

1 **ASSESSING THE BENEFITS OF INSTALLING V2I COMMUNICATIONS ON AN**
2 **URBAN ORBITAL MOTORWAY IN A MEDIUM SIZED EUROPEAN CITY**

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ABSTRACT

As congestion continues to grow in urban areas, attempts to increase road capacity by means of road realignment, widening or removal of at-grade junctions can be very costly. After long periods of austerity in some European countries, funding for large scale infrastructure projects is still difficult to come by. This paper examines a potential cheaper alternative by assessing new technologies such as Vehicle to Infrastructure (V2I) communication. Recent research suggests that V2I can be used to alleviate congestion and improve safety without the need for large scale, disruptive road works which tend to have a negative environmental impact.

The objective of the paper is to test the hypothesis that deployment of V2I communications technology on a three-lane busy orbital motorway (expressway) around a medium sized European city is economically viable. An audit of the M50 motorway around Dublin in Ireland was used to test the hypothesis. The possible benefits of the use of this technology in terms of reductions in both collisions and congestion were assessed. This was followed by calculation of the costs involved in the installation of the technology. The results of this work, a conservative assessment, show a benefit to cost ratio of 3.2 : 1 indicating that the use of V2I communications technology is economically viable and would deliver significant benefits.

Keywords: Vehicle to Infrastructure, V2I, cost benefit analysis, safety improvements

1 INTRODUCTION

2 In recent years the number of fatalities on Irish roads has decreased significantly. Safety
3 features like airbag and seatbelts have lessened the severity of collisions and improved the
4 safety of drivers and passengers when a collision occurs. As the technology in motor vehicles
5 continues to improve it is important that the roads on which these cars drive are also
6 improved. New advances in technology have attempted to reduce the occurrence of
7 collisions. One of the new innovations in safety is V2X (Vehicle to Everything)
8 communications. V2X refers to both Vehicle to Infrastructure (V2I) and Vehicle to Vehicle
9 (V2V) communications.

10 One of the major emerging technologies in modern transportation is the development
11 of autonomous vehicles (AVs). AVs and CVs (Connected Vehicles) are part of the broader
12 trend of using ITS to improve transport infrastructure. There are a number of challenges to
13 the roll out of AVs including technological difficulties, an unclear regulatory landscape and
14 some public reluctance to use the technology. New cars are increasingly equipped with
15 features also present in AVs. These features often referred to as Advanced Driver Assistance
16 Systems (ADAS) include: adaptive cruise control, lane departure warning, automatic lane
17 changing and automated parking control. It is likely that cars will increasingly contain more
18 autonomous features over time until the technological and regulatory conditions allow the roll
19 out of fully autonomous vehicles.

20 As traffic congestion continues to increase, attempts to provide additional road
21 capacity such as road realignment, widening or removal of at-grade junctions can prove very
22 costly. New technology has the potential to increase the capacity of roads at a lower cost
23 than that of major infrastructure upgrade schemes. V2I allows data to be transferred between
24 vehicles and an RSU (Road Side Unit) or if cars are out of range of the RSU they can act as
25 nodes in the network using V2V (Vehicle to Vehicle) communication to extend the effective
26 range.

27 The purpose of this paper is to estimate the possible benefits of deploying V2I
28 communication on an orbital motorway (expressway) around a European medium sized city –
29 in this case Dublin in Ireland. The next section of the paper presents the literature review and
30 this is followed by a description of the methods used. The results and discussion are then
31 presented and the paper ends with a set of conclusions.

32 LITERATURE REVIEW

33 A report by the US Department of Transportation Federal Highways Administration
34 (FHWA) identified collision types that could be prevented or reduced using V2I technology.
35 This amounted to nearly 2.3 million collisions with an estimated cost of over \$200 billion.
36 The total number of annual crashes was estimated at 6 million at a total cost of over \$339
37 billion. The type of collision that could be reduced by V2I technology comprise 59% of total
38 crashes in the US (1).

39 The largest rollout of connected vehicle (CV) technology anywhere in the world is in
40 Japan. The ITS Spots uses V2I communication on highways and expressways around Japan
41 (2). The road infrastructure consists of over 1,600 RSUs which exchange information with
42 ITS Spot compatible OBUs (On Board Units) in vehicles. The scheme aims to improve road
43 safety by providing advanced congestion warnings to motorists on high speed highways.
44 Traffic management is improved by providing dynamic route guidance and electronic toll
45 collection (ETC) is improved by optimising traffic flow through toll plazas. Another
46 important use of the Spots service is real time transmission of data during natural disasters.
47 According to the Japanese MLIT (Ministry of Land, Infrastructure, Tourism & Transport) the
48 introduction of CV technology at the Sangubashi Curve has resulted in a 60% reduction in
49 collisions (3). Iwatake (4) found that public satisfaction with the system was very high.
50

1 Mekker et al (5) used a new methodology to evaluate the impact of variable speed limit
2 signage on individual drivers and found that drivers needed to observe multiple signs prior to
3 any tangible reduction in speed.

