# Expert System to Calculate the Coefficient of Friction- An Approach to Enhance Traffic Safety

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## Abstract

Friction plays a key role in causing slipperiness as a low coefficient of friction on the road may result in slippery and hazardous conditions. Analyzing the strong relation between friction and accident risk on winter roads is a difficult task. Many weather forecasting organizations use a variety of standard and bespoke methods to predict the coefficient of friction on roads. This article propose an approach for predicting the extent of slipperiness by building and testing an expert system. It estimates the coefficient of friction on the winter roads in the province of Dalarna, Sweden by taking the prevailing weather conditions as a basis. Weather data from the Road Weather Information System, Sweden (RWIS) was used. The focus of the project was to use the expert system as a part of a major project in VITSA, within the domain of Intelligent Transport Systems.

***Key Words***
***Expert systems, VITSA model, Friction, Slipperiness, Predictions, Intelligent Transport Systems***

## 1 Introduction

Studies show that there is a strong relation between slippery road conditions and traffic accidents, even in areas where winter road maintenance is performed. Countries like Sweden and Finland experience very bad winter road conditions and as a result, the risk of accidents in such conditions is high. For example, in Finland about 25% of all fatal accidents occur on icy or snowy road surfaces [1]. Friction plays a key role in causing slipperiness (other factors include poor tires, adverse camber, etc.). Bad weather conditions like precipitation of snow and sleet together with low road surface temperatures and other bad weather conditions may result in low coefficient of friction on the road, thereby causing slipperiness. The relation between friction and road accidents in winter, report that most of the winter road accidents in Sweden are caused due to the lack of the driver's ability to adapt his or her driving speeds according to the road condition [2]. Accidents on winter roads may even result from other factors such as bad condition of the vehicle and other factors. However, these reasons can be corrected if a certain amount of attention is paid, like proper maintenance of the vehicle etc. By contrast, the risk of slipperiness on the road due to low coefficient of friction cannot always be anticipated by the road users. So much importance is given to such a factor.

This article is based on the description of the work done by Siril for his master thesis [3]. This paper is organized as follows. Sections 2 and 3 motivate the need for an expert system to predict the slipperiness, its use and description in the VITSA model respectively. Sections 4, 5, 6 and 7 describe further the details of weather and the issues regarding the implementation of the expert system. Section 8 discusses the results of the expert system and validation of the system. The paper finally presents concluding remarks.

## 2 Objective and Design

The idea of an expert system to predict winter road situations was actually taken to serve as an important part in another project in the VITSA model (See Section 3). The purpose of the present expert system and its use in the VITSA is an approach to make the road users enjoy safer drives. Previous studies [2] conclude that the driver is unable to adapt to the driving conditions. Drivers may not be able to adapt their driving situations because of many factors such as improper use or defect in their visual or auditory skills etc, or due to cognitive overload. Moreover, it is stated that similar-looking roadways may have different friction conditions, and on the other hand, different looking roadways may have the same friction conditions. Normally the drivers adapt themselves to the appearance of the environment and not to the bad friction conditions that are clearly not known to them. This need to directly inform the road users with friction values led to the idea of developing an expert system.

This expert system, when integrated in the VITSA model, helps by keeping the drivers informed about a recommended (dynamic) speed limit. Speed limits are estimated according to the prevailing friction values. This yields a sophisticated driver aid device which can be brought to the market at a reasonable cost with the aim of trying to enhance safety measures and reduce the risk of accidents [1, 2].

The expert system was constructed using CLIPS[1] as CLIPS was believed to be able to handle the complexity of the system. It was built using the forward chaining or data-driven approach. This is an appropriate method for pre-emptive fault prediction, as a data-driven approach is indicated (since many possible faults might occur).

