Computational Modelling and Simulation

Project 2 Report(Group 4)

Team Members:

Muhammad Md Nasrein(1497325)

Riwaz Udas(1547555)

Research question

How do policies such as the implementation of dedicated lanes for e-scooters, helmet use, and safety awareness impact accident rates and traffic congestion in an urban grid like Melbourne?

Introduction

E-scooters have become highly integrated into urban transportation systems and have changed the way people travel around cities. They provide flexible, eco-friendly, and cost-effective solutions for short-distance commuting. Shared e-scooter services operated by companies such as Lime and Neuron are fast becoming a popular choice for thousands of commuters in densely populated cities like Melbourne, where people would not want to stand in traffic congestion. But with growing acceptance, concerns about safety and ineffective regulation have in recent times led to prohibitions in Melbourne, underlining a need for well-designed policies that ensure the safety of the riders as well as the smooth operation of urban traffic systems.

This research examines how two policy interventions techniques are used to affect the integration of e-scooters in urban transport and how they impinge on traffic congestion and safety in metropolitan areas: use of safety helmets and e-scooter usage on pedestrian lanes. By narrowing the focus to these two policies, this study attempts to solve the issues of safety and congestion that bear heavily upon the long-term success of e-scooters as a means of transport.

Previous studies have pointed out the potential effects, both positive and negative, to be associated with e-scooters. For instance, a case study in Sweden demonstrates how shared e-scooter schemes are encouraging a mode shift from cars and public transport toward e-scooters, which may help decrease congestion and lower emissions. Yet, there is still a question about safety, considering that no good regulation has been laid down as of this date. G Dias et al.[14] discussed that in the case of e-scooter use during the Covid-19 pandemic, stringent policy for fleet management is a crucial factor in developing a safe and efficient pattern of use of e-scooters. S Gössling [11] also mentions the city struggles to accommodate e-scooters in infrastructure improvement and prevent accidents.

This paper studies a simplified road environment, analyzing the impact of policies on e-scooter usage including designated lanes within a small, well-defined area in an urban area using single-lane roads and the It will make use of readily available summary statistics from previous studies and public reports regarding e-scooter use to simulate realistic scenarios and achieve insight into how such policies can improve safety and flow. We define a safety parameter called safety-scooter-slider that is used to represent how aware e-scooter riders are about traffic safety. The safety variables will be controlled for the case analysis, including accident rates and collision risk, and limitations to comprehensive safety modeling will be noted where appropriate.

Model design

The Overview, Design and Detail (ODD) protocol of our models is as follows:

1. Overview

Purpose

This model's purpose is to simulate different traffic interactions in an urban environment, considering three agent types: car, person, and scooter. It also aims to monitor the motion dynamics and congestion or accidents that might occur among these three types of agents, based on the type of road and the safety measures implied, for example, the use of helmets by scooters, and stopping cars at traffic lights while people cross the roads. It monitors indicators such as travel time, distances, the number of arrivals, and accidents. Subsequently, the model will be used in considering various policy interventions' impacts on the introduction of e-scooters into the urban transport system; the study further considers which specific interventions of the policies tend to diminish the level of congestion in metropolitan area roads while also ensuring a low accident count.

Entities, State Variables and Scales

- **Agents**
  - Cars: move on road and follow traffic lights
  - People: move on footpaths and interact with cars on crossings
  - E scooters: traveling mainly on footpaths, but sometimes using the road, with different safety features (helmet or not)
- **Patches**
  - Grass (brown patches) is the areas where agents do not enter, represent buildings and other structures in real life
  - Road (gray patches) is the area where cars and scooters can move one
  - Scooter-lane (blue patches) is the footpath or scooter lane, is the area where people and e-scooter operate
  - Scooter-intersection(darker blue patches) is the area where the two patches scooter lanes meet, is necessary for identifying places where agents can turn
  - Intersection(occupied by traffic light, one of red, green or yellow color patches) is the area where at least 2 road patches intersect. They are blocks where cars or e-scooters can make turns and is also used to represent traffic lights
  - Crossing (white patches) area where people or e-scooters can interact with cars and able to cross over to the other side of a road

