S-I-R-W-E-C

Development of Variable Speed Limits System Reflecting Pavement and Rainfall Conditions for Real-Time Urban Road in Seoul

(Paper Number of SIRWEC 16-011)

Section of Integrating Road Weather Information and Operations

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KMA Korea Meteorological Administration A New Era of Hope

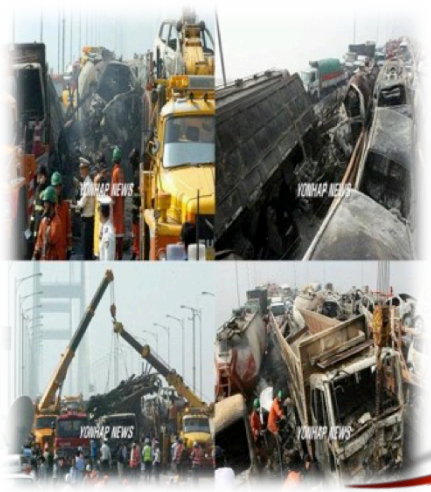
Weather Information Service Engine WISE Institute

Contents

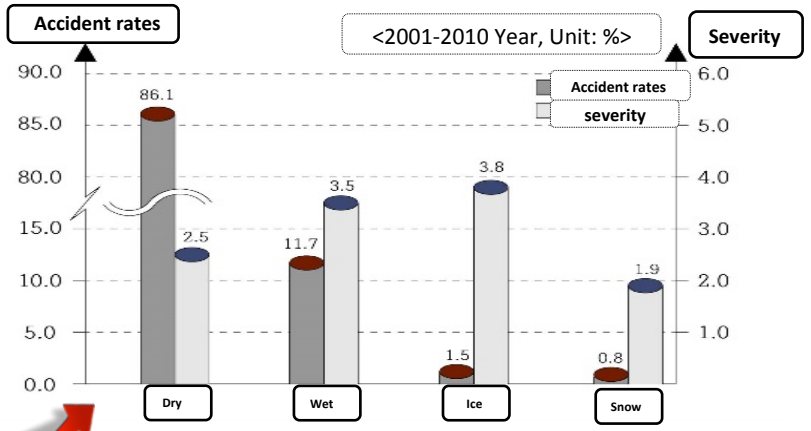
1. Background and Purpose

- **Negative effect of driver's behavior under the rainfall condition.**
- **Probability of high risk crashes during rainfall or after rainfall.**

Traffic Accidents Durin g Heavy Rain



Second Highest Severity Rates in Korea



Reference: Koroad / http://www.koroad.or.kr/

- **Importance of precise rainfall information for traffic safety.**
- **Not directly being measured of rainfall on roads.**

- **Development of the methodology for the variable speed limits in real ti me by rainfall intensity in Seoul City.**

- Development of variable speed limit algorism.

- Application of Interpolation technique (IDW) for Seoul roads and 190 weather stations.

* Inverse Distance Weight

- Evaluation of road weather prediction accuracy according to representative rainfall days from 190 weather stations in Seoul.

- Development of Variable Speed Limit System.

WISE

✓ Process for development of VSL

Road condition
(Dry, Wet, Ice)

Water depth on road surface

Developing

Stopping Sight dist ance (d)

$$d = 0.694V + V^2/254f,$$

Korea Institute Of Construction Technology (2009)

Friction coefficient (f)

$$f = af(W) + b$$

Juga, I., Nurmi, P., & Hippi, M. (2013).
Statistical modelling of wintertime road surface friction.
Meteorological Applications, *20*(3), 318-329.

Visibility distance (s)

$$S_V = \frac{354030{,}6}{I^{0{,}68} \cdot V}$$

where, S_V = visibility sight [m];
I = rainfall intensity [mm/h]; and
V = speed [km/h].

F. I. Kabbach Junior, C. Y. Suzuki, L. C. Trentin.(2011), Case-Studies of Influence in Rainfall Intensity on Safety Conditions, 12th International Conference on Urban Drainage, Porto Alegre/Brazil.

Variable Speed Lim it (VSL)

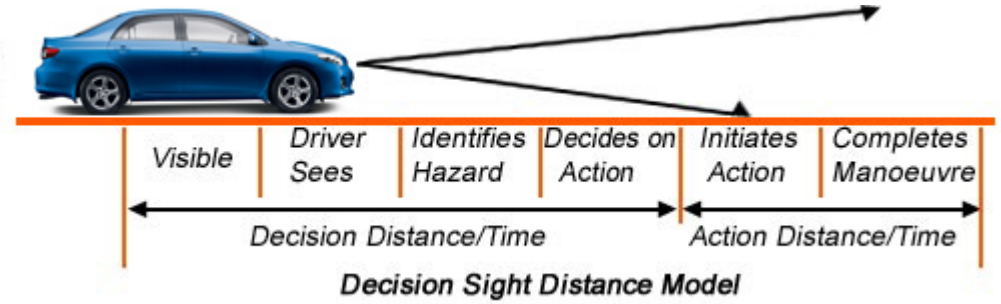
Speed (V) is set to **free flow speed** at each road link.
Real time driving speed can be applied **using OPEN API**.

WISE

✓Stopping Sight Distance

Distance traveled during the two phases of stopping a vehicle: perception-reaction time (PRT), and maneuver time (MT).

- Perception-reaction time
- Driver eye height
- Object height
- Vehicle operating speed
- Pavement coefficient of friction
- Deceleration rates
- Roadway grade



Decision Sight Distance Model

$$d = d_1 + d_2 = V/3.6\ t + V^2/254f = 0.694V + V^2/254f,$$

D: Stopping Sight Distance (m)

d_1: Reaction time Distance (m)

d_2: Braking Distance (m)

V: Speed (km/hr)

t: Reaction Time (2.5 sec)

f: Frictional coefficient (wet)

✓ Visibility Distance

To determine the distance of visibility during rain, the main method is exposed, w here the empirical equation shows that the visibility distance is calculated in term s of speed and storm.

$$S_V = \frac{354030,6}{I^{0,68} \cdot V}$$

where, S_V = visibility sight [m];
I = rainfall intensity [mm/h]; and
V = speed [km/h].

