Analysis of inclement weather on traffic flow – an Irish National roads case study

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ABSTRACT: Transportation networks and infrastructure are increasingly exposed to and effected by inclement weather. The rise in the frequency and intensity of these events is increasingly affecting the normal operation, performance and functionality of roads and highways, leading to costly losses.
Inclement weather creates risky and hazardous situations not only on the main roads, such as motorways, but also, on the smaller roads connecting rural parts of the country that experience lower traffic volumes. The effects of weather events, such as rainfalls or snowfalls, have been primarily addressed in main roads, leaving, smaller roads on hold. This has created a lack of specific policy and poor adaptation strategies for secondary layers of transport networks, and their users. The present paper investigates the link between inclement weather and traffic flow in various locations in Ireland.
The results provide an examination of the impact that weather events such as varying levels of wind and rain can have on road network performance in multiple locations in Ireland. The varying levels of wind exposure (light, medium, intense) on the sections of the Irish road network examined were found to have a greater effect on traffic volumes than comparative levels of rain exposure. This analysis ultimately contributes to a better understanding and knowledge of characteristics of Irish road network and its performance under perilous conditions, which may support the creation of specific measures to improve the resilience of the transport network.
KEY WORDS: Inclement Weather, Traffic Flow, Resilience, Ireland, Rainfall, Wind, Road traffic, Extreme Weather.

1 INTRODUCTION

Transport networks are constantly challenged by the occurrence of inclement weather. Weather events have a significant impact on the operation of transport systems, transforming and influencing user's behavior (e.g. speed, visibility, lane switching, observation, tailgating, use of headlights). In the case of Ireland, in recent years, the transport network has experienced severe operational disruptions, caused by several storms such as storm Ophelia in 2017, storm Emma in 2018, and more recently storm Denise and storm Ciara in early 2020. These extreme events can result in major restrictions to the road network, including road closures, and evacuations, that can last for days or weeks. However, in addition to the extreme events listed, inclement weather is also negatively affecting Irish roads, at a lesser but more frequently scale, which can still have a significant impact on the safety of travellers. In 2017, Ireland had the fifth lowest road fatalities per million inhabitants in the Europe [1] and according to the European Road Safety Observatory [2], 9% of all road fatalities occur in rainy condition, while 1% occur during strong winds. Furthermore, 127 out of 193 road fatalities in Ireland in 2016 took place in outer urban areas on non-motorway roads, indicating that road accidents leading to fatalities are more likely to occur on national primary and secondary single and dual carriageway roads in Ireland than on motorways.

When transport networks are threatened by a hazard, the main goal is of course to mitigate and achieve the maximum reduction of the risk achievable with the available resources. The indicator that determine the performance of the network during a hazard and evaluates the recovery process under these disruptive events is known as resilience, [3]. Understanding the damage suffered by a traffic network and its capacity of response to inclement weather events is essential to reduce the damage of this hazard and to improve the system resilience [4]. In order to realise this, better planning, information provision and capacity management are necessary to develop new strategies for each of the resilience stages and each of the components of the network. Thus, resilient networks will set the stages for well-designed adaptation and mitigation strategies in order to manage risk effectively. It is similarly important to understand that different types of roads will require different strategies and addressing the knowledge base of each of these parts will determine at what level to mitigate, and also the amount of risk that it is acceptable for each of the elements.
A robust resiliency strategy will provide the tools to better understand the networks, to reduce the impact and to accelerate the recovery process, which produces increased protection for users, and an efficient approach to reduce the costs, [5].

The aim of this paper is to quantify the impacts of weather events on traffic flow, as in indicator for how travel behaviour is affected by weather events such as rain and wind. This is in order to provide transportation network operators with the necessary information to mitigate the effects of these events and to investigate the link between inclement weather and traffic in Ireland. In addition, this paper examines the impacts that weather events can have on varying road network classifications/ categories (i.e. national primary and secondary roads). The results obtained and presented in this paper will also help to develop future adaptation strategies to enhance mobility and safety on roads in relation to inclement weather.
This paper is organised as follows, Section 2 provides a brief review of empirical literature concerning the effect of weather on the operation of road networks, Section 3 outlines the methodology and data sources utilised for this study, followed by the results produced in this study in Section 4, and Section 5 will sets out a discussion a conclusion to the paper.

