LAB University of Applied Sciences

Using thermal mapping by Vaisala to benefit winter maintenance actions in Espoo

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Abstract

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Title of the thesis

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Abstract

In winter 2019-2020 City of Espoo decided to improve winter maintenance treatment actions of the road network and cooperated with Finnish Company Vaisala. RoadDSS application which shows minimum road surface temperatures along the whole road network should help the City of Espoo to optimize snow plowing and de-icing of roads in the future. The thesis work studied the thermal mapping work principle, its algorithm of road surface temperatures calculation, and road weather stations' equipment installed by Vaisala.

The goal of the study was to define a correlation between the "cold-spots", the road parts that freeze first and need more treatment in winter, pinned by the measurements done in Vaisala's Thermal Mapping, the "cold-spots" reported by the drivers of snow-plowing machines and statistics of car crashes in wintertime for the period 2015-2019 gained from Destia.

ArcGIS Pro, Esri's product, was used as a tool for analysis and visualization. The final map was created for a visual representation of the correlation between these 3 datasets, which allowed to figure out the benefits of Thermal Mapping, issues that must be considered in the future, and prepare some recommendations for winter maintenance improvement in Espoo. They include an obligatory interview with street masters and drivers to add their findings over all 10 maintenance areas to the final map and the installation of extra sensors to monitor the road surface state near the shoreline and the coldest intersection of the road network.

Further usage of the thermal map for route optimization and creation of a web app showing real-time vehicle location data and progress of snow plowing and de-icing in each maintenance area of Espoo is offered as a recommendation for efficient winter maintenance treatment actions.

Keywords

Winter maintenance, ArcGIS, thermal mapping, road surface, route optimization, car crashes

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1 Introduction

Espoo is a developing network city of five city centres and local centres that will exceed the limit of 300,000 inhabitants in 2022 (City of Espoo 2021). Population and traffic growth causes the necessity to build new residential areas, modify existing infrastructure and optimize public transport routes. Sustainable urban development is controlled by the City of Espoo.

The City of Espoo, specifically the Technical and Environment Services unit is divided into the following departments: Sector Management, City Planning, Building Control, Public Works, Environment Department and Public Utility.

The Public Works Department secures and organizes the development and maintenance of Espoo's urban structure. This unit is responsible for the planning, construction and maintenance of public areas, surveying, mapping services and geotechnical services, as well as the statutory tasks of the authorities within the area of responsibility. The Public Works Department is subdivided into Investments unit, Infrastructure Services, City Surveying and Geotechnics, Administration (Figure 1.1).