- **State Variables**
  - Car-speed, scooter-speed and people-speed: a positive float value that represents the speed for each agent type. Uses a preset average speed value that the user enters along with a random normal distribution to make sure all agents have different values.
  - Destination-road-x, destination-road-y: the destination coordinates that are on the road lane used by cars and e-scooters only. It is selected at setup, by randomly selecting a patch until a valid patch is found.
  - Destination-footpath-x, destination-footpath-y: the destination coordinates that are on the footpath lane, are adjacent to the destination values. It is selected at setup, by randomly selecting a patch until a valid patch is found.
  - Start-x, Start-y: the starting coordinates for each agent at setup
  - Scooter-lane?: a Boolean variable used by scooters only to identify which lane they are on. Use for lane changing and movement.
  - Safety-level: a positive float value that is normally distributed along with an average value given by the user. They represent the safety awareness of a person who is riding the e-scooter and can be determined based on what kind of licensing a person has or how reckless they drive based on age and behavior.

- **Global Variables**
  - Num-agents: integer value that gives the total number of each agent that is spawned in the environment
  - Accident-probability: a float value that gives the probability that any 2 agents that satisfy the accident condition have an accident.
  - Helmet: is a Boolean value that determines if e-scooter riders are wearing helmets or not
- **Spatial and Temporal Scale**
  - 61 patches by 61 patches square grid has been used to define the city where the patches coordinate values range from -30 to 30 in both x and y axes. We have assumed each patch to be 15 meters in length in any direction.
  - For the temporal scale, time advances in discrete "ticks," which represent time intervals during which agents move, interact, and accidents are tracked. Each tick represents 1 second in real world time.

Process overview and scheduling

- **Setup Process**
  1. The environment is fully cleared
  2. Global variables and reporting variables are all initialized
  3. Environment size is set to -30 30 -30 30
  4. Patches are set up by setting up lane types and adding color to each patch based on their type. Traffic lights are set in an alternating sequence among the three colors
  5. People agents are initialized by spawning them in footpaths. Their state variables are set randomly based on the input from the user. A valid destination footpath coordinate is selected randomly.
  6. Car agents are initialized by spawning them in roads. Their state variables are set randomly based on the input from the user. A valid destination road coordinate is selected randomly.
  7. E-scooter agents are initialized by spawning them on footpaths. Based on the policies being tested and the variable values provided by the user, their state variables are initialized. A footpath destination coordinate is selected randomly, and a corresponding destination road coordinate is also calculated for the agents.
  8. Ticks are set to zero

- **Go Process**

At each time the following steps occur:

1. A stopping condition is checked to see if there are no agents left in the environment or if the set time limit has exceeded
2. Agents (cars, people, and scooters) move according to their current heading and lane-type. Movement can be influenced by road type, traffic lights, and nearby agents.
3. If lane change is permitted by the environment setting, then it is checked if any e-scooter will change lanes. This is a probabilistic event that occurs in respect to the safety levels of each individual e-scooter agent.
4. Traffic lights change color every 90 ticks which is 90 seconds
5. Collisions between cars, scooters, and people are detected, with accidents happening based on probabilities. Given that the conditions for accidents are satisfied. If they do occur metrics for accident are updated
6. Travel time, distances, and congestion statistics are recorded for each agent type.
7. Termination of the agent whether the destination coordinates have been reached or if they have been part of an accident.

2. <u>Design</u>

Basic Principles

The model is developed based on agent-based traffic simulation. In the shared grid-based road network, it considers interactions among several heterogeneous agents. Their behaviors are driven by simple movement rules, safety conditions, and traffic lights. Accident probability depends on proximity, safety gear-helmets-and road conditions.

Emergence

Key examples of emergent phenomena are congestion, accidents between disparate agents, and the dynamics of traffic such as bottlenecks at intersections. The interaction of the agents with one another and with traffic lights and lane types leads to the emergence of movement and accidents.

Adaptation

Agents don't learn or adapt over time; instead, they operate according to fixed rules that determine their movements. For example, scooters change lanes based on lane conditions, while people don't move when a car is near them in the crossings.

Objectives

The aim of each agent is to go to their destination patch while trying to minimize the time it takes them as well as the distance they travel.

Learning

There is no learning mechanism in this model; agents follow the predefined rules of movements and decisions all along during the simulation.

