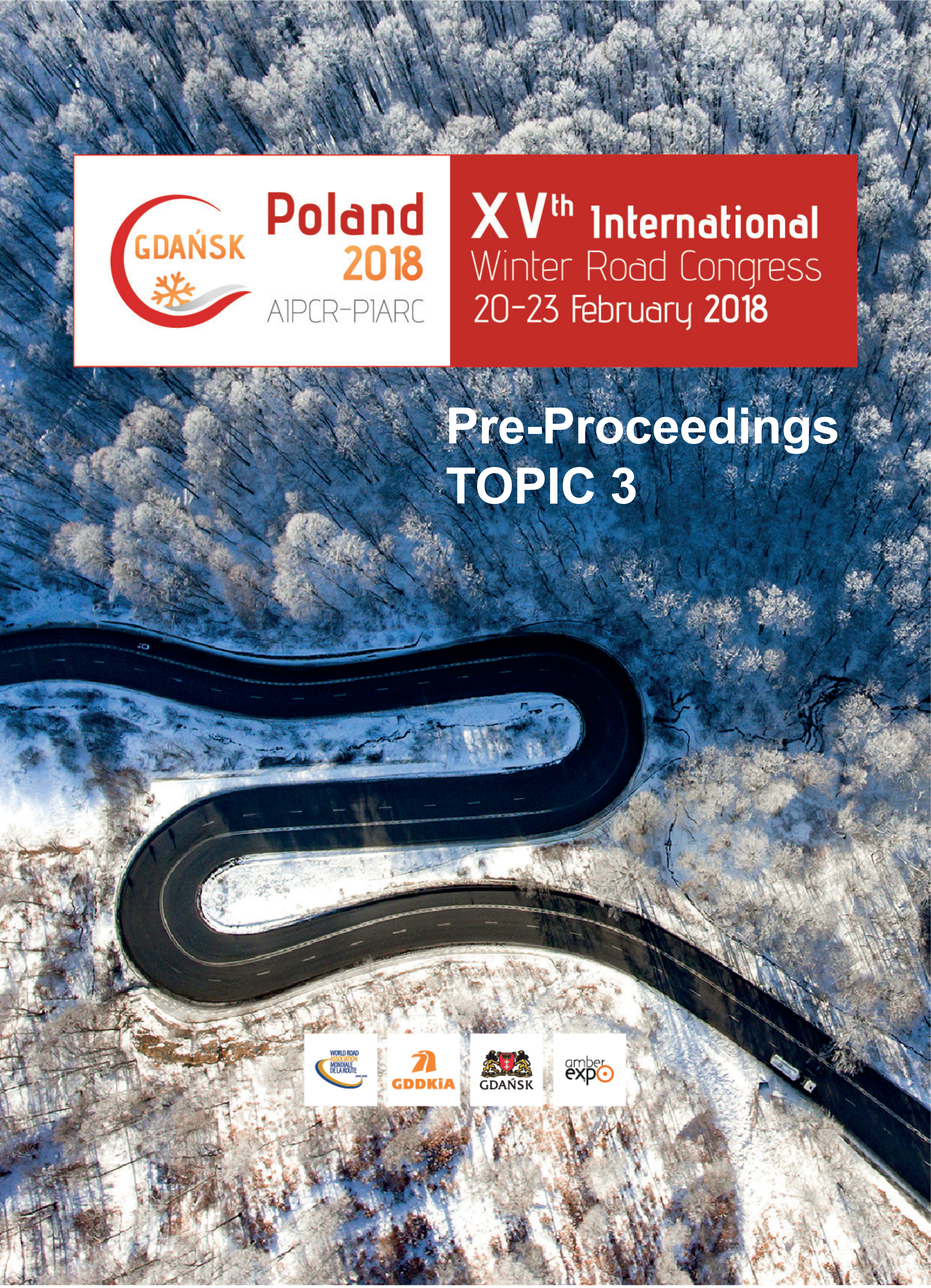

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Evaluation and Application of Data from Road Weather Stations for Winter Maintenance Management

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EVALUATION AND APPLICATION OF DATA FROM ROAD WEATHER STATIONS FOR WINTER MAINTENANCE MANAGEMENT

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ABSTRACT

The paper presents the analysis of road weather data from meteorological stations located at the Polish national roads of Pomerania District during the impact of winter conditions. Presented issue is particularly important from the point of view the problem of winter maintenance and especially for prediction and assurance of quality of asphalt pavement surface ie. resistance to low temperature cracking or risk of glazed frost. The objective of the paper is to define and determine crucial parameters of the weather and pavement conditions during winter season to reveal what are the differences in request for winter maintenance of pavements in (1) particular roads and (2) following winter months and years. To fulfil the objective of the paper data from 12 weather stations located in Pomeranian District of Poland and period of measurements from 2009 to 2016 were analysed. It was developed parameters: W_{glaze}, W_{ice} and W_{snow} to assess the percentage of time with the risk of occurrence of glaze frost, black ice and icy or compacted snow. The risk of low-temperature cracking was also analyzed. It was found that the risk of winter skid can reach very high level of 91% and in average in most severe winter month it equals from 35% to 71%. The main sources of winter skid in Pomerania are glaze frost and black ice. It was also confirmed that road no. 20 is the most exposed to low-temperature cracking and has the highest risk of winter skid. The methodology presented in the paper is universal and can be adopted for any region and could be useful tool for any road authority.

RÉSUMÉ

Ce document présente l’analyse des données climatiques routières collectées par les stations météorologiques situées sur les routes nationales polonaises de la région de Pomerania durant la période d’influence des conditions hivernales. Le sujet présenté est particulièrement important du point de vue de la maintenance hivernale et plus spécifiquement pour la prédiction et l’assurance de la qualité des surfaces de chaussées asphaltiques, c’est-à-dire la résistance aux fissures de basses températures ou le risque de verglas. L’objectif de ce document est de définir et déterminer les paramètres primordiaux du climat et des conditions de la chaussée pendant la saison hivernale afin d’identifier les différences en exigence de maintenance hivernale des chaussées pour (1) les routes particulières et (2) durant les mois et années suivants. Pour remplir l’objectif de ce document, les données de 12 stations météorologiques localisées dans la région de Pomerania en Pologne sur des périodes de mesures allant de 2009 à 2016 ont été analysées. Les paramètres suivants : Wverglas, Wglace et Wneige ont été développés pour évaluer le pourcentage de durée avec le risque d’apparition de givre, de verglas et de neige glacée ou compactée. Le risque de fissuration sous basse température a également été analysé. Il a été découvert que le risque de perte d’adhérence en hiver peut atteindre un niveau très élevé de 91% et en moyenne durant les mois les plus difficiles d’hiver il varie entre 35% et 71%. Les sources principales de perte d’adhérence en hiver en Pomerania sont le givre et le verglas. Il a aussi été confirmé que la route 20 est la plus

exposée à la fissuration à basses températures et à le risque le plus élevé de perte d'adhérence en hiver. La méthodologie présentée dans le document est universelle et peut être adoptée pour toute région et pourrait être un outil utile pour toute autorité routière.

