UNIVERSITY OF CALIFORNIA,
IRVINE

CASE STUDIES IN SECURE CONTRACTING AND COMMUNICATION IN TRANSPORTATION SYSTEMS

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Computer Science

by

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Dissertation Committee:
Professor Amelia C. Regan, Chair
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2021

DEDICATION

This is dedicated to ... EVERY BLACK GIRL AND WOMAN ON EARTH...don't give up! to every person fighting for justice, equality and/or equity, to every Black person in STEM. To God, to Family, to Mentees, to Mentors, to MYSELF, to the future.

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[1] **Amari Lewis**. 2018. The <1%: Black Women Obtaining PhDs in Computing. In Proceedings of the 2018 ACM Conference on International Computing Education Research (ICER '18). Association for Computing Machinery, New York, NY, USA, 282–283.
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ABSTRACT OF THE DISSERTATION

CASE STUDIES IN SECURE CONTRACTING AND COMMUNICATION IN TRANSPORTATION SYSTEMS

By

Amari N. Lewis

Doctor of Philosophy in Computer Science

University of California, Irvine, 2021

Professor Amelia C. Regan, Chair

Advancements in Information and Communication Technologies have led to the proliferation of Intelligent Transportation Systems (ITS). These systems leverage emerging technologies to address the challenges of traditional transportation systems. As the number of connected devices continues to increase, smart cities and communities are reliant on ITS as apart of their ecosystems. ITS are efficient and sustainable mobility systems that leverage emerging technologies to securely interact with other transportation systems and entities. This dissertation explores three case studies in privacy preserving contracting and communication among vehicles in transportation systems. The first case involves paratransit systems where we explore paratransit agency adoption of complementary ride-hailing services through secure contracting. The second case involves Vehicular Ad-hoc Networks in which we analyze the communication and data exchange between vehicles in the network. In the last case, we introduce smart infrastructure in the analysis of ITS and traffic in smart city environments by modeling the shift in traffic behaviors through the use of dynamic traffic lights. The major contributions of this dissertation are in the analysis of the communication, security and sustainability in the three case studies.

Chapter 1

Introduction

Transportation systems are multi-faceted and must address the needs of various populations of travelers. These systems and networks are part of a greater ecosystem, and directly impact the flow of society, contribute to individuals' sense of independence, and impact the overall health of the environment. This dissertation presents an exploration of two major types of Intelligent Transportation Systems (ITS), the first is paratransit and the second, connected vehicles. Paratransit systems are the transportation systems reserved for passengers approved under the Americans with Disabilities Act (ADA). The other category of ITS we examine includes smart, connected and autonomous vehicles. That category of ITS involves vehicles that have the ability to communicate in three major ways that will be addressed in this dissertation: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Vehicle-to-Anything (V2X). V2V communication involves the wireless exchange of information between vehicles, while, V2I communications involves the wireless exchange of data between vehicles and road infrastructure such as traffic signals or road side units. V2X goes beyond the other two types of connections. This category broadly relates to any entity that may affect or be affected by the vehicle. Recognizing ITS as extremely vulnerable to data attacks, the systems reliability and user privacy should be prioritized. Therefore, we introduce the use of Distributed Ledger Technologies (DLTs) in the form of Blockchains to overcome security and privacy issues.

Blockchains are a type of DLT that provide privacy preserving data exchange and maintenance in a fully decentralized environment. In this dissertation, we explore the use of Blockchain in the first two case studies for various aspects of improving transportation systems. We address the cost of the integration of this emerging technology through experimentation and analysis. The computational costs of the use of Blockchain executed by smart contracts are paid in Ether (ETH) which is a type of digital asset. The smart contracts execute the secure transactions between two or more entities in a decentralized trustless environment. In case study I, we analyze the contracts between paratransit users, agencies and Transportation Network Companies such as Uber and Lyft in the U.S. In Case Study II, we analyze the contracts between vehicles in the Vehicular Ad-hoc Network and in Case Study III, we analyze the traffic response to dynamic smart city infrastructure. *Please see Figure 1.1.*

In order to simulate real-world behaviors of ITS in the case studies, we used integrated Open-source micro-simulations and discrete/agent-based simulation frameworks. The tools and implementations are described in later chapters of the dissertation.

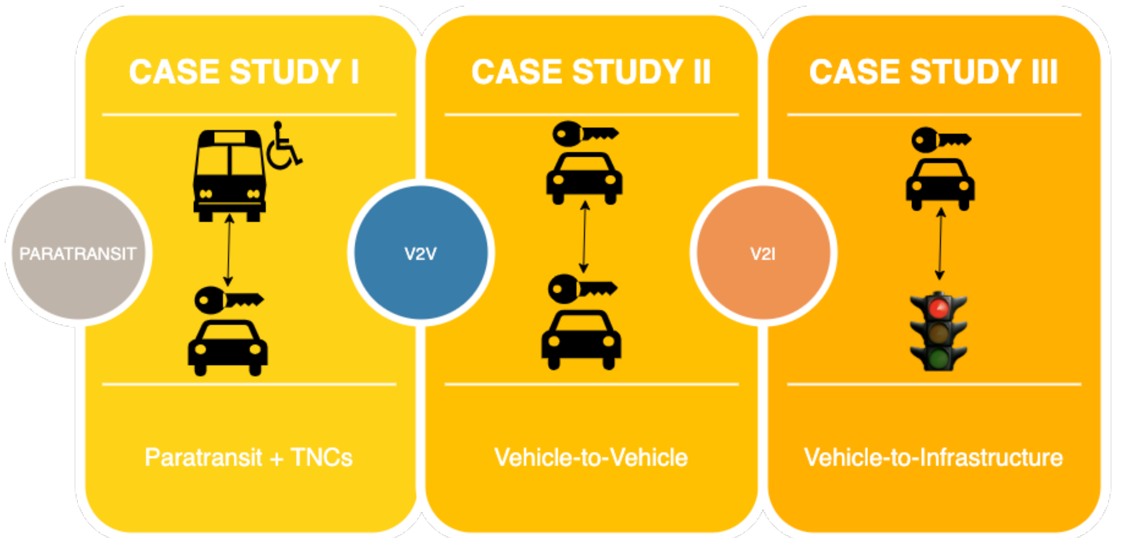


Figure 1.1: Case Study I,II,III

1.1 Paratransit as an Intelligent Transportation System

Access to adequate transportation service is a major concern for many inhabitants of the United States of America and globally. For older adults and persons with disabilities, transportation can be even more of a challenge and a well known barrier. There are many inequalities and social injustices in transportation that play a major role in the barriers that exist. In the U.S. and other countries, it is a human right to have access to adequate transportation, so it is unfortunate that, for many, lack of mobility is a major concern. In this work, we explore the use of various technologies to improve the paratransit systems in the U.S. and show how technology can be used to reduce inequity in transportation.

Paratransit systems are reservation based transportation systems available to individuals approved under the ADA as a solution to overcome the challenges faced by many and to help them gain independence. While most transit vehicles are ADA-compliant, a smaller percentage of transit stations are ADA-compliant [45]. Thus, paratransit provides adequate transport options for passengers with challenges accessing general transit options due to the inadequacies that exist and prohibit them from accessing those services easily. Even though paratransit has been offered for many years, there remains room for improvements with the use of technologies in three main areas; ride requests (reservations), route scheduling, and user data privacy. Considering these improvements, paratransit has the ability to become an ITS and the exploration of paratransit as an ITS is the first component of this dissertation, where we address solutions to the three aforementioned areas of improvements.

Studies have shown that advanced age is associated with functional impairments, greater difficulty with maintaining driving skills and a higher risk of motor vehicle crashes [17][20] [22]. Even healthy, cognitively functional older adults may experience a decline in driving skills due to pre-clinical neurological diseases and comorbidities [16][36][52] [56]. So, it is apparent why many older adults are forced to stop driving on their own and can benefit from paratransit services. Across the United States, older adults' tendencies toward continuing to drive are reinforced by the lack of transportation options available to supplement or replace driving. Drivers in smaller cities, suburban settings, or rural areas have limited access to mass transportation and providing alternative transportation options presents greater challenges [12]. A study in Australia also found that older adults in rural populations experience barriers to public transportation and other services available to them [59], which contributed to their disadvantaged mobility.

Recently, the population of elderly and transportation-dependent people has grown significantly in the United States, in absolute and proportional terms, with over 35% of senior citizens having some disability [50]. The U.S. Department of Transportation Federal Highway Administration's 2017 National Household Travel Survey (NHTS) reported the growth in percentage of individuals reporting travel-limiting disabilities over the age of 50, shown in Figure 1.2. Additionally, the US Bureau of Transportation Statistics reports that workers

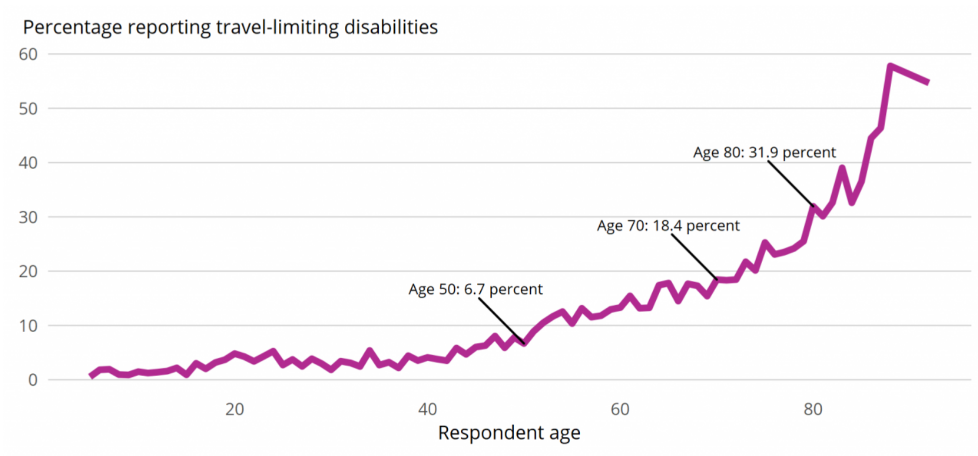


Figure 1.2: U.S. Department of Transportation, Federal Highway Administration, 2017 National Household Travel Survey [46]

age 18 to 64 with disabilities use paratransit for 1.2 percent of their trips; non-workers with disabilities use it for 1.6 percent [13]. While traditional alternative transportation options (e.g., light rail/buses, taxicabs, or e-hail/ridesharing services: Uber/Lyft) are more common in densely populated areas, our research found that many rural populations do not have access to ride-share options, like Uber and Lyft, therefore, older adults in low density areas rely on more flexible service [10].

Prior to the ADA of 1990, paratransit was offered by non-profit human service agencies and public transit agencies in response to the requirements in Section 504 of the Rehabilitation Act of 1973, which prohibited the exclusion of the disabled passengers from *any program or activity receiving federal financial assistance* [29].

Paratransit agencies have considered the integration of ride-hailing services, commonly referred to as Transportation Network Companies (TNCs), providing more flexible options for its passengers.

Although, through our interviews with paratransit agencies, we found that about 20% of paratransit passengers require Wheelchair Accessible Vehicles (WAV), not all passengers require this accommodation, allowing for the possibility of more flexibility in additional fleet through TNCs. But, in our research, we actually found that a major concern of paratransit agencies is the lack of WAV by TNCs [34].

According to the 2017 NHTS, over half (57.8 percent) of all respondents with disabilities use one or more medical devices: Walking canes (36.7%) Walkers (22.9%) Wheelchairs (11.6%) Motorized scooters (4.4%) Motorized wheelchairs (3.9%) Crutches (2.6%) White canes for visual impairments (1.3%) Seeing-eye dogs (1.1%) [46]. Consequently, the additional assistance provided by door-to-door paratransit drivers is a necessity for majority of the passengers without caregivers or service animals.

A crucial aspect of paratransit that we explored are the methods of ride requests for passengers. In a our previous study, we found that a very small amount of California paratransit agencies offered a variety of request options for passengers. 98% use call in advance options as their primary or only option but many are using or exploring other options. Thus, we introduced the use of mobile decentralized apps for requests in [34]. In the next chapter, we present a prototype for a integrated mobile app for paratransit and TNCs: Uber, Lyft, gogograndparaent, recently collaborated with Uber/Lyft, grubhub, doordash..etc. to provide on-demand transportation and services for older adults and TripSpark, which is a scheduling software for demand response paratransit.

Privacy is another primary issue that we address in our work related to the adoption of emerging technologies. Privacy in this area refers to the privacy of user data, and we have also taken passenger safety into consideration as well. With the introduction of new technologies, new vulnerabilities are introduced. The vulnerabilities in cyberspace can compromise the safety and reliability of customer data. Although it may seem unrelated, Health Insurance Portability And Accountability Act (HIPAA) compliance plays a major role in transportation as it relates to paratransit and other medical transportation. Passenger information that includes their medical history and other important data cannot be compromised and must be securely stored and shared with the proper entities. This motivated our exploration of the use of privacy preserving measures in paratransit which we detail in the next chapter. Through our work, we present secure contracting through the integration of paratransit and TNCs deeming paratransit as an ITS.

1.2 Connected Vehicles

The Institute of Electrical and Electronics Engineers (IEEE) refers to the term "connected vehicles" as the applications, services and technologies that connect vehicles to their surroundings. Connected vehicles are embedded with various communication devices which connect the vehicles to external devices, networks and services. This allows for connected vehicles to act as Cyber-Physical Systems (CPS).

According to the statistics provided by Statistica, the automotive industry comprises 35% of the distribution of cellular IoT connections shown in Figure 1.3. Connected vehicles comprise a subgroup of ITS using wireless communication technologies such as short range radio signals and more commonly, Dedicated Short Range Communications (DSRC) to exchange data, Wireless Access in Vehicular Networks (WAVE) and IEEE 802.11p to name a few. For instance, in V2V, wireless communication is used for sending messages between vehicles. We investigate connected vehicles in Vehicular Ad-hoc Networks (VANETs) through Inter-Vehicle Communications (IVC) [65]. IVCs are the communications among vehicles for ITS applications. In this dissertation, we explore vehicular emissions data exchange between vehicles in the network.

