

## **BEHAVIORAL INFLUENCES ON INTERSECTION PERFORMANCE: QUANTIFYING CAPACITY LOSS FROM INFORMAL LANE BLOCKING UNDER MIXED TRAFFIC**

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### **ABSTRACT**

Urban congestion is often attributed to limited infrastructure though much of the delay in mixed-traffic environments arises from driver and rider behavior. This study investigates how short-term lane blocking that are primarily caused by easy-bikes and other informal modes during passenger pickup affects intersection discharge capacity. Field observations over ten days were conducted at a representative urban intersection in Khulna, capturing headways, vehicle composition and temporary lane blockages. Data were analyzed using both saturation-flow and PCU-adjusted methods to quantify the percentage loss in effective flow providing a robust assessment of behavioral impacts on intersection performance. Results reveal a consistent 22–25% reduction in capacity during blocked periods with both measures strongly correlated ( $r = 0.94$ ). Paired comparisons indicate no statistically significant difference between the two approaches confirming that either method reliably captures behavioral effects. These findings demonstrate that even short localized disruptions such as curbside waiting, wrong-lane positioning and intersection crowding can aggregate into substantial operational inefficiency reducing throughput well below theoretical capacity. The study underscores the potential of behavior-focused interventions to improve traffic operations without costly infrastructure expansion. Measures such as regulating pickup and drop-off activity, enforcing box discipline, and introducing designated stopping zones for informal modes can meaningfully mitigate capacity losses and enhance intersection efficiency. By quantifying the behavioral contribution to congestion, this research provides empirical evidence that complements traditional supply-side analyses, emphasizing the need to incorporate human behavior into traffic management strategies. The results are particularly relevant for mixed-traffic urban environments with high informal vehicle activity, offering planners and engineer a practical framework to monitor, mitigate, and sustainably manage operational inefficiencies at intersections.

**Keywords:** Traffic congestion; Mixed traffic; Behavioural impact; Intersection capacity; Lane blocking.

## 1. INTRODUCTION

Fast-growing cities frequently experience urban congestion as a result of an increase in automobiles that exceeds the capacity of the road infrastructure. City officials typically concentrate on large, costly initiatives to upgrade or expand roadways in order to address this. But this strategy commonly misses out one major issue which is the driver's behavior. In the south and south-east Asia a diverse range of vehicles are seen on the streets having almost no tendency to follow the traffic regulations. In spite of the existence of traffic laws their behavior, individual driving habits and lack of respect towards law can lead towards significant traffic bottlenecks.

Previous research indicates that mere non-compliance with lane discipline can severely bring down a road's capacity to handle the vehicles (Mallikarjuna & Rao, 2009). In most of the cases the issue starts with lane blocking by a para-transit like auto-rickshaws or easy-bikes as they pick up or drop of passengers in the middle of the road obstructing the vehicles behind it to pass. Although this halts appear short, they disrupt the flow of the traffic making other vehicles behind it to decelerate or shift lane. Such unforeseen and heterogeneous traffic flow forces drivers to maintain more gap between vehicles (Asaithambi & Shrivani, 2017), studies have shown, thereby bringing down the overall capacity of the road. This disruption is particularly damaging at un-signalized intersections — where traffic does not stop and start regularly — making these points key choke-points in urban traffic networks.” (Fatoni & Zabadi, 2022).

The study measures the amount of capacity loss caused by informal lane-blocking behaviour at a un-signalized intersection in Khulna, Bangladesh. This paper therefore empirically quantifies the capacity loss at an un-signalized intersection in Khulna, Bangladesh, that is caused by informal lane-blocking behaviour, using saturation flow rate and PCU-adjusted flow rate analyses so that the assessment will be accurate and context-specific.