Prediction

Agents do not predict future states of the environment; they react based on the situation presented to them: current road conditions, and other agents and traffic signals around their neighborhood.

Sensing

Vehicles - sense traffic lights and other agents around. Scooters - sense nearby cars and scooters when on footpaths and sense traffic light when traveling on roads. People- sense the cars around them while crossing roads.

Interaction

Agents interact indirectly through spatial proximity. A car stops, for example, if there is a red light or people stop when crossing when someone is in the road near crossings. Similarly, based on the probability, an accident occurs when agents come into close proximity(i.e. within one patch of each other).

Stochasticity

The following elements are stochastic within this model:

- The speed of cars, scooters, and people is drawn from a normal distribution.
- Whether or not an accident occurs is based on probabilities.
- Each agent is assigned a random destination.
- Safety level of e-scooters is also a value that is drawn from a normal distribution

Observation

The simulation keeps tabs of and stores global statistics about total travel time, total distance traveled, congestion level, and number of accidents by agents involved(i.e. car-person, car-scooter, etc.)

3. <u>Details</u>

This section contains details about how the model works at a technical level.

Initialization

At the beginning of the simulation, the environment must be set up-that is, patches with different lane types, and agents(cars, people, scooters). The amount of each agent type depends on the user parameter given by %-cars, %-scooter and %-people. Global variables are initialized such as total travel time, number of arrivals, accident counters.
Agents are placed at random origin points on their respective lane types (roads for cars, footpaths for people and scooters). Along with this agent specific state variables like speed, safety levels and change-lane? and scooter-lane? for e-scooters are set.

Input

In this model the following are inputs:

- The percentage of cars, scooters and people in the system. Along with the total number of agents in the environment.
- The average speed for each agent type is to be set by sliders.
- Accident probabilities and helmets use Boolean switches.
- Boolean switch for allowing e-scooters to change lanes.
- Scooter safety probability set by slider

Submodels

- Setup Patches: This submodel sets up the road environment using patches to represent regions such as lanes and off-road space. It uses mod operation to identify the correct placement of each patch. The visual setup of the roads by this submodel defines where agents, cars, can and cannot move. For example, specific color marking may be used for lanes, and patches are used to define the boundaries or intersections.
- Traffic light: The sub-model uses periodical switching of the traffic light status, green, yellow, red, to conduct the intersection. Agents(cars or e-scooters on the road) react: red and yellow, stop; green, go. It uses ticks to identify the correct time to switch between colors. Every 90 ticks which is equivalent to 90 seconds in real time is used to change colors. It is like how traffic lights today operate based on switches from timers or other input sources which determines the current state of the light and thus determines the rate of flow for key intersections.
- Setup agents: In this submodel, the agents(cars, scooters and people) are created and put onto the road or footpath. Each agent is initialized with a random speed and position in the simulation. A movement heading is also set for each agent based on their destination.
- Agent Movement: Each agent has its own movement style. Cars move on lanes and can only make turns in intersections. They are randomly assigned a heading in the setup phase and will prioritize taking the turn that is determined by the distance they are from their destination. If the x distance is greater than y distance then they will have headings set to 90 or 180 at intersections, otherwise, a heading of 0 or 180 is set. The same process is applied to both people and scooters as well with the only difference being the use of different lanes and how they both will interact with agents in roads while crossing. They will check for upcoming agents, if they are within one block then the agents on the footpath will not move. Agents on footpaths are also assigned headings on setup that are most suitable for them instead of randomly generating them.
- Lane Change: The lane change sub model is applied to e-scooter only given that the user has set lane-change to true when running the model. To change lanes, we first filter out scooter agents and then check what lane they are currently in. If they are on roads then they check for safety level which determines if the scooter changes lanes or not. If a random value is less than safety level it will change lanes. It also works similarly when scooters are on footpaths.

- Accidents: The accident submodel works by first checking if 2 agents are on the same patch. If they are on the same patch, then they have a random change of having an accident given by probability input by the user. Once an accident does occur, necessary metrics are updated, and the turtles are removed.
- Congestion: The congestion submodel is used to record the congestion value of the grid at each iteration. It is computed by calculating the total number of people in road lanes divided by the total number of patches that are roads.