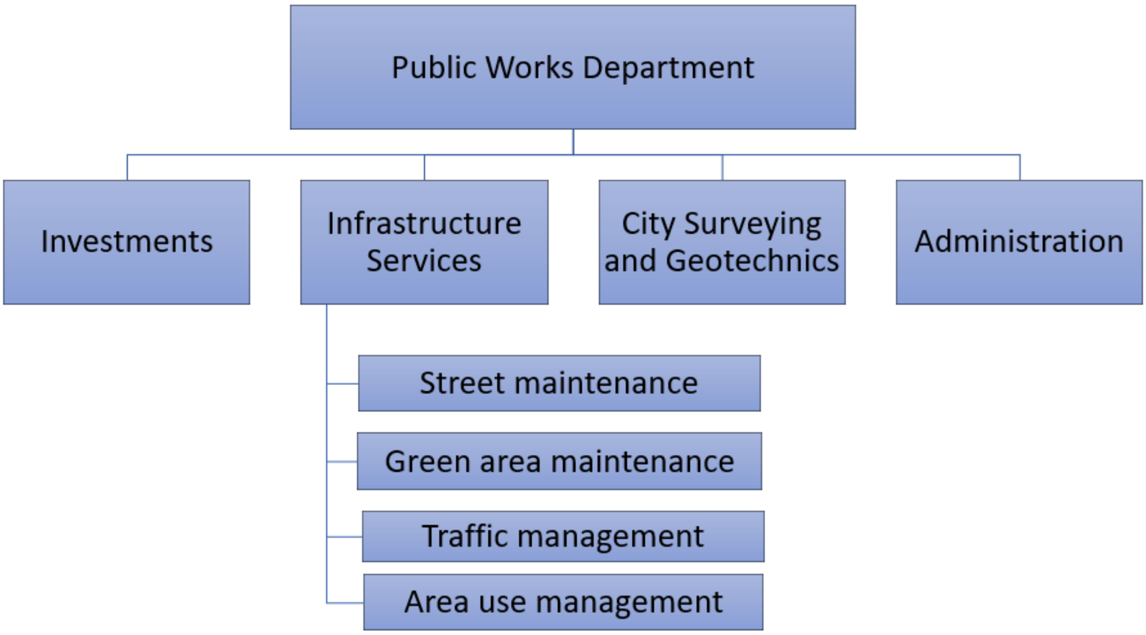


Figure 1.1 City of Espoo. Organization structure 2021

The City of Espoo maintains the street and road network except for motorways, ring roads and other public roads maintained by The Finnish Transport Agency and private roads maintained by road maintenance associations (City of Espoo 2021).

Nowadays the city's road network consists of 1800 km of streets and 600 km of pedestrian ways.

Espoo is divided into 10 maintenance areas: Leppävaara, Kilo, Tapiola, Matinkylä, Olari, Nöykkiö-Kaitaa, Saunalahti, Vanha-Espoo, Espoonlahti and Pohjois-Espoo are maintained by contractors. Northern, western, southern and eastern areas have own road master and foreman.

Street maintenance includes snow plowing, preventing slipperiness, maintaining traffic signs, cleaning street areas, repairing road surfaces, managing drains and culverts as well as levelling the road surface of gravel roads and dust binding (City of Espoo 2021).

My survey is focused on especially winter maintenance. Before this work, the map showing the grades of satisfaction marked by citizens over postal districts was made to analyze the situation with winter maintenance in Espoo. The results of the survey are quite good (Appendix 3).

Year by year the world technology market offers an enormous amount of applications. Some of these innovative technologies can help city governments to control and optimize public works. The City of Espoo has already using Paikannin.com to check the location of public vehicles, speed, time of breaks, RoadAI which is based on machine vision and detects road surface damages.

At the end of 2019, the City of Espoo decided to improve winter maintenance treatment actions of the road network and cooperated with Vaisala to do it. RoadDSS application offered by Vaisala should have helped the City of Espoo to optimize snow plowing and de-icing of roads during next winter. This app represents a thermal map that shows road surface temperatures along the road network. For the operation of this program, two extra road weather stations besides five state weather stations were purchased and installed in Espoo. All details about the RoadDDS app and weather stations' equipment represents in chapter 2.3 and 2.4.

The goal of thesis work is to define a correlation between the "cold-spots" (problem parts of road) pinned by the measurements done in Vaisala's Thermal Mapping, the "cold-spots" reported by the drivers and statistics of car crashes in wintertime for the period 2015-2019. And figuring out the efficiency and benefits of using Thermal Mapping for winter maintenance in Espoo.

To study the topic were used the following methods: data analysis and interviews. In this work, ArcGIS Pro is used as a tool for analysis.

2 Thermal Mapping

During the last winter, the road network of Espoo was surveyed by Finnish Company Vaisala. Vaisala is a global leader in weather, environmental, and industrial measurements headquartered in Vantaa (Vaisala 2021). The aim of the survey was a creation of the Thermal Map, that shows road surface temperatures (RSTs).

Vaisala has been thermally mapping roads and runways for over 30 years, covering in excess of 500 000 km across the world (Western Europe, North America, Japan, Eastern Europe, Scandinavia, New Zealand etc.). Thermal Mapping is the process of identifying the pattern of temperature variation across roads under different weather conditions. Thermal mapping reveals the pattern and distribution of warm and cold sections. This crucially highlights potentially hazardous sections across a network. (Thermal Mapping E-learning 2021).

The results of the survey can be used to optimize treatment routes, find suitable weather station locations or, when combined with a forecast, provide effective decision support tools for winter decision-makers (Thermal Mapping Report 2020, 5).

2.1 Data collection

Thermal Mapping is a process by which the variations in minimum night-time RSTs are measured using a thermopile (an infrared temperature sensor). The sensor is mounted to the underside of a vehicle and connected to a data logger and GPS unit (Figure 2.1).

