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Examine Efficiency of Highway Interchange Using Python and Game Based Simulation Software

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A B S T R A C T

The study outlines the analysis of highway interchange using simulation of game-based simulation software and how it can be effectively used for transportation simulation studies instead of expensive traffic simulation software. Once the required environment for simulation is constructed within the game the data needed to perform the study will be recorded using third party screen recording software which will record the number of vehicles moving along the interchanges and the counting of the vehicles will be processed with Python, utilizing the OpenCV library and its machine learning capabilities. The primary objective of the study is to evaluate the traffic flow of the highway interchange and compare it with other simulation software as well as real life traffic data while considering peak vehicle flow for all three parameters. Highway interchange efficiency assessment has traditionally relied on time-consuming methods, including simulations and AI models, resulting in a lack of a unified approach. Such methods are often complicated and require extensive learning curve with addition of them being expensive. This research aims to address this challenge by proposing an integrated solution using alternative game-based video simulation software and Python to comprehensively evaluate the efficiency of different types of highway interchanges.

Keywords: Traffic simulation, Highway interchange, Python, Game simulation, OpenCV, Traffic efficiency

1. Introduction

1.1 Highway interchange:

A highway interchange is a specialized road junction that allows traffic to flow smoothly between different highways or major roads. Interchanges are designed to facilitate the movement of vehicles, minimize congestion, and enhance safety. [1] They come in various configurations and designs, each tailored to specific traffic volumes, local geography, and other factors. The American Association of State Highway and Transportation Officials (AASHTO) defines a highway interchange as a specialized junction or intersection of two or more highways or roadways, designed to facilitate the movement of traffic between them. Interchanges are critical components of transportation infrastructure, allowing vehicles to transition smoothly from one road to another, thereby enhancing overall mobility, safety, and efficiency.

1.2 Simulation software:

Traffic simulation software encompasses computer programs designed to replicate and analyse traffic behaviour in specific environments, such as road networks, intersections, or entire transportation systems. These software applications employ mathematical algorithms and models to simulate real-world traffic scenarios, allowing for the evaluation of various factors influencing traffic flow. They operate at different levels of detail, ranging from microscopic simulations, which focus on individual vehicle behaviours like acceleration and lane-changing, to mesoscopic and macroscopic simulations, which provide broader views of traffic patterns and congestion. Some advanced software incorporates dynamic traffic assignment and optimization of traffic signal timings to enhance realism. [2] [7] Additionally, these tools often facilitate data analysis and visualization, enabling professionals in transportation engineering, urban planning, and research to make informed decisions about road design, traffic management, and infrastructure development. Popular examples include VISSIM, AIMSUN, and Synchro/Sim Traffic, which play pivotal roles in optimizing traffic flow and planning for future transportation needs. “Cities: Skylines" is a popular city-building simulation game that puts players in charge of creating and managing their own virtual cities. Developed by Colossal Order and published by Paradox Interactive, the game offers a dynamic platform for urban planning enthusiasts. Players have the freedom to design road networks, allocate zoning for residential, commercial, and industrial areas, and oversee vital public services like water, electricity, and waste disposal. The game's economic management aspect requires players to skilfully manage budgets, set taxes, and foster economic growth for the city's prosperity. With robust modding support, "Cities: Skylines" also encourages community involvement, allowing players to enhance and customize

the game with additional features and assets. This study is performed using this game to emphasize that tools in such games such as simulation tools are as effective as expensive traffic simulation software.

1.3 Python:

Python is a high-level, general-purpose programming language known for its simplicity, readability, and versatility. It was created by Guido van Rossum and first released in 1991. Python's design philosophy emphasizes code readability, which makes it easier to write and understand compared to many other languages. It supports multiple programming paradigms, including procedural, object-oriented, and functional programming. Python's syntax is clear and concise, often resembling plain English, making it accessible to beginners while also powerful enough to handle complex tasks. It has a large and active community of developers, which means there are extensive resources, libraries, and frameworks available to help with various tasks.

2. Literature review

2.1. Malik abid, Mamoon Riaz et.al., It provides a comprehensive overview of various types of highway interchanges. It may discuss the design, characteristics, and functionalities of different interchange configurations, serving as a valuable resource for understanding the fundamental principles of interchange engineering. It also talks about advantages and disadvantages associated with the interchanges.

