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Research Article

Transport Sector Impacts of a Border between Ireland and Northern Ireland after a Hard Brexit

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More than half of British voters chose to leave the European Union (EU) leading to a series of negotiations between the United Kingdom and the EU. The withdrawal of the UK from the EU is widely referred to as Brexit. As the only country that shares a land border with the UK, the impact of Brexit on Ireland is expected to be greater than on any other European country. The objective of the research is to evaluate the potential impact of Brexit on the transport sector in Ireland at a micro level by focusing on cross-border commuters and by also assessing the impact on road freight transport. Potential crossing scenarios are examined at six crossing locations. Assuming a hard border is implemented, each crossing is modelled in VISSIM, a microscopic traffic flow simulation software, using traffic data from Transport Infrastructure Ireland (TII) and dwell time estimated based on the US–Canada border crossings. Six scenarios are considered to determine the impact on cross-border traffic at different flow conditions and with varying levels of technology used in border infrastructure leading to short versus long processing times. The paper evaluates travel measures including delays, queue lengths and emissions. The worst-case scenario has a vehicle delay of 18.4 min and the highest delay-associated costs across all locations modelled are estimated at €60.7 million per year. Estimated emissions generated at the border crossings raise concerns about environmental impacts of a hard Brexit. Interviews with stakeholders emphasized the critical role of technology in reducing the impact of a hard Brexit on cross-border commuters and on the freight sector. A key finding is the importance of using technology tools to facilitate controls and reduce processing times. The results indicate that technology use leads to significant time and cost savings as well as reduced environmental impacts.

1. Introduction

Over half of British voters chose to leave the EU by March 2019 and the UK government has been negotiating a deal with the EU regarding the details of the exit but a final agreement has yet to be reached. The EU regulates the movement of goods and services across the border while the Common Travel Area treaty, signed before Ireland and the UK joined the EU, regulates the movement of British and Irish citizens. The uncertainty regarding the nature of the border after Brexit arises from varying views about the movement of non-EU nationals and freight movement. The transport sector affects the movement of both people and goods and it is important to understand how Brexit will impact on it. The aim of this research project is to evaluate this impact with a focus on freight and car transport across the border between Ireland and Northern Ireland.

For the purposes of this research, a hard Brexit is defined as the UK giving up full access to the European single market and full access to the customs union meaning that the UK would fall back on World Trade Organisation (WTO) rules for trade with countries in the EU. A soft Brexit is defined as the situation where after the UK leaves the EU, it would still maintain a relationship with EU countries as close as possible to the existing relationship. Goods and services would continue to be traded with EU countries on a tariff-free basis and the UK would remain within the EU's custom union meaning that exports and imports would not be subject to border checks.

Carson [1] expresses his concerns about the cost of Brexit to Ireland. Time delays due to border controls and processing of customs documentation, the imposition of tariffs, increased transport costs and the potential for a divergence in standards on regulations and labelling of food packaging are among the main challenges that will face Irish businesses in a post Brexit era. Another report [2] describes a hard Brexit as increasingly likely with final details depending on political will and negotiations. Fabbrini et al. [3] shed light on the damaging disruption caused by a hard border on normal mobility on the island of Ireland, including trade and the routine commuting of individuals. While the analysis was not technical in nature, it addressed policy issues affecting the transport sector and supports the need for a detailed study of the impact of Brexit on cross-border travel.

The possibility of a hard Brexit becoming a reality pushed economists and business leaders in Ireland to consider alternative routes for freight diverting it away from the UK to avoid potential tariffs and delays due to border procedures, especially on the land bridge routes [4]. Lyden et al. [5] suggest prudence in planning for a hard Brexit and an evaluation of its impact thereof.

The border between the two countries currently has more than 200 crossing points and a hard Brexit would lead to a drastic drop in that number as checkpoints and customs would be introduced on both sides [6]. Donegal has the largest number of daily commuters accounting for 60% of all cross-border commuters; therefore, assessing a scenario with crossing points in Donegal is needed [7]. A hard border will also affect the monthly volume of 1.85 million cars and 208,000 freight movements crossing the Irish border [8]. Caulfield et al. [9] examined the impact of Brexit on one border crossing along the M1 motorway in the case of a hard border between Ireland and Northern Ireland. The focus on the M1 was due to its significance for trade and for travel linking Dublin and Belfast.

Similar to car transport, freight will be significantly affected by Brexit and the impact will largely depend on the outcomes of the negotiations regarding whether the UK will be part of the European Economic Area (EEA), the European Free Trade Association (EFTA) or Customs Union after Brexit. UK and Irish retailers, manufacturers and businesses in agri-food, among others, operate island-wide supply chains thanks to shared EU membership allowing large volumes of goods (finished, semi-finished goods and raw materials) to be transported across the border [2].

Irish exports to continental Europe are worth €45 billion while the ones to the UK are valued at €15 billion and it is unclear how that number will be affected by Brexit exactly, but it is expected to decrease [10]. The routes these exports go through will also be impacted upon as 80% of Irish road freight heading to mainland Europe goes through the UK saving traders time and allowing them to export perishable goods reaching the EU in less than 12 hours [10]. The percentage of Irish imports that are from markets outside the UK but transported through the UK land bridge is approximately 11% which is significantly smaller than the one for exports [11]. Road transport in Ireland accounted for over 90% of inland freight transport including cross-border freight movement [12]. This high percentage is explained by the lack of a strong rail network that can be used to transport freight in large volumes. It also justifies the need to model freight movement across the border with Northern Ireland.

Two-thirds of Ireland's leading exporters ship their products using a border-free UK land bridge of short-sea crossings

Figure 1: Alternative freight routes [10].

and the Eurotunnel link to France [13]. This implies that increased costs will affect the majority of exporters significantly and detailed estimates are required to accurately quantify this effect. Figure 1 shows potential routes heavy goods vehicles HGVs can take instead of crossing to mainland Europe through the UK, along with the duration of each journey. A hard Brexit requiring customs' checks while entering and leaving each of the UK and EU as well as potential quality control on goods is expected to result in considerable delays and increased costs [10].

Lyden et al. [5] analyze the Irish unitized freight, including goods transported in trailers on roll-on roll-off ferries (Ro-Ro) and in containers on load-on load-off vessels (Lo-Lo), and highlight the critical consequences Brexit will have on the two thirds of unitized freight using the land bridge to access the mainland European market. If the UK leaves the Customs Union, freight following the UK route to the rest of Europe will go through four sets of customs checks causing long queues and costly delays. An example to demonstrate the significant delays was given for the Port of Dover where a passport check delay of 2 minutes for each of the 10,000 trucks passing through the port daily would result in a 17 mile tailback [5]. The report also addresses the growing dominance of Dublin Port in the unitized freight sector over the past three decades.