## 2. LITERATURE REVIEW

Urban congestion in developing cities is an increasing problem that is exacerbated not only by the growth in the number of vehicles but also by driver behaviour-specially in mixed-traffic conditions. Mixed traffic conditions describe a road environment with a diverse mix of vehicles and weak lane discipline, common in developing countries, where different types of vehicles (e.g., cars, auto-rickshaws, easy-bikes, bicycles, pedestrians) share the road space without strict adherence to lanes. These informal vehicles have no regard for conventional traffic rules, resulting in disruptions in the smooth flow of traffic, especially at junctions. Lane-blocking, illegal stopping, and improper use of lanes are various forms of behaviours that are highly contributing factors toward capacity loss at intersections, thus making them major choke points in urban traffic networks. This is the case, especially in cities where there is a minimal amount of enforcement on the regulation of traffic, hence these behaviours go unchecked, furthering the worsening of congestion.

The role of informal modes in decreasing road capacity has gained broad attention in the literature on traffic management. Zhen et al. (2016) have conducted an empirical analysis that illustrated lane-blocking by non-motorized and para-transit vehicles, such as auto-rickshaws and easy-bikes, can significantly reduce intersection throughput. Their findings pointed out that these vehicles, being located on lanes or stopping at unwanted areas, do not simply delay the passing of other vehicles but create ripples that worsen congestion downstream. Indeed, Rahman et al. (2019) point out how such informal vehicles force other drivers to change their speeds, make larger gaps between vehicles, and weave across lanes in unexpected ways, which significantly increases the average headway between the vehicles, thereby reducing the effective capacity of the intersection.

In mixed-traffic situations the understanding of traffic flow becomes more complex as there are a wide range of vehicles with different size, speed and attributes. So the passenger car unit's concept is necessary to imply for measuring various effects of different vehicles on road capacity. It helps to perform a standard comparison vehicle flow by converting different types of vehicles into a single unit. Lee et al. (2019) developed an improved methodology to calculate PCU factors under mixed traffic environment considering the fact that informal vehicles disproportionately impacts road capacity relative to their physical size.

Accounting for space occupation by these vehicles but also considering their slower acceleration and lower speeds, their method more accurately captures the dynamics of the flow of traffic than is typically captured through traditional models of traffic. This offers better appraisals of real-world intersection performance where vehicle classes are highly heterogeneous.

Furthermore, the driver and rider behavior contribution to the traffic flow models cannot be underestimated. For instance, Harata and Yano (2015) highlighted the fact that through the conventional approaches in model development, much concentration is always placed on vehicle characteristics and road infrastructure, thereby minimizing the behavioral attributes pertaining to traffic dynamics. Indeed, their results indicated that improper lane usage, frequent stops, among other acts of disobedience from drivers, can reduce road capacity by up to 30%. These behaviors are more pronounced in a mixed-traffic setting since the operations of informal vehicles are excluded from similar restrictions comparable to those imposed on motorized vehicles. This evidence calls for wider model developments that incorporate behavioral attributes to help in establishing better congestion predictions and management within urban cities.

Finally, there is increasing awareness that measures intended to manage the behavioral aspects of informal transportation modes can substantially enhance the efficiency of traffic flow and intersections. Designated stopping zones, increased enforcement of traffic regulations related to informal transport, and enhancements in the design of areas used for loading and unloading have all been demonstrated to reduce congestion from informal modes of transportation. Chien et al. (2018) assessed the impacts of managing the loading zones at urban-road intersections and reported significant enhancements in the flow of traffic. Their study shows that relatively low budget strategies focusing in human behavioral impact can significantly increase the efficiency of intersections rather than high budget capital investment in infrastructure projects. This supports the current belief that behavioral disruption of traffic flow, such as lane-blocking by unofficial modes, can be a much more affordable and sustainable way to reduce urban congestion.

### **3. METHODOLOGY**

This paper quantifies the impact of behavioral lane-blocking events on intersection capacity under mixed-traffic conditions using a field-based observational approach. Therefore, the methodology involves direct traffic measurements, vehicle classification, and flow analysis based on both saturation-flow and PCU-adjusted approaches. The collection of data is based on the identification of blocked and unblocked periods, computing headways, queue lengths, and vehicle composition to examine effective capacity loss. It combines empirical observations with standardized analytical methods to ensure the reliability and comparability of results. The framework outlined here, provides a systematic way to assess how microlevel behaviors are turned into measurable operational inefficiencies at urban intersections.