1. INTRODUCTION

1.1. Background

Winter road maintenance operations are very important issues for traffic safety and road network accessibility in Northern countries. The use of pavement temperature measurements is one of the most important issue for winter maintenance decisions [1, 2]. Many regions all around the world experience frequent snow, sleet, ice, and also frost events from the late autumn to the early spring. In order to increase the importance of winter road maintenance, more precise information about road surface conditions is crucial. Better utilization of road weather data for planning of asphalt pavement winter maintenance could lead to lowering maintenance costs and increase of traffic safety. Road weather information systems started to be developed since 1970s [3, 4]. The increase of availability of meteorological data from road surfaces made it possible to model and forecast road pavement temperature and winter conditions [5, 6, 7]. Some studies deal with differences of air temperature close to road pavement surface [8]. Another important factors are the effects of climate change on road and highway pavements. According to published scenarios for climate change, the annual average temperatures are expected to rise by between 2ºC and 3,5ºC, by year 2050, depending on the region and scenario [9].

Poland is located in temperate warm transitional climate zone. Its territory is crossed by the air masses from both the Atlantic Ocean and the heart of the Eurasian landmass. The impact of continental climate increases gradually from East to West. Thermal conditions are mostly influenced by: air circulation, solar radiation and elevation above sea level [10].

1.2. Objectives and scope

The objective of the paper is to define and determine crucial parameters of the weather and pavement conditions during winter season to reveal what are the differences in request for winter maintenance of pavements in (1) particular roads and (2) following winter months and years. Winter maintenance of pavements was considered in two ways, 1) skid resistance and winter service and 2) pavement performance and risk of low-temperature cracking. For this purpose the data from road weather stations were analysed. On the basis of this analysis the methodology for determination of several factors describing risk of winter skid and pavement cracking were developed. Further the factors were used to rank roads in terms of request for winter service.

2. METHODOLOGY OF ANALYSIS

2.1. Sources of winter skid

Methodology of analysis is based on the determination of hours when the winter skid can occur on pavement surface. Thus firstly the sources of winter skid should be identified. In general, the cause of winter skid is ice or snow occurrence on pavement surface and its sources can be defined as follows [11]:

- Glaze frost (in UK defined as hoar frost) – occurs when the steam or fog condensate and freeze or desublimate on pavement surface, which temperature drops below 0°C. The phenomena intensify when air relative humidity exceeds 90% and difference between pavement temperature and dew-point temperature decreases below 0°C.
- Black ice – occurs when film of water freeze on pavement surface, when temperature drops below 0°C. The source of water film are rainfalls, snow defrost, steam condensation etc. Black ice is a clear ice that forms on roads due to the freezing of standing water. The term "black ice" is used because the road blacktop can be seen through the clear ice.
- Icy or compacted snow – occurs from not removed snow compacted by traffic.

The pavement surface temperature is the crucial parameter that impacts skid resistance. Decrease of pavement temperature bellow 0°C can result in glaze frost or black ice even if the air temperature is higher than 0°C. In the case of black ice the number of transition for 0°C has a significant meaning. With the increase of this number the risk of black ice occurrence increases.

2.2. Measurement of weather and pavement conditions

The crucial data to perform analysis of winter road maintenance concern pavement temperature and occurrence of water and snow on pavement surface. Generally the pavement temperature is not equal to the air temperature, but there is significant relationship between them. The following factors have significant impact on pavement temperature: air temperature, solar radiation (time of year and day, longitude and cloud cover), pavement structure and subgrade, air humidity, rainfalls and wind. Estimation of the pavement temperature on the basis of air temperature is complex and its accuracy is insufficient, thus data measured from road weather stations were utilized. The road weather stations provide following data: air temperature, pavement temperature on surface, in depth of 5 cm and 30 cm below the surface, air relative humidity, occurrence of water film on pavement surface, occurrence of rainfalls and its intensity, wind speed and direction, and occurrence of salt. Wide range of data provided from road weather stations supplemented by weather forecasts have great potential for usage in planning and management of winter road service and maintenance. The analysis conducted in this paper was based on historical data from weather stations located in Pomeranian District of Poland measured from 2009 to 2016.

2.3. Number of occurrence and duration of pavement low temperatures and snowfalls

The historical data allowed to identify periods of time when the pavement surface temperature dropped below 0°C, or any other low-temperature level, and duration of that time. In the analysis presented in this paper the number of temperature transitions through 0° and the maximum duration of temperature remaining bellow 0°C were determined and signed as $NT_{0°C}$ and $DT_{0°C}$ respectively.

Similarly, the number of snowfalls occurrence and maximum duration periods of snowfalls were determined and signed as NS and DS respectively. With the increase of NT, DT, NS, DS the number of winter maintenance actions increase. This measurements were used to compare particular months, years and to rank roads in terms of needs for winter road services. Additionally increase of the number $NT_{-15°C}$, $NT_{-20°C}$, $DT_{-15°C}$ and $DT_{-20°C}$ contribute to increase of the risk of low-temperature cracks occurrence and it was used to rank roads in terms of maintenance of pavement structure.

2.4. Determination of the risk of winter skid

In the analysis all cases of winter skid occurrence, which were described in the paragraph 2.1, were considered separately in particular hours of measurement. For this purpose following circumstances were set on measurement data:

- Glaze frost – pavement temperature on surface $T_s \leq 0°C$ and air relative humidity $h_{air} \geq 90\%$.
- Black ice – pavement temperature on surface $T_s \leq 0°C$ and water film is detected on pavement surface.
- Icy or compacted snow – snowfall is detected and air temperature $T_{air} \leq 0°C$

Because winter service was performed during measurements, the phenomena listed above could not occur in reality but the goal of analysis was to identify those hours, in which occurrence of winter skid is highly possible. In the next step hours with risk of skid occurrence were summed up and divided through total number of measurement hours, providing the percentage of time with the risk of winter skid occurrence. This approach takes into account differences in measurement time and lacks in data of particular stations. For further analysis the following designation were used: W_{glaze}, W_{ice} and W_{snow} for percentage of time with the risk of glaze frost, black ice and icy or compacted snow respectively. Factors W_{glaze}, W_{ice} and W_{snow} were calculated for particular winter months and particular stations. The maximum value of: W_{glaze}, W_{ice} and W_{snow} expresses the risk of winter skid in a given month and can be one of factors using for winter maintenance planning and management. In the further part of the paper this factor is signed as:

$$W = max\left(W_{glaze}, W_{ice}, W_{snow}\right) \quad (1)$$

where:

W – risk of winter skid for a given month, for W =100% the winter skid occur for a whole month, for W=0% there is no risk of winter skid.

W_{glaze} – percent of hours with pavement temperature on surface $T_s \leq 0°C$ and air relative humidity $h_{air} \geq 90\%$ in total number of measurement hours,

W_{glaze} – percent of hours with pavement temperature on surface $T_s \leq 0°C$ and water film is detected on pavement surface,

W_{snow} – percent of hours with detected snowfalls and air temperature $T_{air} \leq 0°C$.