2.2.Goran Jovanovic et.al., The research paper introduces a novel type of interchange referred to as the "ITL interchange," emphasizing its high effectiveness in improving traffic flow and overall functionality. To rigorously evaluate its performance, the researchers employed a micro simulation tool, a computer-based modeling system that allows for detailed analysis of individual vehicle movements and interactions within traffic systems. Through extensive testing, the ITL interchange was assessed against a range of parameters, including traffic flow rates, congestion levels, travel times, and safety metrics. Importantly, the evaluation did not occur in isolation; the ITL interchange's performance was compared to various other types of interchanges. This comparative analysis serves to establish the relative effectiveness of the ITL interchange design, providing valuable insights for the advancement of interchange engineering practices and potentially influencing future infrastructure projects.

2.3.Jose Raimundo Martinez., It focused on the application of artificial intelligence (AI) techniques, particularly in the context of city simulations. It explored how AI algorithms and models can be utilized to simulate urban environments, which could have implications for understanding traffic patterns and behavior within cities. The provided information outlines the process of creating a simulated city environment using Unreal Engine 4, a versatile game development platform known for its advanced 3D capabilities. This endeavor involves designing intricate city layouts, generating detailed 3D models for buildings, roads, and vehicles, and incorporating dynamic lighting effects to enhance realism. Additionally, artificial intelligence (AI) systems are integrated to govern the behavior of virtual inhabitants, ensuring interactions within the environment mimic those in an actual urban setting. This comprehensive development process culminates in the creation of a virtual city that emulates real-world dynamics, offering a versatile platform for a range of analyses and simulations. Moreover, the statement discusses the validation of advancements in pathfinding algorithms and vehicle AI, particularly within the "Cities Skylines" simulation software. Pathfinding algorithms dictate the most efficient routes for virtual entities, significantly influencing their navigation in the simulated environment. Furthermore, vehicle AI governs behaviors like adherence to traffic rules, response to signals, and collision avoidance. The validation process attests to the effectiveness and reliability of these enhancements, indicating that the "Cities Skylines" software is equipped with cutting-edge algorithms and AI systems. This substantiates its standing as a robust tool for conducting precise and authentic city simulations, bolstering its utility for various applications in urban planning and analysis.

2.4 Jahongir Azimjonov,Ahmet Ozmen et.al., It is centered around the development of a system that employs vision-based technologies for monitoring traffic flow at road intersections in real time. The research may introduce innovative methods for data collection and analysis, potentially offering valuable insights for traffic management and optimization. The developed system encompasses a Python-based algorithm designed to track and associate data of vehicles traversing through intersections. This algorithm serves as a crucial component in capturing and managing traffic flow information. To enhance vehicle detection accuracy, the YOLOv3 model, a state-of- the-art object detection algorithm, was integrated into the system. This model is renowned for its efficiency in accurately identifying objects in real-time scenarios. Furthermore, to streamline the process of extracting traffic flow data, a user-friendly form-based software tool was created. This tool simplifies the interaction with the algorithm, enabling the seamless retrieval of pertinent information about the movement and behavior of vehicles within the intersection. The integration of these components results in a robust and efficient system for tracking, associating, and extracting valuable traffic data at intersections. This system holds great potential for applications in traffic management, urban planning, and transportation analysis.

2.5 Sanjay Tippannavar,Sourab Jainet et.al., The system utilizes the OpenCV library in Python, coupled with morphological algorithms, to effectively count the number of vehicles within a specific lane from a video feed. This process involves employing computer vision techniques to accurately detect and track vehicles as they move through the lane. Once the vehicle count is obtained, it serves as a crucial input for calculating traffic density. This information is pivotal for the development of an intelligent traffic control system that can adapt in real-time based on the prevailing conditions and the time of day. By factoring in traffic density, the system can dynamically adjust signal timings and traffic flow patterns to optimize efficiency and safety. This application showcases the potential of advanced technology in enhancing traffic management and ultimately contributing to more intelligent and responsive urban infrastructure.