2 THE EFFECTS OF WEATHER EVENTS ON TRAFFIC OPERATION

The impacts of inclement weather events on traffic operations has been extensively studied in empirical literature. The effects of weather events can affect several aspects of the road performance, namely the capacity of the road, delay, traffic volume, and speed [6]. The dimension of the impact will depend on several variables, for instance the intensity of the hazard, but other aspects such as the vulnerability of the link will affect the size of the impact [7,8]. Studies show that it is common for the road capacity to be reduced during a weather event, and this reduction can range from 4% to 30% [6, 9, 10, 11, 12, 13]. Traffic fluency is also affected during these events, since users tend to drive slower, for example during heavy rain, flow reductions of 10 to 20% can be expected [14]. However, in a study conducted by Hranac et al. [6] during light rain events little or no effect on flow was observed. Other studies found that during wet road conditions the traffic demand reduces by 4.5%, and during AM or morning Peak hours it can reduce by up to 9% when rainfall is between 1.4 – 1.9mm in an hour [13]. A study conducted in the UK in the M1 motorway between junction 1 and junction 2, showed that during wet weather conditions the traffic flow fell by 40%, while the speed fell by 2.6% [15]. Another study conducted in Ireland studied the effects of rain on the operation of the M50, busiest road in Ireland. This study shows that rain can cause speed reductions from 2.2% to up to 15%, and highlights the need for more local analyses, since these results are not easily extrapolated to other types of roads [16].

The effects of snowstorms on traffic volumes have similarly been examined in the literature. Hanbali and Kuemmel [17] conclude that snowstorms can cause reductions in traffic volume of between 7 and 34%, depending on the intensity of the snowstorm. However, other weather events such as strong or gale force winds have received less attention in the academic literature. Nevertheless, some studies indicate that wind speeds of 24 km/h can be classified as critical, and that strong winds can create vehicle speed reductions of 11.7 km/h [18].

In these areas, roads are built to high standards, and are better prepared to withstand the harsh impacts of weather. However, there exists few studies that evaluate and compare the impacts of inclement weather events in different locations simultaneously, where road conditions may vary significantly on varying road categories such as secondary roads or in rural areas. Thus, this paper presents an evaluation of the effects of weather events in four different locations of the country, including primary and secondary roads.

Furthermore, it similarly provides an analysis of the effects of weather events on roads with high volumes of traffic that usually operate over capacity, and roads with smaller traffic volumes. This variability of location offers a useful comparison to understand the implications of weather events on varying levels of road infrastructure. Similarly, due to the localised nature of weather events, it is essential to develop local area studies of the effects of weather events, the range of impacts of which can vary significantly.

3 DATA AND LOCATIONS

A significant number of Irish roads must deal with high volumes of traffic, and it is expected that these numbers grow even more with the expected rise in demand. For example, in Dublin, the M50 continues to experience growth in levels of usage as measured by Annual Average Daily Traffic (AADT) flows, with the section between Junction 5 (N2) and Junction 9 (N7) carrying in excess of 140,000 AADT. Moreover, some sections of the Irish national road network, managed by Transport Infrastructure Ireland, are experience high traffic flow on a daily basis. In the case of National Primary Roads, approximately 15% regularly operate over their designed capacities, while 30% of National Secondary Roads, operate over capacity [19].

The road sections selected for the analysis in this study are presented in Table 2. The roads chosen are a representation of the main types of roads in the Irish road network. Thus, of the four locations presented in Table 2, two are part of the National Primary road network (Dublin N7 and Carlow M9), while the other two are part of the National Secondary road network (Cork N71, and Ring of Kerry). In addition, a representation of the daily use of roads was also introduced, of which two of the selected locations operate at capacities higher than 100% (Dublin N7, and Cork N71), see Figure 1, and the other two operate at lower ratios of volume over capacity (Carlow, M9, and Rink of Kerry), see Figure 1. In this way, the analysis was performed at four road sections with very different characteristics.

3.1 Data sources

Traffic data for 2015 to 2019 were sourced from Transport Infrastructure Ireland[1]. For each of the road sections presented in Table 2, hourly data of traffic volumes were collected and analysed in conjunction with weather data. Likewise, meteorological data of weather conditions from Met Éireann from the past 5 years was included in the analysis conducted in this paper. Hourly weather data for 2015 to 2019 were sourced from various Met Éireann weather stations. In addition to this, to improve the reliability of the approach, a different station was utilised for each road section in the analysis. Thus, the closest weather station was selected for each road section location. Each of the weather stations included in this analysis are listed in Table 2.

