Development of a Salt Spreader Controller Program Using Machine-Sensed Roadway Weather Parameters

Innovation Webinar

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May 30, 2024

Outline

- Background
- Objectives
- Methodology
- Results
- Conclusions
- Recommendations

Background - Research Needs

- Massachusetts owns over 300 and contracts 1,200 additional material spreaders that deliver salt, salt/sand mixtures, or liquid deicers to more than 15,000 lane miles of the Commonwealth's roadways during winter seasons
  - Controllers by Certified Cirus (Cirus SpreadSmartRx systems) and Bosch Rexroth (Compu-spread systems)
  - Still challenging for equipment operators to judge the surface condition and adjust the spreader

It is critical to deliver the materials **efficiently and effectively** to maximize the material utilization and minimize the potential environmental impacts.

- Mobile road weather information system (RWIS) sensors have been installed primarily in supervisor vehicles and on a District 3 material spreader
  - The introduction of the RWIS sensor is anticipated to improve the supervisor/plow driver's assessment of the road conditions and help make informed decisions
  - Reading RWIS measurements remains a manual task, demanding the supervisor/plow driver's constant attention to the display

There is a need for an automated system that **integrates** the RWIS sensory output, **determines** a local need for roadway deicer treatment, and **controls** the spreader for optimized material application

Background - Opportunities

- Portable RWIS stations have been primarily used for planning and weather estimation purposes
  - Alaska, California, Colorado, Iowa, Indiana, Maryland, Nevada, New York, Ohio, Massachusetts, Michigan, Minnesota, Utah, and Washington

- Mobile RWIS haven not been extensively deployed with current operation
  - Pilot testing (MD30) - Alaska DOT, Colorado DOT, Iowa DOT, Minnesota, Michigan
  - Benefits - Material cost saving (payback 0.08-0.44 years)
  - Practical challenges - sensor setup, logistic solutions
  - Technical challenges - Unknown performance for different measures

Parameters	Lufft MARWIS	Teconer RCM411	Vaisala MD30	Vaisala DSP310	High Sierra Elec. IceSight	PreCise ARC System	RoadWatch	High Sierra Elec. Surface Sentinel
Road Conditions (dry, moist, wet, ice, snow, slush, chemically wet)	✓ All six conditions	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet			
Road Surface Temperature	✓	✓	✓	✓	✓	✓	✓	✓
Water Film Height	✓ Up to 6mm	✓ Up to 3mm	✓ Up to 5mm	✓ Up to 2mm				
Ice Percentage	✓							
Friction	✓ Calculated	✓	✓	✓	✓ Calculated			
Ambient Air Temperature	✓	✓	✓	✓	✓	✓	✓	✓
Dew Point Temperature	✓	✓	✓	✓				
Relative Humidity	✓	✓	✓	✓	✓	✓		
Current Use by DOTs	ARDOT, MNDOT, MODOT, INDOT, NDDOT, NDOT, ODOT, CDOT, and NYCDOT	MNDOT	MDOT, MNDOT and ODOT	Not Reported	MNDOT and NYSDOT	AKDOT, ADOT, CTDOT, IDOT, IADOT, MnDOT, MDDOT, NDOT, NYSThruway, NDDOT, ODOT, SDDOT, TDOT, WSDOT, and WYDOT	CALTRANS and NDOT	Not Reported
Hardware Cost	$10,700	$9,000	N/A	Unavailable	$ 6,680 Software $360/yr Cell Data $220/yr	$918	$600	$ 1,260 Software $360/yr Cell Data $220/yr

Illinois Center for Transportation (2022)

Objectives

- This proposed study aims to develop and validate an automated system that can adjust the spreader controller based on the acquired mobile RWIS sensor data, such as road temperature, grip level, and surface condition
  - The products include a hardware/software program that enables automated roadway treatment with minimum supervisor/plow driver's intervention
  - The research team prepared recommendations on utilizing the developed programs through tutorials and presentations.

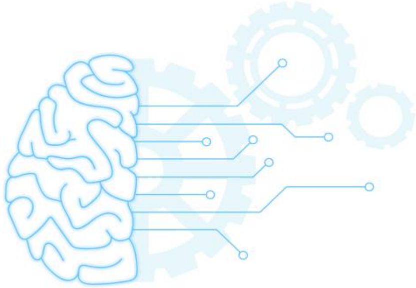
Integration -> Determination -> Control

Mobile RWIS

+

Spread Controller

+



Machine Learning

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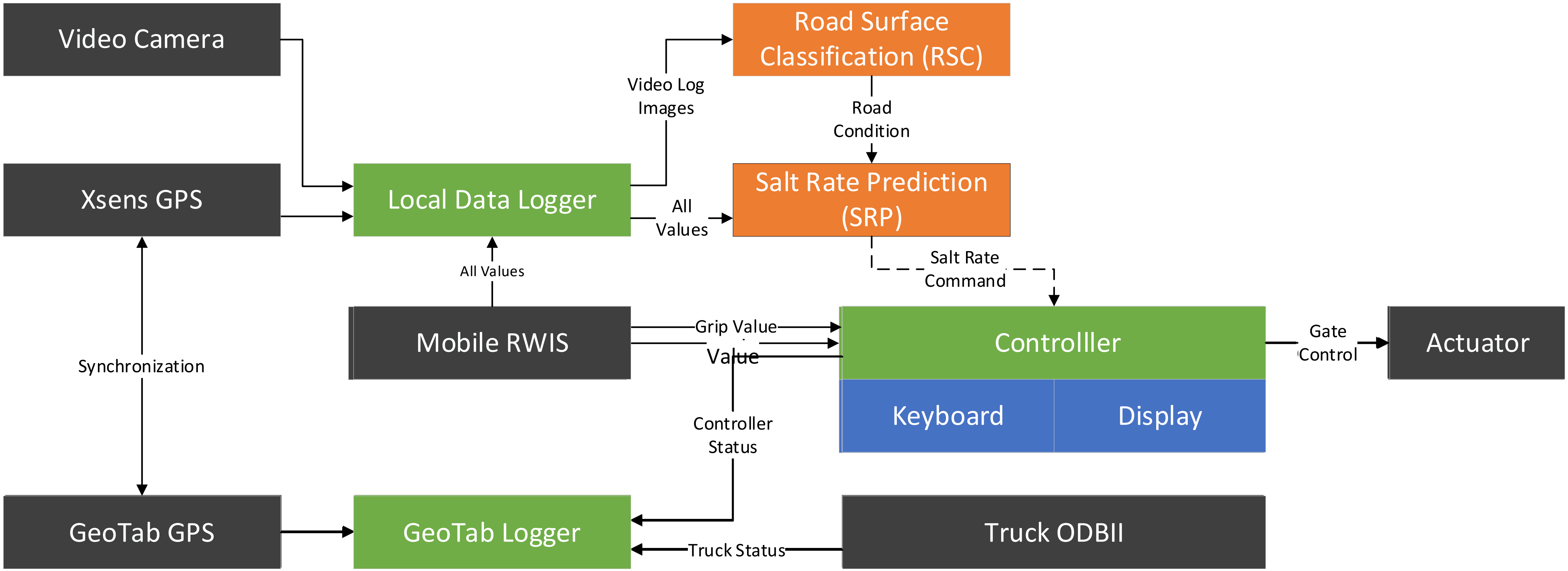
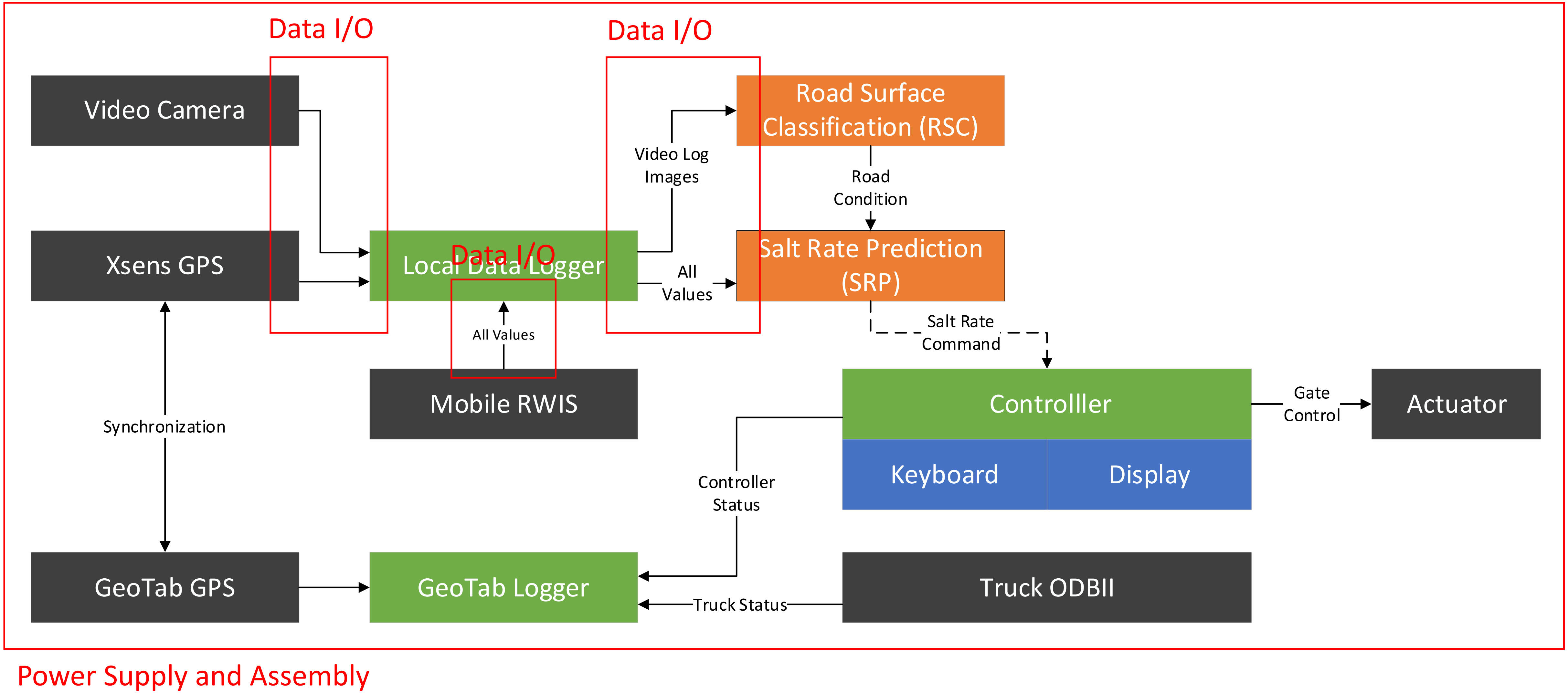
Methodology - Overview (1)

