Intelligent Transportation Systems (ITS):

A Survey Of What It Is, What It Does, Where It Faulters, And Where To Go With It

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Abstract

The world of technology continues to find itself incorporated into an ever-expanding number of fields with a rapidly increasing number of applications. One of these is transportation, under the umbrella of Intelligent Transportation Systems (ITS). The intention of this application at a macro scale is to increase the surface transport safety, efficiency, and convenience. As technological improvements continue to be made, ITS grows in popularity and implementation, and is now found in many cities across the United States. Correct implementation of ITS could have huge benefits in the transportation sector, but without thinking about its implications now, there is a risk of worsening already existing issues. Much of the information regarding ITS is scattered through various research publications making it difficult to understand what it is and what effects it has on the places it is implemented in. The purpose of this paper is to provide an easily accessible reference document that gives a general overview of these factors, allowing decision makers to gain a quick understanding of the topic and thus make better informed choices. Some directions for further research are also given to illustrate what is currently unknown about ITS and where potential improvements could be made.

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Introduction

Intelligent Transportation Systems (ITS) are the implementation of various technological devices and services into a transportation network that is intended to increase surface transport safety, efficiency, and convenience (Shaheen, 2005). The concept began to emerge in 1991 when academic transportation professionals began to realize the application of the internet and other electronic technologies to transportation systems had the potential to greatly expand the efficiency of transport. Since that time, computer, communication, and sensor technologies in all fields have improved dramatically, and along with them, ITS (Puentes, 2016).

Most transportation occurs in urban areas where large numbers of people take many trips throughout the day to reach their various destinations. Currently, the urban population is expected to grow significantly in the coming decades: from 3.9 billion people that already live in cities (54% of the whole global population) to 6.3 billion by 2050 (66% of the global population) (Mangiaracina, 2016). Along with this it is expected that the amount of transportation that people will take part in will also increase dramatically during the same period. With the transportation sector contributing to twenty-eight percent of all greenhouse gas emissions in the United States, it claims the top spot for aggravation of climate change (Environmental Protection Agency, 2021). Because of this, there is great interest in finding ways to make transportation more sustainable, and as a result of this pursuit, ITS has found itself emerging in metropolitan areas worldwide (Wootton, 1995).

With the plethora of technology available for application, there comes a wide variety of uses for these technologies. Adapted from a collection of implemented technologies around the world, the chart below distills these many fields into twelve broad subjects.

Bus Rapid Transit (BRT)	Seeks to improve bus service by reducing travel time and providing enhanced rider information; exclusive rights-of-way, bus lanes, adjusting stop locations, wider doors, preboarding payment, and supportive land use policies all contribute.
Commercial Vehicle Operations	The application of electronic and wireless ITS technologies to address trucking concerns. These include border crossing clearance, automatic vehicle location, vehicle-to-fleet center communications, onboard safety diagnostics, and hazardous materials incident responses.
Electronic Toll Collection	Enables the instant payment of highway tolls when a vehicle passes through a toll station.
Incident Management	Consists of three key areas: traffic surveillance, clearance, and traveler information. Also covered here are emergency management services.
Intelligent Transportation System User Services	User service areas that currently address high-level problems such as route guidance, electronic payment, and parking services.

Ramp Metering	Traffic signals employed at freeway on-ramps to control the rate of vehicles entering the freeway that optimize freeway flow and minimize congestion.
Traffic Management and Surveillance	Includes incident management, ramp metering, traffic signal control, traveler information, and traffic surveillance.
Traffic Signal Control	Can integrate freeway and surface street systems to improve traffic flow and traveler safety while also providing priority services for transit or high-occupancy vehicles. Technologies include traffic surveillance, ramp metering, lane control systems, and traffic signals.
Transit Management	Consists of four key areas: (1) transit vehicle tracking, (2) fare payment, (3) traveler information, (4) and personalized public transportation alternatives.
Transportation Management Center	The hub where transportation, operations, and control data are collected, combined, and distributed to manage the transportation network. It relies on various tools to collect

	data including electronic toll collection, radar, closed circuit video equipment, and loop detectors.
Traveler Information	Provides the traveling public with information regarding available modes, optimal routes, and costs in real time either pre-trip or en-route via in-vehicle information and changeable message signs along roadsides or transit stations.
Vehicle Control Technologies	Technologies that can help to avoid collisions, prevent or lessen injuries when crashes do occur, and lead to full vehicle automation. Some technologies include adaptive cruise control, antilock brakes, and electronic system malfunction indicators.