2.6 Ivan Brikic et.al., This paper presents a framework for accurately calculating traffic flow parameters using aerial videos captured by Unmanned Aerial Vehicles (UAVs). The research may demonstrate how advanced technologies and analytical techniques can be employed to extract valuable traffic data

from aerial perspectives. The proposed framework introduces an innovative and cost-effective approach for the precise measurement of traffic parameters, leveraging Unmanned Aerial Vehicles (UAVs). This framework stands out for its ability to achieve a high level of accuracy without incurring significant expenses. It combines multiple elements including image processing, terrain surveying, vehicle detection, and parameter estimation. These components work in tandem to capture a comprehensive understanding of traffic dynamics. Notably, the framework employs the powerful deep learning capabilities of the TensorFlow library for vehicle detection. This sophisticated technique enhances the accuracy and efficiency of identifying vehicles within the captured imagery. By amalgamating these advanced technologies, the framework offers a promising solution for obtaining reliable traffic data in a cost-effective manner, which holds great potential for applications in traffic management and urban planning.

2.7 Abolfazi samadi Heidar Abadi et.al., It involves a comparative analysis of different types of highway interchanges, specifically evaluating the operational and safety aspects using traffic simulation. The study may offer valuable insights into the performance characteristics of various interchange configurations. The study involved a comprehensive comparison of different type interchanges, specifically in relation to the Pinavia interchange, using the AIMSUN simulation software. This software is a widely used tool for traffic modeling and simulation. The comparison was conducted under the condition of a substantial traffic volume, specifically 10,000 vehicles passing through the interchange in a single hour. This volume level is significant and represents a high-demand scenario, which is crucial for evaluating the effectiveness and efficiency of interchanges in managing heavy traffic flow.

3. Methodology

3.1 Parameter Identification:

The important objective was to identify which parameters should be considered to specific types of Highway interchanges as well as what highway interchanges to use. In the end Cloverleaf interchange was decided to be considered. The reason behind this specific interchange was that it is a versatile interchange covering most used type of interchanges across the globe and it has the most vehicles flow possible throughout the interchange as compared to other prominent interchanges. The diameter and area to construct the interchange including other important parameters were based on AASHTO guidelines.[2] To ensure that AI pathfinding algorithms for the vehicle simulation in the “cities skylines” was subpar past studies regarding the same were referred.[3]

3.2 Simulation data implementation:

Interchanges needed to be built in the Cities Skylines game. For that it is necessary to construct whole city environment in order to have vehicles moving throughout the city and have constant moving of vehicular traffic. For that maximum amount of population based city amounting to 150000 people was constructed. After the construction of city the above interchanges were constructed based on the specifications of highway interchanges given in the OSHTO guidelines as well as referencing to highway interchanges built in previous studies. This was to ensure optimum interchanges are constructed. The final product was the city environment as shown below:

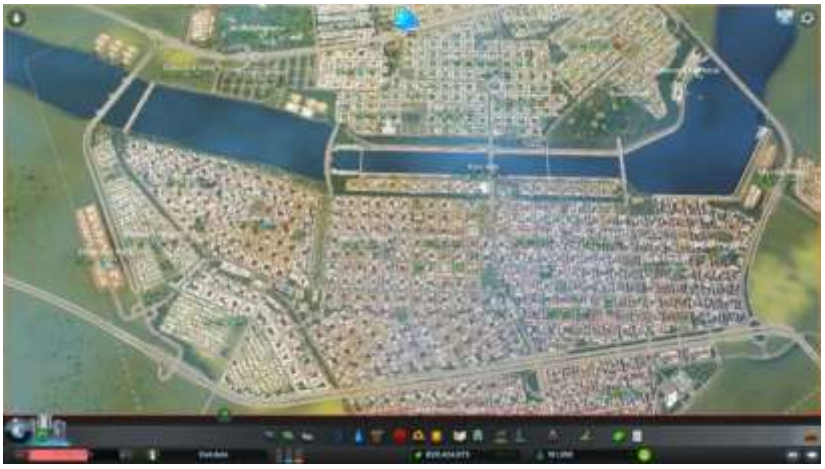

Fig.3.2.1 Final City environment layout

3.3 Analyzation in Python:

First step for analyzation in Python was to find out how the data would be processed in Python. As past studies for vehicle data analyzation whether it be from UAV or real time used different algorithms and micro simulation tools.[4] [5] [6] For this study we utilized YOLO algorithm. It was done due to it being used in previous study. When referencing the use of the YOLO algorithm in our study specifically, we employed the YOLOv3 variant for its balance of accuracy and efficiency. The YOLO model was trained on a custom dataset of annotated video frames, following the methodology outlined in Section The YOLO model was trained on a custom dataset of annotated video frames, following the methodology outlined in Section. The training process involves several key steps: data collection and annotation, data preprocessing, model training, model evaluation, and inference on video streams.

