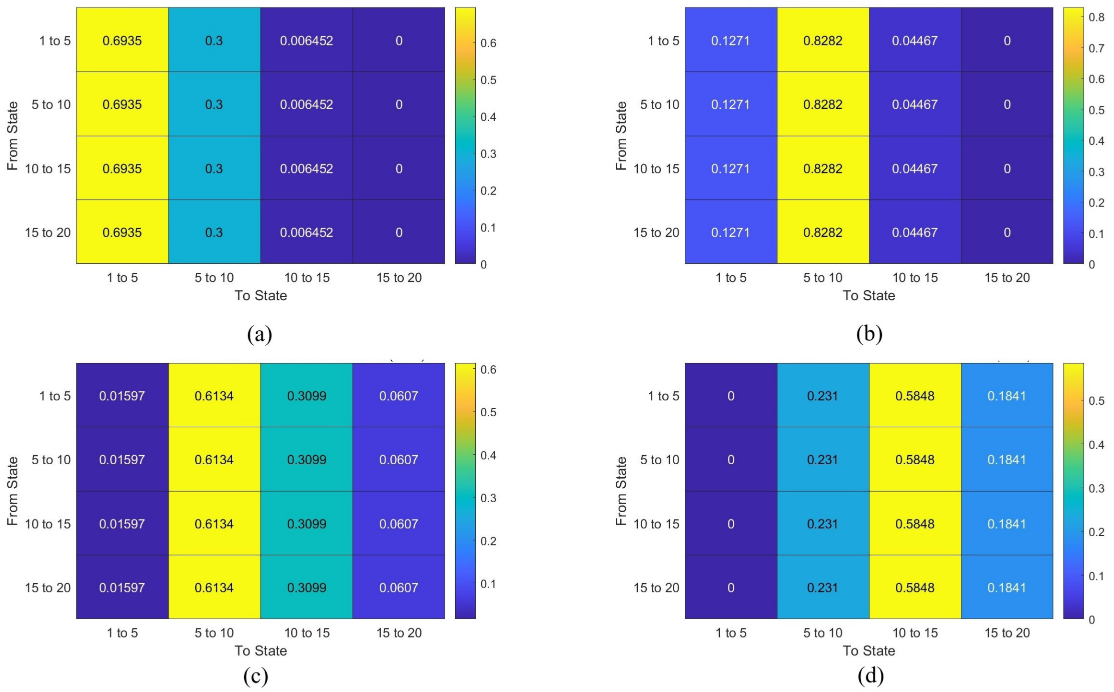

Fig. 8 Markov chain probabilities: (a) Transition Matrix for Vehicle Class 1 (TW); (b) Transition Matrix for Vehicle Class 2 (AUTO); (c) Transition Matrix for Vehicle Class 3 (CAR); (d) Transition Matrix for Vehicle Class 4 (LCV)

extended maneuver durations display broader transition patterns across multiple time intervals.

The highest probability is that the TWs remain in the lowest MT bracket, as TWs tend to execute short, frequent adjustments. The likelihood of TWs shifting to a significantly higher maneuver time category is low.

Autos exhibit high transition probability within mid-range maneuver times. The majority of them remain in the 5–10 sec interval. Turning radius for autos is higher than TWs, restricting quick directional shifts thus the probability of lower MT is moderate. However, due to the risk–taking behavior of auto drivers there is a lower probability of transitioning to longer maneuver times.

Cars exhibited higher flexibility in maneuver transitions, with significant probability (0.6134) of moving to the next maneuver time category. Cars exhibit significant movement across maneuver time states, with higher probability of transitioning to the next time interval showcasing adaptive driving behaviors. They have greater likelihood of transitioning into longer maneuver durations (10 to 15 sec) than TWs and autos, indicating adaptive behavior, possibly influenced by driving conditions (hence resorting to defensive driving while parking), lane changes, or traffic density.

LCVs demonstrate the most notable transition into longer maneuver durations; this suggests that LCVs require more maneuvering time due to vehicle size, engine capacity and load carried. Considering the above, compared to other vehicle classes, LCVs rarely stay within short maneuver durations.

To determine if the Markov transition probabilities align with expected distributions, Anderson-Darling (AD) Test was applied. They fit expected statistical behavior with no significant deviations.

7 Comparison with previous studies

The provided image (Fig. 9) presents a comparison of MT values for different types of vehicles in relation to known literature. The mean MT for cars observed in the present study (10.25 sec) exhibits significant variation compared to the values reported by Transportation Research Board (2016) (18 sec) and a study conducted by Cao and Menendez (2015) (17 sec). However, the acquired results closely align with those reported in the study conducted by Kurek and Macioszek (2022) (9.12 sec).

