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RESEARCH ARTICLE

AN AGENT BASED MODEL TO IMPROVE TRAFFIC FLOW AND ASSESS THE IMPACT OF SMART TRAFFIC LIGHT

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Abstract

The Traffic in developing country undergoes severs perturbations due to either a misunderstanding of the physical phenomenon or in bad calibration of equipment's such as traffic light. Due to this high complexity, mathematical models fail to well represent different scenario. Those issues are mostly due to the high amount of parameter which should be taken into consideration when dealing with some mathematical model and the drivers' behaviors. Since agent-based model is a computational simulation that represents individual entities (called agents) and their interactions within a defined environment. It is a powerful tools used to investigate human behavior impact in a mathematical model. Therefore, this paper proposed a novel agent-based approach framework for effectively making traffic light timing dynamic according to traffic density. Moreover, based on different rules such as lane changing, stop and goat the traffic light, we develop an Agent based model to represent the relationships between the traffic changing and its environment. The use of agent-based models for traffic light time optimization offers a more granular, adaptive, and integrative approach that better capture the complexities of real-world traffic scenarios. Finally, the experimental result is applied on synthetic data and compared to other results in almost the same context for both static and dynamic traffic light. The results show that the travel time distribution is less for dynamic traffic light.

Introduction:-

Traffic congestion has become a pervasive problem in urban areas across the globe, giving rise to substantial economic, environmental, and social consequences (Huang Z. a., 2023) (Litman, 2021).As urban populations continue to expand, and cities experience unprecedented growth, the need for efficient and sustainable transportation systems has never been more crucial. Researchers and policymakers have been exploring various approaches to address these challenges, including the development of more accurate traffic flow simulation models, the optimization of traffic light control systems, and the integration of intelligent transportation systems (ITS) (Barmpounakis, Intelligent transportation systems and powered two wheelers traffic, 2015) (Zhu, 2019)

One of the primary factors contributing to traffic congestion is vehicle density, defined as the number of vehicles per unit of road space (Berhanu, 2023). Higher vehicle densities often result in increased travel times, fuel consumption,

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and greenhouse gas emissions, while simultaneously decreasing road safety and overall quality of life for residents (Kawajiri, 2020). Consequently, a comprehensive understanding of the relationship between vehicle density and traffic flow is essential for the development of effective traffic management strategies that can mitigate the negative effects of congestion.

This paper seeks to contribute to the existing body of knowledge by presenting a comprehensive multi-lane traffic flow simulation model that investigates the impact of lanes number and traffic light timings on urban traffic congestion. Our model employs a simple grid-based representationof a road network with multiple lanes and integrates traffic light control mechanisms that can be adjusted to study their effects on traffic flow. We further examine the potential of incorporating intelligent transportation systems (ITS) and machine learning techniques to optimize traffic light control strategies based on real-time data (Barmpounakis, Unmanned Aerial Aircraft Systems for transportation engineering: Current practice and future challenges, 2016).

By analyzing simulation's results under various scenarios and traffic conditions, we aim to provide a deeper understanding of the factors that contribute to traffic congestion and explore potential strategies for mitigating its adverse effects. Moreover, our study seeks to inform policymakers and urban planners about the potential benefits and challenges associated with implementing advanced traffic management systems and inspire further research in this crucial field.

The aim of this paper is to give the traffic engineer a simulation perspective of traffic evaluation in different scenarios.

RelatedWork:

Traffic light is a crucial infrastructure in mobility management (Nedim, 2023). However, it can be a source of traffic congestion if it's not well calibrated. Therefore, the researchers have evaluated the efficiency through many contexts (Chen, 2018) (Nagel, 1992) (Nedim, 2023).

In analyzing the complex dynamic behavior of traffic streams, simulation tools have a prominent place (Qadri, 2020).

Traffic Control Signal strategies have been classified in fixed-time, adaptive, and actuated control strategies (Ribeiro, 2016). If fixed time is appropriate for traffic signal when the flow is stable and constant, it becomes inadequate when the traffic density becomes heavy. Conversely to fixed-time control strategy, researchers have developed and adaptive control strategy using mathematical model (Bae, 2019).

