**Project Report *A Framework of Autonomous Driving Simulator***

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )

**­­A Case Study of Dublin Bus -**

**The Intellectual Transportation System**

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# Abstract

Intelligent Transportation Systems (ITS) represent a pivotal integration of information technology and communication systems into the transportation framework, aiming to streamline traffic management, enhance road safety, and elevate the overall travel experience. Within the urban fabric, ITS is instrumental in addressing congestion, reducing environmental impact through optimized traffic flow, and bolstering the efficiency of public transport systems like Dublin Bus. This amalgamation of advanced technologies and transportation infrastructure paves the way for a more sustainable, safer, and smarter urban mobility landscape, reflecting a commitment to innovation and progressive urban planning.

In this study we will be reviewing the history of the Dublin Bus of incorporating evolving technologies into their system for the delivery of the promised conveniency, efficiency, and cost reduction. It will also expand the scope to international grade with comparison to other systems worldwide, and the quick growing new technologies such as AI, UAV, and NLP. Some suggestions will also be provided for the Dublin Bus in terms of the strategies of coupling with the current considerations and future challenges.

*Keywords*: ITS (Intelligent transportation system), AVLC (Automatic Vehicle Location and Control), Transportation, Challenges, Artificial Intelligence (AI), Machine Learning (ML), Route Control, Punctuality, Reliability

# Introduction

The World Bank (The World Bank Group, 2011) case study provided a comprehensive historical look at Dublin's ITS, focusing on the commence of the strategic integration of technology in Dublin Bus operations. As a retrospect, we found there was an attempt of addressing the needs on traffic management, efficiency, data acquisition and communication, and service reliability, highlighting the challenges and the financial aspects of implementing such advanced systems. The report underscores the vital role of ITS in transforming urban transportation in Dublin, setting a benchmark for future urban mobility solutions.

Dublin Bus, as the biggest public transport provider in Ireland, operates an expansive public network serving the diverse transportation needs of the city for over 70 years as a part of the PSO (Public Service Obligation) along with other operators including the Bus Éireann, the Local Link, Go Ahead Ireland. The Bulin Bus also provides links to other types of transportations, including the airport, trains, DART light railway, and inter-city bus services.

Despite a €13 million deficit in 2009, the company still decided to move ahead with a system upgrade in order to meet the PSO contract requirements from the NTA for more operational routes, less cancellation, better punctuality, and infrastructure renewing e.g. the Integrated Ticketing System, along with their internal requirements such as better communication system to ensure the driver’s security against the vandalism.

Since 2009, the organization started to upgrade to newer AVLC (Automatic Vehicle Location and Control) systems from its older version of AVM (Automatic Vehicle Monitoring) deployed since 1981, achieved, early functionality targets such as real-time tracking, route control efficiency, communication, data collection and reporting, E-ticketing, RTPI (Real-Time Passenger Information), TSP (Traffic Signal Priority), and better served the company’s vision of providing secure, efficient, and performance optimization (The World Bank Group, 2011).

# Literature Review

The concept of Intelligent Transportation System (ITS) was conceived from 1980s in Japan and Europe as a part of traffic control technologies, and only came up into the terminology of ITS in United States (Andersen & Sutcliffe, 2000), refers to the application of advanced technologies, including information, communication, and control systems, to transportation infrastructure and vehicles.

ITS aims to improve transportation safety, efficiency, and sustainability by managing traffic flow, reducing congestion, enhancing travel experience, and optimizing the overall transportation network (Andersen & Sutcliffe, 2000). It has become a hot topic in recent years, covers a versatile of research topics from technological terms such as telecommunications and 5G, V2X networks, auto-driving, detection, emission control, to supervisory notions such as traffic control, ITS in public transport sector, traffic data and prediction, optimization, etc.

Zulkarnain et. al (Zulkarnain & Putri, 2021) reviewed the researches and found that the topics of Vehicle Communication systems and Traffic Optimization, Prediction, Modelling, Networks and Data have attracted increasing attention since 1980 to 2020, while the interest on the topics of ITS in public transportation were suffer from gradual decrease. This might suggest that the system build upon classical IT infrastructure has been matured in public transport sector, while implying that the data-driven analytics and newer generation of telecommunication and V2X networking technologies will be the new direction of technological upgrades.