4 There is also significant interest in the development of V2I technology from
5 government bodies in both Europe and the United States. In September 2012, the European
6 Commission and the US Department of Transportation (6) published a document outlining
7 their commitment to cooperate in working towards the development of cooperative vehicle
8 systems. Some of the key objectives are harmonisation of technical standards and sharing of
9 results from on-going tests in both jurisdictions.

10 The eCall system automatically notifies emergency services and transmits the location
11 of the vehicle and the number of passengers in the event of a collision. The system is
12 currently being introduced by the EU, and is to be mandatory in all new cars from 2018 (7).
13 Another example of the development of V2I technology in Europe is the Cooperative ITS (C-
14 ITS) Corridor from Vienna, Austria to Rotterdam in The Netherlands via Frankfurt,
15 Germany. This corridor is a major freight route which passes through the industrial Ruhr
16 Valley area in Western Germany; it is notable that this is to date the largest cross border
17 application of V2I technology. It is estimated that a possible reduction in collisions of 8% for
18 motorway driving and between 60% - 80% for urban junction collisions could be achieved
19 using C-ITS technology (8).

20 A number of expert groups have been established at a European level to improve the
21 implementation of ITS technology; two examples of this are the Car 2 Car Communication
22 Consortium (9) and The Platform for the Deployment of Cooperative Intelligent Transport
23 Systems in the European Union (10). The Car 2 Car Communication Consortium is an
24 industry led body of vehicle manufacturers and suppliers, including Audi, BMW,
25 Volkswagen, Renault and Peugeot. It has worked to homogenise standards across car
26 manufacturers, equipment suppliers and research organisations for the development of both
27 V2I and V2V communications. In 2015, members of the Car 2 Car Communication
28 Consortium agreed to put cars equipped with C-ITS technology into production by 2019 (8).
29 The C-ITS Platform is made up of representatives from EU member states, vehicle
30 manufacturers, insurance companies, telecommunications providers, road infrastructure
31 managers and other C-ITS relevant European sector associations (10). They have set out the
32 need for common standards across participating member states to ensure interoperability
33 between systems across the EU. The report included details of a cost benefit analysis (CBA)
34 which was undertaken to estimate the potential benefits of rolling out C-ITS technologies.
35 Over the period 2018 – 2030 the potential benefits were predicted to outweigh the costs by a
36 margin of 3:1.

37 NordicWay is a pilot scheme operating in parts of Denmark, Finland, Norway and
38 Sweden and has received partial EU funding (11). It is a smartphone app using maps which
39 allows users to flag hazardous sections of roads while they drive. The pilot scheme currently
40 has 2000 users. NordicWay is also used by traffic management agencies to improve
41 responses to hazardous road conditions.

42 A number of studies have assessed the potential benefits of V2I technology. In the US
43 (12), a Report to Congressional Responders listed a number of the potential benefits from the
44 introduction of V2I technology. Cazares et al (13) used traffic modelling software to estimate
45 the possible impact of V2I technology to reduce travel times on a congested urban corridor.
46 While the largest savings in travel time occur when the market penetration is relatively high,
47 even at very low rates (10%) there is a significant time saving as shown in the modelling
48 results.

49 Li et al (14) found that the use of V2I communications to warn drivers about
50 upcoming possible dangerous situations resulted in a reduction in the emissions of both air

pollutants and greenhouse gases. The study also showed an increase in safe driver behaviour on approach to the hazardous road conditions. Heutenbos et al (15) used a driving simulator to study the response of drivers to both audio and visual warnings on approach to intersections. The results found that the warning system allowed a vehicle traveling straight through an intersection to maintain a higher average speed while maintaining a safe distance from other road users.

Chen et al (16) used GIS to determine the number of RSUs needed to provide comprehensive coverage on the Oregon highway network. Asselin-Miller et al (17) modelled the possible impacts of rolling out C-ITS technology in Europe and conducted a CBA for a number of different deployment scenarios. Many of the findings were similar to that of C-ITS platform report (10). Depending on the different deployment scenarios this study calculated benefit to cost ratios of between 2:1 and 8:1.