- Integration -> Hardware Development
- Determination -> Software/Algorithm Development
- Control -> Decision-making Strategy Development

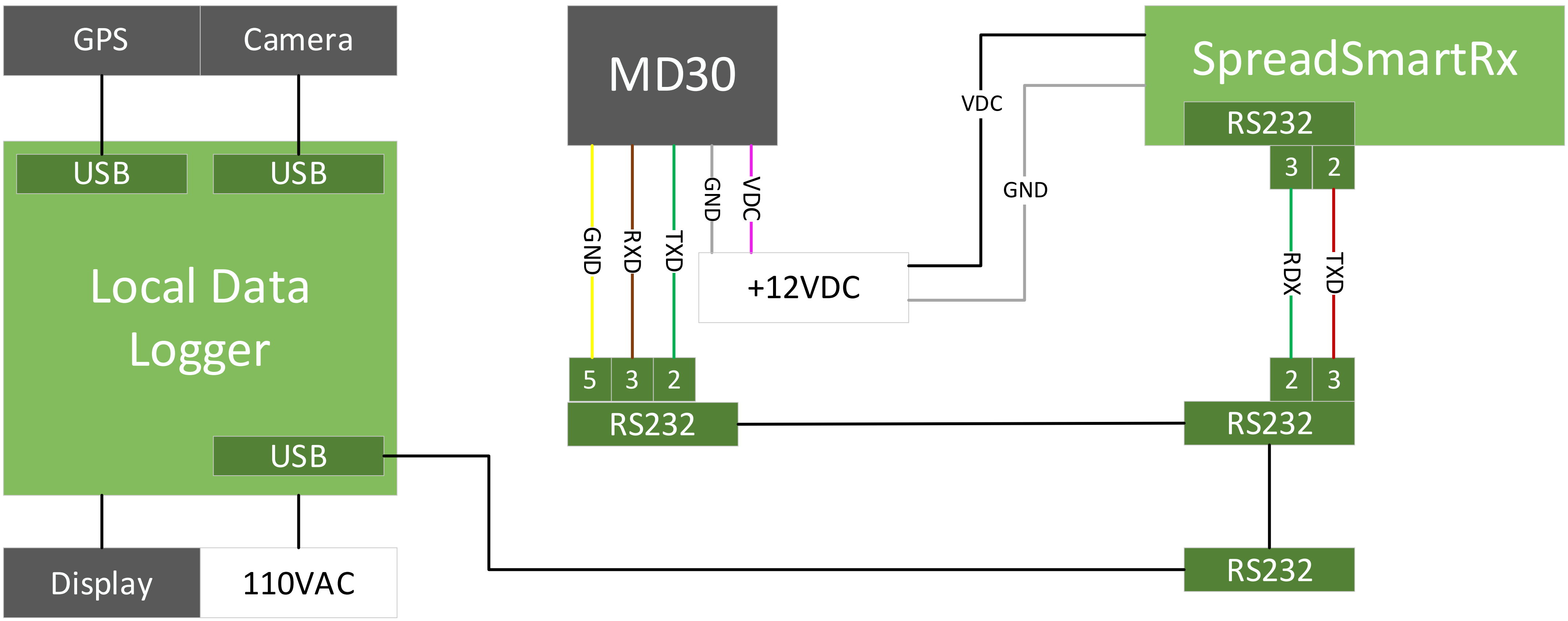
Methodology - Overview (2)

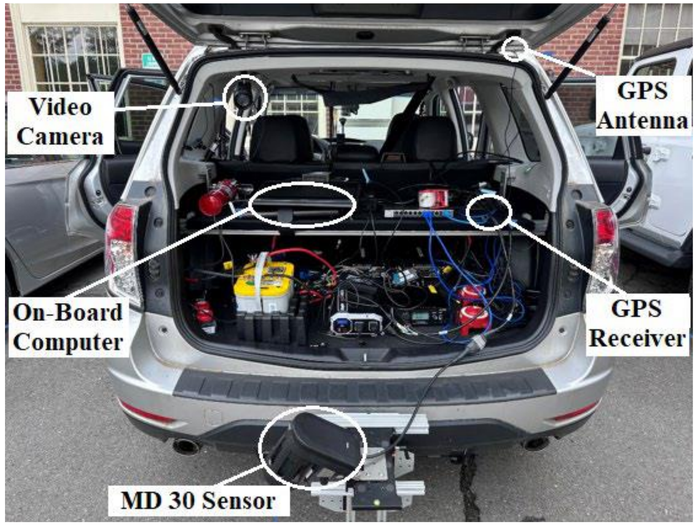


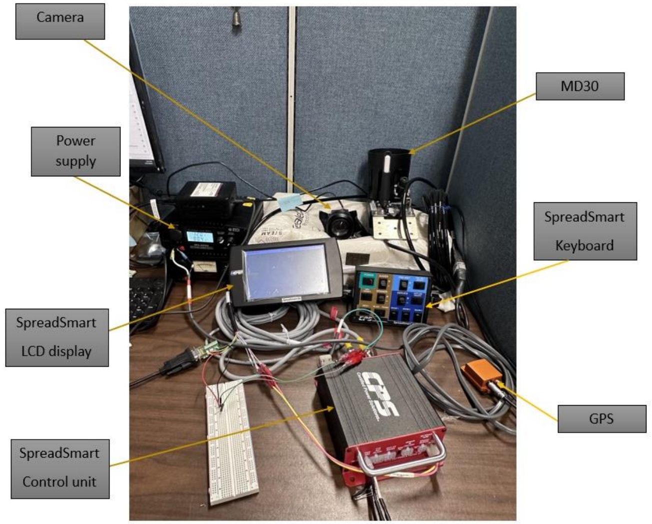
Methodology - Hardware Development (1)

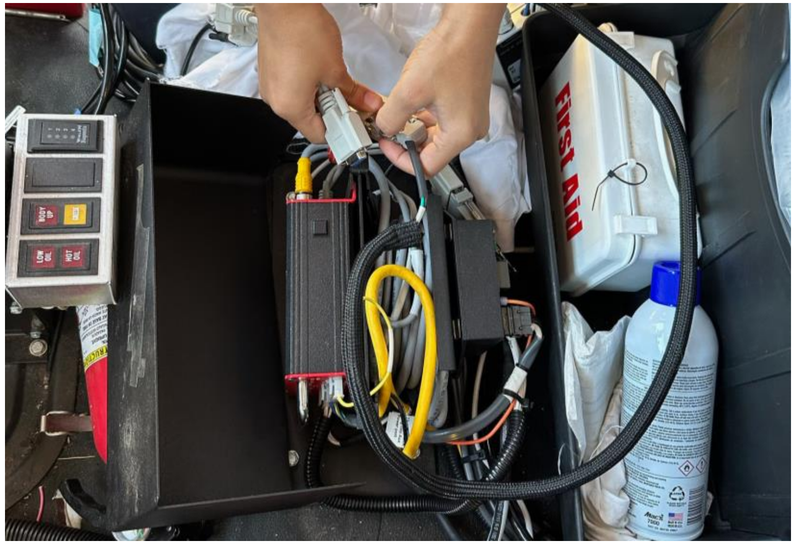


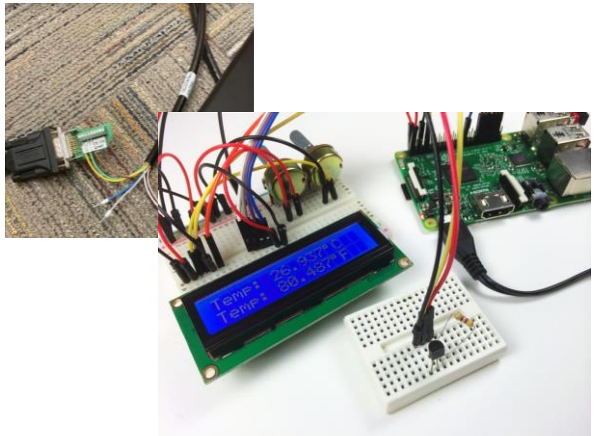
Methodology - Hardware Development (2)




Video
Camera
GPS
Antenna
On-Board
Computer
GPS
Receiver
MD 30 Sensor


Camera
MD30
Power
supply
SpreadSmart
Keyboard
SpreadSmart
LCD display
GPS
SpreadSmart
Control unit