Methods

Approach

We have designed our model using a pattern-oriented approach implementing a city grid with 2 types of lanes that are bi-directional and using 3 different agents including cars, scooters and people as part of the model. For developing a simplified 2D model of the urban environment based on road networks and their congestion as well as agent behavior, we used NetLogo. A baseline model as seen in Figure 1 was implemented that had variables including accident, speed and number of agents on the grid followed by proportion of population of each type. The model uses real traffic data-inputs for speed and accident rates-to realize standard flow in city traffic. Because space on roads and time on roads are partly competitive commodities, changes in the model happen discretely and asynchronously. After developing the base model, we designed a research question related to urban traffic efficiency and safety problem involving variables such as congestion, accident rates, and travel times. Our baseline model uses the grid where scooter riders don't have any form of policies implemented and safety parameters are set to the worst possible value.

Our hypothesis is policies such as the implementation of dedicated lanes for e-scooters, helmet use, and safety awareness can reduce accident rates and traffic congestion in an urban grid. Accordingly, to study this question, two Submodels were implemented: an accident and a congestion submodel. Real-world data were provided for both: the accident submodel was calibrated using statistics from Melbourne with a reported real-world accident rate of 4-6 accidents per 1,000 trips courtesy of the Transport Accident Commission. Congestion patterns are based on data from the TomTom Traffic Index for the creation of typical peak-hour conditions of traffic.

Instead of coding each detail in a myriad of possibilities that may happen in real-world traffic, we were interested in the main dynamics that are safety awareness levels and use of helmets and dedicated lanes, congestion at points such as intersections, and interaction among agents. The detailed explanation of design principles and agent behaviors is continued in the Model Design section.

We ran several simulations to see emerging patterns in traffic flow and congestion spikes due to accidents or other factors around the junctions. Using this model, several experiments were developed that would test our hypotheses and ensure the validity and robustness of the model by estimating model parameters, testing the sensitivity of the model, and studying the uncertainty in agent behavior and traffic dynamics. These experiments gave the quantification of traffic congestion and accident rates with respect to their impact on travel times and overall traffic safety in an urban environment.

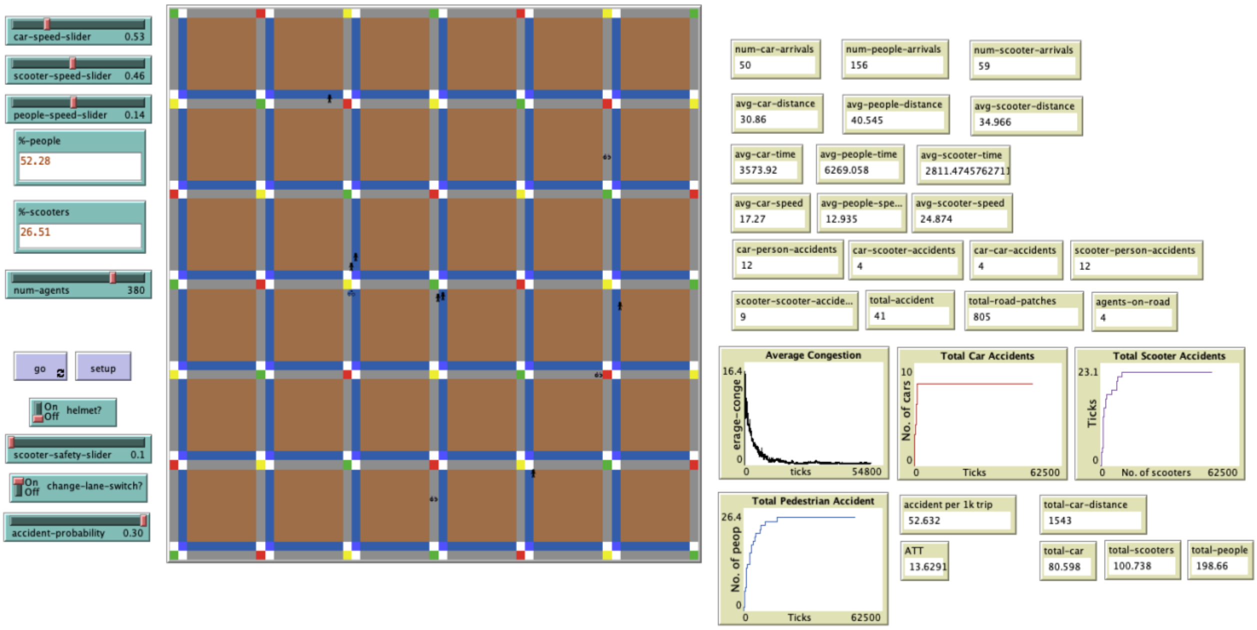

Fig:1 Baseline model of implemented NetLogo Traffic Grid

Experimental Design

In this project we study three factors to evaluate how the agents behave in the model. They are as follows:

1. **Congestion Level**: The model measures the congestion level of agents in the environment. It is calculated by dividing the total number of agents on the road and footpaths by the number of road and footpath patches.
2. **Accident Rate**: Accident rate statistics have also been taken for each agent type
3. **Average Travel Time (ATT)**: Similarly, each agent who ends up in the destination is recorded and the time and distance traveled by them is taken to get ATT. We also expect to see a higher number of agents result in a higher ATT due to congestion.

Parameterisation and Calibration table shows the parameterization table below the values for each variable that we set during experiments.

Key Parameter	Value	Reference
num-agents	385 active agents	Community Profile: The City of Melbourne Estimated Resident Population[4]
agent-percentage	car: 32.98% people:40.51% scooter: 3.97% others (public transport): 22.54% To study scooter better, car: 32.98% people:40.51% scooter: 26.51%	Victoria State Government Department of Transport: Victorian Integrated Survey of Travel & Activity [5]
average-speed	car: 50 km/h or 0.9 patch/tick scooter: 25 km/h or 0.46 patch/tick people:8km/h or 0.14 patch/tick	Car: Transport Victoria[6] Scooter: Transport Victoria: E-Scooter Road Rules[7] People:

		British Heart Foundation: Walks and Treks[8]
traffic-light-frequency	90 seconds interval per state	National Association of City Transportation Officials: Urban City Design[9]
accident-probability	0.1, 0.2 and 0.3	-
scooter-safety-slider	0.2, 0.5, 0.7	-
Helmet switch	True and False	-
Change Lane	True and False	-

Results

The graphs below show the result of using different policies and how they affected congestion and accident rates.

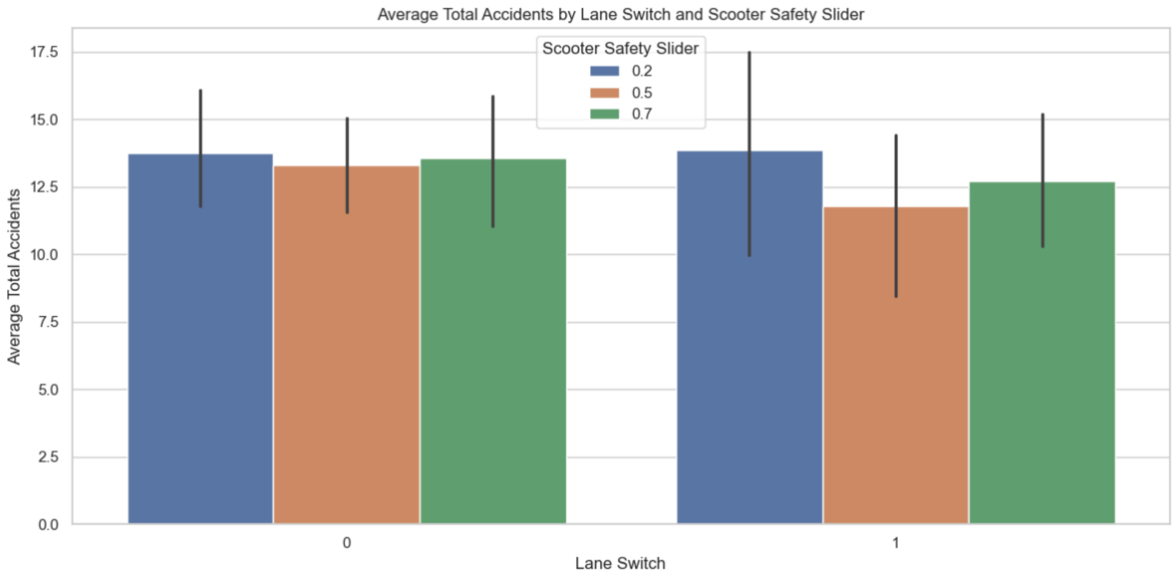

Fig 2: Average car-scooter accidents given various lane switch condition and scooter safety slider configuration