* C-ITS

(Visan et al., 2022) argued that a matured ITS won’t be achieved without addressing the reality that most (Garg & Kaur, 2023)transport systems), which is facing multiple levels of challenges: technical, organisational, and operational (Lu et al., 2018).

The C-ITS requires cooperation between passengers, transport operators, administrators, manufacturers and technical institutions to work together under certain standardizations (Visan et al., 2022). As of the date of this paper dated in 2024, there has been multiple global standards (*ISO, CEN, ETSI*), recommendation (*ITU*) and specifications (*SAE*) published for C-ITS (Visan et al., 2022) (itsstandards.eu, 2024).

* AI and ML

As the complexity of the transport system increased, artificial intelligence techniques has great potential to provides added value to conventional transport systems (Hernández et al., 2002) from driver auxiliary to traffic flow control.

A research (Agarwal, et. al, 2015) also pointed out that there’s an urgent need for applying the AI (Artificial Intelligence) technologies for the Indian smart cities, in order to upgrade the intelligence grade into next level for better transportation experience, cost efficiency, environment friendly, and facilities accessibility.

Beside some systematic reviews (Ullah et al., 2020) relate to the topic about overviews of AI and ML in the intelligent transport was found, there were also abundant researches found in specific topics, for example,  (Mao et al., 2022) presented an application of Boosted Genetic Algorithm in traffic control optimization; (Garg & Kaur, 2023) introduced applying ML algorithms to ITS helped to detect the security vulnerabilities in an effective manner.

Some studies also stressed the need for upgrading the ITS into higher levels, such as C-ITS (Cooperative Intelligent Transport System) (Lu et al., 2018) or Smart Cities (Ullah et al., 2020), by the multi-lateral efforts from stakeholders.

In our latter chapters, focusing on machine learning (ML) in transportation studies is crucial due to its potential to revolutionize system efficiency and security. ML's adaptability to complex patterns enables predictive modelling for traffic, enhancing flow and reducing congestion. Additionally, ML's prowess in anomaly detection ensures robust transportation security. Hence, investing research efforts in ML can significantly advance transportation intelligence, sustainability, and safety, marking a transformative step in urban mobility.

* Autonomous Driving

As a specific case of synthetically applying the AI technologies, autonomous driving as a transformative technology capable of revolutionizing transport efficiency, safety, and environmental sustainability (Dong et al., 2020). It has seen continual technological advancements, striving towards full automation. Autonomous driving offers numerous benefits such as reduced congestion and emissions, enhanced safety, and economic advantages.

However, its future requires overcoming challenges like legal regulations, social acceptance, and technical refinements. Increased collaboration between stakeholders is outlined as a key factor for achieving full autonomous driving potential.

As a part of important topics of C-ITS, Ireland is involving into the researches and legislation for auto-driving (RSA, Ireland, 2024).

# Overview of Dublin Bus ITS Implementation

The Dublin Bus carried about half of total passengers that taking public transportation services, and peaked its capacity in 2019 for 152.7 million passengers, but dropped due to the pandemic restrictions between 2020 to 2021, and recovered for 69.3% in 2022 (NTA, Ireland, 2024a).

In 2011, the Dublin Bus operated approximately 200,000 kms per day with total 980 buses and 3,685 employees (2,545 drivers) (The World Bank Group, 2011). There was no comparable data found to reflect the increase or decrease in the same term, however we can still infer an increase of approximately 25.6% based on the NTA’s statistic report in 2024, for the total annual operated vehicle-seat-kilometers change during 2010 to 2022, with 1,058 buses in operation (NTA, Ireland, 2024a).

Despite the Dublin Bus pioneered to incorporate new technologies into their system known as AVL as early as 1970’s, the old analogy system was facing retirement and inefficient in coping with expanding transportation needs. For example, the system was still using voice radio communication in dispatching, and seriously incapable to provide real-time information.

The new system was designed to incorporate digital technologies which was regarded as an Intelligent Transport System (ITS), and the new system started went into live after 1-2 years preparations and construction, weaponed with the AVL and centralized control, RTPI (Real-time Passenger Information), and integrated ticketing system.

## Electronic Ticket Machines (ETM)

Dublin Bus’s ETM system was initiated from 1989 and supported by the Magnetic Card Validators since 1990s, until its phase-out in 2005 by the newer generation machines equipped with wireless connectivity and higher memory/processing power.

