Journal of Civil Engineering (IEB), 51 (2) (2023) 81-86

Journal of Civil Engineering IEB

Analyzing the traffic efficiency and environmental impact of the cloverleaf interchange at Bhanga, Bangladesh by simulation

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Received 3 August 2023

Abstract

The Bhanga cloverleaf interchange stands as a crucial transportation infrastructure in Bangladesh which connects more than 21 districts in the south and western parts of the country. In light of escalating urbanization and environmental concerns, this research delves into the comprehensive analysis of traffic flow and environmental impact within the context of the Bhanga interchange. Through comprehensive scenario modeling in Cities Skylines, we assessed the interchange's performance under varying traffic conditions, exploring congestion hotspots, travel times, and vehicle density. Leveraging the simulation's capabilities, we also analyzed the interchange's environmental impact, land pollution, focusing on air quality, noise pollution, and land use changes. Our findings offer valuable insights into optimizing traffic management strategies and minimizing the interchange's ecological footprint. By simulating real-world scenarios, this study contributes to the realm of sustainable urban planning, providing a nuanced understanding of the intricate interactions between transportation infrastructure and the environment, thus paving the way for more efficient, environmentally-friendly interchanges in the future.

Keywords: Bhanga cloverleaf, traffic dynamics, congestion patterns, environmental impacts, cities: skylines simulation, sustainable urban planning, traffic management strategies, peak-hour congestion, traffic flow analysis.

1. Introduction

After crossing Padma Bridge, Bangladesh's first six-lane highway begins in Dhaka and would likely conclude in Bhanga, an upazila on the banks of the Kumar River in Faridpur. The building of the Padma Bridge and the highway adjacent has given a new face to a tangle of roads in the upazila known locally as Bhanga Gol Chattar. None of the country's other roadways can compete with this vista. This is Bangladesh’s first ever Cloverleaf Interchange. From Bhanga Gol Chattar, four large four-lane highways branch out in four different directions. The north side road links Rajbari, Kushtia, and Meherpur to Faridpur Sadar. After

passing the Daulatdia ferry port, it is feasible to proceed to Dhaka through Manikganj along the route. The road leading west from Bhanga Gol Chattar connects Gopalganj, Bagerhat, Khulna, and Jashore to Benapole. The road leading south from Bhanga Gol Chattar connects Barishal and Patuakhali to Kuakata via Madaripur. The road east of Bhanga Gol Chattar is Bangladesh's first expressway that connects Padma Bridge to Dhaka.

1.1 Why cloverleaf interchange

For several reasons, cloverleaf interchanges are preferred. For instance, they provide high traffic capacity and efficient vehicle movement between intersecting highways, reducing congestion during peak hours. Second, using loop ramps reduces conflict points, resulting in safer and smoother traffic flow. Furthermore, cloverleaf interchanges allow for continuous mainline flow without the use of traffic signals, improving overall traffic efficiency. Furthermore, these interchanges require less space than other designs, making them appropriate for areas with limited land availability. Finally, cloverleaf interchanges have a proven track record of success, having been widely used for decades to effectively manage traffic flow, especially in freeway-to-freeway connections. (Song, H., et al., 2012)

1.2 Simulation

Cities: Skylines, a city-building simulation game developed by Colossal Order, offers an almost accurate result for data collection due to its sophisticated and realistic mechanics. The game's traffic simulation mirrors real-world behavior, considering road capacity, traffic lights, and intersections, resulting in a close representation of actual traffic flow. Its flexibility allows researchers to model specific scenarios and test various traffic management strategies accurately. With large-scale simulations and time progression mode, researchers can gain insights into peak traffic periods, congestion patterns, and traffic fluctuations throughout the day. The game's visualization of traffic congestion aids in identifying bottlenecks and congested areas. Additionally, Cities: Skylines includes basic environmental mechanics, allowing users to understand potential environmental impacts. While not a perfect substitute for real-world data, the simulation provides a valuable complement to traditional data collection methods, especially for preliminary assessments, scenario testing, and educational purposes. Caution should be exercised in interpreting results, acknowledging the game's limitations, but overall, Cities: Skylines serves as an accessible and effective platform for exploring traffic flow, congestion patterns, and urban planning strategies. Here we generated a most accurate simulation of Bhanga Cloverleaf intersection by adding exact lanes, traffic flow, regions and put the simulation under various conditions and recorded data over an array of time. (Pinos, J., et al., 2020)

1.3 Traffic of Bangladesh

Throughout this research, we remained keenly aware of Bangladesh's unique traffic condition and the complexities it presents. Recognizing the dynamic and diverse traffic patterns prevalent in the country, we incorporated this understanding into the design of our simulation and data collection methodology. Our simulation model in Cities: Skylines was calibrated to account for the peculiarities of traffic flow and congestion observed in Bangladeshi cities, ensuring that it could capture the essence of real-world traffic dynamics.

