Importance of Subsurface Temperature Probes in RWIS Systems

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ABSTRACT

This research study highlights the importance of subsurface temperature probes in RWIS (Road and Weather Information System) by investigating the relationship and potential impact, during winter, on each of the following:

- ➢ Ambient/Surface Temperature.
- ➢ Weather Event (i.e., Icy, Snowy, Wet, Dry).
- ➢ Road Surface Condition (i.e., Hazardous, Dry)
- ➢ Road Clearance Time.

RWIS (Road and Weather Information System) stations deployed on I-35 provide a variety of weather data including ambient, surface, and subsurface temperature. In addition to weather events given by different precipitation levels. Clearance data is collected by a mobile application deployed in ODOT snowplow trucks reporting data including location and time for each clearance trip.

The analysis involved hypothesis testing using Pearson's correlation, ANOVA (Analysis of Variance), and regression analysis, supported by statistical significance tests. Machine learning models were developed to show the impact of incorporating subsurface temperature in classifying road surface conditions and weather events.

Results showed a strong correlation and faster rate change between subsurface temperatures and various weather and road surface conditions, especially at night. Clearance time is inversely related to mean subsurface temperature and directly related to its standard deviation. Machine Learning models showed better results on the test set when temperature probe data were included as features.

OBJECTIVES

The research objectives focus on understanding and quantifying the relationship between subsurface temperature probes and:

- ➢ Ambient Temperature.
- ➢ Road Surface Temperature (RST).
- ➢ Weather Events.
- ➢ Road Clearance Time by snowplow trucks.

Understanding the relationships and utilizing subsurface temperatures in forecasting hazardous conditions during cold weather can ultimately lead to enhanced road safety by:

- ➢ More effective snow removal operations by focusing clearance efforts only when there is a real need for it.
- ➢ Traffic management: by adjusting speed limits during cold and hazardous conditions to prevent accidents.

BACKGROUND

Hypothesis: utilizing subsurface temperature probes in RWIS may lead to enhanced prediction of surface conditions and weather events and more efficient snow clearance.

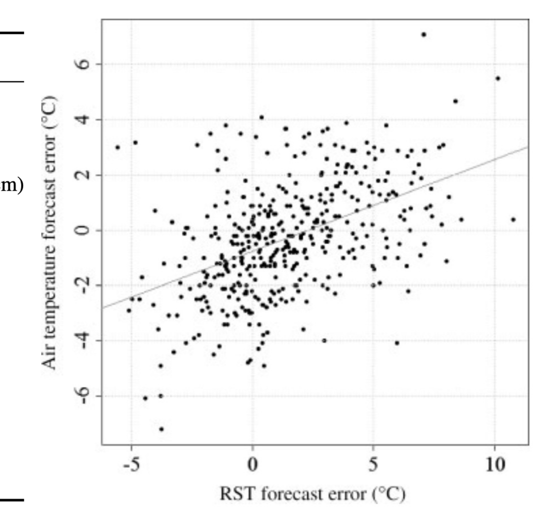
Such findings can improve overall road safety and prompt the effective usage and adoption of these probes into RWIS.

The existing research literature appears to have overlooked the significance of subsurface temperature probes in RWIS, underscoring the need for this study.

Literature studies have rather focused on investigating different methods of forecasting and prediction of RST.

Table 1. Input parameters and abbreviations.

Abbreviation	Meaning
RWS measurements (first letter M)	
MA	Air temperature
MR	Road surface temperature
MD	Road subsurface temperature (30 cm)
MH	Air humidity
MF	Thickness of water film
Weather forecasts for 6 h (first letter F)	
FA_3	3 h air temperature forecast
FA_6	6 h air temperature forecast
FH	Air humidity
FW	Wind speed
FP	Precipitation amount
FL	Longwave radiation
FS	Shortwave radiation
FC	Cloudiness