#### **3.1 Study Area and Scope**

The study was conducted in Khulna city, one of the major urban centers of Bangladesh where traffic flow is mixed, and road geometry varies between lanes per direction. Typical major arterial corridors that face frequent congestion during morning and evening peaks were selected for observation. Traffic composition is dominated by easy-bikes (battery-operated three-wheelers) and motorized rickshaws, alongside private cars, CNG auto-rickshaws, and a small share of buses. Unlike Dhaka, most intersections in Khulna operate without signal lights, and congestion arises mainly from behavioral factors such as illegal parking, curb-side passenger pickup, and lane blockage (Hasan et al., 2018; Verma & Sai Kiran, 2016). The objective of this study was to quantify the effect of such lane-blocking behavior on discharge rate and overall approach capacity. Two methods of quantification were used:

- (i) Headway-based saturation flow and

(ii) PCU-adjusted flow rate under mixed traffic conditions.

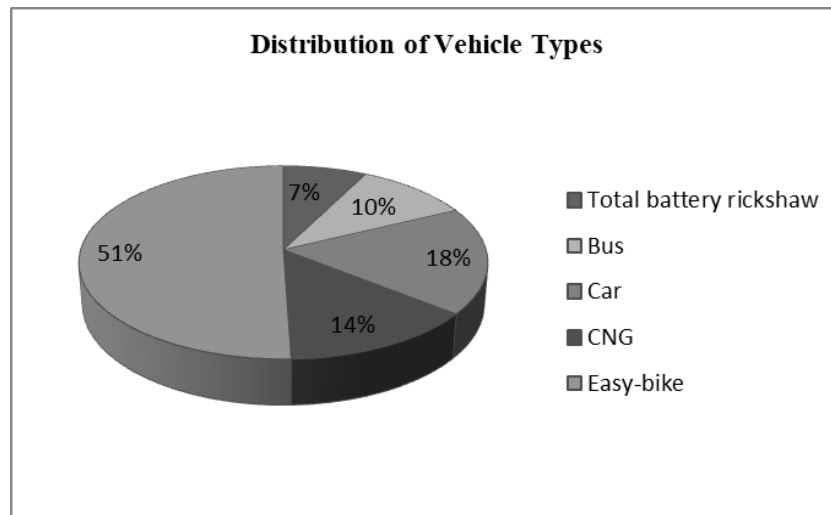


Figure 1: Vehicles categories percent distribution

### 3.2 Data Collection

A standard mobile phone camera and sheet was used for traffic data collection. Where possible, the camera was placed at an elevated location like roadside building's balcony, or over a small building to ensure full visibility of approaching the intersection. The camera was placed at an oblique roadside angle that still allowed for a clear line of sight at locations where elevated positions were not found. This procedure helped to identify the point from which the vehicles were considered to have "departed". Records were taken in daylight hours to maintain consistent visibility.

Each observation day was divided into two distinct 10-minute sessions:

The blocked period is a time frame of high congestion during which easy-bikes and other para-transit vehicles frequently occupied lane space near the intersection or along the curb while waiting for a passenger, creating intermittent congestions that hampered the natural flow and reduced the effective approach capacity. Whereas, the unblocked period refers to relatively free-flowing conditions when most vehicles can move with fewer interruptions and have largely unobstructed lane space, which usually takes place during mid-peak hours or immediately before or after a heavy congestion.

The term "blocked period" does not mean that the lanes were blocked all the time within the full 10 minutes; rather, it means a period of 10 minutes during which there was repeated blockage at some moments. Observations were collected on 10 different weekdays for a total of 200 minutes of observation. All video recordings were manually replayed at a reduced playback speed in order to achieve high accuracy in both time stamping and vehicle classification.