Table 1: Twelve Broad Subjects of ITS (Shaheen, 2005)

Over the past 30 years extensive research has been conducted within the realm of ITS and its many subcomponents regarding its efficacy, implementation, and what advantages and disadvantages usage of these systems provides (Zulkarnain, 2021). This has resulted in an innumerable amount of information collected in various research articles and journals that can speak to these questions, however that information remains difficult to find, both for the general public as well as transportation experts and planning officials looking to develop and incorporate strategies that make the best use of these new technological advances.

The intention of this review is to resolve this issue by creating an easily accessible reference document that the general public, transportation experts, and planning officials can make use of when looking to gain a brief understanding of what ITS is, and how and where it can be implemented to have the greatest positive effect.

This review was conducted through an examination of only peer-reviewed and published research articles in English that evaluated the effects of ITS on traffic management at a macro scale as of spring 2023. Keyword searches were used on various research publication websites (i.e. JSTOR) for work with information relevant to the topic. These findings were then archived as a database to reference when creating this review, and the references within the original findings were used to fill in the gaps.

Positive Impacts of ITS on Traffic Management

With the rapidly increasing population size and density of metropolitan areas globally, and particularly in the developing world, traffic management becomes a key issue to be faced as traffic congestion becomes ever more prevalent (Downs, 2022). A sense of urgency is felt especially within metro areas that have yet to establish major traffic management strategies and infrastructure as it is significantly easier to control the issue prior to the implementation of less effective means (Rahman, 2021).

Traffic congestion is typically comprised of queues, reduced speeds, increased travel durations, and heightened levels of accidents all of which result in an increase in fatigue and stress in commuters (Emo, 2016). When considering where people commute to (most often school or work) these factors play a significant role in the reduction of productivity upon arrival at the commute destination creating intangible social expenses. Aside from the more pragmatic issues created, metropolitan areas associated with heavy traffic are correlated with a lessened desire for residency by their populations, and a generally lower dissatisfaction with living in those locations (Karimi, 2021). For these reasons, traffic congestion poses an issue that is necessary to solve for any city, both growing and established.

As cities became more congested, the first instinct of most jurisdictions was to build either more or larger roads to support and ease the increase in traffic (Pfleiderer, 1995). Unfortunately, this approach only increased the amount of traffic and congestion within these areas as it simply attracted more people and more cars to the location which quickly filled the newly created space (Pfleiderer, 1995). ITS is one approach to the congestion issue that does not require the increase of road construction due to its reliance on data-based technology, and because of this, is often implemented as a calming measure. Regarding traffic congestion, ITS provides governments with real-time data that can be utilized for instant solutions and long-term plans.

An example of this is with the state of California, which has begun to move away from using Level of Service (LOS) when examining a project's impact on traffic. If a project results in the deterioration of LOS, a standard mitigation measure is to require additional traffic lanes and widening. ITS implementation has the ability to improve traffic conditions and vehicle movements, thereby increasing LOS, without the need to add or widen travel ways.

ITS Functionalities	**ITS Infrastructures**	**Instances**
Traffic Data Collection	Traffic monitoring systems Road weather monitoring	CCTV cameras, crowdsourcing traffic data from GPS-equipped cell phones

Traffic Analytics	Data analytics for planning and performance evaluation	Real-time simulation, network prediction
Traffic Management	Active traffic management Driver information provision Ramp management and conventional lane management Diversion management Integrated systems to assist other forms of traffic intervention	Speed harmonization, queue warning, temporary shoulder use, dynamic merge control, dynamic lane markings, dynamic routing Information provision through smartphone apps, websites, or telephone call services Ramp metering, ramp closure, lane controls Divert traffic to avoid incidents, construction, weather, and events Electronic road pricing systems, smart parking,

		regional transit management systems

Table 2: Functionalities, Infrastructures, and Instances of ITS (Cheng, 2020)

In general, ITS attempts to blend network-related data like vehicular cloud computing (Shojafar, 2019), wireless sensor networks (WSNs), and other approaches in a seamless manner for managing traffic congestion efficiently and effectively. The primary traffic handling solutions by ITS can be functionally categorized as traffic data collection, traffic management, congestion avoidance, and travel time prediction (Ravish, 2021).

