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UNIVERSITY OF LEEDS

MSc Sustainable Cities

Smart Transportation and Signalisation in Manchester: Evaluating the Effectiveness of Smart Junctions for Sustainable Urban Mobility

Hande Avtan

FOEV5007: MSc Sustainable Cities
Faculty of Earth and Environment
Supervisor: Dr. David Pierce
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My heartfelt thanks go to Dr. David Pierce for his continued support and patience. I would also like to thank my family and friends for their support. I am grateful to TfGM officials for sharing their data. Finally, I would like to thank the Ministry of National Education of the Republic of Türkiye for enabling me to receive this education and write this dissertation.

KEY WORDS: Traffic, smart junctions, smart transportation, signalisation, sustainable, mobility, ITS, smart city, traffic management

ABBREVATIONS

CBA Cost Benefit Analysis

DfT Department for Transport

MOVA Microprocessor Optimized Vehicle Activation

ITS Intelligent Transport Systems

ROI Return on Investment

TfGM Transport for Greater Manchester

UTC Urban Traffic Control

UK United Kingdom

UN United Nations

R&D Research and Development

SCOOT Split Cycle Offset Optimisation Technique

SDG Sustainable Development Goals

TEŞEKKÜR

Sürekli desteği ve sabrı için Dr. David Pierce'e içten teşekkürlerimi sunarım. Ayrıca aileme ve arkadaşlarıma da destekleri için teşekkür ederim. Verilerini paylaştıkları için TfGM yetkililerine minnettarım. Son olarak, bu eğitimi almamı ve bu tezi yazmamı sağlayan Türkiye Cumhuriyeti Milli Eğitim Bakanlığı'na teşekkür ederim.

DISSERTATION SUMMARY IN TURKISH

Artan kentsel nüfus, geleneksel sinyalizasyon sistemlerinin kentsel trafiği yönetmede yetersiz kalmasına neden olmuştur.Bu yetersizlik, seyahat sürelerinin uzaması ve dolayısıyla hava kirliliğinin artması gibi sorunları beraberinde getirmektedir. Bu tez, sürdürülebilir şehirler elde etmek için Manchester örneğini kullanarak akıllı kavşak teknolojisini incelemek amacıyla yazılmıştır. Akıllı şehirlerin ne olduğu ve sürdürülebilirlikle olan bağlantıları gibi literatürde yaygın olarak tartışılan konulara dayanarak, araştırma Manchester bağlamında akıllı kavşaklara odaklanacak şekilde daraltılmıştır. Bu bağlamda, Manchester'da saha ziyaretleri gerçekleştirilmiş ve sonuçlara ulaşmak için yetkililerle görüşmeler yapılmıştır. Araştırmada izlenen bir diğer metodoloji ise CBA (Maliyet-Fayda Analizi) olarak belirlenmiştir. Akıllı kavşak uygulamasının seyahat süresi ve emisyon seviyeleri üzerindeki etkileri parasal terimlerle açıklanmıştır. Manchester genelinde yapılan hesaplamalara göre, projenin öngörülen on yıllık süre içinde kendini on üç kattan fazla amorti edeceği sonucuna varılmıştır. Bu sonuç, bu teknolojinin trafik hacmi yüksek kavşaklarda karlı bir yatırım olduğunu göstermektedir. Mevcut bir kavşağa akıllı kavşak teknolojisinin entegrasyonunu inceleyen bu makale, çeşitli perspektiflerden literatüre katkı sağlamayı amaçlamaktadır.

ABSTRACT

The increasing urban population has led to the inadequacy of traditional signalling systems in managing urban traffic. This inadequacy brings problems such as longer travel times and, consequently, increased air pollution. This dissertation was written to examine smart junction technology using the example of Manchester to achieve sustainable cities. Building on widely discussed topics in the literature, such as what smart cities are and their connection to sustainability, the research has been narrowed down to focus on smart junctions in the context of Manchester. In this context, field visits were conducted in Manchester, and interviews were conducted with officials to reach conclusions. Another methodology followed in the research was determined as CBA (Cost-Benefit Analysis). The effects of the smart junction application on travel time and emission levels have been explained in monetary terms. According to calculations made across Manchester, it has been concluded that the project will pay for itself more than thirteen times over within the projected ten-year period. This result shows that this technology is a profitable investment in junctions with high traffic volume. This article, which examines the integration of intelligent intersection technology into an existing, aims to contribute to the literature from various perspectives.

1. Introduction

By 2050, 68% of the world's population is expected to live in cities (UN, 2015). As the population grows and economies develop, the number and utilisation rate of motor vehicles are expected to rise, which will likely increase energy consumption due to inefficient traffic management. Higher vehicle ownership is predicted to lead to greater greenhouse gas emissions, and the extra time lost in traffic is likely to cause significant economic losses (Lee and Chiu, 2020). The increase in the current density of cities brings many problems, such as the inadequacy of the infrastructure to meet the needs of the city and the increase in traffic density. When considering an increase in consumption due to a growing population, it becomes increasingly important for planners and stakeholders to collaborate harmoniously.

Goal 11 of the UN's SDGs underlines the necessity to create sustainable cities and communities for supporting resilient and inclusive living conditions (UN, 2018). As an outcome of this goal, a concept called 'smart cities' has gained importance. A city is considered smart when investments in communication infrastructure promote sustainable economic growth and prosperity (Caragliu et al., 2011).

Various cities, including Amsterdam, Singapore, Stockholm, and Seoul, are listed as sustainable urban transportation leaders (McKinsey, 2018). By using integrated mobility platforms, real-time public transport data, and congestion pricing, they invested a vast amount of money on active transport infrastructure. With the help of integrating various technologies and innovative urban planning, these cities are examples of the effectiveness of smart mobility in long-term sustainability goals such as increasing accessibility and reducing emissions (OECD, 2018).

Air pollution, which is one of the major side effects of traffic, is becoming an increasingly significant problem for the UK. The concentration of NO_2, an air pollution indicator and one of the main causes of pollution-related deaths, has been calculated as 34 $\mu g/m^3$ in the city of Manchester, which is close to the annual mean limit value of 40 $\mu g/m^3$ set by the European Union to protect human health (Taleghani et al., 2020). The selection of Manchester as the case study for this article has been influenced by the ongoing efforts in the city aimed at reducing this high level.

It is important to develop innovative solutions to address accessibility and emission issues. Currently, increasing urbanisation and, consequently, an increase in traffic have made intelligent transport systems (ITS) more popular. ITS not only integrates various transport modes by improving traffic flow but also delivers real-time information to users to navigate their travel decisions (Eryilmaz et al., 2014). Manchester was selected as the case study for the examination of ITS applications in this article. It is expected that the findings obtained from this evaluation will contribute to a broader understanding of sustainable urban mobility strategies.

This study consists of six chapters. In this opening chapter, the focus is on explaining the topic, aims, and relevance of the research. In chapter two, national and international literature on smart transportation and junctions' applications are analysed. Chapter 3 will introduce smart transportation technologies in Manchester as a case study. Mixed methodologies were preferred as the methodology for this study; face-to-face and semi-structured interviews were conducted with TfGM officials. Chapter 4 will present the results of these analyses. The CBA analysis will also be compared at different threshold values, and finally, sensitivity analysis will be discussed. In the fifth section, the research objectives will be compared with the results, and a discussion will be conducted, highlighting the lessons that can be learned from Manchester. In the final section, Chapter 6, the entire study will be summarised briefly, and policy recommendations will be presented.

Although smart transportation is a very popular concept, there are significant gaps in the literature regarding the benefits of smart junctions. The purpose of choosing a mixed methodology for this article is to develop a method consistent with the objectives and to conduct holistic research on sustainable urban mobility.

1.1. Research Aims and Objectives

The overall aim of this dissertation is to review the benefits of smart junctions by using mixed methodologies. The present research explores, for the first time, CBA calculation for smart junction in a UK city. Objectives of this study can be listed as:

- To conduct a comprehensive literature review on different aspects of smart transportation.
- To analyse how smart junctions are implemented within Manchester's existing transport infrastructure.
- To use cost–benefit and sensitivity analyses in assessing the scalability and economic feasibility of Manchester's Smart Junction project.
- To examine the benefits, requirements, and integration challenges of smart junctions based on TfGM data and stakeholder insights.
- To provide evidence-based recommendations for policymakers, transport authorities, and urban planners on optimising the deployment of smart junctions for sustainable mobility.

1.2. Research Questions

- What are the steps to implement smart junctions in an existing city to improve transportation?
- In what ways do intelligent transportation technologies support sustainable transportation?
- Considering the CBA analyses, how profitable is the smart signalisation investment?
- What are TfGM officials' ideas about smart junctions and in general smart transportation?

2. Literature Review

The following section aims to provide a conceptual framework for the research. The literature review will cover sustainable transport, smart cities, intelligent transport, ITS, intelligent transport applications in Manchester, traffic models, CBA calculations for intelligent signalling, and the impact of intelligent transport. This section will be concluded by highlighting the literature explanations obtained from all these examinations.

2.1. Sustainable Transportation

To establish a conceptual foundation, it is first necessary to examine the reflections of the concept of sustainability in the academic literature. Sustainable transportation has long been an engaging concept. Indeed, Newman and Kenworthy (1999), who argued that there is an inverse relationship between urban density and energy consumption related to transportation, strikingly demonstrated in their article published more than twenty years ago that private vehicle ownership constitutes a major obstacle to sustainable transportation. Several studies have explored how private car ownership can act as a barrier to achieving sustainable transportation (Etukudoh et al., 2024; Sharma et al., 2023). For a mode of transport to be classified as sustainable, it must meet three main criteria: planning and policy, background, and technical and infrastructure factors (see Figure 2.1.).

As shown in Figure 2.1, to achieve all three factors, requirements in many areas, from economics to politics, must be met. These sustainability principles are important for a better understanding of smart cities.