First Aid



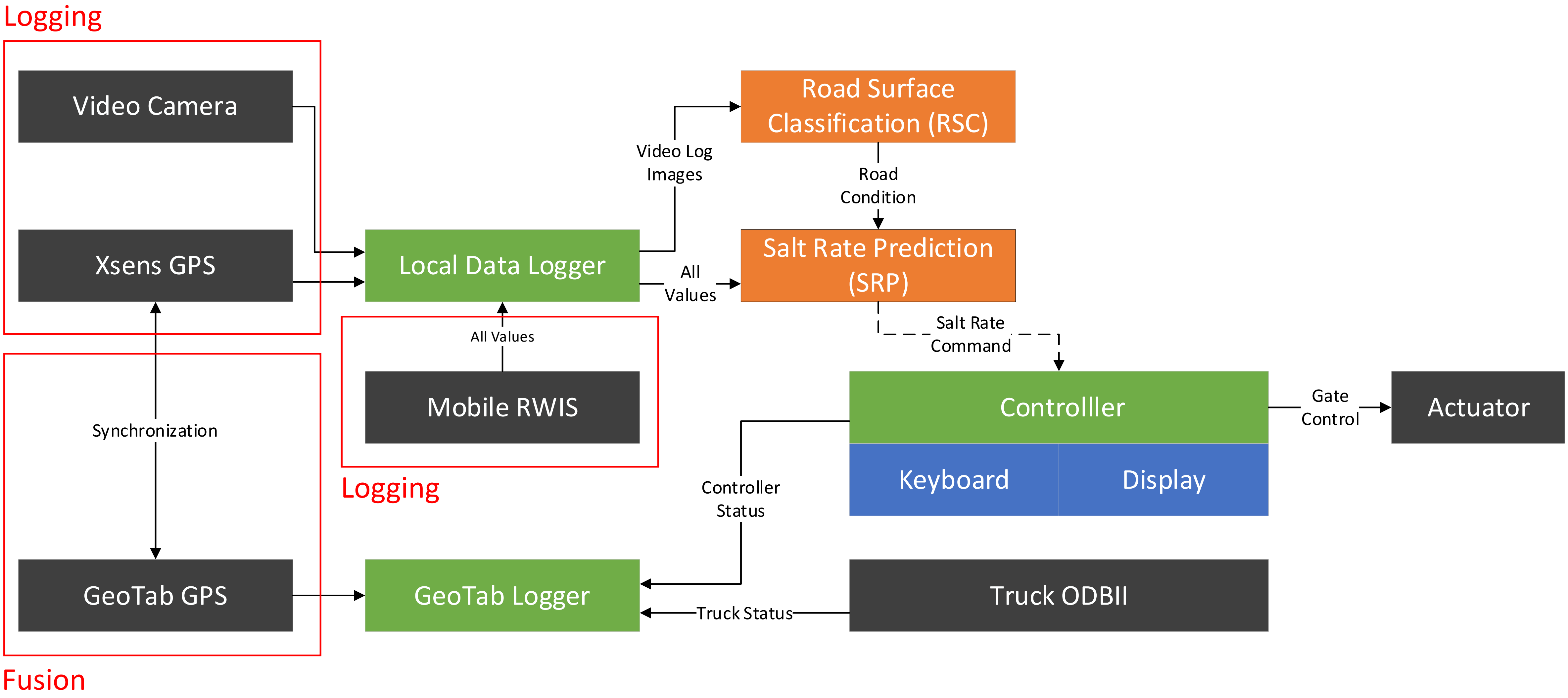
Hardware setup for logging mechanism

Camera

MD30 sensor

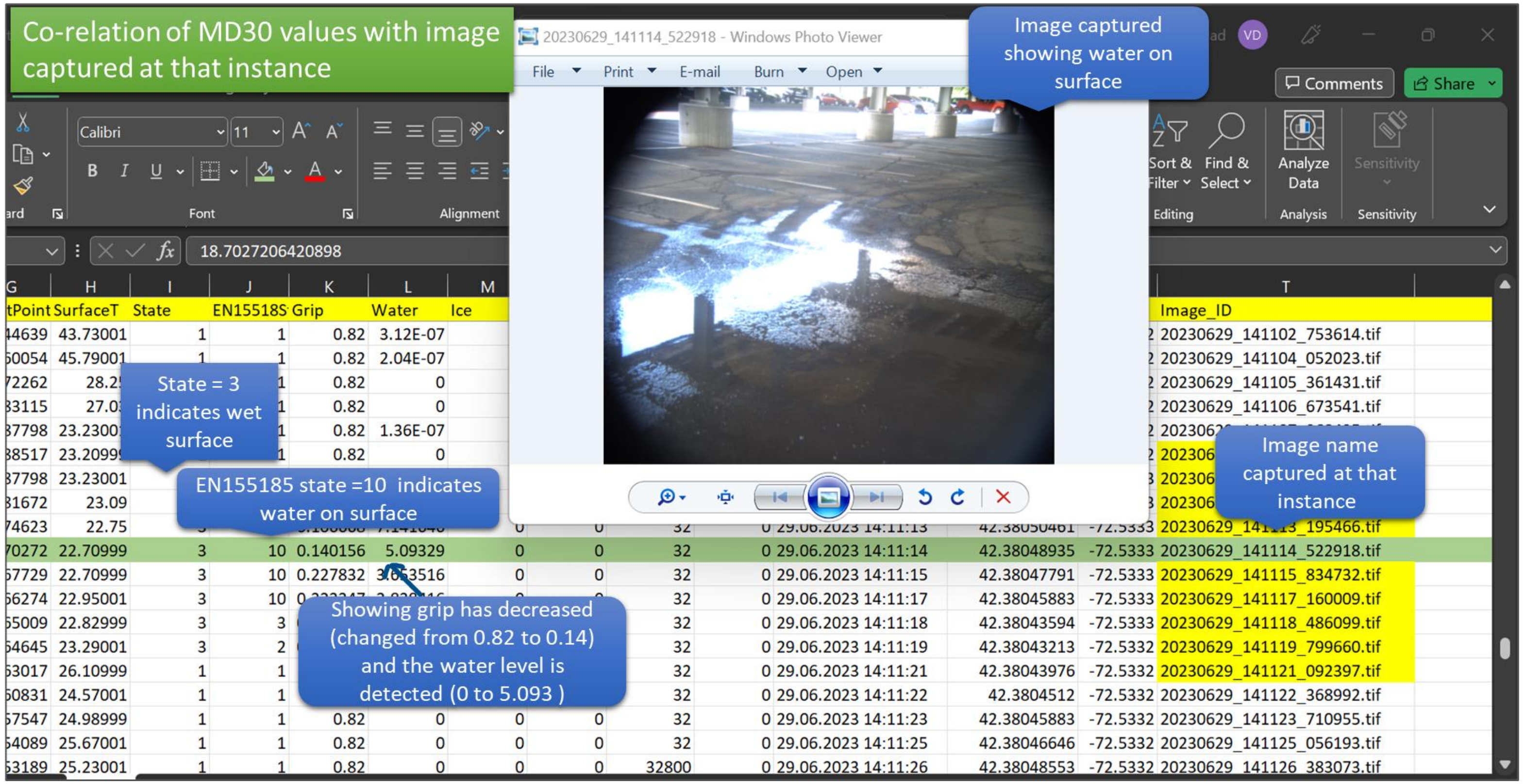
Salt spreader mechanism

Methodology - Software Development (1)



Methodology - Software Development (2)

- Data Logging
  - Python 3.10
  - Vaisala MD30 SDK
  - FLIR SpinView SDK
  - Xsens SDK



Methodology - Software Development (3)

- Data Fusion
  - Synchronization - by time between Local Logger and GeoTab Logger

AnalyzeCount	AirT	RH	DewPoint	FrostPoint	SurfaceT	State	EN15518State	Grip	Water	Time	Lat	Lon	Image_ID
38090	5.8	100	5.79	5.79	2.17	3	10	0.10	16.65	28.01.2024 17:27:52	42.2012558	-71.8227005	20240128_172752_435951.jpg
38094	5.8	100	5.79	5.79	2.17	3	10	0.10	16.72	28.01.2024 17:27:53	42.2012558	-71.82269287	20240128_172753_703325.jpg
38098	5.8	100	5.79	5.79	2.17	3	10	0.10	16.82	28.01.2024 17:27:54	42.2012558	-71.82269287	20240128_172754_973345.jpg
38102	5.8	100	5.79	5.79	2.21	3	10	0.10	16.88	28.01.2024 17:27:56	42.20125961	-71.82269287	20240128_172756_306530.jpg
38106	5.8	100	5.79	5.79	2.21	3	10	0.10	16.90	28.01.2024 17:27:57	42.20125961	-71.82268524	20240128_172757_579334.jpg
38110	5.8	100	5.79	5.79	2.25	3	10	0.10	16.76	28.01.2024 17:27:58	42.20126343	-71.82268524	20240128_172758_849566.jpg
38114	5.8	100	5.79	5.79	2.25	3	10	0.10	16.65	28.01.2024 17:27:59	42.20126343	-71.82268524	20240128_172800_102197.jpg
38118	5.8	100	5.79	5.79	2.25	3	10	0.10	16.64	28.01.2024 17:28:01	42.20126724	-71.82269287	20240128_172801_445299.jpg
38122	5.8	100	5.79	5.79	2.25	3	10	0.10	16.66	28.01.2024 17:28:02	42.20127869	-71.8227005	20240128_172802_778243.jpg
38126	5.8	100	5.79	5.79	2.17	3	10	0.10	16.68	28.01.2024 17:28:03	42.20130157	-71.82272339	20240128_172804_047159.jpg
38130	5.8	100	5.79	5.79	2.17	3	10	0.10	16.75	28.01.2024 17:28:05	42.20131683	-71.82274628	20240128_172805_315064.jpg
38134	5.8	100	5.79	5.79	2.17	3	10	0.10	16.74	28.01.2024 17:28:06	42.20133209	-71.82277679	20240128_172806_578362.jpg
38140	5.8	100	5.79	5.79	2.17	3	10	0.10	16.57	28.01.2024 17:28:07	42.20134354	-71.82280731	20240128_172807_847707.jpg
38144	5.8	100	5.79	5.79	2.27	3	10	0.10	16.59	28.01.2024 17:28:08	42.20135498	-71.82283783	20240128_172809_114651.jpg
38149	5.8	100	5.81	5.81	2.43	3	10	0.10	16.68	28.01.2024 17:28:10	42.20136261	-71.82286072	20240128_172810_369571.jpg
38153	5.8	100	5.81	5.81	2.43	3	10	0.10	16.68	28.01.2024 17:28:11	42.20136642	-71.82288361	20240128_172811_636568.jpg
38157	5.8	100	5.81	5.81	2.27	3	10	0.10	16.66	28.01.2024 17:28:12	42.20137024	-71.82289124	20240128_172812_905807.jpg
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38165	5.8	100	5.81	5.81	2.25	3	10	0.10	16.72	28.01.2024 17:28:15	42.20137024	-71.82289886	20240128_172815_441830.jpg
38168	5.8	100	5.81	5.81	2.17	3	10	0.10	16.60	28.01.2024 17:28:16	42.20137024	-71.82289886	20240128_172816_710031.jpg
38173	5.8	100	5.81	5.81	2.17	3	10	0.10	16.52	28.01.2024 17:28:17	42.20137405	-71.82289886	20240128_172817_968618.jpg
38177	5.8	100	5.81	5.81	2.17	3	10	0.10	16.58	28.01.2024 17:28:19	42.20137787	-71.82291412	20240128_172819_248294.jpg
38181	5.8	100	5.81	5.81	2.13	3	10	0.10	16.61	28.01.2024 17:28:20	42.2013855	-71.82292938	20240128_172820_577729.jpg
38185	5.8	100	5.81	5.81	2.13	3	10	0.10	16.67	28.01.2024 17:28:21	42.20139313	-71.8229599	20240128_172821_845640.jpg
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38193	5.8	100	5.81	5.81	2.09	3	10	0.10	16.62	28.01.2024 17:28:24	42.2014122	-71.82304382	20240128_172824_370110.jpg
38197	5.8	100	5.81	5.81	2.17	3	10	0.10	16.72	28.01.2024 17:28:25	42.20141602	-71.82308197	20240128_172825_645264.jpg
38201	5.8	100	5.81	5.81	2.17	3	10	0.10	16.70	28.01.2024 17:28:26	42.20141983	-71.82313538	20240128_172826_903271.jpg
38205	5.8	100	5.81	5.81	2.17	3	10	0.10	16.81	28.01.2024 17:28:28	42.20141602	-71.82318878	20240128_172828_173046.jpg
38208	5.8	100	5.81	5.81	2.17	3	10	0.10	16.67	28.01.2024 17:28:29	42.20140839	-71.82324219	20240128_172829_445002.jpg
38213	5.8	100	5.81	5.81	2.17	3	10	0.10	16.62	28.01.2024 17:28:30	42.20139694	-71.82330322	20240128_172830_715216.jpg
38219	5.8	100	5.81	5.81	2.17	3	10	0.10	16.63	28.01.2024 17:28:31	42.20138168	-71.82336426	20240128_172831_972219.jpg

