Modeling and Forecasting Freight Delivery for Blocked and Unblocked Streets through Machine Learning Approaches and Analysed by Microsimulation Model


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Abstract: Deliveries of freight on signalized city roads often lead to lane obstructions, contributing to urban traffic congestion. This issue has garnered increasing attention as traffic engineers and city planners seek sustainable solutions to meet growing demand while working within the constraints of limited road capacity. The primary objective of this study is to assess a model designed to quantify the impact of freight deliveries on both the capacity and delay experienced on signalized city roads in Ahmedabad. The model is structured similarly to the approach outlined in the Highway Capacity Manual (HCM2010). The aim of this research is to provide insights into the utilization of these analytical tools in the context of urban freight delivery policies. This research explores the estimation of delay and vehicle capacity, accounting for various factors such as delivery locations, durations, and their distinct effects on different lanes. To predict vehicle capacity and estimate delays, this study employed machine learning techniques, specifically Support Vector Machines and Artificial Neural Networks. The results demonstrate a high level of agreement between our predictions and actual observations.

Keywords: Freight delivery; Ahmedabad; Machine learning; Support vector machine; Artificial neural network, microsimulation model

1. Introduction

Freight deliveries on signalized urban roads are widely recognized for causing lane obstructions throughout their distribution routes. In recent times, the issue of traffic congestion resulting from these urban freight deliveries has gained significant attention. Traffic engineers and urban planners face the challenging task of finding sustainable solutions to meet increasing demand while dealing with limited road capacity. An emerging discourse revolves around the adoption of policies that encourage shifting deliveries to off-peak hours to alleviate the adverse effects on traffic congestion.

Notably, a comprehensive study on the impact of heavy vehicles within the traffic network was detailed in NCFRP Report 31, authored by Dowling and others in 2014. This report offers precise insights into how trucks affect the speeds of mid-block arterials and proposes improved methods for calculating truck-passenger car equivalent factors. These advancements are aimed at enhancing the capacity analysis of signalized intersections.

These approaches fail to adequately address the issues stemming from parked trucks causing obstructions. In their 2016 discussion, Keegan and Gonzales highlighted the challenges posed by freight deliveries within urban areas, such as the obstruction of traffic flow, resulting in reduced street capacity and vehicle delays. To address these concerns, researchers have employed the 'All or Nothing' model and Kinematic wave theory to assess the impact of freight deliveries on traffic and develop appropriate policies. In a 2000 study, Benekohal and Zhao delved into the concept of passenger car equivalents, which serves as a method for quantifying the contrasting effects of heavy vehicles on traffic flow operations. Given their size and slower acceleration/deceleration capabilities, heavy vehicles can significantly disrupt traffic performance at intersections.
Holguín-Veras and colleagues conducted a comprehensive investigation in 2006 into policies aimed at encouraging off-peak hour deliveries within urban areas. Their study explored the necessary conditions for fostering agreements between receivers and carriers for off-hour deliveries and the effectiveness of various policies in promoting such changes, particularly in competitive markets. In 2008, Holguín-Veras emphasized the importance of incentivizing off-hour delivery programs as a means to alleviate traffic congestion. Much of the analysis focuses on the experiences and perspectives of governmental agencies and delivery drivers, who can navigate through less congested roadways during off-peak periods.

In a 2004 discussion, Crainic and his team explored the challenge of ensuring that recipients adhere to off-hour delivery schedules, a task often necessitating the presence of a store employee for proper acceptance and handling. This requires recipients to either remain available after regular business hours or make prior arrangements for deliveries in the absence of a designated receiver. Holguín-Veras and colleagues (2016) delved into the dynamics of agent interactions within supply chains, recognizing the significant role played by supply receivers in determining when and how deliveries occur. Their findings suggested that Residential Loading Zone (RLC) programs could yield substantial benefits for large urban areas, reducing both the number of freight vehicle milestavelled and congestion levels. Yannis et al. (2006) conducted a study on the effects of imposing restrictions on vehicle movements associated with urban delivery operations on traffic. Their conclusions indicated that restricting deliveries to specific types of businesses during peak hours could have favorable impacts on traffic and the environment. Another investigation involved the analysis of data related to city freight deliveries and parking facilities, aiming to optimize urban freight transportation systems and develop a mobile check-in-based parking system for freight vehicles to enhance delivery processes. With the advancements in computing technologies, machine learning models have become increasingly useful for data classification, prediction, and forecasting, as highlighted by Vakharia et al. (2017). In the present context, these models can be effectively applied to larger and more complex datasets, offering decision-makers real-time insights and data estimations. For transportation applications, it is now possible to evaluate individual driver behavior to address traffic congestion problems and predict future traffic flow, given historical data. Yang et al. (2014) explored the application of Support Vector Machines (SVM) in identifying delivery stops using Global Positioning System (GPS) data, considering factors such as stop duration, distance from stops to town centers, and proximity to