During on-site visits and data collection from Google Maps, we took into consideration the presence of various modes of transportation, including rickshaws and auto-rickshaws, as well as the interactions between pedestrians and vehicles. We used this information to create realistic scenarios in the simulation that reflected the unique traffic conditions specific to Bangladesh. (Shamsher, R., and Abdullah, M., 2015)

2. Materials and methodology

In this study, we employed a hybrid approach for data collection, combining real-time data from Google Maps and on-site visits with simulation data gathered from Cities: Skylines. Firstly, we collected real-time traffic data from Google Maps to obtain current traffic flow, congestion patterns, and travel times around the Bhanga cloverleaf interchange.

2.1 Data sources

Google Maps provided valuable information on real-world traffic conditions, ensuring the incorporation of up-to-date data into our analysis. Additionally, on-site visits allowed us to validate the accuracy of the simulation model in Cities: Skylines by comparing the virtual traffic patterns with the actual traffic observed on the ground. This validation process further strengthened the reliability of our simulation results. By integrating data from both real-time sources and simulation, we aimed to create a comprehensive and accurate assessment of the Bhanga interchange's traffic dynamics and optimize the representation of real-world traffic conditions.

2.2 Simulation setup and fine tuning

We manipulated simulation parameters such as traffic signal timings, road capacity, and traffic rules to test different traffic conditions and match with Bangladesh’s traffic flow while keeping the road layout and flow constant. We simulated various scenarios representing different traffic conditions, such as peak hours, low-traffic periods, and traffic congestion events, by varying these parameters. For example, during peak hours, we increased traffic volumes and adjusted signal timings to simulate heavy traffic flow, simulating real-world congestion. Similarly, we reduced traffic volume during low-traffic periods to simulate lighter traffic conditions with smoother flow. We ensured that the simulation accurately reflected real-world conditions by using the same road layout and traffic flow data obtained from Google Maps. This methodology allowed us to comprehensively analyze the interchange's performance under various traffic scenarios, providing valuable insights into its traffic efficiency and congestion patterns. Additionally, it enabled us to explore different traffic management strategies and assess their effectiveness without altering the actual road layout or traffic flow, making the simulation a powerful tool for optimizing traffic planning and management in real-world scenarios.

3. Results

3.1 Traffic flow analysis

Off Peak Hours: Average traffic flow stays near 65% which suggests that the road is neither fully congested nor completely empty, indicating a balanced flow of vehicles with some room for additional traffic. Even though there are some congestions appear near the loop-overpass intersection and entrance-transfer ramp intersection, over all the traffic flow is more than just good when considering Bangladesh’s average traffic flow.

Peak hours: Considering national holidays, accidents etc. we tried increasing the traffic volume to see what happens. The average traffic flow drops down to 33% creating heavy congestions in several parts of the intersection (Especially at the transfer ramps and loops).

3.2 Congestion patterns

Congestion is mainly appearing on at the entrance of transfer ramps because vehicles tend to stay on the side-lanes from early so that they don’t miss out the entrance. Also transfer ramps and loops have only two lanes which creates bottlenecks on several loops and transfer ramps.

3.3 Environmental impact

Air pollution: Congestion often leads to prolonged idling and stop-and-go traffic, resulting in increased emissions of pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs). These pollutants contribute to poor air quality, leading to health issues and exacerbating smog formation in the vicinity of the intersection and the AQI hits 130-140 surrounding the intersection area.

