Winter Road Condition Classification and Reporting – A Risk Based Approach

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ABSTRACT

The paper presents a risk-based approach for classifying the road surface conditions of a highway network under winter weather events. A relative risk index (RRI) is developed to capture the effect of adverse weather conditions on the collision risk of a highway in reference to the normal driving conditions. Based on this index, multiple risk factors can be considered together or individually. The index can also be used to aggregate risk levels on a route with a variety of road conditions. Two example applications are shown to illustrate the advantages of the proposed approach.

RÉSUMÉ

Cet article présent une approche basée sur les risques pour classer les conditions de la roue d'un réseau de routes nationales pendant l'hiver. On introduit un Indice des Risques Relatifs (IRR) pour saisir l'effet des conditions climatiques défavorables sur le risque des collisions d'une route nationale par rapport aux conditions habituelles. Selon cet indice, on peut considérer plusieurs facteurs de risques soit individuellement ou ensemble. L'indice peut aussi être utilisé pour convertir les différentes catégories de conditions de la rue, observé sur n'importe quelle route, à une seule catégorie dominant basé sur le risque relatif entre les catégories individuelles des conditions. Deux exemples de ces applications sont montrés pour illustrer les avantages de cette approche.

1. INTRODUCTION

In countries with severe winter seasons, transportation agencies often face significant challenges in meeting the safety and mobility needs of road users. To address these challenges, most agencies have a comprehensive winter maintenance program in place, specifying service policies and standards, best practices, and performance measurement guidelines. Essential to these programs is monitoring and reporting of road weather and surface conditions, using a variety of methods such as Road Weather Information Systems (RWIS), patrolling, and/or friction measurements. Information on road weather and surface conditions can be used by maintenance operators to assess the need for maintenance service, by researchers to compare the effectiveness of different treatment methods, and by operations managers evaluate the quality of the maintenance. This information is equally valuable to the road users in planning winter travel to avoid hazardous areas or travel delay during inclement conditions.

Road surface conditions are commonly represented in the form of predefined condition classes, such as bare pavement, bare lane, and snow covered. There are however a wide variety of terminologies and classification systems currently being used in practices by different countries and jurisdictions (e.g., Boselly [1]). Some of the attempts have been made to develop consistent and uniform taxonomy on road conditions (e.g., NCHRP [2]; TAC [3]). However, most of the proposed classification systems rely on heuristic rules that are intuitive and easy to implement but have not been validated against driving risk. In this paper, we propose a new approach to classifying winter road conditions with an explicit account of the driving risk that a motorist may experience on a highway. This paper is organized as follows. Section 2 provides a brief review on common road surface condition monitoring and reporting practices. An overview of a risk-based approach is presented in Section 3, followed by two examples of application.

2. WINTER ROAD CONDITION CLASSIFICATION AND REPORTING PRACTICE

A wide variety of terminologies and classification schemes have been developed and used by transportation authorities around the world and across different jurisdictions. Boselly [1] synthesized different formats used by seven states in the US (Table 1). For example, North Dakota Department of Transportation (DOT) groups road surface conditions into seven main categories while Missouri DOT uses only four. The road surface condition information is disseminated to travelers through a common traveler information portal known as 511 system (http://www.fhwa.dot.gov/trafficinfo/511.htm). However, there appears to exist significant inconsistency in reporting road surface conditions both in terms of the number of categories and the terminologies being used to describe the conditions. The author highlighted that the use of inconsistent reporting terminologies could cause problems for road users when crossing states boundaries. A list of terminologies was therefore recommended; however, the categories seem to have been arbitrarily chosen without explicitly considering the risk associated with each of these categories.

Similarly, in Northern European countries and Japan, a variety of road surface categories have been defined (Table 2). For example, Sweden divides road surface conditions into five categories while Finland and Japan (Hokkaido) adopt a system of 6 and 13 categories, respectively. Many of these countries use a friction based monitoring system to determine the condition categories. Note that friction measurements are also used to evaluate performance of ice and snow control activities in order to compare efficiency of alternative treatments and service level [4]. Again, there is a lack of uniformity in condition classification and reporting.