Although a lot of issues existing in nowadays standard, such as cash recognition errors and high management overhead, the system did its job in improving the ticketing efficiency and reduced driver’s workload, as well as served a workable front-end to the back-office control by providing ticketing data.

Rather to say the ETM system was suddenly retired, a better description for its phase out is an evolutionary upgrading, e.g. the Smart Card implemented in 2008, and the Stored Value Card was accepted in 2011, while the underpinned RS485 network was serving for longer term.

## Integrated Ticketing System

The Dublin Bus still maintained their own Fare Collection systems but is compliant with the Integrated Ticketing System responsible by the NTA (National Transport Authority) after it’s launched. The Integrated Ticketing System in Ireland is regarded as a much opened system, now supports not only smart card (TFI Leap Card, (TFI Transport for Ireland, 2024)) , Top-Up App, TaxSaver, and even aim to elevate to higher intelligent level known as NGT (Next Generation Ticketing), open to more payment forms such as credit card, contactless card, and mobile payments (NTA, Ireland, 2024b).

The intelligence of the new ticketing system was reflected by the comprehensive pricing schemes, e.g. age discount (NTA, Ireland, 2018), group discount (NTA, Ireland, 2016) or interim promotion (NTA, Ireland, 2015). Such a complexity and flexibility in pricing requires high computational power in designing, reading, and authenticating for versatile scenarios, a leap forward compared to its predecessor.

## Automatic Vehicle Location (AVL)

The Automatic Vehicle Location and Control (AVLC) system, launched in 2009 for Dublin Bus, enhances bus tracking and operational control. It uses GPS and Odometer data for real-time monitoring every 20 seconds, and includes features for route efficiency and centralized management. Safety protocols prevent drivers from seeing delays, avoiding risky catch-up attempts. Implementation involved meticulous data preparation, including GPS detailing for all 5,000 bus stops and comprehensive journey pattern definitions. The system, supplied by INIT, incorporates a bus radio, driver’s console, on-board computer, and focuses on improving safety and operational efficiency.

## Control Centre operations

The AVLC cluster of back-office systems consists of the AVLC software, the Scheduling system, the Bus-Stop Database, and maintained connections to the front end Radio System, Fare Collection and Ticketing systems, and proposed SMS information system (The World Bank Group, 2011). The AVLC software serves as the central control component, receiving inputs from the other systems and providing feeds to traveller information systems. These systems include Dublin City Council's RTPI and TLP, NTA's Journey Planner, and Dublin Bus' own site.

The control centre also serves as the centralized Operations Management depot which is operated manually for bus dispatching and route overviewing (The World Bank Group, 2011).

On city and national level, the NTA is responsible for public transport services statistics, analysing, planning, and optimizations (NTA, Ireland, 2024d). There’s no information available for the interactive process between the operators and authorities, and with which kind of technologies are currently employed.

## Real-Time Passenger Information (RTPI)

The RTPI system's oversight is the National Transport Authority's (NTA) responsibility, with implementation assigned to Dublin City Council (DCC) for infrastructure authority and to address competition concerns. DCC hosts the RTPI server, manages at-stop displays, and handles mapping, relying on data from Dublin Bus. Despite the lack of a formal agreement, collaboration is effective. The system currently supports real-time information for 1,000 stops, with plans to expand to all 5,000 stops, as of the data in 2011 (The World Bank Group, 2011).

Today, the NTA's TISS, joined with previous RTPI system and the National Journey Planner, delivers dynamic public transport information via apps, websites, and on-street displays, updated regularly for service accuracy (NTA, Ireland, 2024e). Information channels include stop-specific timetables, electronic displays at key locations, and TFI mobile apps. Integration with third-party platforms like Google Maps is enhanced by GTFS-R feeds, improving data accessibility. RTPI displays offer live departure countdowns and service disruption alerts, ensuring comprehensive, real-time passenger information.

## CCTV Integration and Other Developments

Dublin Bus initially did not utilize the CCTV feeds from the Dublin City Council Traffic Control Centre in the AVLC Control Centre. They believed that having access to these CCTV images might distract dispatchers from focusing on the information provided by the AVLC system, which they considered important for proactive decision-making. However, they recognized the value of the CCTV coverage in dealing with disruptions and difficult circumstances. Dublin Bus is now interested in making these CCTV feeds available to the Dispatchers at the AVLC Control Centre, and it seems that funding issues for integration, including the provision of a fibre optic link, have been resolved, and the link is proceeding (The World Bank Group, 2011).