2.5. Comparison of particular road sections in term of winter skid

The priority of winter service is given for motorways, expressways, national roads and local roads respectively. In Poland there are 5 standards of winter maintenance on national roads, which are described in details in the document [12]. Ensuring of given standard consumes resources like winter service vehicles, salt and other de-icing agents, sand etc., and this consumption increases when the winter conditions became more severe. For better planning of winter maintenance in a given road network it is necessary to rank roads that consumes more resources to ensure required standard. Road ranking were performed using the following procedure:

- determining the maximum values of W (after formula (1)) for each analyzed season and for each road separately (signed as $W_{max,season,road}$). The maximum value express the month with the highest risk of winter skid occurrence in a given season,
- determining the maximum values $W_{max, season}$ for all roads,
- calculating an average ratio of $W_{max,season,road}$ to $W_{max, season}$ for whole analyzed period of time according to the formula (2),
- calculating the ranking points MR_{road} for particular roads according to the formula (3).

$$M_{road} = \sum_{season=1}^{n} \frac{1}{n} \frac{W_{\max,season,road}}{W_{\max\,season}} \qquad (2)$$

$$MR_{road} = \frac{M_{road}}{\max M_{road}} \qquad (3)$$

where:

MR_{road} – ranking points in percent for a given weather station, for the station with the highest risk of winter skid MR_{road} = 100%,

W_{max} – maximum value of winter skid for considered seasons or stations in percent.

To analyze the variations of winter conditions in following months or years on particular roads, the methodology described above was adopted. In the first case, to compare and analyze winter conditions in following months, the factor M_{road} was calculated for data narrowed to selected months and all years of measurement. In the second case, to analyze impact of following years, the factors M_{roads} were calculated for all winter months from one year (season).

2.6. Comparison of particular road sections in term of pavement performance

Besides of typical winter maintenance operations that are connected to the problem of winter skid resistance there is also a problem of material behaviour at temperatures much more lower than 0°C. The problem of low temperatures of asphalt mixtures that can appear on the surface during winter season as transverse cracks need to be also taken into consideration. According to the literature [13, 14] that kind of cracks can be observed on Polish national roads and is connected to the behaviour of bitumen that at low temperatures (usually lower than -20ºC) becomes very stiff and brittle. In regions where such low temperatures could occur there is a need for design of asphalt mixture with use of bitumen that is more resist to low temperatures action. The solution can be application to asphalt mixture softer kind of bitumen or more common used in national Polish roads polymer SBS modified bitumen. The knowledge of occurrence of such low temperatures and period of time how long those temperatures could influence the asphalt pavement is of crucial importance for the road administration authority.

The crucial parameters which have impact on low-temperature cracking is minimum pavement temperature and also time of retaining low temperatures due to the phenomena of physical hardening of asphalt mixtures [15]. The ranking of stations in term of low-temperature cracking the following formula was used:

$$C_{road} = \frac{T_{\min,road}}{\min T_{\min,road}} + \frac{NT_{-15^o C,road}}{\max NT_{-15^o C,road}} + \frac{DT_{-15^o C,road}}{\max DT_{-15^o C,road}} + \frac{NT_{-20^o C,road}}{\max NT_{-20^o C,road}} + \frac{DT_{-20^o C,road}}{\max DT_{-20^o C,road}} \qquad (4)$$

$$CR_{road} = \frac{C_{road}}{\max C_{road}} \tag{5}$$

where:

CR_{road} - ranking points in percent for a given weather station, for the station mostly exposed to low-temperature cracking the MR_{road} = 100%,

T_{min} – the minimum pavement temperature observed in the whole analyzed period,

NT – maximum number of temperature transitions trough the -15°C or -20°C for a given weather station,

DT – maximum number of temperature retaining below -15°C or -20°C for a given weather station.

3. DATA ANALYSIS

3.1. Data collection and verification

Data were collected from 12 road weather stations located in national roads of Pomerania District in north part of Poland. Locations of the stations are shown in the Figure 1.