# 3 VITSA

VITSA is an acronym for "Vidareutveckling av ITS Applikationer" in Swedish, which means further evolvement of Intelligent Transport Systems applications. The VITSA [4] project was born in November, 2001 and is the collective name for numerous projects within the area of Intelligent Transport Systems. The Teknikdalen foundation in Borlänge, Sweden is responsible for these projects [4]. One such project is the present topic of discussion. The expert system is an important part of the project. As shown in the figure 1.0, Input to the expert system is from the VVIS database and DATEX-XML (See Section 3.1 and 3.2).

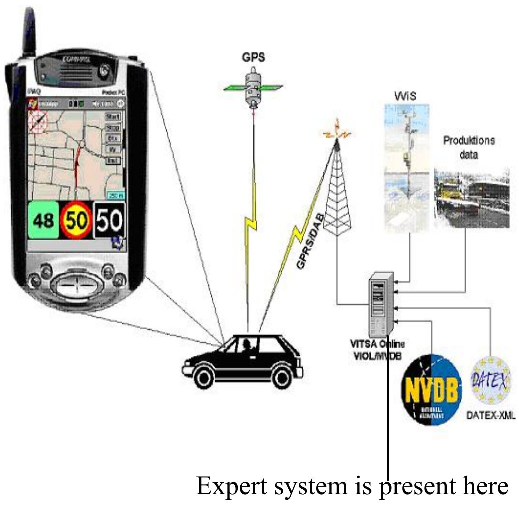



**Figure 1.0 showing the model**

The expert system designed is present within the VITSA online server (VIOL (VITSA online) / MVDB (Mobile road data base or mobil väg databas), the expert system makes predictions about the road conditions and this along with other information like speed is sent via a wireless network to the pocket-PC placed inside the car. The Pocket-PC inside the car stays connected to the wireless network with the help of a General Packet Radio Service (GPRS) or Digital Audio Broadcast (DAB), the Global Positioning System (GPS) locator or receiver is responsible for the position and receiving information from the network [5, 6].

[1] http://www.ghg.net/clips/CLIPS.html

## 3.1 Road weather information system (RWIS)

Information systems for road weather are designed to gather weather information. This system is used by the Swedish National Road Administration (SNRA) and is named as VVIS [7]. VViS today consists of about 640 measuring stations equipped with devices measuring several meteorological variables. The selection of parameters required for the functioning of the expert systems depends on the expert's knowledge. The absolute reasons behind considering those factors to other weather factors in the RWIS database were revealed from some past research work conducted by Norrman [6]. However, some new attributes have also been added and finalized for the expert system in predicting friction [8]. The attributes considered are:

- Station number
- Current road surface temperature
- Current dew point
- Air humidity
- Road surface temperature forecasts for 1, 2, 3 and 4 hours respectively.
- Dew point temperature forecasts for 1, 2, 3 and 4 hours respectively.
- Maximum wind speed
- Type of precipitation
- Amount of precipitation

## 3.2 DATEX-XML

The Datex-XML contains all the information about the happenings on the road in Sweden. It contains information about road accidents reported by the police and feedback from the road maintenance contractors. Winter road maintenance in Sweden is divided into 138 maintenance areas where each area is responsible to the client, the Swedish National Road Administration (SNRA) [7]. The road maintenance contractors supply the important information about surface condition of the road observed in their individual areas. These observations are manual and are performed by experienced supervisors. Road surface conditions (the inputs to the expert system) are classified mainly into four types accordingly:

- Dry: This kind of information is provided only when bare dry roads exist.
- Wet/moist: This information is supplied when the wet or moist road conditions exist.
- Snow: Information of Snow or slush is supplied when the roads are normally covered with any form of snow like loose snow, packed snow etc.
- Icy: This kind of information is supplied when icy or hoar frost conditions exist on the road [9].

## 4 Slippery conditions module

The slippery conditions module forms the heart of the expert system, the rules for the system. The knowledge represented in the present expert system consists of much of the work and reports of researchers and geologists who have done quite a good amount of research in the related areas [3, 8]. The knowledge in the system, are certain circumstances of the weather attributes in combination with others. These rules in the knowledge base together with road surface condition are used to classify the weather data. The rules are checked and result in predictions accordingly.