In Canada, most provinces or territories used to have their own winter road condition classification and reporting system. This situation has however started to change due to a recent effort by Transportation Association of Canada (TAC), in which a consistent and uniform taxonomy and road surface condition (RSC) classification system has been developed [3]. Many Canadian road authorities have started to adopt this system in reporting winter road surface conditions. In the proposed method, road conditions are divided into three general categories (clear, partly covered and fully covered), which are further classified into eight subcategories. A set of heuristic rules are introduced to classify the road surface conditions of any given highway with mixed snow and ice cover. The classification scheme considers the extent of longitudinal and cross sectional coverage (bare, partly or covered) and types of contaminants (wet, snow, snow packed, ice) with priority given to the most severe conditions. While this method has taken into consideration of the relative risk of different types of road surfaces, its underlying logic has not been fully investigated.

Table1- RSC Classification Systems Used by Some of the US DOTs

North Dakota	Missouri	Iowa	Virginia
• Snow covered • Scattered snow or drifts • Frost • Compacted snow • Ice • Wet or slush • Dry	• Covered • Partly covered • Wet • Dry	• Normal winter driving • Partly-mostly snow or ice covered • Snow or ice covered	• Minor • Moderate • Severe

Ohio	Washington State	Montana
• Dry condition • Wet condition • Snow/ice condition • Severe/snow/ice/drifting condition	• Dry • Wet • Ice/Snow	• Snow packed and icy • Intermittent snow pack with possible ice • Icy or frost • Black ice

Source: [1]

Table 2: RSC Classification Systems Used by Some of the European Countries and Japan

Sweden		Finland		Japan, Hokkaido	
RSC categories	Friction coefficient	RSC categories	Friction coefficient	RSC categories	Friction coefficient
• Good • Medium to good • Medium • Medium to poor • Poor	• 0.40 and above • 0.36-0.39 • 0.30-0.35 • 0.26-0.29 • 0.25 and below	• Bare and dry • Bare and wet • Packed ice and snow • Tightly packed snow • Icy • Wet ice	• 0.45-1.00 • 0.30-0.44 • 0.25-0.29 • 0.20-0.24 • 0.15-0.19 • 0.00-0.14	• Dry, Wet • Slush, Granular snow on ice crust, Powder snow • Compacted snow, Granular snow on ice crust • Ice film, Powder snow on ice crust, Ice crust • Very slippery compacted snow, Very slippery ice crust, Very slippery ice film Note: Total 13 categories	• ~0.45 • 0.25-0.35 • 0.2-0.3 • 0.15-0.3 • 0.15-0.20 • ~0.20 • ~0.15

Source: [4,6]

3. A RISK BASED APPROACH

In the present research, a risk-based approach is developed to define and classify the winter driving conditions, including road surface conditions of a highway. A relative risk measure, called relative risk index (RRI), is proposed to represent the overall safety level and drivability of a highway section under adverse winter weather conditions. Specifically, RRI is defined as the ratio of the expected collision frequencies between two conditions as follows:

$$RRI_w = \frac{\mu_w}{\mu_0} \quad \text{Eq. [1]}$$

Where μ_w and μ_0 are the numbers of collisions that are expected to occur on this highway section over a specific time period (e.g., one hour), i.e., collision frequency, under two condition scenarios: the adverse winter weather event (w) and the base condition - normal (non-event) weather conditions, respectively. Statistical models can be calibrated to estimate the collision frequency of a highway based on various condition variables such as traffic exposure, weather variables and road geometry. In our previous study, hourly collision frequency models have been developed with specific consideration of winter weather effects and road surface conditions [5]. In the calibrated models, the mean accident frequency (μ) is assumed to be a function of a set of covariates as given in Equation 2.

$$\mu = e^{(\beta_o + \beta_i \ln(\text{exposure}) + \sum \beta_i * x_i)}$$ Eq. [2]

where exposure is the total vehicle kilometers travelled over an one hour period; X_i's are covariates representing road weather and surface condition factors such as precipitation, visibility, and wind speed; and β_i's are the corresponding model coefficients.

Table 3 shows the model calibration results from Usman et al. [5]. The seven factors were found to have a significant effect on road safety, including traffic exposure, hourly precipitation, wind speed, road surface condition, and visibility. This model can be used to determine the expected collision frequency under the two condition scenarios. For the base condition, the following ideal settings are assumed: precipitation = 0, wind speed = 0, RSI = 1.0, and visibility = 10 km.

Road surface conditions are represented by a surrogate measure called RSI (road surface index) with values ranging from 0 to 1. RSI can be viewed as an indicator of the friction level of a pavement surface, depending on the degree of snow and ice cover. A mapping from descriptive road surface conditions to RSI was proposed by Usman et al. [5] as given in Table 4.