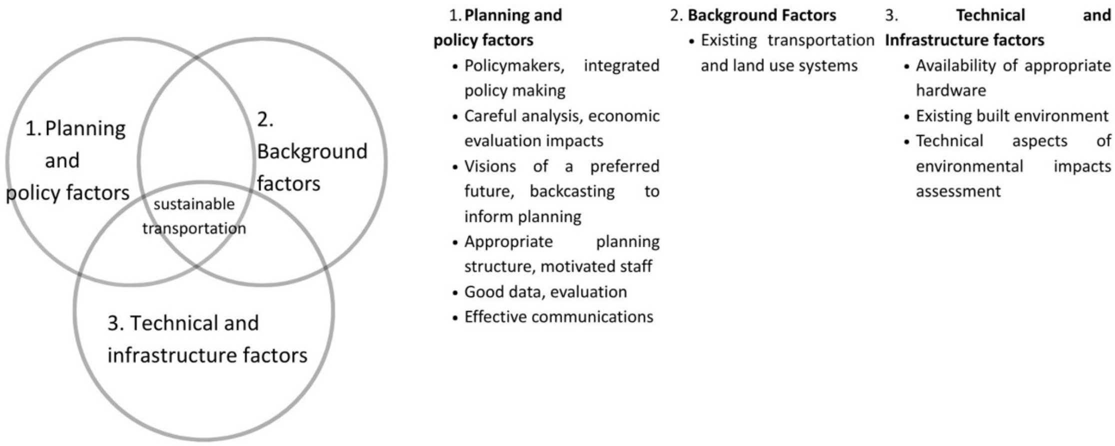

Figure 2.1. A simplified version of the diagram in which Schiller (2010) defines sustainable transportation under three main categories, adapted to the thesis topic

2.2. Smart Cities

The term smart cities defined by British Standard Institute as "the effective integration of physical, digital, and human systems in the built environment to deliver a sustainable, prosperous, and inclusive future for its citizen" (BSI, 2014). Kuntsman and Xin (2024) underlines in their book about smart cities that smartness, ecology and sustainability terms are often interrelated. The UN (2015) highlights the importance of information and communication technologies, stating that they are crucial for modernising infrastructure, protecting the environment, and improving the efficient use of resources. Krivý (2018) argues that top-down planning hinders the individual development of city life, while Greenfield (2006) has raised concerns about data surveillance and monitoring risks. Despite the abundant literature on smart city strategies (Batty et al., 2012; Kenworthy, 2019), smart city policies in Manchester are, unfortunately, a poorly studied area.

Bibri (2021) states in his article that smart cities use big data, Internet of Things (IoT), Information and Communication Technologies (ICT) to gain and collect information about their citizens. However, conscious use of these technologies can only reveal their true potential (Batty, 2018). The European Commission (2018) highlights this transition towards smart cities requires reimagined traditional public services through digital innovation, thus making existing cities more liveable and sustainable. According to the International Standards Institute, maximum efficiency of smart cities is targeted through numerous technologies, including IoT, Geographic Information Systems (GIS), cloud technology, and ICT (ISO, 2015). Since mobility is one of the most critical dimensions of smart cities, the next section focuses on smart transportation.

2.3. Smart Transportation

Smart transportation is the integration of innovative digital technologies into transportation networks with the aim of increasing user satisfaction, reducing carbon emissions, and improving efficiency (Vujadinovic et al., 2024). The most important components of smart transportation systems include real-time data collection, smart infrastructure, smart ticketing, autonomous mobility solutions, and multi-modal travel planning platforms (Wu et al., 2025).

Artificial intelligence (AI) technologies play a key role to develop smart transportation technologies. In managing traffic congestion, optimising routes, forecasting travel demand, and enabling autonomous vehicle development AI gains more importance day by day (Wu et al., 2025). These developments are not only compatible with decarbonisation goals but also shaping more flexible, responsive, and efficient urban transport systems (Chang et al., 2020). A different study in the literature has found that using deep learning and machine learning algorithms can help predict urban transport demand more accurately and quickly in public transport and urban mobility applications (Wang et al., 2022).

Large technology companies such as IBM, Cisco, and Oracle have become key players in the digital transformation of cities by providing tools such as data analytics, sensor-based infrastructure, and artificial intelligence-enabled systems (Cugurullo, 2021). Beyond that, they also hold an influential role in shaping smart transportation, managing energy more efficiently, and enhancing urban security networks (Townsend, 2014).

Acheampong and colleagues (2023) focused on autonomous vehicles (AVs) in their study, examining in detail the impact of this technology on traffic safety, efficiency, and sustainability. As noted by Kumar and colleagues (2024), artificial intelligence technologies may contribute to reducing traffic congestion issues. In its report examining a case about AI's impact on transportation, Business Insider provided information about Urban Freight, which could be one of transportation's applications. According to the news article, the company's CEO, Lior Ron, demonstrated that with the development of AI-based algorithms, empty journeys were reduced by 10–15%. To achieve this, hundreds of variables such as weather, road, traffic conditions, etc., are analysed with AI (Villano, 2025). While AI enables cities to become more flexible and sustainable, it also leads to a decrease in human intervention in the decision-making mechanism; the sociological and political transformations that such results may create are subjects of ethical debate (Cugurullo, 2021). ITS represents one of the most widely adopted forms of smart transport and is therefore discussed in the following section.

2.4. ITS

Reaching safe, efficient, effective transport networks are primary goals of Intelligent transportation systems (ITS) (Xiong et al., 2012). ITS uses contemporary technologies such as communication infrastructure, innovative computing techniques, autonomous vehicles, electric vehicles, and intelligent traffic signals for transportation safety and mobility (Khazraeian and Hadi, 2019). ITS uses technology to provide decision support systems for all stages of transportation, including planning, traffic flow, parking management, safety, and environmental impacts, thereby facilitating the effective management of these operations (Hatcher, 2014). In accordance with Directive 2010/40/EU, four priority areas have been identified for ITS (European Union, 2010, Annex I):

a. Optimal use of road, traffic and travel data related to road transport.

b. Continuity of ITS services in traffic and freight management.

c. ITS applications for road safety and security.

d. Interconnection between vehicles and transport infrastructure. Sreelatha and Roopalakshmi (2021) underlines that there are various components of ITS technologies some of them can be listed as: Advanced Traffic Information System (ATIS), Emergency Rescue System (ERS), Freight Management System (FMS), Electronic Public Transport System (EPTS), Advanced Public Transport System (APTS), Advanced Vehicle Control System (AVCS), and Advanced Traffic Management System (ATMS).

2.5. Application of Smart Transport Policies in Manchester

There are many interventions in the UK in terms of smart transportation (Chen & Silva, 2021). In the report titled as Decarbonising Transport: A Better, Greener Britain, the widespread adoption of electric vehicles, the development of pedestrian paths, and the dissemination of user-oriented solutions are among the primary targeted changes (Department for Transport, 2021). In the Future of Mobility: Urban Strategy report, autonomous vehicles, shared transportation, micro-mobility solutions, and integrated transport are highlighted as key focus points of smart strategies (Department for Transport, 2019). Another report titled as UK Intelligent Transport System Progress Report underlines the importance of public–private sector cooperation in ensuring passenger safety through real-time data management (European Commission, 2022). The Transport Decarbonisation Plan sets an ambitious goal of reducing carbon emissions in the UK transport sector to zero and outlines the efforts to be made on this path (Department for Transport, 2021).

Combined Authorities (CA) have been established in England to accelerate economic development and improve transport infrastructure outside London (Lorencka & Obrebska, 2018). Greater Manchester Combined Authority was established in 2022 and is the first CA (Sandford, 2019).
TfGM, the executive authority responsible for transport, was established to supervise and coordinate transport networks in the region (TfGM, 2021). Applications such as the Bus Service Bill, which support integrated mobility, propose bus franchising systems to promote a more coherent transport model (Department for Transport, 2019). The currently used smart ticketing technology not only encourages the use of public transport but also supports efforts to reduce private car ownership.

When conducting a literature review on projects carried out through public-private partnerships in Manchester, various initiatives stand out. Recent funding provided through the Triangulum project (University of Manchester, 2017a) and the City Verve initiative (University of Manchester, 2017b) offers Manchester additional opportunities for development in this area. The Triangulum Project, a €25 million investment realised through the partnership of Siemens, Clicks and Links, and Manchester Metropolitan University, aims to improve sustainability along the Oxford Road corridor (University of Manchester, 2017a).

The City Verve Project, launched to implement technologies suitable for the application of IoT in transportation, was supported by the UK Government with a £10 million fund in 2015 (University of Manchester, 2017b). As part of this project, partnerships were also established with another initiative named InnovateUK. By them the public transport infrastructure along the Manchester Corridor was transformed by installing sensor-equipped and digitally displayed “talking bus stops” that inform drivers about passengers waiting at the stops (University of Manchester, 2017b).

Additional support is provided by the Manchester Growth Company (MGC), which aims to eliminate barriers to data sharing by bringing together partners across the transport and technology sectors (TfGM,2021). In terms of traffic flow management, TfGM conducts active monitoring using over one hundred security cameras and 5G technology throughout the city (VivaCity Labs, 2022). Complementing these efforts, the CitySwift system, which uses artificial intelligence to prevent traffic delays, has been described by the project manager as the most important traffic innovation of the past forty years (Deslandes, 2024). Despite the availability of numerous sources concerning existing and ongoing projects, the literature review revealed an absence of articles addressing the specific outcomes of smart transport technologies in Greater Manchester, as well as potential ethical discussions related to them; this constitutes a notable gap in the literature.