Barrachina et al (18) investigated different approaches for deploying RSUs based on cost and effectiveness. The three approaches were minimum cost deployment, uniform mesh deployment and downtown based deployment. The minimum cost approach involves deploying RSUs in the cheapest locations which minimises the costs of deployment; this approach can lead to uneven coverage with some of the RSUs overlapping with gaps in coverage elsewhere. The uniform mesh approach deploys the RSUs in an evenly spaced manner and the final approach involves the deployment of the RSUs in a manner inversely proportional to expected vehicle density. The purpose of the latter approach is to increase coverage in areas of reduced vehicle density as in these areas the communication between the vehicles and the RSUs cannot be complemented by using V2V communication. The results showed that the minimum cost approach provided the worst coverage, the uniform mesh approach gave the best notification times and the downtown approach provided better coverage than the other two methods but only when the vehicle density was greater than 90 vehicles/km².

Mekker et al (19) reported on a real-time probe vehicle data-based system for generating texts/emails to alert a local authority to work zone queuing in real time. They found that for almost 75% of back-of-queue crashes, interstate queues existed for 15 or more minutes prior to the crash. The FHWA (1) studied the different leading causes of collisions from 2005 to 2008 and identified 12 collision types that could be prevented or reduced in occurrence using V2I technology. While the number of collisions that could be prevented or reduced by V2I was 38% of total collisions (73% of single-vehicle and 47% of multi-vehicle collisions) the potential cost saving was 59% of the total. The report does not suggest that all collisions could be eliminated using V2I communications.

Stockton et al (20) summarised the benefits associated with the deployment of intelligent transportation systems and found that incident management systems nationwide have typically reduced incident-related delay 50-60% as a results of rapid detection and response to crashes and stalls. Wiles et al (21) assessed the potential effectiveness of detection and advances warning techniques of slow/stopped traffic on freeways. They identified three techniques as having the most promise for application by TxDOT – series of static signs with text message and flashers, series of static signs with international congestion ahead symbols and flashers and a series of portable dynamic message signs (DMS).

METHODOLOGY

Case Study Selection

The initial assessment to establish which roads are most suitable for the initial deployment of V2I technology looked at a number of characteristics of the roads including safety record, the

AADT (Annual Average Daily Traffic), the average speed on the road and the potential costs of deployment. Looking at collision data in Ireland from 2013, of the 4,976 collisions causing injury or death, 30% (1,471) took place at intersections (22). The safety record of each road was assessed based on collision data available from (23). The collision data included length of the section of road, location, the number of collisions, the collision rate per million vehicle km driven and whether the collision rate on that section was above or below the national average collision rate.

On initial assessment of the collision information there appeared to be a number of roads which showed relatively high collision rates, however it quickly became apparent that some of those roads would not be suitable for using V2I technology, in terms of maximising value for money, because of their relatively low AADT. While there was no specific AADT cut-off used in selecting the roads considered, the significant traffic levels on the two-three lane M50 motorway was a significant factor in its selection for the study. The remaining roads were assessed by plotting the collision rate along the length of the road, an example of which is shown in Figure 1.