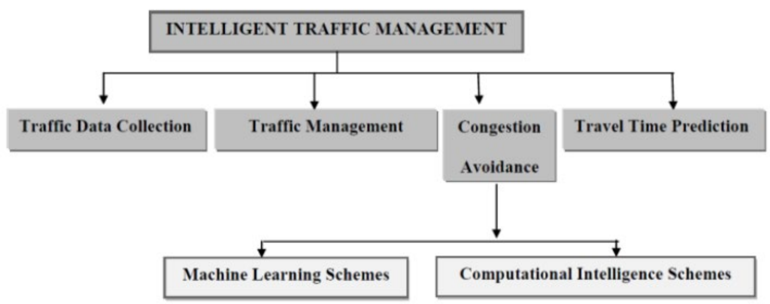

Figure 1: Functional Categories for Congestion Management Solutions by Using ITS (Ravish, 2021)

Collection of traffic data is the primary and most important function in the management of traffic as nearly all other traffic management procedures rely on the accurate prediction of traffic levels. One of the most common methods for collection of this data is through the use of sensors at a fixed specific location (Sen, 2009). These sensors have been implemented in a variety of ways. One data collection methodology uses speakers that collect roadside noise to determine the amount of traffic, though this has its limitations in significantly noisy locations (Na, 2015). The development of machine learning and artificial intelligence has led to sensors collecting data via these technologies at toll collection centers, but the high cost of implementation limits the widespread application of this method (Fan, 2018). Adaptive architecture framework that gathers traffic data through the detection of smart devices with GPS and positional coordinates has been found to be the most effective at the current time with its ability to adapt to the location it is implemented in and avoid the high expenses of machine learning methodologies (Khan, 2017).

Traffic management systems are concerned with the organization, arrangement, guidance, and control of traffic. Here, WSNs are increasingly being used to detect traffic and avoid congestion. WSNs are especially effective because of their fast data transfer, simple installation, minimal maintenance, and small size, all of which results in cost-effectiveness when compared to other network choices. One of the most popular applications of this methodology is through the use of anchor sensing nodes that are employed as pavement readers (Saqib, 2010). As a moving vehicle comes into the operational range of the node, the positional signal is transmitted, and the speed is estimated by measuring the locations of the vehicle within the node range at varied intervals. The increased use of this technology as opposed to others is attributed to its cost-effectiveness and lesser computational requirements, however it does error when traffic becomes too heavy (Saqib, 2010).

Congestion avoidance is the suggestion of alternatives routes when excessive road usage occurs. Two primary technologies are typically utilized for these situations: machine learning and computational intelligence (Ravish, 2021). Machine learning is often used by employing vehicle-to-vehicle communication with the data being gathered from vehicles then processed by fuzzy logic (a form of algebra employing a range of values from “true” to “false” that is frequently used for decision making with imprecise data) (Araujo, 2014). The paths of vehicles are then modified after the probability of congestion is identified, resulting in minimized congestion. However, this often fails to account for accidents that may cause congestion. Another methodology that does account for this deficiency is through the use of a convolution neural networking (CNN) algorithm that utilizes video imagery to count vehicles in a human-like manner and then transfer data to be processed and allow for route alteration (Ma, 2017). As described by Ma, this again has a drawback – it cannot discriminate between moving and sedentary vehicles.

Recently, computational intelligence has begun to be employed for traffic management and congestion reduction. One ant (a probabilistic technique for solving computational programs which can be reduced to finding good paths through graphs) method utilizes a multi-metric ant colony optimization algorithm which uses the least distance and time, optimal road situation, or the combined sequence, suited to the user's preference, to consider real time data for the VTR (Vehicle Traffic Routing) process (Wang, 2015). This method has achieved suitable outcomes in an easy and rapid manner with few drawbacks.

Accurate systems of travel time prediction are a necessity for public transport in the modern era, and also for private transport for users of applications like Google Maps (Kelareva, 2015). Often these approaches are parametric in nature, with the aim to look for temporal patterns in historical traffic information and employ these results for forecasts. Short term traffic can be effectively predicted via the use of Auto Regressive Integrated Moving Average (ARIMA) technology, and these predictions of traffic flow based on historical data help to synchronize traffic signals to ensure a smooth traffic flow and thus create predictable travel times (Ahmed, 1979). Long-term traffic prediction, however, remains an unpredictable measure at this point.