Each step is meticulously detailed, covering aspects such as dataset annotation, model initialization with pre-trained weights, fine-tuning on annotated video data, and model evaluation metrics. Furthermore, it discusses techniques for real-time inference on video streams, including optimization strategies for deployment in diverse applications. A case study utilizing the YOLOv3 algorithm, sourced from publicly available repositories, exemplifies the application of these methodologies. This research contributes valuable insights into the practical implementation of YOLO for video object detection tasks, offering a roadmap for researchers and practitioners in the field. [4]

3.4 Conducted a Traffic survey to analyze average traffic:

Flow Traffic survey was conducted to facilitate a comparative analysis between the study findings and real-life data. To accomplish this, video footage was recorded from local SPUI intercchange available. The recorded video encompassed both the main highway and the adjacent service road. In order to conduct a comprehensive analysis, manual traffic counting was performed. This involved meticulously tallying the number of various types of vehicles present in the footage, including cars, buses, Trucks, two-wheelers, and rickshaws. The only data on peak traffic period was considered out of all available data taken into consideration for calculation.

For Highway:

Table no. 3.4.1: Vehicle data of highway

Sr. No.	**Two wheeler**	**Car**	**Truck/Tempo**	**Bus**	**Rickshaw**	**Total**
1.	83	135	51	5	4	278

For Service Road:

Left Side:

Sr. No.	**Two wheeler**	**Car**	**Truck/Tempo**	**Bus**	**Rickshaw**	**Total**
1.	142	28	7	2	18	193

Table no. 3.4.2.1: Left side of Service Road

Right Side

Sr. No.	**Two wheeler**	**Car**	**Truck/Tempo**	**Bus**	**Rickshaw**	**Total**
1.	124	18	2	3	7	153

Table no. 3.4.2.2: Right side of Service Road

These figures serve as a representation of the vehicular traffic observed during the survey period on the highway segment captured in the video footage. Such data aids in providing a comparative perspective between the actual traffic scenario and the findings of the study, thereby contributing to a more comprehensive understanding of traffic dynamics in the area.

4. Results

Out of all three interchanges maximum results obtained from only one interchange was considered for calculation. Because the traffic flow was most in it. The interchange considered was cloverleaf interchange. Only two-minute video was analysed in Python due to its complex analyzation process and requiring large GPU processing power. This analyzation process itself took more than 2 days to be done to actually train the YOLOv3 model and then obtain the result. The results were obtained as output video of 3 Gigabyte size. Given the technical limitations this 2-minute video data was converted to hourly basis by performing simple calculations as below:

Number of vehicles in 2-minute video analyzation = 73

vehicles per hour from 2 hours: $73 \times 30 = 2190$

for 8 hours:

$$\frac{2190 \times 8}{2} = 8760$$

Efficiency compared to real life scenario

$$Efficiency = \left(\frac{simulated\ vehicles}{real\ life\ max\ vehicles}\right) \times 100 \quad (1)$$

$\left(\frac{8760}{8896}\right) \times 100 = 98.47\%$

Efficiency compared to other traffic simulators:

$$Efficiency = \left(\frac{simulated\ vehicles}{maximum\ vehicles}\right) \times 100 \quad (2)$$

$\left(\frac{8760}{9000}\right) \times 100 = 97.22\%$

5. Summary

"Cities: Skylines" simulation game shows 98.47% efficiency when compared to real-life traffic management scenarios. It's been observed to perform at 97.22% efficiency compared to professional simulation software requiring tedious post processing. This highlights its potential use as a supplementary tool in urban planning and traffic management studies. The game could also be used for comprehensive simulation studies related to noise & ground pollution, Logistics route planning, Traffic management, city planning, water management, urban transport studies and waste management. Ongoing traffic could not be manually controlled except for deciding maximum and minimum vehicles which limits the scope. City simulation requires integration of external coding software to be effective. As AI gets more convenient, seamless integration with other software would be easier. City's skylines itself may have future more advanced versions making it viable on its own and games can be seen more than a means of entertainment providing additional purposes.

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