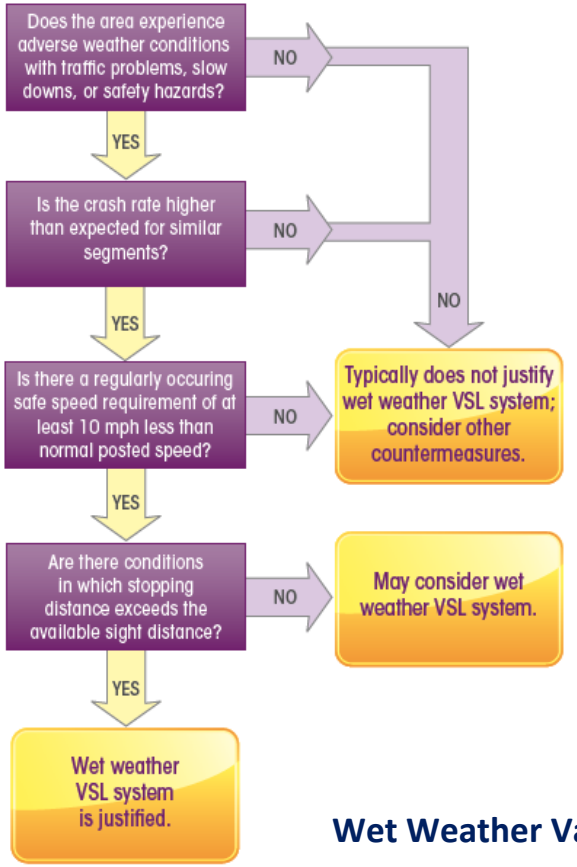
F. I. Kabbach Junior, C. Y. Suzuki, L. C. Trentin.(2011), Case-Studies of Influence in Rainfall Intensity on Safety Conditions, 12th International Conference on Urban Drainage, Porto Alegre/Brazil.

- When the visible distance is reduced to under 100m because of torrential rain, heavy snow or fog, 50% of the maximum speed is applied

✓ Variable Speed Limit

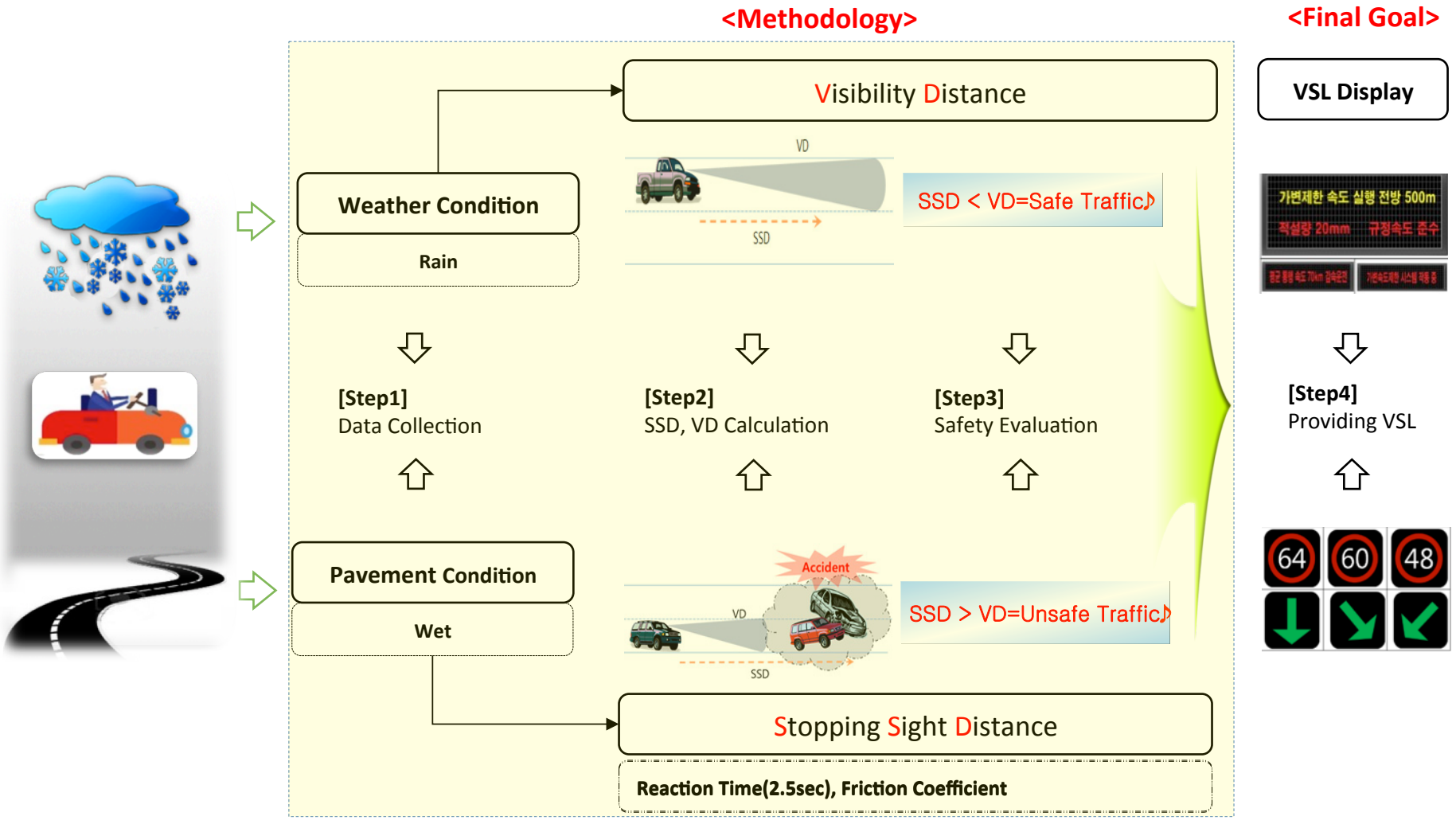
Variable speed limits are speed limits that change based on **road, traffic, and weather conditions**.

Variable speed limits offer considerable promise in **restoring the credibility of speed limts** and **improving s afety by restricting speeds** during advserse conditions. (US. Federal Highway Administration).