The duration of green and red light phases significantly impacts the efficiency of traffic movement, and optimizing these timings can help alleviate traffic issues in urban areas (Huang H. a., 2014). Nonetheless, determining the optimal traffic light timings is a complex problem contingent on numerous factors, such as traffic demand, road network characteristics, and traffic flow dynamics (Nigam, 2023).

Over the years, researchers have employed a variety of computational methods and simulation models to study traffic flow and optimize traffic light control systems (Barmpounakis, Intelligent transportation systems and powered two wheelers traffic, 2015) (Wang, 2020) (Litman, 2021). (Li, 2022)proposed an optimal scheme that reduces the queue delay but the number of passing vehicles remains unchanged.

These methods range from relatively simple cellular automata models (Nagel, 1992) to more sophisticated agent-based simulations (Chen, 2018)and machine learning approaches (Mileti{\'c}, 2022). These studies have provided valuable insights into traffic flow (Qadri, 2020)w dynamics and the effects of various traffic light control strategies on congestion levels.

However, none of this studies tried to investigated the relationship between traffic component through the agent perspective. Therefore, this study is groundbreaking in the sense of traffic light timing modelling.

Methodology:-

The model definition is the first part of traffic simulation. It involves giving a mathematical model of the traffic, describing the global environment (road structures, drivers and their characteristics, traffic light, and rules).

Agent-basedmodeling

A new way of simulating systems with interacting autonomous parts is called agent-based modeling (Cuevas, 2020). Agents are artificial individuals programmed to perform pre-defined operations (Bemthuis, 2020).

Agent represents the different entities that make up the environment (lattice or multidimensional). Hence they can either cooperate to form a multi-agent model or work alone. Therefore, the agent's behavior can be described as a physical system, such as simulations of evacuations, traffic etc.

The main advantage of agents is that they do not need strong mathematical theory or a high level of computing power. Despite their simple behaviors, they are capable of producing several globally complicated models (comportments) as a result of the modeling characteristics generated by the interactions of a group of simple agents. The term "global behavioral models" refers to coherent microscale patterns, such as recognized patterns of temporal, spatial, and behavioral structure, patterns of distribution, or patterns that are temporally, spatially, and behaviorally coherent.

Simulation framework

The model defined later corresponds to a traffic situation where vehicle follows each other near a traffic light. Therefore, the environment is composed by:

Scenarios:

The study focuses on a traffic flow near a junction with a traffic light. The traffic timing is static and we want to check the impact of traffic light timing, vehicle density, and lane number on the flow. The simulation is conducted on a road of 20 meters.

Figure 1:- Road section with Traffic light.

Agent:

To achieve those objectives, we define our agents.

Car agent :
In a simulation context drivers and vehicles could be seen as one entity. However, they are not in real life. Because, the vehicle simulation is straightforward with speed, and acceleration, the driver is a decision-taker through an analysis of the traffic situation. Therefore, we assumed that each agent moved toward a certain direction, could change their behaviors (decisions), and had a set of path solutions. they can be defined as adaptive, reactive, autonomous, and mobile agents. Each agent is considered as he is going at his own speed and thedecision of changing lanes is taken by the observation of the next following cells. Although the driver has preferred cells, he will go to the empty one.

Pedestrian agent:
Pedestrian agents are individuals person who walk through the transportation environment (road). He has to go from one place to another with a velocity from standing to a maximum speed corresponding to running. The pedestrians can either be walking, waiting, or halted due to an obstacle. In the context of this paper, the only interactions considered are the presence of a pedestrian on the road which can yield to an accident and disrupt the traffic.