2.6. Models for Traffic Management

Miller (1963) in his groundbreaking research proposed a signal control technique for dynamically adjusting signal duration. According to Miller's model principle, researchers have introduced several techniques, including the Split Cycle Offset Optimisation Technique (SCOOT). Walmsley (1982) in his article explaining the integration of SCOOT, predicted that this then-new technology could provide a smooth transition due to its easy integration with the existing urban traffic control technology. These other control systems include the Sydney Coordinated Adaptive Traffic System (SCATS), which is widely used in Australia; Urban Traffic Optimization by Integrated Automation (UTOPIA), implemented in Italy since 1985; and the InSync Adaptive system, developed by a transportation-focused company called Rhythm Engineering and widely adopted in the United States (Studer et al., 2015). Ketabdari (2013) underlined in his study about SCOOT that this technology decreased journey time approximately 8% and delays 17% in Toronto. Despite more than 30 years having passed since the introduction and spread of this technology, SCOOT has been shown to be the most efficient among other dynamic signal control systems such as SCATS, UTOPIA, and INSYNC in urban locales (Studer et al., 2015). Building on these traffic models, cost–benefit analyses provide a systematic way to assess their efficiency, as discussed next.

2.7. CBA Calculation for Smart Signalisation

CBA is a methodology that enables the objective comparison of benefits and costs over a specific time (Anderson et al., 2015). This quantitative value enables decision-makers in prioritising and making decisions on projects. Essentially, this value, obtained by comparing benefits to costs, is frequently used in transport related projects (Nellthorp et al., 2018).

Differences have been observed across countries in the cost-benefit analysis (CBA) calculations of smart signalisation systems worldwide. For example, in a study conducted for Utah using the Automated Traffic Signal Performance Measure (ATSPM), the benefit components were classified as institutional benefits and public benefits. Among the public benefits were various advantages such as the reduction of manual data collection and time saved due to fewer complaint calls, while time saved from repairing broken detectors was classified as an individual benefit. As a result of all these calculations, a BCR of 9.33 was achieved (US Department of Transportation, 2020). In another study using the CBA methodology for smart traffic management systems, different types of technologies used in different cities around the world were examined.

In the study conducted in Hong Kong based on machine learning (ML), the BCR was calculated as 3; in New York, studies conducted through real-time traffic data analysis using artificial intelligence yielded a BCR of 3.5; and in Shanghai, the BCR of a study based on IoT-enabled smart traffic signals was found to be 3.2 (Yusuf, 2024). In Yusuf's (2024) study, the reason why different cities have varying BCR values is the differences in fuel savings, time savings, and emission reductions. Yusuf (2024) underlines the following results in his study:

- In Hong Kong, there is an annual saving of 10 million litres of fuel, a 20% reduction in travel time, and a reduction of 15,000 tonnes of CO_2 emissions.
- In New York, there is a saving of 15 million litres of fuel, a 25% reduction in travel time, and a reduction of 20,000 tonnes of CO_2 emissions.
- In Shanghai, there is a saving of 12 million litres of fuel, a 22% reduction in travel time, and a reduction of 17,000 tonnes of CO_2 emissions. These variations in benefits also result in differences in the BCR calculations.

Chen et al. (2023) compared smart roads with traditional roads in Guangzhou, China. The results of this study revealed that the traditional road had a BCR of 11.83, whereas the smart road achieved a BCR of 13.10.

Previous studies of CBA calculations for smart transportation haven't yet dealt with smart junctions. Therefore, CBA analysis specifically on smart junctions was identified as a gap in the literature.

2.8. Smart Signalisation's Impact

Numerous academic studies have focused on the real-world advantages of smart signalisation. Zhang (2025) achieved real-time optimisation of signal durations using artificial intelligence with deep Q network (DQN) modelling, resulting in a 7% reduction in traffic flow, a 40% reduction in accident rate and a 25% reduction in travel time in Beijing case study. This system in Beijing has improved performance during peak hours and at complex intersections.

On the other hand, Balaban and Öztürk (2022) reported a 35% decrease in average vehicle delay. This improvement led to an annual saving of 78,612 litres of fuel and a reduction of 190 tonnes of CO_2 emissions. Their findings came from a study at a specific intersection in Turkey that switched from a fixed-time system to a fully traffic-actuated signalisation system. When looking at smart transportation projects that have gained attention in the UK, the examples from Leeds and West Berkshire stand out.

A leading project was implemented by Leeds City Council by modifying fixed-time traffic lights, resulting in a 3% reduction in nitrogen dioxide levels (Slow, 2018). Another smart traffic intervention was implemented in the West Berkshire region of the United Kingdom. Compared with the project in Leeds, this study demonstrates over four times greater benefits. In addition, the findings suggest that adjusting traffic signals to stay green during peak hours can lower NO_2 concentrations by as much as 12.45% (Munir et al., 2022).

For numerical comparisons, a study conducted at the micro level in Manhattan and at the macro level in Athens can be highlighted as an example in the literature (Worrawichaipat, 2024). In Manhattan it was observed that the average travel time could be reduced by up to 31% (Worrawichaipat, 2024). In the multi-junction part of this study conducted in Athens, a simulation was created using real-time data. This simulation was found to improve travel time by 22% in light traffic scenarios and by 45% in heavy traffic (Worrawichaipat, 2024).

The findings show that dynamic and adaptive systems significantly improve both traffic efficiency and environmental sustainability. Overall, these numerical results support the view that intelligent signalling reduces traffic delays and associated traffic congestion. There are only a limited number of studies examining the impact of AI on traffic in UK. This stands out as a notable gap in the literature.

2.9. Conclusion

This review of the literature shows that artificial intelligence and intelligent transportation technologies have established a presence in academic research. Technologies such as artificial intelligence and machine learning have been supported by numerous examples worldwide that demonstrate their positive effects, such as reducing carbon emissions and improving user experience. However, there are significant gaps in the existing literature on intelligent intersections. In addition, the concrete outcomes of smart transportation technologies and the ethical discussions related to smart transportation have not been addressed academically. Since no smart intersection applications have been identified in a Manchester-scale city evaluated under the CBA framework, one of the objectives of this study is to contribute to this gap in the literature.

3. Methodology

The methodological approach of this dissertation was established based on the study's objectives. During research mixed methodologies, including semi-structured interviews, cost-benefit analysis, and secondary data analysis were applied. Furthermore, face-to-face interviews with TfGM officials were conducted by doing a field trip to Manchester. During the interviews, names have been anonymised in accordance with ethical principles. Consent has been obtained from the individuals for the information and data they provided to be used in the research.

3.1. Case Study: Manchester Smart Transport Technologies

Between 2015 and 2024 it is estimated that 92.000 people will move to Manchester and the city's population will reach 627.700 (Manchester City Council, 2025). The city has the largest population in the North of England. Over 5.6 million journeys are made in the Greater Manchester area daily (Manchester City Council, 2025). Therefore, the city council has set several ambitious targets for transport. As emphasised in the Manchester strategies, one of the most important visions of the city is to improve public transport, making it fast, affordable, clean and reliable. While aiming to create an urban transport network suitable for everyone, cooperation will be made with companies and universities in Manchester on artificial intelligence applications and green technology. Figure 3.1. illustrates Manchester's location between various important roads. Figure 3.2 highlights that the daily trip count increases annually, which makes smart signalling and traffic control more important.

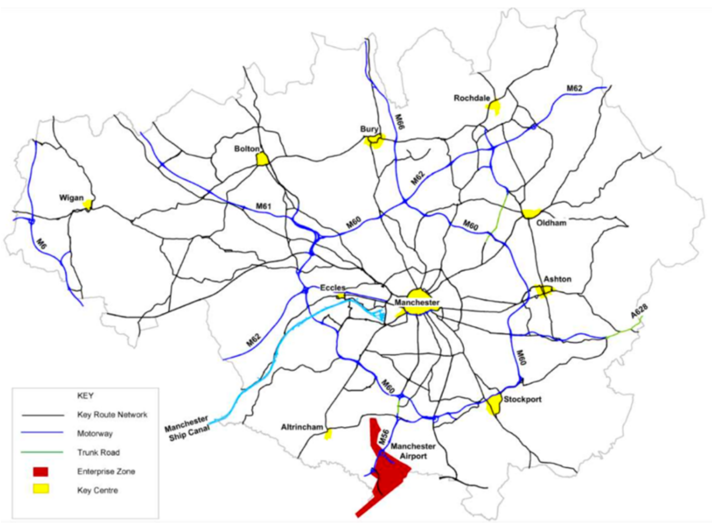

Figure 3.1. Manchester roads map. Retrieved from TfGM, 2021.

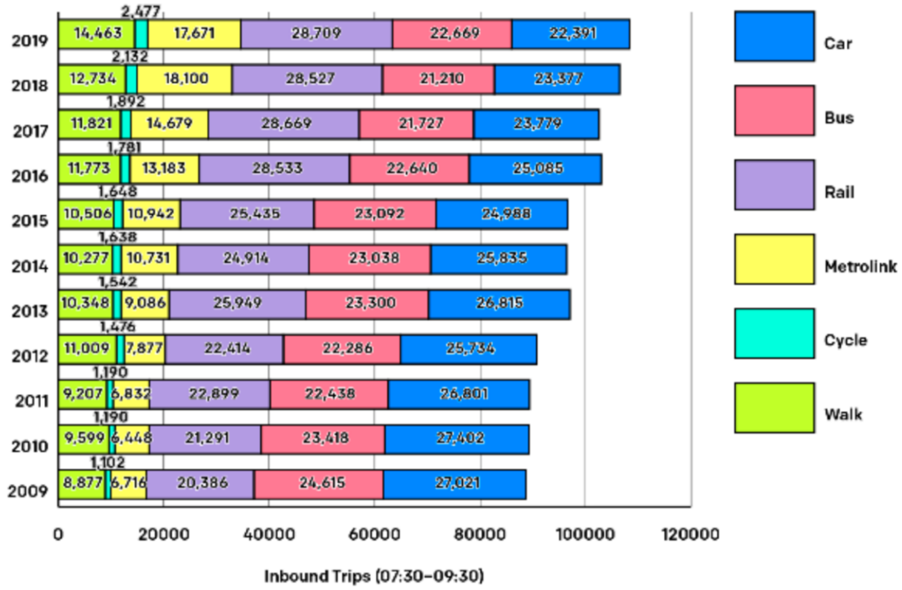

Figure 3.2. Distribution of inbound trips to Manchester city centre by mode of transport during the morning peak period (07:30–09:30) between 2009 and 2019. Retrieved from TfGM SRAD Report 2021, *Transport Statistics 2018–19: Key Centre Monitoring* (Manchester City Council, Salford City Council & TfGM, 2021).