The implementation of these various technologies and the plethora of others not mentioned in this review is highly varied in which methodologies and strategies are utilized. Due to the varying advantages and drawbacks of these technologies, implementation is both location and cost dependent, making some strategies highly effective and usable in some locations, but completely ineffective in others. On the whole though, when these ITS technologies are used in accordance with the nature of their location, travel times and queues are reduced by a significant amount, resulting in better safety and productivity (Mangiaracina, 2016). Longitudinal studies of the use of ITS in urban areas across the United States for the last thirty years show that the increased adoption of these strategies and technologies has decreased traffic congestion to the point of saving $4.7 billion dollars and 175 million hours of travel time annually, along with a reduction of 53 million gallons of fossil fuel consumption and over 10 billion pounds of carbon dioxide emissions (Cheng, 2020). These effects can generally be attributed to ITS helping commuters make better travel decisions, and helping local governments develop effective urban traffic management capabilities.

Known Pitfalls

With ITS integrating sensing, control, analysis, and communication technologies into travel infrastructure and transportation to improve mobility, comfort, safety, and efficiency, all through the use of an interconnected “smart-web” of electronic systems, possibilities for corruption open (Hahn, 2021). The use of all the devices presents a unique attack vector for malicious actors to target, and the mass collection of data in smart cities generates privacy concerns as disruptions to ITS through hacking have been found to cause an increase of 14.6% in delays on average (Ganin, 2019). These two subjects – security and privacy – remain the primary pitfalls for ITS.

Security

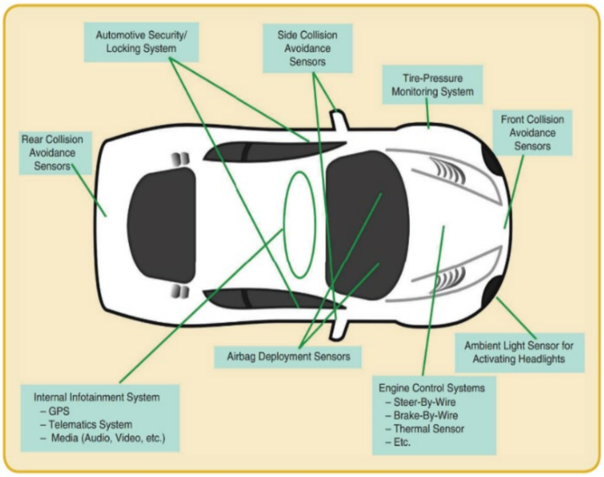

Figure 2: Attack Surface of a Smart Vehicle (Hahn, 2021)

Because of the large variety of technologies and devices that make up ITS, a huge range of surfaces are present for harmful agents to target for attacks (Hahn, 2021). With regards to security, attacks are largely limited to individual vehicles with smart technology inside of them. The table below categorizes a sampling of attacks against each surface for confidentiality, integrity, availability, identification, authentication, and non-repudiation dimensions that the attacks are attempting to disrupt. The attacks are also described as either active or passive to demonstrate the involvement of the attackers in their performance. Some attacks like denial-of-service can occur in a plethora of the technologies and technological functions within ITS, while some such as eavesdropping may only occur in communication networks.

Functional Surface	**Attack Example**	**Security Dimension**	**Attack Type**
Sensing	Denial-of-Service Spoofing	AV IN, AV, ID, AU	Active Active
Computation/Processing	Denial-of-Service Race Condition/Timing Attacks	AV IN, AV, AU	Active Active

Communication Networks	Sybil Attacks	IN, AV, ID	Active
	Jamming/Denial-of-Service	AV	Active
	Man-in-the-Middle	C, IN, AV, ID, AU	Active/Passive
	Eavesdropping	C	Passive
	Loss of Event Data	NR	Passive
AI/Machine Learning	Adversarial	IN, AV	Active
	Examples	IN, AV	Active
	Policy Manipulation	IN, AV	Active
	Data Poisoning	IN, AV	Active
	Environmental		
	Perturbations	C	Active/Passive
	Model Identification		
Analytics	Data Poisoning	IN, AV	Active
	Exploiting Model Constraints	IN, AV	Active
	Loss of Event Data	NR	Passive
Controllers	Denial-of-Service	AV	Active
	Parameter/Dynamic Inference	C	Passive