Traffic Light:
A traffic Light is a road signal device that controls vehicle traffic at an intersection by alternating displaying traffic state. The traffic light interacts with the car agent in the flowing way red(mandatory stop), and green (vehicle move on). The transition between the two states is guided by the traffic density. If the traffic density decreases to a given threshold the traffic becomes red otherwise it stays green. In this paper, the traffic light is supposed to have a random density from an interval

Simulation: Simulating a single agent on a road section is quite simple since it just consists of acceleration and deceleration. However, when other agents get involved, it becomes necessary to take into consideration how the driver evolved and the decision he takes considering other agents. The simulation is done with discrete values, whereby each iteration is a time step. The initialization value is taken for the Ministry of Transportation. Then the traffic evolution is investigated through the analysis of travel time, and traffic throughput. Each agent is simulated by a Class function. The validation is done by real values taken from conductors on busy days. The implementation of an efficient simulation lies in the definition of a set of rules.

Rules:
The scenario is guided by different rules chosen among the traffic parameters. The traffic light timing is static therefore the traffic cannot absorb the flow in different situations.

Mathematical model
Since the traffic flow is an interaction between drivers and their environment. In this paper, we combined a set of mathematical equations describing the actions of considered components.

Considering the aforementioned characteristics of the agents, we will define some guideline rules.

Car followingrules
The car following model used is an extension of Nagel-Schreckenberg (Nagel, 1992) in (Titarmare, 2020) to express the velocity in different situations. The car following rules depends on the other drivers' behavior. Therefore, there is cooperation between a car agent and others in the following situations. In each situation, the car adopts a new velocity V_{new} .

Acceleration:
The car accelerates if the space headway is sufficiently large and the preceding vehicle maintains a velocity higher than the considered vehicle, the car velocity is then between the current one and the maximal velocity given by the preceding. The lane changing and acceleration will be considered in the next section:

Braking:

The car brakes if the preceding is lower than the one of the considered vehicle. However, the driver in this situation maintains a safe space headway sufficient to react to an obstacle. The new velocity is therefore between the current vehicle and minimum velocity V_{min} .

Driving:
When there is no other vehicle, the car chooses its velocity between an interval from a minimum velocity to a maximal velocity given by the authority

Random velocity:
A random velocity can occur when there is an unexpected event on the road. The only unexpected events that can be considered here are an accident or when a pedestrian comes too close to the first lane. Since those situations are discreet events. It's introduced with a binomial negation distribution

Where p is the probability that an accident occurs and q=1-p, k is the number of iteration and n is the number of success

Lane changing grules
The lane-changing rules are taken from the Nagel-Schrenberg model and state guidelines for vehicular agents when deciding to move from their current lane to an adjacent lane. The Lane changing occurs in two situations

1. **Discretionary Lane Changing:** It occurs when the driver sees a queue far away and change lane to go faster
2. **Mandatory Lane Changing:** This is when the driver has to change lanes because of an obstacle or to follow a given direction. Considering the speed loss caused by the mandatory lane-changing behavior
3. Before initiating a lane change, a car agent should consider several options:
4. **Necessity:** A lane change might be triggered by a turn ahead, a slow-moving vehicle in the present lane, or a planned maneuver to reduce the agent's travel time.
5. **Safety:** A lane change should be performed only when it is safe to do so. Safety checks should verify that there is enough space in the target lane and that the speeds of cars in both the current and target lanes are considered.

$$V_{new} = max(V_{new-1}, 0)$$

Expérimental Design
As shown in figure 1, the experiment is conducted on a road section not far from a traffic light. The road has 3 lanes and the priority is to keep right unless overtake. The structure of this intersection is such that in addition to the 4 lanes, there is a mini roundabout. Therefore, the static timing is not optimal during the whole day. Throughout the simulation, the road network acts as a stage for the interactions between vehicles, traffic lights, and the surrounding environment. It provides the spatial context within which the multi-lane traffic flow and traffic light control strategies are evaluated

The cells grid is defined by a basic numpy matrix. The number of cars is generated using the initial density and the number of lanes. the initial car positions are given by the random function of numpy and a loop over the enumeration of car position fill the grid.