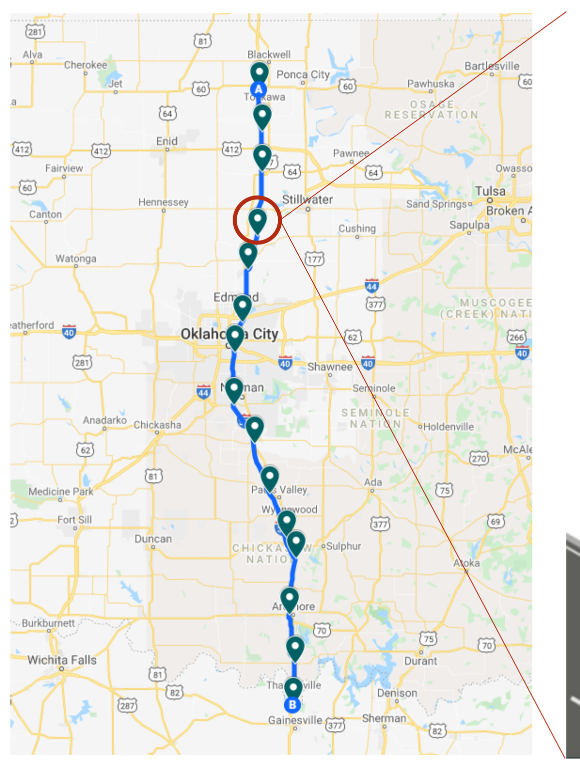


Statistical Approach to Forecasting Road Surface Temperature [Kršmanc, et. Al 2013]

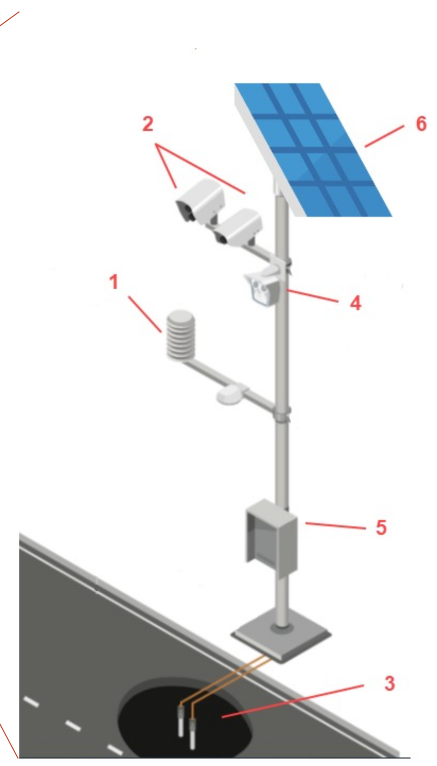
Using a stepwise linear regression model to forecast road surface temperature using various inputs including subsurface temperature at 30 cm (~12 inches).

A small positive correlation between RST prediction errors by the model was reported.

SYSTEM DESIGN & DEVELOPMENT



RWIS station locations across I-35



RWIS station 3D illustration

Weather Data

1) Weather station.
2) Surface temperature sensor.
3) 6-inch and 8-inch underground probes.
4) Camera.
5) IOT cabinet.
6) Solar panel.

Precipitation Type Table

Synop Code $w_a w_a$	Meaning
0	No precipitation.
40	Precipitation present.
51	Light drizzle.
52	Moderate drizzle.
53	Heavy drizzle.
61	Light rain.
62	Moderate rain.
63	Heavy rain.
67	Light rain and/or drizzle with snow.
68	Moderate rain and/or drizzle with snow.
70	Snowfall.
71	Light snow.
72	Moderate snow.
73	Heavy snow.
74	Ice pallets.
89	Heavy hail.

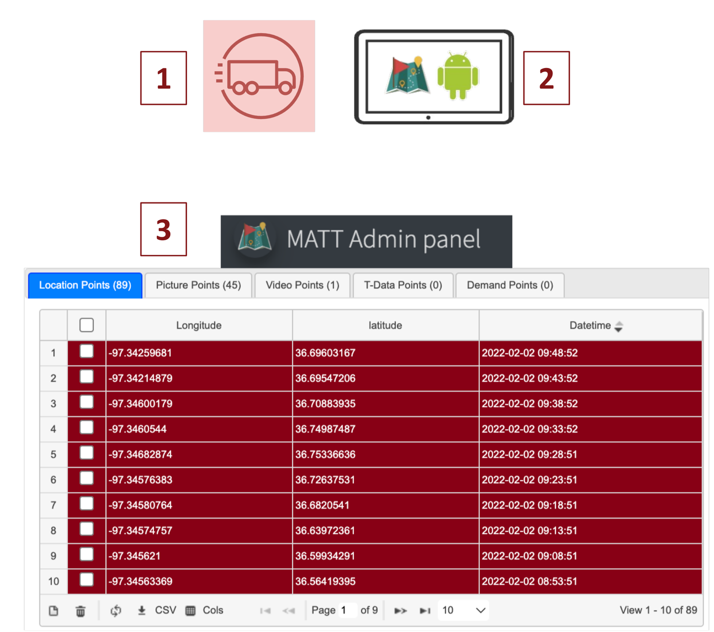
Various weather events are provided by the weather station sensor as the precipitation type