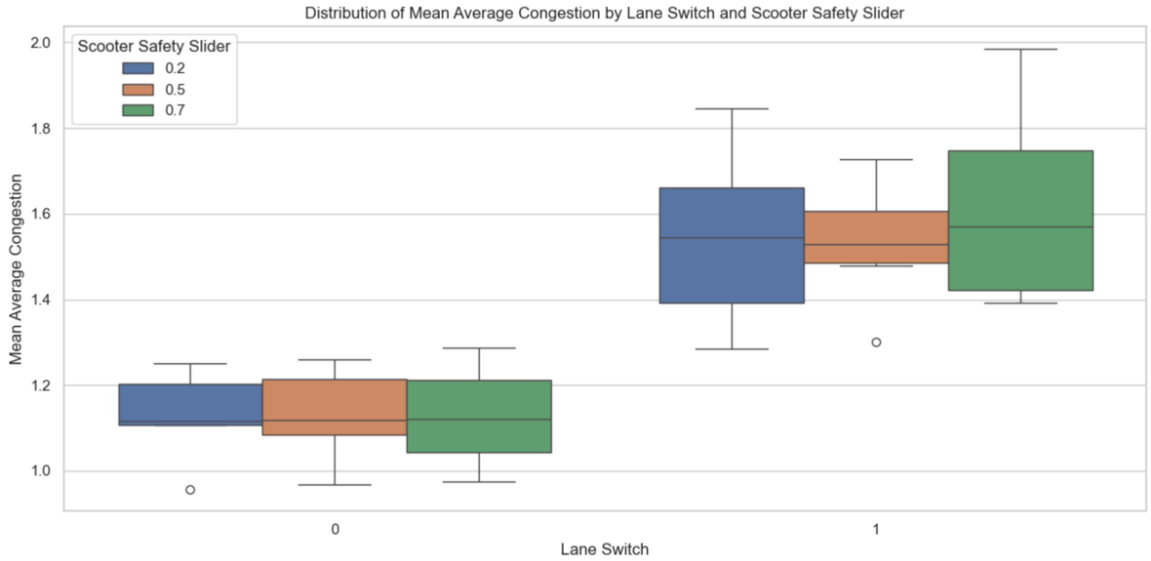

Fig 3: Box & Whisker plot for average congestion by scooter safety levels and lane switch

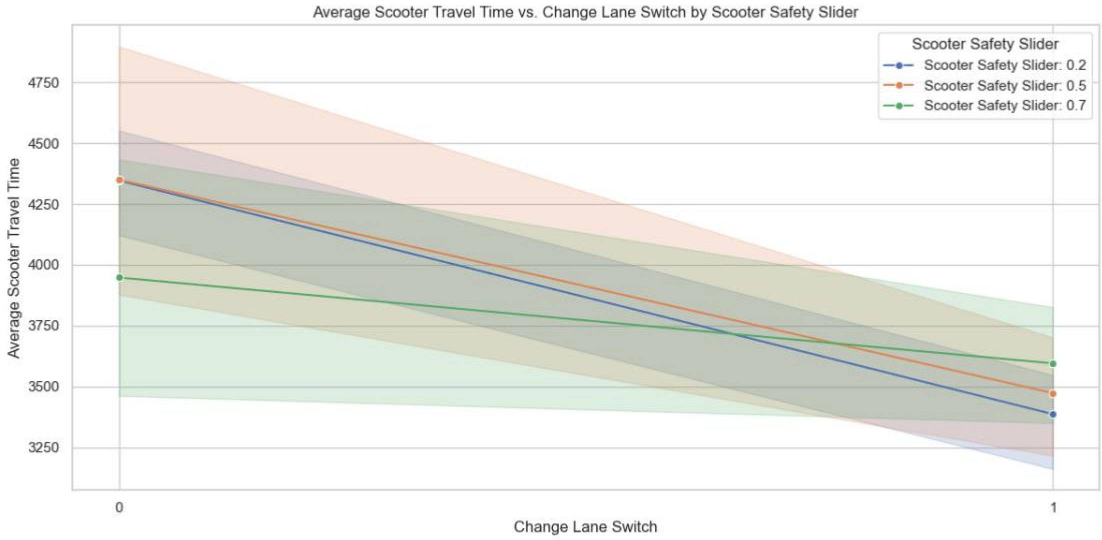

Fig 4: Facet Graph for average scooter travel time by scooter safety level and lane switch