The mean MT reported from the present investigation is significantly lower compared to the majority of previous studies. The comparison of these values with those obtained for buses is not possible in this study, as it did not include an analysis of this specific vehicle class.

8 Conclusions

The performance of a signalized intersection is contingent upon a multitude of factors, with the proximity of parking facilities to the intersection being one among the

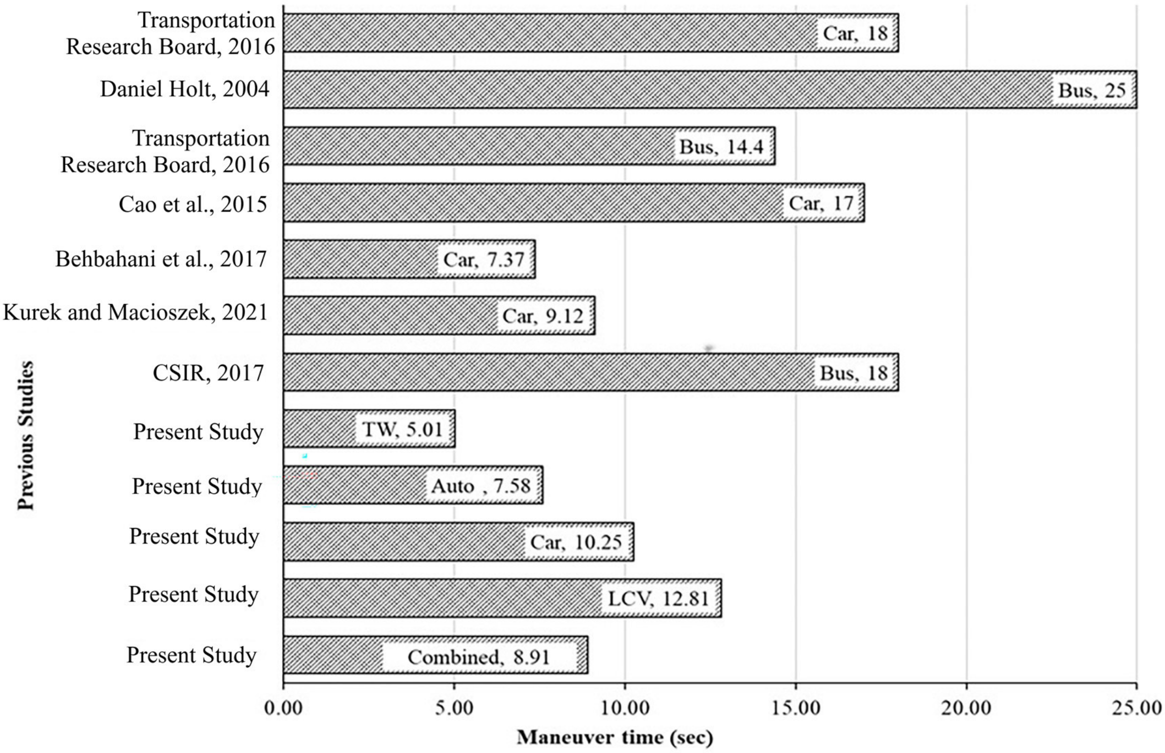

Fig. 9 MT values obtained in the study in comparison with literature

characteristics that influence its effectiveness. The duration of vehicle maneuvering, commonly referred to as blockage time / maneuver time (MT) due to its impact on traffic flow, is a dynamic variable influenced by factors such as vehicle type, vehicle characteristics, traffic composition, and drivers' behavior. The calculation of the saturation flow adjustment factor for parking near signalized junctions heavily relies on the MT, which is considered a key determinant. In particular, in scenarios with diverse traffic circumstances, the importance of these factors is significant due to the substantial differences in MT based on vehicle class and location.

The results of this investigation indicate that MT increases with vehicle size. The underlying factors contributing to this occurrence can be linked to the specific attributes of the vehicle as well as the actions and choices made by the driver. The average MT for cars has been identified as 10.25 sec, but LCVs exhibit a mean MT of 12.81 sec. TWs on the other hand, showed a mean MT of 5.01 sec. The data provided indicates that the average MT of LCVs is roughly 25% higher compared to that of cars. On the other hand, the MT for TWs is around 51% lower. Variations in MT are likely influenced by traffic dynamics within the study area, characterized by mixed traffic and informal lane usage i.e. lane change without signaling. Additionally, geometric road features such as reduced carriageway width, absence of dedicated parking spaces, and closeness to intersection turning zones may further contribute to these differences.

