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A REVIEW OF APPROACHES TO THE STUDY OF WEATHER'S EFFECT ON ROAD TRAFFIC PARAMETERS

Summary. The paper describes selected research achievements into the effect of weather on road traffic from the perspective of various combinations of traffic characteristics and meteorological conditions. Studies to date have focused on different traffic parameters and changes in them as a consequence of weather variety. In making a comparative analysis, researchers identify the optimal weather conditions for road traffic and driver perception. Research in this field is conducted using a variety of data resources, backgrounds, and methodologies. The review of papers shows that results may be strongly dependent on the subject region (especially the climate zone), human behavior, and the legal framework (e.g., speed restrictions). However, the local view is important as well, and information regarding specific road attributes should not be overlooked. Comparison of the results of individual studies can be problematic owing to the myriad of different methodologies, so the description of any analysis of weather's effect on road traffic parameters must include detailed information about the researcher's specific approach to the problem as the following paragraphs of the paper advocate.

1. INTRODUCTION

"What is the weather going to be like today?" is a question many drivers ask at the start of the day as they want to avoid unexpected problems on their journey. It is an important question for many individuals because a sudden change in traffic conditions can result in them not reaching their workplace or a planned meeting on time. It is even a more critical issue for transport companies and their vehicle fleets. Considering meteorological conditions as a cause of traffic congestion, we see the real costs for individuals and businesses: increased travel times; decreased reliability and productivity; and greater pollution, stress, and vehicle wear [1]. Road constructors and operators try to minimize the effects of these problems. Although everyone knows that the weather affects road traffic, answers to the questions of how great is that effect and which aspects are the most significant cannot be reckoned as equally obvious. The information on weather, together with others, such as traffic speed, and occupancy, including specific relationships, is also used by variable speed limit systems (as intelligent transport systems solution) to determine the appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions [2]. The aforementioned reasons are the basis of systematic research and analyses in many studies, and considerations. In the following paragraphs of the paper, the most important features of weather's effect on road traffic studies are presented using examples from selected references to show different possible approaches to the topic.

2. ROAD TRAFFIC CONDITIONS

The effect of weather conditions on road traffic has been the subject of many scientific analyses. The main reason for the interest in this type of research is the improvement of road safety. One of the first researchers was Stohner, who studied speeds on wet and dry pavements [3]. He concluded when considering these conditions that there is a minimal difference in the speed distribution of free-moving passenger cars. A half century later, Xu & et al. used the macroscopic analysis method of the network to report the diminishing effect of rainfall on traffic variables such as production, accumulation, weighted jam density, weighted speed-at-capacity, and finally, weighted free-flow speed [4]. As with speed, road capacity seems to be dependent on weather conditions. Chung & et al. analyzed both qualities and collected precipitation intensity data on major arteries characterized by huge daily volume [5]. As a result of the study, they report that rainfall decreases capacity from 4%-7% in light rain to a maximum of 14% during heavy rain. To better understand the problem and the dependencies among these findings, it is worth analyzing them in the context of the basic variables. Speed, volume, and density are the fundamental traffic stream parameters. Akin & et al. derived two of them from empirical data and estimated the third to present the relationships among them for various weather conditions [6].

A different approach to road traffic research was taken by Kilpeläinen and Summala, who did not focus on counting vehicles or measuring their speeds but on a questionnaire to examine people's behavior [7]. The drivers at service stations were asked questions about themselves, their current journey, as well as traffic and weather conditions. The authors conclude that the behavior of drivers is primarily affected by the prevailing observable adverse weather conditions, but it is not likely affected by forecasts.

The scientists test not only the traffic flow. Ścieszko and Papiernik studied the influence of weather conditions on traffic accidents using a police data set from one Polish region [8]. They conclude that a greater number of such events is observed after a significant change in atmospheric pressure and owing to precipitation. The findings are interesting in regard to seasonal statistical differences: the number of recorded events was lowest during the winter season and highest in the summer and autumn. However, when limited to the number of traffic accidents without injuries, similar statistics peaked in the autumn but declined in the summer.