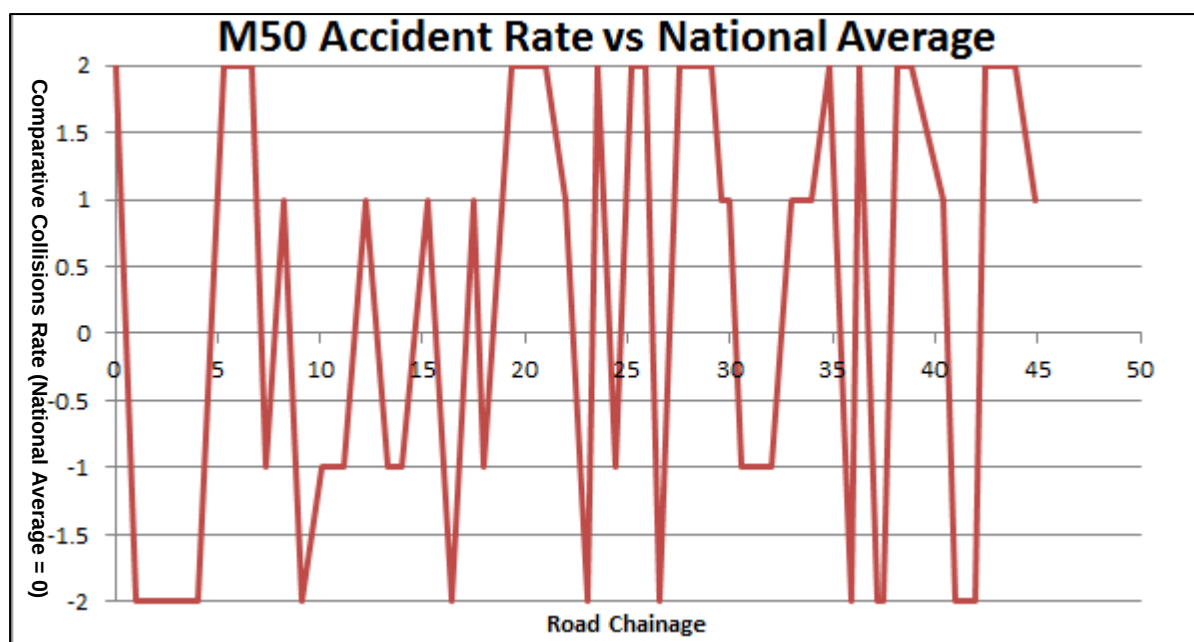


FIGURE 1 Collision rates on the M50

By assessing the information in these figures it was possible to identify the locations of successive sections of the road with collision rates above national average. These areas of road were chosen for further auditing to establish if they would be suitable for the deployment of V2I communication infrastructure. Further research was then conducted into the factors contributing to each collision using data obtained through information requests from TII (Transport Infrastructure Ireland), who keep detailed records of all serious and fatal collisions on national roads.

When estimating the cost of installing a V2I network the majority of the expense required is in installing the RSUs. In particular, the biggest single part of the cost is for backhaul construction, making up over half of the estimated costs of installation. Irish costs were not available for the costing analysis done later so US costs were used (12).

A number of Irish roads already have installed ducting containing fibre optic cabling which can be used for the provision of ITS services. This fibre optic ducting is currently used for communication with recently installed VMS (Variable Message Signs) along a number of motorways including the M50 (the orbital motorway (expressway) around Ireland's capital

city Dublin) and the M1 (motorway between Dublin and Belfast). The cost of deploying V2I technology can be greatly reduced in areas where fibre optic ducting is already in place.

Based on its high levels of AADT, of the order of 120,000 - 140,000 (depending on section), its safety record and the presence of fibre optic cabling, the M50 was selected as the piece of road infrastructure to be audited for the deployment of V2I communication technology.

Collision Mapping

Dublin is classed as a medium sized city in European terms and the Greater Dublin Area has a population of about 1.8 million. The M50 is a critical piece of road infrastructure in servicing the city and its 45 km route can be seen in Figure 2.

