Simulating Traffic Flow in Dhaka City

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***Abstract*—This study addresses the challenges of urban traffic congestion, focusing on Dhaka city. Employing the City Skyline traffic simulator within the Unity game engine, the research utilizes microscopic models like the Intelligent Driver Model to simulate various traffic scenarios. It investigates factors affecting traffic flow, including vehicle occupancy, adherence to traffic laws, and the impact of traffic police or lights. The experiments explore diverse traffic management policies, lane configurations, and scenarios to optimize flow within existing infrastructure constraints. Leveraging City Skyline's modding capabilities, custom policies and lane management strategies are implemented. Results, presented through heatmaps and visualizations, highlight the effectiveness of enforcing traffic laws and deploying traffic light-controlled systems in alleviating congestion. This research contributes valuable insights into urban traffic dynamics, proposing practical solutions. While acknowledging simulation limitations, future work could enhance fidelity by considering real-world factors like parked vehicles and pedestrian behavior.**

***Index Terms*—Traffic simulation, Cities: Skylines, Simulation game, Intelligent Driver Model, Traffic flow, Traffic management, Microscopic models, Dhaka city, Urban planning, Traffic laws.**

I. Introduction

Traffic congestion in urban areas is a pervasive issue with far-reaching implications, particularly in bustling cities like Dhaka. The challenges posed by congested traffic include inconvenience, delays, and environmental pollution. Addressing these challenges requires a profound understanding of the underlying dynamics of traffic flow. This research delves into the intricacies of simulating traffic patterns within a virtual replica of Dhaka city, employing the City Skyline traffic simulator powered by the Unity game engine.

The choice of microscopic models, notably the Intelligent Driver Model, serves as the foundation for representing individual vehicle behaviors in the simulation. The study encompasses a comprehensive exploration of various scenarios, considering factors such as different levels of vehicle occupancy, adherence to traffic laws, and the efficacy of traffic police versus traffic lights for traffic control. The primary goal is to unravel the causes of inefficient traffic flow, identify bottlenecks, and propose effective solutions to alleviate traffic congestion.

In a bid to optimize traffic flow within the constraints of existing infrastructure, the experiments involve testing diverse traffic management policies, lane configurations, and scenarios. Leveraging the advanced modding capabilities of City Skyline, the research implements custom policies, lane management strategies, and dynamic interactions with the simulation environment. The results derived from these simulations provide valuable insights into the multifaceted factors influencing traffic flow in Dhaka city.

The analytical approach considers the impact of variables such as traffic police control, traffic light control, and the adherence to traffic laws. Heatmaps and visualizations are employed to vividly demonstrate the efficacy of various strategies in enhancing traffic flow. Notably, the findings underscore the effectiveness of enforcing traffic laws and implementing traffic light-controlled systems as pivotal methods for mitigating traffic congestion in Dhaka city.

In summary, this study enhances our comprehension of the complex dynamics of traffic in urban environments and presents pragmatic approaches to effectively regulate traffic in densely populated cities. Despite acknowledged limitations in the simulation's accuracy, particularly regarding real-world factors such as parked vehicles, pedestrian behavior, and VIP movements, this study lays the groundwork for future research aimed at refining the fidelity of traffic flow simulation

II. Literature Review

Traffic flow simulation is of paramount importance in comprehending the causes and effects of poor traffic infrastructure in Dhaka city, which leads to extensive traffic jams and millions of dollars in losses annually. Understanding the dynamics of traffic in Dhaka is crucial for effective city planning, congestion management, and infrastructure development. The traffic conditions in Dhaka city are exceptionally challenging, characterized by extreme congestion, especially during peak office hours. The diverse types of vehicles, including buses, private cars, three-wheelers, and rickshaws, contribute to the complexity of traffic flow. Rickshaws, even on highways in certain areas of Dhaka, significantly impact traffic flow.