3.2. Semi-Structured Interviews

The first of these methods, semi-structured interviews, typically involves the interviewer asking questions to gather information from the interviewee (Longhurst, 2009). The interviewer uses open-ended and broad questions to allow the interviewee to share their knowledge on the subject in depth without limiting them. For this reason, this method was chosen for the Manchester case study. One of the most confusing issues regarding semi-structured interviews, which are one of the most common and effective qualitative research methods, is how many interviews are sufficient. In a research article published by Galvin (2015), this question was answered by stating that the number of participants depends entirely on the structure of the study. Anonymity and reliability are very important ethical issues in semi-structured interviews (Longhurst, 2009).

The details of the smart transportation project and the challenges encountered in its management were first discussed online, followed by face-to-face meetings at the TfGM office in Manchester. During the face-to-face meetings, field trip to Manchester conducted by me, and observations related to the city were examined on-site. During the online meetings, verbal permission was obtained from both officials to record the discussions, and the meetings were conducted while ensuring the confidentiality of the individuals interviewed. Additionally, during the face-to-face meetings, some questions were asked about intelligent signalling, and the answers were added to the table created for the discussions. The main aims of the face-to-face meetings were to gain information about the projects that TfGM officials work on daily, visit their offices, and discuss the findings of the face-to-face work.

3.3. Secondary Data/Document Analysis

The structure of document analysis allows researchers to be very flexible in their methods and to use not only sources related to theory, research or literature, but also directly collected data (Cavanagh, 1997).

Public documents such as VivaCity Labs Performance Reports and TfGM Transport Strategy Reports were used as data sources. In addition, non-public websites such as VivaCity Dashboards and the TFGMC website, which were accessed by creating accounts with the help of TfGM officials, were used as data sources for analysis.

3.4. Cost Benefit Analysis (CBA)

CBA is a methodology that enables the comparison of many different effects, such as travel time and environmental impact, based on money, which it sees as a common comparison tool (Department for Transport, 2025a). For a CBA analysis, some principles should be followed. These can be listed as (Department for Transport, 2025a):

- The profit of a project can be determined by comparing two different scenarios; one of them is with a scheme, and the other one is without a scheme.
- Values should be expressed in constant prices relative to the ministry's reference year, taking into account the effects of inflation.
- A sensitivity analysis should be conducted to assess uncertainties.

In ITS projects, cost-benefit analysis can be an important parameter during the initial stage of determining whether to implement the project (Stevens, 2004). In his study, Mouter (2015) discussed the challenges that CBA cannot resolve or quantify, referring to them as the inherent incompleteness of CBA studies, the difficulty of predicting impacts, and the persistent challenge of estimating welfare effects. The terms used in CBA analyses can be explained as follows:

Present Value of Benefits (PVB): It is obtained by discounting all the benefits that a project will provide over time to their present value.

Present Value of Costs (PVC): This value is determined by calculating the current prices of all expenses that will be incurred during the project.

Benefit-Cost Ratio (BCR) = PVB ÷ PVC If this ratio exceeds 1 the project is economically advantageous.

Net present value (NPV) = PVB − PVC. A positive NPV means that the project provides sufficient benefits compared to its costs and is worth implementing. (Department for Transport, 2025, p. 16). In order to summarize calculation an appendix is added to this paper.

4. Results

4.1. Interviews with TfGM Officials

Face-to-face and online interviews were conducted with TfGM, which regularly updates and details its digital strategies. These interviews were conducted with two TfGM officials, whose names have been changed to Interviewer 1 and Interviewer 2 to protect their confidentiality.

QUESTION	INTERVIEWEE 1	INTERVIEWEE 2
ROLE	ITS Development Manager. Develops data and technology driven traffic solutions, ITS related planning and business models.	Works on optimizing detection systems and ensuring multii modal transport sustainability.
STAKEHOLDERS	Emphasized collabration with government like Department for Transportation	Emphasized University of Manchester's support.
FUNDING	Emphasized funding is challenging because it is distributed between ten local authorities which have different priorities.	-
ABOUT MEASUREMENT PROCESS	-	Engineer teams vans in the field to calculate air quality in the field.
BARIERS	-	Emphasized it is expensive to implement and sustain this technology
CHALLENGES	-	Lack of suitable metrics
		Difficult to capture secondary benefits
		May be seen experimental to invest
GOVERNANCE STRUCTURE	-	Partnered with VivaCity on the Smart Junctions initiatives, with the funding coming from national government sources, Innovate UK supported the first Smart Junctions project

Table 4.1. A summarized table that shows main themes and outcomes of interviews

First, the projects carried out by the participants and their roles in these projects were discussed. The first interviewee works as a smart transportation systems development manager. The team is researching how to improve the efficiency of the transportation network using data and technology. To this end, they are responsible for developing various solutions, including traffic management systems, data-driven interventions, new business models, and new technologies. The second interviewee works in the ITS team.

The team is working to optimise different types of sensing to ensure sustainable transport. The second interviewee mentioned that there are many modes of transport in Greater Manchester, such as trams, buses, pedestrians, and cyclists, and stated that the team's role is to ensure that transport needs are correctly identified, met in the best possible way, and that junctions and crossings are prioritised.

In response to a question about partnerships with other public or private organisations, the second interviewee mentioned various correlation studies being conducted with the University of Manchester. In these studies, the University of Manchester is investigating the link between air pollution and traffic density while also examining air quality in urban and rural areas of Greater Manchester using air quality sensors. Drawing attention to the intensity of the fieldwork, the second interviewee stated that five engineers assigned by TfGM were working in caravans in the field and measuring air quality in traffic using air detectors inside the caravans.

After mentioning the university collaboration, the topic of partnerships was discussed in more detail. In this context, the first interviewee noted that budget is always important because local authorities are part of a combined authority. According to the first interviewee: "There is a transport agreement for the combined authorities, and we need to submit a proposal for this agreement. However, the idea that such a digital approach can provide these benefits without requiring large-scale infrastructure projects is gaining increasing acceptance, and this is important. Therefore, the national highways have adopted a digital R&D strategy, and the Ministry of Transport is currently working on an integrated national transport strategy."

To conduct the cost-benefit analysis for the Smart Intersection project, the second interviewee clarified the cost-related question through the work carried out on Trinity Way–Great Ducie Street. As shown in Figure 4.1, the location where the sensors are installed intersects with various important points such as Victoria Station, AO Arena, and part of the university campus. The cost of integrating a smart intersection into this single intersection is approximately £60,000. This cost includes 11 sensors, the repair of the poles on which the sensors are mounted, and the software inside the roadside cabinet. Additionally, an annual maintenance and repair cost of £500 per sensor should be considered.

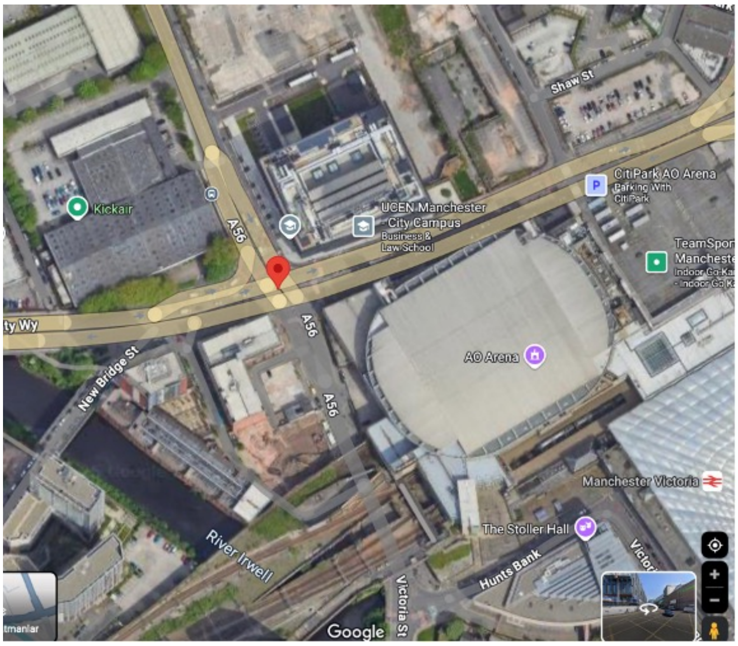

Figure 4.1. Satellite image of smart signalised junction obtained from Google Maps.

Payments made to Greater Manchester are distributed among local authorities based on their investments. Based on the information provided by the first interviewee, who highlighted that there are currently 10 local authorities with differing priorities, Table 4.2. has been prepared regarding local authorities.

In addition, questions were asked about the governing processes of these projects to understand whether they are public–private partnerships (PPP). The second interviewee clarified that the Smart Junctions projects are not PPPs, stating: “We (TfGM) are the transport authority for the region, and we frequently collaborate with local authorities and other partners to deliver projects. We partnered with VivaCity on the Smart Junctions initiatives, with the funding coming from national government sources. Innovate UK supported the first Smart Junctions project, and Smart Junctions 5G was funded by the Department for Digital, Culture, Media and Sport (DCMS). Note: not a public–private partnership (PPP).”