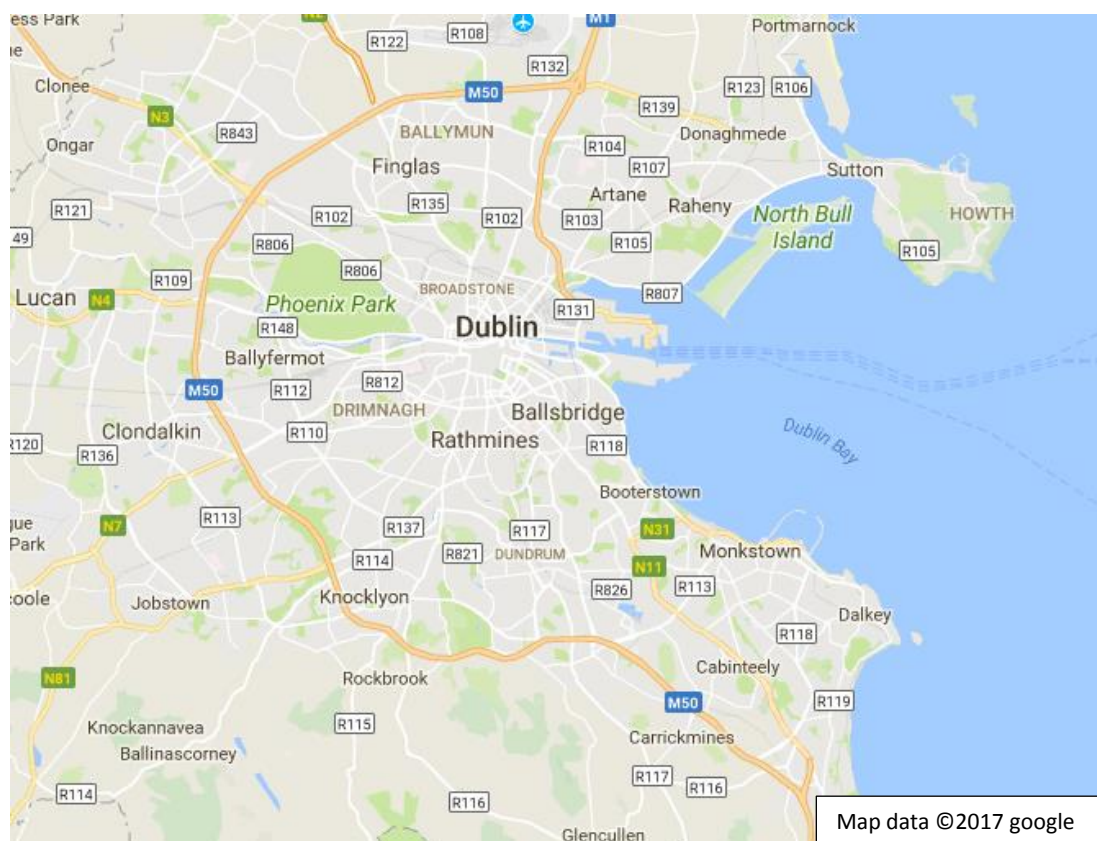


FIGURE 2 Location of the M50 orbital motorway around Dublin

Data relating to collisions on national roads from 2009 - 2013 was obtained from the Road Safety Authority (22). The data included the exact location of the collision, the number of vehicles involved, injuries sustained, weather conditions, and some of the contributory causes. It was not possible to obtain collision data relating to damage only collisions and so only collisions causing injury or death are included in the analysis.

The data were mapped using ArcMap but there were a number of steps required to achieve this. The coordinate system used in the RSA location data changed from ING (Irish National Grid) to ITM (Irish Transverse Mercator) from 2012 onwards. In order to map the locations, conversion from IGN coordinates to ITM was achieved using the Grid InQuest II software which was obtained from the OSI (Ordnance Survey Ireland) website (24).

The work of the US FHWA (1) was consulted to determine which types of collision could be reduced in frequency or prevented using V2I communications technology. Given the standard of road in question i.e. motorway, the collision type chosen to be assessed was rear-

end collisions. By filtering the combined M50 collision data, 92 'rear end, straight', 4 'rear end, right turn' and 2 'rear end, left turn' collisions were identified as occurring from 2009 – 2013. The severity of the collisions was assessed and collision costs from the Department of Transport, Tourism & Sport Common Appraisal Framework (CAF) for Transport Projects and Programmes (25) was used to calculate their costs – see Table 1.

TABLE 1 Average value of prevention of road collisions by severity and element of cost (2011 Prices and 2011 Values) (25).

Collision Severity	Casualty related costs (€/€)			Collision related costs (€/€)			
	Lost output	Human costs	Medical & Ambulance	Police cost	Damage to property	Insurance & admin	Total
Fatal	701,881 / 822,850	1,338,656 / 1,569,373	1,205 / 1,412	21,521 / 25,230	13,952 / 16,356	375 / 439	2,077,589 / 2,435,661
Serious	27,041 / 31,701	186,012 / 218,071	16,382 / 19,205	2,519 / 2,953	6,225 / 7,297	233 / 273	238,412 / 279,502
Slight	2,858 / 3,350	13,617 / 15,963	1,212 / 1,420	653 / 765	3,713 / 4,352	142 / 166	22,053 / 25,853
Damage only	-	-	-	42 / 49	2,346 / 2,750	67 / 78	2,456 / 2,879

Note: €1 = \$1.18

Average Vehicle Speed Calculations

Details of traffic flow characteristics on the M50 were found on TII's online data portals (26). These included AADT, mean daily speed, hourly traffic and mean speed for the morning and evening peaks. To calculate the predicted travel time saving the mean speeds were increased by 2% which was the figure suggested in the C-ITS Platform Report as representative of the typical speed increase if V2I was introduced (8). By dividing the length of the road by the average speed the time taken to drive through each section of the motorway was calculated. The difference between the current travel time and the new travel time using V2I technology was multiplied by the AADT to give a total time saving per day. Values of time (25) were used to estimate the monetary value of the potential time savings. A number of assumptions were made for this purpose:

- The market value for commuting (€14.03/\$16.45/hr) was used to calculate potential savings for all weekday traffic
- The market value of leisure time (€12.75/\$14.95/hr) was used to calculate potential savings for all weekend traffic.
- The market value of in-work time (€34.33/\$40.25/hr) was used to calculate potential savings for all HGV traffic.