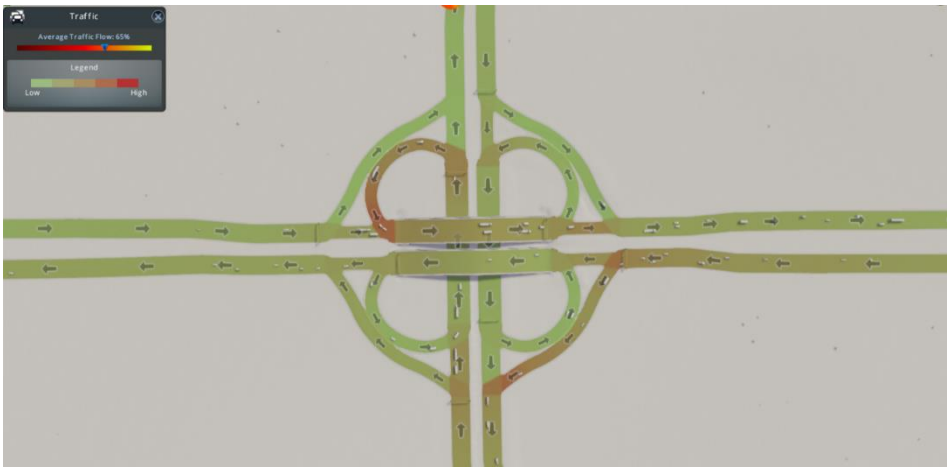

Fig. 1. Traffic flow during off peak hours.

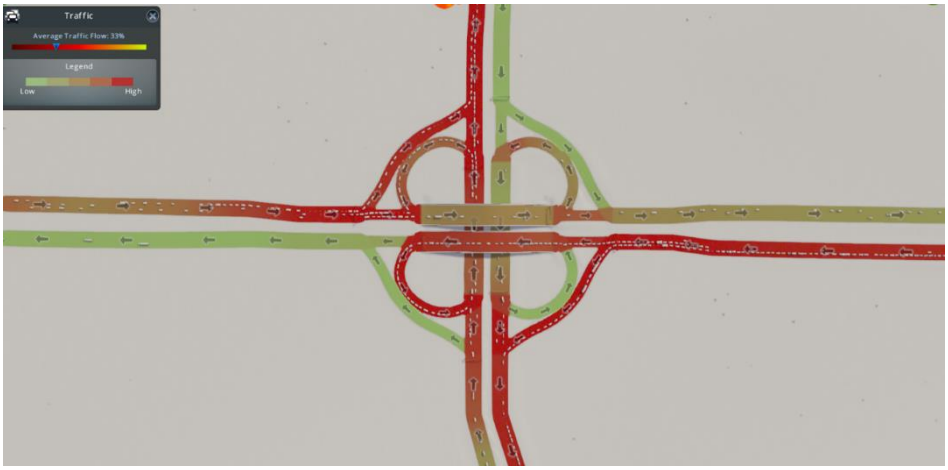

Fig. 2. Traffic flow during peak hours.

Noise pollution: Heavy traffic congestion generates higher noise (>80 dB) levels due to engine noise, honking, and frequent braking. The increased noise pollution can negatively affect the quality of life for residents and workers in nearby areas, leading to annoyance, stress, and potential health problems. (Pinos, J., et al., 2020)

Land pollution: The simulation provides a land pollution map where we can see that, after a period of 3 years of regular traffic flow, the parts where congestions form most of the time, has the highest impact on the land quality. Traffic congestion may lead to increased littering and improper disposal of waste by drivers and passengers. Trash and debris can accumulate along the roadsides and nearby areas, leading to unsightly landscapes and environmental degradation. Also, those are the places where visitors and tourists come and spend time as the Bhanga Gol Chattar, Bangladesh's first and only cloverleaf interchange is nothing less than a tourist spot for the people.

4. Implications, limitations and future recommendation

The simulation results indicate that the cloverleaf interchange is a viable and beneficial decision. However, it is essential to address the observed congestions during peak hours, which can lead to adverse environmental impacts such as land, noise, and air pollution. The implications of this research highlight the importance of implementing traffic management strategies to alleviate congestion and enhance traffic flow efficiency, while considering sustainable urban planning measures to mitigate pollution around the interchange. The simulation has also proved itself to be one of the most precise and accurate one after it is fine-tuned with several factors.