Lastly, since the CBA methodology will be followed, the second interviewee was asked to provide detailed, investment-based information regarding the challenges encountered in this project. Four major challenges were mentioned: “I think the biggest challenge for Smart Junctions is aligning short-term funding with long-term, system-wide benefits that are often hard to quantify. Also:

- High upfront costs vs. delayed, indirect returns like reduced congestion or emissions
- Lack of suitable metrics to justify investment and ongoing maintenance

- Difficulty in capturing secondary benefits (e.g., data insights for planning, safety analytics) in traditional business cases
- Innovations like Smart Junctions may be seen as experimental, making it harder to secure funding without extensive pilots or demonstrable ROI"

As can be seen from the Table 4.2., although each council has important transport-related objectives, it would not be a realistic expectation to assume that they will allocate their different funds to achieve the same priorities.

FUNDS OF GM		
TfGM	Growth Deal	Transforming Cities Fund
National Highways and Network Rail GM Transportation Fund	City Region Sustainable Transport Settlement	
GM COUNCILS	**PRIOTIRIZED AIMS ABOUT TRANSPORTATION**	**SHARED COMMITMENTS ABOUT TRANSPORTATION**
Bolton	To work towards a zero-carbon transport network that is inclusive, safe, resilient, and sustainable; taking a balanced approach, ensuring that all modes of travel are considered and connected, and responsive to technological change and innovation (Bolton,2024).	DELIVER A LOW CARBON LONDON STYLE FULLY INTEGRATED PUBLIC TRANSPORT SYSTEM ACROSS BUS, TRAM AND BIKE.
Bury	By 2040, the borough's towns will be connected to each other, to Greater Manchester and beyond by an affordable, safe, reliable and well-maintained low carbon transport system. It will be easy to get around by public transport, on foot and by bike. Walking and cycling will be the first choice for short journeys for those who are able to walk and cycle. Investment in transport will help to grow the economy, reduce deprivation and improve the health and well-being of residents (Bury Council, 2023).	
Manchester and Salford	A well-connected, zero-carbon city centre at the heart of the North, offering our residents, employees and visitors a great place to work, live and visit (TfGM, 2021).	
Oldham	The council will look to use a greener fleet and we will also invest in our infrastructure – creating more electric charging points and promoting access to shared mobility clubs, cycle hire, e-bikes and cargo bikes. This will help make the switch to cleaner options easier, especially for businesses and residents (TfGM, 2021).	
Rochdale	By 2026 Rochdale Borough will have an affordable, sustainable, reliable, accessible and integrated transport network that offers travel choice for all, serves its communities, tackles air quality and climate change, enhances social inclusion, public health and supports economic growth and regeneration of the local area (Rochdale Borough Council, 2014)	
Stockport	The Stockport's transport infrastructure can support corporate aspirations whilst maintaining long term financial sustainability over the period from 2015 to 2034 (Stockport Council, 2025).	
Tameside	Corporate Plan to ensure modern infrastructure and a sustainable environment that works for all generations and future generations (Tameside Council, 2021)	
Trafford	The Council will support and encourage the development of a sustainable integrated transport network in the Borough that is accessible and offers a choice of modes of travel to all sectors of the local community and visitors to the Borough (Trafford Council, n.d.).	
Wigan	The new transport strategy for the borough will ensure that the transport networks will support the significant economic development forecast to 2030 (Wigan Council, 2024).	

Figure 4.1.2. Ten local authorities of GM (Carter et al., 2015)

Table 4.2. Table showing funds and aims of Greater Manchester Council's prepared by the author. Information is obtained from official websites of GM Councils.

4.1.1. Trafford Road Corridor Project

The project, implemented by TfGM, includes the installation of 4 automatic traffic counters, 4 variable message signs, 3 CCTV sites, 7 junctions with enhanced cycle detection, and high-speed fibre connectivity across the corridor to improve access to the Trafford football and cricket grounds. The signals are currently operated by SCOOT and support pedestrian use of buses, trams, vehicles, bicycles, and walking.

4.1.2. Smart Junctions 5G Project

This project, which involves collaboration with VivaCity, is also notable for being a research and development (R&D) project. It enables the integration of 5G technology into selected existing smart junctions in Salford. Additionally, the project, which uses artificial intelligence to reduce waiting times at traffic lights, can reduce travel times and, consequently, pollution. During meetings held at their offices with TfGM officials, the proposed documents related to the Smart Junctions 5G Project stood out in terms of efficiency. According to the information obtained from these documents, AI-powered sensors will detect road users at smart intersections, while Reinforcement Learning (RL) methodologies will optimize this data to adjust traffic signals. The Smart Intersections 5G Project will be implemented by integrating a 5G Private Network into this system. This project aims to reduce travel time by 3% compared to 4G technology (see Figure 4.2.).

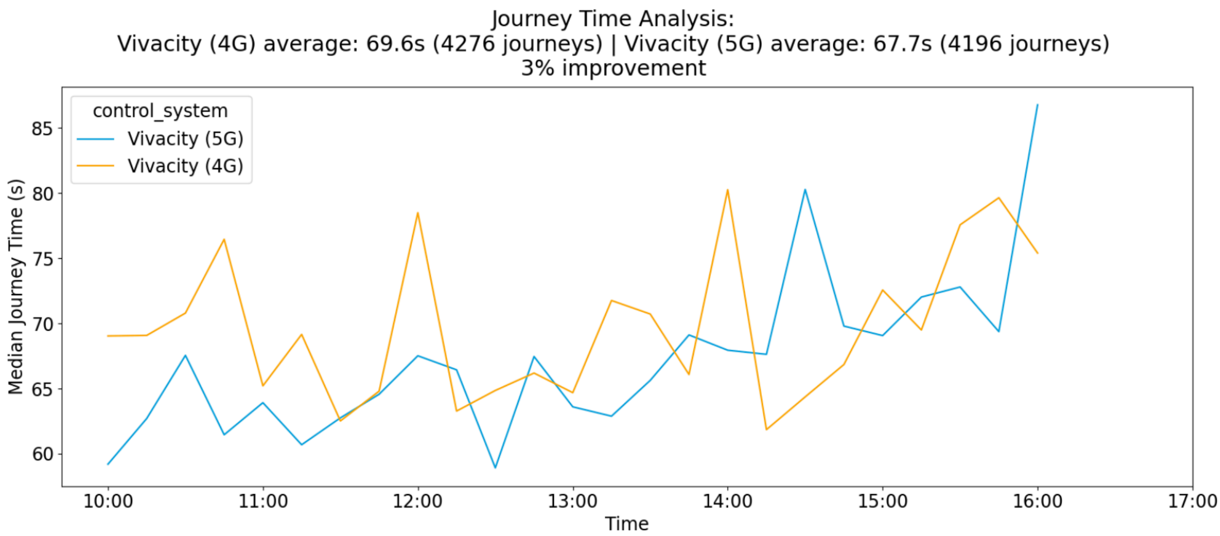

Figure 4.2. Smart Junction 5G vs Smart Junction 4G. Retrieved from VivaCity (2023).

4.2. Smart Signalisation in Manchester

This section below describes smart signalling studies specifically in the city of Manchester. Firstly, the history of traffic signalling in Manchester will be discussed. Most traffic control systems employ pre-timed traffic signals derived from prior traffic condition analyses (Studer et al., 2015). This results in outputs that limit processes and obstruct adaptation to current circumstances, such as the necessity to replicate research annually.

Smart junctions can be summarised as initiatives that aim to organise smart signalisation efforts specifically at intersections that play a significant role in traffic flow. Smart junctions aim to improve traffic flow and make traffic management more efficient. Unlike traditional junctions, they use sensors, cameras, artificial intelligence, and digital technologies to optimise traffic flow (Studer et al., 2015). Sensors installed at intersections aim to ensure that traffic lights are timed correctly. Since it continued as the Greater Manchester Council (GMC) until 1986, traffic lights and CCTV cameras were purchased not only for the city but also for the entire region to examine traffic flow (TfGM, 2023). In 1993, the first MOVA (Microprocessor Optimized Vehicle Activation) was added to Wigan from cities in the GM region, followed by SCOOT in the Wigan city centre three years later (TfGM, 2023). While SCOOT provides more accurate results in higher-density traffic flows, MOVA is preferred because it can respond more quickly to pedestrian needs and also this technology can be used in isolated, small junctions (Siddall, 2015). SCOOT is fundamentally an adaptive control mechanism that determines the optimised timing between traffic signals based on three main parameters: the journey time (JNYT), which is the travel time between the detector and the stop line; the maximum queue clearance time (QCMQ), which depends on the time spent in the queue; and the saturation occupancy (STOC), which represents the time required for traffic to build up again during the green phase in addition to these, it also relies on traffic signal and vehicle presence data (Davies, 2020).

After detailing some of the technologies related to smart signalisation, it would be useful to refer to the information obtained from VivaCity, one of the key companies conducting these initiatives in the context of Manchester. In its implementation report, VivaCity presented a critical perspective on SCOOT. The report published by VivaCity criticises SCOOT primarily for invalidating the investments made up to that point. Additionally, since SCOOT is known to experience performance degradation of up to 30% over time, and its recalibration must be carried out manually, this would pose a financial challenge for a local authority like Manchester (VivaCity, 2021). Following discussions with the authorities, access was granted to recent presentations not available in the public domain. Based on the information obtained from presentations, it is calculated that there are currently a total of 2400 traffic signals operated by TfGM since the day it was launched at 2018. (VivaCity, 2021).

4.3.CBA Calculation for Smart Junctions in Manchester

In this section, a cost-benefit analysis has been prepared using data obtained from interviews conducted with officials responsible for the implementation of smart junctions. This analysis takes the TAG document published by the UK Department for Transport as a reference in order to demonstrate the feasibility of the investment in Manchester. Accordingly, both direct economic and environmental contributions have been included in the calculations. The details of these will be discussed in the following sections.