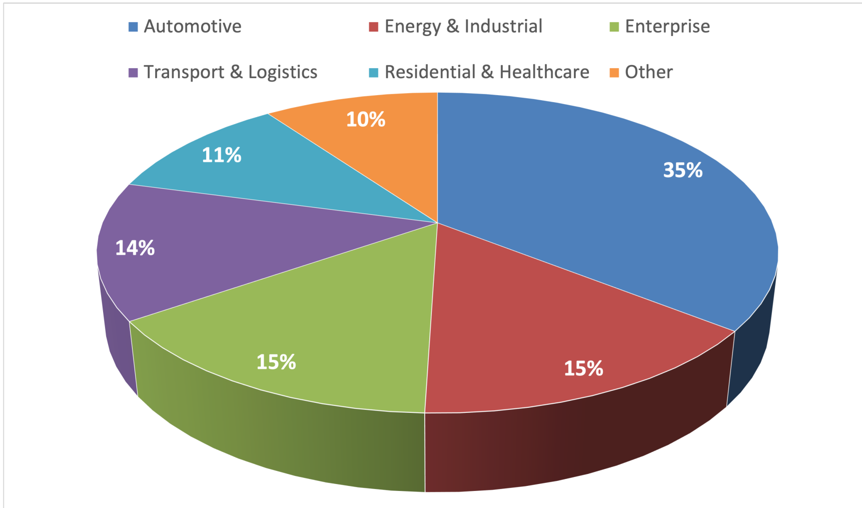


Figure 1.3: Distribution of Cellular IoT connections in the US for the first half of 2019 by industry application according to Statistica

In 1999, the Federal Communication Commission proposed Dedicated Short Range Communication (DSRC) as the standard for vehicle communications. This reserved 75 MHz of bandwidth in the 5.9 GHz frequency (5.850-5.925 GHz) to support early V2V and V2I communication. This involved the system incorporating On-Board Units (OBU) and Road Side Units (RSU) [7]. The IEEE committee has developed the IEEE 802.11p standard for VANET [5] the official standard for Wireless Access in Vehicular Environments [7], based on CSMA/CD and interframe-spaces used in IEEE 802.11b and 802.11g [26] and provides a set of protocol architectures with the primary goal of ensuring road safety and improved traffic management [48].

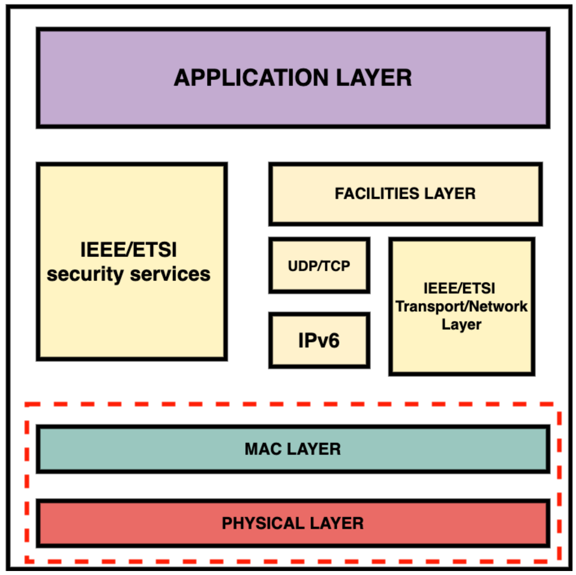


Figure 1.4: Vehicular Communication Protocol Stack

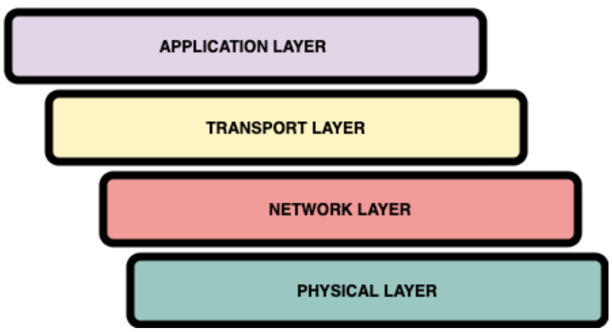


Figure 1.5: General Wireless Communication Protocol Stack

The protocol stack for DSRC is outlined in Figure 1.4 [67]. The traditional Open System Interconnection (OSI) model involves 7 layers: Application, Presentation, Session, Transport, Network, Datalink, and Physical. A general wireless communication protocol stack mentions the four layers in Figure 1.5: Application Layer, Transport Layer, Network Layer, Physical Layer. In the vehicular communication protocol stack, where the transport and network layer lies in the traditional protocol stack, for vehicular communications we now have security services, and a facilities layer. In figure 1.4, IEEE is the Institute of Electrical and Electronics Engineers, and the ETSI is the European Telecommunications Standards Institute. The application layer defines the types of messages used by vehicles to enable ITS applications, for non-safety applications, event driven decentralized environmental notification messages (DEBNMs) are shared among vehicles. The additional new layer *facilities layer*, is the layer that defines the data structures for vehicle sensor data maintenance, filtering and aggregation of received traffic information messages and communication management [67], researchers also mention the introduction of a new protocol to support the high reliability and low latency needs of autonomous vehicles, *802.11bd*. Our work mainly relies in the transport/network layers, the analysis is detailed in Chapter 4.

1.3 Smart City Infrastructure and ITS

Smart cities leverage communication technologies to continuously collect data from large amounts of sensors. These urban cities are integrated environments with Internet of Things (IoT) devices and Information and Communication Technologies (ICT). Within smart communities are smart infrastructures which are a major component of the ecosystem. As it relates to transportation, the more common infrastructures include smart traffic light management systems (TLMS). TLMS dynamically allocate the Traffic light phases in response to traffic demand. Globally, dynamic speed bumps have been implemented in smart communities in Spain, England and Switzerland. In this dissertation we explore the use of smart TLMS to improve the smoothness of traffic in smart cities through the analysis of vehicular routes and emissions. We analyze the traffic patterns of vehicles traveling in residential roads in comparison to high-capacity roads and the significant impacts on travel and emissions for both areas in addition to assessing the travel times. This approach is informed by traffic theory that assumes that travel time increases as flow period increases. The flow period is the time interval in which an average demand flow rate (q) persists where the time-dependent function assumes no initial queue at the start of the flow period. In their work, the corresponding time-dependent travel time function is defined as the following equation:

$$t = t_0 + 0.25T_f[z + (z^2 + 8J_A x/(QT_f))^{0.5}]_{0.5} = \mathrm{t}_0 1 + 0.25r_f[z + (z^2 + eJ_A x/(Qt_0 r_f))^{0.5}] \quad (1.1)$$

Table 1.1: Notation I

Symbols	**Descriptions**
t	average travel time per unit distance (e.g. secs per km)
t_0	minimum(zero-flow) travel time period per unit distance
J_D	a delay parameter
Q	capacity (veh/h)
q	demand (arrival) flow rate (veh/h)
x	q/Q - degree of saturation
r_f	T_f/t_0 ratio of flow period to minimum travel time
z	x-1

Road Class	Description	v_o (km/h)	Q (veh/h/lane)	J_A	v_m / v_o
1	Freeway	120	2000	0.1	0.63
2	Arterial (uninterrupted)	100	1800	0.2	0.57
3	Arterial (interrupted)	80	1200	0.4	0.49
4	Secondary (interrupted)	60	900	0.8	0.44
5	Secondary (high friction)	40	600	1.6	0.41

Figure 1.6: Parameters for Travel time functions representing various road classes ($T_f = 1$h) reproduced from [6]

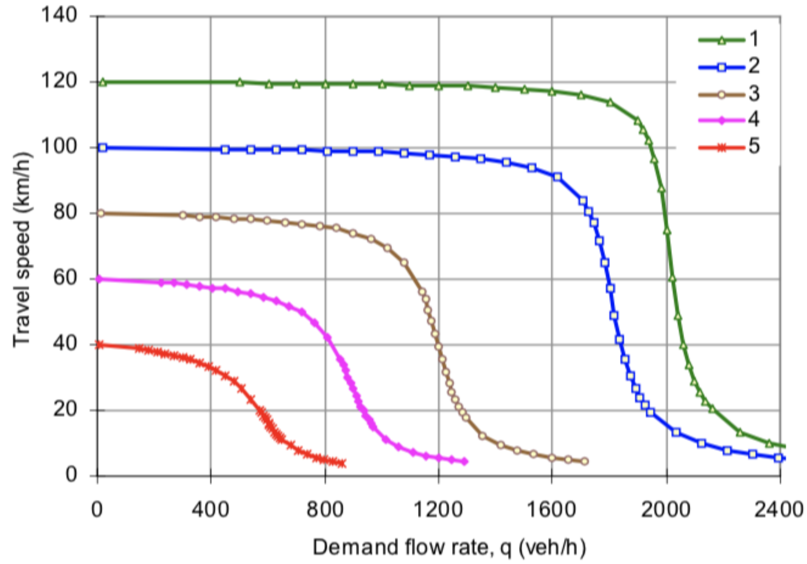


Figure 1.7: Speed-flow graphs for 5 road classes defined in 1.6 reproduced from [6]

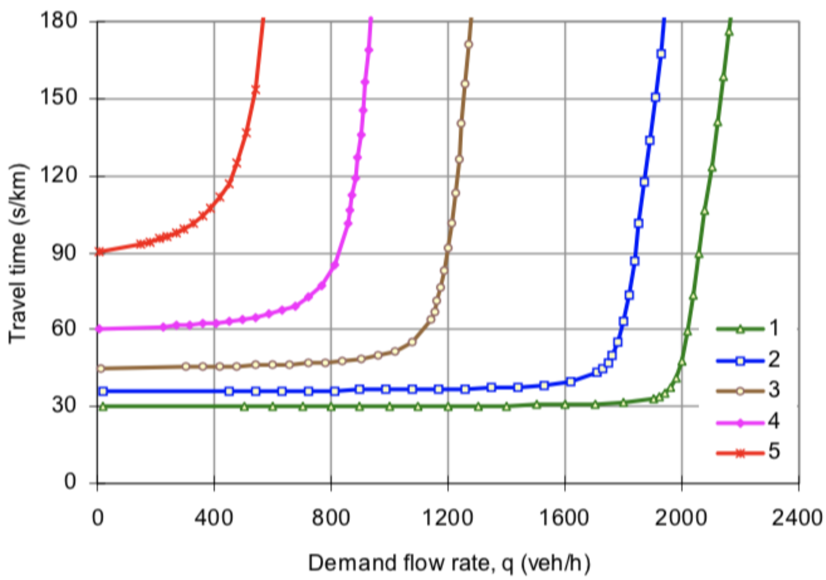


Figure 1.8: Speed-flow graphs for 5 road classes defined in 1.6 reproduced from [6]

Figure 1.6 displays the travel-time flows per a corresponding time-dependent travel time function as it pertains to the 5 road classes. While, Figure 1.8, displays the speed-flow graphs for the 5 road classes. These figures are taken from Akçelik et al., 1991 [4]. In our work, we focus on the higher capacity roads (freeways) and the secondary road classes (residential roads).

Traffic flow modeling is a widely studied sub-field of transportation science. Many researchers have explored various aspects of traffic in order to understand the overall flow. Two areas that are particularly interesting include peak and active spreading. Researchers have defined peak spreading as the process of reducing the proportion of traffic demand in the most severely congested or critical part of the peak period with corresponding increases in demand at the time periods immediately after and before the critical peak. Additionally, active spreading involves travelers making conscious decision to reschedule the beginning of their trips whereas passive spreading is where peak period travellers experience delays to their trips due to congested traffic conditions. Ultimately, peak period traffic congestion introduces negative environmental, economic, financial and social impacts due to reduced operational efficiency of the transport system. In [62], Van Aerde and Rakha describe a new method for calibrating a relatively new generalized speed-flow relationship. Their work considers speed, flow and density as dependent variables, considering the calibration of speed-flow relationships for highways by presenting a multivariate procedure for performing automated fitting of speed-flow relationships based on loop detectors.

Hence, we introduce the use of TLMS in smart cities to assist the flow of traffic through dynamic calming methods. The use of traffic calming measures in smart cities is not a new topic, researchers have explored this as an option and as a result, it has shown to help reduce vehicle speeds, traffic congestion, emissions and traffic accidents. However, our approach is unique as we focus on the shift of traffic out of residential areas and analyze the environmental impact of that shift through real-world simulations.

1.4 Background

1.4.1 Americans with Disabilities Act

Even though, paratransit was introduced earlier in 1973, in this section, we focus on the requirements of the Americans with Disabilities (ADA) act of 1990 to provide better understanding of the regulations. The purpose of the 1990 act was to prohibit discrimination and ensure equal opportunity and access for persons with disabilities. Within the Federal Transit Administration (FTA) there is an office of civil rights responsible for civil rights compliance and monitoring to ensure nondiscriminatory provision of public transit services. In addition to providing wheel chair accessible services the FTA allows agencies to acquire inaccessible sedans or other inaccessible vehicles for use in complementary paratransit service. And, according to chapter 7 of the FTA circular "The Americans with disabilities act: guidance" [2] a demand responsive system, when viewed in its entirety, shall be deemed to provide equivalent service if the service available to individuals with disabilities, including individuals who use wheelchairs, is provided in the most integrated setting appropriate to the needs of the individual and is equivalent to the service provided other individuals with respect to the following service characteristics: (1) Response time; (2) Fares; (3) Geographic area of service; (4) Hours and days of service; (5) Restrictions or priorities based on trip purpose; (6) Availability of information and reservations capability; and (7) Any constraints on capacity or service availability.

In response to the COVID19 epidemic, in summary, the Center for Disease Control (CDC) makes the following regulations for passengers of paratransit:

- Wear a mask covering your nose and mouth
- exemptions for wearing a mask: children under 2 years of age, person with a disability who cannot wear a mask, or cannot safely wear a mask for reasons related to their

disability. A person whom wearing a mask would create a risk to workplace health and safety.

- When possible, consider traveling during non-peak hours
- When possible, sit in the back of larger vehicles
- Limit close contact with the driver.

Many paratransit agencies have limited their capacity to adhere to the CDC recommendations. For instance, AccessLA, the paratransit service in Los Angeles, California, announced the following on their website: Effective May 1 2021, due to the increase in customer demand, Access will be making the following service changes:

- The temporary same-day program, implemented in May 2020, will end. All Access trips should be booked the day before.
- Shared rides will be reintroduced on all Access vehicles. While we try to limit The number of customers on a vehicle, this cannot be guaranteed.
- All of Access vehicles will continue to be disinfected at least once a day.
- All scheduled trips to COVID-19 vaccination sites, including those at pharmacies and medical offices, will continue to be non-shared ride trips.
- All Access riders are still required to wear a face covering and should not ride Access while sick. Additional riders are encouraged to get a COVID-19 vaccination.

Demand Responsive Transportation (DRT)

Demand Responsive Transportation/systems (DRT) are any transportation system provisioning designated public transportation service by public and private entities. Examples of these services include complementary paratransit, traditional dial-a-ride service, taxi subsidy service, vanpool and route deviation service.