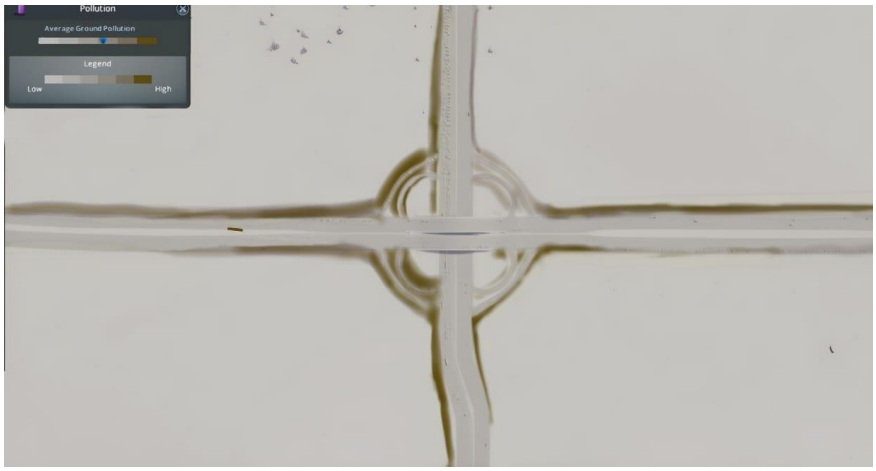

Fig. 3. Land pollution map after 3 years of regular flow.

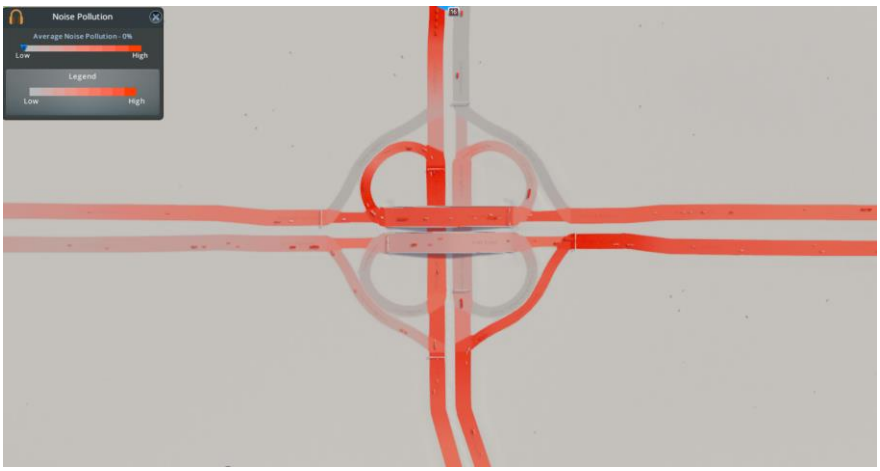

Fig. 4. Noise pollution map during regular flow.

The study's limitations emphasize the need for further data validation and real-world traffic analysis to improve the accuracy and reliability of the simulation results. Additionally, accounting for seasonal variations and long-term traffic trends can provide more comprehensive insights.

For future recommendations, conducting long-term data collection at the interchange can facilitate a deeper understanding of traffic patterns and trends. Collaborating with transportation authorities to access real-time traffic data can enhance the research's validity. Comparative studies between different interchange designs and traffic management strategies can help identify the most effective solutions for optimizing traffic flow. Furthermore,

performing an environmental impact assessment can guide the implementation of eco-friendly practices and sustainable infrastructure development to mitigate the interchange's environmental effects. By addressing these aspects, the research can contribute to improved traffic management, environmentally conscious urban planning, and the overall efficiency and sustainability of the transportation system.

5. Conclusion

This study of the Bhanga cloverleaf interchange and its traffic dynamics provides important insights into the interchange's effectiveness and its implications for traffic management and sustainable urban planning. The simulation results show that the cloverleaf interchange is a good decision, allowing for smooth traffic flow under normal conditions. However, peak-hour congestion highlights the need for traffic management strategies to alleviate bottlenecks and improve overall traffic efficiency. Furthermore, the research shows that the interchange's congestion during peak hours can have negative environmental consequences, such as land, noise, and air pollution. Addressing these environmental issues is critical to creating a more healthy and sustainable transportation environment. While the study provides valuable findings, it does acknowledge some limitations, such as the accuracy of simulation results and data availability. Future research should concentrate on validating simulation data with real-world traffic observations and taking long-term trends into account to improve the research's reliability. The study's implications highlight the importance of implementing traffic management strategies and sustainable urban planning measures to optimize the interchange's performance while minimizing its environmental impact. Collaboration with transportation authorities and comprehensive environmental impact assessments can help to support environmentally friendly practices and guide infrastructure development around the interchange.

By addressing these issues, the research contributes to more informed transportation planning decisions, promoting more efficient, environmentally friendly, and long-term traffic solutions. Finally, this study provides valuable insights that can help policymakers and urban planners design transportation systems that benefit both commuters and the environment.

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