Figure 2.1. Surface Patrol Pavement Temperature Sensor Series DSP100 (Vaisala 2021)

The overall network to be mapped is first divided up into smaller sectors and then series of overlapping routes. This allows routes to be completed under the same weather conditions and reduces the chance of weather changing during the survey. (Thermal Mapping Report 2020, 35).

For the Espoo road network, the data were collected from December 2019 to February 2020. It was surveyed 321 km of the road network. The thermal mapping surveys were carried out under 7 nights with Extreme (clear sky throughout, no or light wind) and 3 nights with Damped (cloudy sky with higher wind speeds) weather conditions. (Thermal Mapping Report 2020, 3). Vaisala has developed an algorithm to generate an Intermediate Thermal Map based upon the results of the Extreme and Damped surveys (Thermal Mapping Report 2020, 35).

The Thermal Mapping data is now online in Vaisala's RoadDSS Software and can be used as a tool for making winter maintenance decisions.

2.2 Variation in Road Surface Temperature (RST)

RSTs vary across the road network due to variable (meteorological) and fixed (non-meteorological) factors.

Variable factors include traffic volume, different weather conditions such as air temperature, humidity, cloud, wind.

Fixed factors:

- Sky view factor. SVF is the proportion of the sky which is visible from the road surface. Maximum exposure SVF 1 means that all the sky is visible, whereas within a tunnel SVF will be 0. E.g. road surface temperatures are likely to be relatively warmer closer to the trees than in the centre of the road during night-time. (Rachel Adams 2018, 5). Another example of sky view factor impact you can see in Figure 2.2.

Figure 2.2. Sky view factor example from the Extreme Thermal Mapping, Espoo (Thermal Mapping Report 2020, 18)

Figure 2.2 shows a location where a bridge crosses over another road, in which event the road underneath is likely to display above average RSTs as the sky-view factor is lowered by the bridge above.

- Altitude. Upland and mountain RST will tend to be relatively colder than lowland RST (Rachel Adams 2018, 9).
- Water bodies. Water has the capacity to maintain heat for a longer period after sunset than land. RSTs tend to be warmer near the shoreline, lakes and rivers. (Thermal Mapping Report 2020, 33).
- Road surface. E.g. highways with a deeper construction retain heat longer or sections of the road are made of dense concrete can be warmer than other surfaces.
- Tunnels. SVF 0 inside tunnels means that heat from the road surface which has built up from traffic will not escape. Roads travelling through tunnels will be relatively warmer than approach roads. (Rachel Adams 2018, 9).
- Bridge decks. The distribution of RSTs of bridge deck and approaching roadway is shown in Figure 2.3.

Figure 2.3. Bridge deck example from the Extreme Thermal Mapping, Espoo (Thermal Mapping Report 2020, 17)

Any stored heat escapes from both above and below the structure, that's why the bridge deck is clearly colder than the warmer approaches as you can see in Figure 2.3, and ice will likely form on the bridge before the approaching roadway.

- Urban heat island. It is the phenomenon observed in towns and cities whereby the built-up area can be several degrees warmer than the suburbs or surrounding rural area (Thermal Mapping Report 2020, 33).

2.3 Road weather stations

After the survey results were got it became possible to find suitable weather station locations (Figure 2.4).