<table>
<thead>
<tr>
<th>Nomenclature</th>
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<tbody>
<tr>
<td>Ssr,dl= average saturation rate for shared right turn</td>
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<tr>
<td>laneCsr capacity of shared right turn lane</td>
</tr>
<tr>
<td>Ct capacity of through laneC cycle length</td>
</tr>
<tr>
<td>ddl delay time with freight delivery T duration of analysis period</td>
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<tr>
<td>td duration of blockageG effective green time</td>
</tr>
<tr>
<td>Er equivalent no of through cars for a protected right turn G green time</td>
</tr>
<tr>
<td>Nsr no of lane in the shared right turn LaneNt no of lane in the through Lane.</td>
</tr>
<tr>
<td>lt phase lost time</td>
</tr>
<tr>
<td>Pr proportion of the right turning vehicle in the shared laneAR red time</td>
</tr>
<tr>
<td>Cdl= revised lane group capacityVdl revised vehicle arrival rate</td>
</tr>
<tr>
<td>Ssr saturation flow rate for the shared right</td>
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major obstructions. Mrówczyńska et al. (2017) provided an extensive examination of the application of artificial intelligence techniques for road freight transportation prediction. Their research involved the use of double exponential smoothing, double exponential smoothing with artificial immune system support, and Bayesian networks to forecast freight volume, yielding promising results and highlighting the potential of machine learning models in the realm of freight applications.

After conducting a comprehensive literature review and recognizing the imperative need to assess traffic conditions within smart cities, it became apparent that there was a significant gap in the research related to the utilization of machine learning models for predicting and validating capacity and delay times associated with freight deliveries on both obstructed and unobstructed streets.

In this current study, we conducted an experimental investigation employing the 'All or Nothing' model, a methodology developed in the Highway Capacity Manual of 2010. Following the calculation of positions and delay times, we harnessed the power of machine learning techniques, specifically Artificial Neural Networks and Support Vector Machines, to predict and validate the experimental data. The step-by-step process utilized in this study is visually represented in Figure 1.

2. Machine learning techniques

Machine learning comprises a diverse set of algorithms designed to uncover patterns within provided datasets. Machine learning techniques can be broadly categorized into three types: supervised learning, which requires labeled data for tasks like classification or regression; unsupervised learning, where unlabeled data is analyzed; and semi-supervised learning, which utilizes both labeled and unlabeled data. Several widely-used algorithms, such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Random Forest, find application in various domains, including fault diagnosis (Vinay et al., 2015), rotor fault identification (Singh and Kumar, 2015), EEG signal analysis (Upadhyay et al., 2015), among others.

Artificial Neural Networks (ANN) function as computational models inspired by the workings of the human brain, relying on interconnected neurons. ANNs typically comprise inputs, each multiplied by specific weights representing signal strength. Computation is achieved through activation functions within the neurons. By adjusting these weights, ANNs can produce desired outputs for specified inputs (Vakharia et al., 2016).

Support Vector Machines (SVM) belong to the realm of supervised learning algorithms primarily employed for classification and regression tasks. SVM's core principle is grounded in structural risk
minimization. In binary classification problems, SVM seeks to maximize the margin between separating hyperplanes, enabling the classification of data into distinct classes. Thanks to its strong generalization capabilities, SVM has garnered significant interest among both academic and industrial communities (Vakharia et al., 2017)."

3. Experiments conducted

Ahmedabad has emerged as one of India's most rapidly growing cities over the past decade, experiencing substantial industrial and commercial development. In light of this, addressing traffic congestion has become a paramount concern. It is crucial not only for optimizing transport capacity but also for enhancing economic performance, mobility, and environmental sustainability, all of which ultimately benefit the city’s residents.

The primary focus of this research centers on the issue of urban freight deliveries within the city, which often result in traffic obstructions, leading to reduced street capacity and delays for vehicles. The study encompasses three key intersections in Ahmedabad, commencing from Kalupur market, traversing Kalupur railway station, and culminating at Sarangpur junction. Among these intersections, two grapple with heavy traffic congestion primarily caused by freight deliveries, while Kalupur railway station enjoys an unobstructed road due to the absence of such deliveries.

In our study, we adopted the 'All or Nothing' model, a methodology elaborated in the Highway Capacity Manual, to conduct calculations pertaining to both unblocked streets and streets affected by freight deliveries. The outcomes of our investigation, including the total capacity and delay times for both blocked and unblocked streets, are presented in Table 1 and Table 2.