In order to examine the effects of varying levels of wind and rain on traffic volume, this study considered the following categories for rain (mm/h) and wind (mph) presented in Table 1.

Table 1 Weather Events Categories

Weather events	Rain (mm/h)	Wind (mph)
No event	0	0-10
Light	0-0.5	10-20
Medium	0.5-4	20-25
Intense	>4	>25

[1] Traffic Infrastructures Ireland. Traffic Data Counter.

Table 2 Locations of Analysis (Road section images source: Google maps)

Location	Description	Road type	Road section	Weather station
Dublin- N7	N07 Between Jn02 Kingswood and Jn03 Citywest, Kingswood, Co. Dublin	National Primary road		Casement (stno: 3723) Distance to road section: 1km approx.
Carlow- M9	M09 Between Jnc 3 Kilcullen and Jnc 4 Castledermot, Co. Kildare	National Primary road		Oak Park (stno: 375) Distance to road section: 6km approx.
Cork- N71	N71 Between Innishshannon and Ballyhassig, Southwest of Ballinhassig, Co Cork	National Secondary road		Cork Airport (stno: 3904) Distance to road section: 6km approx.
Ring of Kerry-	N70 Between Caherciveen and Glenbeigh, Gortaforia, Co. Kerry	National Secondary road		Valentia Observatory (stno: 2275) Distance to road section: 10km approx.