### 3.3 Vehicle Classification and PCU Factors

Accordingly, each vehicle was categorized into one of the five classes that represent the normal composition of traffic in Khulna, which comprises easy-bikes, motor rickshaws, CNG auto-rickshaws, private cars, and buses or minibuses. For a uniform comparison of this heterogeneous stream of traffic, all vehicles have been converted into PCU by using the equivalence factors from relevant local and regional studies (Islam, Sadeek, & Miah, 2020; Saha, Chandra, & Ghosh, 2017). This brings mixed traffic onto a common scale that reflects the comparative contribution of different types of vehicles to road capacity and flow characteristics. Easy-bikes were assigned a lower PCU value

considering compact size, limited acceleration, and relatively low operating speed, whereas the buses and minibuses were assigned higher equivalence values that capture larger spatial occupancy and stronger influence on the dynamics of traffic.

### 3.4 Data Extraction and Processing

For each vehicle crossing the reference line, data were recorded in Excel including day and observation condition (blocked/unblocked), timestamp (s), vehicle type with PCU factor and number of lanes blocked (0-2). Headways were calculated as the time between two consecutive vehicles under the same traffic condition and converted to saturation flow rates (veh/h). The mean headway ( $\bar{h}$ ) for each period was obtained by averaging all the individual headways, and the corresponding saturation flow  $S$  was determined by using the standard relation  $S = 3600 / \bar{h}$ , which expresses the maximum discharge rate per lane. Later, all vehicles were converted to PCU equivalents and summed up into an hourly PCU flow (pcu/h). Comparing these measures between blocked and unblocked periods quantifies the capacity reduction due to short-term lane-blocking or irregular stopping, giving a data-driven estimate of operational inefficiency at intersections (Saha, Chandra, & Ghosh, 2017).

### 3.5 Statistical Analysis

#### 3.5.1 Summary and inference framework

The data analysis started with the calculation of percentage loss in both saturation flow and PCU flow using the general formula:

$$\%Loss = \frac{(\text{Unblocked Rate} - \text{Blocked Rate})}{\text{Unblocked Rate}} \times 100 \quad (1)$$

This equation provides with two sets of daily values across 10 observation days which are %Loss (Saturation) that is derived from vehicle discharge rates and %Loss (PCU), derived from equivalent flow rates.

The average, standard deviation (SD), and standard error (SE) were computed for both parameters. Confidence intervals at 95% level were determined using the respective formula:

$$CI = \bar{X} \pm t_{0.05, n-1} \times \frac{SD}{\sqrt{n}} \quad (2)$$

Where,  $\bar{X}$  = sample mean,  $t_{0.05, n-1}$  = tabulated critical value, and  $n$  = number of observation days.

#### 3.5.2 One-Sample significance test

To assess whether the observed capacity loss was statistically significant, a one-sample t-test was conducted for both sets of losses. The null hypothesis assumed no loss ( $\mu = 0$ ) while the alternative hypothesis tested if the mean loss was greater than zero. Such statistical methods to validate the difference in flow have also been implemented in previous studies related to intersections under mixed-traffic conditions (Verma & Sai Kiran, 2016).

$$t = \frac{\bar{X} - 0}{SD / \sqrt{n}} \quad (3)$$

If the calculated t-value exceeded the critical t from the table; the null hypothesis was rejected, confirming that lane-blocking had a statistically significant negative impact on flow rate.

### 3.5.3 Paired comparison between methods

Because both % Loss (Saturation) and % Loss (PCU) originated from the same 10-day sample, a paired t-test was conducted to determine whether the two indicators differed significantly. The difference for each day ( $D_i$ ) was computed as:

$$D_i = (\%LOSS_{Saturation})_i - (\%LOSS_{PCU})_i \quad (4)$$

Then:

$$t = \frac{\bar{D}}{SD/\sqrt{n}} \quad (5)$$

Where,  $\bar{D}$  = mean of differences and  $SD$  = standard deviation of differences.

If the result is not significant, this suggests that the estimates for the reduction of capacity are consistent between methods.