Over time, the weather's effect on traffic flow has been more and more extensively studied in the literature, so new approaches to the topic have to be more sophisticated and complex. One of the newest research has focused on the effects of rainfall on the spatial distribution and changes in traffic-congestion bottlenecks throughout a mega-city [9]. Another example of recent studies presents how local weather conditions affect real-time traffic flows both spatially and temporally [10]. A completely different idea to investigate the topic next, the authors have been checking the effect of strong wind on dynamic characteristic of traffic flow to improve car-following model and explore fuel consumption [11].

3. WEATHER CONDITIONS

Some weather conditions are extreme in nature (e.g., tornados, floods, typhoons, and hurricanes). These situations are hard to analyze. Although they can be the cause of road destruction or a reduction in traffic demand to nearly zero, they are quite rare. Usually meteorological conditions are more standard and repeatable but do not have such extreme effect on driving. Generally, statistics and research are focused on parameters such as precipitation, temperature, wind, visibility, and pavement surface condition. These factors are also mentioned in the Highway Capacity Manual (HCM, 2000) report sponsored by the US Federal Highway Administration [12] - a significant publication among transportation literature with last extended 2016 edition [13].

Among all the weather factors, the most common in road traffic research appears to be rainfall. A synthesis of older studies relating wet conditions to speed and capacity can be found in the paper by Prevedouros & et al. [14]. In a more recent study, Akin & et al. reported that rain reduces the average vehicular speed by 8%-12% [6]. To increase the precision of the analysis, rain severity is also considered. Ibrahim and Hall's study finds that during free-flow conditions, a 2 km/h reduction in operating speeds is found in light rain and a 5-10-km/h decline in heavy rain [15]. Going into greater detail, researchers divide rain severity into additional categories as in Wang and Luo [16]. The authors claim that free-flow speed decreases by 4.4%, 7.3%, and 10.6% because of light rain, moderate rain, and heavy rain conditions, respectively, and provide detail regarding the weather specifications, as presented in Table 1.

Table 1

The rainy condition classification proposed by Wang and Luo [16]

weather condition	rain from	rain to	visibility from	visibility to	speed decrease
normal weather	without rain		$V \geq 2000$ m		
light rain	0 mm/h	5 mm/h	1500 m	2000 m	4.4 %
moderate rain	5 mm/h	10 mm/h	1200 m	1500 m	7.3 %
heavy rain	10 mm/h		$V \leq 1200$ m		10.6 %

Tsapakis & et al. reached a similar conclusion that the effect of precipitation is a function of its intensity, and they extend the research with additional weather factors [17]. They found that total travel time increases owing to light, moderate, and heavy rain by 0.1%-2.1%, 1.5%-3.8%, and 4.0%-6.0%, respectively. They examined the effect of snowfall as well and report travel time increases of 5.5%-7.6% during light snow and 7.4%-11.4% due to heavy snow.

The extended scope of research concerning influences of rainfall on traffic-flow characteristics such as volume, speed, and occupancy has been conducted by Zang & et al. [18]. Through the integration of massive traffic-flow data and related rainfall data, a comparative analysis of various models was done (to investigate the most satisfying model), and it quantified the effect of rainfall on traffic flow characteristics.

Closely related to precipitation – and sometimes calculated with it like one interactive element – is the factor of visibility. The previously cited study by Wang and Luo [16] incorporated information about visibility in their rainfall impact study. Going further, Hablas treats visibility separately [19]. He calculates that this aspect has minimal effect on free-flow speed, with a reduction in the range of 1%-3% but not until visibility falls below 1.2 km. Kyte & et al. were more rigorous, reporting a 14 km/h speed drop when visibility falls below 0.16 km [20]. This conclusion suggests that the results reported in Akin et al [6], which did not find a significant effect of fog/mist/haze, could have been caused by too great visibility distance in the adopted weather class criteria. The condition is not precisely described in that paper.