Table 3: Attack Surface Analysis of ITS (Hahn, 2021)

A major element in current and likely future ITS technologies is AI-enabled autonomy. This ranges from driver assistance technologies all the way to city-level analytics and planning. Recent research has demonstrated that all types of machine learning are vulnerable to various exploitations at any stage of the learning process, namely at training, testing, and deployment (Papernot, 2018). For example, many of the control applications in autonomous vehicles have been trained to detect objects via sensor input (as shown in Figure 2). These objects (i.e. other vehicles) are interpreted to form intelligent and appropriate responses to keep both passengers and pedestrians safe. But these AI algorithms are subject to adversarial examples (Behzadan, 2017), which are modified inputs also known as perturbations that are crafted to manipulate the system into generating a particular output. In the context of classification (a widely used application of AI) adversarial examples can be created to force a target AI model to cause misclassification in a category, leading to an accident (Li, 2017). This is just one of the many ways that a smart vehicle could have a security breach. Each of the components shown in the figure above are susceptible to attacks like this and many others.

Privacy

In contrast with security, which is mostly vulnerable regarding attacks directed at individual smart vehicles, privacy concerns and vulnerabilities are more macro in scale. This is because of the reliance on the Internet of Things (IoT) which makes people's private information significantly easier to access through hacking than it would be through closed network devices (Palmer, 2016). This easy access makes privacy protection a highly necessary consideration in the implementation of ITS. Issues can be largely defined along three over-arching categories: identity privacy, behavioral privacy, and location privacy (Kahn, 2021).

Identity privacy with regard to ITS refers to the privacy of a driver, traveler, passenger, pedestrian, or participant's real-world identity. These identities can take the form of their legal names, driver's license numbers, car registration numbers, etc. Much recent research has pushed for the idea of using pseudonyms (pseudo-IDs) in place of linking real-world identities to vehicles that are part of the system (Feiri, 2013). These pseudonyms have the ability to protect the link between message broadcasts carrying safety information, but it is still possible for malicious actors to track specific vehicles using these pseudonyms (Wiedersheim, 2010).

As an alternative, attribute-based credentials have been proposed. These allow users to authenticate to verifiers (an entity that requests and confirms a user's information) so that users are not linkable between authentication events and only reveal those attributes from their credentials that are relevant to the verifier (Camenisch, 2014). However, according to Camenisch, this method is significantly more difficult to implement because of high resource requirements and the necessity of the creation of shared attributes for all desired services.

With abundant and detailed information of users in ITS ranging from financials to location, as well as user's habits within the system, there lies a massive opportunity for invasion of an individual's behavioral privacy. For an ITS system to protect this privacy, it must have the ability to anonymize and protect collected user data from exposure, as well as mask common behavioral patterns of ITS users from unwelcome eyes (Hahn, 2021). Preserving privacy actions taken by ITS users is a necessity in averting attackers from tracking and drawing inferences on individuals and groups within the system. As ITS collects information on routing patterns to make routes safer and more efficient, movement patterns of individuals are also recorded in the system, the analysis of which can provide inferences about individual and group behaviors. Differential privacy is one method that can be used to preserve privacy of ITS users (Kargl, 2013). The goal is to preserve privacy by furnishing ways to maximize the accuracy of queries from statistical databases while minimizing the probability of identifying its records.

Location privacy within ITS is classified as the privacy of location and space, or the right of a user to travel or move about a system without concern of their location information being exposed. While precise location information is beneficial for ITS to provide location aware services, such information can be used effectively to attack the privacy of individuals (Hahn, 2021). It is extremely difficult for GPS-based navigation systems to provide their services while also preserving the location privacy of users, which makes it crucial to find a balance between providing beneficial and accurate services to users while preserving location privacy. Location cloaking or location obfuscation is one technique that can be employed which protects a user's location privacy slightly by generalizing the user's location to avoid full disclosure of their exact position (Yigitoglu, 2012). Of course, this still leaves vulnerabilities to gathering general travel habits of individuals, as well as the locations of large groups of individuals.

Direction for Future Research

Despite ITS's existence as a field for over thirty years, it is still an emerging space with a plethora of directions which future research can explore. Some of these directions, ranging from security and privacy concerns to the overall effectiveness of the technology, are given here as some insight regarding what is most popular and important to study further. Some of these directions are suggestions inferred from the information in this review, while others are remarks of prior research.