Various traffic flow simulation techniques, such as microscopic, macroscopic, and mesoscopic models, have been employed in existing research. While there has been notable work in Dhaka, a comprehensive simulation addressing the unique challenges of the city's traffic conditions is still lacking in the literature. Despite the substantial volume of traffic-related research, our study introduces a distinctive element by exploring the potential consequences of partial or total non-compliance with traffic rules, a facet not extensively covered in previous literature. This contribution provides a deeper understanding of traffic conditions in Dhaka, offering insights that can be instrumental in finding solutions to major issues such as severe traffic jams affecting millions of people in the city.

Our simulation, while valuable, acknowledges its challenges and limitations, such as the dissimilarity of the created city to Dhaka and the inherent lack of 100% accuracy. Nevertheless, the simulation proves effective in offering insights into traffic conditions in Dhaka, especially in evaluating the potential impacts of new traffic infrastructures like bridges, flyovers, roads, overpasses, and underpasses.

In the context of implementing the "public transit priority" strategy, Pan and Cao (2018) emphasizes the significance of studying traffic flow in bus stop areas to address traffic problems. Using VISSIM simulation software, the study investigates the impact of bus arrival frequency and non motor vehicle traffic volume on traffic flow in bus stop areas. The research considers three representative station types and proposes a station type optimization plan for Pengyuan Ximen Bus Station in Xuzhou based on simulation results. This work contributes valuable insights into mitigating mixed traffic flow conflicts and improving bus station service levels.

According to Song and Min (2018) focuses on urban traffic analysis and simulation technology to understand various methods for analyzing urban traffic states. It introduces a traffic demand estimation process for urban traffic simulation, utilizing a trip estimation model based on L1 regularized regression and trajectory data. The case study in Gangdong-gu, Seoul, demonstrates the effectiveness of the proposed method, with simulation results from the SALT Traffic Simulator based on SUMO reflecting real traffic patterns within approximately 10% error coverage.

Lin (2019) introduces DynasTIM, a real-time software system for online simulation, prediction, and optimization of dynamic traffic flows in urban and intercity networks. Developed over 15 years, DynasTIM incorporates features such as dynamic OD flows estimation, mesoscopic traffic models, and urban area signal optimization. The case study in Futian CBD, Shenzhen, China, validates its capability to reproduce real-world traffic conditions and highlights the potential for signal optimization, leading to a 13% reduction in average travel delay.

According to Skorobogatchenko et al. (2022) discusses the introduction of automated traffic control systems as a key priority for urban street and road network development. It proposes the use of Simulation of Urban Mobility (SUMO) software for simulating the influence of adaptive traffic lights on road network capacity. The study shows that even at individual intersections, adaptive traffic control can increase overall road network capacity by 20-30%.

Potuzak (2022) provides a survey of existing methods for road traffic network division in the last two decades. While not a systematic review, it maps and categorizes these methods, serving as a valuable resource for researchers dealing with road traffic network division and distributed or parallel road traffic simulation.

In the broader context of traffic flow simulation and urban planning research, the understanding of traffic dynamics, optimization of bus stop areas, urban traffic analysis, real-time simulation, and the impact of adaptive traffic control systems has been collectively advanced by the papers discussed. These contributions, while valuable, underscore a notable gap in the existing literature—a lack of a comprehensive simulation addressing the specific challenges posed by traffic conditions in Dhaka city. Crucially, this gap extends to considerations of non-compliance with traffic rules, a critical factor in the chaotic traffic landscape of Dhaka. This research aims to bridge this void by presenting a detailed simulation of traffic conditions in Dhaka, offering insights into the repercussions of both partial and total non-compliance with traffic rules.

Within this landscape of traffic flow simulation, a parallel narrative emerges in the form of the utilization of simulation games, prominently Cities: Skylines, in urban planning research and education. Noteworthy studies have explored the diverse applications of Cities: Skylines, shedding light on its potential benefits and limitations in educational contexts. These studies reveal how the game serves as a powerful tool for visualizing real-world places, contributing to urban planning education, and, with thoughtful modifications, enhancing its suitability for addressing city planning problem-solving scenarios. The integration of artificial intelligence in city design optimization further expands the horizon, showcasing the game's potential as a platform for exploring advanced technologies in the urban planning domain. Thus, these studies collectively enrich the discourse on the gamification of urban-related processes, bringing attention to the multifaceted role of simulation games in advancing knowledge and understanding in the fields of traffic flow dynamics and urban planning.