### 3.5.4 Correlation Analysis

In the end Pearson's correlation coefficient ( $r$ ) was calculated to find out the degree of association between % Loss (Saturation) and % Loss (PCU):

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \quad (6)$$

A strong positive correlation would be close to one which will confirm that both flow measurement approaches respond similarly to lane-blocking disruptions, hence validating the consistency of the dataset and supporting the behavioral nature's impact on the capacity loss.

### 3.6 Data Analysis Tools

All calculations were done within Microsoft Excel, where formulas embedded into cells allow for transparency and reproducibility. Later on, identical data were cross-verified with Python statistical libraries to verify results. Descriptive charts and correlation plots were also generated to visualize variations across observation days and the strength of association between different loss measures.

### 3.7 Hypotheses

Therefore, this research hypothesis is that driver and rider behavioral patterns, especially lane obstruction and intersection blocking caused by easy bikes and other informal modes—substantially decrease the operational efficiency of urban roadways in Khulna. Verma & Sai Kiran, 2016; Hasan et al., 2018 observed that these types of behaviors increase average headway and reduce effective saturation flow, causing calculable loss in roadway capacity. In a quest to statistically determine this hypothesis, the following hypotheses were formulated where  $H_0$  states that, there is no significant difference in the traffic discharge rates or percentage capacity loss when it comes to blocked versus unblocked conditions. On the other hand  $H_1$  states that, the hypothesis that there is a significant difference in traffic discharge rates and percentage capacity loss between blocked and unblocked conditions, reflecting a measurable impact of behavioral factors on flow efficiency.

Paired and one-sample t-tests were used to determine if the mean percentage loss under behavioral blocking conditions was significantly higher than zero. Additionally, a correlation analyses were

performed to examine how the saturation-flow-based losses are associated with PCU-based (mixed traffic) losses across the observed days.

## 4. RESULTS AND DISCUSSION

### 4.1 Overview of Observed Flow Conditions

Traffic observations were conducted for ten days during mixed-flow conditions along major intersections in Khulna. The road segments predominantly carried easy bikes, motor rickshaws, and CNGs, with a comparatively less number of private cars and minibuses. Peak-hour congestion was dominated with frequent intersection blocking events, primarily caused by easy bikes stopping across lanes seeking for passengers. Intermittent obstructions frequently decreased discharge efficiency and caused local queue spillback, even though total standstill situations were uncommon.

### 4.2 Comparative Flow Performance

While blocked periods produced lower discharge rates between 910 to 1500 vehicles per hour, average saturation flow rates during unblocked conditions varied from around 1290 to 1760 vehicles per hour. The average PCU-based flow rates decreased from around 1,100–1530 PCU/hr (unblocked) to 800–1,300 PCU/hr (blocked) when converted into PCU units to account for mixed traffic composition.

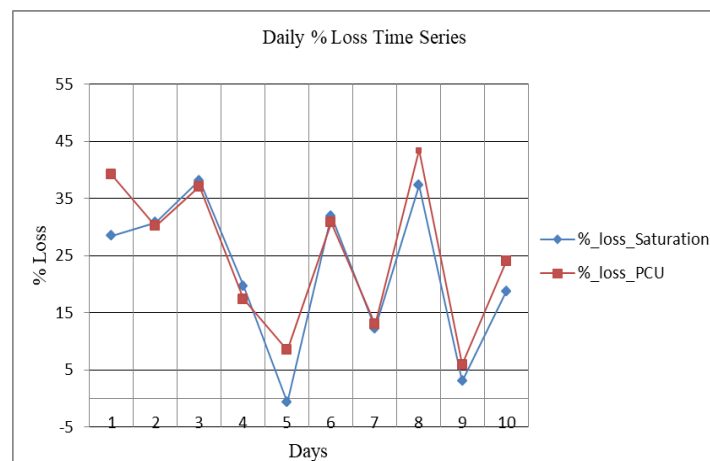


Figure 2. Day-to-day variation of percentage capacity losses for saturation-flow and PCU-based estimates.

These differences correspond to an average percentage loss of 22–38% in saturation-flow-based capacity and 24–35% in PCU-adjusted capacity, confirming that behavioral blockages significantly decrease effective discharge rates even without full lane closures. This time-series shows that while daily losses fluctuate due to traffic composition and event frequency, both methods move in parallel, reaffirming their reliability and internal consistency.