Log Data and Collisions Report

Massachusetts Department of Transportation

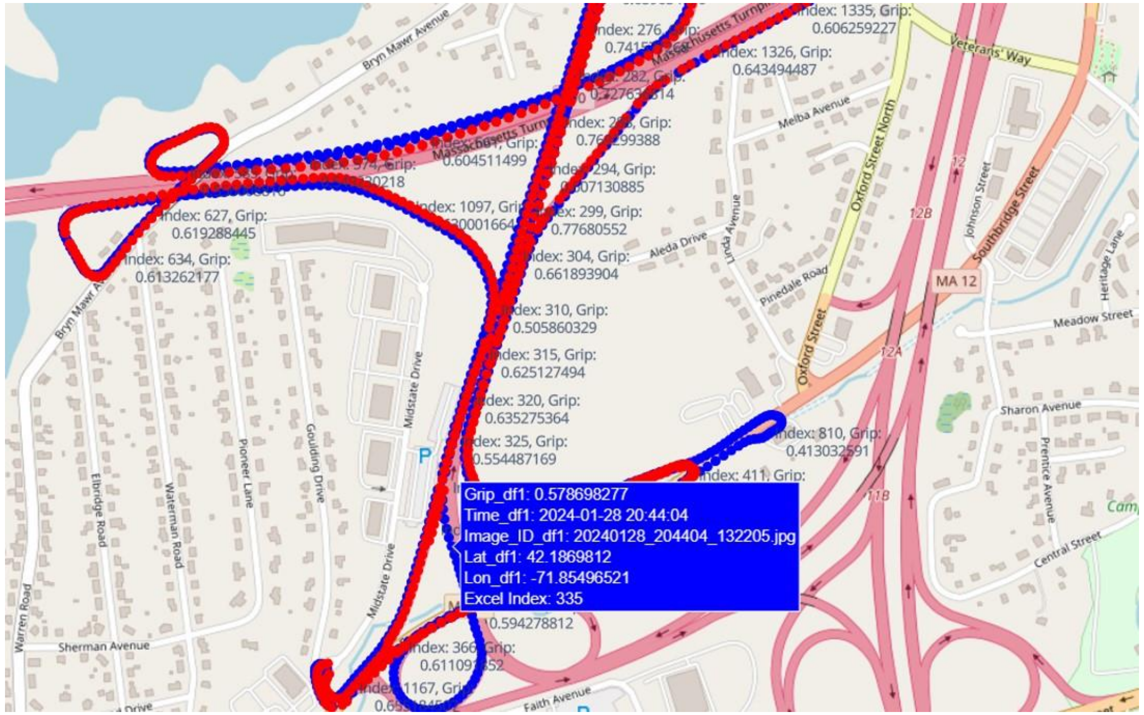
Date	
From	Jan 07, 2024
To	Jan 07, 2024
Days	0

Time Zone	America/New_York
Speed Unit	mph

Device	Device Group	First Name	Date	Log Time	Record Type	Speed	Longitude	Latitude	Reason for Log
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:20 AM	GpsRecord	0	-71.82259	42.20119	CurveTimeOut
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:21 AM	DebugRecord				61309
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:43 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:47 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:47 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:48 AM	GpsRecord	1	-71.82259	42.20124	CurveZeroSpeed
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:48 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:51 AM	DebugRecord				61309
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:51 AM	GpsRecord	3	-71.82259	42.20122	CurveSpeed
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:52 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:54 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:54 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:33:54 AM	GpsRecord	0	-71.82259	42.20119	CurveZeroSpeed
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:02 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:07 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:16 AM	EngineStatusRecord				
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:21 AM	DebugRecord				61309
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:51 AM	DebugRecord				61309
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:34:59 AM	GpsRecord	0	-71.82259	42.20119	CurveTimeOut
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:35:21 AM	DebugRecord				61309
Auburn STL942	Vehicle, Diesel, UMass Stuc		Jan 07, 2024	9:35:30 AM	EngineStatusRecord				

Methodology - Software Development (4)

- Data Fusion
  - Spatial Correlation - by location between different runs



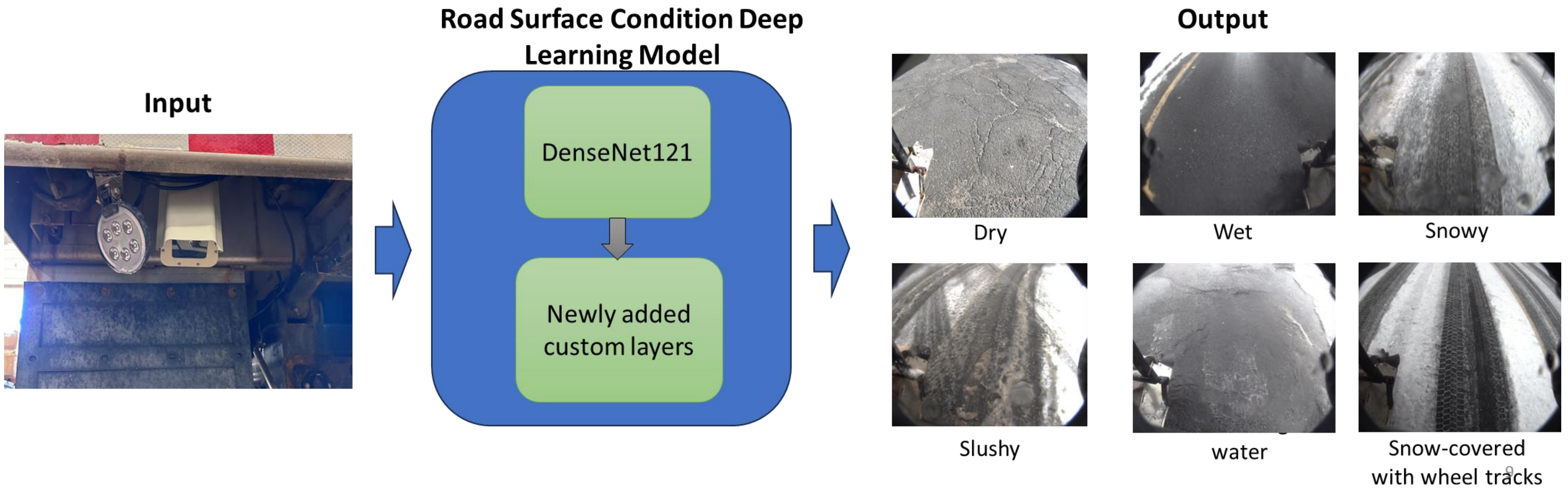
$$a = \sin^2\left(\frac{\Delta \mathrm{lat}}{2}\right) + \cos(\mathrm{lat}_1)\cdot\cos(\mathrm{lat}_2)\cdot\sin^2\left(\frac{\Delta \mathrm{long}}{2}\right)$$

$$c = 2\cdot \mathrm{atan2}\left(\sqrt{a}, \sqrt{1-a}\right)$$

$$d = R \cdot c$$

Methodology - Algorithm Development (1)

- Road Surface Classification (RSC)
  - Deep learning model (DenseNet121) for road condition classification
  - Training and testing dataset (80/20): Dry (4624), Wet (2886), Snowy (373), Slushy (1316), Streaming water (363), Snow covered with wheel tracks (439)