If we are only interested in the relative risk index with respect to one particular factor, x_i, (e.g., road surface conditions – RSI), the associated RRI can be determined by holding other condition variables constant, i.e.,

$$RRI = e^{\beta_i \cdot (x_i - x_{i0})}$$ Eq. [3]

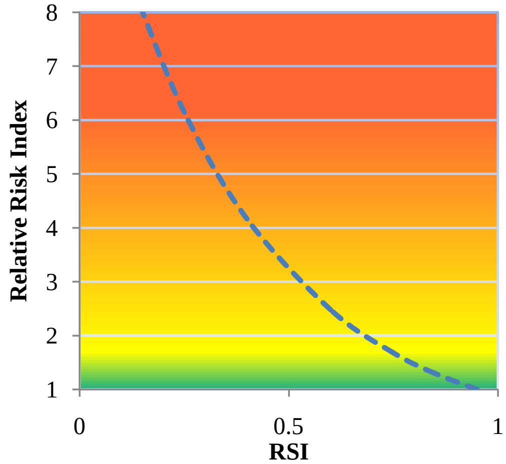
Figure 1 illustrates RRI as a function of individual risk factors. As expected, road surface conditions have the most important effect on the risk level of a highway. Lower RSIs are associated with higher RRIs, which is intuitive as a lower RSI indicates unfavorable driving conditions due to lower frictional level. Similarly, Figure 1 (b-e) illustrates that higher RRI levels are associated with severe weather conditions (e.g., higher precipitation, lower temperature, lower visibility and higher wind speed). However, the degree of impacts of these weather factors on road safety is far less than that caused by RSI. A more extensive discussion on the implications of these findings can be found in Usman et al. [5].

Table 3- Summary of Model Results

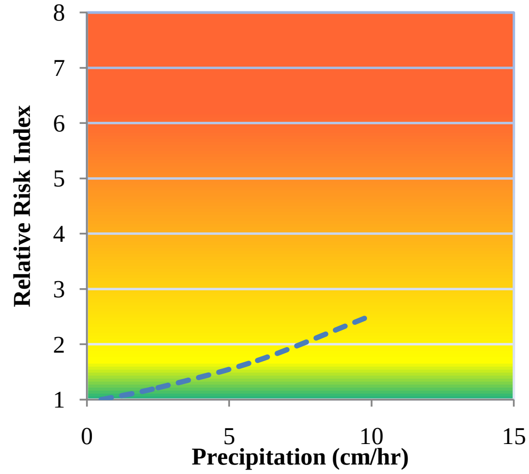
Category	Variable	Coefficient	Sig
	Constant	-1.249	0.006
Temporal trend	October	0.000	
	November	-1.029	0.000
	December	-1.262	0.000
	January	-1.308	0.000
	February	-1.536	0.000
	March	-1.278	0.000
	April	-1.134	0.000
	First hour (FH=1)	-0.302	0.001
	Other Wise (FH=0)	0.000	
Weather Condition	Temperature	-0.011	0.021
	Wind Speed (Km/hr)	0.005	0.017
	visibility (km)	-0.039	0.000
	Hourly Precipitation	0.097	0.079
Road Surface Condition	RSI	-2.594	0.000
Traffic exposure	Ln(Exposure)	0.235	0.000

Table 4- RSC Types and Corresponding Relative Risk Index

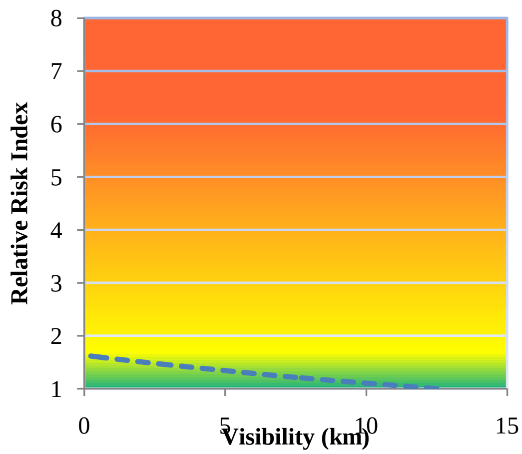
RSC Type	Description	Road Surface Index (RSI)			Relative Risk Index (RRI)		
		Max	Min	Ave	Max	Min	Ave
1	Bare and Dry	0.9	1	0.95	1.14	0.88	1.00
2	Bare and Wet	0.8	0.9	0.85	1.48	1.14	1.30
3	Slushy	0.7	0.8	0.75	1.91	1.48	1.68
4	Partly Snow Covered	0.5	0.7	0.6	3.21	1.91	2.48
5	Snow Covered	0.3	0.5	0.4	5.40	3.21	4.16
6	Snow Packed	0.2	0.3	0.25	7.00	5.40	6.15
7	Icy	0.05	0.2	0.125	10.3	7.00	8.50