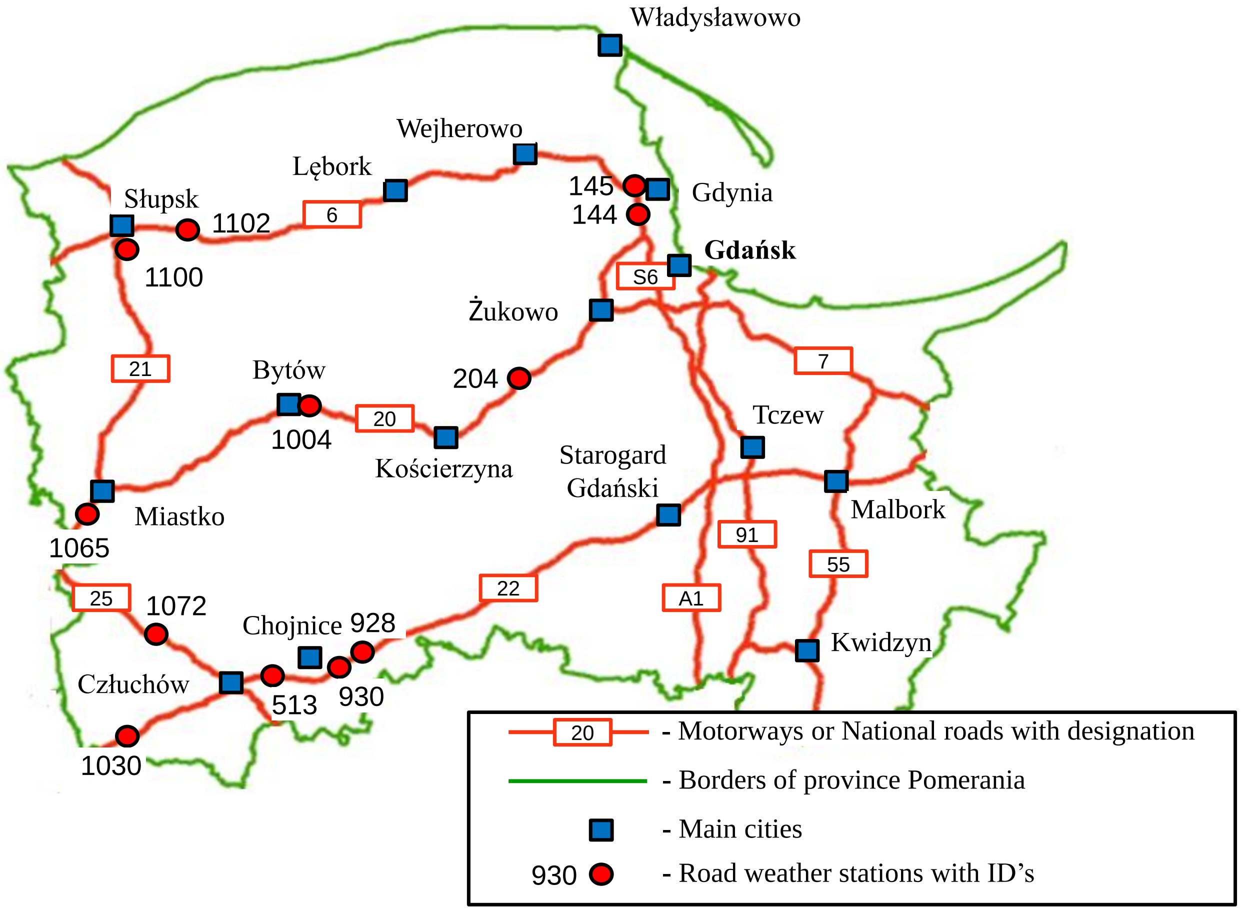

Figure 1. Location of weather stations in national roads of Pomerania District

Raw data were collected with intervals of one hour, however measurement allows to use 10 minutes time interval. The period covered winter months from November to April for each year for period from November 2009 to April 2016, what cover seven winter seasons. Raw data were verified and all records including uncomplete or invalid whether data were discarded. The detailed information concerning measurement time for particular station is given in the Table 1. As it is visible in Table 1, some of the months not include or include too little number of measurement hours to perform reliable calculations. It was assumed that minimum limit of measurement hours equals 490, what corresponds to minimum 65% of total time in month. Months which were discarded from further analysis are marked in the Table 1. To sum up, more than 250 000 records (hours) were used in analysis. Data for following stations:

- 928 (national road no 22 near Chojnice),
- 1065 (national road no 20 near Miastko),
- 144 (expressway S7 in Gdynia),
- 204 (national road no 20 near Koscierzyna)

are mostly complete and represent different regions in Pomerania District thus this stations were selected as examples to present results of analysis. The highest level of gaps in data were found for the season 6 (2014/15) so it was excluded from the analysis of comparison of particular roads.

Table 1. Number of measurement records (hours) used in the analysis

Year	Month	Stacion ID / road no											
		144	145	204	513	928	930	1004	1030	1065	1072	1100	1102
		S6	S6	20	22	22	22	20	22	21	25	6	6
Season 1													
2009	11	685	491	680	683	689	661	0*	683	688	311*	0*	0*
	12	703	669	667	711	675	689	0*	674	694	665	0*	0*
2010	1	712	712	712	713	713	713	0*	702	713	713	0*	0*
	2	625	625	607	608	607	608	0*	625	608	608	0*	0*
	3	666	664	666	666	666	666	0*	666	666	666	0*	0*
	4	510	509	510	510	510	510	0*	510	504	510	0*	0*
Season 2													
2010	11	690	689	688	690	690	690	0*	690	690	690	0*	0*
	12	713	713	704	705	713	713	0*	713	713	713	0*	0*
2011	1	713	713	713	713	713	713	448*	713	713	713	0*	713
	2	640	644	644	644	644	644	639	644	644	644	0*	639
	3	671	629	670	671	671	661	671	667	636	671	0*	671
	4	468*	248*	510	510	510	503	510	510	510	509	0*	509
Season 3													
2011	11	615	288*	654	176*	686	686	690	690	690	690	0*	690
	12	666	139*	713	713	713	713	713	516	713	713	0*	713
2012	1	574	34*	713	713	713	713	713	0*	713	713	713	713
	2	67*	185*	667	667	667	667	667	627	667	667	667	667
	3	198*	322*	654	671	671	671	671	671	671	671	671	671
	4	507	183*	510	506	498*	510	510	506	508	510	504	510
Season 4													
2012	11	690	662	690	690	690	644	690	680	690	690	690	690
	12	711	607	713	713	710	713	713	678	713	713	713	710
2013	1	713	462*	713	713	713	713	713	713	711	713	713	713
	2	644	409*	644	644	642	644	644	644	644	644	644	644
	3	395*	650	707	707	707	707	707	707	707	707	707	437*
	4	510	488*	505	510	506	510	306*	510	510	510	510	317*
Season 5													
2013	11	690	626	687	690	690	690	0*	423*	690	604	673	529
	12	713	660	690	713	713	713	0*	350*	698	713	713	713
2014	1	713	649	713	713	713	713	0*	433*	667	713	713	713
	2	644	644	641	644	644	530	0*	491	644	644	644	644
	3	701	701	615	701	650	213*	0*	495	697	701	701	701
	4	510	510	406*	510	502	44*	0*	213*	510	510	510	510
Season 6													
2014	11	690	690	0*	621	690	0*	0*	115*	690	690	690	690
	12	711	651	0*	186*	708	0*	0*	69*	557	713	713	713
2015	1	713	459*	0*	173*	713	0*	0*	0*	122*	713	713	713
	2	633	633	0*	210*	644	0*	0*	0*	5*	492	641	629
	3	695	597	0*	408*	695	0*	0*	1*	14*	0*	694	0*
	4	472*	0*	0*	382*	507	0*	0*	0*	266*	0*	503	28*
Season 7													
2015	11	690	690	690	690	686	674	0*	501	659	0*	686	659
	12	713	555	713	650	711	713	0*	713	712	0*	703	647
2016	1	713	660	712	710	713	713	0*	703	713	0*	708	593
	2	660	652	663	667	644	667	0*	667	667	0*	667	663
	3	682	630	681	683	583	683	0*	683	682	0*	683	647
	4	491	448*	493	493	403*	493	0*	493	491	0*	491	491
sum of records used in analysis		24320	18525	22952	23556	26923	22251	9251	19485	24793	21536	18378	19508

* month excluded from analysis

3.2. Analysis of pavement temperature and snowfalls

Figure 2 shows number of temperature transitions bellow 0°C NT. The number NT represents one cycle of drop of the pavement temperature bellow 0°C and rise up 0°C. It is visible in Figure 2 that NT varied from 25 up to 85 in last seasons. Years with high NT do not have to overlap with years with the lowest temperatures or years with high sum of snowfalls, however it could highly increase the risk of glaze frost. The maximum duration of temperature retaining bellow 0°C DT is presented for selected stations in Figure 3. Parameters NT and DT do not correlate with each other.

Figures 4 and 5 concern snowfalls and present total number of snowfall NS during season and maximum duration of snowfalls DS respectively. For most seasons number of snowfall occurrence NS is lower than number of temperature transitions bellow 0°C NT what indicates that the winter skid is more often caused by glaze frost or black ice than snowfalls. It is worth to notice that snowfalls occur much more often in station 204 than in other stations.

While the parameter NT is on similar level for each season, the rest of the parameters - DT, NS and DS indicate that the seasons 2009/10 and 2012/13 were the most harsh and at last three seasons from 2013/14 to 2015/16 were mild. It is also visible that in each year the maximum duration of temperature retaining below 0°C DT, the highest number of snowfalls NS and maximum time of snowfalls occurred for station 204 near Koscierzyna, what means that demand for snow removal will be highest in this region.