### 4.3 Statistical Analysis of Percentage Loss

Descriptive statistics for ten observation days showed the following:

Table 1: Summary Statistics of Capacity Loss Metrics

Metric	n	Mean (%)	SD (%)	SE (%)	95% CI (%)
%Loss (Saturation flow)	10	21.98	13.75	4.35	[12.15, 31.81]
%Loss (PCU flow)	10	24.95	13.27	4.2	[15.46, 34.45]
Difference (S – P)	10	-2.97	4.63	1.47	[-6.29, 0.34]

CI's calculated using  $t_{0.025, 9} = 2.262$ .

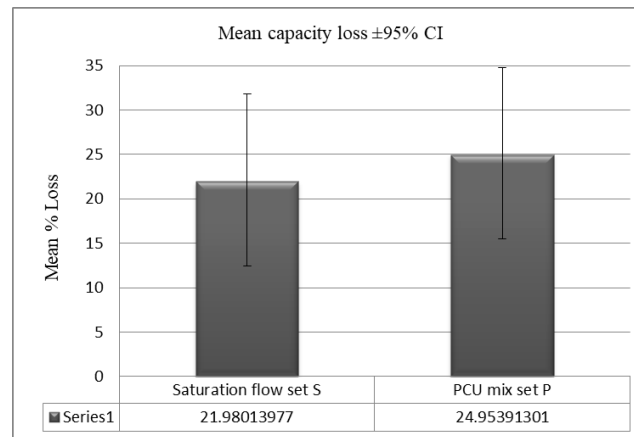


Figure 3. Mean percentage loss in approach capacity ( $\pm 95\%$  CI) based on saturation-flow and PCU-adjusted methods.

The mean losses indicate that lane blocking reduces capacity by roughly 22–25%, which is operationally significant. The SD shows notable daily variability, while the SE and CI provide confidence in the mean estimates. The difference between S- and P-based methods is small, and the CI for the difference includes zero, suggesting the two methods produce broadly comparable estimates. The error bars in the figure demonstrate moderate daily variability yet reinforce a clear central tendency of loss across all observation days.

#### 4.4 One-sample t-tests ( $H_0$ : mean = 0):

Table 2: One-Sample t-Test Results for Capacity Loss Measures

Metric	t(9)	p (two-tailed)	Interpretation
S	5.06	0.000684	Loss significantly > 0
P	5.95	0.000217	Loss significantly > 0

Both S- and PCU-based losses are significantly greater than zero, confirming that blocking events have a measurable and statistically meaningful effect on approach capacity.

Thus, both measures show that mean percentage losses were significantly greater than zero, rejecting the null hypothesis that blocking behavior has no effect on flow efficiency.

#### 4.5 Paired Comparison between Methods

A paired t-test comparing the two loss measures results in  $t(9) = -2.03$ ,  $p = 0.073$ , suggesting no statistically significant difference between losses computed from saturation-flow and PCU-adjusted

flow. The mean difference was  $-2.97\%$ , indicating PCU-adjusted losses slightly higher. Pearson correlation analysis indicated a strong positive relationship between the two measures ( $r = 0.942$ ,  $p < 0.001$ ), showing that both metrics reliably track the same day-to-day fluctuations in capacity loss.

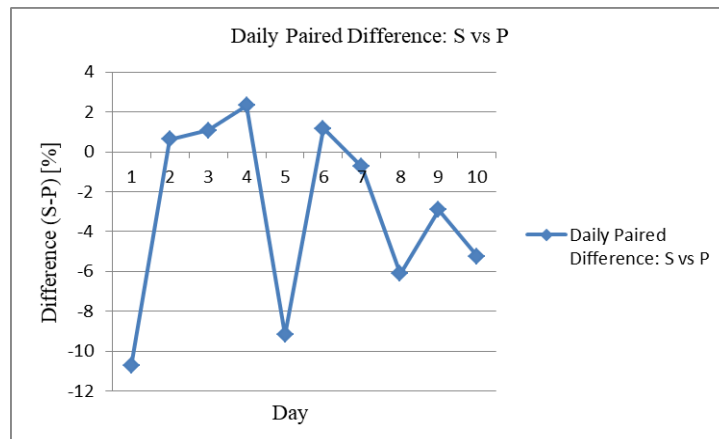


Figure 4. Paired daily differences between saturation-flow-based and PCU-based loss estimates.