The Use of Artificial Intelligence

The adoption of AI and machine learning techniques within ITS technologies is growing at an increasingly intensified rate. While the advantages of utilization of these technologies is widely publicized, the security implications of their integration within ITS specifically remains largely unstudied, and crucial to their eventual use. As mentioned earlier, virtually all machine learning techniques are prone to intrinsic vulnerabilities that can be exploited to compromise the security of ITS. While AI safety and security research is gaining traction, it would be of interest to study the relevant aspects of this research to ITS technologies.

The Value Creation of ITS

As evidenced by this report, the majority of research conducted in the field of ITS focuses on the technicalities of the technology and what is has the potential to do, rather than the value creation (i.e. cost-benefit analysis) and the actual affects of implementing ITS at a macro scale. While expected impacts on travel time reduction and environmental mitigation are examined regularly, there remains a lack of measurement of the overall impacts of ITS within the urban context once the systems have been implemented. Currently there are few quantitative methods for studying ITS's effectiveness regarding cost reduction, travel time reduction, or VMT reduction, once it has been implemented. Research in these areas is necessary to determine whether ITS should continue to be pursued (Mangiaracina, 2016).

Privacy by Design

As a concept, privacy by design stresses the proactive involvement of data controllers and processors in addressing the privacy elements of linked systems not only during the complete life cycle of each system, but also during the design and planning phases. While several studies have applied privacy by design to the ITS sector, there is still a significant difference between being cutting-edge and just following basic legislative criteria. Blockchain-based techniques and homomorphic encryption are two attractive technical initiatives to investigate, since they might possibly provide a distributed means of sharing and analyzing data while maintaining anonymity and privacy (Cavoukian, 2012).

Improvement of Data Collection

Because of the constant mobility of vehicles, collected data is frequently inaccurate, incomplete, or undependable. Research on techniques that can yield better quality of data would significantly improve both the research of ITS topics as well as the implemented systems themselves. With the Internet of Things, many sensing methods could help in the improvement of data acquisition and quality, particularly in the realm of automatic data-capturing techniques that reduce manual data entry.

Integration of Non-Homogenous Data Sources

There is an abundance of devices and data gathering techniques within ITS that each have their own standards. Because mobility is a public service, systems require common standards to act within.

Data Management

Data is reaching massive proportions with the growth and use of the Internet of Things. Seamless integration and processing of data is another challenge that is largely unexplored, yet necessary, due to the public nature of mobility and ITS. The use of technologies like cloud computing and edge computing could be considered. Using big data technology to gather traffic data of an entire city, practical data can be provided for guiding traffic and urban planning and help solve problems of traffic congestion and traffic flow.

Long Term Traffic Forecasting

Current technology enables efficient and accurate forecasting of traffic, and has existed since the 1970s with continual improvement to the effectiveness we see today in applications such as Google Maps. Long term traffic forecasting, however, remains unpredictable. Accurate reporting of such information would be invaluable to the field of ITS and many others, making further research and development toward that end crucial.

Adoption of ITS Strategies

ITS strategies are becoming commonplace in the developed world, but in the United States much of these strategies are done by individual cities. With a system like transportation that requires and revolves around the interconnection of a plethora of destinations, it could be beneficial for policies to be considered at a regional level to encourage greater harmony between jurisdictions. One regional entity taking this approach that could be analyzed in its effectiveness is the Southern California Area of Governments (SCAG). Research comparing the positives and negatives of implementation at a local versus a regional scale will help determine which scale is more apt for a particular situation, and which strategies are worthwhile.

References

Ahmed, M., & Cook, A. (1979). Analysis of Freeway Traffic Time-Series Data by Using Box-Jenkins Techniques. In *Urban Systems Operations* (pp. 1–9). essay, National Academy of Sciences.