RESULTS AND DISCUSSION

Cost Calculations

The costs of installing V2I technology on the M50 were estimated using figures contained in the Final Report of the C-ITS Platform (27). The costs include those of the:

- Central ITS sub-systems
- Personal ITS sub-systems (e.g. mobile phones)

- Vehicle ITS sub-systems
- Roadside ITS systems

Personal ITS and in-vehicle sub-systems have not been included in this study.

The C-ITS Platform report notes that the main costs in rolling out C-ITS technology are the hardware costs for both OBUs and RSUs, and that once these are in place the cost of adding new services is relatively low. For this reason the services detailed in the report are broken down into Day 1 services which are expected to be fully functioning when roll out begins and Day 1.5 services which may or may not be active in some locations and can be deployed later in others (27).

When estimating the costs for the scheme a number of assumptions were made. First of all it was assumed that the central control system could be integrated into an existing traffic control system so there would not be a requirement to acquire new office space. The most likely location for this facility would be in TII's Motorway Traffic Control Centre in the Dublin Tunnel Control Building. The initial capital cost of the traffic control centre which has already been covered was assumed to be €1.5 million (\$1.77 million) and the annual maintenance costs were calculated at 10% of capital costs; €150,000 (\$177,000) (23). All of the costs mentioned below are taken from the C-ITS Platform report (23). The costs of connecting the RSUs with the traffic management centre were taken to be €1 million (\$1.18 million) and the cost of integration on the M50 was taken to be €350,000 (\$413,000); due to the presence of fibre-optic cables in ducting along the entire length of the motorway. Additional to this capital expenditure, the maintenance and operational costs were taken to be €400,000 (\$472,000) per year; €100,000 (\$118,000) for maintenance and €300,000 (\$354,000) for on-going software development. This amounts to a total capital cost of €1.85 million (\$2.18 million) and €550,000/yr (\$649,000/yr) (23) in maintenance and operational costs.

The second cost considered was the cost of the RSUs. One RSU will be needed per km in each direction (27), (16) and so, based on a length of 45 km for the M50, 90 RSUs will be needed. To ensure full coverage, a number of RSUs will also be located on approaches to the M50; a further 30 RSUs. For locations where an upgrade of an existing device or connection occurs the cost is significantly lower as some of the facilities required to connect an RSU are already in place. Examples of the types of location that could be upgraded are toll collection points; located at the beginning of the Port Tunnel, on the M50 mainline between Junction 6 - 7 and the network of existing traffic counters along the motorway. The cost of installing an RSU is taken to be €13,500 (\$15,930) (27). The cost is made up of €6000 (\$7,080) for the unit and the average installation cost will vary depending on the complexity of the location.

The annual maintenance and operational costs per unit are taken to be €356 (\$420) for new locations and €206 (\$243) for upgraded locations; this amount consists of 5% of equipment capital costs for routine maintenance (€300 (\$354) for new locations and €150 (\$177) for upgraded locations), €18.4/yr (\$21.7/yr) for power consumption and €37.68/yr (\$44.5/yr) for secure communications (23). The secure communications cost is intended to cover the costs incurred from a security credentials management system. The C-ITS report (23) also included an annual cost of €200 (\$236) to cover the cost of mobile data to transmit from the RSU to the central control system; this cost was not included in this calculation as the RSUs on the M50 can use fibre optic cables located in the road ducting for the transfer of data.

The total capital costs of the central control system and the RSUs are €3.27 million (\$3.86 million). The annual maintenance and operational costs are estimated to be €589,430 (\$695,565), over a predicted lifetime of 10 years the total for the costs would be €5,894 million (\$6,96 million). The project lifetime of 10 years was taken from the C-ITS report

(27). Summing all the costs mentioned above gives a total cost of €9.17 million (\$10.82 million) for the scheme (excluding the costs of OBUs).

After calculating the gross costs associated with the rollout of V2I technology on the M50 and application of the shadow cost of public funds of 130% with a discount rate of 5% as specified in CAF (25), the total calculated cost of installing V2I equipment on the M50 cost was €11.86 million (\$14 million).

Benefit Calculations

Reduction in Collisions

Figure 3 shows the location of the 98 rear end collisions on the M50 between 2009 and 2013 and also indicates whether collision rates are above or below the national average (22).