Most differences lie close to zero, with PCU-based values slightly higher on average. This visual supports the statistical finding that the two methods yield consistent results, with no significant mean difference. This implies that either approach provides a consistent estimation of behavioral impact under the observed mixed traffic conditions.

#### 4.6 Correlation between Flow Loss Measures

Correlation analysis between saturation-flow-based and PCU-based percentage losses yielded a Pearson's  $r = 0.942$  ( $p < 0.001$ ), indicating a very strong positive relationship according to conventional interpretation ( $r > 0.8 \rightarrow$  very strong,  $0.5 < r < 0.8 \rightarrow$  moderate,  $r < 0.5 \rightarrow$  weak).

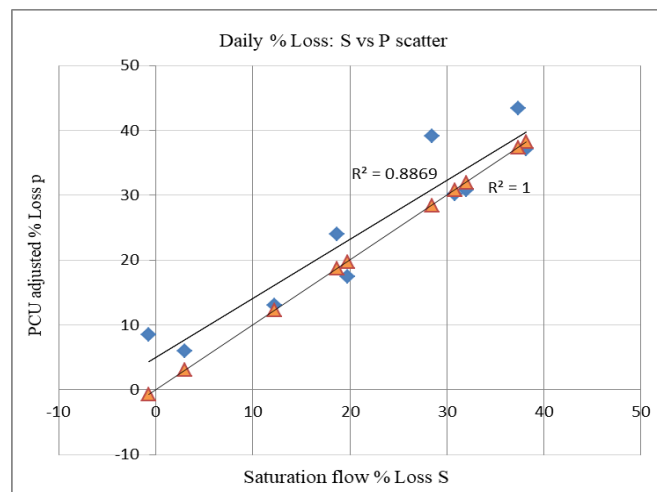


Figure 5. Correlation between saturation-flow-based and PCU-based percentage capacity losses ( $r = 0.94$ ,  $p < 0.001$ ).

The strong linear association indicates that both measurement methods capture similar behavioral effects on flow. The near 1:1 trend confirms that mixed-traffic composition does not distort the detection of capacity losses caused by short-term blockages. This confirms that despite vehicle heterogeneity, both methods consistently capture the same behavioral disruptions, including headway expansion, lateral friction, and temporary lane blockage by informal modes.

#### **4.7 Interpretation of Findings**

The findings indicate that intermittent blocking of lanes by informal modes, and in particular easy-bikes during passenger pick-up and drop-off, leads to a decrease of approach capacity by around 22–25%. This is a significant operational loss, particularly for urban intersections which are limited by space and exhibit traffic heterogeneity. The two methods of based on saturation-flow and PCU-adjusted inputs resulted in similar and statistically significant estimates of capacity degradation, associated with a very strong correlation ( $r = 0.94$ ,  $p < 0.001$ ). This validates that across different vehicle configurations, the two methods successfully extract the same behavioral impairments — headway-out crossing, lateral friction and short-term lane-occupancy by undisciplined vehicles. The lack of significant difference due to the two methods indicates that either can be used with confidence on mixed-traffic situations as well.

The results might not show up-most precision owing to day-to-day variation and statistics due in part to the low sample size ( $n = 10$ ), but the overall pattern is clear: vehicles' informal maneuvers substantially reduce intersection effectiveness, even without geometrical obstructions or signal presenter failure. The results substantiate that micro-level behaviors, e.g., roadside waiting, wrong-lane queuing and most importantly intersection blocking sum up to macroscopic flow loss, leading to smaller discharge capacity and more severe intersection congestion. Results further indicate that behavioral aspects, instead of static design capacity are one of the most significant determinants to flow reduction in low and middle-income city settings like Khulna.