Another consequence of precipitation is the factor of pavement condition. Snow or ice covering the roadway is the reason for a nearly 10 km/h vehicle speed drop compared with dry pavement conditions as Kyte & et al [20] report. A wet surface causes an average speed drop of 6%-7% according to the calculations of Akin & et al [6]. However, not all studies give the same results. Lamm & et al. in their paper report that speed is not influenced by the presence of wet pavement as long as visibility is not appreciably affected by heavy rain [21].

Some of the foregoing examples suggest that generally separate meteorological elements are affected by the interactive effect of other weather factors. Even if we agree with Tsapakis & et al., who reported that temperature has nearly negligible effect on travel times [17], it is hard not to recognize that temperature can interact with other factors during the winter. Hablas confirms this suspicion by measurements at two different locations [19]. The first has free-flow speed reduced by 14% at the onset of freezing rain, with a maximum decrease of 27% at intensity of approximately 0.53 cm/h. The measurement at the second location shows a constant drop to a value 31% lower. According to his other observations, freezing rain causes greater reductions in free-flow speed than rain or snow.

Apart from the importance of factor intensity and the interactions between meteorological elements, there are cases in which more complex descriptions and classifications of separate weather aspects must be considered. Wind is a good example in that this factor (like speed) has an additional important attribute, which is direction. Liu & et al. uses three components of wind force, lift force and side force preparing improved car-following model and during fuel consumption analyses [11]. The result of the research by Kyte & et al. appears less rigorous because it merely reports that wind speeds above 48 km/h cause a 9.0-km/h free-flow speed reduction, with no mention of wind direction [20].

Related to the wind and visibility factors but not obvious for the population of moderate zones is the phenomenon of sandstorms. Islam & et al. among other factors report that sandstorms are responsible for the increase in the rate of road accidents [22]. However, owing to a limited sample size, the authors do not report certain values.

Finally, another important weather factor is the effect of sun glare, which is not common in research because considerable data are required to conduct a valid study. The effect of sun glare seems to be the most difficult factor to analyze because of the requirement to incorporate additional attributes such as time of day, season, road direction and geometry, and even topography, surrounding buildings, and detailed information about clouds. According to the investigation of Pegin and Sitnichuk, this element can be classified into two categories [23]. Direct effect is defined as the situation when the sun shines directly into the driver's face, and indirect effect is when the sun is reflected off a surface like a mirror, a hood, a side window, a wet road surface, or snow. In studies of sun glare, the greatest interest appears to be in the frequency of traffic accidents rather than in any effect on vehicular speed. Based on police statistics, Hagita and Mori report that the direct effect of sun glare causes a higher rate of pedestrian and bicycle accidents, accidents at intersections, and a slightly higher occurrence of right-turn and winter accidents [24].

To close this review of the characteristics of adverse weather factors, it is appropriate to note the conditions that are the best for driving a car. This is crucial for every study because, when researchers try to find the value of the change in speed, they must know the base value calculated from measurements made under optimal conditions. In the report by Szczuraszek [25] based on biometeorological literature, the ideal weather for drivers in Poland is described as follows:

- stabilized high-pressure;
- sunny weather, without clouds (i.e., the sun is high above the horizon);
- temperature from 20°C to 23°C;
- low air humidity (below 50%); and
- windless or wind speed below 3m/s.

However, even when researchers know the best meteorological conditions, it can be difficult to collect a large enough set of data during perfect weather condition to conduct a valid study.