## 4.1 Events in the expert system

The rules in the rule base of the expert system are based on a certain criteria called "events". Assigning the events in the expert system is a very important part of the system because they play a very important role in classifying the given input data. The events in the expert system are as follows:

- Road Condition
- Precipitation
- Sublimation
- Surface condition of the road

### 4.1.1 Assigning the event Road condition

The event Road condition is divided into 4 classes namely Dry, Wet/Moist, Snow and Icy, depending on the kind of conditions, each of the classes are built up as events of their own, they are explained individually as follows [3]:

**Events – Dry, Wet/Moist and Snow**

The dry event is used to decide whether the road condition is dry or not depending on the input data. Similarly, the event Wet/Moist decides whether the road condition is either Wet or Moist, depending on the input data and the event Snow likewise. The weather attributes used in the event Dry, Wet/Moist and Snow are shown in Table 2.0, Table 2.1 and Table 2.2 respectively. The rules for the event Dry, Wet/Moist and Snow were built by experiment by identifying the similarities in the weather data from some past Dry, Wet/Moist and Snow situations respectively. The past situations were manual observations collected between December 2002 and February 2003. This idea of obtaining the prevalent conditions from observing the data was considered as the best approach since there was no appropriate expert's data that categorize the weather conditions of dry, wet/moist and snow situations. In all of the above cases, the weather conditions on the respective days were examined and the weather data on those days exhibited similarities in combination of the weather attributes. Therefore, as per the similarities between the weather on the above dates, the events were concluded to possess the following features.

**Table 1.0 explaining the abbreviations of the weather attributes used in the system.**

| Weather attributes | Explanation |
|---|---|
| P | Precipitation |
| $T_{surface}$ | Road surface temperature |
| $T_{air}$ | Air temperature |
| Wind | Wind speed |

**Table 2.0 showing the weather conditions for the event Dry**

| Weather attributes for the event | Readings and presence of the weather attributes. |
|---|---|
| Precipitation | None(0) |
| Surface temperature | < 0 |
| Surface temperature, one hour prognosis | < 0 |
| Air temperature | < 0 |
| Humidity | > 80 |
| Max wind speed | < 25 |
| Sublimation | None |

**Table 2.1 showing weather conditions for the event Wet/Moist**

| Weather attributes for the event | Readings and presence of the weather attributes. |
|---|---|
| Precipitation | None, Rain or Snow (0,1 or 2) |
| Surface temperature | >= 0 or <= 0 |
| Surface temp. , One hour prognosis | >= 0 or <= 0 |
| Air temperature | >= 0 or <= 0 |
| Humidity | > 80 |
| Max wind speed | <= 40 |
| Sublimation | Any(0,1,2 or 3) |

**Table 2.2 showing weather conditions for the event Snow**

| Weather attributes for the event | Readings and presence of the weather attributes. |
|---|---|
| Precipitation | Snow (2) |
| Surface temperature | < 0 |
| Surface temp. , One hour prognosis | < 0 |
| Air temperature | < 0 |
| Humidity | >80 |
| Max wind speed | >20 |
| Sublimation | No, Light or medium (0,1,2 or 3) |

**Event- Icy**

Unlike the above discussed Dry, Wet/Moist and Snow, this event was built from the defined prevalent icy conditions in various situations and various ways of ice formation on winter roads taken from a previous study [8]. There are several mechanisms through which ice can develop on the road surface. Therefore, this event is further divided into nine types - all indicating very serious slippery conditions with friction coefficient dropping below threshold. These 9 conditions cover all the important possibilities and various forms of them; ice formation like hoarfrost, freezing of water cover, precipitation on frozen surfaces [8]. If the feedback from the maintenance contractors about the road surface condition is not available, then the event is assigned as "Not available". In this event the expert system makes decisions based on the type of precipitation.