FIGURE 3 Rear end collisions and average collision rate

The percentage of accident reduction figures attributable to V2I as suggested in (27) were applied to the number of rear end collision that occurred from 2009-2013. When looking at the collisions, given the relatively low number of fatal and serious injury collisions (2 and 1

collisions respectively) over the 5 years of data, the potential reduction in these types of collisions was not factored into the results. It was not possible to obtain collision information for damage only collisions. For these reasons only minor injury collisions were considered when calculating the benefits of a reduction in collisions as a result of deploying V2I technology. When looking at rear end collisions, based on an average of 20 collisions per year with an average annual cost of €674,000 (\$795,360) (20* the average cost of a slight injury collision from CAF (21)) a reduction of 14.6% (rate of reduction for minor injuries from (27)) would result in a decrease of 3 collisions per year and a saving of €98,400.

After the annual collision saving was calculated, a discount rate of 5% was applied for each year thereafter and the total saving from a 14.6% reduction in rear end collisions was therefore calculated to be €789,664 (\$931,854) over 10 years.

Time Savings

To quantify the potential benefits of using V2I technology to improve the flow of traffic on the M50, different values of time from CAF were used (25). The market value for commuting (€14.03/hr) (\$16.56/hr) was used to calculate the value of potential savings for weekdays and the market value of leisure time (€12.75/hr) (\$15.05/hr) was used for weekends. To calculate the potential time saving for HGVs the percentage of HGVs passing each traffic counter was multiplied by the AADT. This number of HGVs was multiplied by the potential time saving on each section of the motorway to give the total HGV time saving. This time saving was multiplied by the value of in work time from CAF (€34.33/hr) (\$40.51/hr) to give the value of HGV time saved.

The total time saved based on a 2% increase in average speed on the M50 was 849 hours on an average day; an average of 45 hours would be saved by HGVs (Heavy Goods Vehicles) and the remaining 804 hours would be saved by other motorists. An example of the calculation for the time saving is shown in Table 2. The daily time saving for cars was multiplied by 260 to get the weekday time saving and by 105 to get the weekend time saving.

TABLE 2 Example of time saving calculation

Junction	% HGV	Length (km)	2016	AADT		138,945
				Speed (km/h)		94.1
				Time (minutes)		2.69
J5 - 6	7.20%	4.22	With V2I	Speed (km/h)		95.98
				Time (minutes)		2.64
				Difference (minutes)		0.05
				Hours Saved per day	Car	107
					HGV	8
				Hours saved per year	Car	39,220
					HGV	3043

The daily value of time saved on an average weekday was €11,280 (\$13,311) and €10,250 (\$12,095) for weekends with both of these having an additional saving of €1,540 (\$1,817) for freight. This works out as an annual saving of €4,571,256 (\$5,394,379) per year. A discount rate of 5% was applied to the calculated value of time saved. The total annual time was calculated to be 310,000 hours. Over a 10 year lifetime of the project the calculated time saving would be 3,100,000 hours and using the values of time saved from CAF (25) this was calculated to result in a potential saving of €36,685,521 (\$43,291,299).

Benefit to Cost Ratio

Using the calculated cost of €11,86 million (\$14 million) for installing V2I technology calculated earlier and the savings to accrue due to collision reduction, €789,664 (\$931,854), and time saving, €36,685,521 (\$43,291,299), the calculated benefit to cost ratio was found to be 3.2:1. The level of benefit to cost ratio would be considered strong and convincing in the case for funding of a road infrastructure project and in this case the benefits of introducing V2I technology on the M50 motorway would be greatly beneficial.

Many of the assumptions made in this CBA were made on a conservative basis, so as not to overestimate the possible benefits or underestimate the costs of the V2I technology. One of the conservative assumptions made was that the lifetime of the project would be 10 years. The suggested lifetime of a transport project in CAF is typically 30 years (25) and if the lifetime considered here was extended accordingly the scheme would have resulted in a higher benefit to cost ratio. Having said that, the rapid developments in the complexity of transport technology, especially autonomous vehicles, could render technologies like V2I communications obsolete in a much shorter timeframe.

While the effects of varying MPR (Market Penetration Rate) were not studied in this CBA it has been shown that even at relatively low MPRs there are likely to be significant benefits in terms of both safety and time saving (13). Given that all the car manufacturers participating in the Car 2 Car Consortium have agreed to install V2I compatible technology in new cars by 2019 it can be assumed that there will be a rapid increase in the number of connected vehicles on Irish roads in the coming years. It is also assumed that many motorists will choose to install OBUs (on Board Units) in their cars once they become an as-standard feature in satellite navigation devices as has occurred in Japan (8).