4.3.1. Assumptions and Time Value

This section will explain the assumptions made for the calculations.

- In the CBA analysis it is aimed at understanding the feasibility of intelligent intersection systems.
- Calculations are based on data obtained from the TAG Transportation Guide and the TAG Data Book dated May 2025 (Department for Transport, 2025a; Department for Transport, 2025b).
- The Half Rule was used to calculate monetary values in the benefit section. When calculating the discounted value, a 3.5% discount rate was used based on the year 2023.
- The VoT value was taken from the handbook as shown in Figure 4.3. Since it is assumed that most benefits will increase during peak traffic hours rather than during working hours or off-peak hours, the non-work travel values listed in Table A1.3.2 of the TAG Data Book were considered.
- Price information obtained from TfGM officials has been included in the analysis as an assumption cost for calculations.
- By DfT(2025b) the expected lifespan of the technology has been proposed as 10 years. Approval has been obtained from TfGM officials.

Year	Non-Working Commuting
2025	15.49
2026	15.72
2027	15.94
2028	16.15
2029	16.36
2030	16.59
2031	16.81
2032	17.06
2033	17.31
2034	17.56

Figure 4.3. Screenshot from TAG Data Book showing non-working commuting value of time change adapted for dissertation (DfT, 2025b)

4.3.2. Travel Time Savings Calculation

In the example pilot project presented by VivaCity, it was observed that before the implementation of the system, the average travel time for 103,525 trips was recorded as 55 seconds at the junction. After the integration of smart junctions, as shown by the blue line in Figure 4.4., the average travel time for 57,660 trips was reduced to 43 seconds. Accordingly, it has been assumed that the implementation of smart junctions results in a 23% improvement and a time saving of 12.65 seconds per vehicle. Based on the information from the TSB0111 document, the average travel time in Greater Manchester by car is stated as 31 minutes, or 1,860 seconds (DfT, 2023, Table TSGB0111). Thus, it has been determined that the time saved at each intersection is equal to 0.68% of 12.65 seconds.

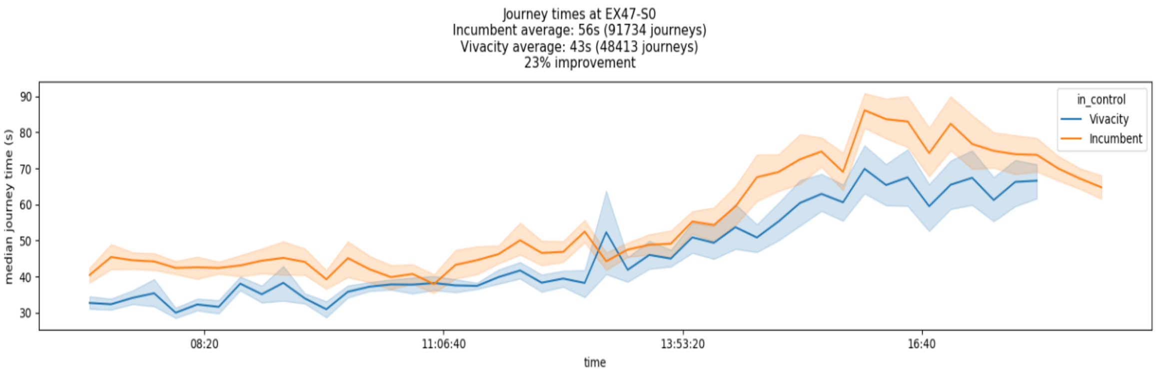

Figure 4.4. Graph that shows median journey times according to hours (VivaCity, 2021)

4.3.3. Annualization of Traffic Demand and Elasticity

The BCR value was high based on data obtained from a measurement device located near an intersection with heavy daily traffic flow. The data used in GM's calculations was compared with average daily traffic volumes in Manchester. Average Annual Daily Traffic (AADF) data was obtained in JSON format from the official statistics portal of the UK Department for Transport (DfT, 2024). From data obtained from this website average daily count of 24,256.21 vehicles was reached. The fact that the average of 24,256.21 vehicles found for all of Manchester was calculated as 35,254 on Trinity Way, one of the roads with the highest average daily traffic, demonstrates the consistency of the data obtained from Node (see Figure 4.5.). Therefore, the remaining calculations were continued using the figure of 35,254 vehicles. After finding the daily vehicle number, some assumptions were made to annualise this number. Since an increase in traffic density and the occurrence of delays are necessary for us to observe the benefits of signalisation, the assumptions were made accordingly. Therefore, by excluding weekends and public holidays from the annual 365 days, it was decided to consider days with heavy traffic, such as school and workdays, and the calculation was made based on 250 days. As time savings will occur during peak hours, it was also decided to include a rate of 40% in the calculation. Therefore, the annual vehicle number was calculated as follows:

35,254 × 0.4 × 250 = 3,525,400 vehicles/year

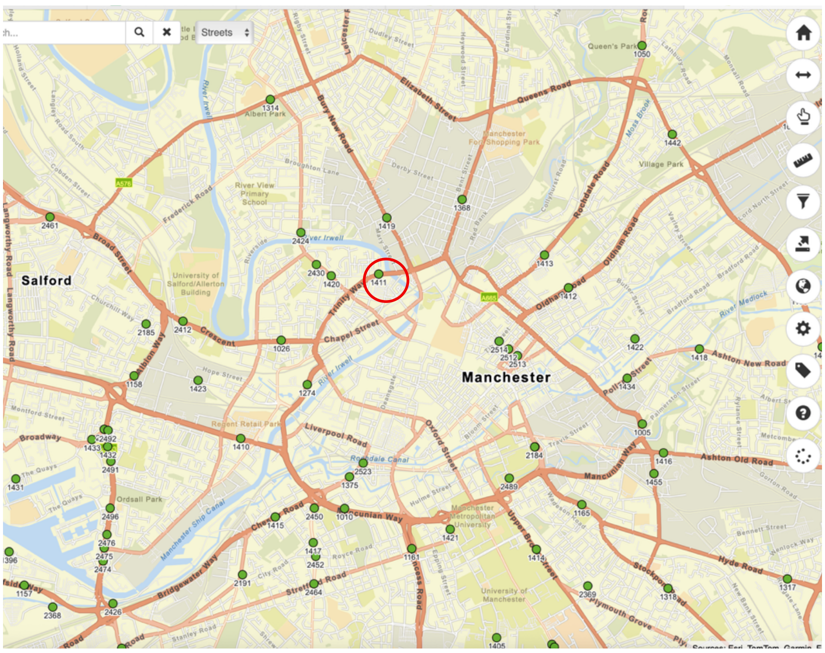

Figure 4.5. Satellite imagery of the data source circled in red obtained from cloud traffic data of TfGM (TfGM, 2025).

SITE ID :000000001411					
Site:1411 Trinity Way (A6042) /75m E of Springfield Ln, Salford(ATC)					
Node:GM_PERMANENT_ATC					
Year	**ADT**	**Average Spe**	**Speed 85%**	**% HGV**	**Coverage**
2025	35,254	26.6	32.9	7.0%	49.0%
2024	29,383	26	32.9	5.2%	31.7%
2023	11,753	25.6	32.9	3.5%	85.9%
2022	29,963	27.6	35.2	4.6%	100.0%
2021	33,163	29.1	35.8	4.7%	98.2%

Figure 4.6. Number of Average Daily Traffic (ADT) (TfGM, 2025).

Wardman (2022) discusses the concept of elasticity, noting that travel demand tends to increase as travel time decreases. In this calculation, the value of −0.21 included in the analysis indicates that when travel time decreases by a certain percentage, travel demand is expected to increase by approximately one-fifth of that percentage. Using this time elasticity and assuming an average travel time of 31 minutes (DfT, 2023, Table TSGB0111), an 11-second saving per vehicle corresponds to a 0.591% reduction in travel time, which in turn results in an estimated 0.124% increase in demand. The adjusted annual traffic volume is thus as follows: **3,525,400 × (1 + 0.00124) = 3,529,778 vehicles/year**

4.3.4. <u>Rule of Half Approach</u>

DfT (2025a) advises in their guidebook to use rule of for our calculations without scheme P0 and with scheme P1.

ΔCS (Consumer Surplus) ≈ ½ × (P1 − P0) × Δt × VoT (DfT, 2025a)

Average demand = (P0 + P1) / 2 = (3,525,400 + 3,529,778) / 2 = 3,527,589 vehicles/year

Annual time savings (hours) = ((P0 + P1)/2) × (Δt / 3600), where Δt = 11 seconds per vehicle, and 3600 is the number of seconds in an hour used to convert seconds to hours.

Annual time savings (in hours) = (3,527,589 × 11) / 3600 ≈ 10,778.74 hours/year

4.3.5. <u>Value of Time Discounting</u>

The real Value of Time (VoT) grows in line with forecast growth in UK GDP per capita. This value is assumed to grow by 1.5% annually (see Figure 4.7.).

Annual benefits are Hours × VoT**,** then discounted to 2023 prices using discount factors (DF) taken from the TAG Data Book Excel (standard 3.5% rate for years 0–30 see Figure 4.7).