Road Surface Conditions (RSC)
Slick Spots Highway
Slick Hazardous Highway
Light Snow
Moderate Snow
Heavy Snow
Snow Packed
Blowing Snow
Ice

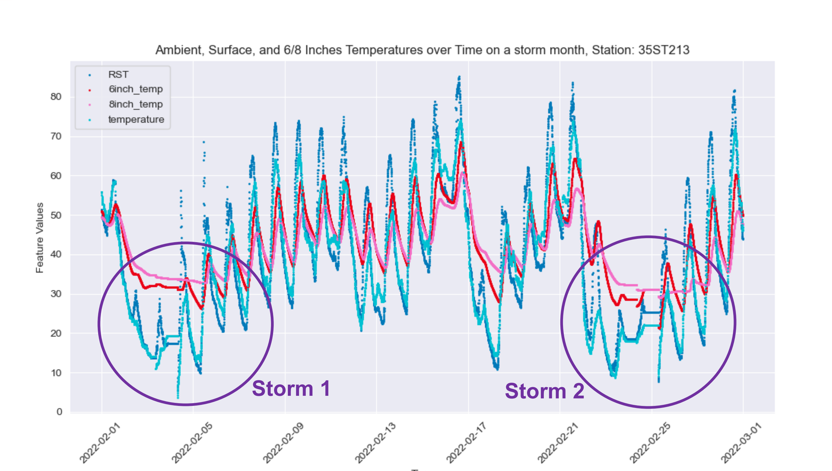
Hazardous Conditions
Conditions are manually observed and recorded by human operators

Clearance Data

1) Snowplow Truck
2) MATT Application: collecting real-time clearance data.
3) Dashboard Website: data available for view and download.



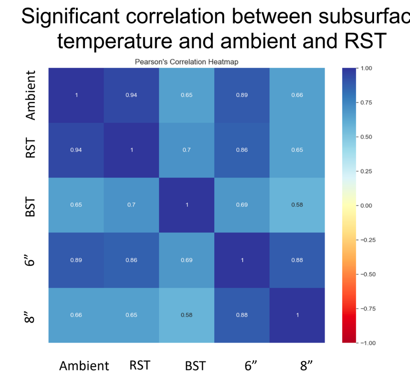
METHODOLOGY



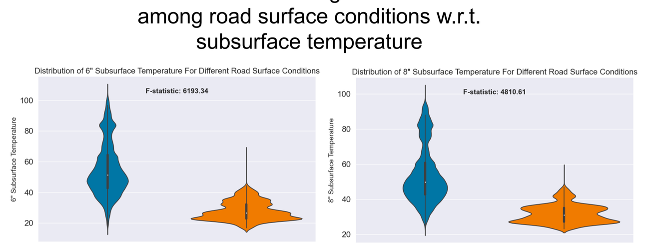
During storms, ambient/surface temperatures drop below subsurface temperatures.
Subsurface temperature has minimal variation during these drops.

Hypothesis Testing: using Pearson's correlation, ANOVA (Analysis of Variance), and statistical significance tests ($p < .05$).

Significant correlation between subsurface temperature and ambient and RST

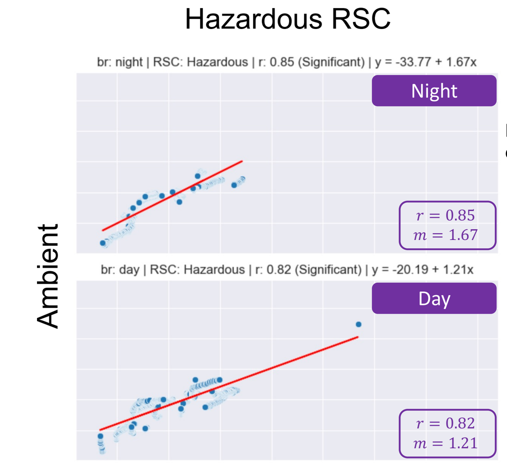


ANOVA test shows a significant difference among road surface conditions w.r.t. subsurface temperature



Regression Analysis: study the regression relationship, correlation strength, and statistical significance for various surface conditions, weather events, and time of day (day and night determined by brightness measured value).