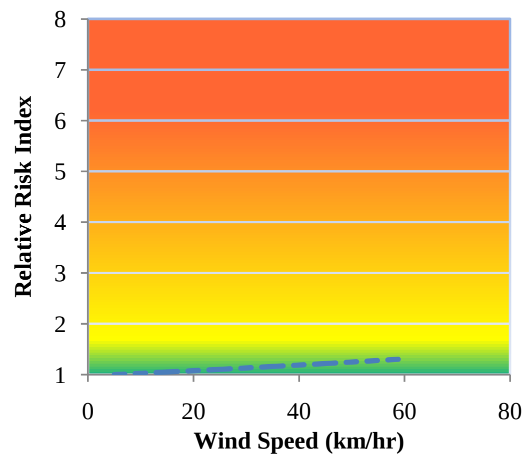
a) Road Surface Condition



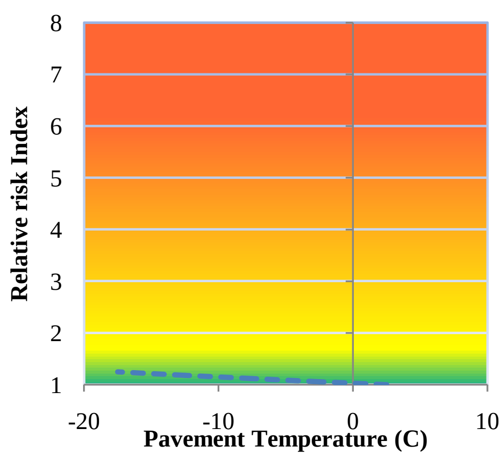
b) Precipitation



c) Visibility



d) Wind Speed



e) Temperature

Figure 1- Effect of Road Weather and Surface Condition Factors on RRI

4. APPLICATIONS

The Relative Risk Index (RRI) defined in Equation (1) provides a direct link between road safety and the contributing factors including road weather and surface conditions. It can be used to combine multiple risk factors together based on their levels of contributions to the overall risk of collision (Equation 1 and 2). As a result, road authorities can report the relative driving risk of a road section, taking into account all major factors such as precipitation, wind speed, visibility, and road surface conditions. Figure 2 shows an example visualizing the relative driving risk of a regional network.

It is also possible to report individual condition factors separately in terms of their relative contribution to the overall collision risk. For example, in the context of this research, we are interested in reporting road surface conditions in particular. Equation 3 can be used to estimate the RRI associated with different types of road surface conditions, as represented by RSI.

In addition, the RRI can be used as a basis for determining the overall risk level of a route that has multiple road surface types (e.g., bare, fully snow covered, bare track) and classify it in a way that is consistent with this overall risk level. The following two methods are proposed:

1) Classification based on average RRI (*RRI-based Method 1*): The average RRI of a route is defined as the length-weighted average relative risk of all subsections as follows (Equation 4).

$$\overline{RRI} = \frac{\sum RRI_i * l_i}{\sum l_i} \qquad \text{Eq. [4]}$$

   Where l_i is the length of subsection i of the route and RRI_i is the corresponding relative risk index for the subsection. The overall road surface condition type could be decided accordingly based on the mapping between RRI and road surface conditions (Table 4).

2) Classification based on total RRI (*RRI-based Method 2*): The total RRI of a subsection (l_i) is defined as the product of its relative risk index (RRI_i) by its length (l_i) by, i.e., l_i x RRI_i. The subsection with the highest total RRI is considered as the dominant subsection of the route and its road surface condition type is used to designate the condition of the whole route.

Figure 3 shows four examples comparing the classification results of the proposed risk based methods using a hypothetical highway route. The route is 20 kilometers long and divided into 20 sections of equal length (one kilometer each) with each section's road surface type being generated randomly according to some assumed condition scenarios. For each example, the sections are sorted by the road surface condition type (from RSC Type 7 to RSC Type 1, as described in Table 4).

The first example (Figure 3-a) is intended to simulate conditions that are relatively severe with RSC ranging from RSC Type 5 (fully snow covered) to Type 7 (fully ice covered). As can be seen, the RSI Method 2 has classified the route into Ice Covered (RSC Type 7), which is more severe than the overall route condition identified by the RRI-based Method 1.