At a policy and management level, the results highlight the importance of behavioral and operational policies over expensive infrastructure expansion. It becomes intuitive that disciplining the box, controlling passenger pick-up behaviors of easy-bikes near intersections, and setting up parking bay helps largely increase throughput and decrease local jams. These low-cost management prescriptions may bring sustainable and significant advances in network performance and sustainability by addressing the accumulated impact of micro-level behavioral inefficiencies.

#### **5. CONCLUSION**

This study investigates how behavior based lane blocking hampers intersection capacity under mixed-traffic conditions. We identify the critical role of user behavior at the micro level, particularly informal vehicles such as easy-bikes, in reducing effective discharge; in contrast standard appraisals emphasize infrastructure capacity constraints as the dominant cause of congestion. Saturation-flow and PCU-adjusted procedures were applied to ten days of traffic data from the field, offering accurate results for capacity loss.

The analysis reveals that narrow lane blockages had a significant impact on intersection operations by reducing capacity of the intersection by 22–25%. Overall, strong level of correlation between these two forms of measurement ( $r = 0.94$ ,  $p < 0.001$ ) confirmed that both methods validly captured the behavioral effect. Pairwise comparison results indicated the PCU-adjusted losses were slightly higher, but there was no statistically significant difference between them, showing an agreement between two implied methods. Our results justify the view that behavioral dynamics approve the phenomenon of congestion in mixed-traffic settings, owing to minor (temporal) practices such as curbside waiting or wrong-lane positioning and intersection crowding which compound into significant flow loss. In terms of real life implications, the findings suggest that behaviors can play a vital role in improving system performance without additional physical infrastructure. “Using your road management system, you can decrease capacity loss and increase overall throughput by performing actions such as enforcing box discipline on the roads, control pickup and drop off behavior of your traffic and setup some designated stopping zones to ease congestion. This also

matches studies in which behavioral control led to an improved performance at intersections in other country's south Asian cities like Khulna.

While the study contributes valuable insights, it is limited by a small scale dataset, potential measurement variability and the exclusion of certain vehicle classes, which may affect the credibility of the findings. The dataset was modest covering only ten days and two intersections, which may limit applicability. In spite of using standard PCU conversion factors it may not perfectly capture vehicle heterogeneity or dynamic interactions. Measurement variability and unobserved factors, such as weather or atypical traffic events might introduce additional uncertainty. Additionally, some vehicle classes particularly two-wheelers such as motorcycles and bicycles, as well as certain non-motorized vehicles were present at the sites but were not included in the analysis. This may slightly underrepresent total traffic activity. Finally, secondary impacts including safety, emissions and noise were not assessed. Future work should extend observations across multiple intersections exploring off-peak and peak periods and incorporate modeling to examine a wider range of behavioral scenarios.

In conclusion, this research provides empirical evidence that behavioral disruptions are a significant contributor to intersection inefficiency in mixed-traffic urban environments. Even brief, localized lane blockages can reduce throughput considerably demonstrating that addressing human behavior is as crucial as infrastructure for congestion management. These insights provide a foundation for designing low-cost, behavior-oriented operational strategies that enhance urban traffic performance while minimizing the need for structural upgrades.

#### **Declaration of Use of AI:**

The authors would like to state that AI tools like ChatGPT, DeepSeek, Perplexity were used as in a certain manner as supporting tools. At different stages of preparing the manuscript these tools were used predominantly for text generation to better describe the ideas, clarifying explanation of the outcomes and for describing results. So in short AI was used for wording, clarity and organizing sentence structures. But the fundamental ideas, explanations and procedure of the work was solely created by the authors' understanding and judgement. AI didn't influence any technical judgement in this paper. Moreover, any suggestions about the write-up generated by AI were carefully checked and adjusted so they matched what the authors intended to describe within academic practice. All the responsibility for the content's integrity rests with the authors and they acknowledge the supporting role of AI shaping the write-up of the respective manuscript.

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