A. GeoSkylines: A Geographically Accurate Visualization Tool

A significant contribution to the field is the GeoSkylines game modification, as discussed by Pinos et al. (2020). This modification employs automatic methods scripted in the Cities: Skylines API, allowing for the creation of geographically accurate visualizations of real-world places within the game. The methods encompass the generation of road and rail networks, tree coverage, water basins, planning zones, buildings, and services. Moreover, GeoSkylines facilitates the export of game objects into a Geographic Information System (GIS) data format, positioning Cities: Skylines as a valuable tool for data collection in redevelopment design projects.

B. Cities: Skylines in Urban Planning Education

Extending beyond its entertainment domain, Cities: Skylines has been introduced into urban planning education, as highlighted by Commey (2023). The study assesses the effectiveness of the simulation in teaching urban planning principles from the perspective of students. Qualitative methods, including questionnaires, reveal that the visual elements of the game enhance students' understanding of various urban planning concepts and contribute to the development of critical thinking and problem-solving skills. The study underscores the pivotal role of instructors in optimizing the educational benefits derived from the simulation.

C. Computer Games in Education: Potential and Modifications

Haahtela et al. (2015) delves into the broader landscape of using computer games, including Cities: Skylines, as a teaching method. It emphasizes the comprehensive yet simplified view of reality that games offer, fostering inner motivation among students. While acknowledging Cities: Skylines' potential for educational purposes, the paper suggests that well-thought modifications could enhance its suitability for city planning problem-solving scenarios.

D. Gamification of Urban Planning: Student Perspectives

Khan and Zhao (2021) evaluates the effectiveness of Cities: Skylines for teaching urban planning through gamification. In-depth semi-structured interviews provide insights into students' perspectives, indicating that the game fosters conceptual understanding, critical thinking, and problem-solving skills. However, internal limitations hinder the confident application of knowledge in real-world scenarios, emphasizing the importance of the instructor's role.

E. AI in City Design Optimization

Venturing into artificial intelligence and machine learning, Duncan et al. (2021) presents a project involving the creation of an artificial intelligence agent to design optimized city layouts in Cities: Skylines. This initiative illustrates the viability of using AI as a tool in urban planning for real cities, leveraging the customization and control offered by the game environment.

Incorporating insights from these studies into the literature review enriches the discussion, showcasing the multifaceted role of Cities: Skylines in education, urban planning, and the potential integration of artificial intelligence for city design optimization. These findings collectively contribute to the broader understanding of the gamification of urban-related processes and its implications for educational and planning contexts.

III. METHODOLOGY

We will simulate traffic in urban areas to identify the bottlenecks. After analyzing the data we will try out various policies, lane management order, traffic obedience of people. We will be testing our changes and we will find the best possible solution for a particular scenario. Furthermore, adapting the changes for each scenario and combining them. After adapting all the changes we will compare the model with the pre-existing model and show the changes of traffic flow, congestion level. In recent times most of the urban area is preoccupied with infrastructure. As a result we can not construct any new road or lane. We have limited space and unchangeable roads. We have to work with the existing infrastructure. Various traffic policies can be tweaked in this stage. A good traffic laws, policies and law abidance of the citizen plays a massive role in modern day traffic flow. It is really important to simulate new policies and laws before implementing them in the real world. The room of error in the real world is hazardous. As city infrastructure is connected more than ever, a tiny error possesses a massive threat to the overall city traffic. We will try to find the optimal policies for any given Urban city. For this paper we will be using the model of Dhaka city. Simulating new policies, analyzing the change and comparison will be done in this paper.

We will be using a correlational design model. Identifying the policies and their impact on the overall traffic will be done. In this experimental design using Unity engine to simulate the traffic flow in a city. We would like to observe the effect of various variables such as: Traffic congestion, policies, traffic flow, lane management etc on our city.