Due to the visit region limitation set by the Dublin Bus’s website (Dublin Bus, 2024), there’s no more its up to date information available for further evaluation of its CCTV system. However, some blogs (Fiona Gartland, 2011) (Keith Byrne, 2018) did provide implications that the CCTV system are only internally available instead of open to public or third parties applications.

## Traffic Signal Priority (TSP)

Traffic Signal Priority (TSP) is a transportation management strategy designed to improve the efficiency and reliability of public transportation systems, particularly buses. TSP involves the use of technology to grant priority to buses at signalized intersections, allowing them to move more swiftly through traffic. This technology may include GPS-based systems that communicate with traffic signals to extend green lights or shorten red lights for approaching buses.

Traffic Signal Priority (TSP) refers to a transportation management system that aims to alleviate urban congestion and reduce commuter delays by providing priority treatment to transit buses at signalized intersections (Ahmed & Hawas, 2015). TSP systems operate in real-time, addressing both recurrent and non-recurrent congestion, with the potential to enhance their effectiveness through incident detection and response strategies, and could be effective under specific traffic conditions, including moderate-to-heavy bus volumes, minimal interference from turning movements, moderate cross street traffic ratios, far-side bus stops, and coordinated signals during peak traffic hours.

However, it may lead to delays for non-priority traffic, which transit agencies strive to minimize through preferential treatments to signal control systems. The integration of TSP with incident detection and management capabilities in Advanced Traffic Control Systems (ATCSs) remains an area of limited exploration in existing research and practice.

In Dublin, TSP was not implemented ahead of 2011 (The World Bank Group, 2011) but a Quality Bus Corridors (QBC) gave public bus with traffic priority to bus users, and the result has been positive (McDonnell et al., 2006) (Caulfield & O’Mahony, 2004) in improving the quality of public transportation to attract more users from using private cars. The QBC was replaced by the BusConnects (NTA, Ireland, 2024c) project in 2017 and will further escalated (Department of Transport, 2022).

BusConnects is not specifically designed to enable the Traffic Signal Priority, but as it treats the public bus with priority aim to solve the problem of congestion under the prediction of increasing population. Certain traffic signals were already, or planed to, given to public buses for priority (BusConnects, 2018). By improve the capacity of the public bus network, it has reached an effective inclination from the passenger to choose public buses, therefore should be regarded as an implementation of the TSP system.

# Challenges and Benefits

Dublin is one of the pioneers of implementing the Intelligent Transport System (ITS), especially with the initiation from the Dublin Bus, to meet the challenges maintaining efficient service operations. One major issue was the reliance on individual depots for dispatching, resulting in inefficient coordination and increased complexity. The lack of real-time location information following the closure of the original Automatic Vehicle Monitoring (AVM) system in 1994 forced dispatchers to depend on drivers for vehicle locations, leading to reactive decision making and substantial guesswork. This was in addition to the issue of bus bunching, detrimental service reliability.

The implementation of earlier phase ITS helped Dublin Bus in improving the operational efficiency, internal communication, and customer satisfaction. For example, by centralizing all informative data into a single Control Centre, route control is significantly improved. Bus journey times have been reduced, while service reliability and consistency have been enhanced. This approach has also tackled the problem of bus bunching and uneven headway, resulting in better fleet utilization. ITS also has considerably improved the passenger experience, with features like real-time passenger information, advanced ticketing systems, and route planning applications.

However, due to the continuous expansion of the system, challenges have shifted towards the complexity of utilizing and continual updating and maintenance. The achievement of efficient control also depends on the skillful handling by dispatchers in the new setup.

The efficiency of the system is also subject to further upgrades despite the improvements. The operators (Dublin Bus, Luas and Go Ahead) was recently fined for over €5 million for delays, cancellations, and under routing (Ferghal Blaney, 2022) (Emma Nevin, 2022), which implied the great improvement space to an acceptable level.