Hazardous RSC

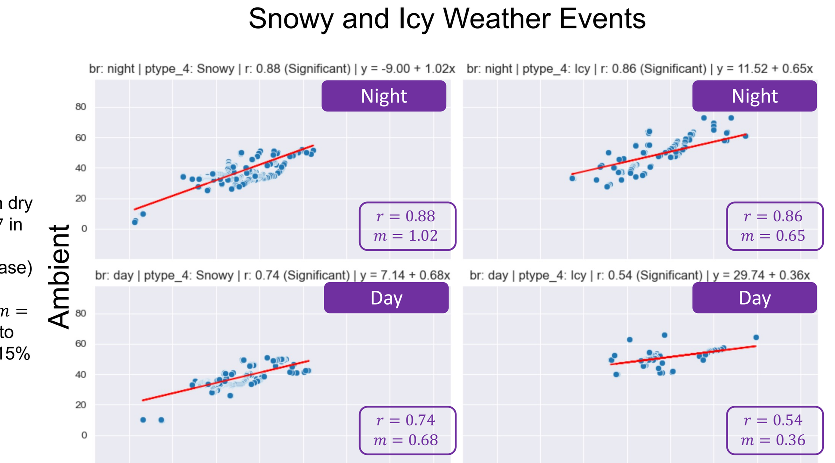


6" Subsurface Temperature

Hazardous vs. Dry conditions:

- ❑ Night: from $m = 1.04$ in dry to $m = 1.67$ in hazardous (60% increase)
- ❑ Day: from $m = 1.05$ in dry to $m = 1.21$ (15% increase)

Snowy and Icy Weather Events



6" Subsurface Temperature

Weather Events

The correlation between subsurface and ambient temperatures is stronger at night.

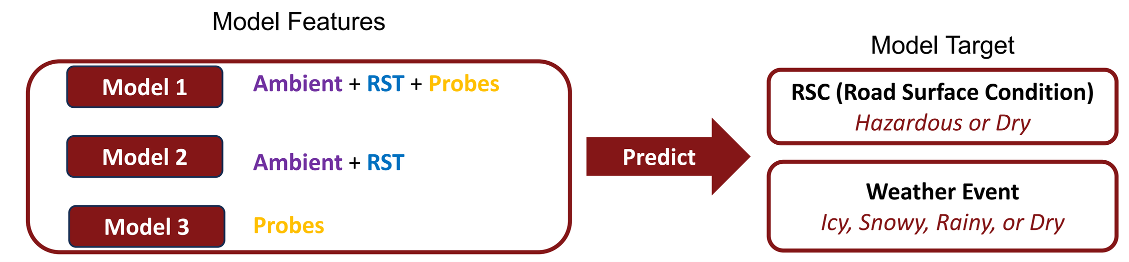
- ❑ Snowy: 0.74 to 0.88 (a 19% increase)
- ❑ Icy: 0.54 to 0.86 (a 59% increase)

The slope is steeper at night, corresponding to a faster rate change.

- ❑ Snowy: 0.68 to 1.02 (a 50% increase)
- ❑ Icy: 0.36 to 0.65 (an 81% increase)

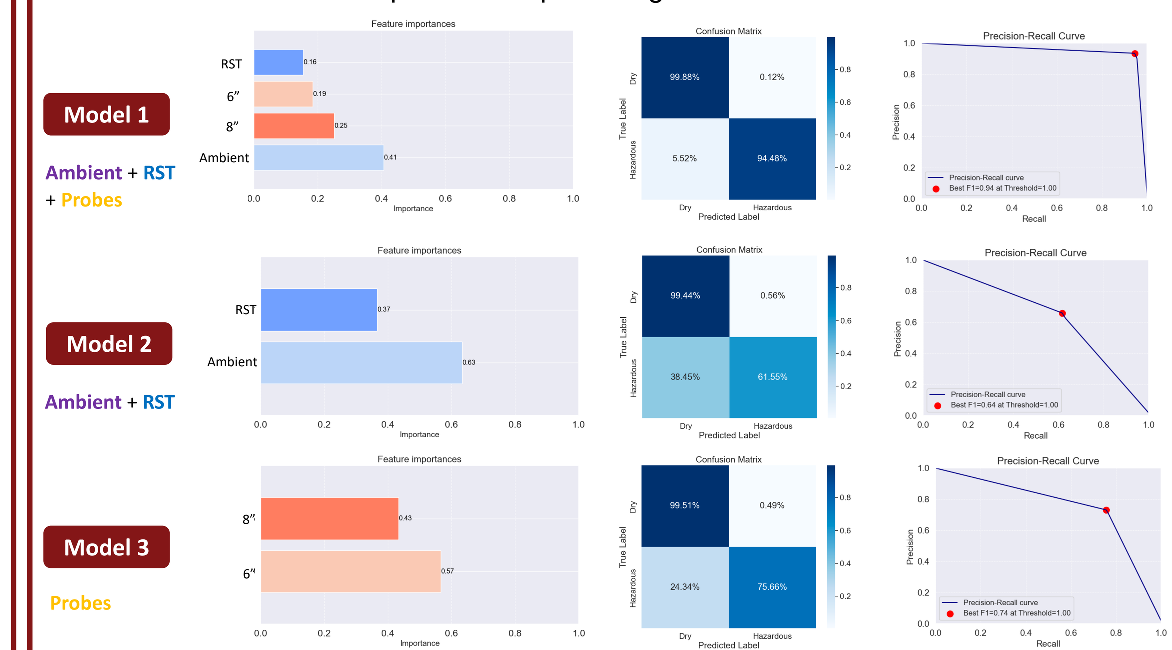
Dry and rainy conditions do not display a stronger correlation or steeper slope at night compared to day.