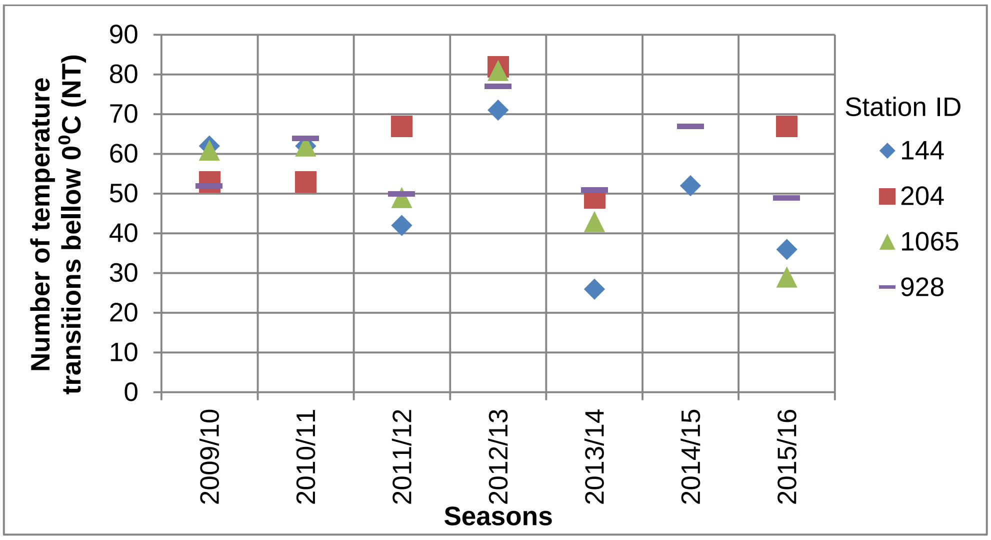

Figure 2. Selected results of the parameter $NT_{0^\circ C}$ - number of temperature transitions trough 0°C

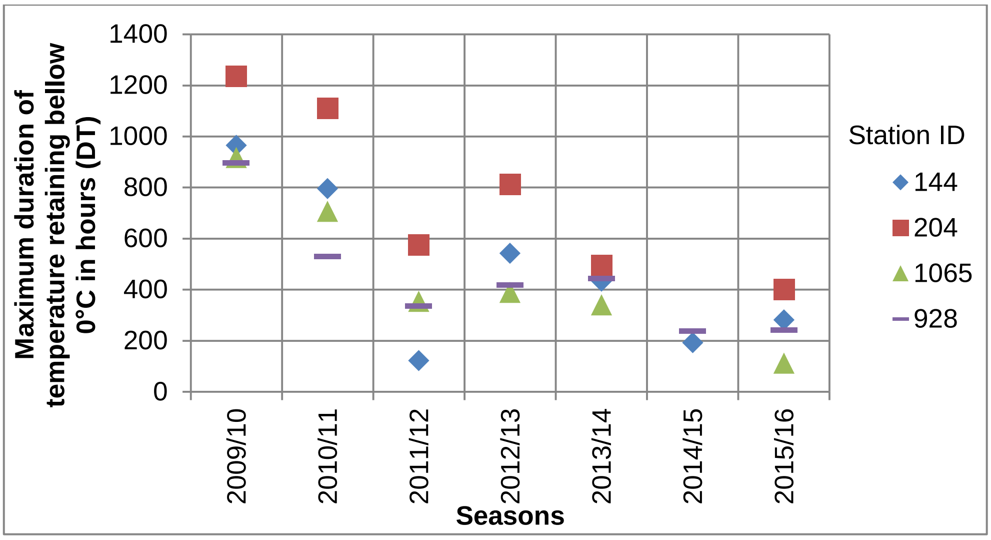

Figure 3. Selected results of the parameter $DT_{0°C}$ - the maximum duration of temperature retaining bellow 0°C

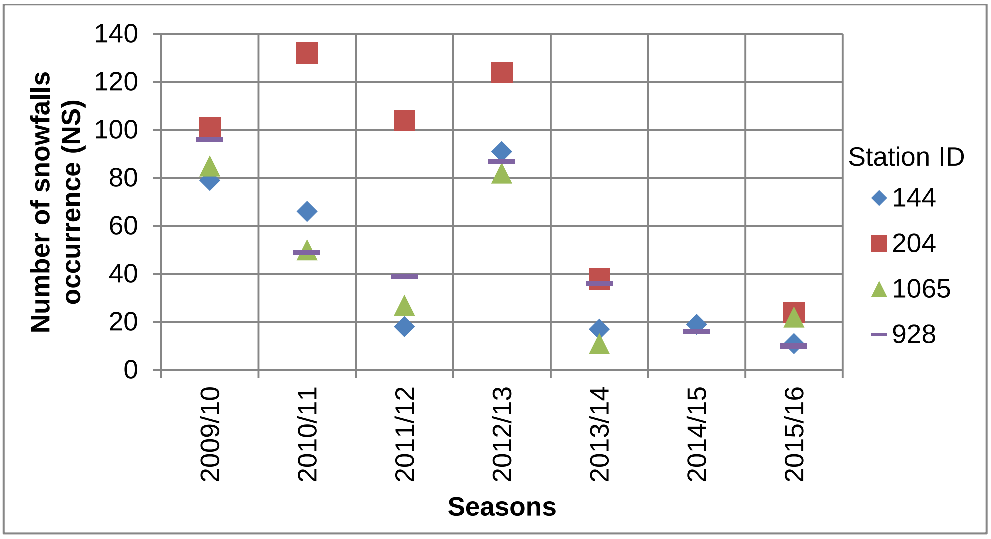

Figure 4. Selected results of the parameter NS - number of snowfalls occurrence

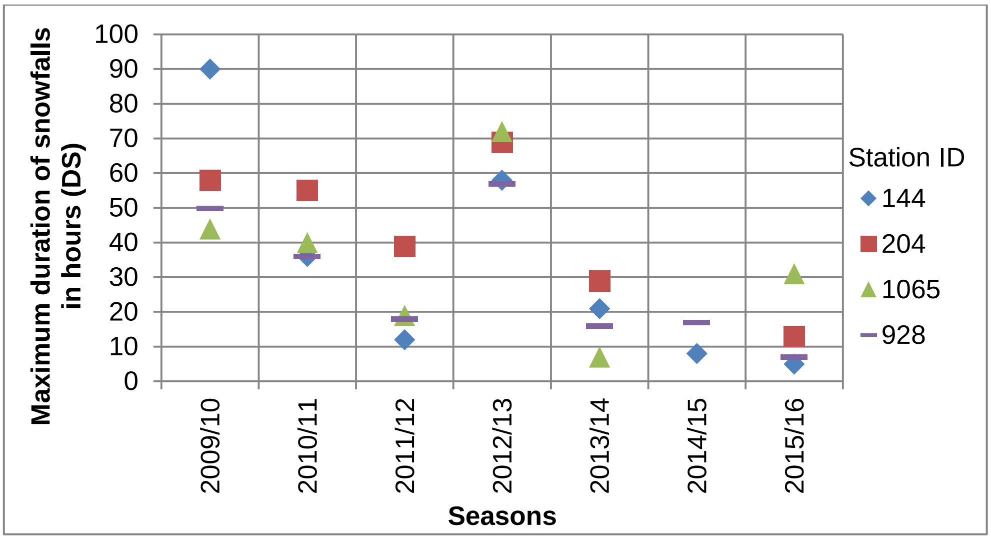

Figure 5. Selected results of the parameter DS - the maximum duration of snowfalls

Table 2 contains the maximum values of parameters NT, DT, NS and DS obtained for each station separately and include whole analysed period of 7 winter seasons from 2009 to 2016. The maximum transition trough 0°C NT in one season equals 124 and was observed in station 1100 near Słupsk in season 2014/15. Temperature retained bellow 0°C maximally through 1237 hours (51 days). Snowfalls occurred most often in station 204 near Koscierzyna and can retain for a several days.