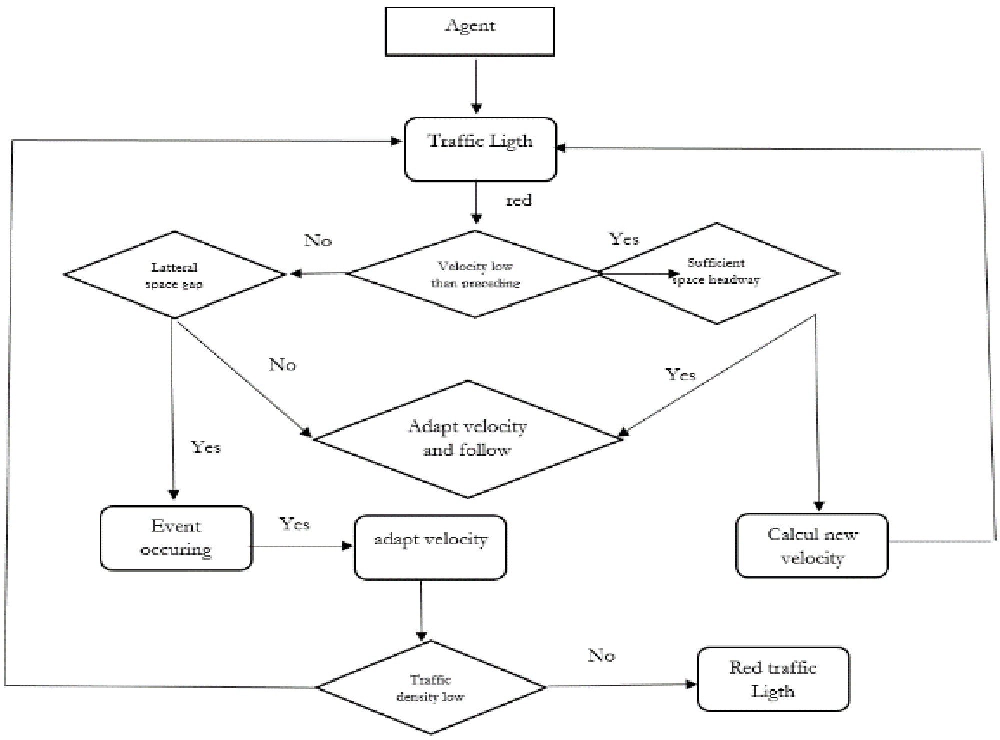

Figure 2:- Driver decision process.

Basically, the most important part of the evacuation is in the search module. When the traffic light goes from red to green, the drivers initiate a movement from one cell to the other. However, before he could move, he has to check if the desired next cell is empty.

Model Validation

The model validation is conducted by checking an obvious assumption, the correlation between traffic density and road congestion.

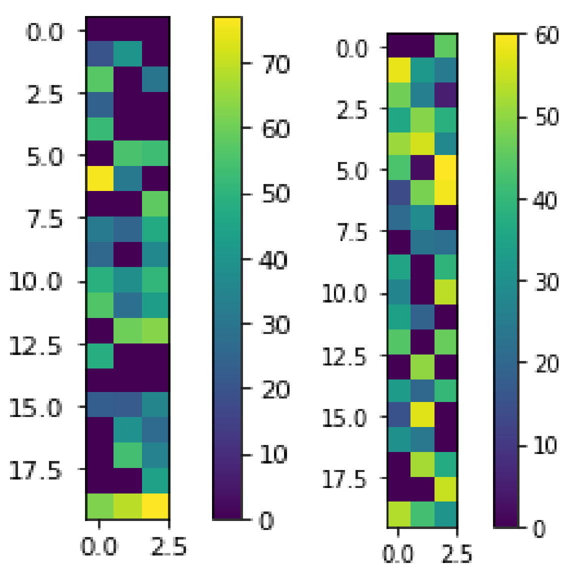

Figure 3:- Simulation during 15 seconde.

The simulations show that the traffic flow is smooth when vehicle density is low. In the left Figure there are fewer empty cells than in right. So the model could be used to improve traffic scenario by adding more realistic assumptions (lane changing, pedestrians, and buses) to check the impact of density, light timing, and lane number on the flow.