Araujo, G. B., Duarte-Figueiredo, F. de, Tostes, A. I. J., & Loureiro, A. A. F. (2014). A Protocol for Identification and Minimization of Traffic Congestion in Vehicular Networks. *2014 Brazilian Symposium on Computer Networks and Distributed Systems*. https://doi.org/10.1109/sbrc.2014.13

Behzadan, V., & Munir, A. (2017). Vulnerability of Deep Reinforcement Learning to Policy Induction Attacks. *Machine Learning and Data Mining in Pattern Recognition*, 262–275. https://doi.org/10.1007/978-3-319-62416-7_19

Camenisch, J., Lehmann, A., Neven, G., & Rial, A. (2014). Privacy-Preserving Auditing for Attribute-Based Credentials. *Computer Security - ESORICS 2014*, 109–127. https://doi.org/10.1007/978-3-319-11212-1_7

Cavoukian, A. (2012). Privacy by design. *Privacy Protection Measures and Technologies in Business Organizations*, 170–208. https://doi.org/10.4018/978-1-61350-501-4.ch007

Cheng, Z. (Aaron), Pang, M.-S., & Pavlou, P. A. (2020). Mitigating Traffic Congestion: The Role of Intelligent Transportation Systems. *Information Systems Research*, *31*(3), 653–674. https://doi.org/10.1287/isre.2019.0894

Downs, A. (2022, March 9). *Traffic: Why It's Getting Worse, What Government Can Do*. Brookings. https://www.brookings.edu/research/traffic-why-its-getting-worse-what-government-can-do/

Emo, A. K., Matthews, G., & Funke, G. J. (2016). The Slow and the Furious: Anger, Stress and Risky Passing in Simulated Traffic Congestion. *Transportation Research Part F: Traffic Psychology and Behaviour*, *42*, 1–14. https://doi.org/10.1016/j.trf.2016.05.002

Environmental Protection Agency. (2021). *Sources of Greenhouse Gas Emissions*. EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Fan, S.-K. S., Su, C.-J., Nien, H.-T., Tsai, P.-F., & Cheng, C.-Y. (2017). Using Machine Learning and Big Data Approaches to Predict Travel Time Based on Historical and Real-Time Data from Taiwan Electronic Toll Collection. *Soft Computing*, *22*(17), 5707–5718. https://doi.org/10.1007/s00500-017-2610-y

Feiri, M., Petit, J., & Kargl, F. (2013). Efficient and Secure Storage of Private Keys for Pseudonymous Vehicular Communication. *Proceedings of the 2013 ACM Workshop on*

Security, Privacy & Dependability for Cyber Vehicles. https://doi.org/10.1145/2517968.2517972

Ganin, A. A., Mersky, A. C., Jin, A. S., Kitsak, M., Keisler, J. M., & Linkov, I. (2019). Resilience in intelligent transportation systems (ITS). *Transportation Research Part C: Emerging Technologies*, *100*, 318–329. https://doi.org/10.1016/j.trc.2019.01.014

Hahn, D., Munir, A., & Behzadan, V. (2021). Security and Privacy Issues in Intelligent Transportation Systems: Classification and Challenges. *IEEE Intelligent Transportation Systems Magazine*, *13*(1), 181–196. https://doi.org/10.1109/mits.2019.2898973

Kargl, F., Friedman, A., & Boreli, R. (2013). Differential Privacy in Intelligent Transportation Systems. *Proceedings of the Sixth ACM Conference on Security and Privacy in Wireless and Mobile Networks*. https://doi.org/10.1145/2462096.2462114

Karimi, H., Ghadirifaraz, B., Shetab Boushehri, S. N., Hosseininasab, S.-M., & Rafiei, N. (2021). Reducing Traffic Congestion And Increasing Sustainability In Special Urban Areas Through One-Way Traffic Reconfiguration. *Transportation*, *49*(1), 37–60. https://doi.org/10.1007/s11116-020-10162-4

Kelareva, E. (2015, November 10). *Predicting Future Travel Times With The Google Maps APIs*. Google. https://www.blog.google/products/google-cloud/predicting-future-travel-times-with-the-google-maps-apis/

Khan, N. A. (2017). *Real Time Predictive Monitoring System for Urban Transport* (dissertation).

Li, Y. (2017). Deep Reinforcement Learning: An Overview. *ArXiv, abs/1701.07274*.