To simulate the traffic flow in Dhaka city, a model has to be chosen which can represent the traffic system of Dhaka city in mathematical representation. This kind of model can be used to simulate

the traffic flow in Dhaka city using some input parameters such as road network geometry, vehicles per minute, speed of the vehicles etc. There are mainly 3 types of traffic simulation models such as -

- **Macroscopic models:** Such models depict both the overall flow and density of traffic as it relates to vehicle mobility.
- **Microscopic models:** These models are used to distinguish between various vehicles, which makes it easier to replicate the distinct driving styles of each individual.
- **Mesoscopic models:** These models are hybrid meaning they are a combination of microscopic and macroscopic models.

We used Unity Engine where traffic flow simulation has been implemented using Microscopic models. We used Himite (2021) models as the guide for our microscopic model.

A. Microscopic models

Microscopic model is one kind of model that simulates the movements of a vehicle which is called a tiny model.

Therefore, the system must be multiple agent based, with every vehicle operating independently and utilizing distinct environmental input data. Each vehicle in this model has a label that reads "i." The i-1 - th vehicle comes before the i-th vehicle. Let's denote x1 as the position of it, l1 as its length and v1 to be its speed.

$$\text{IV. } s_i = x_i - x_{i-1} - l_i$$

$$\text{V. } \Delta v_i = v_i - v_{i-1}$$

Here s_i is the distance between two vehicles and Δv_i is the relative velocity between i-th vehicle and i-1 - th vehicle.

Intelligent Driver Model

The Intelligent Driver Model is a model that Treiber Hennecke invented in 2000. It explains how the i-th vehicle accelerates**.** The respective equation is as follows:

$$\frac{dv_i}{\mathrm{dt}} = a_i\left(1 - \left(\frac{v_i}{v_{0,i}}\right)^{\delta} - \left(\frac{S^*(v_i,\Delta v_i)}{S_i}\right)^2\right)$$

$$S^*(v_i\ ,\ \Delta v_i) = \ S_{0,i} + v_i T_i + \frac{v_i \Delta v_i}{\sqrt{2a_i b_i}}$$

These parameters are as follows:

- $s_{0,i}$: *is the minimum required distance between i − 1 th and i − th vehicle.*
- $v_{0,i}$: *is the maximum required speed of i − th vehicle*
- δ : *is the acceleration exponent.*
- T_i : *is the reaction time of i − th vehicle driver.*
- b_i : *is the comfortable negative acceleration for the i − th vehicle.*
- a_i : *is the highest acceleration allowed for vehicle i*
- S^* : *is the actual required distance between (i − 1)th vehicle & i − th vehicle.*

A. How Intelligent Driver Model works

It is assumed that vehicles move along straight line and follow the below equations:

$$\frac{dv_i}{\mathrm{dt}} = \ a_{\text{free road}} + a_{\text{interaction}}$$

$$a_{\text{free road}} = a_i\left(1 - \left(\frac{v_i}{v_{0,i}}\right)^{\delta}\right)^2$$

In this case, acceleration on an open road—that is, a route with no oncoming traffic—is considered free road acceleration.

$$a_{\text{interaction}} = \ -a_i\left(\frac{S^*(v_i,\Delta v_i)}{S_i}\right)^2 - a_i\left(\frac{S_{0,i}+v_i T_i}{S_i} + \frac{v_i \Delta v_i}{2S_i}\right)^2$$

When acceleration occurs with the car ahead is referred to as the interaction acceleration.

B. Traffic Road Network Model

We need to simulate a network of connected roads. We require the directed graph G = (V, E) for this.

- V represents the set of nodes
- The set of edges that stand in for roads is E.

C. Traffic Light

Traffic lights, which have two distinct zones, such as a stop zone and a slow down zone, are situated at vertices.