Table 2. The maximum values of parameters $NT_{0°C}$, $DT_{0°C}$, NS and DS

Station ID	144	145	204	513	928	930	1004	1030	1065	1072	1100	1102	Maximum
$NT_{0°C,max}$	71	73	82	84	77	100	73	89	81	75	124	57	124
$DT_{0°C,max}$	966	417	1237	969	898	775	496	916	918	557	564	418	1237
NS_{max}	91	63	132	95	96	106	51	85	85	83	36	45	132
DS_{max}	90	176	69	52	57	196	68	63	72	55	14	20	196

Parameters $NT_{0°C}$, $DT_{0°C}$, NS and DS can be useful in assessment or forecasting the number of interventions of winter service, however this parameters depend on number of measurement hours thus any comparison analysis should be treated with reserve. To perform comparison of particular stations or seasons analysis should base on standardized parameters, which include influence of available measurement time.

3.3. Risk of winter skid and its main sources

The comparison of particular stations and winter seasons is possible with the usage of the parameter W - risk of winter skid occurrence. The approach of calculating parameter W is given in details in the chapter 2.4. Each measurement hour were considered by computer algorithm in term of occurrence of glaze frost, black ice or snow on pavement surface. Further particular hours which revealed high possibility of winter skid occurrence were summed up and divided through total number of measurement hours given in the Table 1 and this operation provided values of W_{glaze}, W_{ice} and W_{snow}, which are presented for an example station 928 in the Figure 6.

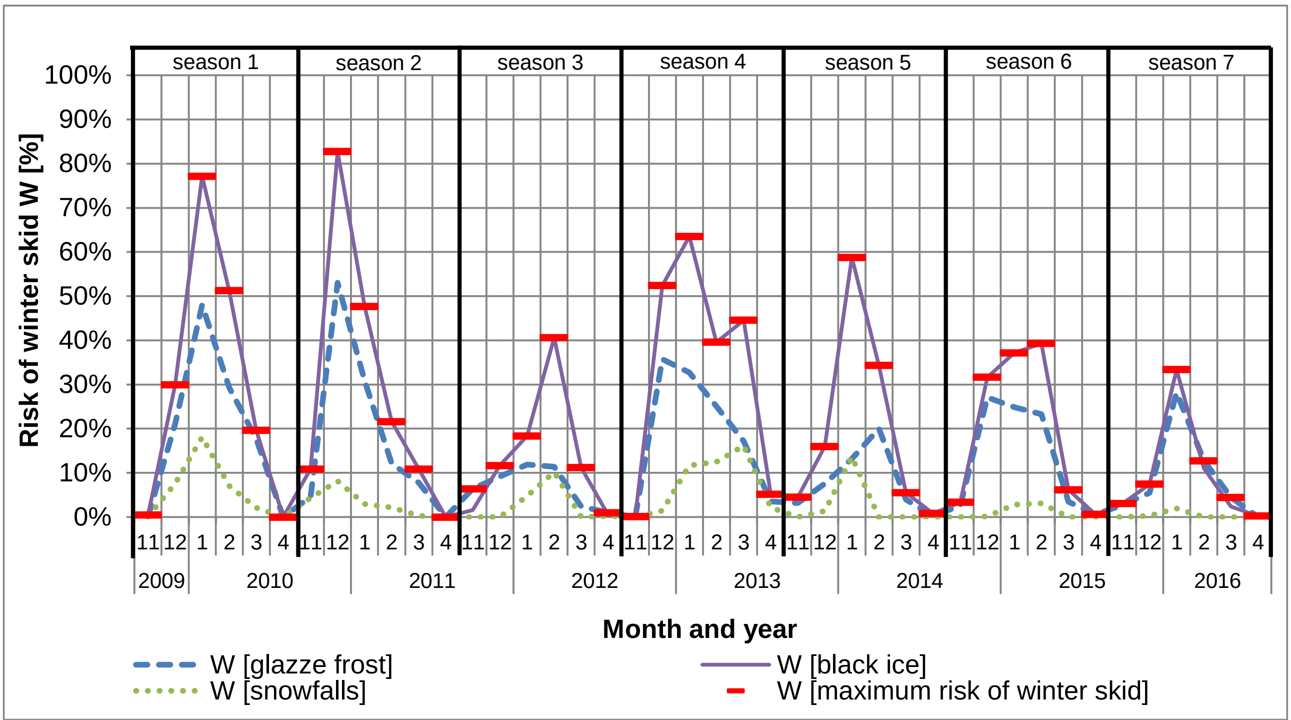

Figure 6. Selected results of the parameter W_{glaze}, W_{ice}, W_{snow} and W in months of winter seasons for station 928 and years 2009 – 2016

Calculations performed both for station 928 (Figure 6) and for all other stations indicate that black ice and glaze frost are the main reasons of winter skid due to the highest values of parameters W_{glaze} and W_{ice}. Parameter W_{snow} expresses percent of time with snowfalls and it rarely exceed 20%. However snow remains on pavement surface for a longer time and this fact is included in the factor W_{ice}.

The further comparison of stations and seasons based on the parameter W (see formula (1)) which expressed the total risk of winter skid. The physical meaning of parameter W corresponds to total percentage of time when pavement needs to be maintain by winter service to ensure traffic safety. In other words, parameter W expresses demand for winter service. The comparison of parameters W for particular months and for four exemplary stations is presented in the Figure 7.