As part of the background to the research presented here, a review of other international border crossings was completed as a means of assessing their potential characteristics for use in the Ireland–UK border context. They include the Switzerland–EU border where Switzerland is a member of the European Free Trade Association, the Norway–EU border where Norway is part of the European Economic Area and the Canada–US border where both countries are members of the North American Free Trade Agreement (NAFTA) [14].

The majority of Swiss citizens in 1992 voted against joining the European Economic Area while their neighbors in Liechtenstein voted for the membership. Given the small size of Liechtenstein and its regional union with Switzerland, recognized in the EEA agreement, reintroducing a border control area would have inhibited the European integration Liechtenstein was hoping for through joining the EEA. Special bilateral agreements to resolve the issue involved parallel

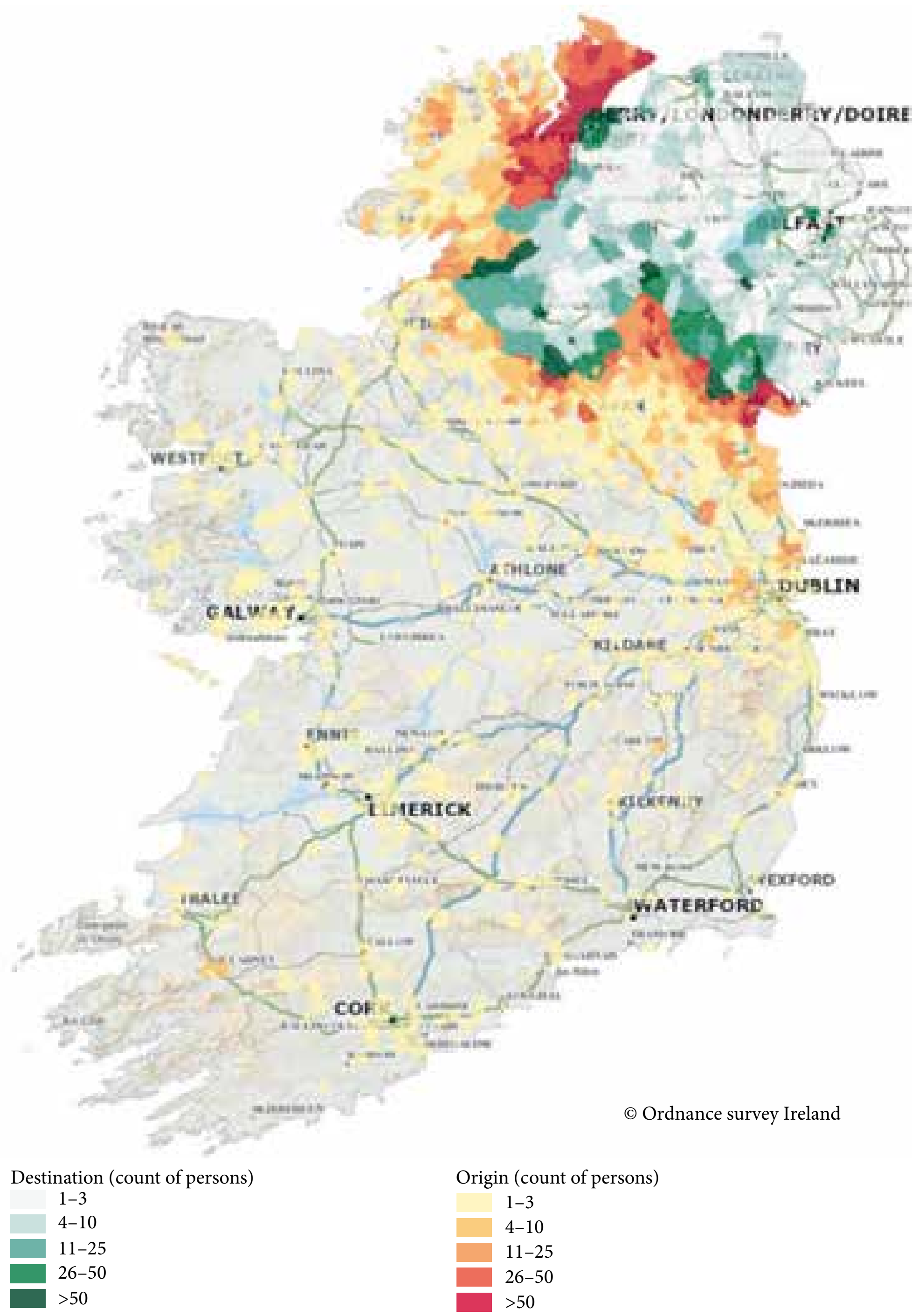

Figure 2: Cross-border commuters from Ireland to Northern Ireland [7].

marketability of goods, requiring the application of EU and Swiss regulations in the Liechtenstein market [15]. Liechtenstein created control systems to ensure that EEA products that differ from Swiss standards are not marketed in Switzerland, and that Swiss products that do not comply with EEA regulations are not exported to EEA countries. Most products covered under this deal were medicinal, chemical, or agricultural products. These types of products are highly relevant for the case of Ireland as 50% of medicines produced in the country are exported, the majority of which go through the UK for other European countries. Scotland and Northern Ireland are larger in size than Liechtenstein and have a different and arguably more complex political context that adopting such a principle and assuming its success based on the Liechtenstein model is not a viable approach [15].

Norway is a member of the European Economic Area (EEA), but is not a member of the EU Customs Union, which makes its border with Sweden an EU–external border

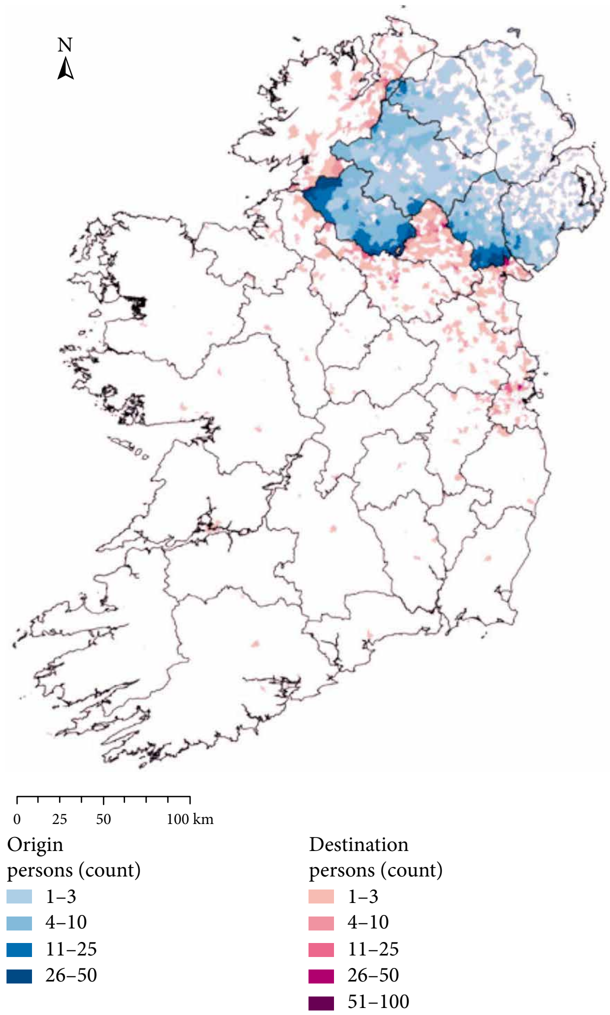

Figure 3: Cross-border commuters from Northern Ireland to Ireland [7].