- **Stop Zone:** The term "stop zone" refers to the space between stops for moving cars. This can be expressed using the following equation:

$$\frac{dv_i}{\mathrm{dt}} = -b_i \frac{v_i}{v_{0,i}}$$

- **Slow down zone**: A zone where vehicles slow down is defined by both a slow down factor and a slow down distance. This is made possible by the equation that follows:

$$(v_{0,i} := \alpha \ \mathrm{v}_{0,i} \text{ with } \alpha \ < \ 1)$$

We will be using Cities: Skyline which is a very renowned city-building simulator. We will create our own cities.Cityskiline lets us build our cities with very intricate design, road topology, grid layout. From a very complex road network to a simple layout can be designed here. We can change various traffic policies and observe their changes. Such as banning certain vehicles, restricting vehicles to certain zones, setting speed limits, forcing use of public transport, specifying vehicles to use certain lanes, and many other more.We can also create our own set of policies. CitySkyline supports advanced modding support. Modding refers to modifications. We can run our own scripts and dynamically interact with the unity engine. We are able to access the environment variable directly and commit any changes. Mods help us to create a specific setting for the virtual environment. We can control traffic lights, lane swapping, lane interaction, agent behavior, changing lane arrows, adding vehicle restrictions, priority signs and much more.Moreover the traffic system used in CitySkyline is complex and realistic. For using a microscopic model each individual agent has a source, destination, route. They will behave according to the road network, policies, destination and route. This model lets us simulate various scenarios and compare various urban planning models.We are also provided with built-in statistical and data overlays. This information allows us to track, monitor, and analyze the traffic patterns. We can also observe traffic volumes, congestion level, traffic flow on each road, intersection. We can also find the mode of transportation (car, public transport, metro, bike or foot) the agent is using and their destination (home, shopping, work, hospital, food-places) along with pathing.We are provided with a dynamic environment that has a day-night cycle, weather system. As a result they affect the traffic conditions. We can see the difference between the rush hour and off-peak time traffic flow. Weather elements like rain also change driving behavior.

VI. Experiment

We used the city skyline, a city building simulator in this paper. We have custom built a city from scratch for the experiment. The city is designed keeping the current Dhaka city in mind. It closely resembles a real time urban city. We tested the traffic flow in various vehicle occupancy rates. For instance, when road occupancy is at 20%, it represents off-peak hours. An occupancy of 50% is akin to a busy hour, while 90% occupancy suggests peak rush hour. Using these occupancy levels as default parameters, we conducted tests on various policies. We compared the traffic flow under two conditions: one where Traffic Police manually controlled the intersections, and another where control was fully automated via traffic lights. The traffic lights were programmed to maintain a priority queue based on the various intersections. Another parameter we examined was adherence to traffic laws. This included behaviors such as refraining from lane switching, cutting lanes, blocking intersections, and parking at the side of the road. In this scenario, we relied solely on Traffic Police for control, without the use of traffic lights.

Simulating Traffic Flow

We used the city skyline to simulate the traffic flow in our custom made Dhaka city where for simulating, microscopic models were used which use the following equations for modeling the traffic system:

Intelligent Driver Model was used which works with the following equations:

It is assumed that vehicles move along straight line and follow the below equations:

$$\frac{dv_i}{\mathrm{dt}} = a_{\text{free road}} + a_{\text{interaction}}$$

$$a_{\text{free road}} = a_i \left(1 - \left(\frac{v_i}{v_{0,i}}\right)^{\delta}\right)^2$$

The acceleration on a free road, or a road with no cars in front of it, is known as the free road acceleration.

The acceleration with the car in front is known as the interaction acceleration, which can be expressed as:

$$\begin{aligned} a_{\text{interaction}} = & - a_i \left(\frac{S^*\left(v_i, \Delta v_i\right)}{S_i}\right)^2 \\ & - a_i \left(\frac{S_{0,i} + v_i T_i}{S_i} + \frac{v_i \Delta v_i}{2 S_i}\right)^2 \end{aligned} \quad (1)$$

To model traffic lights, which have two distinct zones, such as a stop zone and a slow-down zone, are situated at vertices.