Moreover, the difference in MT between locations is also noteworthy. For autos, cars, and LCVs, the MT has a non-linear relationship with the width of approach. Specifically, the MT initially increases and then decreases. The observed trend can be linked to changes in driving behavior that arise when the width of the approach is increased. When the approach width is narrow, vehicles often start to park from whichever lane they are traversing, leading to a reduced MT. When the width of the approach is wide, drivers have a tendency to shift into the lane adjacent to the shoulder and then park their vehicles, which leads to a decrease in the time required for maneuvering. The observed behavior could potentially be influenced by various circumstances, including but not limited to traffic conditions, availability of parking spaces and choice of the individual driver and the driving traits. Further, the study revealed a positive association between the width of approach and the MT for TWs. The relative ease with which the TW drivers can make the turning maneuver helps to explain this behavior, frequently commencing the maneuver from a lane positioned at any distance from the roadside. As the width of the approach increases, the TW drivers will have to cover a greater distance and encounter a higher number of conflicts with other vehicles, thereby resulting in the increase in MT for some of the vehicle classes.

Additionally, a statistical analysis and Markov chain probability-based prediction was conducted, highlighting significant variations in maneuver time (MT) across different geographical locations, vehicle classifications, and traffic compositions. The observed differences in MT across vehicle classes not only highlight the role of approach width in shaping parking behavior but also reinforce broader maneuvering patterns seen at signalized intersections. The transition matrices presented for different vehicle types further illustrate how maneuver durations vary in response to vehicle-specific characteristics and operational constraints. The transition matrices presented for different vehicle classes reveal distinct maneuver time characteristics near signalized intersections. TWs predominantly exhibit shorter maneuver durations, with a high probability of remaining in the 1–5 second interval, indicating quick adjustments and minimal hesitation. Autos, constrained by a larger turning radius, show moderate maneuver persistence but maintain a lower likelihood of transitioning to longer maneuver times due to risk-taking behavior. Cars demonstrate varied maneuver durations, with significant probabilities of extending to mid-range intervals, reflecting strategic positioning in dense traffic. LCVs display extended maneuver times, primarily transitioning between 5–15 second intervals, likely influenced by their larger size and operational constraints.

The observed deviation from the Highway Capacity Manual's (Transportation Research Board, 2016) 18-second benchmark for maneuver time (MT) underscores the limitations of applying uniform standards to traffic environments characterized by heterogeneity and informal behavior. In the study area, MT is notably influenced by mixed vehicle types, informal lane discipline, and constrained road geometry—factors not adequately captured by the HCM 2016 (Transportation Research Board, 2016) framework. Understanding these maneuver patterns in both moving and stationary contexts is essential for developing integrated urban planning strategies. Aligning signal timing with parking space allocation, optimizing curbside accessibility, and refining vehicle-specific traffic control measures will ensure smoother transitions between vehicular movement and stationary phases. By incorporating both dynamic and stationary maneuver characteristics into transportation models, policymakers can create holistic solutions that minimize congestion, enhance roadway efficiency, and improve overall urban mobility. The findings highlighted a compelling rationale for formulating adjustment factors tailored to Indian traffic contexts. Embedding these into national manuals could significantly enhance the precision, fairness, and applicability of infrastructure planning tools.

Contributions of the present study

This study investigates the variation in MT of parked vehicles near signalized intersections, with a focus on how different traffic compositions influence these patterns. By comparing the MT values derived from field observations with those reported in existing literature, the research identifies both consistencies and deviations across vehicle classes. These comparisons yield critical insights into the behavior of various vehicle types in mixed traffic environments, particularly in the presence of undesignated on-street parking. The findings contribute meaningfully to the evaluation of signalized intersection performance and offer a robust foundation for refining parking adjustment factors used in saturation flow estimation under real-world, heterogeneous traffic conditions. The findings from this study offer a valuable empirical basis for developing new parking adjustment factors tailored to the Indian Highway Capacity Manual (CSIR, 2017).

Limitations and future scope

The study was conducted at only four different locations, which may not represent the entire range of signalized intersections and traffic conditions. In order to enhance the precision of outcomes, the scope of implementation might be widened to include other geographical areas. External factors like pedestrian activity can also affect the MT of vehicles. This aspect presents a promising approach for future research. The current analysis did not account for variations in the time of maneuvering that may arise from changes in the angle of parking. Further studies can be done to incorporate the angle of parking. Implementing a system for real-time data collection could help in understanding the variations in maneuvering time with changes in parking angles. Conducting simulation studies considering various parking angles and observing the effect on maneuvering time could also be a part of future work. During our observational period, buses were not observed to be parked or stopping near the studied intersections and were therefore excluded from the current analysis. However, other vehicle classes such as buses can be incorporated in future studies, as they are one of the critical components of urban traffic.