requiring customs control. Agricultural products and fisheries are excluded from the EEA agreement so imports in this category are controlled and made subject to tariffs and quotas while other goods require minimum compliance checks as certification procedures and standards are consistent with those of the EU [16]. Given that both Norway and Sweden are part of the Schengen Agreement, there is limited passport control for people moving across the border that spans 1600 kilometers and over 80 crossings. Fourteen of these crossings have checkpoints for customs control regulated by administrative arrangements that Norway made with Sweden after it joined the EU in 1995. These arrangements replaced the customs agreement between the two countries since the 1962 Helsinki Treaty [16]. Norway and Sweden use Automatic Number Plate Recognition (ANPR) cameras at the border crossings where neither Swedish nor Norwegian customs posts are present, while the other crossings use an online system where declarations and pre-arrival information are submitted. This facilitates customs operations and reduces delays at the border proving that investing in technology is crucial and should be given a high priority in the case of a hard Brexit. The cross-border trade value between Ireland and Northern Ireland is significantly lower than the one between Sweden and Norway but lessons can be learnt from the Norwegian model as it is considered the most advanced customs solution in the world [16].

The US and Canada are both part of the North American Free Trade Agreement (NAFTA), but are not part of a customs union so customs procedures are followed for goods crossing the border. American and Canadian citizens travel between the two countries visa free but passport control is required at the 120 land ports of entry spanning the 8,891 kilometer long border [16]. The benefits of technology used at the border makes checkpoints more efficient on both sides [16]. More than 5 million trucks cross the US–Canada border every year and 32% of traded goods by value are intra-firm trade, which sheds light on the high integration of the Canadian and American economies. Technology is extensively used at the border for risk management, from automatic number plate recognition and barcode scanning to Radio Frequency Identification (RFID) and biometric data for approved drivers' cards. RFID readers are available at 39 crossing points accounting for 95% of all trade, which expedites the crossing process based on agreed compliance measures and preapprovals.

Another example that might be considered for the Irish border in the case of a hard Brexit is the Free And Secure Trade Program (FAST) between the US and Canada which allows low risk commercial goods to be cleared faster. Bar code scanning of customs documentation, automatic number plate recognition, RFID technology, and biometric data in cards for approved drivers are used to speed up vehicle crossings. RFID reader technology has been installed on 95% of the 39 border crossings. Dedicated FAST lanes are located at four border locations. An investigation at the Pacific Highway crossing in 2007 found that participants in the FAST program experienced time benefits of up to 81% (15.6 minutes versus 81 minutes in a regular lane) [17].

An eManifest system is used by the US and Canada for compulsory pre-arrival information from carriers. Information is submitted no less than one hour prior to arrival at a land border, or thirty minutes in the case of FAST members. Data collected in 2013 showed average waiting times at three major crossings for trucks into the US at between 18.9 and 27.1 minutes and for Canada between 16.8 and 17.6 minutes [18].

Rajbhandari et al. [19] state that stakeholders at border crossings need sufficiently accurate information about delays and their related costs as conditions vary by time of the day. Previous reviews make assumptions about a hard vs. soft border or provide recommendations at a general level about the future of Irish-British border. However, a common conclusion from our literature review is the necessity for a detailed study on the impact of Brexit on the transport sector in Ireland. This paper evaluates the potential impact on a micro level by focusing on car commuters crossing the Irish and Northern Irish border and on freight transport between Ireland and the rest of Europe. The microlevel review uses the VISSIM model to estimate travel delays for different crossing scenarios, caused by the introduction of border controls. The environmental impacts of these delays are evaluated and the delay-associated costs are calculated to quantify the financial impact of a hard border on cross-border travel.

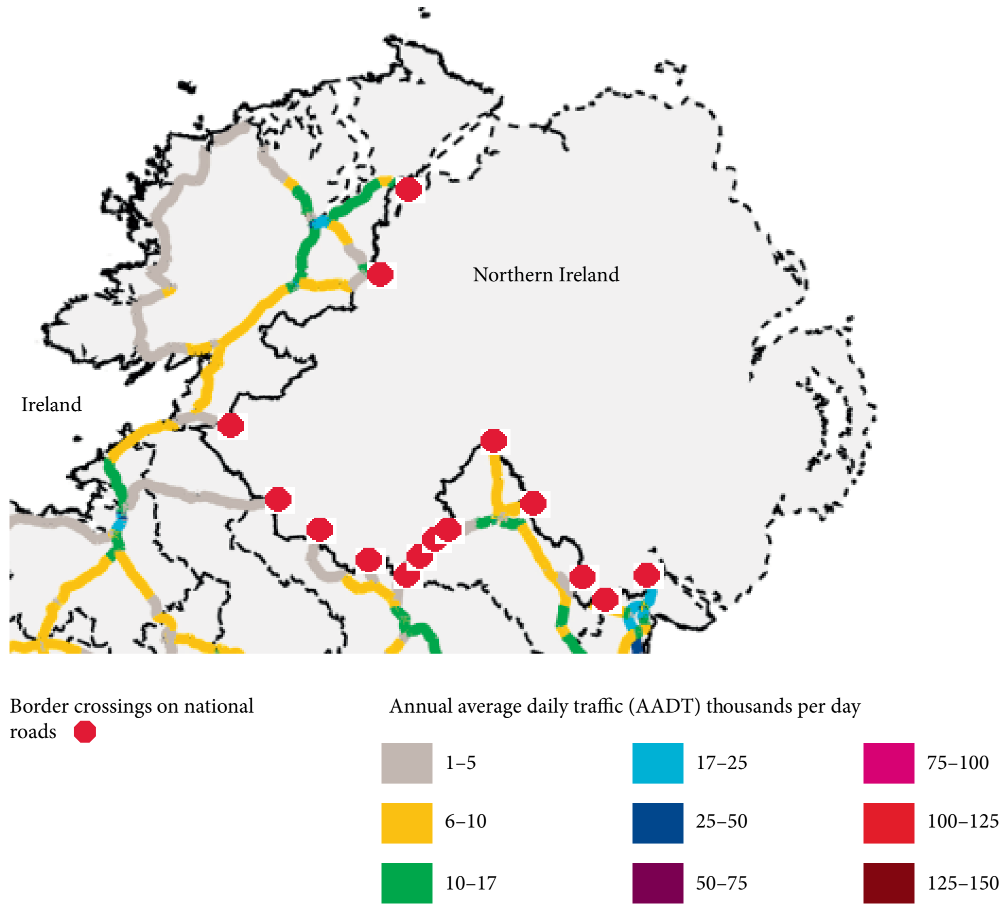

Figure 4: Locations of existing crossing points on national routes and the traffic flow in AADT at each [21].