The saturation flow rate for the shared right lane is determined by...

\[ S_{sr} = \frac{St}{(1 + Pr(Er - 1))} \]  

Each road group’s capacity is established by considering variables like the saturation flow rate and signal timing. When dealing with a pre-timed traffic signal, the capacity for both the through lane and the shared right-turn lane can be referenced in the 2010 edition of the Highway Capacity Manual.

\[ Ct = \frac{StNt}{g/C} \]  

The capacity of the shared right-turn lane is determined as follows:

\[ C_{sr} = S_{sr} \times N_{sr} \times g/C \]  

The calculation of control delay at the intersection is conducted separately for each lane group. D = (0.5c(1-g/C)^2)/(1-((\min\{d;[1,v/c]\}g)/C))

The calculation of capacity in the presence of freight delivery, using the All or Nothing model, is as follows:

\[ S_{sr,dl} = S_{sr}(1-Td/T) \]  

The capacity of the shared right-turn lane is determined as follows:

\[ C_{sr,dl} = S_{sr,dl} \times g/C \]  

The calculation of delay in the context of freight delivery, utilizing the All or Nothing model, is determined as:

\[ D_{dl} = 0.5 \times (C(1-g/C)^2)/(1-\min\{d;[1,v/dl]\}g/C) \]

<table>
<thead>
<tr>
<th>No</th>
<th>Blocked location</th>
<th>Capacity (veh/hr)</th>
<th>total capacity</th>
<th>Delay time(sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>through lane</td>
<td>Shared right turn lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Kalupur market</td>
<td>914</td>
<td>1560</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>Sarangpur junction</td>
<td>914</td>
<td>1560</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Bapunagar junction</td>
<td>923</td>
<td>1576</td>
<td>16</td>
</tr>
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</table>
4. Results and Discussion

In this study, an ALL or Nothing model was employed to assess the capacity and delay times of both unblocked and blocked streets obstructed by freight delivery. The findings indicate a significant reduction in road capacity when the street is blocked due to freight delivery, leading to increased delay times. It is evident that the capacity of unblocked streets surpasses that of blocked streets in such scenarios. To enhance the accuracy of capacity and delay predictions for both blocked and unblocked conditions, machine learning techniques, specifically Support Vector Machines (SVM) and Artificial Neural Networks (ANN), were utilized. These techniques were assessed using key parameters such as the Correlation Coefficient, Root Mean Square Error, and Absolute Error to evaluate their predictive capabilities. The Correlation Coefficient serves as a valuable metric for quantifying the relationship between two variables, which may be measured on ordinal or continuous scales. It is important to note that correlation does not imply causation but rather signifies an association between the variables being examined. The Correlation Coefficient is a numerical value ranging from -1 to +1, with a higher value indicating a stronger relationship. When assessing blocked capacity and delay times, the ANN model exhibited a notably higher Correlation Coefficient compared to the SVM model. This pattern of results was consistently observed throughout the analysis. The unblocked capacity and delay data presented in Table 4 reveal significant insights. Root Mean Square Error (RMSE) serves as a critical metric for evaluating the disparities between the predictions made by a machine learning model and the actual observed values. Essentially, RMSE gauges the adequacy of the fit between the real data and the model's predictions. In the context of prediction models, an optimal RMSE is characterized by its minimal value. Examining Table 4, it becomes evident that in all four cases under consideration, the Support Vector Machine (SVM) model exhibits higher RMSE values when contrasted with the Artificial Neural Network (ANN).

Meanwhile, Mean Absolute Error (MAE) stands as a measure of the divergence between two continuous variables. When assessing the prediction capabilities of a machine learning model, the goal is to minimize MAE as much as possible. Again, upon inspecting Table 4, it is clear that the ANN model consistently yields lower MAE values for all four cases, namely, Blocked Capacity, Blocked Delay Time, Unblocked Capacity, and Unblocked Delay, which are central to our current investigation. The cumulative evidence from the results suggests that the ANN model outperforms the SVM model across all three key parameters - Correlation Coefficient, RMSE, and MAE.
5. Conclusion

In this current investigation, the study focused on quantifying the impact of freight deliveries on both blocked and unblocked streets within the Ahmedabad district. This examination encompassed various locations, where the total capacity and delay times were meticulously computed, guided by the principles outlined in the Highway Capacity Manual (HCM) and employing the All or Nothing model. To enhance the accuracy of these calculations, machine learning techniques, specifically Support Vector Machines (SVM) and Artificial Neural Networks (ANN), were harnessed to predict the experimentally derived parameters. The performance of these machine learning models was rigorously assessed using three key metrics: Correlation Coefficient, Root Mean Square Error, and Mean Absolute Error.

The outcomes of this investigation consistently demonstrated the superiority of the ANN model over SVM for all four scenarios under consideration. This encompassed a thorough analysis of the three essential parameters, namely, Correlation Coefficient, Root Mean Square Error, and Mean Absolute Error. The proposed methodology offers valuable insights and potential applications in predicting online freight delivery in real-world scenarios.

References

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