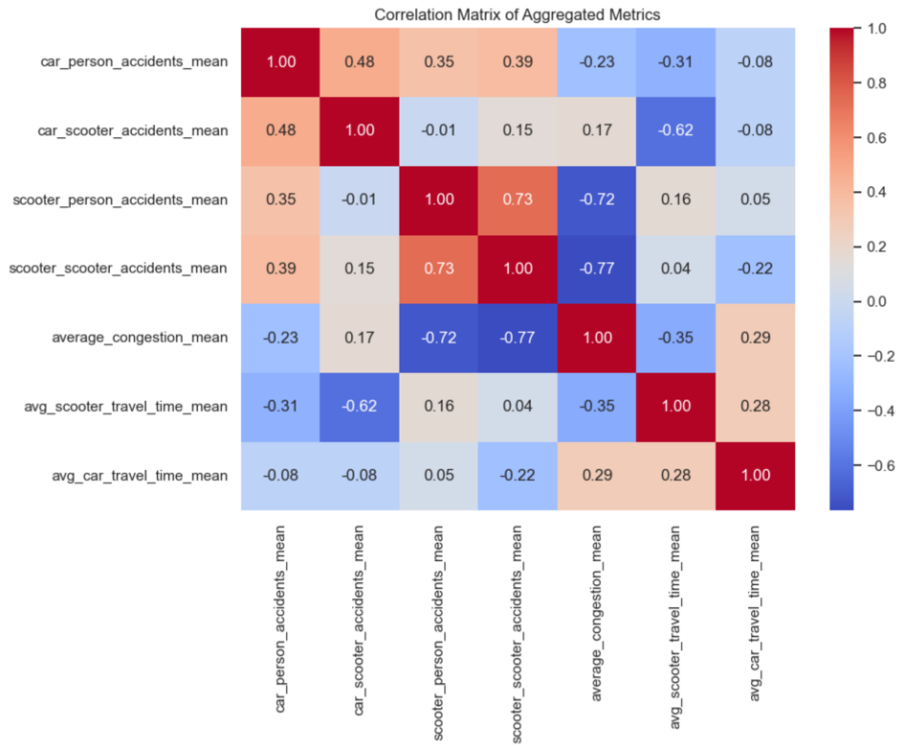

Fig 5: Heatmap of correlation between evaluated metrics

Fig 6: Radar chart for evaluation metrics for top 5 policy combinations

param_id	accident_probability	helmet	change_lane_switch	scooter_safety_slider	total_accidents
3	0.1	0	1	0.2	17.754294
4	0.1	1	0	0.7	15.813668
5	0.1	0	1	0.7	20.854621
9	0.1	1	1	0.2	21.758761
10	0.1	1	1	0.5	22.542231

Table 2: Top 5 parameter combination with regards to total accidents in radar graph

Discussion

The results of the experiments can apply to practical urban traffic management, especially regarding e-scooters. As Figure 2 shows, with lane-switching allowed, compared to scenarios in which lane-switching is disallowed, there is little increase in the overall number of accidents. Also, as can be seen from the figure, a high scooter safety parameter constantly leads to lower overall accident numbers under both conditions. That would mean lane-splitting can conceivably be safe in concert with stringent safety precautions taken, such as the use of helmets and adherence to safety guidelines. In real-life naturalistic urban settings, cities can permit splitting in certain areas with no increase in accident rates, provided there are stringent safety regulations that are in place. Policies of compulsory helmet wear, speed limits, and education for riders can ensure that lane splitting will not increase the rate of accidents. In optimizing traffic flow, certain routes or areas may be specified for lane splitting. The more safety measures are in place, the fewer accidents happen. This again brings into view another avenue of research: rewarding safety standards by offering incentives, maybe through discounts or other perks, to riders who consistently wear their safety gear.