2. Methods

Data from the Central Statistics Office (CSO) following the 2016 census put the number of daily commuters from Ireland to Northern Ireland crossing the border for school or work at 9,336 in 2016. This is down from 9,536 in 2011 with a 26% decrease in the number of people crossing for school and a 10% increase in the number of commuting workers [7]. Figures 2 and 3 show the areas where the concentration of cross-border commuters is higher.

Although there are currently more than 200 crossing points, it is expected that crossing points under a hard Brexit scenario for consideration would be limited to national road crossing points of which there are fifteen. The locations of the existing crossings and the annual average daily traffic at each are shown in Figure 4. Using the information from the CSO about current commuting demand, six locations were selected for modelling the impact of a hard border, as shown in Figure 5. They include:

(1) N01 North of Jn20 Jonesborough, Ravensdale, Co. Louth.
(2) N02 Between NI Border and Emyvale, Mullinderg, Co. Monaghan.
(3) N03 Between Belturbet and George Mitchell Bridge at NI Border, Belturbet, Co. Cavan.
(4) N16 Between Enniskillen and Sligo, McNean Court, Co. Sligo.
(5) N14 between Lifford and Letterkenny, Drumbuoy, Co. Donegal.
(6) N13 Between Bridgend and Burnfoot, Co. Donegal.

The N01 accounts for 28% of all recorded vehicles on the national roads crossing the border, followed by the N13 and N14. The 3 routes combined make up 53% of all traffic volumes and 52% of all goods vehicles [20].

2.1. Scenario Design. For each crossing location, annual traffic volumes provided by TII are used to estimate an average growth rate, which is then used to estimate traffic volumes in 2019 when the UK is expected to leave the EU. It is assumed that traffic volumes will grow at a rate similar to the average growth rate over the past 2–4 years and any reduction in volumes as a result of Brexit is not accounted for. Data from the past 4 years are available for the first location, while only the past 2 years' volumes are available for the other 5 locations.

At each crossing location, traffic data provided by TII are analyzed for hourly traffic volumes in the first 6 months of 2018 and the day with the highest volume is used for vehicle inputs. Three volumes are identified from that day for each direction (Ireland–UK and UK–Ireland) in order to assess flow

Figure 5: Locations of crossings points to be modeled [22].

Table 1: Time distributions for dwell times (s).

Time distribution	Lower bound	Upper bound	Std dev	Mean
Low car	0	20	0.5	15
Low HGV	0	35	0.5	30
High car	0	40	1	30
High HGV	0	70	1	60

Table 2: Value of travel time [24].

Type of travel	Value of time €/hour (2011)	Value of time €/hour (2019)
In-work	€34.33	€42.72
Leisure	€12.75	€15.86
Commuting	€14.03	€17.46

situations at different times of the day: peak volume, off peak volume and free flow volume. Peak volumes are taken as the highest volumes recorded that day while free flow volumes are the lowest. Off-peak volumes are assumed to occur during an average off-peak hour. Each volume is considered with low delay (technology used such as pre-authorisation) and high delay (no technology used), which leads to 6 scenarios per location and 36 scenarios modelled overall.

The desired speed is obtained from the speed limit of each road modelled and speed distributions are created in VISSIM accordingly. The Border Control Area (BCA) requires vehicles to slow down and eventually come to a stop so 3 speed decisions are defined before the BCA on each direction: 80 km/h at 300 m, 50 km/h at 150 m and 20 km/h at 50 m and a speed decision is defined after the BCA to allow vehicles to travel at the initial speed. Reduced speed areas are created at the BCA on each direction with a desired speed of 12 km/h for both cars and HGVs. Each area is 12 m long ending at the checking counters and the 12 m accounts for enough space for 2 vehicles and a safe space between them [9]. Similar speed profiles are also created at the cross-border bridges where the speed limit is 40 to 50 km/h.

Processing times will vary based on how much technology is used. Looking at the US–Canada Border, a program called NEXUS was implemented to expedite the processing of preapproved vehicles by allowing them to use dedicated NEXUS lanes at border crossings. The processing time in NEXUS lanes was 25 seconds while general lanes had an average processing time of 58 seconds [16]. These averages are used as a benchmark in estimating processing times at the Irish border. If technology tools are used to preapprove certain vehicles or to facilitate the crossing in other ways, then a short delay is expected. Otherwise, a longer delay is modelled for the worst-case scenario. The terms "short delay scenario" and "short processing time scenario" are used interchangeably in this paper and the same applies for long delay scenarios. Processing times for cars are shorter than those of HGVs and values found in the US–Canada model are used. In the case of cars, a processing time in the case of a short delay is considered to be 20 sec and in the case of a long delay 40 s. In the case of HGVs, a processing time with a short delay is considered to be 35 s and with a long delay of 70 s.

In order to model the crossing of vehicles, a number of channels are assumed to be built at the border. The US–Canada border has 6 channels at the Niagara Falls crossing on either side while the Vancouver crossing has 9 channels. The American–Canadian border also has separate checkpoints for each country, a few meters apart. Given the relationship between Ireland and Northern Ireland and for the sake of efficiency, the border checkpoints designed are assumed to handle both exit and entry checks for both countries. An example where this is the case is the Argentinian–Chilean border where one office has officials from both countries and gives exit stamps from one country and entry stamps to the other at the same time. The first crossing location is assumed to have 6 channels in each direction while the other 5 locations have 4 channels in each direction given their relatively lower traffic volumes compared with crossing 1.

2.2. VISSIM Model. The modelling software used for the microsimulation is VISSIM [23]. It is typically used to model traffic patterns and to compare different demand scenarios. It is highly flexible and different road geometries can be considered in detail along with different classes of vehicle. In this case, a VISSIM model is created for each of the 36 scenarios based on the data discussed above. The length of the road section modelled varied by location with the first one (N1/M1) being the longest at ~9 km and the other 5 locations having an average of 6 km in length. Table 1 summarizes the time distribution created in VISSIM. The processing times are assumed to be the same at all crossing locations.

Measures reported from VISSIM are distance traveled, travel time, queue length, vehicle delay, stop delay, number of stops, and Level of Service (LOS) for both the Ireland–UK and UK–Ireland directions. Level of Service uses letters A through F to specify the quality of traffic where A corresponds to free flow (best) and F corresponds to forced flow (worst). Total delays and average speed are also reported for each scenario modelled. Given the volume of the outputs, the results presented in the paper will focus on vehicle delay.

The environmental impact of a hard Brexit goes beyond emissions caused by delays at the border but it is nonetheless important to measure these emissions by location. Carbon Monoxide (CO), Nitrogen Oxides (NOx), and Volatile Organic Compounds (VOC) emission levels will be calculated.