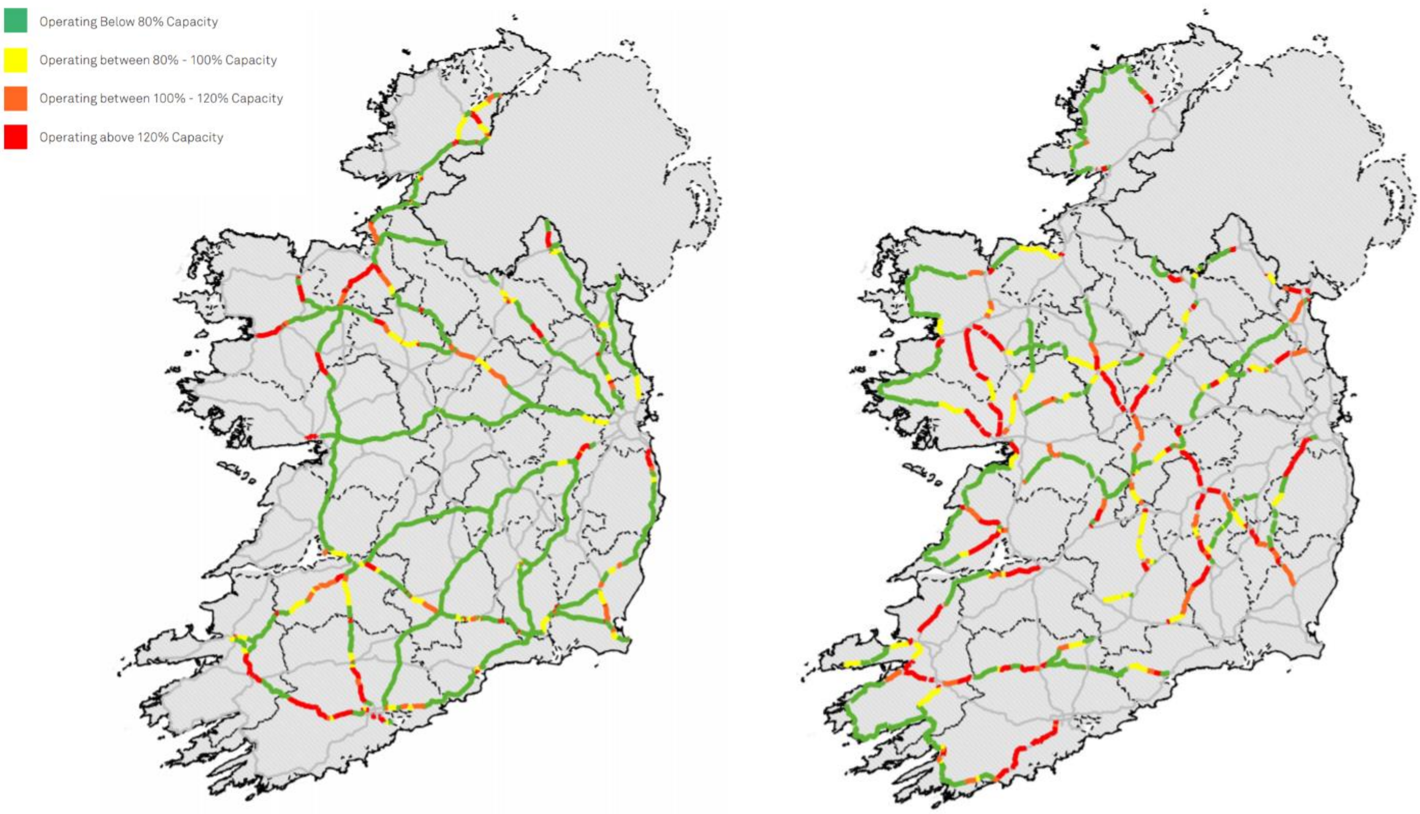

Figure 1: Volume to capacity ratio: Irish National Roads. Left: National Primary Roads, Right: National Secondary Roads. (Source: Transport Infrastructure. Ireland- National Roads Network Indicators 2018)

4 RESULTS

In this section, the results produced from the analysis for the four locations are presented. In Figures 2a and 2b, the results for Dublin-N7 are shown. In these graphs, the variations on traffic volume caused by different intensities of wind and rain are presented, respectively. In this location, the effects of weather, including wind and rain, are considerably small. While it is noted that the traffic volume is not significantly affected by conditions of light and medium rain, it was found that when the road was operating at higher capacities (during peak hours of the day), the impact of rain was on traffic flow more pronounced. This finding highlights the fact that spare capacity is an important factor when improving transport resilience.

In Figures 2c and 2d, the results for Carlow-M9 are presented. In this road section the effects of wind are considerably more significant than on the Dublin N7. However, the findings showed that rain has a minimal affect on traffic volume during the day. It is noted that this road operated under capacity, and as a result this improved the road resilience when affected by light and medium rain intensities.

Figures 2e and 2f illustrate the effects of wind and rain events on Cork - N71 road section. Traffic volume was again considerably affected by the effects of medium and intense winds, but in the case of rain events, the traffic performance was found to be lightly affected, except at the peak hours, when the road operates at an over capacity state, hence its ability to withstand the impact of rain is reduced.

Finally, in Figures 2g, and 2h, the results for the Ring of Kerry road section are shown. It is apparent that in this rural location, the effects of both wind and rain are significantly higher than in the rest of the road sections analyses. This can be attributable to the specific design characteristics associated with this road, its geographic location, and low levels traffic demand. The evident impact of rain and wind conditions on traffic performance as shown in this study, highlights the necessity of conducting more analysis on rural locations such as this due to the exposure and vulnerability of this road infrastructure to harsh weather events.

In addition to the analysis presented in the graphs in Figure 1, the average reduction in traffic volume was similarly calculated for each of the road sections in the study, which are presented in Table 3. In this table the average percentage reduction in traffic volume is shown from 8:00 am to 18:00 pm in instances of different levels of rain and wind.

5 DISCUSSION AND CONCLUSION

This the research presented in this paper examines the effects of inclement weather conditions on vary levels of traffic volume, such as rain, and wind, on multiple locations in Ireland. The analysis was conducted using data collected in a 5-year period (2015-2019), with a focus on 4 road sections, including two National Primary roads, and two National Secondary roads.

Table 1 Average Reduction in Traffic Volume in Categories of Wind and Rain

Average reduction (%) (8:00am – 18:00pm)	Rain		Wind	
Dublin- N7	Low	-0.09	Low	0.7
	Medium	-1.19	Medium	-3.4
	Intense	-	Intense	-4.47
Carlow- M9	Low	-1.56	Low	-0.47
	Medium	-1.64	Medium	-8.84
	Intense	-	Intense	-21.
Cork- N71	Low	-1.41	Low	-0.67
	Medium	-1.64	Medium	-5.43
	Intense	-	Intense	-12.27
Ring of Kerry	Low	-10.03	Low	-1.2
	Medium	-12.60	Medium	-23.38
	Intense	-	Intense	-34.28