Dial-a-ride (DAR)

Public DAR services are commonly available in suburban areas which do not have sufficient population density to support fixed route service. These services are funded by 5311 and 5307 funds A.0.1. These services often require riders to call in advance to request a pickup time and service providers develop schedules and routes according to the requests. Additionally, some agencies operate DAR services for seniors and persons with disabilities where these services are offered as a supplement to fixed route and complementary paratransit service with 5310 funding support. Also, it is important to note that many DAR services combine individual transportation and group (shared) transportation. Agency offerings may vary, some agencies that operate both general public DAR and fixed route service generally use the general public DAR service to meet all or part of their complementary paratransit service. Agencies monitor the amount of complementary paratransit riders they are receiving.

The FTA recommends that agencies record and analyze trip requests and completed trips by type of rider (ADA paratransit eligible or not) which permits agencies to document compliance with requirements. All public dial-a-ride portion of a transit agency's service cannot accommodate all trip requests, complying with the requirements means giving scheduling priority to ADA paratransit eligible riders and ensuring service for these riders operates without capacity constraints.

Taxi Subsidy

Taxi subsidy programs allow transit agencies to contract with taxi companies in order to subsidize service to passengers. With this option, there are two types; user-side, and provider-side subsidy. User-side subsidy involves agencies selling discounted vouchers to riders who arrange trips directly with taxi companies. And, the provider-side subsidy programs involve riders to arrange trips through a transit agency and the agency contracts a taxi company for the service and subsidizes a portion of the taxi fare through direct payment to the taxi company and the rider pays a fare or agreed upon amount for each trip. The use of FTA funds requires agencies to provide equivalent service to individuals with disabilities who qualify for such services. In these cases, agencies must monitor response times for riders with disabilities and wheelchair users to ensure they are provided comparable response times as other riders.

Vanpool Service

Vanpool services differ from the previously mentioned services as, with this option, it is a voluntary commuter ride-sharing agreement using vans with a seating capacity traditionally greater than 7 or these can include buses which provide transportation to a group of individuals traveling directly from their homes to their work places within the same geographical area. However, due to the COVID19 pandemic, many vanpool services had to adjust and set new requirements in order to accommodate health and safety regulations. The center for Disease Control (CDC) makes the following recommendations for shared public transit:

- Limit the number of passengers in vehicles
- Avoid shared rides with multiple households
- When possible, sit in the back of the van

Vanpool services operated by public entities are expected to provide equivalent service requirements as DRT. Although these services are not specifically reserved for one group. Vanpools can accommodate ADA passengers with or without wheelchair accessibility needs but, all riders will be charged equivalent fares even if operating costs are higher for accessible vans. To make the contributions or fares the same, FTA suggests that sponsoring agencies consider further subsidizing vanpools that accommodate riders with disabilities or assessing a surcharge to all vanpools to offset any higher rider costs of accessible vanpools.

Route Deviation

Route deviation is a service provided by some agencies in order to accommodate passenger demand. These services operate on fixed routes but, between the predefined stops, vehicles deviate from an established route to pick up or drop off riders within a defined off-route service area who have called in advance to request rides. Fortunately, this service is typically equipped with accessible vehicles so ADA passengers can use these services if an accessible vehicle is available. Route deviation services vary across agencies, some accommodate this service at peak times and often service rural populations.

Operating Complementary Paratransit Through Route Deviation

The FTA denotes an option to operate paratransit through route deviation where services that do not deviate for all riders must provide complementary paratransit service in full compliance the regulations. An example of this service could be in very rural areas where the travel demand is low. In this case, transit agencies are able to meet the complementary paratransit requirements through off-route deviations. Additionally, there's an approved option of operating both complementary paratransit and route deviation trips in the same vehicle such that it meets the expectations outlined by the FTA.

Operating Complementary Paratransit Through Supplemental DAR

With consideration to higher demands, there is an option to operate paratransit through supplemental DAR. Commonly in rural areas, agencies use their existing DAR to meet paratransit requirements. The FTA urges agencies using this approach to ensure they track and analyze the combined services (deviations and dial-a-ride trips) to ensure compliance with all Subpart F requirements, which provides several documents on operating Paratransit as a Complement to Fixed Route Service. including the prohibitions against capacity constraints.

More recently, many agencies have decided to improve services by incorporating additional options providing more flexability to their passengers. Many of these programs start as pilot programs and based on the performance and program outcomes, the program will be either cancelled or implemented. The pilot programs have proven to benefit agencies in many ways but especially in the optimization of schedules and lowering operational costs to agencies and in some cases the cost of service for passengers has been reduced.

1.4.2 Transportation Network Companies and Ridesharing

Transportation Network Companies (TNCs) are the app-enabled ride-hailing services offered to the public. Most notably, Uber and Lyft in the U.S. TNCs offer on demand services with dynamic pricing dependent upon the demand of service and driver availability. Dijkstra's algorithm is the foundation of routing algorithms and majority of TNCs are built on top of Dijkstra's shortest path algorithm for routing including Uber and Lyft.

Dijkstra's algorithm identifies the shortest path between two points. The algorithm is considered efficient, but for long trips it take too long to calculate an accurate ETA. TNC companies develop their own heuristic methods which take real-time traffic information into account and which canculate the ETAs more quickly. Since 2015, Uber has been using a

Algorithm 1 Dijkstra(s) Algorithm

```
FOR each v ∈ V DO
    d[v] = ∞
    INSERT(Q, v, ∞)
S = ∅
d[s] = 0
CHANGE(Q, s, 0)
WHILE Q not empty DO
    u = DELETEMIN(Q)
    S = S ∪ {u}
    FOR each e = (u, v) ∈ E with v ∈ V \ S DO
        IF d[v] > d[u] + w(u, v) THEN
            d[v] = d[u] + w(u, v)
            CHANGE(Q, v, d[v])
            parent[v] = u
```

system called Gurafu for routing and Flux, Uber's historical traffic information system based on GPS data collected from phones. Uber also tracks ETA accuracy for full trip length ETAs [44].

Paratransit agencies have considered the use of TNC services to supplement or offset their fleets. Tri Delta Transit in the Bay Area, California, launched a pilot program partnering with Uber and Lyft in February of 2018. The pilot became very popular and the transit agency experienced a significant reduction in ride costs, from $32 to $8 a ride. Other transit agencies have also partnered with TNC according to the American Public Transportation Association:

APTA Paratransit and TNC Pilot Programs		
Agency Name	Location	TNC, year
Massachusetts Bay Transportation Authority (MBTA)	Boston, MA	Lyft, Uber (September 2016- present)
Omnitrans	San Bernadino, CA	Lyft, RIDE Taxi (July 2016-present)
Denton County Transportation Authority (DCTA)	Denton County, TX	Lyft, Uber (October 2016- present)

The pilot programs were successful, resulting in positive customer feedback. With the pilot programs, ADA approved passengers were able to request rides 2 hours in advance rather than 24 hours in advance. Such accommodation is more convenient for passengers and makes is more likely that riders will use the service for work or shopping trips and not just doctor's appointments which can be scheduled in advance.

1.4.3 Secure Contracting and Communication in ITS

As data and AI privacy research continues to evolve, many of these research areas are affecting ITS. Thus, in this dissertation, we have confront these issues directly through proposing methods of secure contracting and communication in ITS in two areas: 1) contracting services, 2) V2V communication.

For the purposes of this dissertation, in secure contracting, we investigate the secure subcontracting options for paratransit and the various TNCs with the use of emerging technologies including Blockchain. The main advantages of this method is that it ensures the privacy of passenger and agency data, and improves the overall experience of paratransit passengers through a seamless integrated system.

Futhermore, V2V secure communications. V2V secure communications is achieved through the integration Blockchain for the vehicles to communicate in VANETs. The use of Blockchain is proposed for secure communications between the vehicles in the network in communicating sensitve data. Smart contracts are in place to securely manage these interactions between entities in a fully decentralized environment.

1.4.4 Sustainability in ITS

Vehicles are generally responsible for around 30% of the total Greenhouse Gas (GHG) emissions in the US. The goal of reducing GHG emissions is a worldwide issue and governments are continually implementing new regulations to contribute to the reduction of GHG. The European Union has established themselves as a leader in this area. In 2005, the European Union's Emissions Trading System (EU-ETS) established the world's first Cap-and-Trade system with the ultimate goal of reducing the overall GHG emissions in cost-effective ways. The EU-ETS remains the biggest carbon market and emissions allowance trading. The EU-ETS establishes a cap (maximum) amount of GHG emissions companies/organizations can emit each year. Over time, the cap is reduced and the GHG emissions will be completely reduced. This method has proven to work well. However, the current system is mainly for point source emissions, localized sources of air emissions typically from power plants, chemical plants, factories. The EU-ETS currently comprise of 11,000 factories and power plants. We propose a system modeled by the EU-ETS for vehicles. Vehicular emissions are a major contributor to GHG emissions and with the implementation of a cap and trade system like the EU-ETS, we are able to motivate and ensure much lower emissions from vehicles.

The EU-ETS monitors vehicular emissions through their CO_2 emissions performance. The target for fleet-wide CO_2 emissions for the 2020-2024 period are as followed: cars: 95 gCO_2/km, Vans 147gCO_2/km. Also, from 2021 onward, the emission targets for manufacturers will be based on the new Worldwide Harmonised Light Vehicle Test Procedure (WLTP) emissions test. The targets are based on the EU-fleet-wide targets and consider the average mass of the vehicle manufacture's new vehicles registered in a given year, using a limit value curve. Additionally, the targets for 2025-2030: cars: 15% reduction from 2025 and 37.5% reduction from 2030. Vans: 15% reduction from 2025 and 31% reduction from 2030.

Recently the European Union has announced a super-credits system this is an incentive mechanism for zero-and low-emissions vehicles. Specifically, this program applies to passenger cars with emissions of less than 50g CO_2/km where the cap is set to 7.5g/km per car manufactures in 2020-2022. From 2025, the crediting system will include cars and van manufactures with the following benchmarks: cars: 15% from 2025 and 35% from 2030. Vans: 15% from 2025 and 30% from 2030. The implementation of penalties for excess emissions is a tactic that is effective. If the average CO_2 emissions of a manufacturer's fleet exceeds the target emissions in a given year, the manufacturers are required to pay an *excess emissions premium* of €95 per g/km of target exceeded. However, manufacturers responsible for fewer than 1000 cars or vans newly registers in a given year are exempt from meeting the emissions target of the EU unless voluntarily apply for a derogation target. Beginning in 2021, the EU has agreed to begin assessing their efforts through collecting real-world vehicular data (cars and vans) using on-board fuel consumption monitoring devices [15].

In this dissertation work, we have proposed a vehicular emissions monitoring and emissions credit trading system and conducted real-world simulations to evaluate the performance of the system. This section directly correlates with the previous section as, we believe that the emissions trading system must use secure communication technologies to ensure the privacy preservation. This decision is influenced by the 2015 Volkswagen emissions scandal. The U.S environmental Protection Agency found the Volkswagen manufacturer guilty of violating the clean air act. Essentially, some of the vehicles were cheating their emissions and in reality were emitting large amounts of nitrogen-oxide NOx emissions up to 40 times higher than the federal limits which is extremely dangerous. NOx is a pollutant that is linked to lung cancer and contributes to the formation of smog (smoke fog). This ultimately led Volkswagon subject to pay over €30billion in regulatory fines. But, despite this downfall, Volkswagen is now the leader of fuel efficiency in Western Europe. The proposes system would overcome potential scandals as the emissions are verified and added to a tamperproof ledger.

1.5 Traffic Management

In the third case study, we address traffic management in controlled *smart city* environments. Our analysis involves the Bureau of Public Roads (BPR) function. This function, denotes the travel time of a link or corridor calculated as:

$$T_a = t_a^0[1 + \beta(\frac{f_a}{c_a})^n], a \in L \tag{1.2}$$

In equation above, a refers to the particular link and L is the set of directed links. t_a^0) is the travel time of link a. Thus, we assume that link a of travel time function T_a is associated with flow f_a and capacity c_a). β and n are the undetermined parameters [68]. However, in the following, we will model the traffic choices of road users, basing our analysis on the classic BPR formula [54]. The BPR formula is used to compute travel time on a congested road as a function of the traffic flow f, as well as on four parameters that depend on the road. The equation is given by:

$$t(f) = t_0 \left(1 + \alpha \left(\frac{f}{C}\right)^{\beta}\right), \tag{1.3}$$

where t_0 is the free flow travel time, C is the road capacity, and α and β are parameters that way drivers react to congestion. We also define d as the distance traveled. There are other functions that can represent road capacity, considering freight traffic or more complex models of congestion, but the BPR formula is the most common standard.

The effect of speed limits on travel times has been investigated in [63], giving the following adaptation of the BPR formula for a maximum speed v:

$$t(f, v) = \max\left(\frac{d}{v}, t(f)\right). \tag{1.4}$$

As we would expect, the speed limit has no effect if congestion naturally slows traffic down to a lower speed, but sets a hard limit on the maximum speed.

We can extend the formula to include the effect of intersections as well, as given in [38]:

$$t(f, N, L, G, v) = \max\left(\frac{d}{v}, t_0\left(1 + \alpha\left(\frac{f}{C}\right)^{\beta}\right)\right) + \frac{C(L-G)^2}{2L(C-f)}, \tag{1.5}$$

where N is the number of intersections on the path, L is the duration of a traffic light cycle and G is the duration of a green light. For simplicity's sake, we assume that all intersections have the same activation pattern. Naturally, this formula only holds if the traffic load is smaller than the capacity C. We list the parameters for a three-lane highway and a secondary road in Table 1.2, as derived in [57].

Table 1.2: BPR parameters for the two roads

Parameter	Highway	Secondary road
t_0 (min.)	20	20
C (vehicles/hr)	5070	1380
α	0.467	0.618
β	3.82	2.77
d (km)	40	20
f_p (vehicles/(hr)	6000	600
v (km/hr)	100	50
N	0	10
L (s)	-	60
G (s)	-	30

Chapter 2

Literature Reviews

2.1 Paratransit

The literature in paratransit improvements through technologies is vast and provides perspectives on approaches to the integration and inspiration for our work. In a study conducted by Mitra, Bae and Ritchie [39], the use of ride-hailing services by older adults was evaluated using the data from the 2017 NHTS. The results of the study is the first national survey in the US to collect data on an individual's frequency of the use of ride hailing services from March 2016-May 2017. This dataset contained a sample of 73,409 older adults (aged above 65). The study found that the presence of rail service in residential locations was an important predictor of ride-hailing adoption amongst older adults. The researchers concluded that public agencies should address the digital divide by providing technology training programs for older adults which would enable them to interact with new technology [39]. This claim is addressed in our work; from the semi-structured interviews in [34], we found that education of paratransit travelers is important to agencies and majority of them have already implemented some forms of educational programs for passengers and paratransit drivers.