2.3. Estimating Cost. Using the Common Appraisal Framework 2016 provided by the Department of Transport, Tourism and Sport (DTTAS), the costs associated with the delays caused by the implementation of a hard border are calculated [24]. The framework provides a value of travel time for in-work, leisure, and commuting in 2011 and estimates the growth rate to be 1.4% between 2010 and 2014 and 3.6% between 2015 and 2019. Market prices are used in the cost calculations and Table 2 shows the value of time by type of travel in 2011 and 2019. The latter values are multiplied by the total delay (in hours) for each type of travel in order to obtain the delay-associated costs of a hard Brexit at each crossing location modelled. The overall cost of a hard Brexit includes the cost of extra fuel consumed by vehicles on the road, the cost of additional infrastructure that needs to be put in place at each checkpoint, operating costs at the border in addition to the delay-associated costs evaluated in this research project.

HGVs trips are assumed to be in-work regardless of the time of day the trip is made, while car trips are assumed to split between commuting and leisure. Trips made between 5am and 9am are assumed to be 100% for commuting while the rest of the day is distributed between commuting and leisure in a 50–50 split or 30–70 split.

It is worth noting that 5 pm to 8 pm is prime commuting time but many leisure trips occur during that period as well and exact data on the distribution of trips by type are not available so the two scenarios of 50–50 and 30–70 are considered for commuting-leisure. Weekends tend to have a higher percentage of leisure trips but the days modelled are the ones with the highest traffic volumes observed whether they are weekdays or weekends so a generalization is made in this regard to get an estimate of the delay costs per day and per year.

The scenarios modelled at each location are peak, off peak, and free flow. From observing the trends of different traffic volumes along the day, it is assumed that 6 h per day correspond to peak traffic, 11 h to off-peak traffic and 7 h to free flow traffic (10 pm–5 am). Within off-peak travel for cars, the 5am to 9am segment is assumed to be 100% for commuting so 4 h of off -peak cost results are calculated using the commuting value of travel time and the other 7 h are calculated for the 50–50 and 30–70 scenarios. The overall result obtained is the delay cost per day and two estimates are calculated: short and long based on best and worst case scenarios (technology vs. nontechnology used).

2.4. Qualitative Analysis. Interviews were conducted with experts such as representatives of the Irish Exporters Association, the Department of Transport, Tourism and

Table 3: Summary of scenario design values for CL1.

Scenario	Direction	Time of day	Volume (2018) (veh/h)	Volume (2019) (veh/h)	Car (%)	HGV (%)	Dwell time(s)		Speed (km/h)
							Car	HGV	
Peak-short delay	IE–UK	16:00–17:00	1331	1395	92.6	7.4	20	35	100–120
	UK–IE	16:00–17:00	1362	1427	93.7	6.3	20	35	100–120
Peak-long delay	IE–UK	16:00–17:00	1331	1395	92.6	7.4	40	70	100–120
	UK–IE	16:00–17:00	1362	1427	93.7	6.3	40	70	100–120
Off-peak-short delay	IE–UK	07:00–08:00	449	471	78.2	21.8	20	35	100–120
	UK–IE	07:00–08:00	904	947	85.4	14.6	20	35	100–120
Off-peak-long delay	IE–UK	07:00–08:00	449	471	78.2	21.8	40	70	100–120
	UK–IE	07:00–08:00	904	947	85.4	14.6	40	70	100–120
Free flow-short delay	IE–UK	01:00–02:00	107	112	73.8	26.2	20	35	100–120
	UK–IE	01:00–02:00	51	53	78.4	21.6	20	35	100–120
Free flow-long delay	IE–UK	01:00–02:00	107	112	73.8	26.2	40	70	100–120
	UK–IE	01:00–02:00	51	53	78.4	21.6	40	70	100–120

Table 4: Base data for CL3-6.

CR no.	2018 AADT (vehs)	Growth rate (%)	Peak volume date	Peak daily volume in first half of 2018 (vehs)	% HGV (2018)	Peak; off-peak; free flow hours	Speed profile (km/hr)
3	3,991	3.96	24th June	682	9.8	11:00–12:00; 07:00–08:00; 04:00–05:00	80–100
4	2,739	2	18th Feb	412	5.6	12:00–13:00; 07:00–08:00; 04:00–05:00	80–100
5	12,106	7	4th May	1,347	4.2	18:00–19:00; 7:00–8:00; 2:00–3:00	80–100
6	8,891	3.5	21st Mar	1,166	4.1	17:00–18:00; 7:00–8:00; 2:00–3:00	80–100

Table 5: Summary of peak vehicle delays.

Crossing	Peak delay (min)		Time saving improvement by using technology (%)
	Short (technology employed)	Long (no or minimal technology employed)	
1	10.83	18.47	41
2	11.65	18.02	35
3	0.99	8.75	89
4	0.52	1.10	53
5	0.18	0.21	11
6	0.55	5.31	90

Sport in Ireland, Freight Transport Association UK, Transport Infrastructure Ireland, the Irish Business and Employers Confederation (IBEC) among others with the aim of providing a qualitative analysis of the impact of Brexit on the freight sector. A summary of the findings from the interviews will be included later in the discussion.

2.5. Data Input. The data used as inputs to VISSIM are summarized below for the model year 2019. Detail on how the data were processed before inputting to the model are presented below for Crossing Location (CL) 1 and similar methods were used for the other CLs. CL1 is located on the M1 north of Jn20 Jonesborough, Ravensdale, Co. Louth. The annual average daily traffic (AADT) volumes provided by TII for the last four years are used to estimate the average growth rate of 4.8%, which is then used to estimate traffic volumes for 2019 when Brexit will be in effect. The AADT in 2018 was 24,216 vehs and the % HGVs is assumed to remain at the same value as in 2018 at 10.5%.

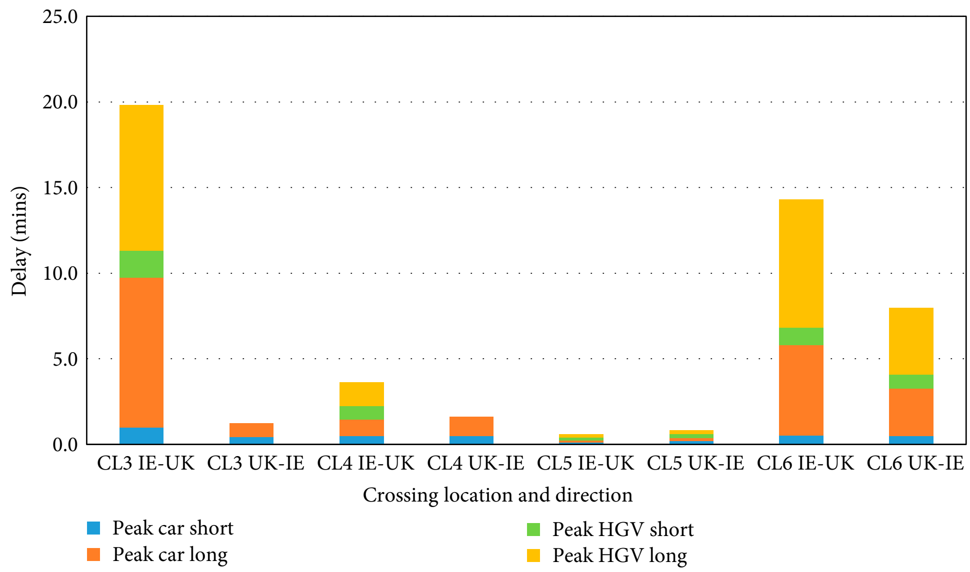

Figure 6: Delay at crossings by scenario.