**Table 2.3 showing the possible situations for the event Icy [8]**

| | |
|---|---|
| Icy, Precipitation rain on a frozen surface | P = Rain, $T_{surface}$<= 0, $T_{surface}$ (t+1) <= 0, $T_{air}$ > 0. |
| Icy, Precipitation snow on a frozen surface | P = Snow, $T_{surface}$<= 0, $T_{surface}$ (t+1) <= 0, $T_{air}$ < 0, Sublimation = Any. |
| Icy, Precipitation snow on a warm surface. | P = Snow, $T_{surface}$>0, $T_{surface}$ (t+1)> 0, $T_{air}$ <= 0, Sublimation = Any. |
| Icy, Hoar frost and low visibility | P=No,$T_{surface}$<0,$T_{surface}$(t+1)< 0, Humidity > 80, Sublimation Light, Medium or high. |
| Icy, Freezing dew followed by hoar frost. | P = No,$T_{surface}$>0 , $T_{surface}$ (t+1)<=0, Humidity > 80, Sublimation Light, Medium or high. |
| Icy, Strong formation of hoar frost. | P = No, $T_{surface}$<=0, $T_{surface}$ (t+1)<= 0, Humidity <95, Wind>=45, Sublimation Light, Medium or high. |
| Icy, Weak formation of hoar frost | P = No, $T_{surface}$ <= 0, $T_{surface}$ (t+1)<=0, Humidity < 95, Wind < 45, Sublimation Light, Medium or high. |
| Icy, Hoar Frost | P = Any, $T_{surface}$ <= 0, $T_{surface}$ (t+1) <= 0, Sublimation Light, Medium or high. |
| Icy, Water cover that freezes. | P = No, $T_{surface}$>0, $T_{surface}$ (t+1) <= 0, Humidity<95, Sublimation high after 3 hrs. |

### 4.1.2 Assigning the event Precipitation

The precipitation event plays a very important role in the functioning of the expert system as the kind and amount of precipitation are involved with every event in the expert system.

**Table 3.0 classes necessary for the event precipitation**

| Class | Kind of precipitation | Amount of Precipitation |
|---|---|---|
| Dry | No, type=1 | 0 |
| Wet/Moist | Rain, type =2 or 3 | > 1 |
| Snow | Snow, type = 4 or 6 | > 1 |
| Error | Type = -9 or -99 | = -9 |

The event precipitation is formed from three classes called dry, wet and snow respectively, the conditions essential for the three classes to be satisfied are listed in Table 3.0 [3, 9].

### 4.1.3 Assigning the event Sublimation

The sublimation event is the calculated difference between the surface temperature and the dew point temperatures. If the dew point temperature is greater, then it means water is condensing on the road and frost will form on the road surface. The sublimation event was divided into five classes, based on the temperature differences taken from a previous study [3, 9]. The sublimation calculation is even made for 1 hour and 2 hour prognosis of both surface and dew point temperatures.

**Table 4.0 showing the sublimation classes**

| Class | Sublimation ($T_{Dew}$ -$T_{surface}$) |
|---|---|
| 0 | No sublimation, $T_{surface}$> $T_{Dew}$ |
| 1 | Light, 1.7 <= $T_{Dew}$ -$T_{surface}$ >= 0.5 |
| 2 | Medium, 3.0 <= $T_{Dew}$ -$T_{surface}$ >= 1.7 |
| 3 | Strong, $T_{Dew}$ -$T_{surface}$ >= 3.0 |
| 4 | Even after 3 hrs, $T_{Dew}$ -$T_{surface}$ >= 0.5 |

## 5 Rules for making predictions in the expert system

The knowledge of various prevailing conditions and situations are represented in the form of rules in the expert system, which forms the most important part of it, the inference engine.