Due to the lack of traffic information available from TII the section of the M50 between Junctions 3 - 4 was not included in the time savings calculation. Due to the fact that Junction 4 is a relatively minor junction it could be assumed that the volume of traffic using this section of the road is similar to the volume between Junctions 4 – 5. The potential time saving between Junctions 4 – 5 was calculated to be almost €500,000 (\$590,000) per year or €4 million (\$4.72 million) over the lifetime of the project once a discount rate of 5% is applied. Given this potential saving and that the section of the M50 for which there was missing data was still included in the costing of rolling out V2I technology, it should be noted that the result of the CBA most likely underestimates benefits due to time saved.

Due to a lack of data it was not possible to assess the number of damage only collisions occurring on the M50. This meant only collisions causing injuries were taken into account when calculating the potential safety benefits. Although the cost of damage only collisions is relatively low they tend to occur in much greater numbers than injury causing collisions. In 2013, there were 4,976 collisions in Ireland resulting in injuries or fatalities compared to 21,734 damage only collisions (22).

Other significant assumptions were made when calculating the potential benefits of the scheme. When breaking down the time savings for different values of time it was assumed that all vehicles using the M50 on weekdays were commuting and all vehicles using it on weekends were travelling for leisure purposes. While this assumption clearly does not hold, it gives a reasonable approximation of the breakdown in usage of the M50 for these purposes. It was also assumed that all HGVs on the M50 were travelling during in-work time which may have resulted in overestimation in calculated benefits in terms of time saved.

Another assumption made was that the level of traffic on the M50 would remain static at the level recorded in 2016 over the 10 year duration of the project. While there was a significant decrease in traffic on the M50 due to the economic recession (28), in more recent years there has been an increase in the number of vehicles using the motorway every day e.g. the AADT on one stretch of the M50 in 2013 was 111,045 compared with 129,641 in 2016.

If a similar increase was to occur over the lifetime of the project the time savings would be significantly higher than was estimated.

Other Costs and Benefits

As described in the literature review, there are a number of other costs and benefits that would be present after the deployment of V2I technology on Irish roads which have not been calculated in this study. Many of these are difficult to quantify including a potential medium term reduction in the cost of insurance due to a reduction in the number of collisions occurring; a potential reduction in CO₂ and air pollutant emissions due to earlier deceleration on approach to traffic jams and an improvement in both the quality and quantity of traffic data available to transport planners. As shown by Nasir et al (29), the use of real time traffic information can result in a decrease in vehicular emissions as well-informed drivers can select a more efficient route. Some of the savings in greenhouse gas emissions are offset by the power consumption of the RSUs, OBUs and the central computer system and also by the embodied greenhouse gases from the manufacturing of these system components.

Improved tolling efficiency is another potential benefit of using V2I technology. Toll plazas can be expensive to maintain and cause significant traffic delays. Barrier free tolling already exists on the M50 between junction 6 – 7 but this has been criticised as being inequitable as the charges only apply to drivers using one section of the motorway and do not take account of the distance travelled. This means someone traveling 3.3 km between junctions 6 – 7 pays the same amount as someone traveling nearly the whole length of the motorway from north to south (45 km). The use of electronic toll collection as part of a roll-out of V2I communications on the M50 could allow road administrators to introduce a more equitable tolling system.

It should be noted that the analysis depends entirely on the unverified V2I related crash reduction rates cited by the FHWA (1) and unspecified assumptions regarding market penetration rates to which such an analysis would be particularly sensitive.

CONCLUSIONS

The objective of the paper was to test the hypothesis that deployment of V2I communications technology on a three-lane busy orbital motorway (expressway) around a medium sized European city is economically viable. Based on the results of the cost benefit analysis, it can be concluded that it would be economically viable to deploy V2I communications technology on the M50 motorway around Dublin in Ireland. Based on both the collision reduction (€789,664) (\$931,854) and time saving (€36,685,521) (\$43,291,299) compared to the costs of installing V2I technology (€11,860,000) (\$14 million) the calculated benefit to cost ratio was 3.2:1 which suggests this project would offer good value and generate significant benefits. The potential benefits due to improved travel times dominate the total savings, far outweighing the potential safety benefits, which suggests that a high AADT should be the main consideration when selecting other routes for a future suitability audit.

While the M50 was selected for an audit to establish the feasibility of this emerging technology there are also a number of other roads which would also prove to be suitable locations for the use of V2I communications technology. They include a number of the major interurban motorways which connect to the M50 on approach to Dublin or the N40 southern ring road in Cork. Further work could feature an assessment of the potential benefits of both V2I technology and V2V on the M50.

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