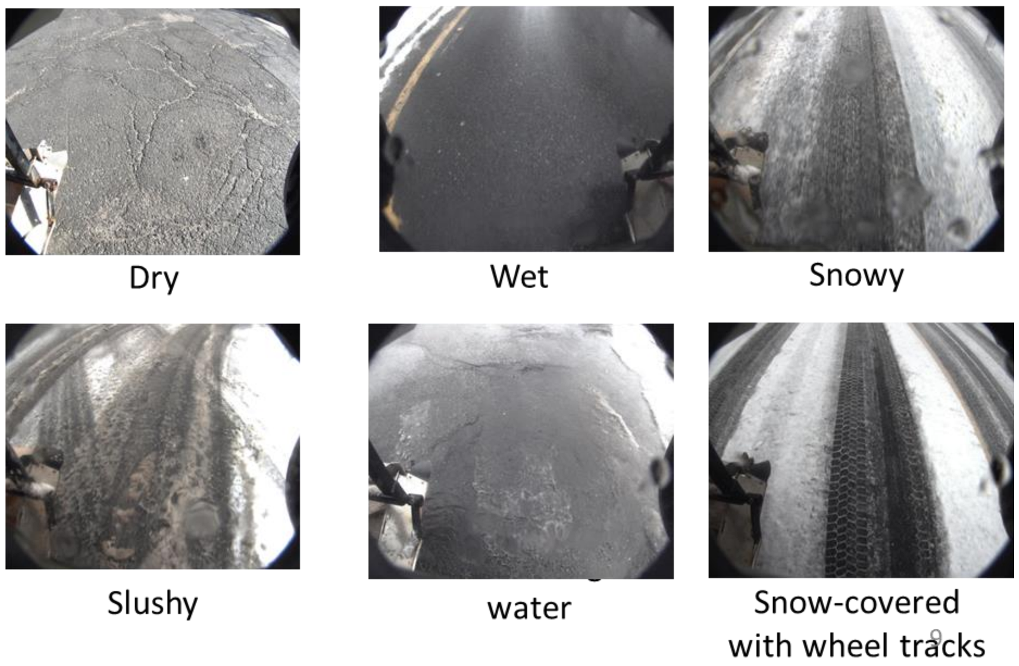
Methodology - Algorithm Development (2)

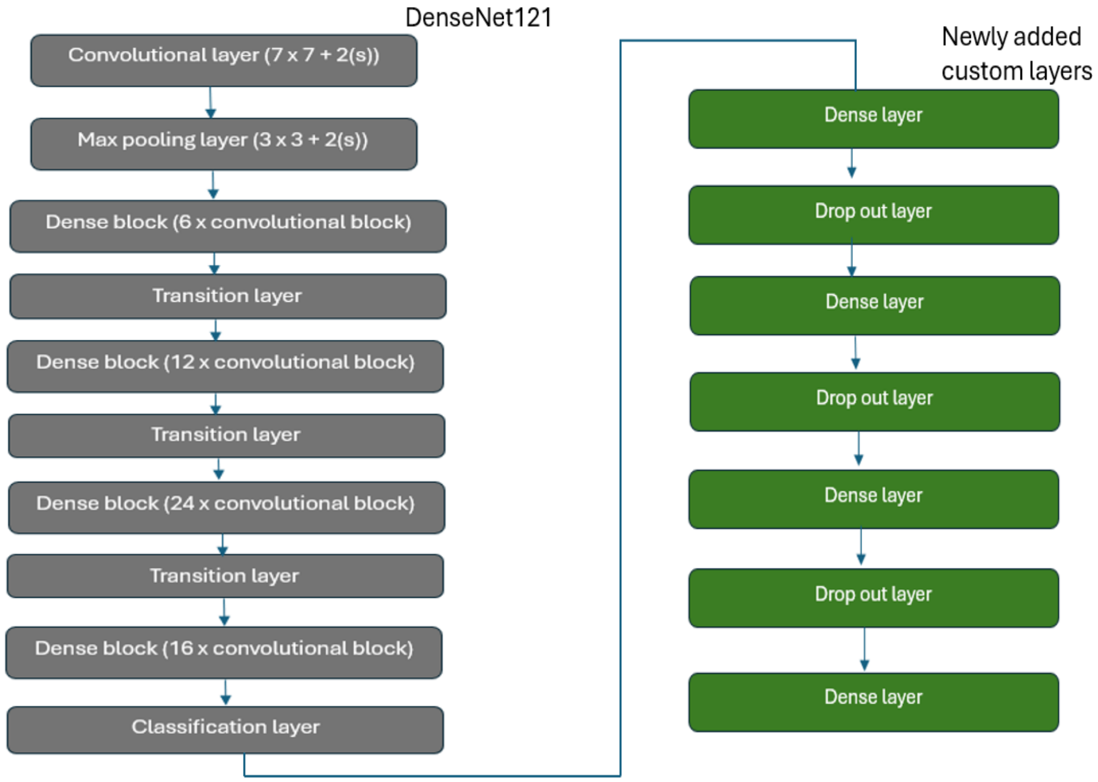
- MD30 state : Road states determined by MD30 in Vaisala format.
- EN1558 state : Road states determined by MD30 in European standard norm.

Road Surface Classification Model	MD30 state parameter		MD30 EN1558 parameter	
	Value	Description	Value	Description
Dry	1	Dry	1	Dry
Wet	2	Moist	2	Moist
	3	Wet	3	Wet
Snow	6	Snowy	11	Slippery
Snow-covered with wheel tracks				
Slushy	7	Icy	11	Slippery
	9	Slushy		
Streaming water			10	Streaming water

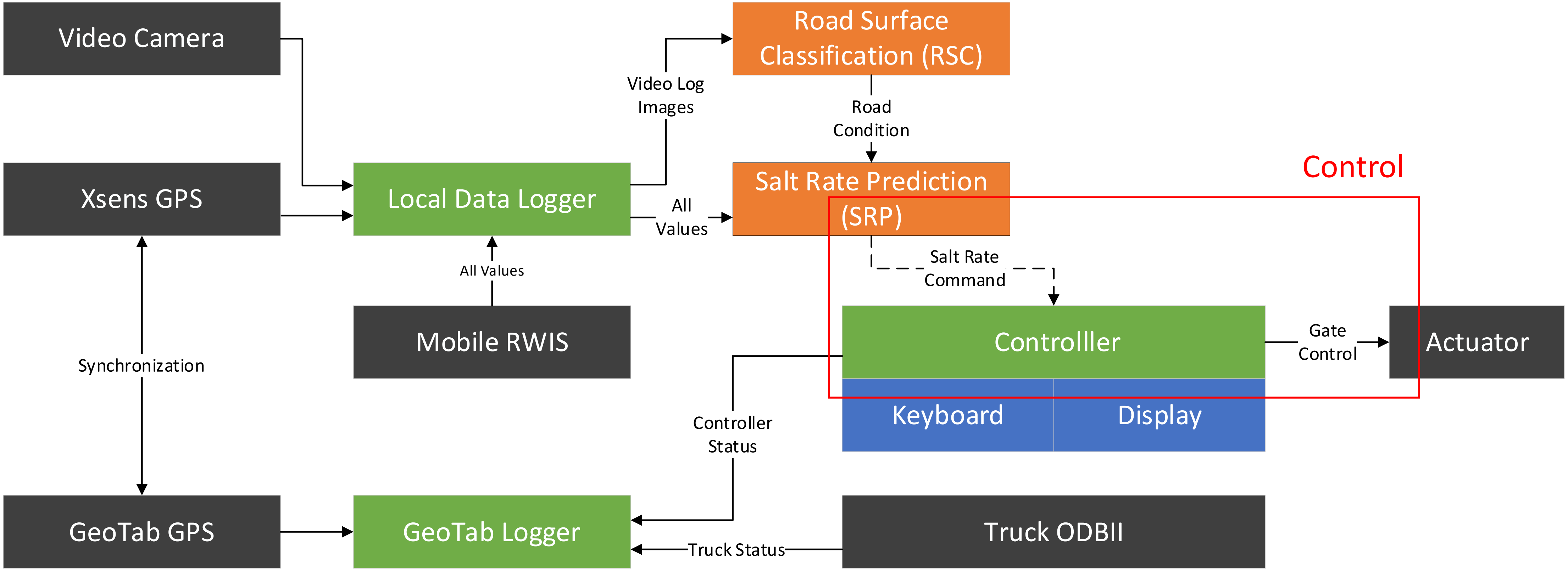
Methodology - Algorithm Development (3)

- Customized transfer learning layer for flexibly defining RSCs





Methodology – Decision-Making Strategy Development (1)