4. THE REGION OF THE OBSERVATIONS

When comparing the myriad of research attempting to explain the effect of the same weather factor on the same traffic variable, it may be surprising that individual studies can present different results that suggest there may be more than one valid answer. Upon further investigation, however, it is revealed that there are other influential aspects that may be the reason for the difference in value. As an example, the analysis of separate studies by Tsapakis & et al. [17] and Akin & et al. [6] shows a significant difference in results. The first research reports travel time value increases of 5.5%-7.6% as a consequence of light snowfall and 7.4%-11.4% caused by heavy snowfall. The second study yields opposite results, reporting a 4%-5% increase in speed during a snowfall. Although the lower travel time values in the second study would seem to be invalid, they are likely accurate because the data were collected in the metropolitan area of Istanbul, Turkey, a region where only a few hours of snow are typically reported per year, and such weather affects demand, leading to a 65%-66% reduction in traffic volume as Akin & et al. report [6].

A similar problem – but not one always as clearly visible in statistics – can be observed when comparing other meteorological aspects when traffic observations are made in different climatic zones. Mashros & et al. report free-flow speed reduced by 1%-14% during monsoon season in the tropical climate of Malaysia [26]. The same indicator calculated by Hablas for roads in Baltimore, Minneapolis/St. Paul, and Seattle in the United States is reported as only 2%-5% [19]. Fig 1 presents the locations of selected measurements of speed decrease under rainy conditions. The numbers on the map identify which of the studies included in Table 2 relates to that location. The table provides details about the weather and traffic characteristics under study in each case.