Wet Weather Variable Speed Limit Flowchart

✓ Definition of Research



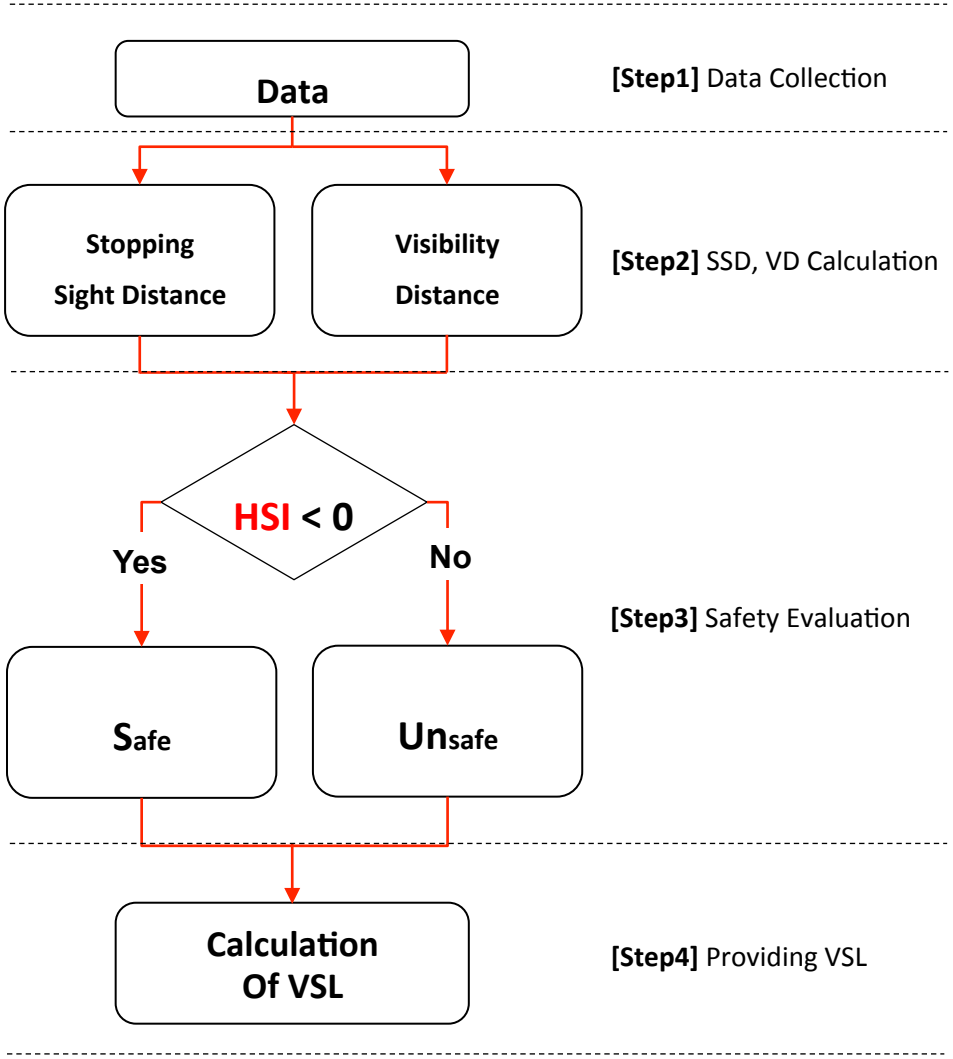
✓ Flowchart of Algorithm

HSI = SSD-VD

Traffic Condition(X_1)=
- *Safe, HSI < 0*
- *Unsafe, HSI > 0*

Where,

HSI: Hazardous Spacing Index
SSD: Stopping Sight Distance(m)
VD: Visibility Distance(m)



✓ Analysis

- Visibility Distance

  - Analysis Conditions

    : Road (Tangent), Weather (Rainfall)

  - Formula

$$S_V = \frac{354030,6}{I^{0,68} \cdot V}$$

where, S_V = visibility sight [m];
I = rainfall intensity [mm/h]; and
V = speed [km/h].

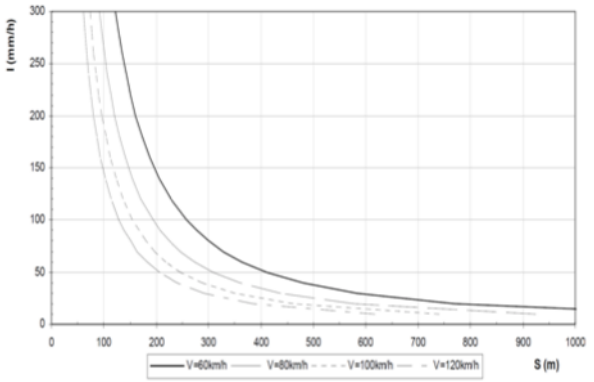
Reference:

- F. I. Kabbach Junior(2011), Case-Studies of Influence in Rainfall Intensity on Safety Conditions, 12th International Conference on Urban Drainage

- Result

[unit: m]

Speed (km/h)	Rainfall intensity (mm/h)							
	5	10	15	20	25	30	35	40
120♪	988	616	468	385	331	292	263	240
110♪	1,077	672	510	420	361	319	287	262
100♪	1,185	740	561	462	397	350	316	288
90♪	1,317	822	624	513	441	389	351	320
80♪	1,481	925	702	577	496	438	394	360
70♪	1,693	1,057	802	660	567	501	451	412
60♪	1,975	1,233	936	769	661	584	526	480



- Stopping Sight Distance

  - Analysis Conditions

    : Road (Tangent), Pavement (Wet)

  - Formula [AASHTO(2010)]

$$D = d_1 + d_2 = \frac{V}{3.6}t + \frac{V^2}{254f} = 0.694V + \frac{V^2}{254f}$$

D: Stopping Sight Distance (m)

d_1: Reaction time Distance (m)

d_2: Braking Distance (m)

V: Speed (km/hr)

t: Reaction Time (2.5 sec)

f: Frictional coefficient (wet)

  - Result

[unit: m]

Speed (km/h)	Frictional Coefficient (f)						
	0.2	0.25	0.3	0.35	0.4	0.45	0.5
120♪	367	310	272	245	225	209	197
110♪	315	267	235	212	195	182	172
100♪	266	227	201	182	168	157	148
90♪	222	190	169	154	142	133	126
80♪	182	156	140	128	119	112	106
70♪	145	126	113	104	97	91	87
60♪	113	98	89	82	77	73	70
50♪	84	74	68	63	59	57	54
40♪	59	53	49	46	44	42	40
30♪	39	35	33	31	30	29	28
20♪	22	20	19	18	18	17	17