The Synthesis of information related to transit problems [49] includes a literature review and profile of 29 transit agencies that responded to the administrative survey and reflects various service models used for ADA (and coordinated) paratransit systems. The study found that the most important benefits relayed by the 13 agencies that use taxis and other Non Dedicated Service Providers (NDSPs) were the reduction in unit costs from the use of taxis to serve peak overflow and longer trips and to address the same-day service need not offered by paratransit. However, the most prominent shortcomings include the degradation in service quality and not knowing the identity and location of a particular vehicle assigned. Another issue is security concerns that were raised by the agencies, stating that there were increased opportunities for fraud. These concerns are complementary to those we identified in our empirical work and the mobile app integration displayed in the next Chapter, is a potential solution to these concerns. Trips served by subsidy programs are not considered a part of the ADA paratransit service model and do not contribute to agencies meeting the ADA paratransit obligation. Major findings from the synthesis include: 41% of the surveyed agencies offer taxi-based alternative subsidy programs to their ADA paratransit customers. While, in our survey, we found that 47% of survey respondents have considered TNC partnerships, only but, 17% have conducted a pilot.

Early emerging technologies in paratransit was introduced in 2002, where authors propose a conceptualized system for automation to paratransit Advanced Paratransit Operation System APOS [25] The system includes static and dynamic databases where the static database includes the vehicles, drivers, road information GIS, customers, service records..etc., while the dynamic database included the vehicle location, status, traffic conditions, new requests, cancellations and new schedules. The scheduling components provides offline and online scheduling capabilities. AVL systems are used to track and locate vehicles. Their simulation model consists of nine principal models: Service area and network model, trip model, vehicle model, vehicle schedules, AVL model, communication system model, dispatcher model, on-line dynamic scheduling. In [50] their work presented a paratransit system integrated with public transportation called VIA. The proposed system helped increase their ridership in general presence of Via services impacts the ridership of Handitran, which is the special transit division of Arlington, TX. 62% of Handitran trips originate from groups without Via services. Additionally, Arlington, Texas, USA, has launched an An on-demand autonomous transit program called RAPID Rideshare with wheelchair accessible options, accommodating up to two passengers. It is reported that the FTA funded nearly $1.7million for this service. The city said that Drive.ai conducted 760 trips serving 1,419 passengers. Between Aug. 22, 2018, and May 6, 2019, it logged more than 440 miles in autonomous mode without incident [19]. Riders told the city in a survey that 98% of them felt safe, and 91% said they thought their ride was smooth [41]. There is no data available on the accessibility system's performance and experience but, the rides are requested through an app which includes payment Idemonstration in Texas with wheelchair accessibility.

In terms of route optimization and improvements to efficiency, two approaches were explored by Gupta et. al in [27]. Their first approach seeks to re-optimize routes developed at the end of each day. The second approach evaluaof th e s of oted the benefit to state agencies use of non-dedicated service providers (like taxis). In their work, both approaches were tested on data obtained by Metro Mobility. This study proves the savings of re-optimizing 5% of Metro Mobility's operating costs.

Additionally, many research efforts exploring elderly populations and wheelchair users focus on improving autonomy and quality of life for wheelchair users for instance, a comparison between smartphone sensors and bespoke sensor devices for wheelchair accessibility studies and how placement of smartphone effect the measurements, whether it was mounted or held in a pocket. That study found that there are inevitable effects that cause loss of accuracy when phones are not mounted (like leg movements, coupling between phone & frame, error in calculating phone direction. However, the measurements are still sufficiently accurate when the phone is held in pocket. The measurements from the phone and bespoke sensor devices are highly congruent and can be used in wheelchair accessibility studies with high level of credibility. This work validates the use of smartphones as an inclusive option for paratransit passengers with wheelchairs.

Using the euclidean distance (equation 2.1), modified to represent the distance between a pair of stops instead of the actual route (equation 2.2, researchers were able to simulate a dynamic insertion scheduling strategy for paratransit vehicles in [60]. The euclidean distance:

$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{2.1}$$

$$d(p, q) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2} \tag{2.2}$$

The objective of their work was to evaluate a new strategy for scheduling paratransit vehicles which would allow unscheduled customers in close proximity (within the Demand Response Area (DRA)) to pre-scheduled stops to be picked up. Pre-scheduled customers are considered static and it operates in a *greedy until capacity* manner. The driver selects the customer with the lowest trip time to service first. The dynamic customers are those unscheduled trips that the agent serves if they have not met capacity and have one or more seats available. If those conditions are met, the agent selects the dynamic customer within the DRA in a first come first served manner. Through the use of agent-base simulations, the researchers were able to conclude that their proposed strategy is able to serve more customers using the same fleet size experiencing only a small increase (6%) in travel times. Ultimately, this work proved that including dynamic customers does not significantly affect the scheduled customers travel distance or their in-vehicle travel time, for example, a 14% increase in the number of dynamic customers served only resulted in a 1% increase in the total vehicle-hours traveled. This further motivates us to propose a paratransit service that includes dynamic customer pick-ups as well.

As it relates to the sustainability of paratransit fleet, researchers have explored this area through the proposal of systems like the Electric Paratransit Anti-idling and Rider Comfort (EPARC). This concept, introduced by Penney et al.in [47], involves the electrification of bus accessories and HVAC using high voltage batter and alternator system. Through this, during vehicle stops, the engines can be turned off to reduce vehicular emissions, increase fuel economy and reduce engine idle time. However, while the engines are off, the high voltage battery will provide HVAC for passenger comfort and safety. Ultimately, the goal of this system is to lower paratransit bus emissions, improve fuel economy and reduce engine idle time. Their initial tests results validate the modeling system power generation and consumption.

2.2 ITS and Emerging Technologies: Paratransit and VANETs

Predictions for the future of technology influenced transit made by Schweiger et al [53] are that the following technologies will become an integral part of public transit:

1. Fully Autonomous Transit
2. MaaS (Mobility as a Service)
3. Bots (applications that perform automated tasks)
4. Blockchain Protocols (AI)

Interestingly enough, privacy preserving technologies have emerged in the transportation industry in various ways. Generally, Blockchain technology has the ability to impact the way transportation is perceived and utilized. In terms of supply-chain logistics, traffic management and smart infrastructure in smart cities and communities. In this section, we provide an overview of the literature in this area as it relates to transportation and its implications in paratransit and VANETs. Researchers have found that the growth in the theoretical or practical application of Blockchains in ITS has grown significantly, noting that between 2018 and 2019, the number of published articles almost doubled and the number of citations tripled. Also, over the years, many companies have invested in car sharing and data sharing Blockchain Technology -based business, such as Arcade City and La'Zooz. [9] Researchers realize Blockchain has the potential to help establish a secured and trusted decentralized ecosystem [66]. One of Yuan et al. suggestions for the use of Blockchain in ITS involves the use of smart-contract-based intelligent transportation, this is an area that is explored in this dissertation. La'zooz, a Blockchain-based Decentralized App is a well known ITS-oriented app using blockchain. The users real-time data is verified and stored in a community-maintained cryptoledger where all ride-sharing behavior, schedules and payments are coordinated and executed. Developing their own consensus protocol, proof-of-movement encourages road miners to drive using the decentralized app (on smartphone) or on their computers. Road miners, users registered as computing nodes, are rewarded with tokens called *zooz* which can be used to pay for ridesharing and other transportation services. "Security is vital for message dissemination routing protocols because illegal message tempering will result in overwhelming penalties. Without secure communication, many applications will have an impact on life or death decisions" [4].

Additionally, CreditCoin was introduced as a privacy preserving Blockahin-based incentive announcement network for communication of smart vehicles in [35]. Researchers developed a novel privacy-preserving incentive announcement network (VANET) based on blockchain via an effective anonymous vehicular announcement aggregation protocol. The users are able to set their role as an initiator or as a replier. The initiator invites others to witness while the repliers agree with announcements and generate announcement with traffic information and responses signed by the repliers.This process motivates users with incentives to share traffic information through the incorporation of the Blockchain-based incentive. In order to assess the message reliability, in this work, threshold authentication methods were used. Threshold authentication [51] is a standard method to prove message reliability in VANETs, in this protocol, the reciever only accepts a message when the message is confirmed by the threshold number of vehicles in VANETs.

The IEEE editorial on the decade of technology intelligence [18] published two papers in 2020 that the decade as the decade of Technology Intelligence emphasizing the importance of ITS. 1) the A Decision Making Framework for Maintenance and Modernization of Transportation Infrastructure: Z. Dowd, A. Franz, and J. Wasek proposed a decision framework based on systems thinking approach and leveraging network analysis and Bayesian networks for the aging transportation infrastructure [21]. 2)Mass Customizing Paratransit Services with a Ridesharing Option: D. Mo, Y. Wang, E. Lee, and M. Tseng explored a unique form of transportation service and how it can be customized for many [40].

In addition to the previously mentioned literature, more literature has appeared with consideration to sustainability and environmental impacts. Researchers have also explored data trading in markets [43] Which has motivated our work.

2.3 Smart Cities and Infrastructure

As devices become more connected, it is clear that smart cities are the future of communities worldwide. In [11], researchers define ITS a as large and heterogeneous set of applications related to collecting and managing data in smart cities involving mobility including the following:

- Demand control systems for access to reserved areas (cordon pricing, congestion pricing, electronic tolling, with GPS, pay as you drive)
- Integrated parking guidance systems
- Variable Message Signs
- Urban Traffic Control
- Video surveillance systems for area and environment security
- Integrated systems for mobility management
- Traffic data collection systems
- Expert systems for the correlation and filtering of events

All of which are apart of smart city infrastructure contributing to its ability to function and control traffic. And, according to the Italian National Agency for new Technologies, Energy and Sustainable Economic Development, experiences made so far in the EU countries, USA and Japan show that the introduction of ITS technologies has significantly contributed to improve the efficiency, safety, environmental impact and overall productivity of the transportation system. In fact, in Italy traffic signals are usually set on static signal plans which are calculated only once and then applied to variable traffic conditions, thus producing undesired congestion and pollution [8].

In the United States, paratransit trips increased by 38 million from 1995 to 2006, a 3.3% average annual increase in ridership. During the same period, operating expenses increased on average by more than 10% annually. Additionally, the cost per patron for paratransit services is much higher than for regular transit. In 2007, paratransit ridership comprised only 2% of total public transit ridership, but 13% of total operating costs in the United States [American Public Transportation Association (APTA) 2009]. Hence, an improvement in productivity without sacrificing service quality is a very desirable and much- needed goal for these services. Centralized zoning involves the entire service area treated as a single zone and decentralized where multiple zones are defined and managed independently to downgrade the operational complexity of the services.

2.4 Traffic Modeling in Smart Cities

Traffic becomes a major issue in most urban cities, heavily contributing to the flow of society and the overall environmental health. As traffic congestion increases, fuel consumption and CO_2 emissions increases proportionally. Since the introduction of navigation apps like Google maps, WAZE, Apple maps..etc. residential areas have been plagued with "shortcut" traffic. This is a growing issue that has only gotten worse over time. In [37] Macfarlane et al. emphasize the existing *Waze problem* which heavily motivated the third case study in this dissertation. The widespread use of routing apps like Google, Apple maps, and Waze has caused the increase in traffic congestion in residential neighborhoods. This is due to the apps routing drivers through residential areas as shortcuts. The ultimate goals of many apps is to present the driver with real-time routing and re-routing with the shortest path to their destination, neglecting important aspects of the route like the road capacity. Macfarlane mentions that: "around 2013, Here Technologies, TomTom, Waze, and Google went beyond just flagging traffic jams ahead. they began offering real-time rerouting suggestions, considering the current traffic on top of the characteristics of the road network. That gave their users opportunities to get around traffic slowdowns, and that's how the chaos began...The real problem is that traffic management apps are not working with existing urban infrastructures to move the most traffic in the most efficient way." The underlying routing algorithms are useful to users in short term but, these shortcuts have major negative impacts on the areas.

In 2018, researchers explored the *cut through* traffic phenomenon and its impact on traffic trends and disruption of mobility and congestion patterns. While shortcuts were once known only to locals, these routes are now available to anyone using navigation apps [14]. Their findings indicate that an increasing number of drivers might be using shortcuts, leading to a 3X flow increase on some off ramps over four years and a 14% decrease in speed on some arterial roads over one year. Through the use of two models, the cognitive cost model [58] and a restricted path-cost model, the researchers were able to capture the impacts of app-induced reroutes on traffic patterns. Last, micro-simulations were run using Aimsun, in which routing behavior is encoded at the vehicular level.

As it relates to the environmental impacts of congestion caused by traffic, researchers have investigated the impacts of the COVID19 pandemic. In [64], the authors explored the direct effects of air pollution from urban traffic before and after the COVID19 stay at home orders were in place in Seattle. Considering the unprecedented decrease of urban traffic due to the COVID-19 responses, a relatively large decrease in urban air pollutant levels was anticipated in Washington and other urban areas around the world. The pollutants were monitored at a roadside air quality monitoring station, approximately 10 m east of the loop detectors, with hourly measurements of PM2.5, black carbon (BC), NO, NO2, NOx, and CO.

Chapter 3

Case Study I

3.1 Paratransit

The first case study in this dissertation involves the exploration of paratransit transportation services as the use case. In our exploration of improvements, we sought feedback and collected data from paratransit agencies. The results of the two stage qualitative analysis are available in [34]. We followed up this work with further quantitative analysis and co-design of a phone app based reservation system. Our work was influenced by feedback from 30 paratransit agencies in California. Although there are many factors that prohibit the use of TNCs with paratransit, most users have, or will soon have a smartphone. Therefore, the use of smartphones in paratransit requests and other activities was explored as a solution. The use of smartphones inspires the integration of TNCs with paratransit, this will benefit the paratransit agencies as well by reducing their operational costs and through providing on-demand services for passengers rather than resorting to the route deviation or other DAR solutions mentioned previously, which do not typically offer on-demand (day-of) passenger requests. Also, none of the agencies in our study reported using app based booking systems.

Therefore, we developed a prototype app for this application.