- **Stop Zone:** The term "stop zone" refers to the space between stops for moving cars. This can be expressed using the following equation:

$$\frac{dv_i}{\mathrm{dt}} = -b_i \frac{v_i}{v_{0,i}}$$

- **Slow down zone**: A zone where vehicles slow down is defined by both a slow down factor and a slow down distance. This is made possible by the equation that follows:

$$(v_{0,i} := \alpha \ \mathrm{v}_{0,i} \text{ with } \alpha \ < \ 1)$$

A. Simulation Environment

To recreate and replicate our simulation study of traffic conditions in Dhaka city, we employed a combination of simulation tools and modifications to existing platforms. The following tools and mods were instrumental in creating a realistic and dynamic traffic environment:

1) CitySkyline Simulation Platform:: We utilized the CitySkyline simulation platform as the foundation for our work. This versatile simulation engine provided a robust framework for developing and analyzing complex urban traffic scenarios. CitySkyline's flexibility allowed us to modify and adapt its features to suit the specific characteristics of Dhaka city.

2) Customized Dhaka City Environment:: In order to accurately represent the unique challenges of Dhaka's traffic conditions, we extensively modified the CitySkyline environment. This involved creating a customized Dhaka cityscape that considered the diverse types of vehicles, road structures, and traffic behaviors specific to the region.

3) Harmony:: Harmony, a simulation management tool, played a crucial role in orchestrating and coordinating various elements within our simulated environment. It facilitated the integration of different modules, ensuring a harmonious interaction between traffic flows, infrastructure changes, and real-time modifications.

4) Traffic Manager Mod:: The Traffic Manager mod served as a pivotal addition, offering advanced traffic management features that enhanced the realism of our simulations. This mod allowed us to fine-tune traffic signals, control vehicle behavior, and implement dynamic changes in response to simulated events.

5) PGT (Propositions for a Greater Traffic Realism):: PGT, along with other traffic mods, contributed to the authenticity of our simulated traffic. PGT provided additional features and parameters that align with real-world traffic scenarios, enabling a more accurate representation of Dhaka's complex traffic dynamics.

6) Infrastructure Mods:: We incorporated various infrastructure mods to simulate the impact of new developments on traffic flow. These included mods for bridges, flyovers, roads, overpasses, and underpasses, allowing us to assess the potential effects of different infrastructural changes.

7) Crosswalk Mod and Additional Enhancements:: To address pedestrian dynamics and enhance the overall realism of our simulation, we integrated a crosswalk mod and other enhancements. These modifications considered factors such as pedestrian traffic, crosswalk efficiency, and safety measures within the simulated urban landscape.

VII. Result Analysis

We generated the traffic flow result by running the simulation based on multiple input parameters such as percentage of total vehicles in the city, traffic police, traffic light, traffic law obedience by the pedestrians and the drivers. Based on the various data of these input parameters we found the following simulated data:

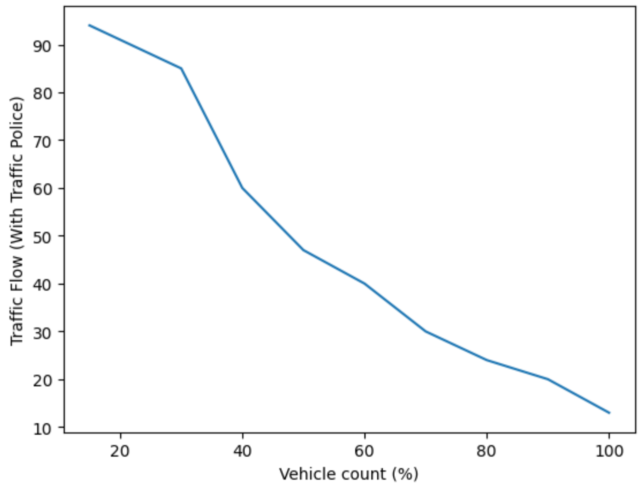

Fig. 1. Traffic simulation with traffic police controlled traffic system

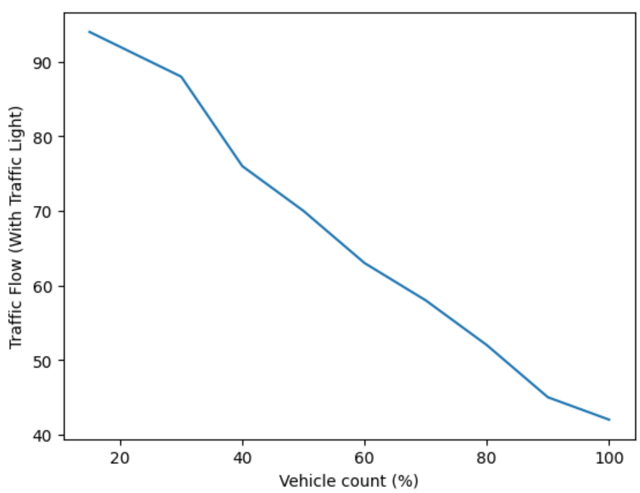

Fig. 2. Traffic simulation with traffic light controlled traffic system

After analyzing these simulated data it is visible that the causes of poor traffic flow leading to traffic jams are massive numbers of vehicles in peak hours with not enough roads, highways, poor law obedience by the pedestrians and drivers. It is also visible that traffic light controlled traffic systems are more efficient than traffic police controlled traffic systems resulting in better traffic flow when traffic light controlled traffic systems are used. So some of the solutions of poor traffic flow leading to traffic jams in Dhaka city are as follows:

- Increasing number of roads, highways, making well spacious highways, roads with more lanes.
- Traffic law should be strictly followed by both drivers and pedestrians.
- Traffic light controlled traffic systems should be introduced to all traffic zones in Dhaka.