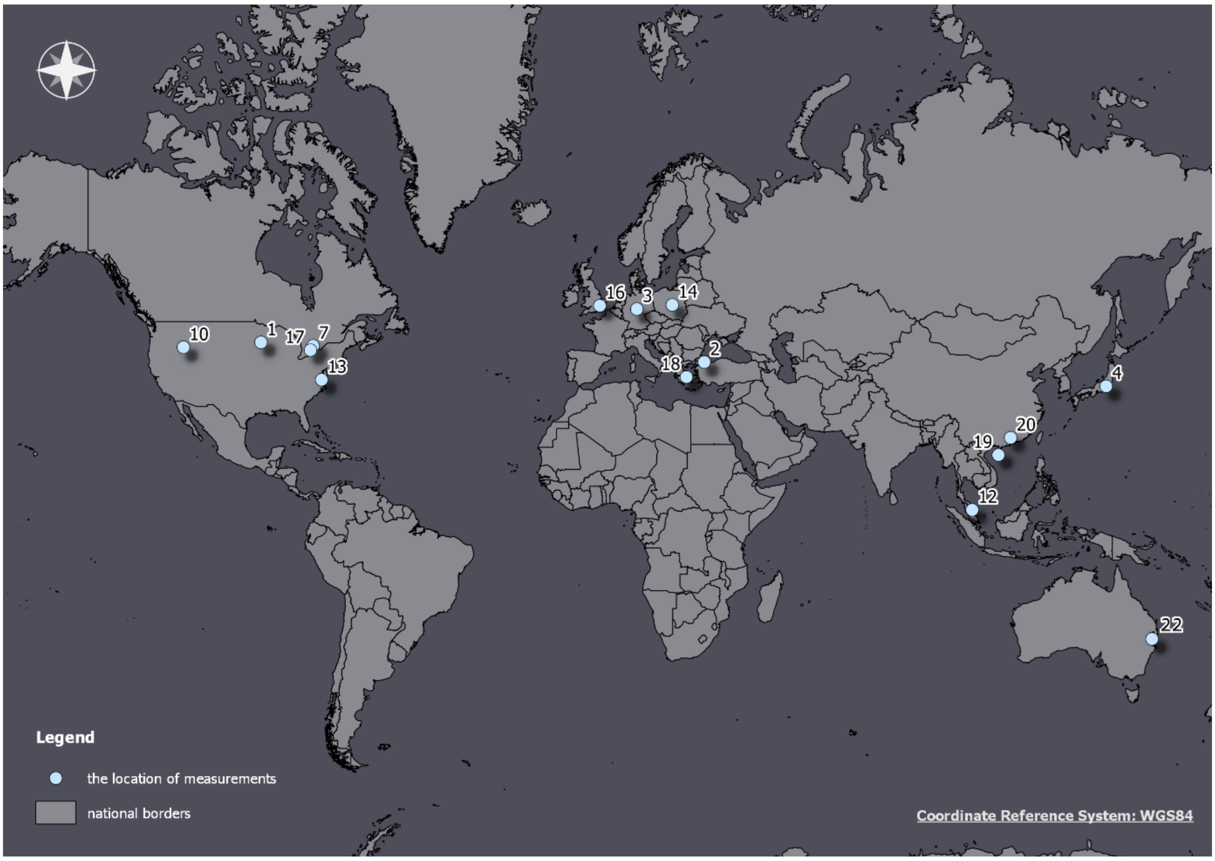

Fig. 1. Locations of selected measurements of speed values under rainy conditions for studies included in Table 2

5. ROAD TYPES

Apart from regional aspects, the specification of the measurement location and detailed information about the route must also be well planned and then described. Many researchers stress this by including the type of road in the title – e.g., "Impact of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity" [27], "Comparison of Operating Speeds on Dry and Wet Pavements of Two-Lane Rural Highways" [21] and "Assessing the Impact of Rainfall on Traffic Operation of Urban Road Network" [4]. The number of lanes of the subject route is also crucial information that should not be omitted. Unrau and Andrey decided to provide even more precise selection and description. They used traffic data collected only from the middle lane or the lane closest to the center median, because in Canada, this is the lane with the lowest number of trucks [28].

Vlahogianni and Karlaftis in their research on the effect of precipitation on the temporal evolution of freeway speed also investigate the variability of travel speed across lanes on freeways [29].

The predominant type of travel along the route (e.g., errand trips, leisure trips, commuting or work-related trips) is also important information, although this is not commonly included in reports most likely because such information is not easy to obtain. Although Smith & et al. do not have precise trip statistics, they include some information about the route by providing a detailed road description: "3-lane freeway links experience heavy commuter and recreational traffic" [30]. Furthermore, it is hard to find in research papers information about road geometry, but there are authors who do include it. One example of good practice is a description by Lamm & et al. who wrote about "two-lane rural state route sections throughout northern New York, normally consisting of a sequence of tangent to curve (or curved section) to tangent" [21].

It is advisable to collect comprehensive information about the route before starting the process of selecting the location for the study. Agarwal & et al. avoided using segments with transitional geometries (e.g., lane drops, weaving sections, and significant grades) to get clear results from the observations [27]. Attaching all available information about the road type can lead to interesting conclusions. Tsapakis & et al. [17] analyzed more than 380 travel links in the Greater London network and found that inclement weather conditions have greater effect on travel time decreases on the longer links within outer London than those in inner London, and even greater decreases than the shortest links in central London. Similar type of conclusion but with different results was obtained by Qi & et al. who pointed that the urban inner space, such as the central business district, is more likely to be affected by rainfall compared with other suburbs [10].

6. HUMAN BEHAVIOR AND THE LAW

Like the aforementioned factors, human decisions are also significant. Wang and Luo examined the change of the traffic flow characteristic under an adverse weather condition as a result of driver behavior [16]. Kilpeläinen and Summala, who analyzed a questionnaire for drivers, reported that acquisition of weather information before the trip was associated with minimal recent driving experience, increasing age, the female sex, a long trip, and the driver's perception of very poor (local) conditions [7]. They report that well-informed drivers made more changes to travel plans, but their on-road driving behavior was not affected. An additional observation is that leisure trips were clearly underrepresented during forecasts of very poor driving conditions, suggesting that some trips are postponed as a result of adverse weather conditions or forecasts of them. Tanner tried to explain the reasons for situations like this. He says that the journey itself may be particularly unpleasant when the weather is bad or the purpose for making the journey may be insufficient in case of a change in weather [31].

Apart from human decisions, there is also a human condition that can be affected by weather. Szczuraszek [25] reports that one of the reasons for weather's effect on traffic is a negative change in the human nervous system and a hormonal imbalance. Direct consequences of this can be a disease-like deterioration in concentration and a longer reaction time. In extreme situations, some people can experience headaches or cardiovascular symptoms.