TNC's are typically app-based, thus, to benefit from the services passengers would need to use smartphones for the best experience. Although, there are web-based (desktop) request options, these are less convenient for passengers. Paratransit agencies are in support of the use of mobile app, through our interviews, participants mentioned: "We're hoping that agency X has self-sustaining app in the near future."

A commonly used software for transit agencies is Trapeze. Trapeze is a global platform used by many agencies providing solutions for over 80% of the U.S., and spans across Europe and Asia, helping contractors book trips and form vehicle routes based on requests received from certified users in a dynamic fashion. However, one of the participants stated that: "It would be nice if the companies that make the software that we rely on everyday had more of an understanding of how that software should be used..." This agency uses Trapeze TripSpark. The focus for TripSpark Technologies is to partner with mid-sized agencies as well as private operators to align solutions with their unique business needs. In 2013, Trapeze introduced SARTA as an online resource for passengers and PASS-IVR for passengers to schedule, confirm, or cancel their rides a mobile app was released called PASS; where passengers can access their profile, track their ride, receive alerts, communicate special instructions. This app is currently online on the Trapeze website for live demo purposes. Since agencies have begun exploring the use of mobile apps for their services, we propose an iOS app that would integrate Trapeze and other paratransit services with TNCs; called pTNC. The mobile app is displayed in Figure 3.2a. The app incorporates a multi-platform paratransit service for passengers with both demand response and on-demand options. pTNC offers services of local paratransit through trapeze, on-demand services through Uber, Lyft, or Gogograndparent integrated in the app. With the pTNC app, the agencies are able to obtain the information from the ADA personnel's trip inclusive of the service choice, date, care attendant information, as well as other accessibility needs. This is used for data collection purposes, through the survey, respondent 3 answered that they have not considered the partnership due to their concerns about ADA access and data reporting. Another agency admits that their data collection is done by a consultant. Through the app, the need for consulting services and the worry about data collection is alleviated and could save time, resources and expenses to agencies.

The proposed integrated platform stores all user information securely and is maintained separately from TNCs. pTNC app addresses the agency concerns about unknown drivers and locations as the passenger has access to the driver information displayed and their location and allows for in-app purchase of rides. The app is embedded with accessibility features such as: read-on screen, enlargements to text, inverted colors. The app is portable and flexible, even if a user is in an area that does not service TNCs, they are still equipped with alternative options including connecting with the local paratransit.

3.1.1 Methodology

The work began with contacting agencies across California, the goal in the first step was to maintain a database of current paratransit operators in California for future partnerships, exploration and feedback. We contacted a total of 167 agencies through phone call and/or email from the we scrapped the website for the contact information. The flowchart of the methodology is presented in Figure 3.1. The next step was to invite the current paratransit operators to participate in our research study where we would then ask the agencies to complete an online survey. Following the survey, we invited the respondents to participate in the second stage of the data collection, semi-structured interviews. From there, we conducted interviews with a 6 representatives. The purpose of this stage of our research was to gain insight from agency experts. Transit professionals with up to 20 years of experience allowed us to obtain diverse perspectives from industry experts and included Paratransit services department managers, ADA compliance and program managers, field managers, mobility planners and a chief administrative officer from a Metropolitan Planning Organization. After completion of the surveys, we analyzed both the survey data and the interview data by transcribing each interview. The interview analysis involved a code weight statistical analysis in order to assess the major themes that emerged from the interviews. The iOS app design and simulation were achieved using the swift iOS language in Xcode and the app is simulated on an iPhone 8 plus for the purpose of this work. The evaluation of the app is essential to the progress, we plan to conduct focus groups with passengers in the future, more details are discussed in the last section.

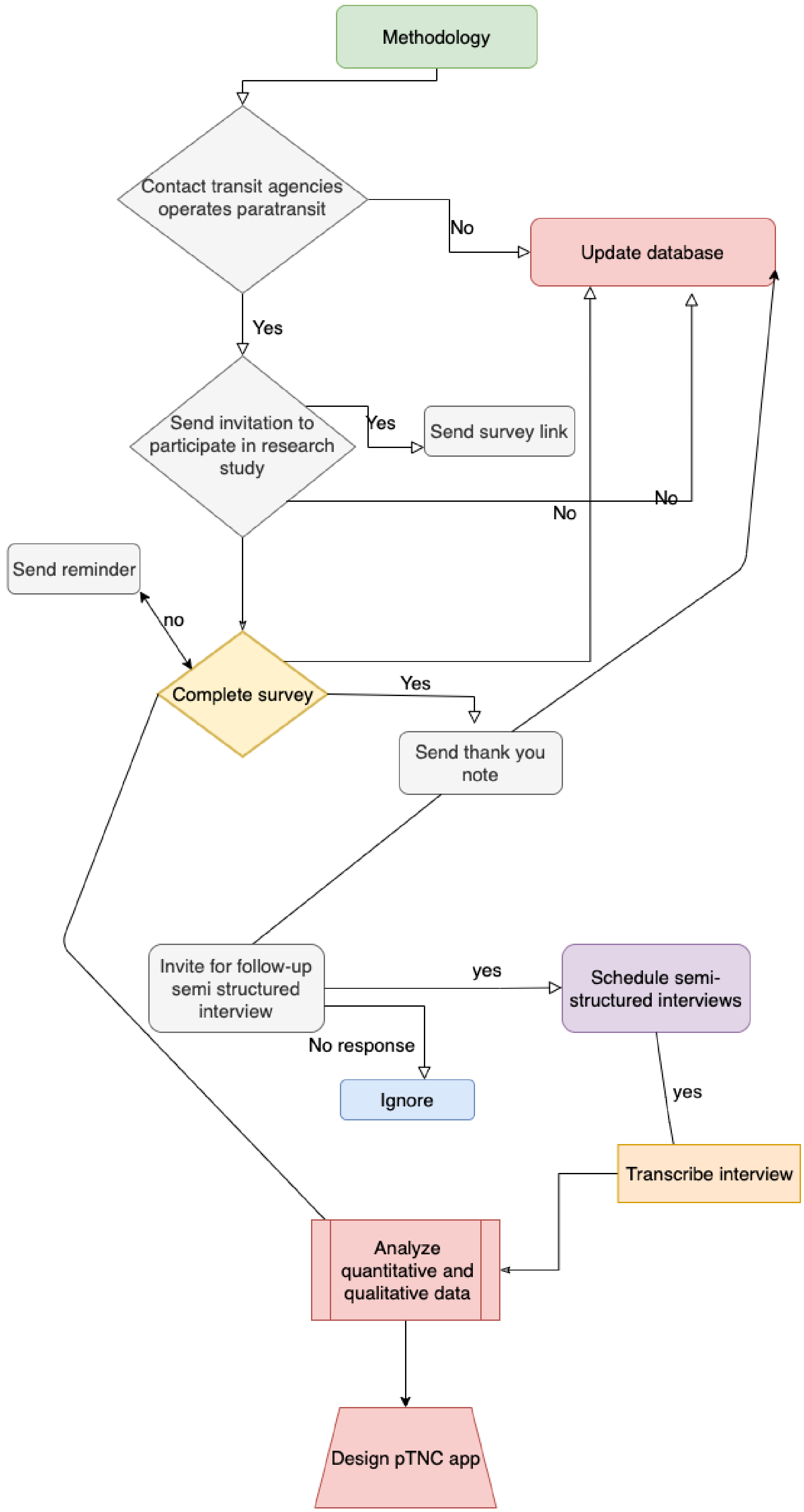


Figure 3.1: Methodology Flowchart

Although we are able to emulate the functionality of the app, we foresee many challenges with the integration of these two platforms. Mainly, the approval of this integration with agencies and the TNCs. Detailed agreements must be in place. The platform must maintain high security and reliability. Drivers must be vetted beyond the normal TNC vetting process. We proposed the use of decentralization as researchers have introduced in [30]. Additionally, pricing within the apps are another challenge as paratransit has specific price requirements for ADA passengers and the integration must ensure that the prices are within the approved ranges. Though we cannot project the surge pricing of TNCs, collaboration between those companies and paratransit requires firm agreements to be established. We imagine that paratransit users could be limited to off-peak times to eliminate the need to consider surge pricing. The pricing must align with requirements of the ADA. These agreements will ensure that TNCs do not abandon passengers without warning – a worry of some of our survey respondents. Some TNCs can be unreliable, negatively impacting the sub-contracting experience.

3.2 Results

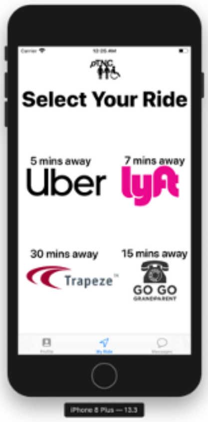
The pTNC app displayed in Figures 3.2a-3.2f demonstrates the capabilities of the integration of the TNC services with paratransit. For the ride matching of pTNC, the app uses the proposed algorithm shown below. Ultimately, the user is matched with best option based on their user preferences indicated in their personal user profile. The user is presented with the availability for all as depicted in figure 3.2c and the user is able to make their preferred choice.

Algorithm 2 pTNC pseudocode

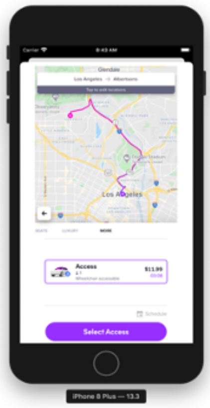
```
Result: pTNC app passenger ride matching
initialization; O ∈ O_1, O_2, O_3, O_4, O_5, O_6;
while passenger > 0; & mobilePay =TRUE do
    CheckProfileSettings;
    if wheelchairUser= TRUE & careAttendent = TRUE or servAnimal = TRUE then
        display O_1;
        seat++;
        if caneUser = TRUE & careAttendent = TRUE or servAnimal = TRUE then
            display O_2;
            seat++;
            if hearingImparied=TRUE & careAttendent = TRUE or servAnimal = TRUE
             then
                display O_3;
                seat++;
                if visionImparied = TRUE & careAttendent = TRUE or servAnimal =
                 TRUE then
                    display O_4;
                    seat++;
                end
                Return O;
            end
        end
    end
end
```

Inspired by the recent work of Torkjazi and Huynh [60] we have adopted a dynamic insertion method that can be used to integrate these services effectively. The underlying algorithm ensures that the passenger is matched to the best choice as it relates to their specific needs. O_1 - O_6 represent the options available from local paratransit, services such as gogograndparent, and Uber and lyft providing the ability to accommodate dynamic passenger requests. The HIPAA Privacy Rule establishes national standards to protect individuals' medical records and other personal health information and applies to health plans, health care clearinghouses, and those health care providers that conduct certain health care transactions electronically. The Rule requires appropriate safeguards to protect the privacy of personal health information, and sets limits and conditions on the uses and disclosures that may be made of such information without patient authorization, thus, with respect to HIPAA regulations,

Figure 3.2: pTNC App Displays



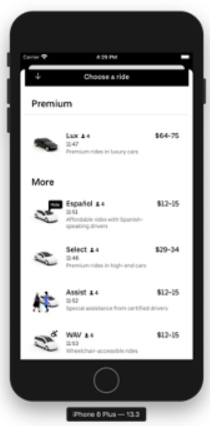
(a) pTNC splash screen



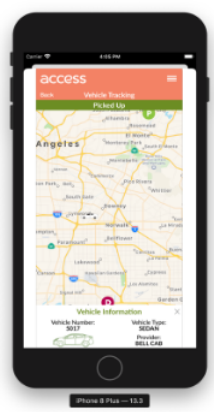
(b) pTNC homepage

(c) pTNC user profile

(d) pTNC local paratransit view



(e) pTNC Uber view



(f) pTNC Lyft view

we have proposed secure, privacy preserving methods to exchange passenger information is considered.

3.3 Blockchain Prototype Design

In order to simulate the decentralized blockchain-based paratransit environment, we use popular Ethereum blockchain tools. Ethereum blockchain is an open source, public blockchain-based distributed computing platform that runs on the Ethereum Virtual Machine (EVM) which executes opcodes.

3.3.1 Materials

The tools included in this project are Truffle suite and Ganache. Truffle is a development environment, testing framework and asset pipeline for blockchain using the EVM. Within Truffle, we use Ganache, a personal blockchain on Ethereum to deploy contracts, develop applications and run tests.

Using these open source blockchain tools; Truffle and Ganache, we are able to simulate the transactions between the nodes in the network. The nodes consist of the various TNCs such as Uber and Lyft, taxi services and paratransit services that we wish to incorporate on the network.

Figure 3.3 shows how the ecosystem will be managed. All of the entities on the network are securely connected to each other in a decentralized environment. The blockchain maintains the blocks and transaction ledger. The entities are representative of the IoT devices which will be used to requests, accept and pay for the transportation. These devices include; mobile phones and wearable devices such as smart watches.

3.4 Architecture

The next few sections will detail the architecture of the proposed systems frontend and backend.

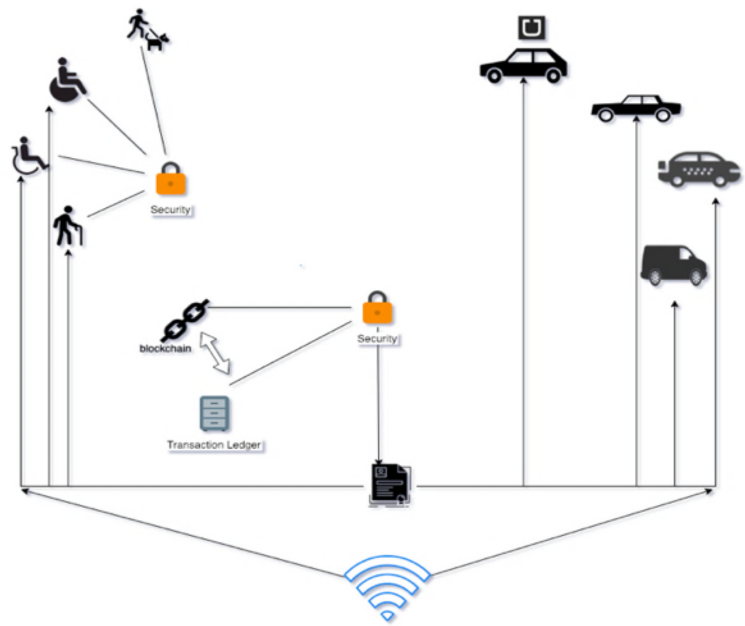


Figure 3.3: The ecosystem for blockchain-based IoT paratransit

3.4.1 Frontend

The frontend of the prototype involves the use of HTML, CSS and JavaScript to connect to the blockchain. The blockchain testing framework that is used is in Ganache. Ganache is a test blockchain that allows us to access a personal Ethereum blockchain to run, execute commands and inspect the state of the blockchain. It can be used through the command line or the Graphical User Interface (GUI).