- Example

*** SSD**

[단위: m]

Speed (km/h)	Frictional Coefficient (f)						
	0.2	0.25	0.3	0.35	0.4	0.45	0.5
120♪	367	310	272	245	225	209	197
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100♪	266	227	201	182	168	157	148
90♪	222	190	169	154	142	133	126
80♪	182	156	140	128	119	112	106
70♪	145	126	113	104	97	91	87
60♪	113	98	89	82	77	73	70
50♪	84	74	68	63	59	57	54
40♪	59	53	49	46	44	42	40
30♪	39	35	33	31	30	29	28
20♪	22	20	19	18	18	17	17

*** VD when rainfall 30(mm/h)**

[단위: m]

Speed (km/h)	VD
120♪	292
110♪	319
100♪	350
90♪	389
80♪	438
70♪	501
60♪	584
50♪	701
40♪	876
30♪	1,168
20♪	1,752

** Calculation*

HSI= SSD-VD

Traffic Condition(X1)=
- Safe, HSI < 0
- Unsafe, HSI > 0

where,
HSI: Hazardous Spacing Index
SSD: Stopping Sight Distance(m)
VD: Visibility Distance(m)

*** Matching work**

[단위: m]

Speed (km/h)	Frictional Coefficient (f)						
	0.2	0.25	0.3	0.35	0.4	0.45	0.5
120♪	367	310	272	245	225	209	197
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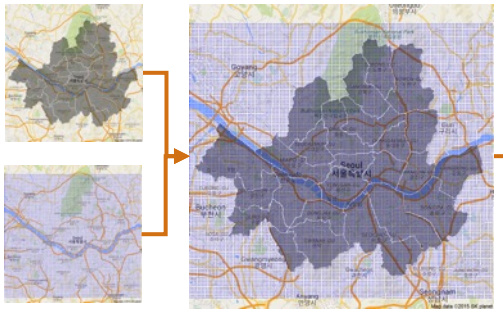
70♪	145	126	113	104	97	91	87
60♪	113	98	89	82	77	73	70
50♪	84	74	68	63	59	57	54
40♪	59	53	49	46	44	42	40
30♪	39	35	33	31	30	29	28
20♪	22	20	19	18	18	17	17

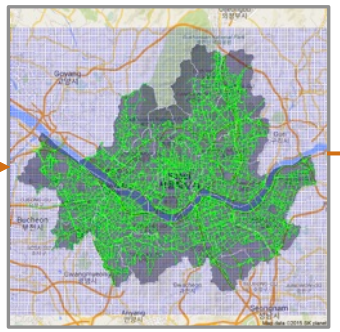
4. Application of Road and Weather Information

-S-I-R-W-E-C-

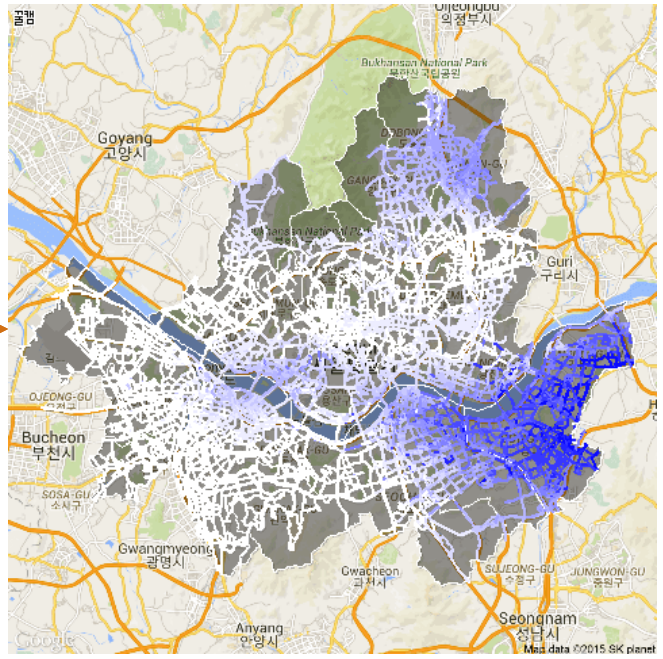
Map (Seoul, 250m resolution)



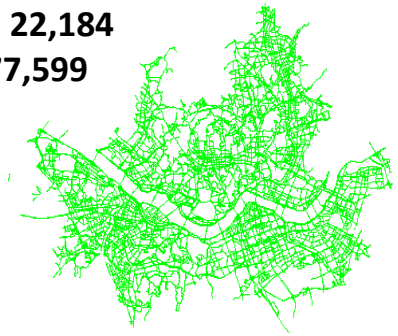
Road Information

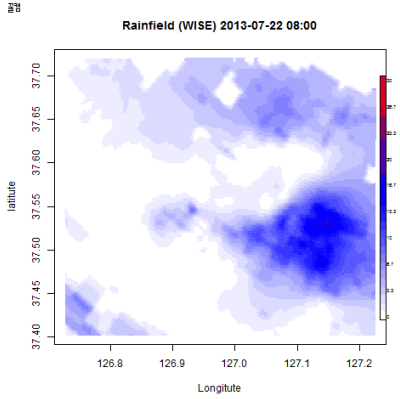


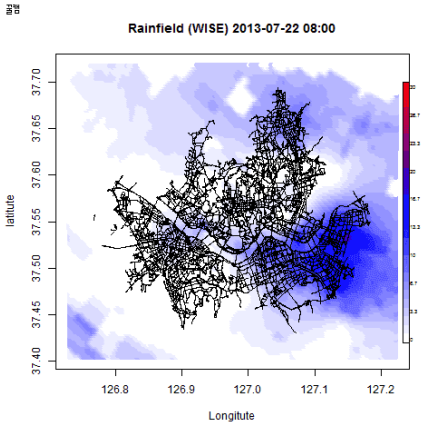
Road Weather Monitoring System



Node Link (Seoul)
Number : 22,184
Point : 177,599







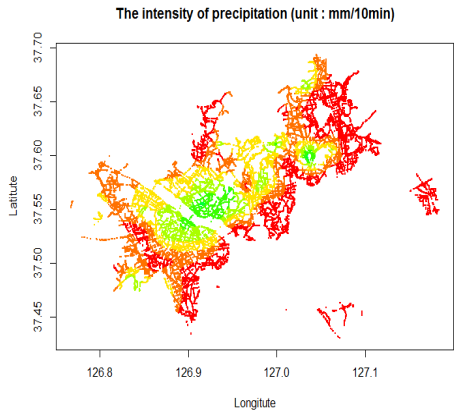
Weather Information

Information of Rain in Real Time (250m resolution)