Results and Discussion:-

Impact of lanenumber on traffic Congestion

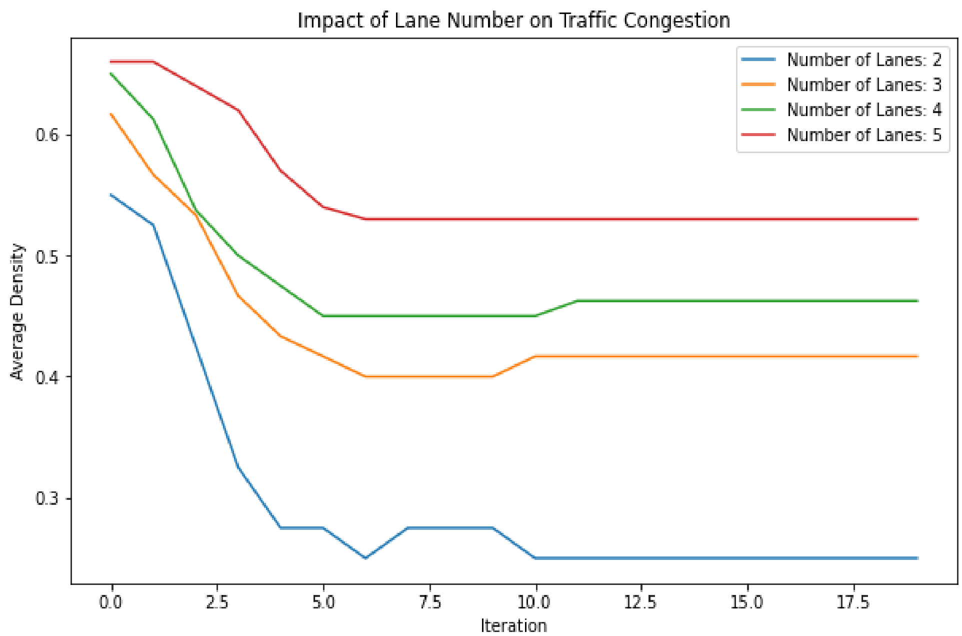

Figure 4:- Impact of lanenumbers on the Traffic.

Figure 4 result on the variation of lane number with a constant density equal to 0.8. The plot show that the average density function has an inverse variation to the lane number. This is because more lane allows a huge number of vehicle to cross the junction. Since the result can help traffic regulator to increase the mobility experience, the model should take consideration of others perspectives like speed limit, number of interaction and light timing. Moreover, the result is consistent with Texas Transportation Institute who found that increasing the number of lanes from two to four can reduce traffic congestion by up to 20%.

Impact of Traffic Light Timing on Traffic congestion

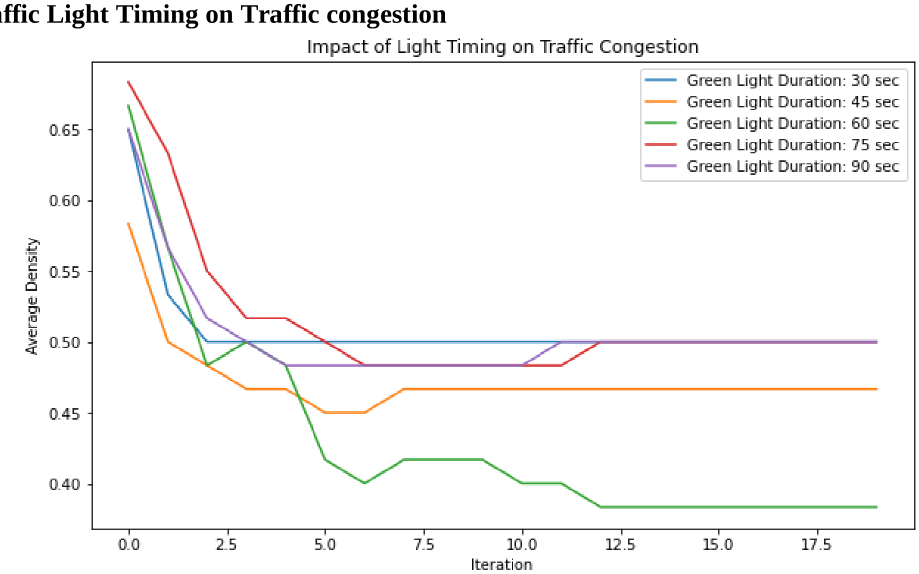

Figure 5:- Light timing varies from 30 to 91 s.