Ganache, provides users with an account and the resources (Ether) to deploy and process transactions between entities on the network. Ether is used to pay for the computational resources needed to run an application or program. Ganache connects via a Remote Procedure Call (RPC) server.

3.4.2 Backend

The backend of the implementation is in Ethereum. The transactions are collated into blocks; blocks are chained together using a cryptographic hash as a means of reference forming the blockchain. Each block has access to the information of the previous blocks as well. The cryptographic hash function provides an extra layer of security, assuring that each transaction is verified. Ethereum works on the backend of decentralized applications. Through mining, each block on the chain comes to a consensus to approve the newest block. This is a brute force process. Proof of stake and the proof of work are the two main algorithms used in Ethereum blockchain.

3.5 Smart Contracts

Blockchain has proven itself useful in many business applications, and has the potential to improve processes and enhance business models in logistics and Supply Chain Management (SCM). In [28] four use cases were addressed as areas of significant opportunities of improvement by incorporating blockchain technologies, including: ease of paperwork processing, identifying counterfeit products, facilitating origin tracking and, the operation of IoT.

Many new companies have emerged over the years and the pace of development is increasing. One such example is Fetch.ai, a company that is combining blockchain technology and machine learning applications with the goal of developing "a decentralized digital representation of the world in which autonomous software agents perform useful economic work" [3]. While the company is working in many domain areas, it seems clear that transportation will be an early application. In [33], we developed prototypes for the integration of TNCs and paratransit. Smart contracts are secure transactions between two or more entities in a trustless environment. There are several programming languages for writing smart contracts but, the most popular is Solidity. Other examples include: Golang, Vyper, JavaScript and Simplicity.

Since we are dealing with large scale environments with a large number of potential users, it is essential to incorporate smart contracts as the method of transactional execution. The transactions within this network consist of the requests, approval and payment of transportation service.

3.5.1 Nodes on the network

Within the network, the nodes represent the various vehicles in the ecosystem. The vehicles are paratransit vehicles, TNCs or taxi services.

3.5.2 Mining/Miner

Miners are the peers on the blockchain. The role of the miner is to verify the legitimacy of each block. The miners are responsible for the maintenance of the decentralized ledger. The miner will run the block's unique header metadata through a hash function only changing the nonce value. If the hash matches the target, then, the miner is awarded ether and broadcasts the block on the network for each node to validate and add their own copy of the ledger. When the proceeding miner finds the correct hash, the previous minor will stop the current block and repeat the process for the next blocks. This process is computationally intensive but, as a result, the miner will be rewarded.

3.5.3 Consensus Protocols

Consensus is best defined as a fault tolerant mechanism that is used in computer and blockchain systems to achieve the necessary argument on a single data value or a single state of the network among distributed processes or multi-agent systems [19]. Through the consensus protocols, the network remains secure and each transaction is verified. Below, the most common protocols are defined:

- Proof of Work (PoW) – Is the well-known protocol that is very time consuming, its execution time is about 15-30 transactions per second. Each node must store the entire blockchain to verify transactions. This protocol is dependent on computing power. Mining nodes have to complete a cryptographic puzzle before they can post new blocks on the blockchain. The miners have to predict the input of the cryptographic hash, such that the output is less than the difficulty number. PoS protocol is modeled by the famous computing problem, the byzantine general problem.

- Proof of Stake (PoS) – This protocol was established after PoW as a more energy efficient and secure consensus protocol. In contrast, PoS depends on a nodes' amount of ether (stake). Any node that wants to participate in the creation of a new block must put down a deposit and join the pool of miners. The miner with the largest stake has a greater chance of successfully mining a new block. Within this protocol, if any miner is malicious they would lose initial stake and privilege to be selected from the mining pool. There are two selection algorithms: randomized and coin age selection, to select the miner from the pool.

3.6 Discussion and Limitations

We believe that through the use of blockchain-based smart contracts, paratransit services could be improved in several ways. Enabling new technologies will allow for secure collaborations with TNC and taxi services, thereby proposing a cost effective solution for transit agencies. But, there are several limitations. These include: access to resources, initial costs associated with development and deployment of blockchain, and the real-world implementations at transit agencies. Following our qualitative interviews, we have determined that agencies are interested in the use of these emerging technologies. But, agencies have reasonable concerns regarding the costs and logistics of its use.

Chapter 4

Case Study II

4.1 VANETs

Vehicular Ad-hoc Networks (VANETS) rely on extensive network communication protocols for vehicles to communicate information and exchange data. The most common protocol is the Dedicated Short Range Communication (DSRC) IEEE 802.11. There is also, WAVE which is the high-speed IEEE 802.11p extension vehicular environment which provides high network throughput, low end-to-end delay, and high delivery ratio. this relies on access points. Each vehicle in the network is regarded as a mobile node. Within such systems, the vehicles can communicate in a V2V manner where vehicles are communicating information amongst themselves, or in a V2I manner, where the vehicles are in communication with infrastructure. Figure 4.1, depicts a scenario where vehicles are communicating in a VANET. The important aspects that are explored in this dissertation include the end-to-end latencies and pathloss. In this work, we are defining the end-to-end latency as the delay in communicating the message from the sender to the receiver in *ms.* The pathloss is the signal attenuation between transmission and receiver antenna as a function of the propagation distance and other parameters. We used equation 4.7 to calculate and derive the performance of the communications in the system, results are presented in the next section.

4.1.1 Vehicular Emissions

Vehicular emissions make up roughly 20-30% of overall emissions, in 2019, the U.S. EPA reported 29% from Transportation [61]. As mentioned in the background section, many nations are focused on the reduction of Greenhouse Gas emissions. In this dissertation we focus on the U.S and the E.U. Modeled after the EU-ETSs cap and trade principle, we have developed the B-ETS mechanism to securely monitor an evaluate the vehicular emissions in a VANET. In order to control individual emissions, we use the Emissions Allowance Balances (EAB) which act as the individual accounts (wallets) for the credit based incentives. Moreover, the smart contracts ensures the balances remain positive, otherwise, to promote the overall health in the environment, we regulate the vehicles through driver restrictions.

Considering the EU-ETS carbon emissions targets for vehicles set to 95 g/km, we use this as the 'CAP' in our system. As displayed in figure 4.3, when emitter A is below the allowed emissions, emitter A can sell credits o emitter B is above the emissions capacity. The system encourages communication between vehicles to securely share vehicular emissions at specific time points. The use of emerging technologies is explored to understand and evaluate the secure communication and storage of vehicular emissions. Major pollutants like $CO_2$are analyzed. Other pollutants including NOx PMx and other HCx can be evaluated. The emissions are calculated based on the Handbook Emission Factors for Road Transport V3.1 (HBEFA). The simplified function for accordingly computing the energy consumption rate e is calculated using equation 4.1 below. This function was used for all pollutants, c changes for each emissions class:

$$e(v, a) = c_0 + c_1 va + c_2 va^2 + c_3 v + c_4 v^2 + c_5 v^4 \tag{4.1}$$

Additionally, the Passenger and Heavy Vehicles Emission Model (PHEM) called PHEMlight is used to calculate Fuel Consumption, provides basic emission factors for HBEFA 3 and Calculation of air Pollutant Emissions from Road Transport (COPERT) and thus can be regarded as a de facto European reference [1]. The amount of emissions produced by a vehicle (as well as the amount of consumed fuel) during a simulation step are determined by computing the power needed by the vehicle, first. The overall power is computed as shown in [32]:

Table 4.1: Notation II

Symbols	**Descriptions**
$n_{gearbox}$	Driver train loss(set to 0.95)
$m_{vehicle}, m_{load}$	Masses of vehicle and its load
i	Vehicle $i \in \mathcal{V}$
g	Gravitational constant $(6.673 * 10^-11 m^3/(kg * s^2))$
$F_{r_0}, F_{r_1}, F_{r_2}$	Friction coefficients
v	Current vehicle velocity
A	Cross-sectional
P	Air density (1.225 kg/m^3)
$m_r ot$	Rotational mass

$$P_e = (P_{roll} + P_{air} + P_{accel} + P_{grad})/n_{gearbox} \tag{4.2}$$

$$P_{roll} = (m_{vehicle} + m_{load})xgx(F_{r0} + F_{r1}v + F_{r2}v^4)xv \tag{4.3}$$

$$P_{air} = (c_d * A * \frac{P}{2})v^3 \tag{4.4}$$

$$P_{accel} = (m_{vehicle} + m_{rot} + m_{load})av \tag{4.5}$$

$$P_{grad} = (m_{vehicle} + m_{load}) * gradient * .01 * v \tag{4.6}$$

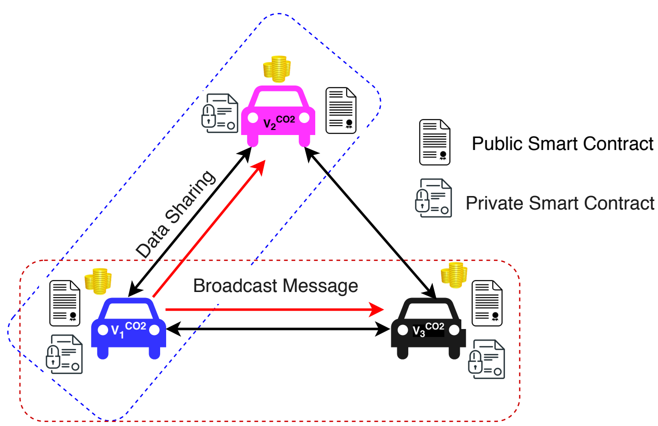


Figure 4.1: Scenario

Our System, as shown in figure 5.8 above, we are interested in the secure exchange of vehicular CO_2 emissions that rely on smart contracts and on top of that, we have included the incentive mechanism.

4.1.2 Methodology

The B-ETS framework displayed in figure 4.3. The system is built on top of DLT (Blockchain) and the use of smart contracts. The smart contracts define the behaviors and actions of the systems. These are written in Solidity which is an object oriented programming language for smart contracts on Blockchain. We were able to leverage privacy preserving DLT through the use of Blockchain. In order for the Blockchain system to come to a consensus about the nodes entering the network, a validation process is done in the form of a consensus. The consensus mechanisms can vary but, the ultimate goal is to achieve an agreement among the distributed processes. In our work, we used the quorum consensus protocol Istanbul which is a Byzantine Fault Tolerance (BFT) consensus, this consensus algorithm is a state machine that uses a three phase consensus: PRE-PREPARE, PREPARE and COMMIT. The system can tolerate at most F faulty nodes in a N validator network where N= 3F+1 in the quorum consensus protocol to verify the nodes added on the chain.

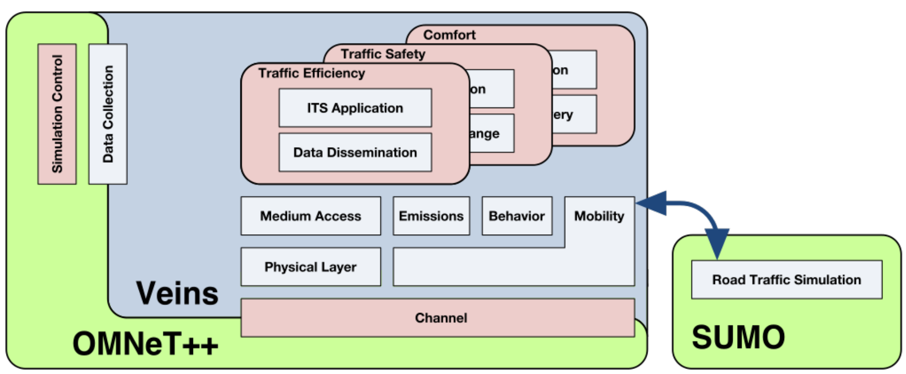


Figure 4.2: Integrated Simulation Architecture [55]

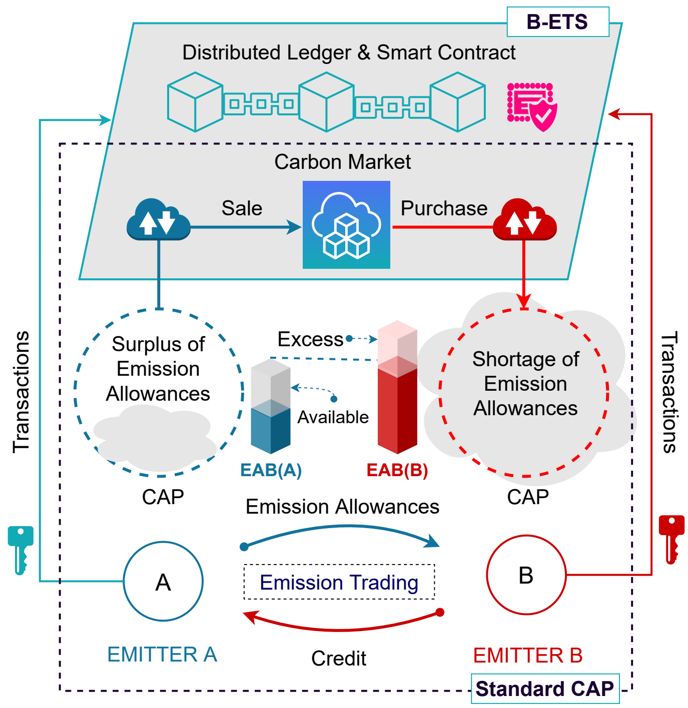


Figure 4.3: B-ETS cap and trade mechanism [42]

Agencies are concerned with additional costs associated with using privacy preserving technologies but, we have examined the costs associated with the use of Blockchain.

4.1.3 Results

To evaluate the system, we ran experiments on 120 vehicles and analyzed both the emissions and the Blockchain performance.

The time needed to complete a trade between two vehicles i and j in B-ETS can be divided into two parts. First, the communication between vehicles, simply denoted as L_{trans}, and, second, the time needed for the verification process in the distributed ledger, denoted as L_{comp}. Hence, a trade is completed successfully if and only if:

$$L_{total} \geq L_{trans} + L_{comp}. \tag{4.7}$$

From there, we define the probability of successful data trading as

$$P_{success} = \Pr\left(L_{comp} + L_{trans} \leq L_{total}\right) \tag{4.8}$$

In our experiments, we analyzed 120 vehicles in the VANET. Our analysis involved comparing the standard performance with the B-ETS system performance. As a result, we experienced the reduction of the emissions specifically we focused on CO_2 and NOx. Figure 4.7 illustrates the generated CO_2 and NO_x per simulation time in seconds. We also show the V2V communication latency in Figure 4.6 for the standard and the DLT-based trading. In the DLT-based trading, vehicles follow defined rules such as decreasing the speed in order to reduce the emitted CO_2. These results prove that our system has the ability to reduce the overall CO_2 emitted from vehicles.