WISE

✓ Process of Verification

Generation of the map of road weather
By using Auto Weather Station



Observed Sites (190)

Model fitting (157)

Inverse Distance Weight Method

Interpolation technique

Predict Validation Sites

Model Validation (33)

Prediction Performance

RMSE

Criteria for road weather prediction

✓ Inverse Distance Weight method (IDW)

- Inverse distance-based weight interpolation computes a **weighted average**,

$$Z(S_0) = \sum_{i=1}^{n} w(s_i) Z(s_i) / \sum_{i=1}^{n} w(s_i)$$

where $Z(S_0)$ is a value of a prediction location (s_0) and $Z(s_i)$ is a value of observational location (s_i).

The weights $w(s_i)$ for observations are computed according to their distance to the interpolation location, where are consisted by **Euclidean distance** and a

The predicted values never **outside the range of observed values.**

$$w(s_i) = \| s_i - s_o \|^{-p}$$

✓ Model validation criteria

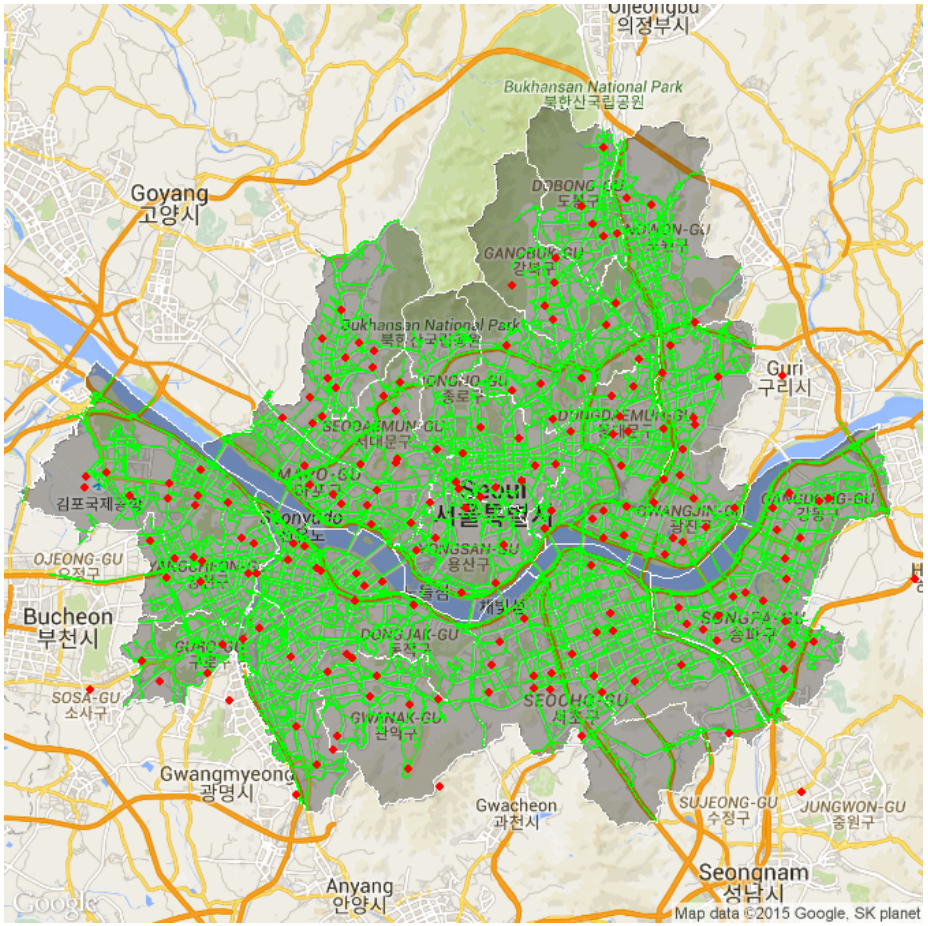
- Two measures are used for evaluating the prediction performance.

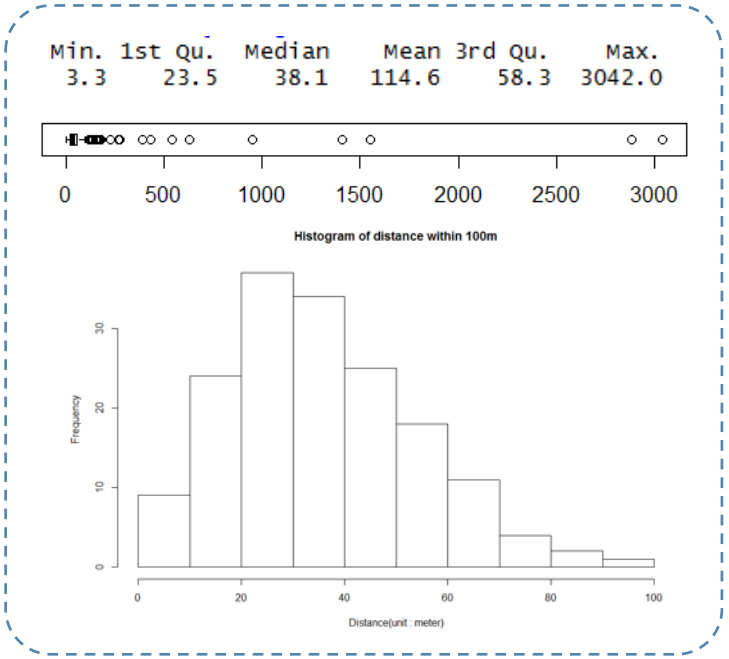
$$\mathrm{RMSE}=\sqrt{1/N_p \sum_{i=1}^{N_p} (y_i - y_i)^2}$$

where y_i is the observed values, y_i is the predicted value.