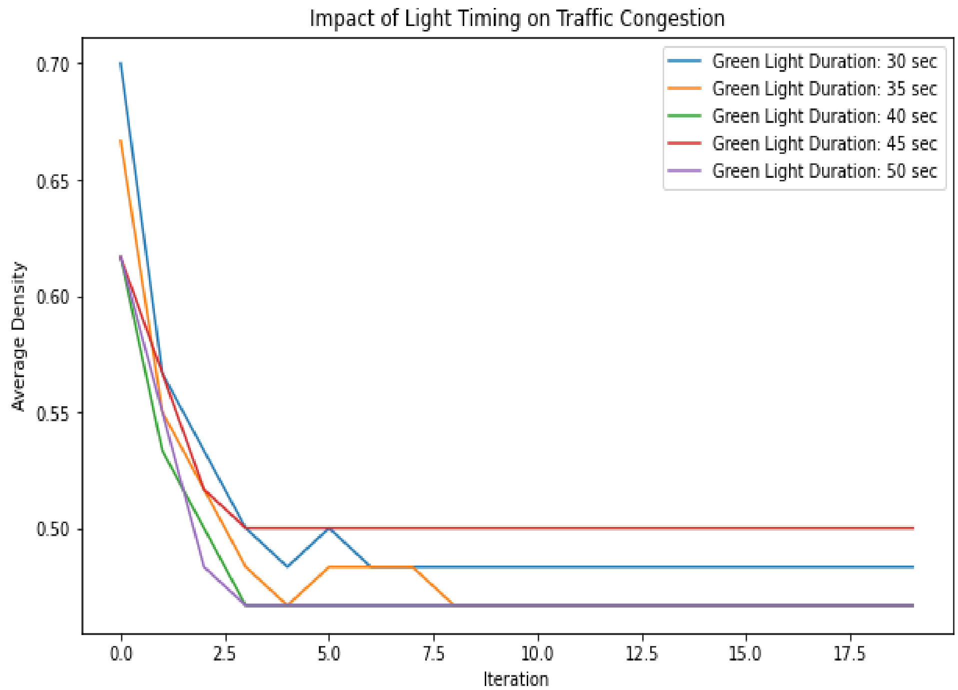

Figure 6:- Light timing varies from 40 to 70 s.

Figure 5 and Figure 6 show the relationship between a green light duration and traffic congestion. It can be seen that increasing the light timing reduces the traffic congestion. However, the rate improvement decrease over time as traffic reaches a more balanced state.