Furthermore, not all decisions are the responsibility of drivers. Each road section typically has an imposed speed limit to prevent dangerous situations. Within the European Union, French law states that the speed limit on motorways is automatically reduced from 130 km/h to 110 km/h during rain or snow, in order to compensate for the increase in breaking distance on a slippery pavement [32]. For example, with a deceleration rate of 6 m/s2 on a wet road, the breaking distance is shortened by 31 m when speed is reduced from 130 km/h to 110 km/h. Northern countries want to prevent risky situations as well and adapt the law to their regional meteorological problems. Finland and Sweden apply different general speed limits in wintertime. In Finland, the speed limit on motorways is reduced from 120 km/h to 100 km/h and in Sweden from 110 km/h to 90 km/h (EU 2019). Dynamic traffic management systems are of particular importance as they provide drivers with information about the current road conditions, for example in bad weather or surface condition, which affects the adjustment of speed or appropriate distances. Moreover, as research indicates, drivers are more likely to comply with variable speed limits than to classic, not providing for exceptions [33].

Table 2

The main attributes of studies on the effect of weather on road traffic

	authors	year	weather aspect studied	traffic characteristics studied	type of road	period
1	Agarwal M., Maze T.H., Souleyrette R.	2005	rain, snow, pavement surface conditions	speed, capacity	freeways	4 years
2	Akin D., Sisiopiku V.P., Skabardonis A.	2011	rain, fog/mist/haze, snow, surface conditions	speed, volume	urban freeways	1 year
3	Brilon W., Ponzlet M.	1996	pavement surface conditions	speed, volume	autobahns	3 years
4	Chung E., Othani O., Warita H., Kuwahara M., Morita H.	2006	rain	free flow speed, capacity	metropolitan expressway	2 years
5	Hablas H.E.	2007	precipitation, visibility	free flow speed	freeways	2 years
6	Hagita K., Mori K.	2014	sun glare	traffic accidents	all types	4 years
7	Ibrahim A.T., Hall F.L.	1994	rain, snow	flow-occupancy, speed-flow relationships (volume, occupancy, speed)	freeway	17 days
8	Keay K., Simmonds I.	2006	rain	traffic accidents	urban network	3 five-years
9	Kilpeläinen M., Summala H.	2006	air temperature, road temperature, wind speed, relative humidity, precipitation, dew point temperature	effects of adverse weather and traffic weather forecasts on driver behavior	ordinary two-lane main highways outside urban areas	16 days
10	Kyte M., Khatib Z., Shannon P., Kitchener F.	2000	precipitation, wind, visibility, pavement surface conditions	free flow speed	freeway	2 winter periods
11	Lamm R., Choueiri E.M., Mailaender T.	1990	pavement surface conditions	free flow speed	two-lane rural highways	3 years
12	Mashros N., Ben-Edigbe J., Hassan S.A., Hassan N.A., Yunus N.Z.M.	2014	rain	average volume, capacity, mean speed, free flow speed, speed at capacity	two-lane highway	3 months
13	Smith B.L., Byrne K.G., Copperman R.B., Hennessy S.M., Goodall N.J.	2004	rain	speed, capacity	freeway	1 year
14	Szczuraszek T.	2010	air preassure, air humidity, precipitation, temperature, visibility, sun location, wind	free flow speed	main roads	
15	Ścieszko J., Papiernik Ż.	2013	air preassure, precipitation, temperature, wind, visibility, pavement surface conditions	traffic accidents	all types	5 years
16	Tsapakis I., Cheng T., Bolbol A.	2012	rain, snow, temperature	travel times	urban network	10 days
17	Unrau D., Andrey J.	2005	rain	volume, average speed, occupancy	urban freeway	1 year
18	Vlahogianni E.I., Karlaftis M.G.	2012	rain	lane speed variability	freeway	2 days
19	Wang Y., Luo J.	2016	rain	speed, density	freeway	4 days
20	Xu F., He Z., Sha Z., Zhuang L., Sun W.	2013	rain	production, accumulation, weighted speed	urban network	12 days
21	Islam M.M., Alharthi M., Alam M.M	2019	rain, temperature, sandstorms	traffic accidents	all types	10 years
22	Qi Y., Zheng Z., Jia D.	2020	rain	traffic flow spatially and temporally	urban network	12 days
23	Yao Y., Wu D., Hong Y., Chen D., Zhaotang L., Guan Q., Liang, X., Dai L.	2020	rain	traffic-congestion bottlenecks	urban network	12 days