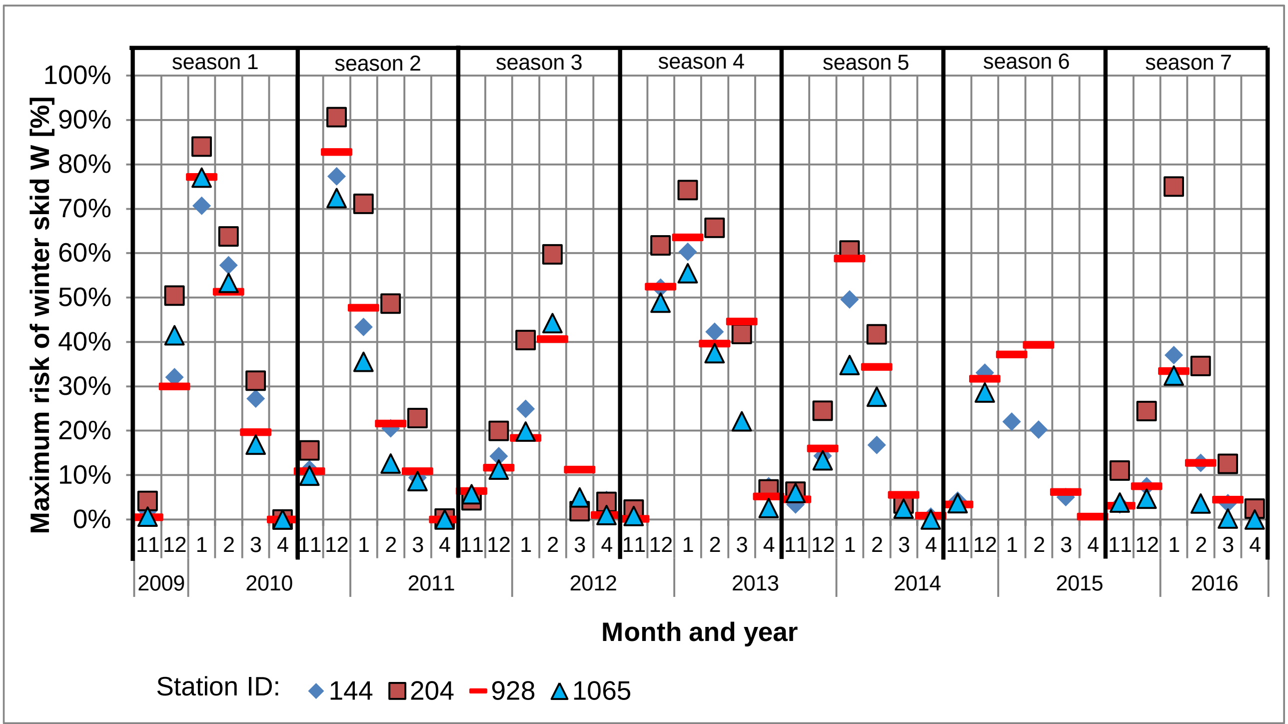

Figure 7. Comparison of maximum risk of winter skid W in particular months for station 144, 204, 928 and 1065 in years 2009 – 2016

It is visible in Figure 7 that the highest values of W occurs most often in January, less often in December or in February. The highest risk of winter skid was observed in December 2010 (season 2) and reached level of 91%. In contrary in November and in August the risk of winter skid W exceed 10% very rare, nevertheless in each year the parameter W is higher than 0%, what indicates that winter service have to be ready in this months. In seasons 4 the risk of winter skid W reached the highest average value of 44%, what indicates that this season was the most consuming of winter service. It is clearly visible in the Figure 7 that station 204 in road no 20 reached the highest values of W almost in each considered month. It indicates that demand for winter service in the section of road no 20 near station 204 is the highest. The summary of the maximum risk W in particular seasons and stations is given in the Table 3. It can be concluded from the table 3 that highest risk of winter skid occurred for station 204 near Koscierzyna and the lowest for station 1100 near Slupsk. In average in the most harsh winter month the risk of skid occur from 35% to 74% of time and extremally can occur in 91% of time.

Table 3. The maximum risk of winter skid occurrence W in following seasons for particular weather stations

Season	$W_{max,road}$												W_{max}
	144	**145**	**204**	**513**	**928**	**930**	**1004**	**1030**	**1065**	**1072**	**1100**	**1102**	
1 (2009/10)	71%	62%	84%	65%	77%	52%	*	73%	77%	48%	*	*	84%
2 (2010/11)	77%	62%	91%	73%	83%	74%	*	83%	72%	49%	*	34%	91%
3 (2011/12)	25%	*	60%	45%	41%	54%	52%	47%	44%	*	45%	46%	60%
4 (2012/13)	60%	*	74%	65%	64%	76%	62%	52%	55%	44%	46%	55%	76%
5 (2013/14)	50%	24%	61%	52%	59%	60%	*	*	35%	40%	27%	42%	61%
6 (2014/15)	33%	15%	*	*	39%	*	*	*	29%	34%	24%	28%	39%
7 (2015/16)	37%	34%	75%	52%	33%	46%	*	24%	32%	*	32%	43%	75%
Maximum from all seasons	77%	62%	91%	73%	83%	76%	62%	83%	77%	49%	46%	55%	-
Average from all seasons M_{road}	50%	39%	74%	59%	56%	60%	57%	56%	49%	43%	35%	41%	-

* data in a given season were uncomplete and the season was excluded from analysis

3.4. Minimum pavement temperatures and times of its retaining

The aim of analysis of minimum pavement temperatures is phenomena of low-temperature cracking of asphalt pavements and the phenomena is wider described in chapter 2.6 and in publications [16-20] Figure 8 presents the lowest pavement and air temperatures that were observed during winter months in station 928. Pavement minimum temperatures are higher than minimum air temperatures. Extreme temperatures in the last seven seasons occurred twice, in season 2009/10 (January) and 2011/12 (February) and reached level of nearly -20°C. Such low temperatures significantly increase the probability of low-temperature cracking occurrence [13-16]. Besides minimum temperatures a significant impact on increase of the risk of thermal cracking has time of low temperature retaining. The summary of minimum temperatures, number of its occurrence and maximum period of retaining of minimum temperatures is given in the Table 4.

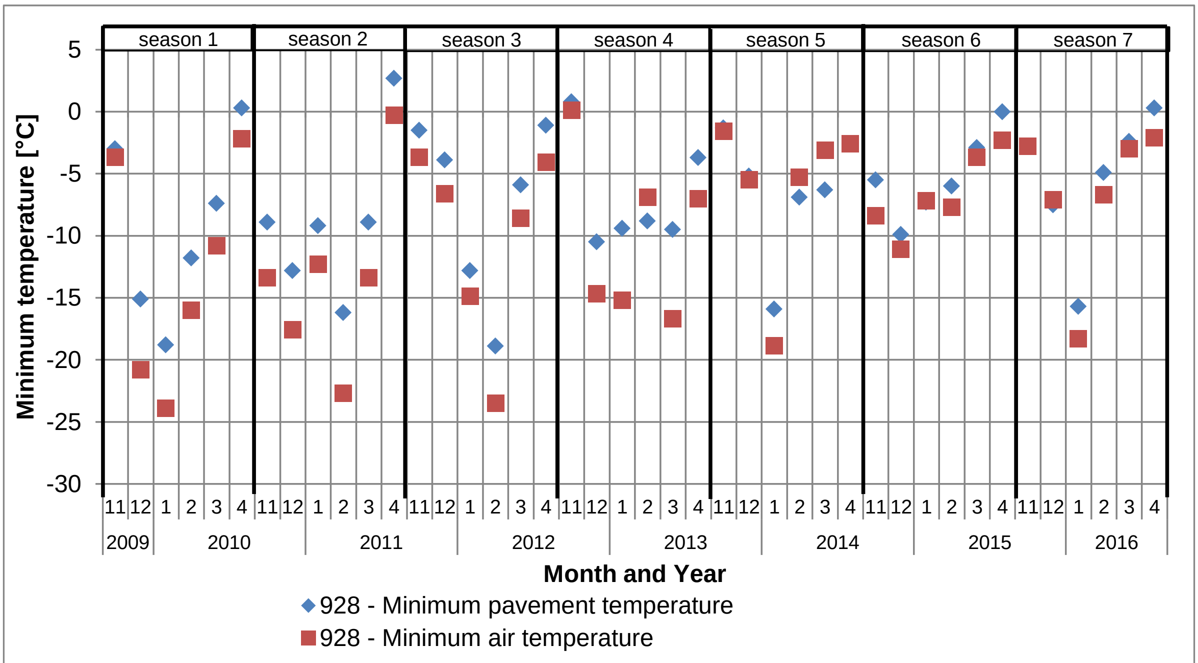

Figure 8. Minimum air and pavement temperatures in following winter months measured in station 928