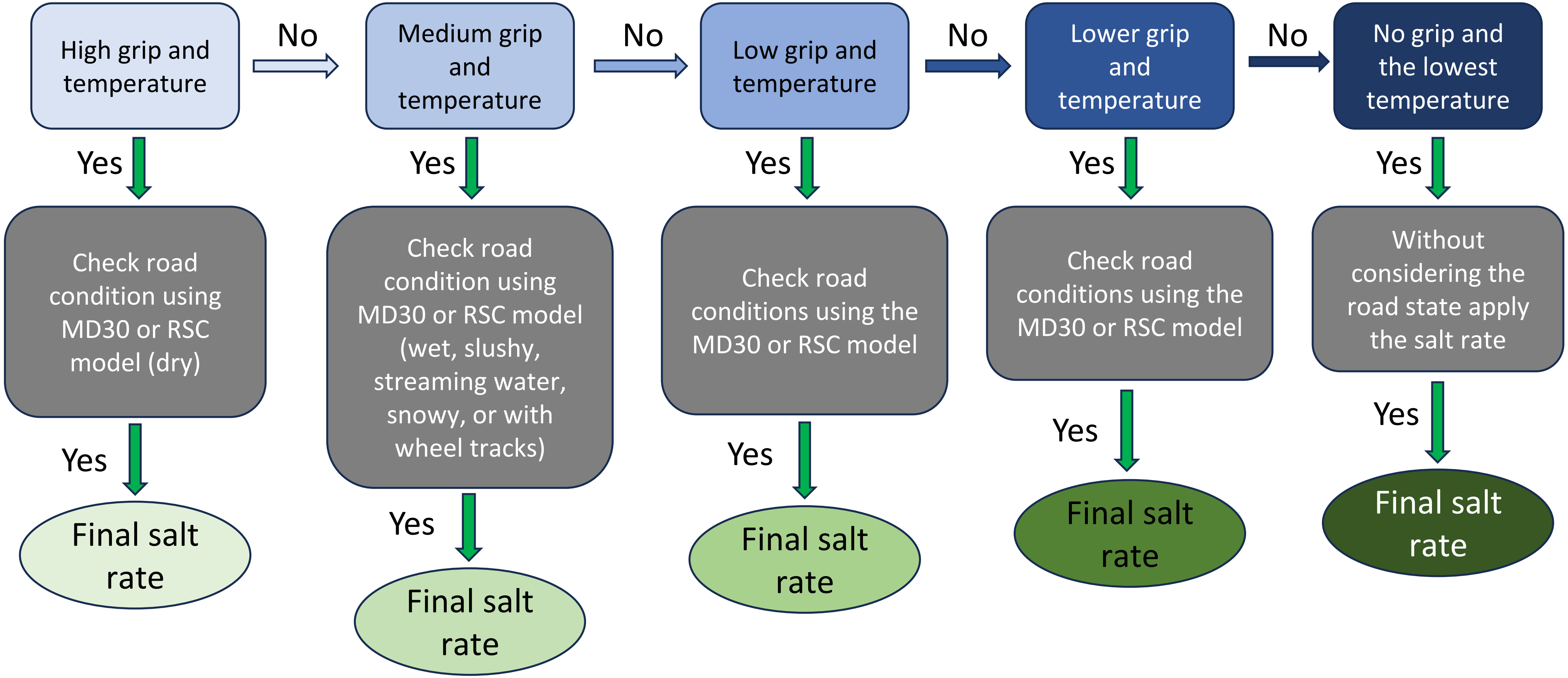


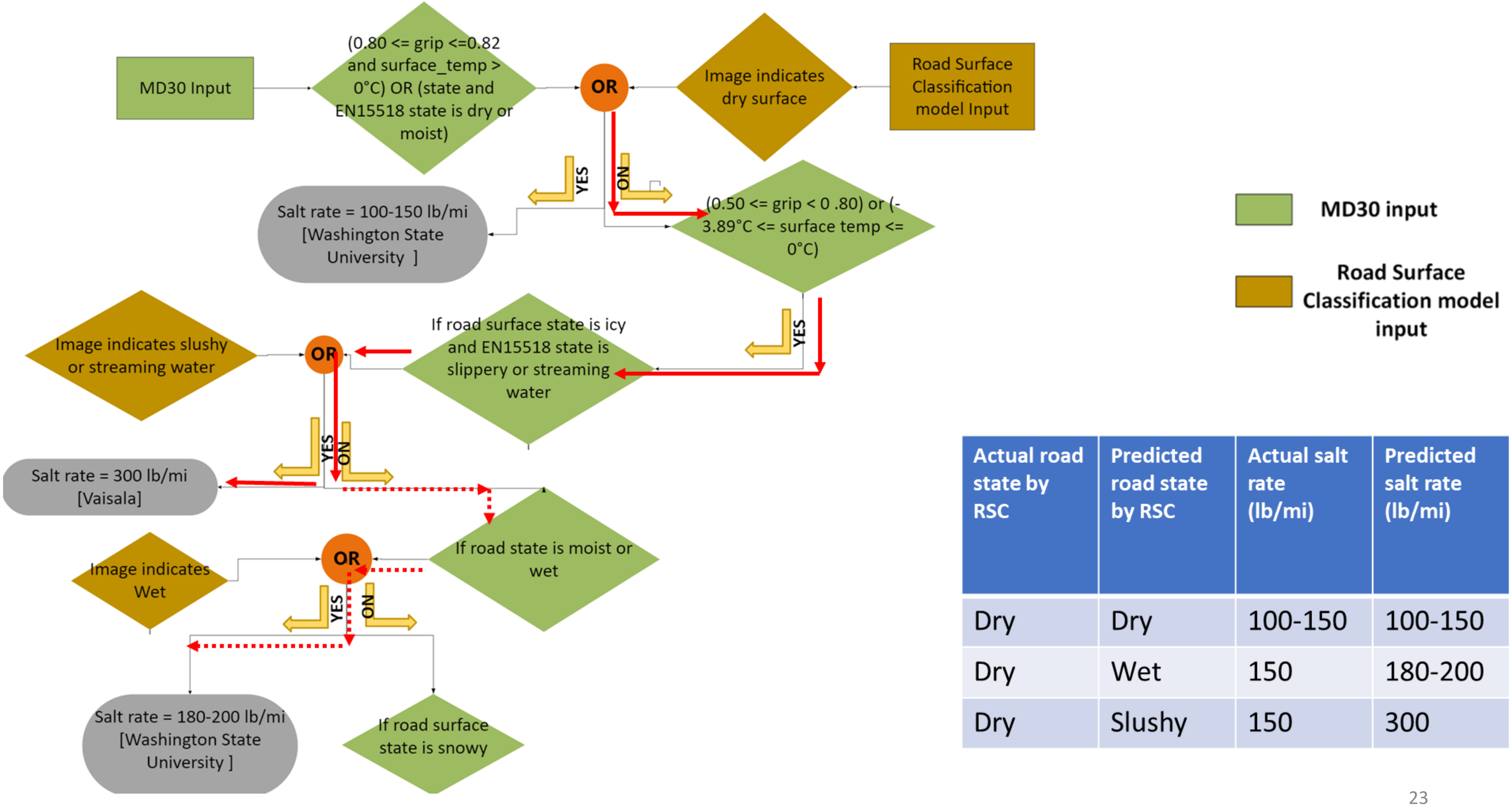
Methodology – Decision-Making Strategy Development (2)

- Literature review reveals that neither surface temperature nor grip alone should decide the salt rate
  - Salt rate should be decided by considering all road conditions including pavement surface condition, grip, weather event, temperature (and its trend)

Winter Storm Event	Pavement Temperature and Trend	Pavement Surface	Arizona DOT	Highway Winter Maintenance Guide	Washington State University
Light snow-storm	Above 32 °F, steady or rising.	Dry, wet, slush, or light snow cover			120 – 160
	Above 32 °F, but falling	Dry	75 – 150	100	
		Wet	100 – 200	100	140 – 180
	25 to 32 °F,	slush, wet or light snow cover	100 – 210	100	160 – 200
	20 to 25°F		100 – 210	100	200 – 250
	15 to 20 °F, remaining in range	Dry, wet, slush, or light snow cover	200 – 240	200	250 – 300
	Below 15 °F	Dry or light snow cover			

Grip	Pavement Temp	Roadway Description	Action (Pavement Temp Rising)	Action (Pavement Temp Falling)
.82-.60	30-34	Dry to generally wet	None	50 – 100 lbs/lnm
.50-.60	25-32	Slushy to snow covered	50 – 100 lbs/lnm	100 – 150 lbs/lnm
.40-.50	20-25	Snow covered perhaps wheel tracks	100 – 150 lbs/lnm	150 – 200 lbs/lnm
.40-.45	15-20	Snow covered with possible pack	150 – 200 lbs/lnm	250 – 300 lbs/lnm
.30-.40	15-20	Slippery and ice likely	200 – 300 lbs/lnm	250 – 300 lbs/lnm
<.30	<15	Icy covered	350 – 400 lbs/lnm	400 lbs/lnm


High grip and temperature
No
Medium grip and temperature
No
Low grip and temperature
No
Lower grip and temperature
No
No grip and the lowest temperature
Yes
Check road condition using MD30 or RSC model (dry)
Yes
Check road condition using MD30 or RSC model (wet, slushy, streaming water, snowy, or with wheel tracks)
Yes
Check road conditions using the MD30 or RSC model
Yes
Check road conditions using the MD30 or RSC model
Yes
Without considering the road state apply the salt rate
Yes
Final salt rate
Yes
Final salt rate
Yes
Final salt rate
Yes
Final salt rate
Yes
Final salt rate



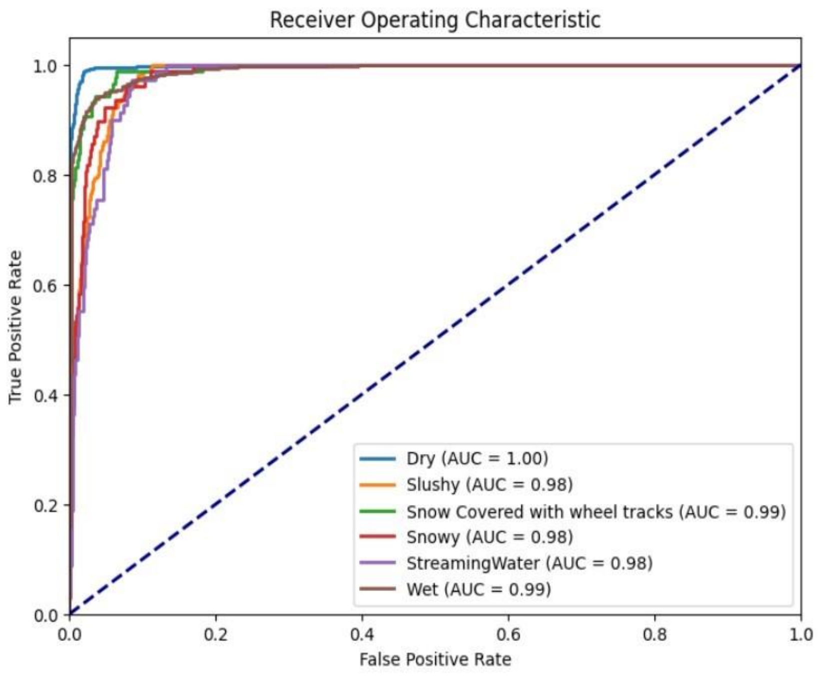
Actual road state by RSC	Predicted road state by RSC	Actual salt rate (lb/mi)	Predicted salt rate (lb/mi)
Dry	Dry	100-150	100-150
Dry	Wet	150	180-200
Dry	Slushy	150	300