- Basic statistics for verification

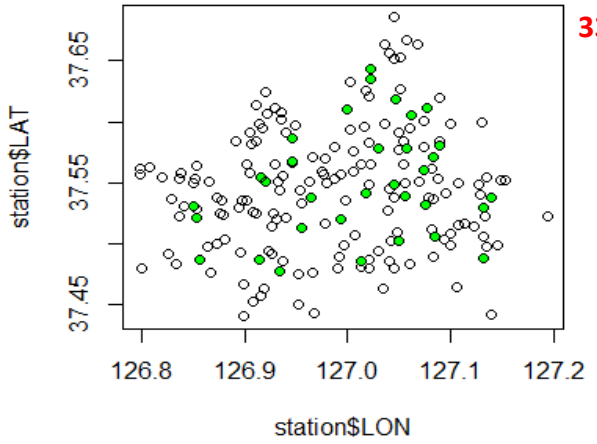
Site Information of Weather Observation and Road Position in Seoul





33 weather observations within 20m away from roads (17.3%)

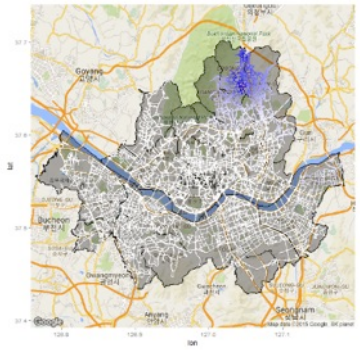
Others are 157 observations 20m away from roads (82.7%)



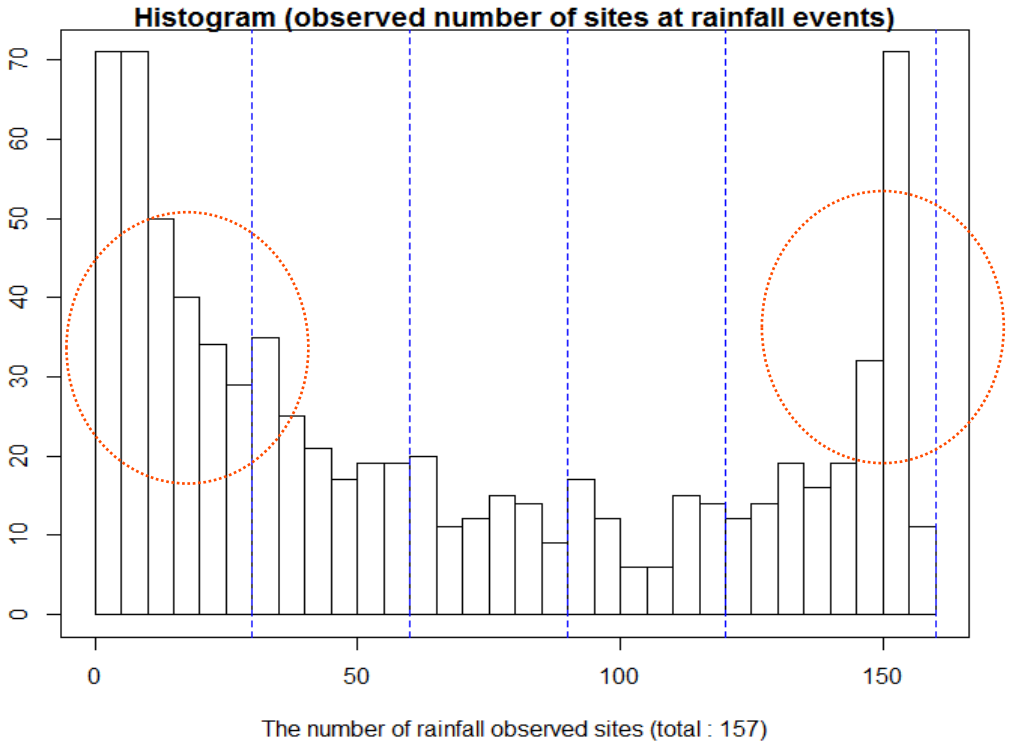
33/190

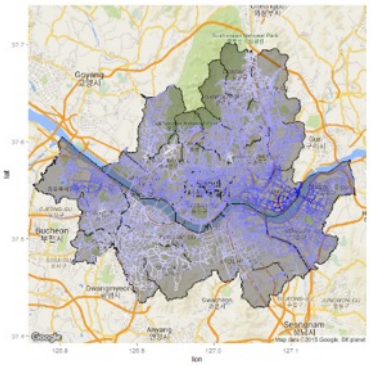
✓ Result

- Rainfall events would be affected by the ratio of rainfall observed sites.
  - Sites : 190 (SKP+KMA)
  - Time : 2013 (8 days/ 10min)
    8*24*6=1,152
  - No rain : 403 (34.98%)
  - Rain : 749(65.02%)



Locality rainfall events





Globality rainfall events

- Model validation results (RMSE)