References

Bak, R., Kiec, M. (2012) "Influence of Midblock Pedestrian Crossings on Urban Street Capacity", Transportation Research Record: Journal of the Transportation Research Board, 2316(1), pp. 76–83. https://doi.org/10.3141/2316-09

Bang, K. L. (1995) "Impact of Side Friction on Speed-Flow Relationships for Rural and Urban Highways", Institute of Road Engineering, SWEROAD, Indonesia.

Behbahani, H., Jahangir Samet, M., Moghaddam Gilani, V. N., Amini, A. (2017) "Determining of the Parking Manoeuvre and the Taxi Blockage Adjustment Factor for the Saturation Flow Rate at the Outlet Legs of Signalized Intersections: Case Study from Rasht City (Iran)", IOP Conference Series: Materials Science and Engineering, 245(4), 042017. https://doi.org/10.1088/1757-899X/245/4/042017

Biswas, S., Chandra, S., Ghosh, I. (2017) "Effects of On-Street Parking in Urban Context: A Critical Review", Transportation in Developing Economies, 3(1), 10. https://doi.org/10.1007/s40890-017-0040-2

Cao, J., Menendez, M. (2015) "Generalized Effects of On-Street Parking Maneuvers on the Performance of Nearby Signalized Intersections" Transportation Research Record: Journal of the Transportation Research Board, 2483(1), pp. 30–38. https://doi.org/10.3141/2483-04

Cao, N., Li-ying, Z. (2021) "Analysis and simulation of pedestrians' behaviors at signalized intersections considering jaywalking" Transportmetrica B: Transport Dynamics, 9(1) pp. 491–518. https://doi.org/10.1080/21680566.2021.1914770

Cao, Y., Yang, Z., Zuo, Z. (2017) "The Analysis Method of Capacity and Delay on Entrance Lane with Road-side Bus Lane", Periodica Polytechnica Transportation Engineering, 45(1), pp. 1–7. https://doi.org/10.3311/PPtr.8677

Chiguma, M. L. M. (2007) "Analysis of side friction impacts on urban roads links: Case study, Dar-es-salaam", doctoral thesis, Royal Institute of Technology, Stockholm, Sweden. ISBN: 978-91-85539-17-8

CSIR (2017) "Indian Highway Capacity Manual (Indo-HCM)", [pdf] Council of Scientific and Industrial Research, New Delhi. Available at: https://crridom.gov.in/sites/default/files/files/Indo-HCM%20Snippets.pdf [Accessed: 01 June 2025]

Edquist, J., Rudin-Brown, C. M., Lenné, M. G. (2012) "The effects of on-street parking and road environment visual complexity on travel speed and reaction time", Accident Analysis & Prevention 45, pp. 759–765. https://doi.org/10.1016/j.aap.2011.10.001

Gayah, V. V., Guler, S. I., Gu, W. (2016) "On the impact of obstructions on the capacity of nearby signalised intersections", Transportmetrica B: Transport Dynamics, 4(1), pp. 48–67. https://doi.org/10.1080/21680566.2015.1052111

Kladeftiras, M., Antoniou, C. (2013) "Simulation-Based Assessment of Double-Parking Impacts on Traffic and Environmental Conditions", Transportation Research Record: Journal of the Transportation Research Board, 2390(1), pp. 121–130. https://doi.org/10.3141/2390-13

Kurek, A., Macioszek, E. (2022) "Impact of Parking Maneuvers on the Capacity of the Inlets of Intersections with Traffic Lights for Road Traffic Conditions in Poland", Sustainability, 14(1), 432. https://doi.org/10.3390/su14010432

Purohit, S., Chattaraj, U., Panda, M. (2014) "Experimental Study of Non-Motorized Vehicle Characteristics and Its Effect on Mixed Traffic", International Journal for Traffic and Transport Engineering 4(4), pp. 425–436. https://doi.org/10.7708/ijtte.2014.4(4).06

Transportation Research Board (2016) "Highway Capacity Manual 6th Edition: A Guide for Multimodal Mobility Analysis", The National Academies Press. ISBN 978-0-309-36997-8 https://doi.org/10.17226/24798