Years from current year	Discount rate (standard)
0-30	3.50%

Figure 4.7. Discount rate for 0-30 year. (Department for Transport, 2025 b)

The resulting per-year line items are:

Year	Hours	VoT (£)	Total (£)	DF	PV (£)	Calculation
2025	10778.74	15.49	166,963	0.93351	155,861	10778.74 * 15.49 = 166,963 ; 166,963 * 0.93351 = 155,861
2026	10778.74	15.72	169,442	0.90194	152,826	10778.74 * 15.72 = 169,442 ; 169,442 * 0.90194 = 152,826
2027	10778.74	15.94	171,813	0.87144	149,725	10778.74 * 15.94 = 171,813 ; 171,813 * 0.87144 = 149,725
2028	10778.74	16.15	174,077	0.84197	146,567	10778.74 * 16.15 = 174,077 ; 174,077 * 0.84197 = 146,567
2029	10778.74	16.36	176,340	0.8135	143,453	10778.74 * 16.36 = 176,340 ; 176,340 * 0.81350 = 143,453
2030	10778.74	16.59	178,819	0.78599	140,550	10778.74 * 16.59 = 178,819 ; 178,819 * 0.78599 = 140,550
2031	10778.74	16.81	181,191	0.75941	137,598	10778.74 * 16.81 = 181,191 ; 181,191 * 0.75941 = 137,598
2032	10778.74	17.06	183,885	0.73373	134,922	10778.74 * 17.06 = 183,885 ; 183,885 * 0.73373 = 134,922
2033	10778.74	17.31	186,580	0.70892	132,270	10778.74 * 17.31 = 186,580 ; 186,580 * 0.70892 = 132,270
2034	10778.74	17.56	189,275	0.68495	129,644	10778.74 * 17.56 = 189,275 ; 189,275 * 0.68495 = 129,644

Table 4.3. Calculation of PV per year. (See Appendix A for more detailed calculation.)

4.3.6. Cost Calculations (PVC)

According to documentation and prior scenarios, the capital cost of implementing the smart junction system is £60,000. Discounted back two years to 2023 at 3.5%, this yields:

Capital cost (present value) = £60,000 / $(1.035)^2$ ≈ £56,010

Annual operation and maintenance costs are estimated at £5,500. When discounted over a 10-year period (2025–2034) to 2023:

Operation and maintenance present value ≈ £45,742

Thus, the total present value of costs (PVC) is: £56,010 + £45,742 = £101,752

Indicator	Value (£)
Present Value of Benefits (PVB)	1,423,416
Present Value of Costs (PVC)	101,752
Net Present Value (NPV)	£1,321,664
Benefit–Cost Ratio (BCR)	13.99

Table 4.4. Summary of discounted benefits and costs

4.3.7. *Comparison With Examples in the Literature*

The value of 13.99 obtained as a result of this study is quite high when compared with other results in the literature. Yusuf (2024) highlighted that the BCR value was 3 in Hong Kong, 3.5 in New York, and 3.2 in Shanghai. In a study conducted in the state of Utah in the United States, this ratio was reported to be 9.33 (US Department of Transportation, 2020). The BCR ratio of 13.10 obtained from the smart road study in Guangzhou, China, is the result closest to that obtained in Manchester. The reasons for the differing results from other studies in the literature may be due to the high density of the Trinity Junction in Manchester and the fact that the study included results calculated specifically for high-density junctions. Overall, the obtained value demonstrates that this study represents a highly meaningful investment for high-traffic junctions. The aim is to enhance the reliability of the results by comparing them with examples from the literature in this section.

4.4. Threshold Analysis for CBA Calculation

Trinity Way is one of the main roads with the highest traffic density during the day. Located in the city centre and used for entering and exiting the city, this road has a high BCR value of 13.99, which means that traffic density will vary significantly depending on the traffic on the road. For this reason, the number of vehicles that must pass through the traffic flow has been determined for three different threshold BCR values. The formula used for this is:

Required Daily Flow= Current Daily Flow* (Target BCR/ Current BCR)

It has been calculated that with the application of this formula, the BCR will be 4 if 10,080 vehicles pass daily, 2 if 5,040 vehicles pass, and 1.5 if 3,3780 vehicles pass.

Target BCR	Required daily flow (veh/day)	Annualised P0 (veh/year)	PVB (£)	PVC (£)	NPV (£)
4	10,080	1,007,977	407,008	101,752	305,256
2	5,040	503,989	203,504	101,752	101,752
1.5	3,780	377,991	152,628	101,752	50,876

Table 4.5. Threshold analysis for different BCR values.

4.5. Sensitivity Analysis

This analysis aims to show how small changes in the three main parameters used could affect the results. Sensitivity analysis was performed on three variables and showed the extent to which the result obtained may vary depending on the variable.

The results suggest that if cost saving could be achieved even for ten per cent this would allow the technology to become more viable at quieter junctions. The technology is likely to have a stronger business case at busier junctions as the time savings can cover the cost of the technology.

Scenario	PVB (£)	PVC (£)	NPV (£)	BCR
Baseline	1,423,417	101,752	1,321,665	13.99
Traffic −10%	1,281,075	101,752	1,179,323	12.59
Traffic +10%	1,565,759	101,752	1,464,007	15.39
Time saving −20% (8.8 s)	1,138,734	101,752	1,036,982	11.19
Time saving +20% (13.2 s)	1,708,100	101,752	1,606,348	16.79
Costs +10%	1,423,417	111,927	1,311,490	12.72
Costs −10%	1,423,417	91,577	1,331,840	15.54

Table 4.6. Sensitivity analysis on different scenarios about time, cost and traffic.

5. Discussion

This section has been written to discuss the research conducted and the findings obtained in line with the aim of the study. Firstly, the answers derived from the thesis to the research objectives mentioned in the first chapter will be explained. In the second part, the potential challenges and limitations that may arise from the use of smart junctions will be addressed. The final part of this section aims to outline the lessons that can be learned from the Manchester case.

5.1. Research Findings

To analyse how smart junctions are implemented within Manchester's existing transport infrastructure.

In relation to this topic, documents prepared by TfGM have been utilized, particularly incorporating materials and visualizations in the results section. Additionally, the literature review includes global examples, focusing on the integration of smart intersections into existing cities around the world. Currently, there are 1,400 traffic signals in operation across Greater Manchester, of which 128 use the SCOOT system and 338 use MOVA. Limiting the implementation process exclusively to the provision of technical infrastructure and the transformation of signalisation systems would be insufficient. The benefits of this process should be considered through a holistic approach and addressed in a multidimensional manner.

<u>To conduct a cost-benefit analysis of Manchester's Smart Junction system while evaluating its economic viability.</u>

In this article, by selecting cost-benefit analysis as a methodology, it is aimed to contribute to the literature through the potential applicability of similar calculations in other cities. As Stevens (2004) stated in his article examining the impact of the CBA methodology in the ITS sector, the government's decision is rational if it improves the welfare of the public. To conduct this analysis, the data required for CBA analysis was collected from TfGM documents and interviews. During the CBA analysis, certain items that are difficult to measure qualitatively have been excluded from the analysis. This indicates that some elements within the benefit component may be underestimated. For example, smart signalisation systems may reduce bus waiting times, which can improve accessibility and service quality, especially for low-income individuals without private vehicles. Another example of not included benefits is an increase in public health due to reduced air pollution and reductions in noise pollution.

Furthermore, the inclusion of reduced travel time as a benefit could potentially incentivise increased car usage, thereby undermining the anticipated environmental gains. As a result, due to the omission of certain relevant factors in the calculation, the predicted BCR value of 13.99 may not accurately reflect the actual value.

<u>To explain the benefits and requirements of smart junctions, as well as the challenges faced in integrating this system, using available data and insights from local stakeholders.</u>

As revealed by the calculations based on information obtained from local authorities, a single smart junction provides an annual time saving of 10,778.74 hours/year This indicates that over a ten-year period, it could generate a substantial profit of approximately £1,423,417. In addition, AI-powered multi-layered analyses enable rapid adaptation to changing traffic conditions.

In terms of requirements, interviews revealed that each junction necessitates eleven sensors, and an annual maintenance cost of £500 is required. A live data processing infrastructure and various algorithms are also among the essential components for the operation of this system.

Another challenge identified as a research finding is the difficulty of quantifying the benefits at the system level. Receiving indirect benefits such as reduced traffic and gas emissions in return for a high initial investment may cause investments in this system to appear experimental. In this case, it becomes essential to present a successful feasibility analysis.

When it comes to challenges, a remark by Interviewee 1 stands out: *"There's a transport settlement for combined authorities, which we have to bid into..."* This indicates that local governments must apply for separate funds for each project.

Interviewee 2 mentioned the vans used by engineers working in the field for measurement purposes and the protocols that must be followed regarding data sharing.

In large-scale cities such as Manchester, collecting and analysing all data in real time creates scalability issues. Additionally, the reliability of the data may sometimes be questionable. It was noted that the use of artificial intelligence in smart signalisation works as a "black box," meaning that in some cases it can be difficult to understand why AI behaves in a certain way.

The project's use of Reinforcement Learning (RL) algorithms allows traffic lights to be controlled in real time, and while doing so, AI provides non-monetized contributions in areas such as system development, public value, data quality, and learning capacity. Therefore, the numerical value obtained through the selected methodology does not capture all relevant impact factors.

In the process of maturing smart junction projects, the use of existing infrastructure may also pose various administrative challenges. Road congestion during the integration of smart signalisation into existing traffic lights and the need for administrative approvals can slow down implementation. In conclusion, although being a unique and effective solution to congestion problems, smart junctions also have their own limitations and challenges.

5.2. Lessons to Be Learnt from Manchester in Smart Transport Applications

<u>Lesson 1: The Importance of Governing Projects</u>

Since major infrastructure and transport projects in the UK are usually carried out as public-private partnerships (PPPs), it was expected that the smart junction project would also be a PPP. The primary aim of Public–Private Partnerships (PPPs) is to develop infrastructure with the involvement of the private sector to ensure the provision of public services. In addition, they also aim to support economic growth. Since the 1990s, the UK has developed public–private partnerships and has become one of the leading countries in terms of private capital investment in infrastructure (Edwards et al., 2004). Although there may be high demand on certain routes, transportation projects are generally seen as high-risk investments, as achieving profitability can be challenging due to high overall demand thresholds, and the required investment may not be sufficient to cover the operational costs of the systems (Shaoul et al., 2012).