**Table 5.0, explaining the rules used for making prediction in the expert system**

| Rule No. | Surface Condition, Slippery Conditions | Resulting Situations and their respective Predictions |
|---|---|---|
| 1 | Dry, Slippery 1 | Situation-1 - Prediction-01 |
| 2 | Wet, Slippery 2 | Situation-2 - Prediction-02 |
| 3 | Snow, Slippery 3 | Situation-3 - Prediction-03 |
| 4 | Icy, Slippery 4 | Situation-4 - Prediction-04 |
| 5 | Icy, Slippery 5 | Situation-4 - Prediction-05 |
| 6 | Icy, Slippery 6 | Situation-4 - Prediction-06 |
| 7 | Icy, Slippery 7 | Situation-5 - Prediction-07 |
| 8 | Icy, Slippery 8 | Situation-6 - Prediction-08 |
| 9 | Icy, Slippery 9 | Situation-6 - Prediction-09 |
| 10 | Icy, Slippery 10 | Situation-6 - Prediction-10 |
| 11 | Icy, Slippery 11 | Situation-6 - Prediction-11 |
| 12 | Icy, Slippery 12 | Situation-6 - Prediction-12 |
| 13 | Not available Slippery 1 | Situation-7 - Prediction-13 |
| 14 | Not available Slippery 2 | Situation-8 - Prediction-14 |
| 15 | Not available Slippery 3 | Situation-9 - Prediction-15 |

The expert system is aimed to output predictions one hour ahead, of the roads being slippery. To achieve this, 15 types of predictions are assigned to nine kinds of situations that are each associated with a frictional value to reduce ambiguity. Fifteen rules were used for classifying the different kinds of weather conditions, one rule each for dry, wet/moist & snow conditions and nine rules for classifying hazardous icy conditions, and three rules for categorizing unavailable surface conditions [3].

# 6 Friction

The rule base of the expert system contains several rules classifying many different kinds of slipperiness, which are collectively termed as "Situations" according to their characteristics for easiness of representation. These situations are nine in total. They are assigned to a particular frictional value each, as shown in the Table 6.0 below. The coefficients of friction are a result of research done on various types of Swedish roads under various road conditions [2].

**Table 6.0 the coefficient of friction for different predictions made in different situations, by the expert system**

| Surf Condition | Fric.Coef | Prediction | Situation |
|---|---|---|---|
| Dry | > 0.50 | 1 | 1 |
| Wet/Moist | > 0.50 | 2 | 2 |
| Snow | 0.50 < 0.25 | 3 | 3 |
| Icy | < 0.25 | 4 | 4 |
| | | 5 | 4 |
| | | 6 | 4 |
| Icy | < 0.35 | 7 | 5 |
| Icy | < 0.25 | 8 | 6 |
| | | 9 | 6 |
| | | 10 | 6 |
| | | 11 | 6 |
| | | 12 | 6 |
| -NA-, Dry | > 0.50 | 13 | 7 |
| -NA-, Moist | > 0.50 | 14 | 8 |
| -NA-, Snow | 0.50 < 0.25 | 15 | 9 |

# 7 Running the expert system

When all the events have been assigned values, the rules are checked to see whether any of them have been triggered. The rule that matches is triggered and the desired output is generated as shown in table 7.0 [3].

**Table 7.0 the warnings generated by the expert system as per the situations**

| S. No | Warning |
|---|---|
| 1 or 7 | Dry road. Not slippery on the road 50045 |
| 2 or 8 | Wet road. Not slippery on the road 70020 |
| 3 or 9 | Snow, fairly slippery on the road 70015 |
| 4 or 6 | Icy, very slippery on the road 50050 |
| 5 | Icy, and low visibility. Very dangerous…. |

# 8 Results

The results of the expert system and its use in the VITSA have been shown to be quite satisfactory. However, the system proved to be wrong in some conditions. Although, experts and researchers reveal important information of various situations from their prior knowledge, work and experience, there are often some unexpected occurrences that are out of the experts' thought or knowledge. As a result, an expert system may sometimes produce bad results; the complete workings of nature have not been identified completely by mankind.