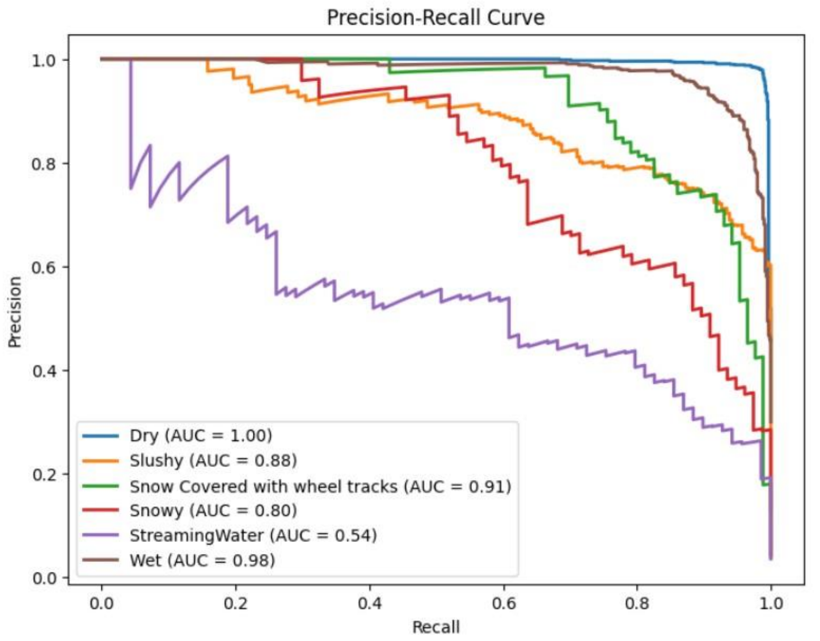
Results - Campus Test (1)

- UMass SUV Instrumentation
  - Validated the real-time logging functionality of the local logger
  - Achieved synchronization among GPS, MD30 and camera
  - Collected road surface data in 4 snow events for RSC training

Results - Campus Test (2)

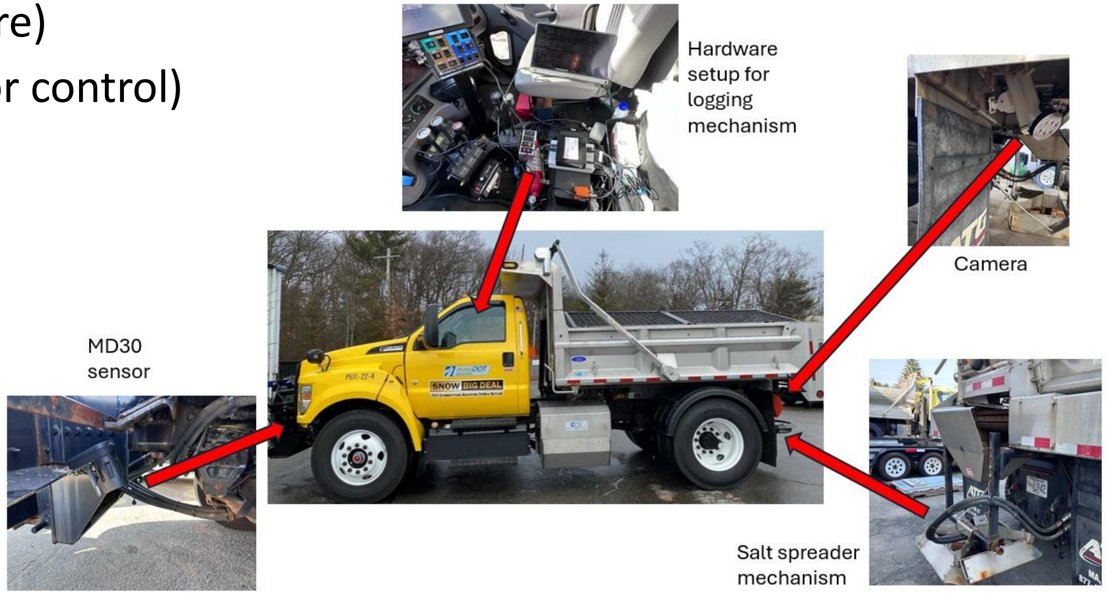
- Accuracy - 86.7%
- RSC model was evaluated using precision-recall curve and ROC
- Model shows excellent overall performance
  - Streaming water road condition has poor performance because of class complexity and limited dataset.



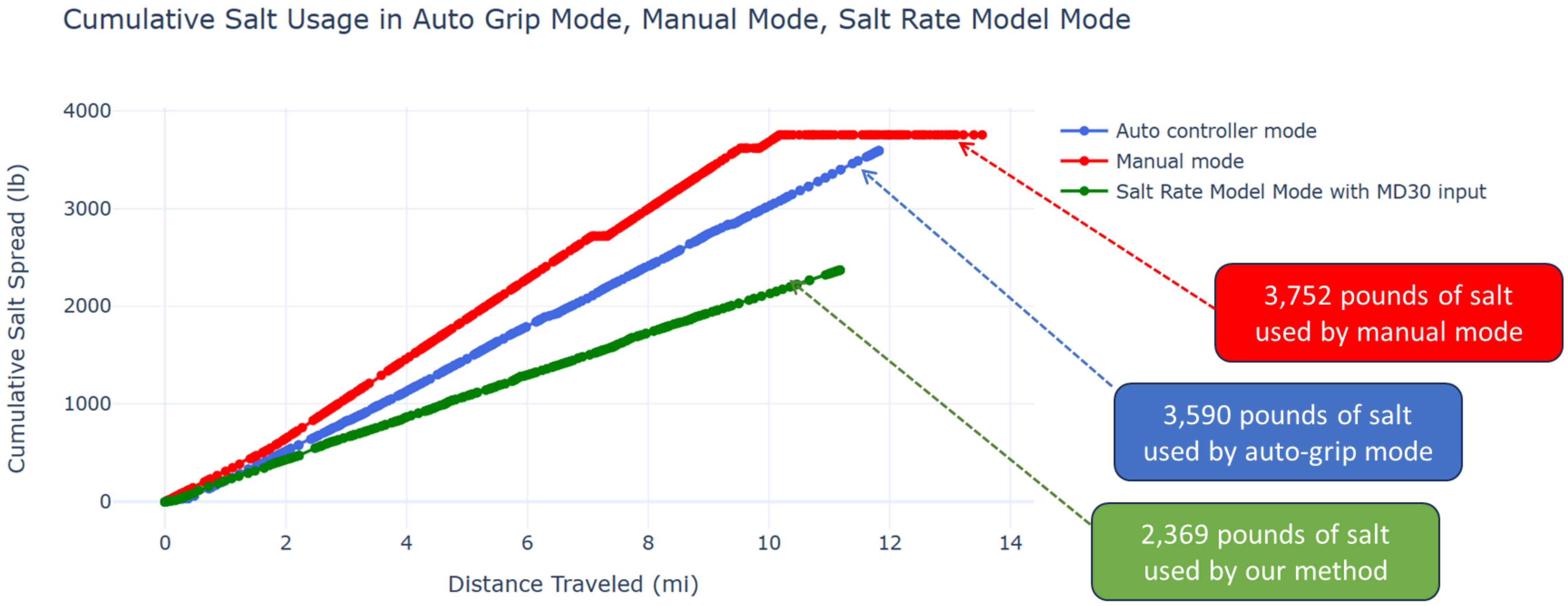


Results - Field Test (1)

- MassDOT STL942 truck instrumentation
  - Validated the real-time logging functionality of both the local logger and the GeoTab logger
  - Achieved synchronization among GPS, MD30, camera, and salt rates
  - Evaluated the performance of the developed salt rate prediction and compared with other methods
- Collected before/after data for each mode
  - Auto grip mode (i.e., auto rate in the current firmware)
  - Manual mode (i.e., current practice with full operator control)
  - SRP mode (i.e., proposed rate in this study)



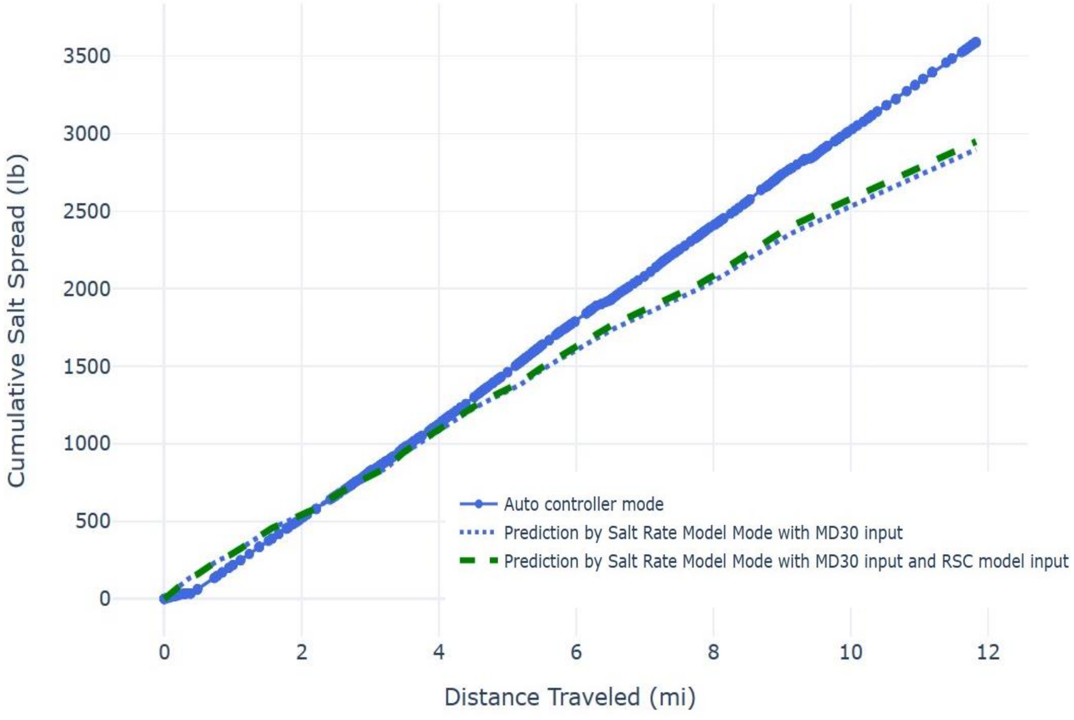
Results - Field Test (2)