Impact of Pedestrian On the Traffic flow

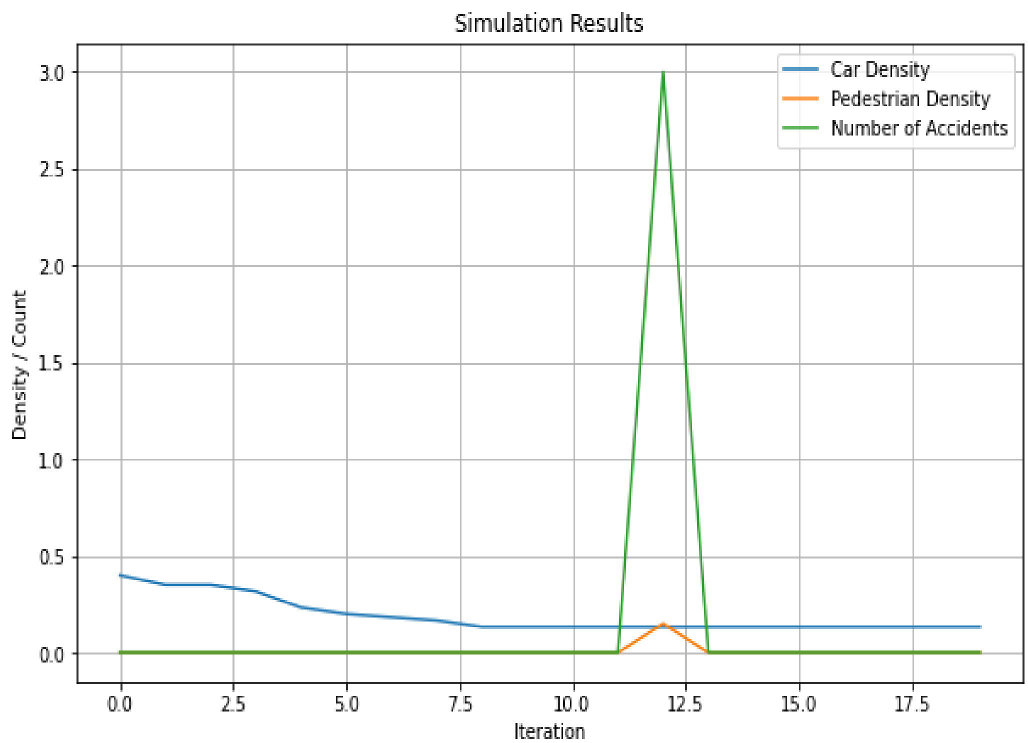

Figure 7:- Impact of Pedestrian on The Flow.

In Figure 7, we considered a side walker randomly placed. However, this requires drivers to slow down when approaching them. This results to an increasing probability of accident at each iteration. Accidents disrupt traffic flow and demonstrate the impact of unexpected events on congestion. By incorporating these assumptions, we are more comprehensive about the reaction of traffic on unexpected events.

Travel Time Comparison

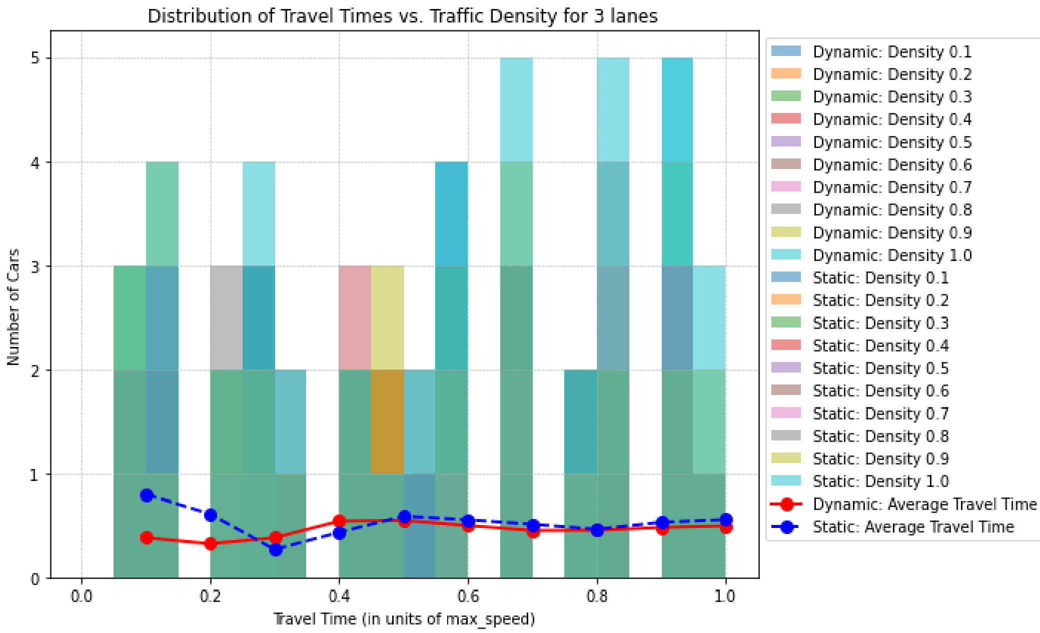

Figure 8:- Travel time comparison with distributions.