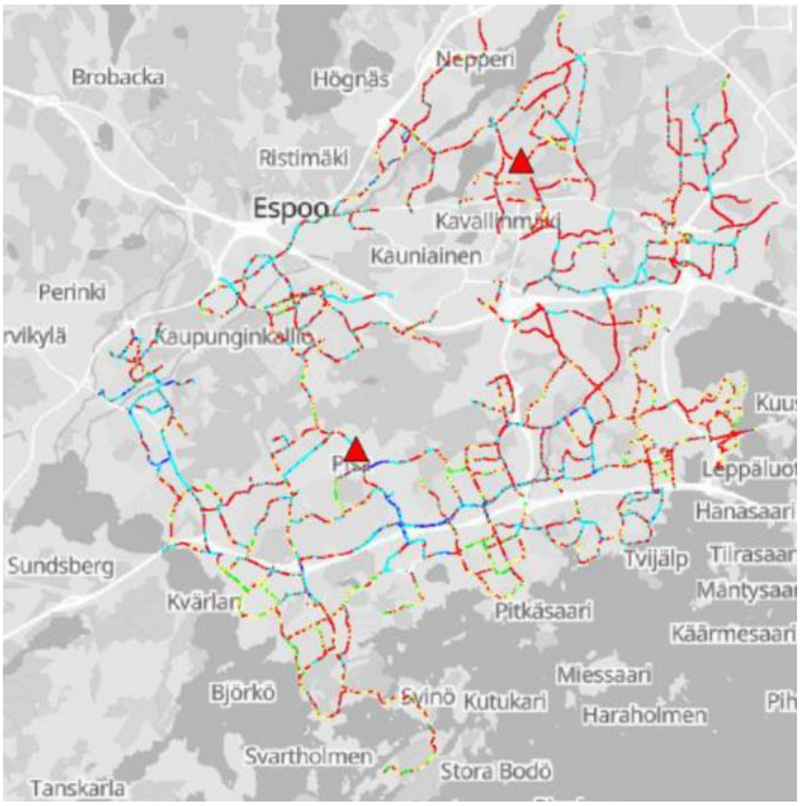


Figure 2.4. Weather stations on the Extreme Thermal Map (Thermal Mapping Report 2020, 21)

As shown in Figure 2.4 the two current weather stations at Puolarmetsä and Karakallio are both located within sections of average RSTs (red colour) under all three weather types (Extreme, Intermediate and Damped). Therefore, both were appropriate to be used as the forecasting site for the Thermal Map within RoadDSS. The Puolarmetsä station was selected as it is within a more stable section of temperature distribution on the Extreme Map. The Thermal Mapping results suggest that these are good locations as the forecasts produced should scale well to the whole network rather than being either optimistic or pessimistic, which could potentially lead to under or over treatment. (Thermal Mapping Report 2020, 20).

The main idea of Thermal Mapping that it measures how RST varies from one point to the next along a road network (Figure 2.5).

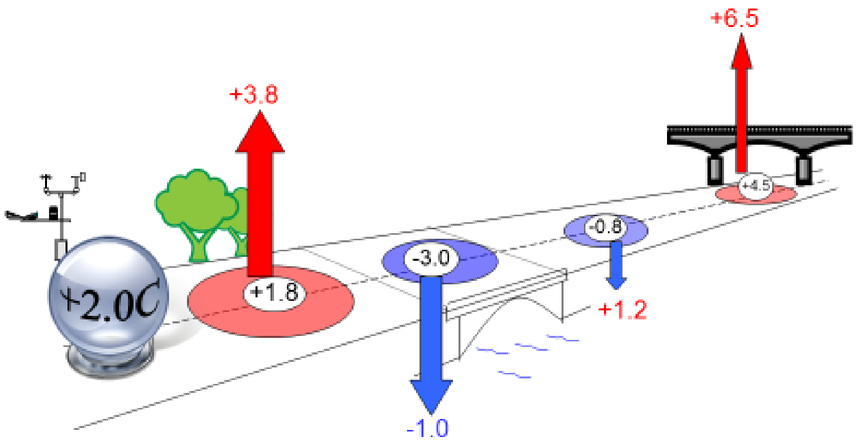


Figure 2.5. RST measuring principle (Rachel Adams 2018, 15)

As you can see in Figure 2.5 a quantifiable relative minimum RST relationship is built across a road network. By inputting a known parameter (RST at weather station location) to that relationship, it is possible to extrapolate value across the road network.

Weather stations' equipment

At the end of 2018, two Vaisala RWS200 weather stations were acquired and equipped as follows (set for one station):

- RWS200 Base Structure
- DRS511AB Embedded Road Sensor with 20m cable
- DRS511AB Embedded Road Sensor with 30m cable
- Interface for 2pcs DRS511 road sensors
- DTS12G Subsurface temperature sensor, 30m cable
- Interface for DTS12G subsurface temperature sensor
- Heated HMP155 Air T + RH sensor with purge
- DTR13 Radiation Shield for T/U Sensor
- M12 Connection Cable L%310m
- Interface for HMP155A/E Sensor with PWD
- PWD22 Heated visibility/present weather sensor
- Mast Cable 10 m PWD-Sensors
- Interface for PWD22 sensor
- WMT700 Transducer heated ultrasonic wind sensor
- Connection Cable 10 M WMT70
- Bracket Kit D-60 for Sensor Arm Fixing
- Interface for WMT700 sensor
- Sensor arm and mounting kit for 80-600mm pole mast (2 EA)