Machine Learning Model Development: to highlight the effect of probes in predicting adverse road surface conditions and weather events, the following experiment was designed:

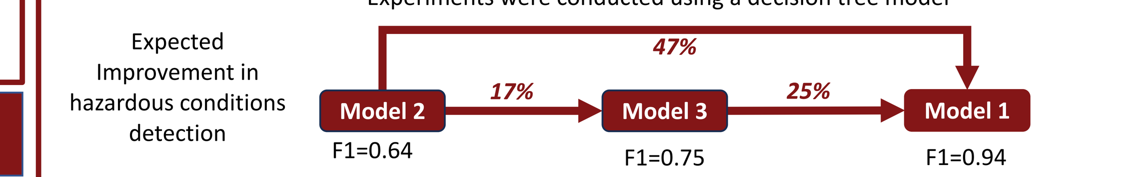


RESULTS

Probes Importance in predicting road surface condition



Experiments were conducted using a decision tree model

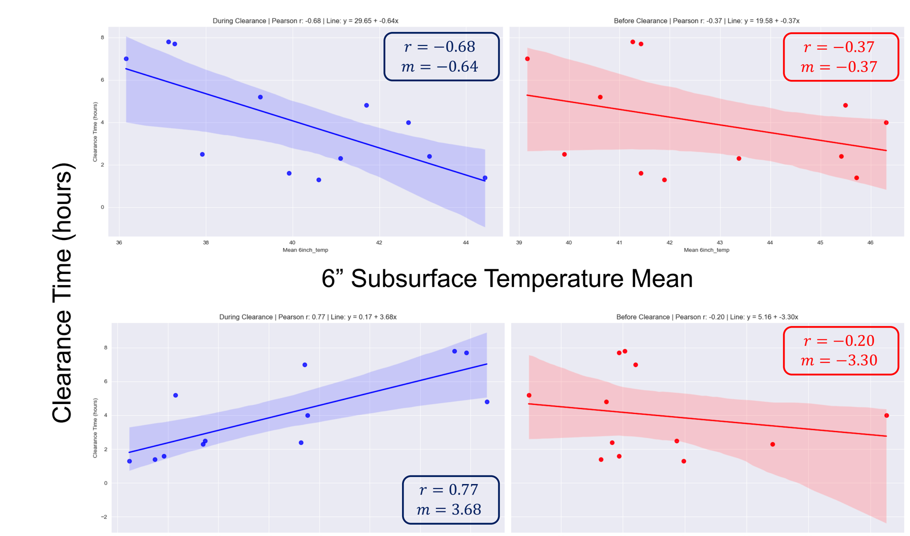


Probes Importance in predicting weather events

F1 Score for Icy, Snowy, and Rainy weather events

Event	Model 1	Model 2	Model 3
Icy	**0.58**	0.54	0.52
Snowy	**0.61**	0.28	0.30
Rainy	**0.55**	0.12	0.27

Subsurface Temperature and Clearance Time



6" Subsurface Temperature Standard Deviation

- ❖ Clearance time increases as the mean subsurface temperature decreases with a negative correlation ($r = -0.68$) and a slope of ($m = -0.64$).
- ❖ Clearance time increases as the standard deviation of the subsurface temperature increases with a positive correlation ($r = 0.77$) and a slope of ($m = 3.68$).
- ❖ The correlation between subsurface temperature and clearance is more prominent during the event as opposed to the preceding hour

CONCLUSION

Results have shown a significant correlation between subsurface temperature and ambient & surface temperatures, weather events, and clearance time. A faster rate change in the relationship and a stronger correlation between subsurface temperature and ambient is noticed at night. Incorporating probe data in prediction models yields almost twice as good an F1 score compared to models depending only on ambient and surface temperature for decision-making.

Further analysis is being conducted to better understand the relationships and derive more insightful conclusions.

ACKNOWLEDGMENTS

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