## 8.1 Results of the expert system

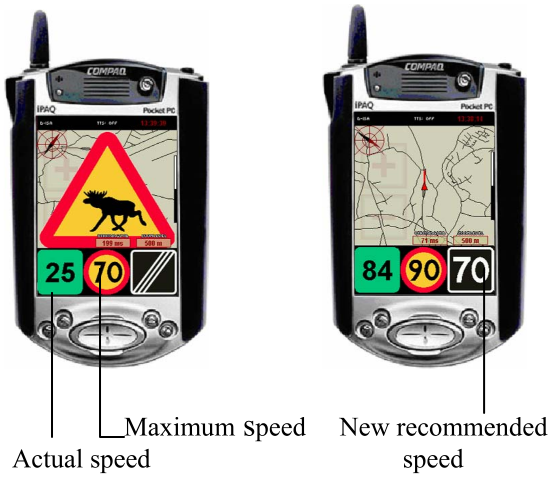
The predictions made by the expert system are compared to the actual manual observations, recorded between December 2002 and February 2003. The validation of the system produced good results. The success rate of the system in various conditions can be observed in Table 8.0. The failures encountered by the expert system in different situations are due to the difference in the values of the prevailing weather attributes to that of values of attributes assigned in the rules [3]. In situations like Wet/Moist the rules represented, contradict with some of the prevalent conditions in terms of precipitation etc. resulting in low success rates. An effort to correct the rules in Dry and Wet conditions was made but the system came up with even less success rates. The rules represented are the best of the effort.

**Table 8.0 showing the success rate of the expert system**

| Situation | Success rate |
|---|---|
| Dry | 77.78% |
| Wet/Moist | 66.66% |
| Snow | 83.33% |
| Icy | 100% |

## 8.2 Results of model - in VITSA

The results of the model are quite satisfactory. They inform the driver about the various possible zones on the road apart from dynamic speeds. Figure 2.0 (a) shows the actual speed of the vehicle and the maximum speed limit on the road. Figure 2.0 (b) shows the results of dynamic speeds by informing the new speed limit. The model also informs the driver about the possible animal-crossing zone, Figure 2.0 (a). Usage of GPS, enables route information too. The system in the car has collectively all the information as described above, making the drive more enjoyable and safe.




**(a)** **(b)**

**Figure 2.0 showing the results of VITSA**

## 9 Discussions

The expert system was built to function and predict only for the state roads in the province of Dalarna, Sweden. At first the idea of constructing for the whole (state roads and country roads) of Dalarna was taken, but was later discarded due to the various differences between the state roads and country roads, in terms of clearing and maintenance activities and other reasons like traffic etc. Another important thing that made it impossible to consider the country roads was the assignment of appropriate station to a particular road, to read the weather attributes. Normally each station is assigned an area where the data from the station are effective for the whole of that area. Appropriate information is available about the state roads belonging to their respective stations, where as ambiguity exists for country roads, in terms of assigning a road to a station [3].

## 10 Conclusions and Further work

There is a lot of contemporary research on Intelligent Transport Systems that attempts to get information from the drivers, or give information to the drivers. Considerable work has also been done on vehicle-to-vehicle communication and vehicle-to roadside communication. However, developing dynamic safety measures to enhance traffic safety has not been thoroughly explored and much work remains to be done.

The present online expert system and the model in VITSA present an idea of enhancing traffic safety by dynamically warning the road users about hazardous conditions. The expert system proved to be a good tool for predicting slipperiness, though it does not predict correct in some cases. However, the faulty situations can further be explored to find out the exact conditions responsible in such situations, rather than just using manual data to frame the rules in such situations. Fortunately, the performance of the system was very good while evaluating icy situations, which are considered to be the most hazardous, among the situations. Hundred percent results were achieved in such cases.

We aim to extend the project further so that it can even predict situations in the whole of Dalarna province, even on the country roads. The idea is to establishing relationships between the roads and station in terms of altitudes and other topographic information to allow extrapolation between the weather stations. Use of satellite and radar images for much more accurate predictions is another area which the team is focusing on. Another aspect is to integrate mobile data sources, for example the anti-lock braking systems of vehicles could report on slipperiness to a central server. In the longer term, this technology has the potential to be much more widely used in the field of ITS, its dynamic nature makes it an ideal application.

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