Figure 8 is a scenario conducted when the traffic density varies from 0,1 to 1,0. It can be shown that the static traffic light reacts better when the traffic density is low. This because the drivers have more time to adjust theirs speed to the traffic light. And the dynamic traffic tends to behaves like a static traffic light.

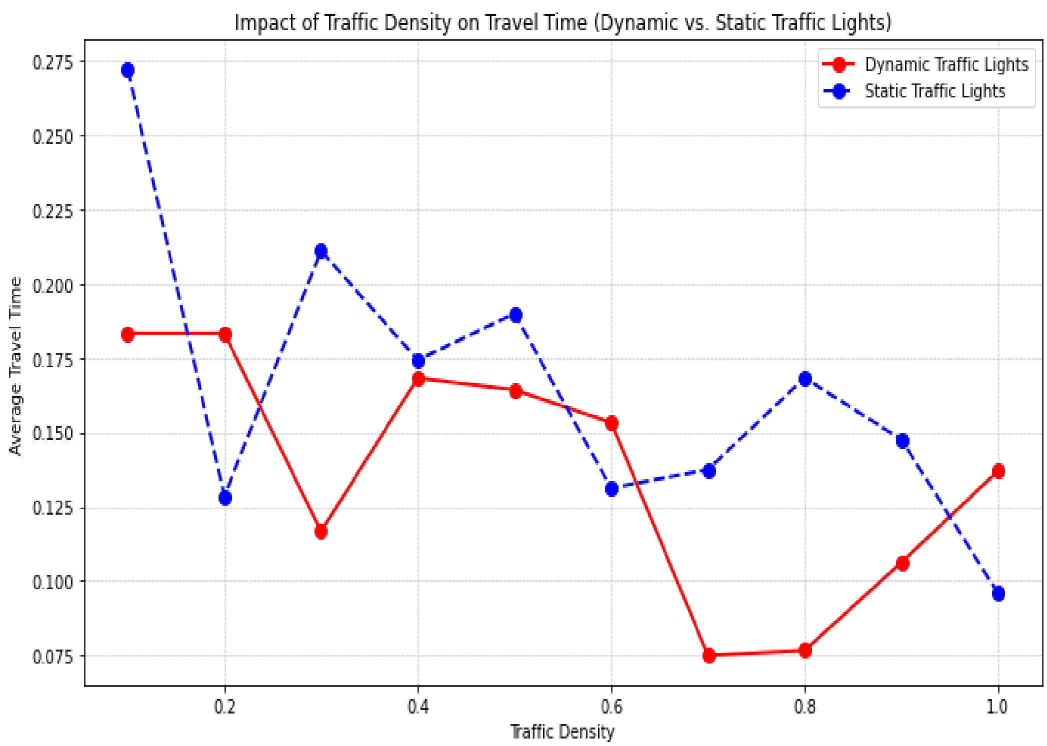

Figure 9:- Travel distribution.

In Figure 9, we have a heavy jam, where we can see that the dynamic traffic light travel time is less than the one of static traffic light. This is because the driver agent are better used by the traffic light agent to regulate the mobility.

Conclusion:-

This paper is a multi-agent-based model where agent rules are based on the cellular automata equation. The simulation shows that this pattern is a good representation of traffic congestion. However, the model could be improved with streaming data provided by the sensor whereby the density of the different agents would be more accurate. Furthermore, the slightly difference between dynamic and static travel time can be due to the use of empirical data during simulation.

However, this result may prompt road planners to consider implementing other technologies such as fly-over or fully connected traffic light to reroute the traffic in case of emergency.

Summary of results:

Our study demonstrated that the use of Agent Based Model gives a better understanding of the microscopic interactions between different agents. The different scenarios showed that dynamic traffic light deals better with traffic jam

Practical implications:

Thepractical implications of our research are numerous. Firstly, our approach can contribute to more enhance urban mobility, reducing the time spent at traffic light. It can also help traffic planner to size up different path when there is in emergency.

Future prospects:

For future research, there are several interesting avenues to explore. Firstly, implementing the solution in real situation. Then, the solution could be enhancing with a Deep Learning prediction to better predict the different timing.

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