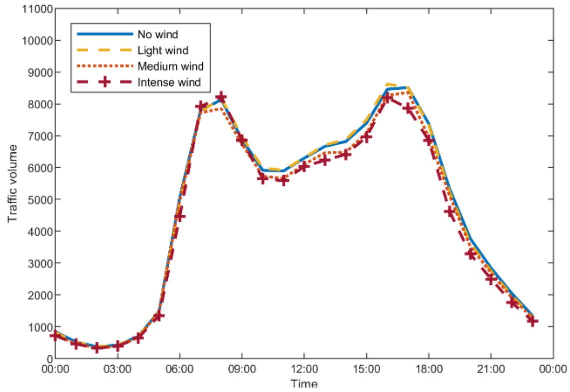

Figure 2a Dublin – N7 (wind)

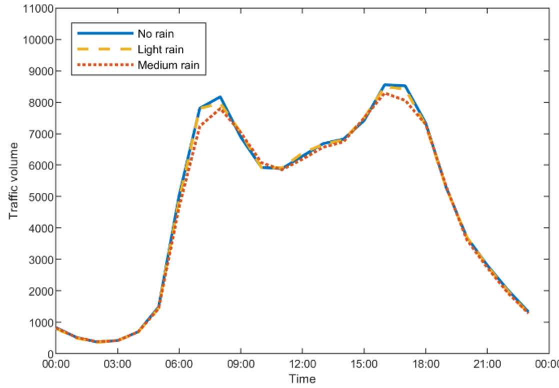

Figure 2b Dublin - N7 (rain)

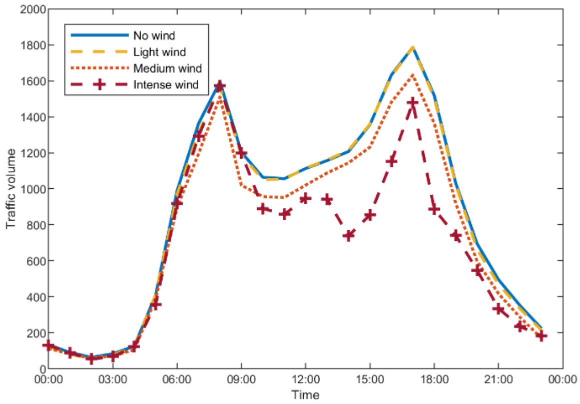

Figure 2c Carlow - M9 (wind)

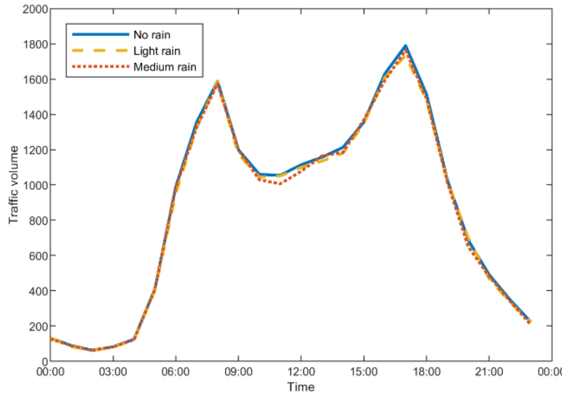

Figure 2d Carlow - M9 (rain)

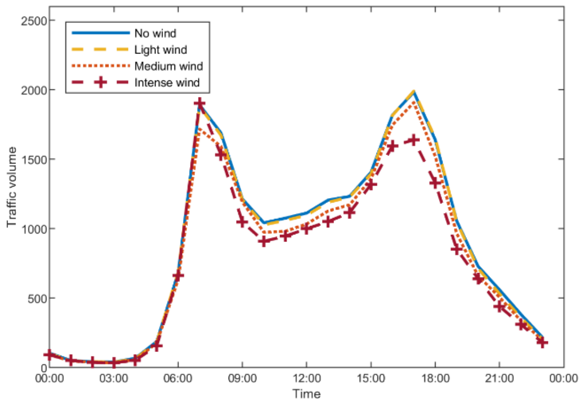

Figure 2e Cork - N71 (wind)