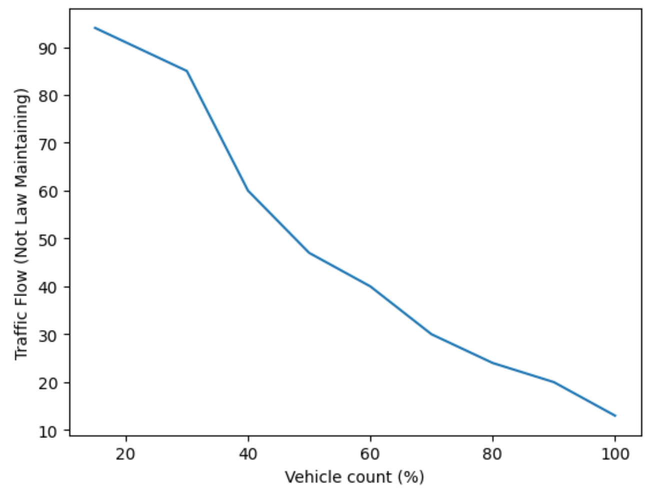

Fig. 3. Traffic simulation with not traffic law properly maintaining

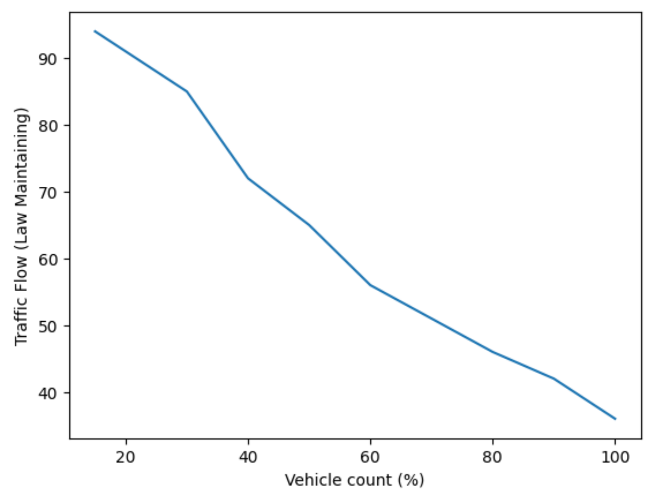

Fig. 4. traffic simulation with maintaining traffic law properly

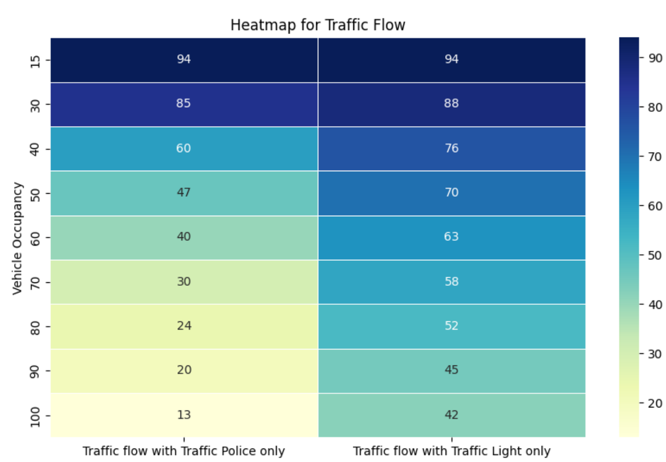

Fig. 5. Heatmap showing traffic flow with traffic police only and traffic

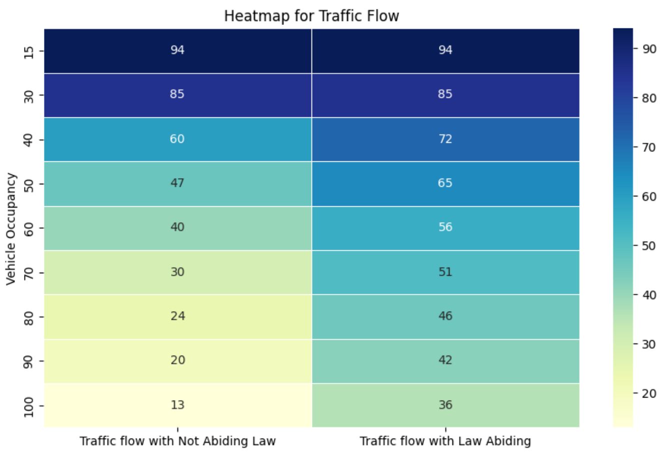

Fig. 6. Heatmap showing traffic flow with law abiding and not abiding.

References

Commey, J. (2023). *City Building Games as Pedagogical Tools in Urban Planning*. PhD thesis.

Duncan, C., Cunningham, J., Wang, A., and Kennedy, A. (2021). Urban planning optimization via “cities: Skylines”.

Haahtela, P., Vuorinen, T., Kontturi, A., Silfvast, H., Väisänen, M., and Onali, J. (2015). Gamification of education: Cities skylines as an educational tool for real estate and land use planning studies.

Himite, B. (2021). Simulating traffic flow in python.

Khan, T. A. and Zhao, X. (2021). Perceptions of students for a gamification approach: cities skylines as a pedagogical tool in urban planning education. In *Responsible AI and Analytics for an Ethical and Inclusive Digitized Society: 20th IFIP WG 6.11 Conference on e-Business, e-Services and e-Society, I3E 2021, Galway, Ireland, September 1–3, 2021, Proceedings 20*, pages 763–773. Springer.

Lin, Y. (2019). Dynastim: A real-time online traffic simulation and optimization system. In *2019 Chinese Automation Congress (CAC)*, pages 163–168.

Pan, Y. and Cao, Z. (2018). Simulation research on traffic flow characteristics of bus stop area based on vissim software. In *2018 Prognostics and System Health Management Conference (PHM-Chongqing)*, pages 1325–1330.

Pinos, J., Vozenilek, V., and Pavlis, O. (2020). Automatic geodata processing methods for real-world city visualizations in cities: Skylines. *ISPRS International Journal of Geo-Information*, 9(1).

Potuzak, T. (2022). Current trends in road traffic network division for distributed or parallel road traffic simulation. In *2022 IEEE/ACM 26th International Symposium on Distributed Simulation and Real Time Applications (DS-RT)*, pages 77–86.

Skorobogatchenko, D. A., Frolovichev, A. I., Sokolov, A. A., and Vlasova, J. M. (2022). Simulation of facilities that ensure adaptive functioning of urban street and road network. In *2022 International Conference on Information, Control, and Communication Technologies (ICCT)*, pages 1–5.

Song, H. and Min, O. (2018). Statistical traffic generation methods for urban traffic simulation. In *2018 20th International Conference on Advanced Communication Technology (ICACT)*, pages 247–250.