The Dublin Bus is also facing new issues from changing environment and social challenges, and driver shortage was the most acute one (Neil Fetherstonhaugh, 202 C.E.) (Olivia Kelly, 2022) (Sam Tranum, 2023a) and unfriendly driver monitoring has exacerbated the situation (Sam Tranum, 2023b). As a common critical issues worldwide, the shortage of bus drivers indicates the future direction of the ITS to **higher levels**, by escalating and integrating technologies such as Traffic Signal Priority, Artificial Intelligence, Autonomous Driving, C-ITS, and eventually Smart City, with the joint effort not only by the efforts from public transportation operators alone.

# Comparison with International Standards

There’s no explicit details about the implementation of International Standards for the Intelligent Transport System (ITS) in Dublin Bus prior to 2011.

However, as a member of the European Union Cooperative-Intelligent Transport Systems, Ireland has effort on sticking to major C-ITS standards (*ISO, IEEE, EN, CEN, ETSI*), and specifications (*SAE*), which could affect the infrastructure of ITS connect to Dublin Bus’s sub system.

# Case Studies and Examples

As previously studied, the future C-ITS is a systematic project and likely to go along the direction of escalating the intelligence level based on improved infrastructure including the 5G/6G. It is hard to give out a clear boundary between current ITS and C-ITS, as each part of the system is dynamically evolving intrinsically, and pushing each other forward.

There are already enriched cases of practices and experiments for applying cutting edge techniques around the world at different levels.

For example, Machine Learning is also a hot researching topic and ad hoc research are found. For example, in New Zealand, the Robinsight use EROAD data to predict and prevent crushes for the heavy vehicles and effectively reduced the chance of crushes (Gareth Robins, 2022). And using ML for traffic data collection (Gillani & Niaz, 2023) and AVL/GPS data for accurate bus journey prediction (Taparia & Brady, 2021) in Ireland. Some research and experiments were implemented at broader level, e.g., the safety Management plan for Ankara city in Turkey, speed and flow rate forecasting and improvement in Berlin, taxi demand forecast in New York City (Abduljabbar et al., 2019).

ITS especially kernelled with the AI/ML could even become a national strategy and aim to global competitiveness to lead the technological development. For example, the IOT, ITS and Smart City have been listed in the nation’s Five-Year Plan in China (Zhu & Liu, 2015); it is even expected the autonomous driving will be matured since 2022 and commercialized in short term, with the first two unmanned taxi operators have been approved for experimental operation in Beijing (China Daily, 2022).

# Future Directions and Recommendations

To further enhance its Intelligent Transport System, Dublin Bus should collaborate with stakeholders including governmental bodies, peer operators, infrastructure developers, and international ITS standard bodies. These alliances are crucial to address infrastructural, regulatory, and technological challenges, and to ensure alignment with global standards. As a path to improve efficiency and future readiness, Dublin Bus requires more than internal strategizing - a cooperative plan with multi-lateral partners is paramount.

To further enhance the ITS framework at Dublin Bus, the following actionable recommendations could be considered:

* Cooperative Intelligent Transport Systems (C-ITS):

Dublin Bus can incorporate C-ITS to facilitate seamless communication between vehicles, infrastructure, and other traffic participants. This can reduce traffic congestion, improve route efficiency, and promote road safety.

* AI and ML Technologies:

AI and ML can be strategically deployed in areas like predictive maintenance, where these technologies can predict possible system failures before they happen, thus, reducing downtime. Through demand forecasting, AI and ML could analyse historical data patterns to predict passenger volume, helping in efficient scheduling and resource allocation. Additionally, real-time traffic management can utilize AI to analyse current traffic patterns and adjust routes dynamically. Personalized passenger information can also be enhanced by predicting individual passenger's preferred routes and updating them with customized, real-time information.

* Autonomous Driving:

As the result of numerous experiments around the world shows, the implementation of autonomous driving holds revolutionary potential in public transport sector, especially to alleviate the driver shortage issue. By deploying practical level self-driving buses, it is also possible to improve passengers’ satisfaction, e.g. by reducing the interval, or increasing bus routes, which will substantially change the passenger’s behaviour in selection travelling tools.

# Challenges and Considerations

There are certain challenges and considerations ahead to escalate the current ITS with AI and ML technologies.

First of all, the financial concern is critical to Dublin Bus as abiding to the obligations of PSO has limited its power of free pricing, while the operational cost is continuously increasing. In the situation of failure in reach certain operational targets, they are endangered for losing financial subsidies or even be fined. This has curbed the incentive of continuously investing into the system upgrading and applying cutting edge technologies, and eventually set them into a deadlock of incapable to achieve higher service quality.