The UK Intelligent Transport System Progress Report emphasises the importance of PPPs in developing smart strategies (European Commission, 2022). Many public–private partnerships require long-term contracts and relationships, especially when private financing is involved (OECD, 2018). Overall, these findings support the view claimed by Shaoul et al. (2012), stating that infrastructure services must either be sufficiently flexible to adapt to changing needs or be supported by contracts that remain valid for 30 years. Much of the criticism that PPPs have attracted relates to their managerial and profit-oriented nature (Shaoul et al., 2012). TfGM's emphasis on its stakeholders and the partnerships it establishes to support the implementation process through various collaborations can serve as an example for other projects in this regard. Since Manchester aims to reach its zero-carbon target by 2038—12 years earlier than the rest of the UK—it has developed several partnerships focused on sustainability (Alderson, 2020). A smart city is considered not as an outcome but as a process itself; all stakeholders contributing to this process are of great importance (Ersoy, 2019). Governance structures play a crucial role in determining the success of smart transport projects. As a first lesson, it becomes clear that governance models should be holistic, interconnected, and tailored to local goals.

Lesson 2: The Importance of Real-Time Data Usage

Firstly, real-time intelligence, which enables faster processing of data across the network and thereby enhances users' travel experiences, is of great importance (TfGM, 2021). During the peak hours, real-time data sharing aims to improve the utilization of roads. To meet this objective, artificial intelligence is combined with reinforcement learning to support further development.

The CBA results indicate that the investment is not only technologically effective but also economically advantageous. With a benefit–cost ratio of 13.99, which the DfT classifies as very high, the findings suggest that this area deserves investment priority due to both its substantial benefits and its strategic relevance. Furthermore, since these significant benefits have been observed to increase particularly at high-density junctions, it is important to assess whether similar outcomes can also be achieved in low-density junctions. As a result, more feasibility studies should be carried out to examine the relevance of these findings across diverse contexts.

Data Reliability and Transparency Are Significant Issues

According to the information obtained from the interviews and presentations, artificial intelligence and smart transport applications are systems that require continuous investment and development. However, it is now well established that the removal of humans from the decision-making mechanism can, at times, make it difficult to understand why certain decisions are made and may increase complexity. The ethical issues that arise when humans are excluded from processes, as highlighted by Cugurullo (2021), have been increasingly recognised as significant concerns, and these should also be considered in the Manchester case.

There is a growing body of literature that recognises the importance of integrating both ethical and economic dimensions in the implementation of smart transport systems. Accordingly, not only transparency and ethics but also economic sustainability are now widely regarded as fundamental issues. Ensuring long-term viability is largely dependent upon the reliability of data-driven decisions as well as the reduction of costs, thereby sustaining public and political support.

6.Conclusion and Policy Recommendations

Sustainability is a general term that encompasses the measures and decisions we must take to leave a liveable world for future generations. To achieve this, it is important and necessary to seek holistic solutions. The integration of smart transportation technologies into existing cities is another step in this quest.

This study is set out to objectively measure and assess smart signalisation’s contribution to Manchester’s transportation. In this article, smart transportation applications, which are key components of the journey toward the utopia of achieving a smart city, have been examined in detail. As highlighted in the research objectives, the literature has been reviewed, challenges have been identified, a CBA analysis has been conducted, and the views of local communities on this issue have been included.

This research followed mixed methodologies. Semi-structured interviews with TfGM officials and secondary document analysis were used to examine smart transport strategies in Manchester in depth. Economic outputs were then calculated using CBA analysis.

For this purpose, the city of Manchester, a pioneer city since becoming the world's first industrial city in 1780, has been selected (Ware,2020). Ubiquitous technologies such as smart signals not only support existing transport systems but also make smart mobility solutions more accessible in practice. The data obtained throughout the study has examined in detail the contributions of smart transport applications to achieving sustainable urban mobility. One of the most significant aspects of this study in terms of literature is that it provides CBA analysis results for smart junctions, which are considered one of the key components of smart transport applications. The existing literature has already shown that among the benefits of smart junction applications are reductions in carbon dioxide emissions and waiting times. In terms of academic contribution, this study has contributed to intelligent transportation research as it is the first detailed CBA analysis conducted specifically for the UK for intelligent intersections.

The CBA analysis, based on real-time data and feedback from officials, has shown that the Smart Junctions project could not only cover its costs but also generate more than thirteen times the economic return over its projected 10-year lifespan. Based on this result, it has been concluded that smart transport technologies are worth investing in and scaling up.

By using this snapshot about Manchester's current transportation status, policy recommendations can be made for cities with similar socio-economic characteristics. The policy recommendations are summarised below.

- To secure long-term financing, pilot projects should be developed.
- Providing incentives to finance a project that may be considered experimental, such as smart signalisation, would be meaningful for local governments.
- Collaboration among different stakeholders should be integrated by TfGM.
- Data sharing among these stakeholders should be regulated through various protocols prepared by national government.
- The successful result obtained from the CBA analysis should be regarded as a precedent, and calculations should be repeated for different cities as well.

This research examines intelligent intersections as an example of intelligent transportation technology and investigates an area with unique challenges in generalisation. The data and results may provide more consistent insights in the United Kingdom context compared to other countries.

Additionally, inconsistencies in data obtained from certain sensors have prevented further analysis based on the time of day or intersection arms. Certain limitations have emerged from the selected approaches, particularly those arising from the application of CBA. As underlined in the research findings section, the reliability of the CBA methodology is open to question, as there are no strict rules for the parameters to be included in the method.

Another significant limitation is that the relatively high BCR ratio is valid and consistent for a high-traffic intersection (Trinity Way). Since this result is derived from calculating the benefit in terms of time saved, it may lead to different outcomes in different contexts. Consequently, BCR can change dramatically in different intersections, as highlighted with threshold analysis. Since this study was conducted based on quantitative assessments such as time savings, further studies could analyse qualitative assessments such as noise pollution and increased safety for pedestrians and cyclists. To gain more holistic results in future studies, various cities can be analysed.

All in all, these findings contribute in several ways of our understanding of smart junctions and provide a basis for CBA calculations in future studies. All these findings and policy-related examples have the potential to serve as inspiration for transport systems in other cities with similar socio-economic characteristics to Manchester. In terms of directions for future research, further work could focus on comparisons between different results of smart signalisation's impacts.

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Appendix A: Detailed Cost-Benefit Analysis (CBA) Calculations

Assumptions and Parameters

Parameter	Value
Project lifespan	10 years[1]
Discount rate	3.5% [2]
Average journey time	31 minutes[3]
Elasticity value	−0.21[4]
Daily traffic volume	35,254 vehicles [5]
% peak traffic considered	40%
Working days per year	250
Value of Time (VoT)	Yearly values (2025–2034) from TAG Data Book

Traffic Demand Calculations

Annual traffic demand = 35,254 × 0.40 × 250 = 3,525,400 vehicles/year.

Adjusted with elasticity −0.21 → 3,529,778 vehicles/year.

Travel Time Savings

Before implementation: 55 seconds/vehicle. After implementation: 43 seconds/vehicle.

Saving = 12.65 seconds per vehicle (~0.68%).

Annual time saved = 10,778.74 hours/year.

Rule of Half

Formula: ΔCS (Consumer Surplus) ≈ ½ × (P1 − P0) × Δt × VoT.

Applied using traffic demand values (P0 = 3,525,400; P1 = 3,529,778), Δt = 11 seconds, VoT from TAG Data Book (2025–2034).

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Value of Time Growth & Discounting

Year	VoT (£)	Annual Hours Saved	Annual Benefit (£)
2025	15.49	10,778.74	166,963
2026	15.72	10,778.74	169,442
2027	15.94	10,778.74	171,813
2028	16.15	10,778.74	174,077
2029	16.36	10,778.74	176,340
2030	16.59	10,778.74	178,718
2031	16.81	10,778.74	181,020
2032	17.06	10,778.74	183,800
2033	17.31	10,778.74	186,580
2034	17.56	10,778.74	189,360

Discount factor annual calculation formula =1/ (1+0.035) ^ (Year-2023)

Year	**DF**	**Calculation**
2025	0.93351	10778.74 * 15.49 = 166,963 ; 166,963 * 0.93351 = 155,861
2026	0.90194	10778.74 * 15.72 = 169,442 ; 169,442 * 0.90194 = 152,826
2027	0.87144	10778.74 * 15.94 = 171,813 ; 171,813 * 0.87144 = 149,725
2028	0.84197	10778.74 * 16.15 = 174,077 ; 174,077 * 0.84197 = 146,567
2029	0.8135	10778.74 * 16.36 = 176,340 ; 176,340 * 0.81350 = 143,453
2030	0.78599	10778.74 * 16.59 = 178,819 ; 178,819 * 0.78599 = 140,550
2031	0.75941	10778.74 * 16.81 = 181,191 ; 181,191 * 0.75941 = 137,598
2032	0.73373	10778.74 * 17.06 = 183,885 ; 183,885 * 0.73373 = 134,922
2033	0.70892	10778.74 * 17.31 = 186,580 ; 186,580 * 0.70892 = 132,270
2034	0.68495	10778.74 * 17.56 = 189,275 ; 189,275 * 0.68495 = 129,644

Annual house saved*Value of Time=Annual Benefit; Annual Benefit* Discount factor= Net Benefit
Sum of yearly net benefits Present Value Benefit (PVB)= 155,861 + 152,826 + 149,725 + 146,567 + 143,453 + 140,550 + 137,598 + 134,922 + 132,270 + 129,644= £1,423,416

Cost Calculations

Capital cost: £60,000 (discounted to £56,010 with 3.5 ratio).
Operation and maintenance cost: £5,500/year → PV ≈ £45,742.
Total PVC = £101,752.

BCR and NPV Results
PVB = £1,423,416
PVC = £101,752
BCR = 13.99
NPV =£1,423,416 - £101,752 = £1,321,664.

Word Count: 390