Local

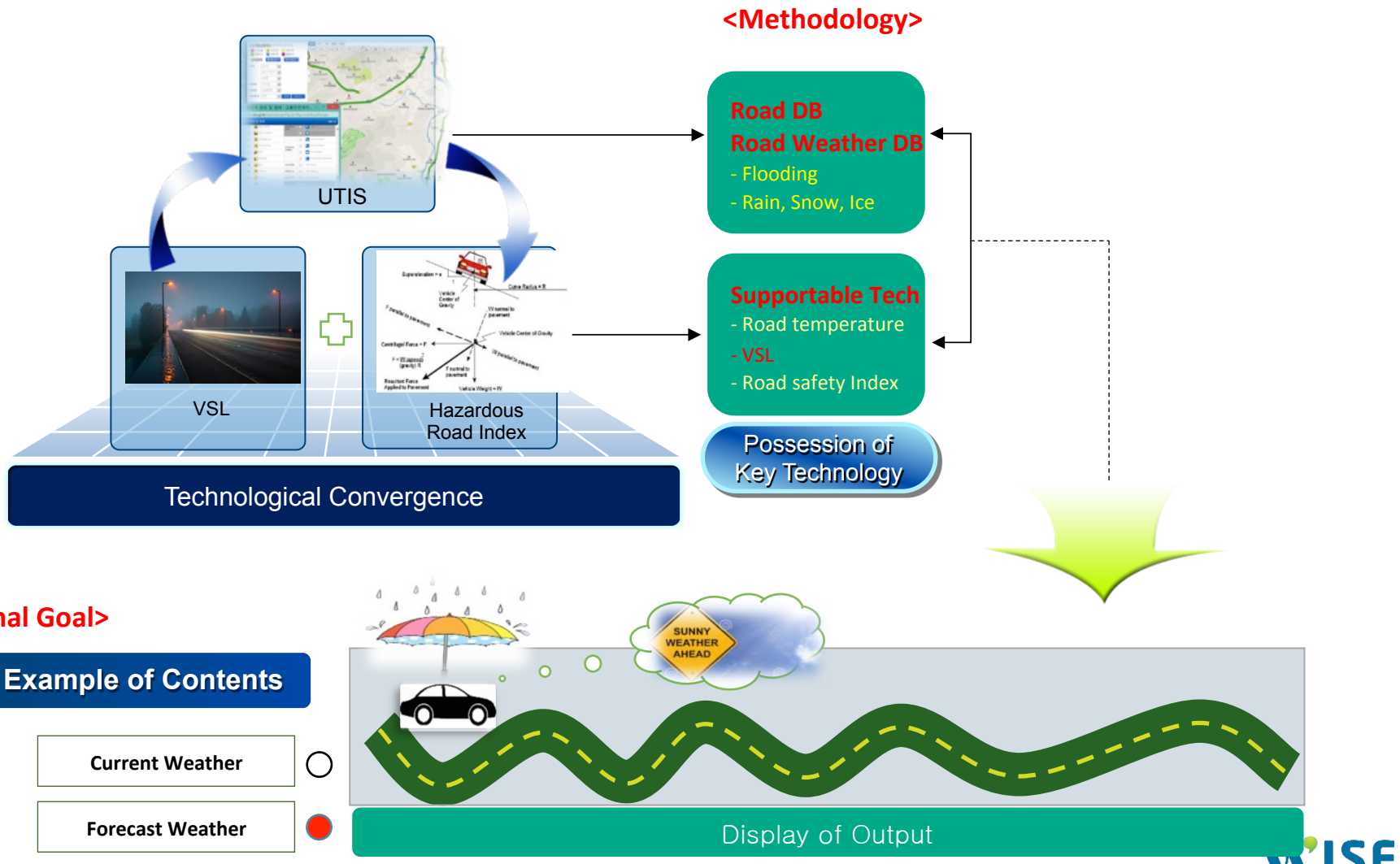
Global

Observed sites (model fitting)		RMSE IDW
1~30	mean	**0.041**
19.1%	sd	**(0.064)**
31~60	mean	**0.155**
38.2%	sd	(0.176)
61~90	mean	0.307
57.3%	sd	(0.465)
91~120	mean	0.343
76.4%	sd	(0.503)
121~157	mean	0.848
100.0%	sd	(0.675)
total	mean	0.318
	sd	(0.519)

WISE

5. Technology Application with UTIS

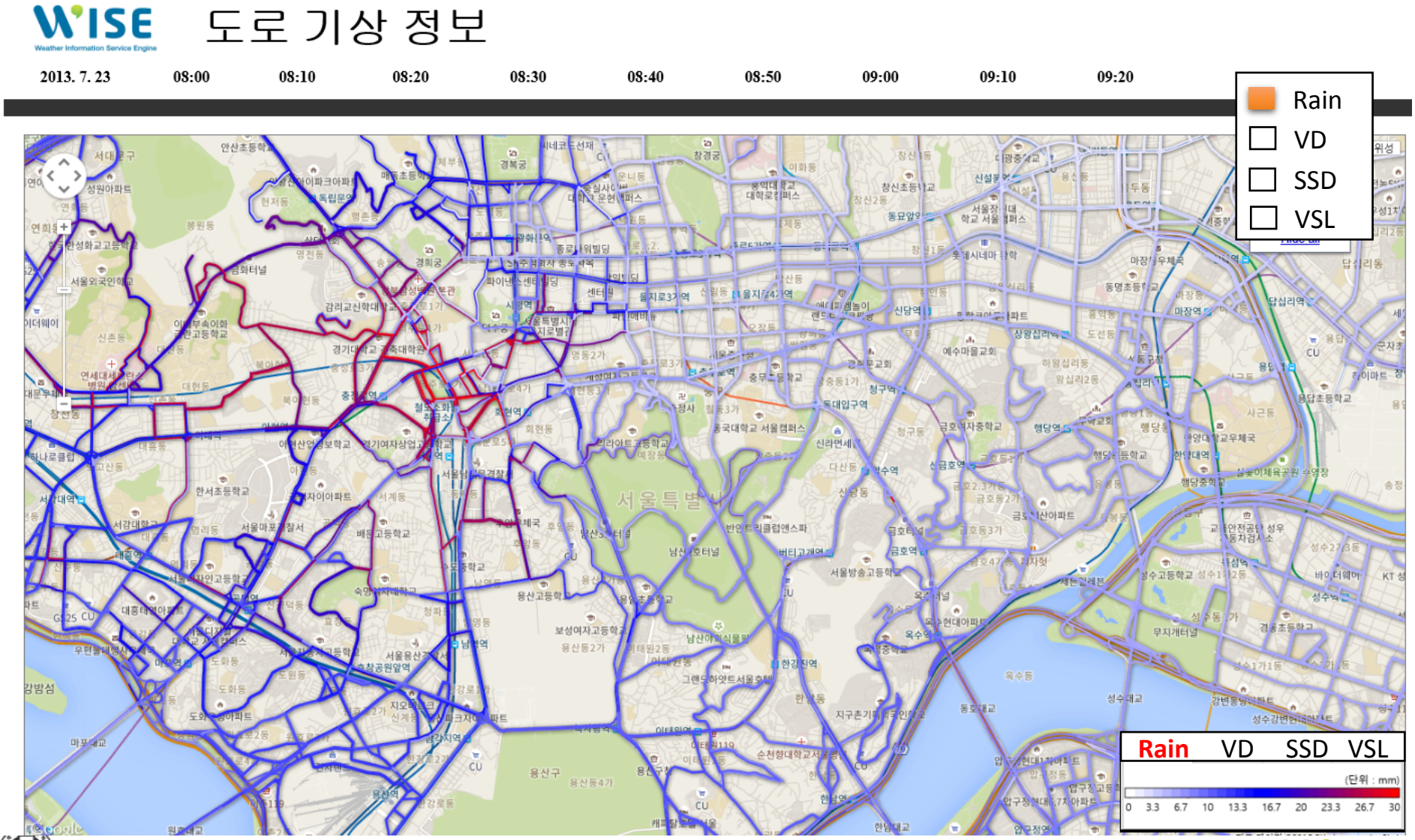
- UTIS (Urban Transit Information System) operated by Korean Police Agency
  - This system Provides all road information such as traffic, unexpected accidents and road weather.