The second example (Figure 3-b) simulates highly mixed road surface conditions, with RSC varying from RSC Type 1 to RSC Type 7. In this case, the route would be classified as being Snow Packed (RSC Type 6) by Method 2 while it would be in the less severe category of Snow Covered (RSC Type 4) based on its overall risk.

Method 2 indicates a higher overall risk in the other two examples (Figure 3-c, Figure 3-d) which simulate two mild conditions with the first one being relatively uniform (RSC Type 1-5) and other having a combination of two extremes (RSC Type 1, 2 and 7).

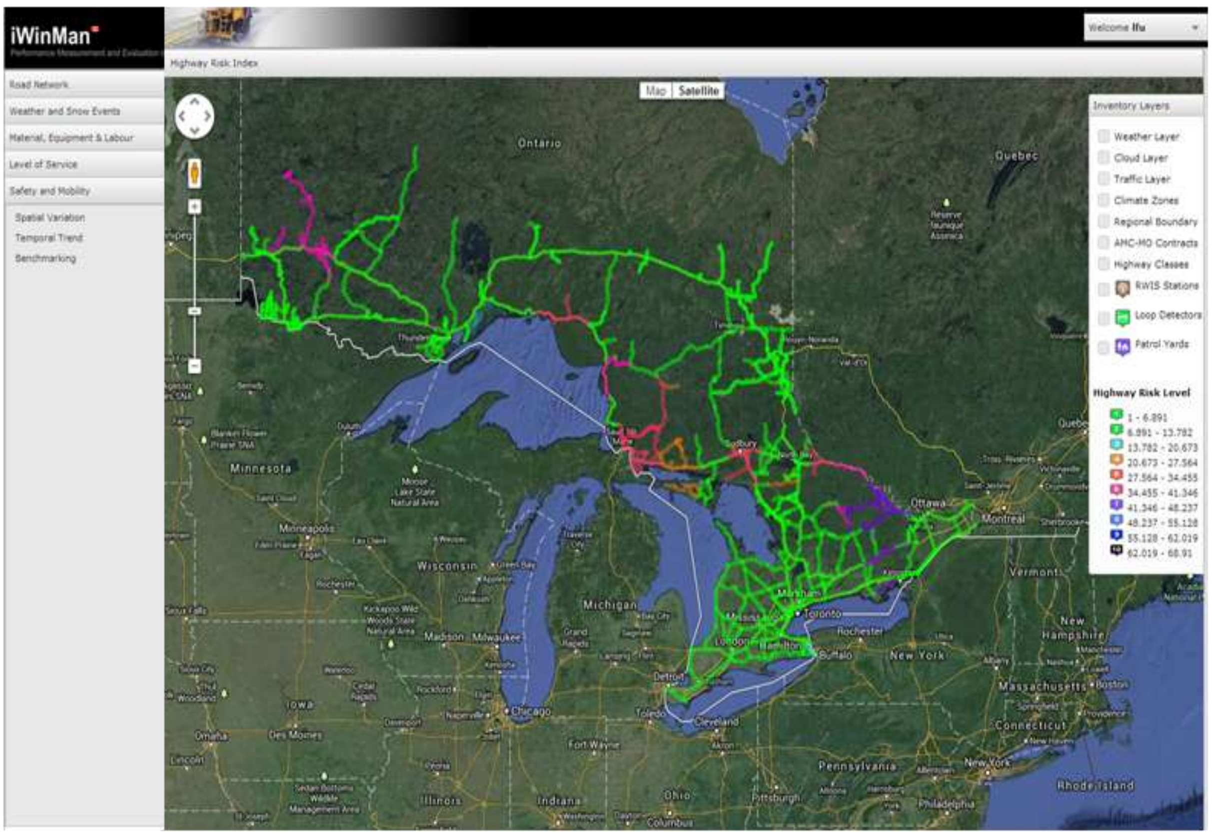
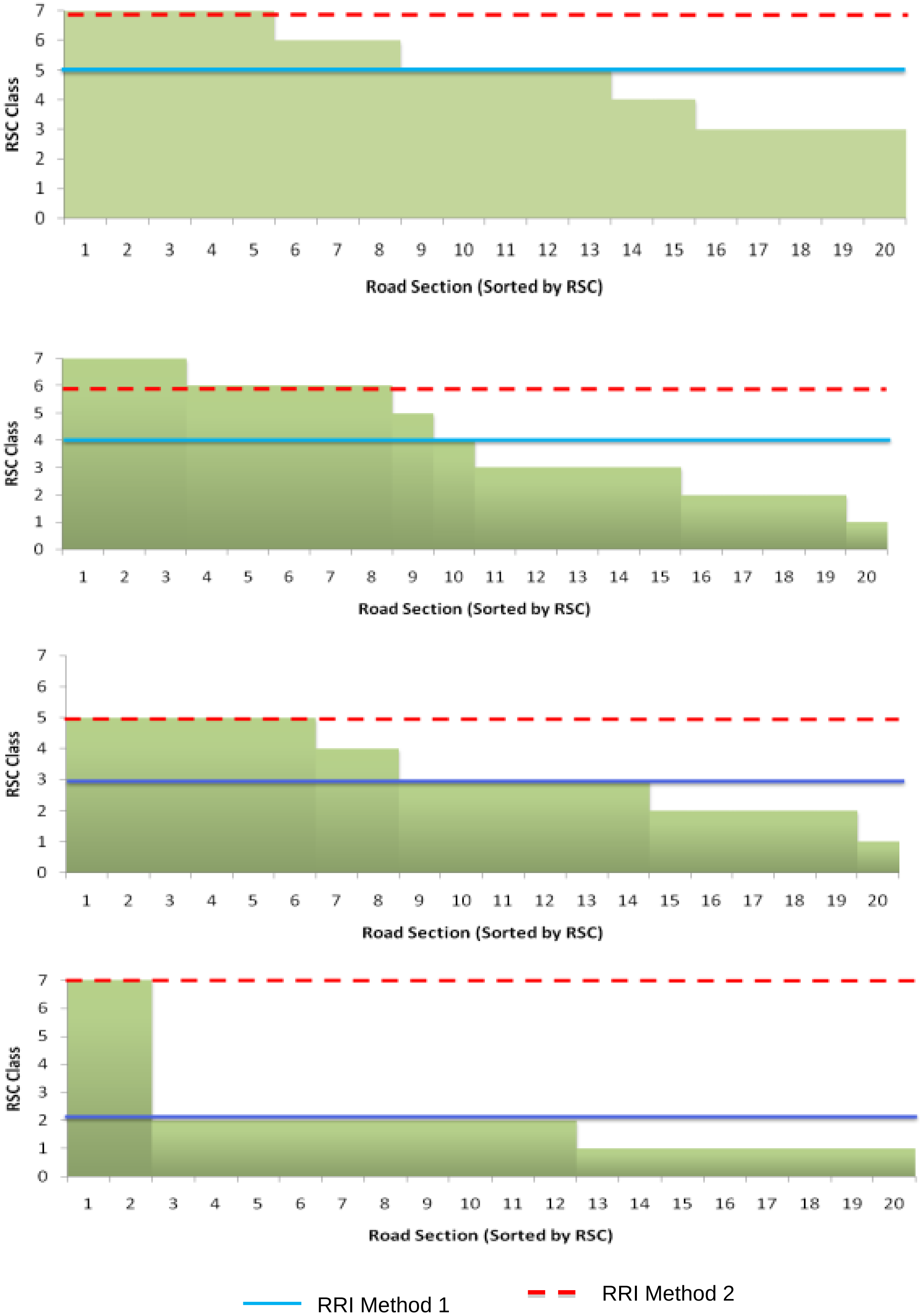


Figure 2- An Example of Risk-based Road Conditions Reporting



(a)

(b)

(c)

(d)

Figure 3- RSC Classification Using Risk-based Methods

5. CONCLUSIONS

In this paper, a risk based approach is introduced for the classification and reporting of winter road conditions with an explicit account of the collision risk that a motorist may experience on a highway under adverse road weather and surface conditions. The risk is estimated using a collision model calibrated using historical collision data with weather and road surface condition variables as the risk factors. A new risk measure, called relative risk index (RRI), is defined to combine multiple risk factors related to road weather (e.g., visibility, precipitation, temperature and wind speed) and surface conditions (e.g., snow cover) into a single risk indicator which represents the relative increase in risk as compared to normal conditions. Two approaches are proposed to apply the RRI concept for classifying the winter road surface condition of a highway route with varied snow and ice coverage. The first approach is classifying the overall condition of the route based on its average RRI while the second approach is selecting the condition of the dominant subsection. An example is used to show the differences between these two approaches.

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