Table 6: Summary of delay costs per day.

Crossing	Commuting–leisure distribution			
	50–50		30–70	
	Short	Long	Short	Long
1	€53,704	€122,483	€52,927	€120,886
2	€15,584	€23,731	€15,293	€23,291
3	€1,366	€7,772	€1,341	€7,626
4	€555	€1,083	€545	€1,063
5	€1,938	€3,251	€1,911	€3,205
6	€2,153	€7,968	€2,124	€7,843
Total	€75,300	€166,288	€74,140	€163,914

Table 7: Summary of delay costs per year.

Crossing	Commuting–leisure distribution			
	50–50		30–70	
	Short	Long	Short	Long
1	€19,601,944	€44,706,464	€19,318,262	€44,123,459
2	€5,688,008	€8,661,673	€5,581,981	€8,501,137
3	€498,486	€2,836,944	€489,380	€2,783,364
4	€202,543	€395,363	€198,785	€388,008
5	€707,547	€1,186,488	€697,515	€1,169,883
6	€785,848	€2,908,279	€775,104	€2,862,662
Total	€27,484,376	€60,695,211	€27,061,028	€59,828,514

Traffic data at this location can be found on the TII website for every day of the year [25]. Hourly volumes from January to July 2018 were assessed to obtain the hour with the maximum volume of 2,693 vehs (both directions included) on June 15th. Peak, off-peak and free flow hourly volumes were then obtained for that day to which the 4.5% growth rate mentioned previously was applied to obtain the projected volumes for 2019. The percentage of HGVs is also obtained from the TII data set for each of the scenarios modelled. The desired speed is obtained from the speed limit of 120 km/h on the M1, N1 and A1 and a speed range of 100–120 km/h is considered.

Peak volumes are observed at 16:00–17:00 which is a prime commuting time. The crossing is not close to any major town or city and so the off-peak volume was obtained from traffic flows at other times of the day when peaks were not observed. The modelled hour representing off-peak in this case was 07:00–08:00. Free flow volumes are observed at 01:00–02:00 when most people are sleeping and minimal road traffic is expected. Over a fifth of the traffic at this time is made up of HGVs. A summary of the inputs to VISSIM for the six scenarios modelled for CL1 is presented in Table 3.

Similar tables of input values were produced for the other CLs from the following starting positions. In the case of CL2, located on the N2 close to Emyvale, Mullinderg, Co.Monaghan, a 2.8% growth rate over the previous four years was obtained and used with the 2018 AADT of 6,429 vehs to obtain the model input flow for 2019 with the proportion of HGVs at 12.1%. In this case, the peak hour volume of 1,060 vehs in the period Jan–Jun 2018 occurred on May 20th. The speed range used was 80–100 km/hr and this is different to the previous CR as this is a national road with a speed limit of 100 km/hr, whereas CL1 is on a motorway standard road. Peak volumes in this case were observed at 13:00–14:00, for off-peak a model hour of 07:00–08:00 was used and free flow volumes were observed at 05:00–06:00. The starting position for determining inputs for the other CLs is presented in Table 4.

3. Results

The scenarios were evaluated using a number of VISSIM output measures including peak vehicle delays, delay associated costs and emissions.

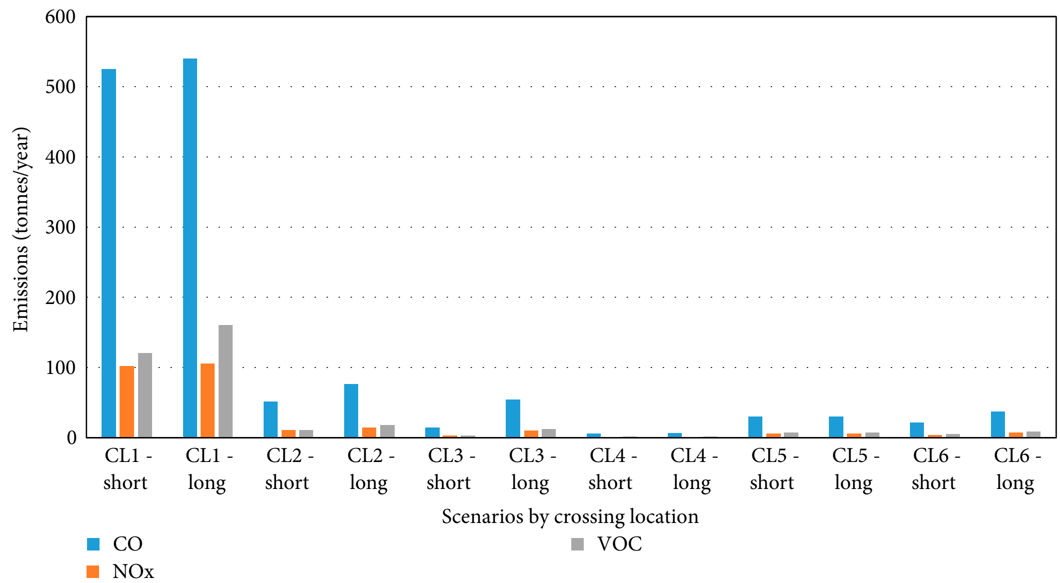

Figure 7: Emissions levels produced for each scenario.

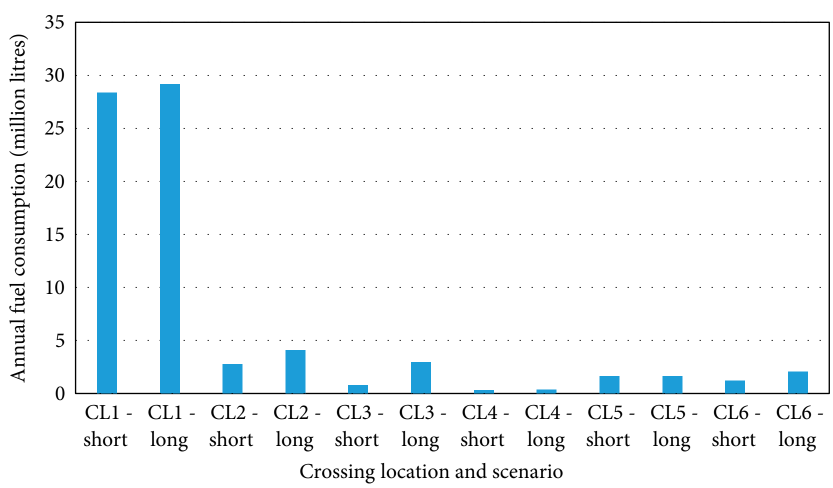

Figure 8: Annual fuel consumption for each scenario.