In B-ETS, the transactions exchanged between vehicles are encrypted, and verified before attached in the distributed ledger. Therefore, the trusted recording and trading data is guaranteed in comparison with standard system. However, because of extra verification steps in Blockchain, the time to complete a transaction between vehicles is higher. This is a trade-off between trust and latency in Blockchain-based systems.

From our results, we ultimately found that our system is able to reduce the overall CO_2 and NOx emissions in the simulations see Figures 4.7 a and b. Both emissions were reduced by about 30% which is great, as these pollutants are extremely harmful to the environment and they can have severe effects on human health.

We also observe the increased latency with the B-ETS system 4.6, but, this is due to the additional computational communications with the DLT. The increase does cause a concern for VANETs as it typically requires very low latency. Nevertheless, The B-ETS approach introduces a more secure, trustworthy and reliable approach to the monitoring and communication of vehicular emissions in VANETs.

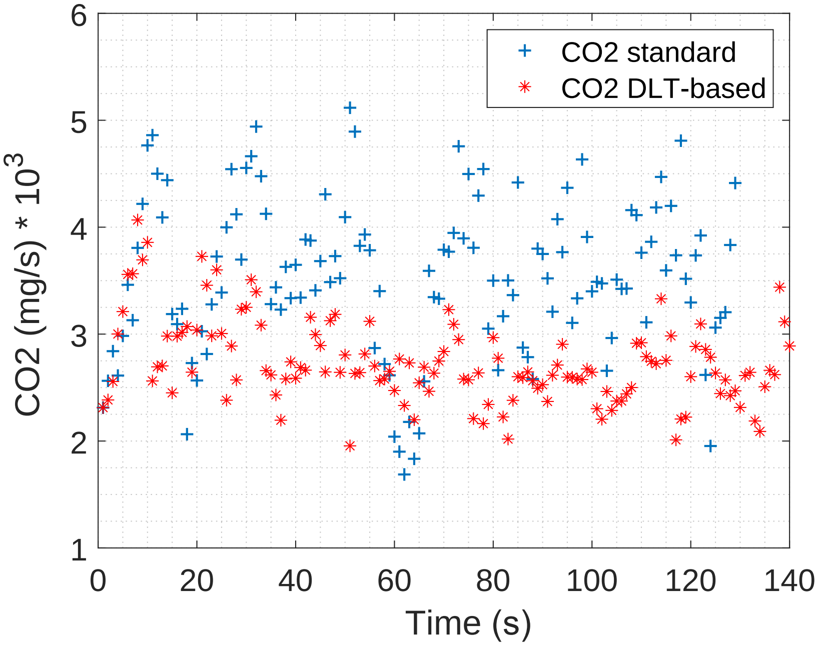


Figure 4.4: a. CO2 Emission

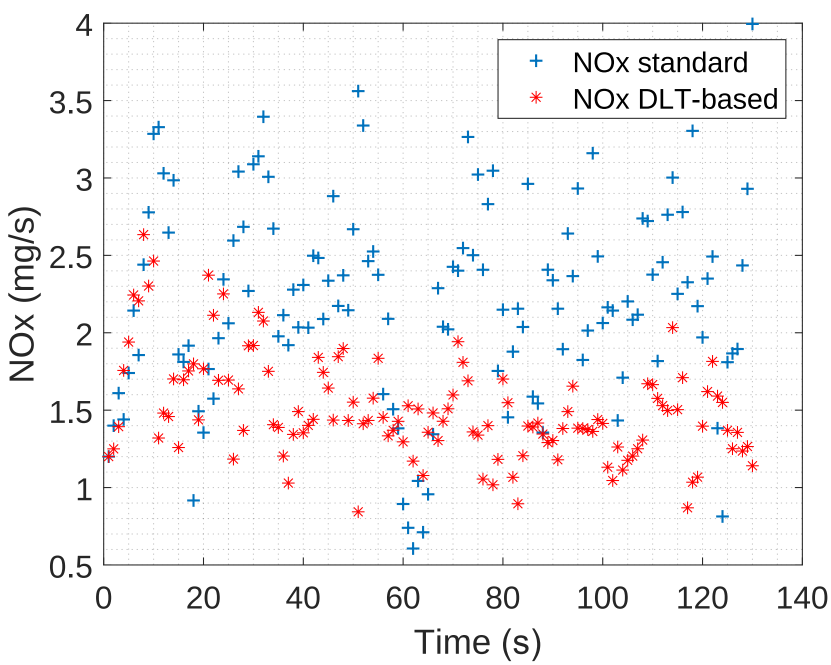


Figure 4.5: b. NOx Emission

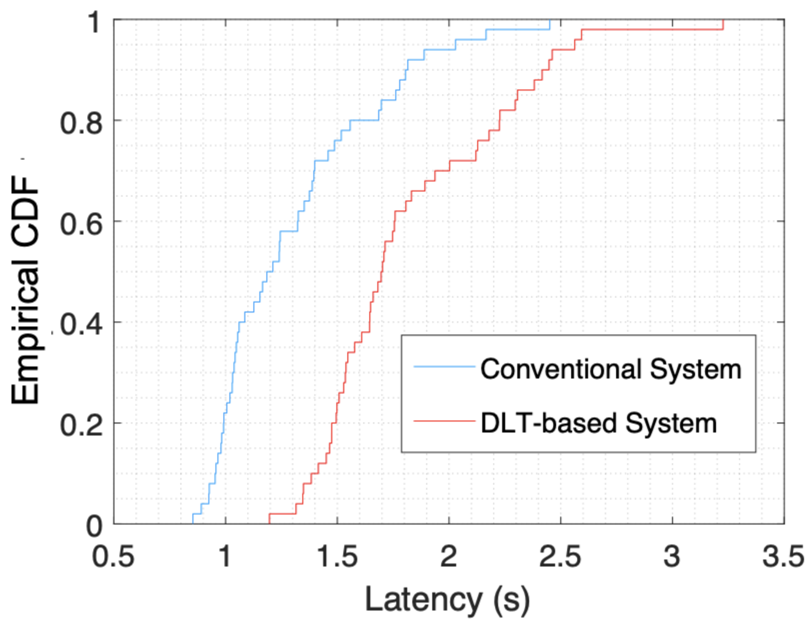


Figure 4.6: c. V2V communication latency

Figure 4.7: Performance Evaluation. *(a) and (b): The CO_2 and NOx emission generated in standard and DLT-based systems; (c) Communication latency between standard and Blockchain-based system.*

Table 4.2: Notation III

Symbols	Descriptions
T	Considered system period [hours]
$\mathcal{V}$	Set of vehicles
i	Vehicle $i \in \mathcal{V}$
T_s	CO_2 sampling period
$\epsilon_i(t)$	Average CO_2 emissions per km for
	vehicle i at time t
$B_i(t)$	Emission allowance balance of
	vehicle i at time $t \in [0, T)$
$p_i(t)$	Penalty/tax for vehicle i at time t
$s_i(t)$	Incentive (subsidy) for vehicle i at time t
L_{total}	Total allowed latency
L_{trans}	Communication latency
L_{comp}	Blockchain verification latency
R	Communication data rate [packets/s]
$\mathbf{v}_i(t)$	Speed of vehicle i at time t [km/h]
S_B	Blockchain block size in bits
$\mathbf{v}_{ij}(t)$	Relative speed between i and j at time t
r_{ij}	Communication Range between i and j
$e_{i,j}(t)$	Allowances sold by j to i at time t
$\mathcal{T}$	Maximum allowed CO_2 emissions generated by vehicles per km.

Table 4.3: Smart Contract Execution Costs

Smart Contracts	**Gas**	**Ether**	**USD**
UserAuthority	159430	$15.9{\cdot}10^{-5}$	0.0723
RecordData	152443	$15.2{\cdot}10^{-5}$	0.0692
AlertControl	213924	$21.3{\cdot}10^{-5}$	0.0971
Incentive	224934	$22.4{\cdot}10^{-5}$	0.1021
RecordData	276394	$27.6{\cdot}10^{-5}$	0.1254
EABTransfer	246374	$24.6{\cdot}10^{-5}$	0.1118

* 1 Ether = 10^9 Gwei; 1 USD = 4,182,471.9949 Gwei

Chapter 5

Case Study III

5.1 Smart City - V2I

Traffic infrastructure heavily influences the flow of traffic. Reaching an equilibrium among drivers will result in smoother traffic flow of traffic. The Danish Congestion Commission called for improved traffic signal control in [31] to reduce congestion, travel time and energy consumption [24], thus, contributing to reducing the emissions. In the third case study, an exploration of the ideas of traffic management through smart city infrastructure are analyzed where we address coordinated traffic lights and dynamic Traffic Light Management Systems.

Figures 5.5 shows the effect of setting a speed limit on the shortcut through the residential area: a speed limit over 45 km/h has no effect on the trade-off, as congestion becomes the primary factor in the travel time on the shortcut, but setting a 35 km/h speed limit can remove 80% of extra traffic, while increasing travel time through the residential neighborhood by less than 4 minutes. Lower traffic limits would have no effect on commuters' decisions, as the shortcut is already slower than the normal route, but would increase the delay for residents, and is then undesirable. The dynamic nature of the measure can prevent further annoyances to residents outside rush hour, as they might wish to have a less strict speed limit when there is no risk of congestion. We can see the effect of altering the red light duration, while maintaining a green light duration of 30 seconds, in Fig. 3. The required duration to discourage all commuters from taking the road is approximately 2 minutes, while setting a red light duration of 90 seconds can reduce the extra traffic by 70% while increasing travel time by approximately 4 minutes. Overall, speed limit control seems to be slightly more effective as an incentive measure, but traffic light control can be implemented without additional signage or infrastructure, as traffic lights are already remotely controlled in most cities. Furthermore, speed limits are violated significantly more often than red lights, so the real effect might be smaller [23]. We were able to model the performance of this mechanism through the simulation of two road networks, one in Italy and the other in the USA.

5.1.1 Methodology

In this case study, we analyzed the effects of routing apps on the traffic in a smart communities. For the experimentation, a smart city in Padova, Italy and Los Angeles, California, USA are used as the test-bed. For this work, we wanted to emulate a real smart city environment. Thus, we used Padova City as shown here in Figures 5.1-5.4.

Also, we compare the results to the mecca of traffic congestion in the USA, Los Angeles, shown in Figures 5.3 and 5.4. Our goal is to model the shift of traffic from the *app* users who will contribute to the high emissions in residential areas by traveling on residential road using the Bureau of Public Roads formula, (BPR). The analysis is done under the assumption that drivers that are assigned routes via the routing apps are to strictly follow the directions. Thus, through the implementation of dynamic road infrastructure, the apps will adjust to the new traffic patterns and the increased traffic light duration will discourage routing along certain routes.

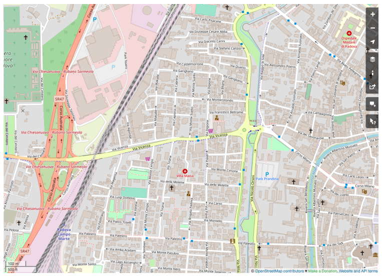


Figure 5.1: Padova, Italy City Open Street Map View

Figure 5.2: Padova, Italy City Traffic Light View

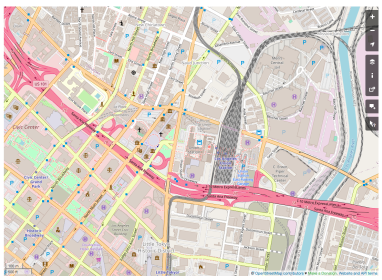


Figure 5.3: Los Angeles, CA City Open Street Map View

Figure 5.4: Los Angeles, CA City Traffic Light View

We are most interested in the shifting of traffic from residential roads, effectively reducing the GHG emissions in those areas, this work is focused on two major road types, namely, residential and high capacity roads. Our simulations are performed using SUMO with additional python scripts to assess the experimentation. The road types included in the simulation are defined in the table below 5.1.