7. OTHER FACTORS AFFECTING STATISTICS

In addition to all the listed aspects, road traffic can be affected by other factors, which can also be interactive. First, most routes at night have significantly lower speed values. Kilpeläinen and Summala [7] reported that darkness reduces mean speed by 2.7 km/h, snow by 1.6 km/h, and both together by 5.1 km/h. To the contrary, Unrau and Andrey reported a 3% reduction of average speed in uncongested conditions in light rain at night and approximately a 10% drop during the daytime [28]. To avoid any unspecified effect of darkness, Smith & et al. limited the analyzed traffic set to daylight hours, filtering out data before sunrise or after sunset from their calculations [30]. Xu & et al. were interested in other time intervals and reported that rainy conditions produced weighted speed at capacity 4% lower but weighted speed during evening peak from 4.4% to 15.6% lower [4]. Like the time of day, the day of the week has an effect on observations. Saturdays and Sundays – and even Mondays and Fridays – can be different from typical workdays. Seasons and specific time periods like holidays can be a factor as well. Brilon and Ponzlet [34] present speed-flow relationships on German autobahns and detect lower average speeds during periods of predominantly leisure traffic, such as on Sundays or during the summer vacation season. Using the knowledge that sun glare tends to be worse in winter, Hagita and Mori decided to carry out an analysis by season [24]. Obviously, periods of some special events like festivals or roadworks cannot be used for standard comparisons as they should be treated as interesting but separate traffic problems. Finally, the sequence of events can influence statistics too, as in the situation when precipitation arrives for the first time after a period of good weather. Keay and Simmonds proved [35] that rainfall after a dry spell has a higher negative effect on the road accident count owing to the increased slipperiness of the road surface.

However, some of these differences can be explained by the generic nature of the vehicles themselves. Trucks have special speed restrictions and limited capacity to alter their speed quickly. In situations where the opportunity to pass is constrained, trucks affect the speed of other vehicles. To present this difference, Kyte & et al. calculated separate mean values for passenger cars and for trucks [20]. When the exact volume cannot be collected, the suggestion of Akin & et al. to calculate the percentage of heavy vehicles in the traffic mix [6] seems be a good solution as well.

8. COLLECTED DATA SETS

The discussed type of research requires at least two important kinds of data sets in the same time period: traffic and weather. It is possible to collect very detailed data. For example, Unrau and Andrey use a double-loop system to gather information in 20-second intervals for four variables: volume, average speed, occupancy, and average vehicle length [28]. However, this information had to be aggregated to 5-minute intervals to be consistent with previous studies and to reduce the degree of scatter in the data. Another factor that must be considered depending on demand is the time period of the measurement. Agarwal & et al. collected data for the four-year period between January 2000 and April 2004 [27], whereas Xu & et al. prepared their analysis based only on comparisons repeated six times: a rainy day versus the same weekday in dry weather from the previous or the following week [4].

A critical aspect of this type of project is the source of information. For traffic data, not only can loop detectors be used to gain information about vehicles but also speeds on the road network can be calculated using taxis' GPS data [4] or Floating Car Data technology in general [9]. A different approach was used by Qi & et al. to analyze the real-time traffic flow data of Traffic Signal Controllers [10], and Tsapakis & et al. used data collected from Automatic Number Plate Recognition cameras that cover a significant part of the city [17].