Ma, X., Dai, Z., He, Z., Ma, J., Wang, Y., & Wang, Y. (2017). Learning Traffic as Images: A Deep Convolutional Neural Network for Large-Scale Transportation Network Speed Prediction. *Sensors*, *17*(4), 818. https://doi.org/10.3390/s17040818

Mangiaracina, R., Perego, A., Salvadori, G., & Tumino, A. (2016). A Comprehensive View of Intelligent Transport Systems for Urban Smart Mobility. *International Journal of Logistics Research and Applications*, *20*(1), 39–52. https://doi.org/10.1080/13675567.2016.1241220

Na, Y., Guo, Y., Fu, Q., & Yan, Y. (2015). An Acoustic Traffic Monitoring System: Design and Implementation. *2015 IEEE 12th Intl Conf on Ubiquitous Intelligence and Computing and 2015 IEEE 12th Intl Conf on Autonomic and Trusted Computing and 2015 IEEE 15th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UIC-ATC-ScalCom)*. https://doi.org/10.1109/uic-atc-scalcom-cbdcom-iop.2015.41

Palmer, D. (2016). *IoT Devices Can Be Hacked In Minutes, Warn Researchers*. ZDNET. https://www.zdnet.com/article/iot-devices-can-be-hacked-in-minuteswarn-researchers/

Papernot, N., McDaniel, P., Sinha, A., & Wellman, M. P. (2018). SoK: Security and Privacy in Machine Learning. *2018 IEEE European Symposium on Security and Privacy (EuroS&P)*. https://doi.org/10.1109/eurosp.2018.00035

Pfleiderer, R. H. H., & Dieterich, M. (1995). New Roads Generate New Traffic. *World Transport Policy and Practice*, *1*(1), 29–31. https://doi.org/10.1108/13527619510075657

Rahman, Md. M., Najaf, P., Fields, M. G., & Thill, J.-C. (2021). Traffic Congestion And Its Urban Scale Factors: Empirical Evidence From American Urban Areas. *International Journal of Sustainable Transportation*, *16*(5), 406–421. https://doi.org/10.1080/15568318.2021.1885085

Ravish, R., & Swamy, S. R. (2021). Intelligent Traffic Management: A Review of Challenges, Solutions, and Future Perspectives. *Transport and Telecommunication Journal*, *22*(2), 163–182. https://doi.org/10.2478/ttj-2021-0013

Saqib, M., Chankil, L. (2010) Traffic Control System Using Wireless Sensor Network, 2010 The 12th International Conference on Advanced Communication Technology (ICACT), Gangwon, Korea (South), pp. 352-357.

Sen, R., Sevani, V., Sharma, P., Koradia, Z., & Raman, B. (2009). Challenges In Communication Assisted Road Transportation Systems for Developing Regions. *NSDR*.

Shaheen, S. (2005). Intelligent Transportation Systems. In *Encyclopedia of Energy* (pp. 487–496). essay, Elsevier Academic Press.

Shojafar, M., Cordeschi, N., & Baccarelli, E. (2019). Energy-Efficient Adaptive Resource Management for Real-Time Vehicular Cloud Services. *IEEE Transactions on Cloud Computing*, *7*(1), 196–209. https://doi.org/10.1109/tcc.2016.2551747

Wang, Z., Li, J., Fang, M., & Li, Y. (2015). A Multimetric Ant Colony Optimization Algorithm for Dynamic Path Planning in Vehicular Networks. *International Journal of Distributed Sensor Networks*, *2015*, 1–10. https://doi.org/10.1155/2015/271067

Wiedersheim, B., Ma, Z., Kargl, F., & Papadimitratos, P. (2010). Privacy in Inter-Vehicular Networks: Why Simple Pseudonym Change is Not Enough. *2010 Seventh International Conference on Wireless On-Demand Network Systems and Services (WONS)*. https://doi.org/10.1109/wons.2010.5437115

Wootton, J. R., García-Ortiz, A., & Amin, S. M. (1995). Intelligent Transportation Systems: A Global Perspective. *Mathematical and Computer Modelling*, *22*(4–7), 259–268. https://doi.org/10.1016/0895-7177(95)00137-q

Yigitoglu, E., Damiani, M. L., Abul, O., & Silvestri, C. (2012). Privacy-Preserving Sharing of Sensitive Semantic Locations under Road-Network Constraints. *2012 IEEE 13th*

International Conference on Mobile Data Management. https://doi.org/10.1109/mdm.2012.48

Zulkarnain, & Putri, T. D. (2021). Intelligent Transportation Systems (ITS): A Systematic Review Using a Natural Language Processing (NLP) Approach. *Heliyon*, *7*(12). https://doi.org/10.1016/j.heliyon.2021.e08615