3.1. Peak Vehicle Delays. Vehicle delays are evaluated for each scenario at the 6 crossings modelled and values from the peak flow scenarios are shown in Table 5 by crossing location and by delay type. Delays in minutes for vehicle crossing from Ireland to Northern Ireland are provided for more practical interpretation and the percentage of time savings is calculated to highlight the difference between vehicle delays in short and long delay scenarios at similar traffic conditions. Short delay scenarios correspond to shorter processing times where technology tools are assumed to facilitate the border control processes, while long delay scenarios correspond to longer processing times where no or minimal technology infrastructure is used at the border. Processing times are not included in the delays below.

The longest vehicle delay of 18.47 min is observed at CL1 in the long delay scenario followed by CL2. This is reasonable as CL1 on the M1–N1 is the busiest route on the border and long delays are expected. For short delay scenarios, the longest delay is 11.65 min at CL2 followed by CL1. CL1 has the highest traffic volumes of all crossings and is expected to have the worst vehicle delays. However, 6 channels in each direction are used at CL1 while only 4 channels are used at CL2. This explains the similarities in vehicle delay results between CL1 and 2 even though peak volumes at CL1 are higher. It can be seen that a hard border will have a significant negative impact on vehicles traveling through these two crossings, especially with long processing times. CL4 and CL5 have the shortest vehicle delays at peak flow conditions so a hard Brexit will have minimal impact on vehicles crossing the border at these locations. Vehicles going through at CL3 and CL6 will experience considerable delays in the case where no technology is employed. As can be seen from Table 5, using technology to speed up processing times of vehicles is beneficial and will lead to shorter vehicle delays at all crossings. Time savings

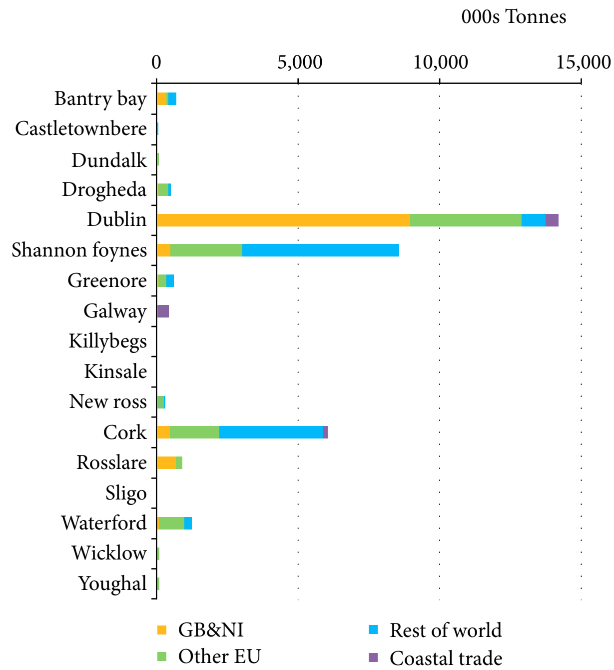

FIGURE 9: Tonnage of goods received by Irish ports and trade partners in 2015 [20].

range between 11% at CL5 (which already has negligible delays) to 90% at CL6.

It can be seen in Figure 6 that HGVs experience longer delays than cars in the peak hours. There are no HGVs traveling at the selected peak hour on the UK–IE direction at CL3 and CL4 so the delays are shown as 0. The longest car delay and longest HGV delay are both along the IE–UK direction at CL1, which is expected given the importance of the M1-N1 (name of road in Northern Ireland) as a major road connecting Dublin and Belfast. The shortest car and HGV delay are both along the IE–UK direction at CL5 if the 0 values are excluded. Technology use at CL5 leads to small improvements in car delays and HGV delays while the time savings gained by using technology in border controls at all the other crossings range from 41% to 89%. This confirms the need to invest in effective technology tools that facilitate the processing of cars and HGVs at the border leading to shorter delays.

3.2. Delay Associated Costs. The daily and annual costs at all crossings are summarized in Tables 6 and 7, respectively using the values of time in Table 2. A total cost is calculated for each scenario to obtain an overall estimate of the cost of a hard Brexit on the 6 crossings modelled. The long delay scenario for the 50–50 commuting–leisure distribution is the worst-case scenario at all crossings. CL1 has the highest daily cost estimated at €122,400 and consequently the highest annual cost estimated at €44.7 million. This further highlights the importance of CL1 and the scale of the impact a hard Brexit would have on it. CL4 on the other hand has the lowest daily and annual costs due to low traffic volumes along the N16. Of the total delay costs of €59.8 million shown in Table 7, €11.6 million are those imposed on HGVs.

The total delay-associated costs across all 6 locations in the long delay scenario compared to the short delay scenario puts the financial gains at stake in perspective. For all 6 crossings combined, technology use can save up to €90,900 per day and €33.2 million per year for car commuters and HGVs. Savings for HGVs would be almost €7 million. All of the cost savings mentioned here only account for the costs of time savings from delays and it is expected that costs associated with reduced emissions and other benefits observed when technology is used at the border will increase the overall cost savings and provide even more reasons to justify the use of technology.

3.3. Impacts on Emissions and Fuel Consumption. A summary of the level of CO, NOx and VOC emissions generated for each of the scenarios is presented in Figure 7. When no or minimal technology is employed, the crossing with the highest CO emissions at 540 tonnes per year is at CL1 and lowest of 7 tonnes at CL4. One hundred and thirty seven tonnes of NOx and 163 tonnes of VOCs are generated at CL1, again when no technology is employed. Employing technology to reduce the delays, generates 14.6, 3.65, and 40.15 tonnes in savings of CO, NOx and VOC emissions respectively. The overall environmental impacts of a hard Brexit are significant especially as Ireland tries to meet its national emissions ceiling targets.

Estimates of fuel consumption were also made for each of the scenarios, the results of which are shown in Figure 8. Again CL1 has high levels as might be expected. Fuel consumption savings as a result of using technology at the border crossings can reach 2 million litres a year at some crossings.

4. Discussion

To put perspective on the findings, a number of stakeholders were interviewed as part of the research. They included representatives from large banks, EU country ambassadors, the Irish Exporters Association, former European Commission staff, freight associations and representatives from Irish government departments. Most reflected that they expected that there would be an arrangement where there would not be a hard border crossing and that some version of technology would be used for minimal impact. An example would be the use of a pre-approved system for HGVs to enter and leave the UK. Others mentioned proposals for more direct routes from Ireland to other EU countries that would not involve the land bridge through the UK. Indeed some associations have already conducted pilot assessments of IT solutions that can facilitate intermodal and multimodal freight transport.