The Box plot shows that when there is no lane-switching-the congestion stays low-while when lane-switching is on, the congestion goes considerably high. That would suggest that lane-switching behavior, even in high-safety environments, introduces a level of chaos and disrupts traffic flow, increasing congestion. It is likely that these findings, applied to the real world, would imply that unrestricted lane-switching policies for e-scooters would result in increased urban congestion-particularly where scooters and cars share the roadways. The urban planner might consider imposing limitations on lane changing in cases of high traffic or mixed use-for example, the center of a city at crossroads, or at peak hours of traffic-to help mitigate this. These discussions provide support to findings for lane separation for e-scooters from cars, which could reduce congestion in traffic while offering much safer mobility for all users.

Figure 4 illustrates that lane-switching greatly reduces the travel time of scooters; this is especially true for those designed with increased safety, such as helmets or adherence to a high level of safety. It follows that while lane-switching increases the efficiency with which scooters deal with traffic, this must also be supported by strict safety measures. In real traffic, this means that the more safety restrictions there are in place, the more stable and less dangerous the driving is. At the same time, lane-switching does contribute to the speed at which people travel within cities. However, the risks involved in lane-switching can be limited when strict rules of safety are followed by the riders.

One central observation that we can take from Figure 5 is that while improved scooter mobility and reduced congestion sound positive, in fact, they are associated with an increase in accidents, particularly collisions between scooters and cars. Further, the very strong positive correlations observed between scooter-scooter and scooter-pedestrian accidents confirm the conjecture that high levels of interaction between these groups lead to higher accident rates. This leads to a very practical real-world need for dedicated e-scooter lanes to reduce these interactions and further improve safety among all road users. Most interestingly, the findings also demonstrate that higher congestion may provide a natural cushion of safety in that slower speeds in congested environments were associated with fewer scooter-related accidents. Although congestion is generally perceived to be undesirable, with traffic flow lumpiness, urban planners need to rethink its role and accept that controlled moderate congestion can minimize accident rates since it does limit the speed of vehicles in general, including scooters.

The analysis of the radar chart and the table of policy configurations shows the trade-offs between reducing accidents, congestion, and travel times. Param ID 4, which enforces helmet use, a high scooter safety level, and prohibits lane-switching, results in the lowest number of accidents (15.81), but it comes at the cost of slightly moderate travel times. This demonstrates that prioritizing safety through strict regulations, such as helmet mandates and banning lane-switching, effectively reduces accidents but may slow down traffic flow. In contrast, Param ID 9, which allows lane-switching with helmet use but has lower safety standards, reduces congestion but leads to a significant increase in accidents (21.75). This reflects that while lane-switching improves traffic flow, it raises safety risks, particularly when combined with lower safety compliance. Policies like Param ID 5, which allow lane-switching but enforce high safety standards, balance safety and travel efficiency better, indicating that higher safety measures can mitigate some risks associated with lane-switching. The key takeaway is that no single policy excels across all metrics, and urban planners must adopt a context-specific approach, tailoring policies to the needs of different areas—such as restricting lane-switching in high-traffic zones while allowing it in safer areas, all while enforcing strong safety regulations to ensure both efficiency and safety.

Conclusion

Our analysis clearly indicates that an ideal blend of safety, efficiency, and congestion in urban traffic policy is multivariate; the radar chart shows that no one policy stands out in that the performance of each policy, although excellent in reducing congestion or generally cutting travel times, must be weighed against the added benefit of increased accidents. For instance, Param ID 9, which has the least congestion, provides the highest accident count-a probable trade-off between smooth traffic flow and road safety. Conversely, Param ID 4 balances the reduction of accidents with relatively moderate travel times and congestion, showing the importance of prioritizing safety while keeping efficiency in mind.

The real implication of the above analyses is that city policymakers should not take any single metric as the target. Policies to balance safety with infrastructure improvements, such as helmet-wearing and creating lanes for e-scooters, can reduce accidents without serious repercussions on travel time. In fact, lane-sharing could be allowed in some areas if it were complemented by strict safety measures to avoid any increase in accidents. Eventually, safety measures are improvement in infrastructure coupled with the regulation of behaviors, which will help attain safe and efficient urban mobility.

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