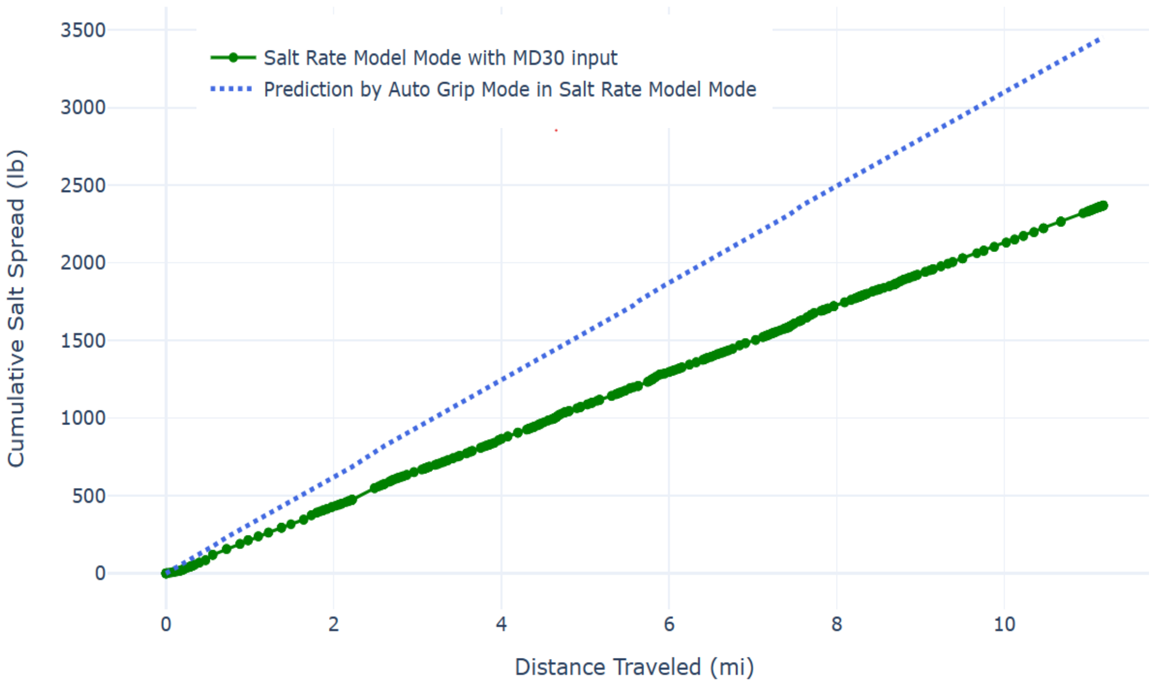


Results - Field Test (3)

Results - Simulation Test (1)

- We wanted to fairly compare the salt uses and better understand the necessity of the RSC model better





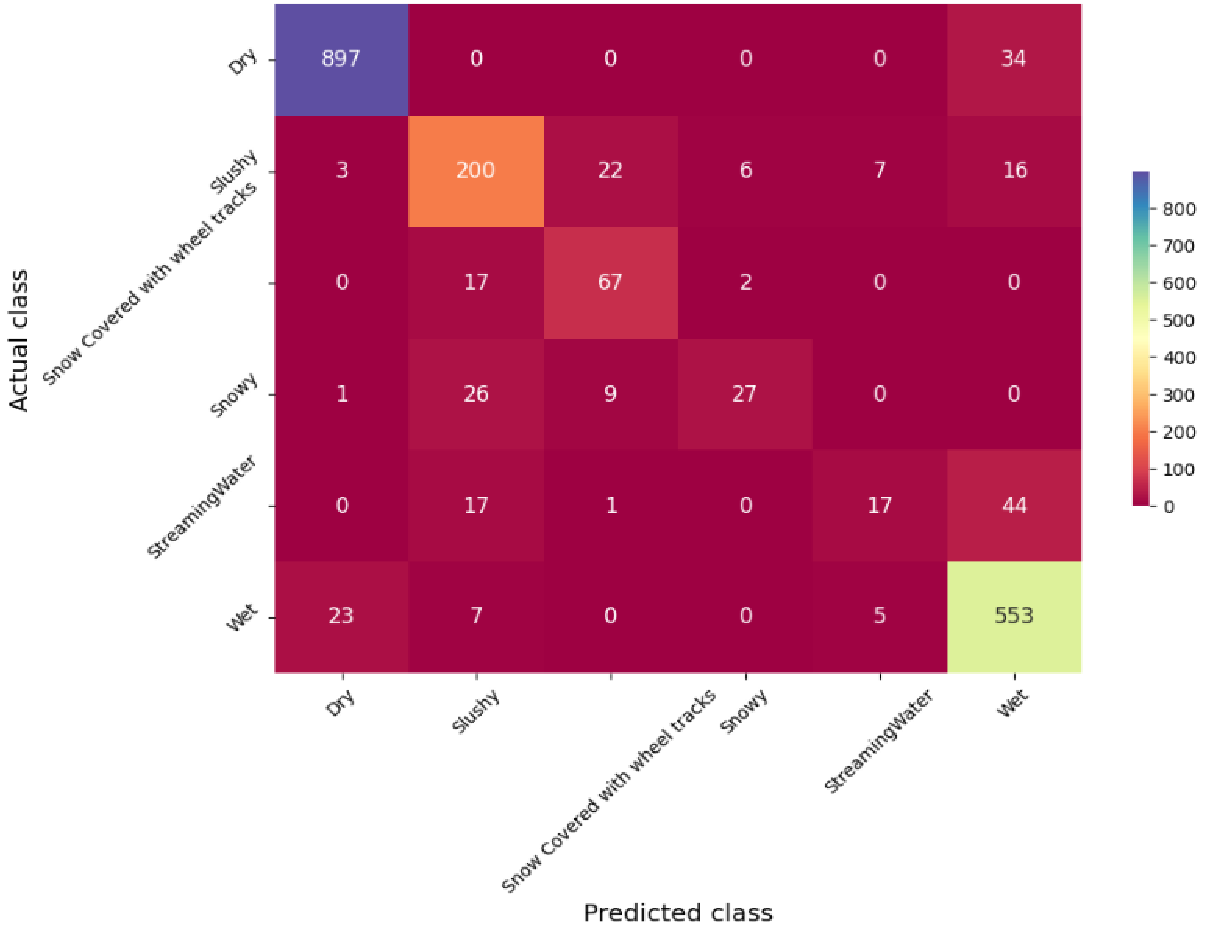
Results - Simulation Test (2)

Controller Mode	Weather Condition (Before)	Weather Condition (After)	Mean Grip Value (Before)	Mean Grip Value (After)	Total Salt Used/Calc	Difference
[FIELD DATA] Auto grip mode	Moderate heavy snow event	No snow	0.56	0.59 **(0.03)**	3590 pounds	
[SIMULATION] Proposed mode (using Auto grip mode file data)	Moderate heavy snow event	No snow			2949 pounds	**- 641 pounds**
[FIELD DATA] Manual mode	Sleet plus snow	Sleet plus snow	0.58	0.59 **(0.01)**	3752 pounds	
[FIELD DATA] Proposed mode	Sleet plus snow	Snow	0.59	0.62 **(0.03)**	2369 pounds	
[SIMULATION] Auto grip mode (using Proposed mode data)	Sleet plus snow	Snow			3453 pounds	**+ 1084 pounds**

Results - Simulation Test (3)

- We wanted to better understand the sensitivity of the RSC performance on salt rate

Condition	Predicted Condition	Grip Value	Actual Rate (lb/mi)	Predicted Rate (lb/mi)	Rate Difference (lb/mi)
Dry	Wet	(0.50 <= grip <0.80)	100-150	180-200	65
Dry	Snowy	(0.50 <= grip <0.80)	100-150	200	75
Dry	Snowy	(0.40 <= grip <0.50)	100-150	250-300	150
Dry	Snowy	(0.30 <= grip <0.40)	100-150	325-350	212
Dry	Slushy	(0.50 <= grip <0.80)	100-150	300	175
Dry	Slushy	(0.40 <= grip <0.50)	100-150	350	225
Dry	Slushy	(0.30 <= grip <0.40)	100-150	400	275
Slushy	Wet	(0.50 <= grip <0.80)	300	180-200	-110
Slushy	Snowy	(0.50 <= grip <0.80)	300	200	-100
Slushy	Snowy	(0.40 <= grip <0.50)	350	250-300	-75
Slushy	Snowy	(0.30 <= grip <0.40)	400	325-350	-63



Results - Limitations

- The current RSC model only works during daytime
- The identification of “Streaming Water” condition needs improvement
- Black ice and packed snow conditions were not treated separately
- The current system was only tested on a limited number of winter events

Black ice on roads after freezing streaming water

Nighttime

Daytime

Conclusions

- Through this study, a complete hardware/software system with automated RSC and SRP algorithms has been developed, pilot-tested, and validated with promising performance
  - [Integration] The research team explored the full integration feasibility of mobile RWIS sensor, high-resolution camera, GPS, and GeoTab logger, and developed prototype software for comprehensive data collection
  - [Determination] The research team developed an automated road surface classification algorithm using the DenseNet121 deep-learning model with an 86.7% accuracy
  - [Control] The research team integrate the detailed road surface classification outcome, the key parameters from the mobile RWIS sensor with a comprehensive salt rate decision tree
- The performance of the developed system showed promising results, and can potentially save significant amount of the salts once implemented in a larger fleet of MassDOT's winter operation

Recommendations

- The research team recommends further investigation and improvement with respect to the limitations identified from the experiments
  - The current RSC model only works during daytime
  - The identification of “Streaming Water” condition needs improvement
  - Black ice and packed snow conditions were not treated separately
- The research team recommends larger-scale testing and implementation for the future phases of the study if programmed
  - To include more diverse weather and surface conditions
  - To include stationary RWIS and regional weather prediction data with the current strategy
  - To walkaround the existing firmware (or develop new firmware) in the SpreadSmartRx controller and execute the spreader control fully automatically

Acknowledgements

- Mr. Mark Goldstein and his team from statewide snow and ice operation and D3 for providing technical and engineering support, and oversight for this project
- Dr. Hao Qin and Mr. Michael Flanary from the Office of Transportation Planning for providing management support and constructive suggestions
- Mr. Michael Smith from the UMTC for his technical support in winter operation and snow plowing machine operation
- Mr. Matt Mann, Ms. Kimberley Foster, and Ms. Michelle Augustinowicz from the UMTC for their administrative support
- Mr. Bryan Remache-Patino from AI Lab at UMass Amherst for assisting hardware development and data collection

Questions?

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