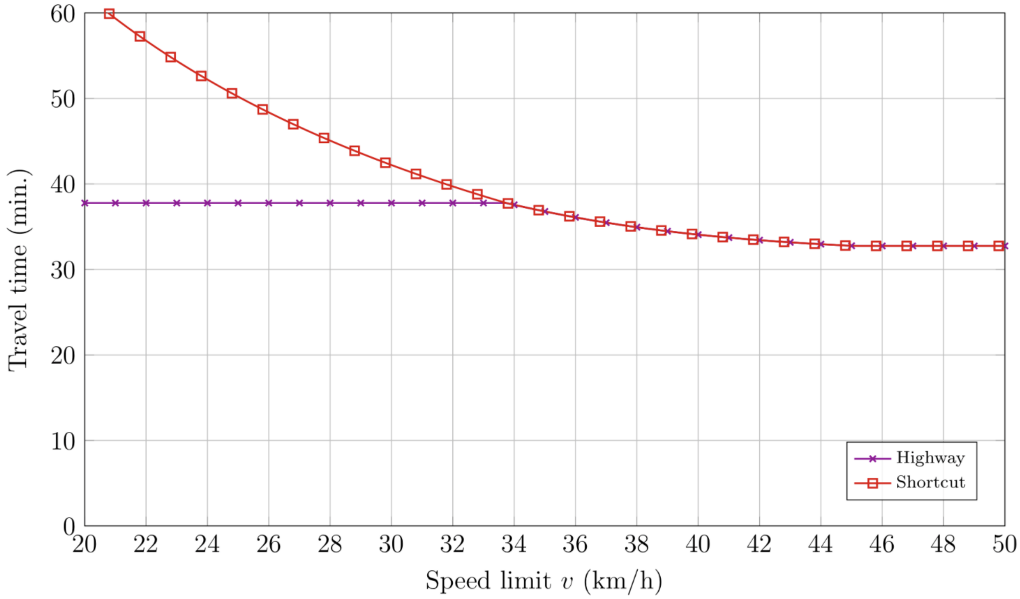


Figure 5.5: Travel Times on Highway and Residential Roads

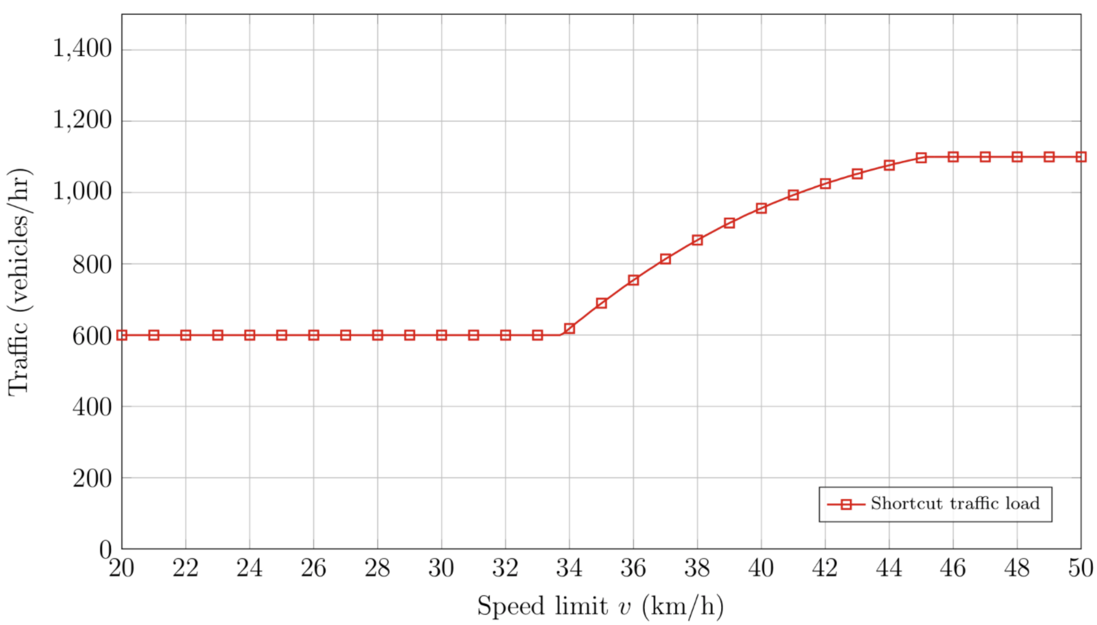


Figure 5.6: Traffic Load in Residential Areas

Fundamentally, we are viewing the *highway.residential* as one category and all other road types as high capacity roads to model this shift.

Table 5.1: Notation IV

Symbols	**Descriptions**
highway.residential	Roads accessing residential areas
highway.track	Roads for agricultural traffic
highway.primary	Main roads on highways
highway.unclassified	Roads below tertiary, still interconnecting but not in a residential area
highway.trunk	High performance roads that don't meet the requirements for motorway typically one directional
highway.trunk_link	Links are usually subordinate to the road that leads to the trunk (e.g. a secondary or tertiary road
junction	
highway.tertiary	Roads connecting smaller settlements or in large settlements roads connecting local centers

5.2 Results

Post-pandemic traffic patterns are somewhat unpredictable, we have conducted this work under the assumption that the traffic will return to normal with slightly more vehicles on the road due to the hesitation of shared transportation options for anyone but, especially for individuals with compromised immune systems. Under this assumption, we posit that drivers will continue to use routing apps which direct them to take shortcuts through residential areas. Although carbon emissions are expected to increase following the pandemic restrictions, in this paper we propose the shifting of traffic from residential roads to high capacity roads using the famous BPR formula. We show the effects of this traffic shifts with the aid of dynamic infrastructure which led vehicles to reroute.

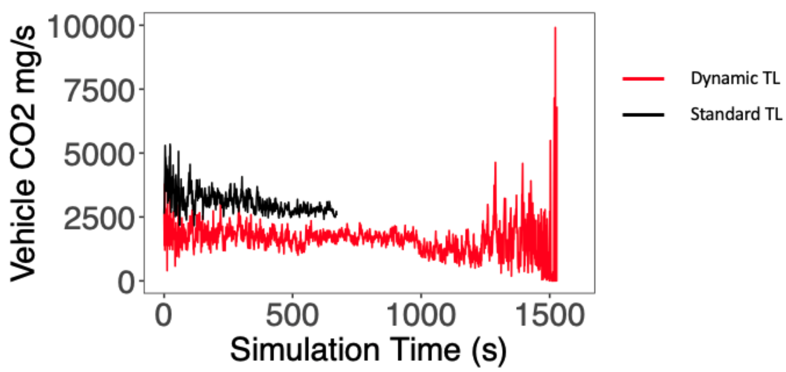


Figure 5.7: CO_2 emissions at each simulation timestamp

As a result, our analysis shows the direct affects of our model on the pollution of residential areas. For the Padova network, there were a total of 3,864 highway residential roads and 6,428 other high capacity roads. Overall, the CO_2 emissions were reduced by 6% with this traffic smoothing approach. But, considering the changes made in the traffic, the vehicles are in response to this which caused the simulation time to double and effectively, the route duration per vehicle were effected as well. We found that our results led to reduced travel duration per vehicle ID and large increase in route lengths per vehicle ID increased by 1,167 m, we prove these results through the model captured in Figure 5.9 where we demonstrate the increase of travel times as the red light duration increases during rush hour.

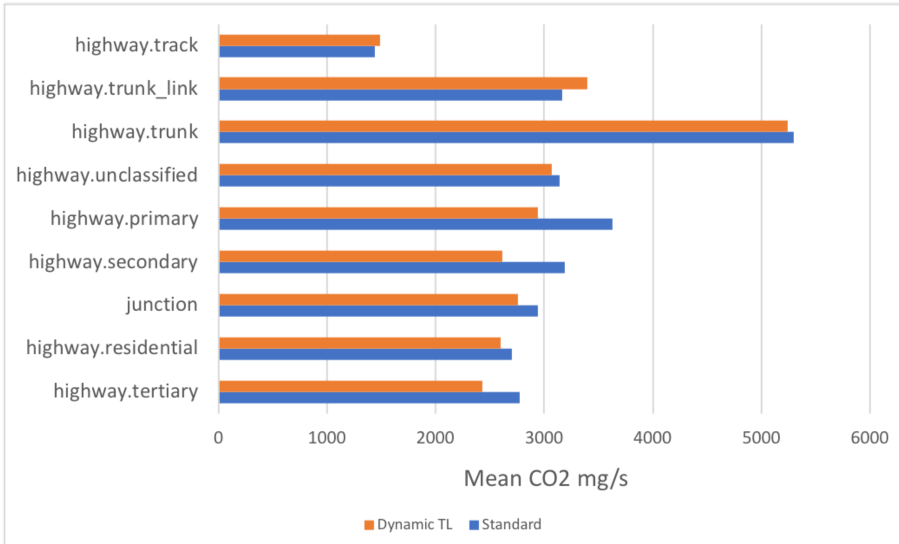


Figure 5.8: μ Standard and Dynamic TL CO_2 emissions by Road Type

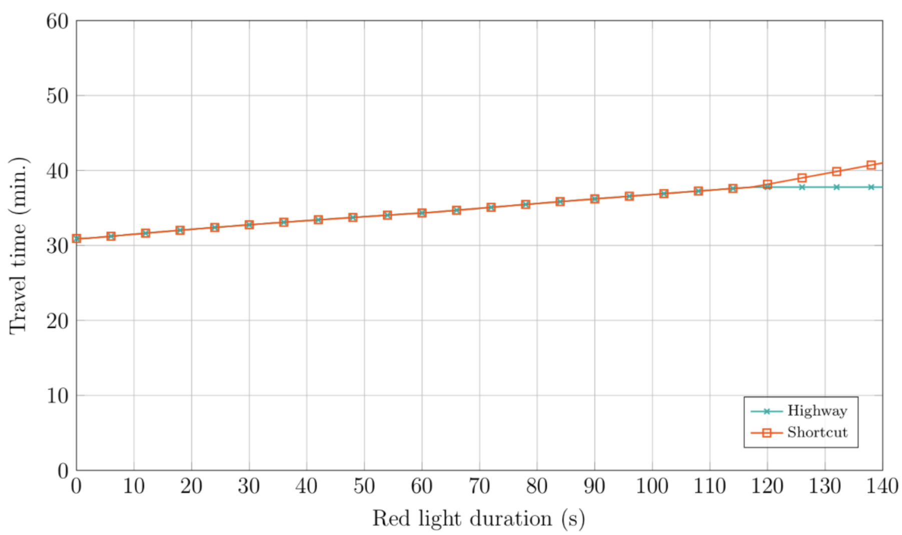


Figure 5.9: Dynamic Red Light Duration during Rush Hour

Additionally, our simulations in the LA area demonstrates similar performance.

Ultimately, finding the proper traffic smoothing mechanism that will improve the traffic performance, shift drivers out of residential areas and reduce GHG emissions is our major challenge. The hope is to Lower the vehicular emissions overall, as well as benefit the drivers. Through our first phase of analysis, we note that the dynamic traffic lights alone cannot help us gain s realistic equilibrium. And, although we cannot control routing apps, we have the ability to shift traffic and effectively, the routing apps make adjustments following the traffic shifts. As the motivation for this work, we truly believe in the importance of improving the conditions of residential areas.

Chapter 6

Conclusion

The transportation industry is continually evolving. In this dissertation we have addressed several major issues in transportation systems which are ever changing due to advances in technology. In the first case study, we focused on paratransit which is a service with specific requirements and for passengers approved under the rules of the ADA. Presenting the results of our empirical work, an integrated app and proposed Blockchain-based system design, we demonstrated improvements that could be made to paratransit by providing increased flexibility for passengers, and reduced costs to agencies.

Secondly, considering the new goals of many governments, more initiatives are put in place to monitor, regulate and encourage the reduction of green house gas emissions. We have taken connected vehicles into consideration for identifying methods for reducing vehicular emissions through the use of emerging technologies. We also investigated the computational costs and communication between vehicles in VANET environments.

Additionally, the investigation of traffic in smart cities through dynamic infrastructure is done in the third case. Here, we found that the dynamic traffic lights have the ability to reduce congestion and vehicular related emissions in residential areas.

Thus, the major contributions of this dissertation are the introduction of emerging technologies for the integration of paratransit and TNCs, including the integrated app design and Blockchain implementation. Additionally, the communications analysis between Vehicles in VANETs and introduction of novel cap and trade system for VANETs. Last, the traffic modeling and analysis of shifting traffic from residential areas to reduce traffic congestion and ultimately reduce vehicular emissions in residential areas.

Chapter 7

Future and Ongoing Work

Extensions of the work will involve the analysis of the associated costs related to the use of Distributed Ledger Technologies. An analysis of the feasibility of such technologies will address the major concerns of transportation agencies, TNCs and drivers.

7.1 Case Study I -Paratransit

This ongoing work has a promising future, with the current framework, researchers are able to replicate our empirical work in other states and countries that offer similar ADA paratransit services. The next stage includes gaining paratransit customer feedback to the pTNC app. We anticipate leading virtual focus groups to obtain that feedback. Leveraging the paratansit agency relationships maintained in the first stage of the work is also important. For the focus groups, we will identify 10-20 active paratransit users and have them go through the virtual experience with the pTNC app simulator. From this, we can use the feedback from passengers on further iterations of the app and its features. The use of an online app simulator allows us to adhere to ongoing CDC recommendations as well as receive feedback from passengers who may not have a smartphone. The feedback from passengers is necessary to better understand the needs and desires of the customers. Furthermore, we would like to use agent-based simulations to assess the performance of the dynamic insertion methods in real-time we are also interested in assessing the environmental impacts of paratransit and TNC integration.

7.2 Case Study II-VANETs

In the second case study, we are continually improving the system in various ways. With regards to the EU-ETS charging an excess premium to auto manufacturers for exceeding the target CO_2 limits in a given year, we strongly believe that our B-ETS system can significantly reduce those charges. In 2020, Volkswagen had to pay €100M for exceeding the EU'S target by .05 g/km. Thus, in our further exploration of this work, we are interested in analyzing one years worth of vehicular emissions data and ultimately comparing the additional costs to vehicular manufacturers with the use of our B-ETS system. Since, the B-ETS system ultimately monitors vehicular emissions more closely, we posit that our method will lead to minimal additional costs to vehicular manufacturers in a given year. Also, with the use of Blockchain in our system, we aspire to assess the additional CO_2 emissions from its use. In terms of the communication latency, in the future, we would like to implement an additional component that will locate and identify the areas with better network connections to ensue lower latency and better network connection. Moreover, in our simulations we expect to include more vehicle types other than standard passenger vehicles, this would enhance the realistic approach to our model and analysis.

7.3 Case Study III- Smart Cities

For the third case study, the introduction of distributed ledger technology in the form of Blockchain proposes an interesting extension of this work. The purpose of this adoption, similar to the previous case, is to ensure the privacy of the data being exchanged as well as providing a completely decentralized approach in smart communities. Also, we are interested in exploring a hybrid environment where the VANET incorporates V2V and V2I interactions for traffic management. Further, it would be interesting to introduce smart speed bumps in VANETs and to incorporate reinforcement learning algorithms to enhance the overall performance of traffic and further analyze the effects in residential areas.

Chapter 8

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Appendix A

Appendix

A.0.1 Acronyms

- ADA - Americans with Disabilities Act
- APOS - Advanced Paratransit Operating System
- GIS - Global Information Systems
- AVL - Automated Vehicle Location
- IEEE -Institute of Electrical and Electronics Engineers
- ITS - Intelligent Transportation System
- ICT - Information and Communication Technology
- IVC - Intra-Vehicle wireless Communication
- CPS - Cyber PHysical Systems
- DLT - Distributed Ledger Technology

- SUMO - Simulation for Urban Mobility
- EU-ETS - European Union Emissions Trading System
- EPA - Environmental Protection Agency
- ETSI - European Telecommunications Standards Institute
- TLMS - Traffic Light Management System
- CSMA/CD - Carrier-sense multiple access with collision detection
- ETA - Estimated Time of Arrival
- COPERT - Calculation Of air Pollutant Emissions from Road Transport
- HBEFA - Handbook Emission Factors for Road Transport
- NHTS - National Household Travel Survey

Supplementary material goes here. See for instance Figure **??**.

A.0.2 Transportation Funding Policies

5311- formula grants for rural areas

5307 urbanized area formula grants

5310 enhanced mobility of seniors and individuals with disabilities

"It's only those who are persistent,

and willing to study things deeply,

who achieve the master work."

"all people who are happy have God

within them" *Paulo Coelho The Alchemist*

YOU GLOW DIFFERENT WHEN YOU'RE ALIGNED. YOU MOVE DIFFERENT WHEN YOU'RE FOCUSED - Joe Kay Apple Music Soulection Radio