A major area of concern is the exporting of agricultural produce from Ireland to the rest of Europe, as bypassing the UK would take longer reducing product shelf life. Policymakers remain optimistic that IT solutions can be found to allow produce to continue to go through the UK. Exact data on Irish freight going through the UK to mainland Europe are not available; so the Irish Maritime Development Office (IRMO) was requested by DTTAS to prepare a report on volumes of traffic using the UK land bridge and have it completed by

October 2018. Data are available for freight volumes going to the UK as seen in Figure 9, but some of these volumes are then transported to mainland Europe. In the case of a no deal Brexit, checks will be required at Dublin port on an unprecedented scale and part of contingency planning is to prepare ports and airports and develop the IT infrastructure necessary to facilitate customs checks. Dublin port handles the highest volumes of goods compared to other Irish ports, as seen in the figure below, and will therefore require more border infrastructure investments.

Other policy makers emphasized the challenges that come with a hard border including the high cost of border infrastructure and the social and psychological effects caused by creating a disconnect between the people of the north and the south of Ireland. None of the national roads crossing the border have the necessary lands for a border control area so more challenges arise. References were also made to other international borders to highlight the scale of the facilities required including customs offices, parking spaces, and immigration checkpoints.

A representative from an Irish national agency focusing on enterprise emphasized the need for Irish industry to prepare for Brexit because some form of restrictions affecting freight will be put in place whether it is a soft or a hard Brexit. In addition to the effect on freight routes, Brexit's effect on currency has a direct impact on Irish exports as seen by the recent depreciation of sterling. A hard Brexit will involve World Trade Organisation (WTO) tariffs that can reach up to 55% for food products. Despite high volumes of food products traded, the effect of a hard Brexit will be significant given the sector's low margins unless special tariffs are negotiated. An Irish business organization network echoed other views about the large spectrum of impact of Brexit depending on the type of products exported or imported. The percentage of transport costs out of the total product cost for the pharmaceutical and medical technology industries is much smaller than the one for perishable goods so the former is likely to pay additional costs to go through the UK land bridge while the latter will suffer and cause price increases for consumers. However, many stakeholders are optimistic that the potential impacts of Brexit on freight will be dealt with in the ongoing negotiations and a hard border will be avoided. However, if a hard border is implemented, big carriers can take the burden off individual businesses and recalibrate their distribution networks, adjust their business models and repackage goods into bigger containers to minimize delays and costs.

A potential impact in the case of crossings that are close to each other will be users switching between crossing points as a result of better operation and less delay at some. Cross-border commuters are likely to change schools or switch jobs if possible to avoid travel delays and associated costs in the case of a hard Brexit. The freight sector on the other hand will be forced to pass additional costs to the consumer but logistics companies are exploring innovative ways to respond to Brexit and shipping companies are providing alternatives to the UK land bridge. The new routes and expanded routes linking Dublin port directly to France, Belgium, the Netherlands, and Spain will help future-proof Ireland against a hard Brexit but might not be a viable option for Irish perishable goods heading to mainland Europe.

Limitations of the work include a general treatment of what technology on the border might mean. Cost estimates for freight movements relating to commodity mix and inventory costs were not included due to lack of data. Processing times used in the VISSIM model are based on broad assumptions about the potential of technology to speed up processing times. Given the scope of this project, specific technological solutions were not considered separately, as there have been suggestions that no appropriate technology is yet available, but more accurate results could be provided if processing times were based on particular technology tools that have been developed and tested in an Irish context.

The scenarios modelled at each location use data from the day with the highest traffic volumes recorded in the January to June 2018 period. This provides results for the worst-case scenario whether it is a weekday or a weekend. Trip purposes generally differ between weekdays and weekends so such a distinction can lead to more traffic scenarios modeled and can provide more detailed recommendations about ways to minimize delays at the border based on trip purpose trends.

5. Conclusions

The research assessed the impact of Brexit on the transport sector in Ireland assuming a hard border between Ireland and Northern Ireland. Six crossing locations were selected along the Irish border based on the density of cross-border commuters. VISSIM was used to simulate traffic flows at each crossing evaluating the impact of a border with short vs. long processing times at peak, off peak and free flow conditions. VISSIM inputs are obtained by analyzing TII traffic data, estimating projected volumes for 2019 and using other international border crossings as a reference for the design of the border control area. Short processing times are facilitated by technology tools implemented at the border and short delay scenarios are compared to long delay scenarios to estimate time savings, cost savings and reductions in emissions made possible by technology. Car delays and HGV delays are used to calculate delay-associated costs for car commuters and road freight at the 6 crossings.

In the worst case scenario, the N1 crossing has the longest travel delay of 18.5 min and the highest daily cost of €122,483, which highlights the significance of the M1-N1 and the importance of managing traffic flows across the border at this location to reduce the impact of a hard Brexit on commuters and freight. A hard Brexit will cost up to €60.7 million worth of delays per year across all the 6 crossings modelled, 11.6 million of which is the annual delay-associated cost of a hard border to the freight sector. It will also generate up to 704 tonnes of Carbon Monoxide, 137 tonnes of NOx and 163 tonnes of VOCs per year leading to significant environmental impacts in a country that is already struggling to meet its national emissions ceiling obligations.

This research shows that technology use in border infrastructure can significantly reduce the impact of a hard Brexit on cross-border traffic through time savings, cost savings and a reduction in emissions and fuel consumption. Specific types of potential technologies used at the border need to be investigated given the significant benefits they can offer to cross-border commuters and HGVs traveling between Ireland and Northern Ireland.

Another key issue relates to staffing requirements at the border crossings. The Office of the Revenue Commissioners in Ireland expect the staffing and physical infrastructure costs associated with implementing of the order of eight border controlled crossings to be significant [26]. Given the length of the geographical boundary between Ireland and Northern Ireland, it will be necessary to accommodate all users at each border crossing i.e., passenger cars and freight movements. There have been some suggestions that customs offices for one country might carry out clearance checks for both countries in a similar arrangement to that between Sweden and Norway, particularly at minor crossings. Any such arrangement would require extensive re-training of customs officers from both jurisdictions to comply with both EU and UK legislation. Even if an e-flow-style technology can be employed, a physical customs presence would still be required to meet a range of EU obligations. In addition, mobile patrols and checkpoints will also be necessary to control the remaining unapproved routes to deter and detect abuse [26].

Further research is needed once the border issue is resolved in Brexit negotiations. A cost benefit analysis of the specific technologies that may be used in the future will be valuable for the Irish entities that will design and build border infrastructure in the case of a hard Brexit.

Data Availability

All data used can be obtained from the sources throughout the paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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