Regarding weather data, the most common source appears to be weather stations, which must be located near the network to accurately reflect the situation on the road. Creators of polish ITS system called TRISTAR to collect data independently added to the system a module for measuring meteorological parameters from 13 weather stations as Wawrzonek [36] describes. However, this is not the only way to collect data. In the study by Wang and Luo [16], rainfall intensity was monitored by the

Vaisala WTX520 ultrasonic rain gauge, and Chung et al [5] used the radar rain gauge system called Tokyo Amesh, which can observe an area within a 50-km radius and monitor conditions every minute.

In addition to direct measurement, other efforts sometimes must be undertaken to obtain statistics for research. Kilpeläinen and Summala distributed questionnaires at a total of 11 service stations located along ordinary main highways in Finland [7]. They asked drivers to rate current driving conditions and to classify the degree of slipperiness, the weather in relation to traffic, and the perceived general accident risk. Additionally, the authors inquired whether drivers had obtained weather-related information before the trip and about their decisions before and during the trip. They asked them to estimate their target speed, typical headway and overtaking frequency, and finally to provide some demographic data as well. During the period of collecting questionnaires, information from 267 automatic traffic counters along highways and motorways in the country was used to report the number and average speed of each type of vehicle in 15-minute periods. At the same time, roadside weather stations measured numerous traffic related weather parameters.

Regarding the research on road accidents, access to sufficient reliable police statistics is essential. Hagita and Mori used National Police Agency assets to analyze the situation in Japan [24]. The database included all traffic accidents resulting in injury as collected by the local police departments. The available records contained such attributes as time and place, the road traffic environment, the accident type, information about drivers, the vehicles, and safety facilities. This project, however, required additional data to check the effect of sun glare. In this case, the authors had to obtain information about the vehicles' travel direction and calculate the solar position.

9. CONCLUSIONS

Weather is a factor that brings uncertainty to road traffic. It can be the reason underlying additional costs for drivers, transport companies, and road operators when speed, volume, density, the accident rate, or other parameters change. Researchers within many disciplines have tried to estimate the real cost of a specified change in order to improve the situation. This has to be done with special regard to local information such as the level of regional urbanization, the type of route under study, the number of lanes, and road geometry. General information about the country of the tests is important, as well any special driver habits and restrictions in the motoring law, especially speed limits. Different climate zones can produce different types of issues: although some regions try to deal with the consequences of snowfall, rain, strong winds, low temperatures, or low visibility, others focus on the effect of sun glare or sandstorms. Additionally, the tested data sets must be collected carefully as different seasons or days of the week can represent separate groups of primary travel types. Darkness and peak hours are other factors that can interact with the previously mentioned elements. The development of technology, more advanced equipment, and new methodologies offer opportunities to estimate the effect of meteorological factors on road traffic more precisely and for larger test fields. Traditional weather stations are being replaced by radar, whereas cameras and loop detectors are displaced by GPS tracks and other methods. Open access to large data sets provides the ability to perform many new studies, whereas the experience gained from previously published papers helps prepare a better plan for subsequent research. Comparison of the results of individual studies can be problematic owing to the myriad of different resources, backgrounds, and methodologies. The appropriate meaning takes the transformation stage of the data to the same time intervals and periods, before the certain analysis. Analyses of earlier reports can result in more precise models of weather's effect on road traffic, with attention to the full array of other influencing factors. Such information nowadays can be helpful in planning the trip of a single driver and, even more, in supporting the decisions of large fleet operators. Finally, this research helps predict safe speeds under different conditions for specific routes to be used for variable message signs or by autonomous vehicles. However, to be reliable and comparable, the research must include detailed information about the researcher's specific approach to the problem, as this paper advocates. The described selected examples of studies and results cited in this review and the highlighted important methodological aspects may be a helpful preparation for the continuation of research in this area.

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