Second, the ITS is no longer an isolated project operate by a single company. It has become a cooperative and integrated system which requires join efforts from multiple stakeholders, sometime even bide to the standards or regulations at European Union level. Under such a scope, any action is subject to external limitations and potentially lower down the speed of implementing new technologies.

The safety risks are also concerned for employing new technologies such as autonomous driving as human are still giving low tolerance to the potential accidents resulting from technological errors even if the AI technologies have out-performed human driving. This might take longer time before the new technology is accepted by this world and more efforts of improving the reliability is needed.

Lastly, the privacy concerns might also be critical as there are debates around whether or how to collect and use the public data for commercial purpose. The cases of applying CCTV (Keith Byrne, 2018) (Fiona Gartland, 2011) for bus monitoring, reflecting the extreme concern of expose the data to external users.

Despite these challenges and concerns, the application of AI technologies has become an inevitable trend since 2023 especially in a environment where countries are competing for leadership in this direction.

# Recommendations for AI and ML Integration

Integrating AI and ML into Dublin Bus's ITS services have vast potential, but successful implementation will depend on careful planning, taking into account the cooperative requirements with external stakeholders identified in this case study. With the pre-assumption of merging into the C-ITS framework, a recommendation is given to integrate the AI and ML into its current ITS system:

* Enhanced predictive techniques

AI and ML can significantly improve the accuracy of traffic prediction models, helping to anticipate congestion and delays.

* Real-time decision-making

AI can enable real-time decisions based on an analysis of traffic data and commuter travel patterns, reducing travel times, and enhancing passenger satisfaction. It shall also be an effective method by optimizing the individual route without increasing the total number of operated routes.

* Personalised services

Machine learning algorithms can analyse passenger data to provide personalised travel recommendations, acting as a powerful tool to enhance the passenger experience, increase the use of public transport, and promote sustainable urban mobility.

* Advanced safety measures

AI and ML can help implement advanced safety measures such as collision-avoidance systems, real-time vehicle diagnostics, and proactive maintenance scheduling.

* Intelligent driver assistants

Using AI based driving assistants has potential to improve the efficiency of human driver, while alleviating the pressure of being continuously monitored.

* Experiments for unmanned driving

In certain area with conditions enable potential unmanned bus driving, it is suggested experiments shall be undertaken to prepare future autonomous bus operation.

# Conclusion

The case study on the Intelligent Transportation System (ITS) for Dublin Bus provides vital insights into the potential for technology to revolutionize transportation networks. Advancements such as real-time information, telematics, and machine learning have been shown to significantly improve operational efficiency, passenger satisfaction, and safety measures.

A critical finding was the potential of Artificial Intelligence (AI) and Machine Learning (ML) when integrated into ITS. By utilizing these technologies, Dublin Bus can improve tracking functionality, enable real-time decision-making based on traffic data, provide personalized services to passengers, and advance safety measures. However, the implementation of these advanced technologies also comes with challenges, such as concerns for data privacy and significant initial investment.

The success of Dublin Bus's ITS underscores the vital role that data and technology can play in advancing public transportation services. The system's ability to predict and respond to traffic conditions, breakdowns, and other challenges greatly enhances passenger experience and facilitates more effective and sustainable resource management. Moreover, it exemplifies how urban areas can employ technology to improve public services and promote sustainable lifestyles.

The application of AI and ML into ITS is not just an opportunity for Dublin Bus—it offers an exciting avenue for future research and development in the sector at large. By persistently exploring, adopting, and integrating advanced technologies, public transport systems globally can significantly minimize operational inefficiencies and maximize service delivery, leading to greener, smarter, and more connected cities.

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# Chart 1. PRISMA chart of research resources

Eligibility

Excluded due to no/low relevancy of creditability  
(n = 2 )

Full-text articles excluded, with reasons  
(n = 0 )

Partial assessed for eligibility  
(n = 42 )

Full-text articles assessed for eligibility  
(n = 0 )

Additional records identified through other sources  
(n = 0 )

Records identified through database searching  
(n = 103 )

Included

Identification

Screening

Records after duplicates removed  
(n = 102 )

Studies included in qualitative synthesis  
(n = 42 )

Studies included in quantitative synthesis (meta-analysis)  
(n =0 )

Records screened  
(n = 100 )