Table 4. Summary of minimum pavement temperatures, number of its occurrence and period of its retaining in particular weather stations period

Station ID	Road no.	Minimum pavement temperature	Maximum number of temperature transitions NT bellow:		Maximum period in hours of retaining pavement temperature DT bellow:	
			-15°C	-20°C	-15°C	-20°C
144	S6	-17,3	7	0	16	0
145	S6	-17,7	2	0	9	0
204	20	-20,1	5	1	16	2
513	22	-20,3	8	1	17	2
928	22	-18,9	6	0	14	0
930	22	-18,9	11	0	15	0
1004	20	-21,6	6	2	16	8
1030	22	-20,8	5	1	15	7
1065	21	-21,7	5	1	15	8
1072	25	-20,8	6	1	15	7
1100	6	-24,0	6	2	11	6
1102	6	-22,0	3	1	14	7
Extreme values for all stations		-24,0	11	2	17	8

4. ROAD SECTION RANKING

The information of demand for winter maintenance is important for road authority for planning of cost for winter service and for repairs of pavement damages caused by action of low-temperatures. The ranking of roads was performed in two ways:

- on the base of winter skid risk for planning winter service,
- on the base of low-temperature cracking for planning maintenance of pavement structures.

Formula (3) and (5) were used to calculate ranking points for particular weather stations. The results of calculations are presented in the Figure 9.

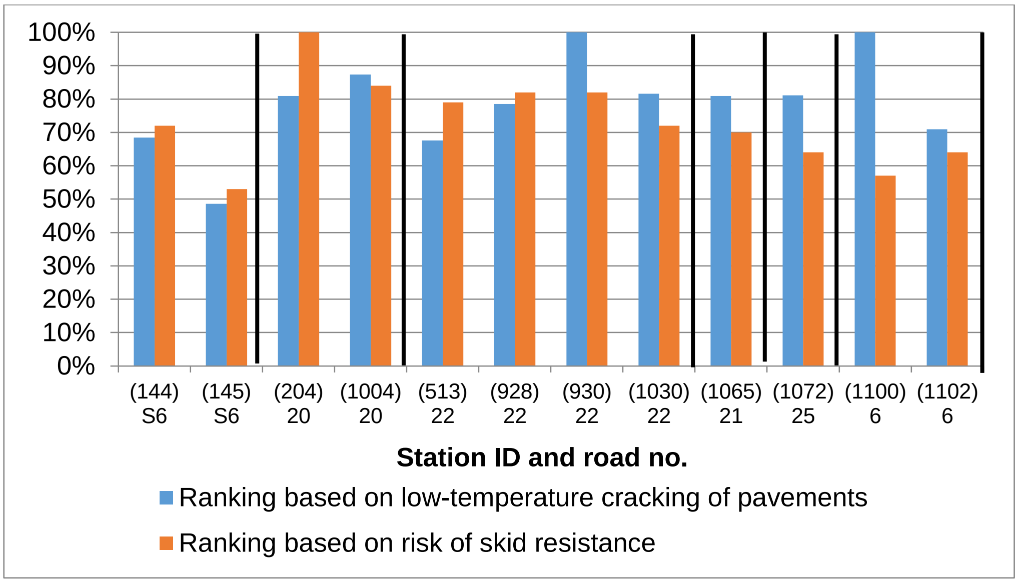

Figure 9. Ranking of weather stations on the base of risk of skid resistance and on the base of low-temperature cracking of pavements

It can be concluded from the Figure 9 that road no 20 (stations 204 and 1004) in section from Zukowo to Bytow proved the highest demand for winter service due to the highest risk of winter skid. The risk of winter skid is the lowest in road no 6 near Slupsk. It must be noticed that winter service planning also depends on other important parameters like road class, traffic etc.

Road no 20 is mostly subjected to low-temperature cracking while the road S6 on section near Gdynia seems to be at least subjected to low-temperature cracking. The exposition of pavement structure to low-temperature cracking is not related with the risk of winter skid, what is clearly visible for station 1100, where the risk of winter skid is relatively low and the exposition for low temperature cracking is high.

5. SUMMARY AND CONCLUSIONS

The methodology of evaluation and application of data from road weather stations for winter maintenance management was developed and described in details in the paper. The methodology was used to perform the analysis of data collected from 12 road weather stations located in Pomerania District (the north part of Poland) during 7 winter seasons. The analysis allows to drawn the following important conclusions:

1. The maximum transition trough 0°C, which in Pomerania District equals maximally to 124 times, indicate the problem of winter skid on particular roads but cannot be used for comparison of particular stations or seasons. The reason is that gaps and unreliable measurements can occur in data from road weather stations, causing uneven period of measurements on particular stations. Parameters used for comparisons of stations or seasons in terms of winter skid should be standardized.
2. The risk of winter skid W express total time in month when the winter skid occur. Parameter W include effect of uneven measurement period and can be used to compare particular stations or seasons. The risk of winter skid can reach very high level of 91% and in average in most severe winter month it equals from 35% to 71%.
3. The main sources of winter skid in Pomerania are glaze frost and black ice. Snowfalls occurs less frequently than glaze frost but snow can retain in pavement surface for a longer time and this effect is included in analysis and recognized as black ice.
4. The risk of winter skid express the demand for winter service. The paper presents a methodology of raking of roads in terms of winter skid. The ranking can be very useful for road authority to plan budget of winter maintenance and to identify roads with higher priority of winter service.
5. Minimum pavement temperatures and maximum period of retaining very low temperatures express the exposition of pavement structure to low-temperature cracking. The methodology described in the paper allows to perform a ranking of roads in terms of exposition of pavement structure to low-temperature cracking. The exposition of pavement structure to low-temperature cracking is not related with the risk of winter skid.
6. It was confirmed that road no. 20 has the highest risk of winter skid and is the most exposed to low-temperature cracking. However weather stations in Pomerania do not cover the whole area and all road sections. It is recommended to increase the number of weather stations to make the statistics more accurate. The methodology presented in the paper is universal and can be adopted for any region and could be useful tool for any road authority.

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