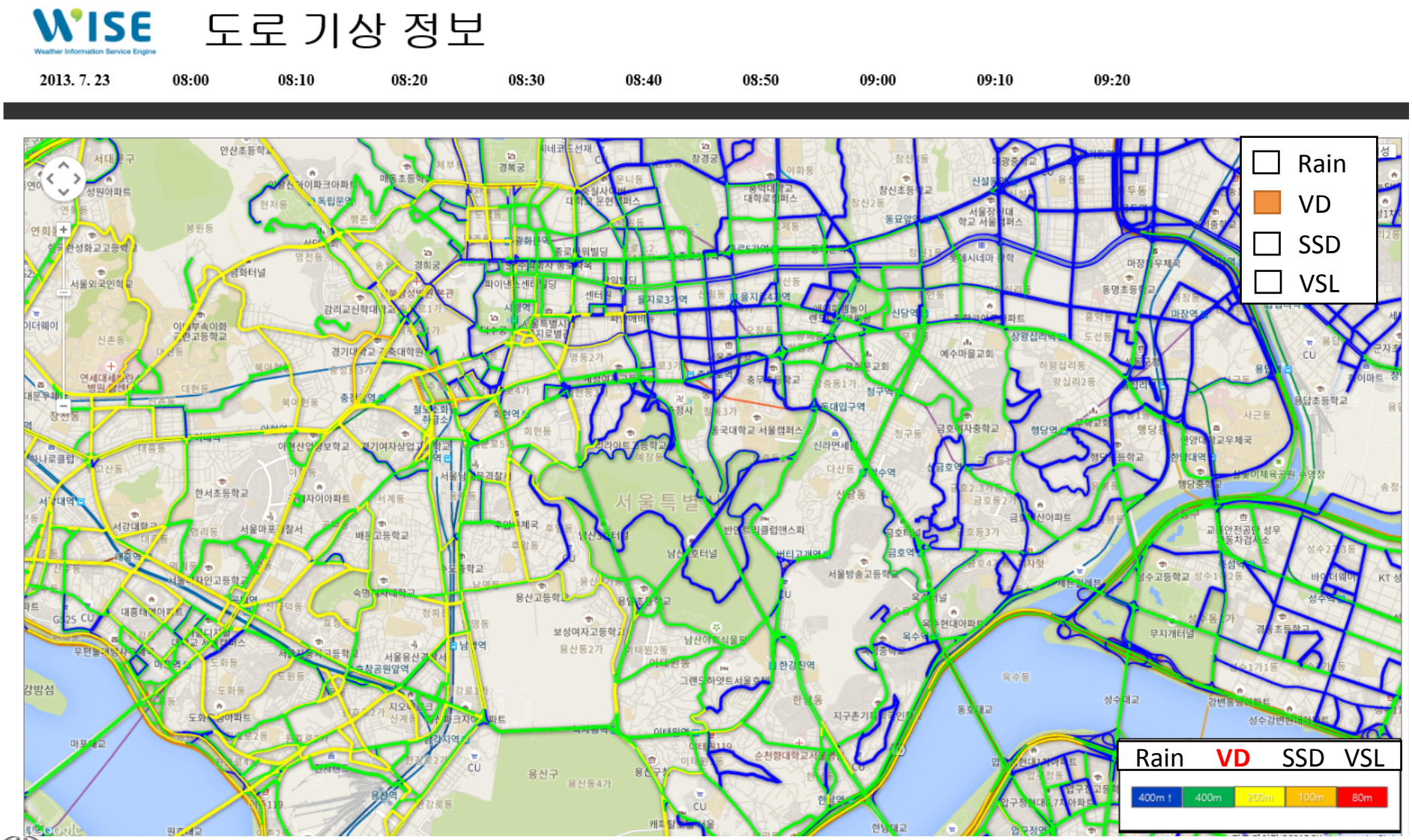
✓ Development of VSL System

- Example of tested-operation system

- Example of rain information



- Example of visibility distance information



✓ End Users

Example of End-user product

Please Drive Slowly

6. Summary

- Assessment of road weather based on the distance.
  - Validation sites : 33 (within 20 meter from road)
  - Fitting sites : 157
  - Inverse distance weighting (IDW) was considered.
- **IDW** is the best model at **locality rainfall events** in the sense of RMSE.
- However, it is not at **globality rainfall events**.
  - VSL was calculated from rainfall intensity by considering stopping sight distance, and visibility distance.

✓ Further Study

- Process of Research

Calculation Process for Pavement Friction (f)

Rainfall Intensity (mm/h)

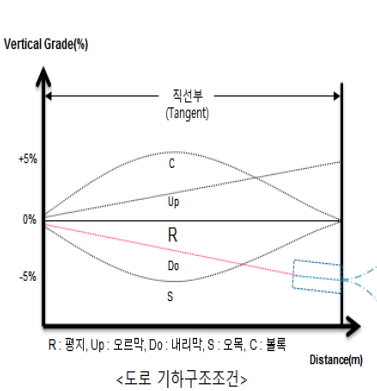
Road Alignment Type

R Up Do S C

Grade (%)

Pavement Type

Output
Pavement Friction Coefficient (f)



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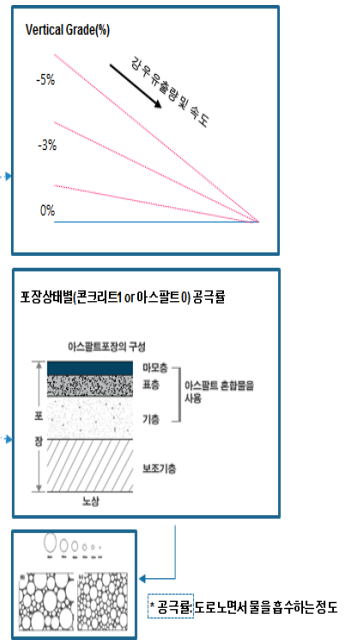

Thanks for Your attention