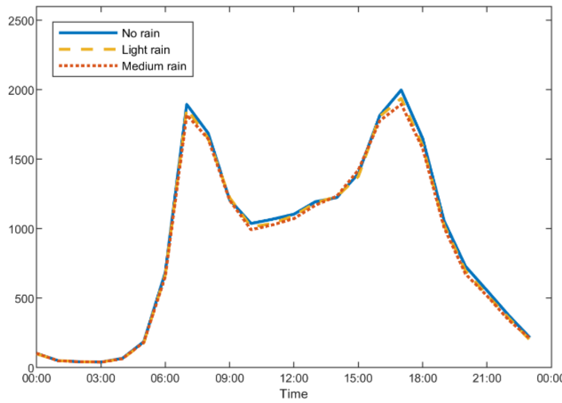

Figure 2f Cork - N71 (rain)

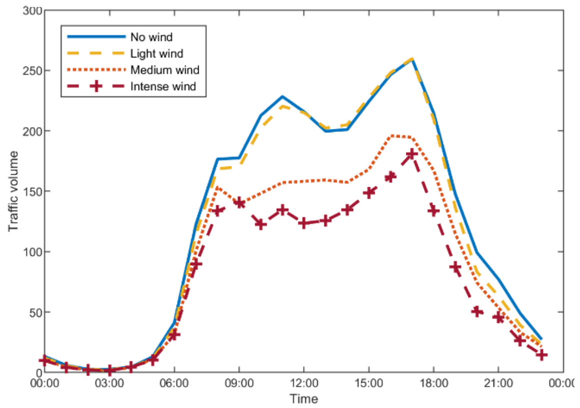

Figure 2g Ring of Kerry (wind)

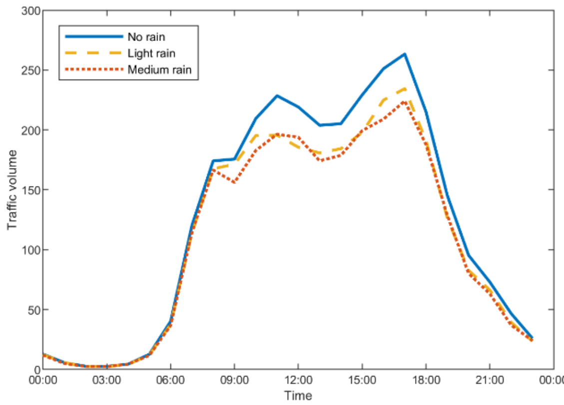

Figure 2h Ring of Kerry (rain)

Figure 2: Wind and Rain Categories vs Traffic Volume

This study allows for establishment of a better knowledge base for the Irish National road network, specifically examining performance levels under inclement weather conditions. In this way, the results presented may prove useful for network operators to understand and quantify the potential impacts that weather conditions can have on road operation, contingent on the type of road, its location and other design characteristics. In addition, it is expected that these results help to support the creation of specific measures to improve the adaptation strategies of the road network and improve road transport network resilience. Overall, the following conclusions have been obtained from the analysis:

It has been demonstrated that the intensity of rain and wind show a clear trend and correlation between an increase in the intensity of these events and reduced traffic volumes. In addition, it is noted that the results obtained in this analysis are in line with similar studies presented previously in Section 2.

- In the case of intense wind, the traffic operation and traffic flow were found to be highly affected. With reference to the locations analysed in this study, an average traffic volume reduction of up to 34.4% was recorded in the Ring of Kerry

- In relation to rain conditions, the associated reduction on traffic volume were found to be smaller, and in most instances of light or medium rain the impact on the traffic volume was between -1% and -2%, expect for the Ring of Kerry location. However, this can be because there was not enough data for long periods of intense rain in Ireland from 2015 to 2019, and therefore, conclusions on the average reduction of intense rain could not be obtained in this analysis.

- It is noted that effect of rain on traffic volume is more significant when the roads are operating at over capacity. Larger reductions on the traffic volume were obtained at peak hours of the day on the road sections analysed that usually operate over capacity.

To conclude, the importance of performing local analyses to understand the effects of weather events on traffic performance is highlighted in this paper. This analysis presented clearly demonstrates that the effects can be highly variable. For example, for intense wind, the reduction of traffic volume can range from -4.47% to -34.28%, and for medium wind from 3.4% to 23.38%. These insights may provide guidance to road operators in managing traffic flow and minimising potential road accidents and fatalities during adverse weather events in Ireland.

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