- 1x Camera with Optics
- 1x Mounting Frame Kit with 10M Cable
- Interface for 1pcs Mobotix Camera
- EU /EFTA Installation Country
- Cellular 4G router
- BOX652SET enclosure and radiation shield
- Enclosure mounting kit for 80-600mm pole mast (2 EA)
- Mains power with EU socket
- 26Ah backup battery

Pictures of sensors and other equipment represent in Figure 2.6.

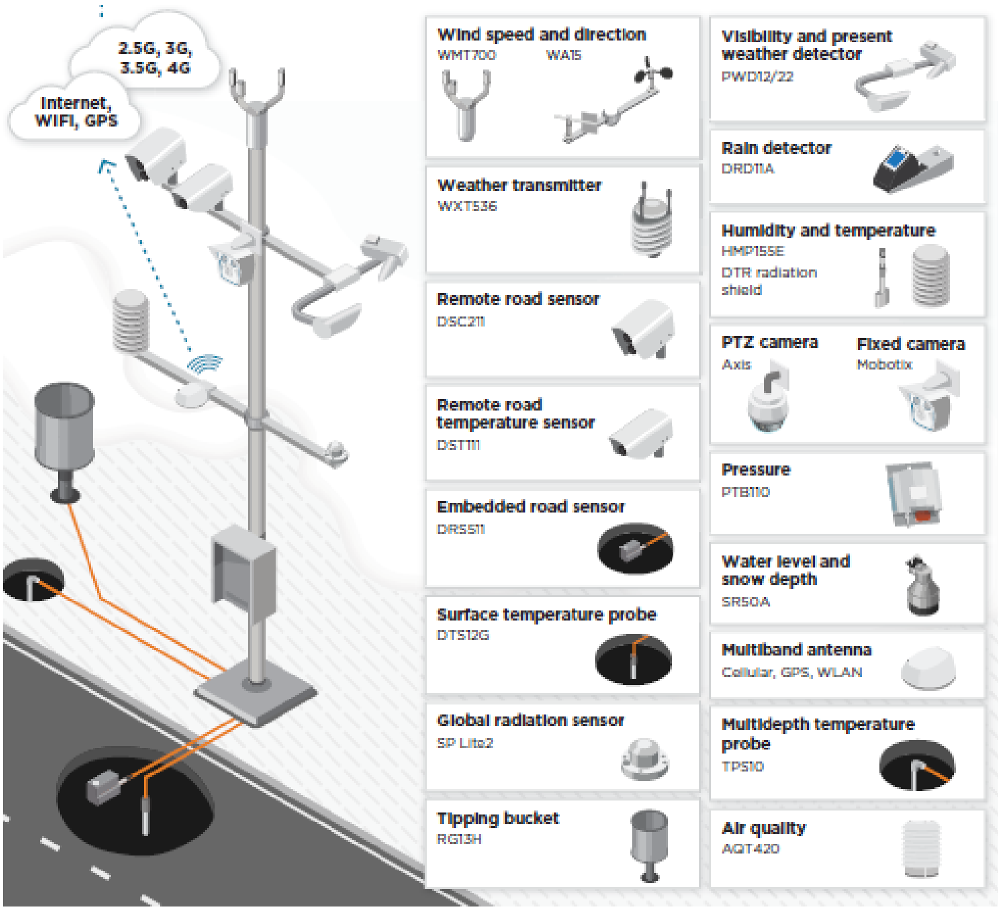


Figure 2.6. Road weather station's equipment (RWS200 Product Catalog 2019)

2.4 RoadDSS

The Vaisala RoadDSS Navigator is a hosted web user interface for viewing past, present and future road weather data. The application displays data collected by the Vaisala Global Data Management Center. The application consists of a set of dynamic web pages that can be viewed with a simple Internet connection. (Vaisala 2021).

Map tab presents surveyed road network of Espoo, specifically bus lines, and shows road surface temperatures in real-time. The time slider feature allows seeing on the map page all the observations and any forecasts that are available for 24 hours on either side of the actual time (Figure 2.7).

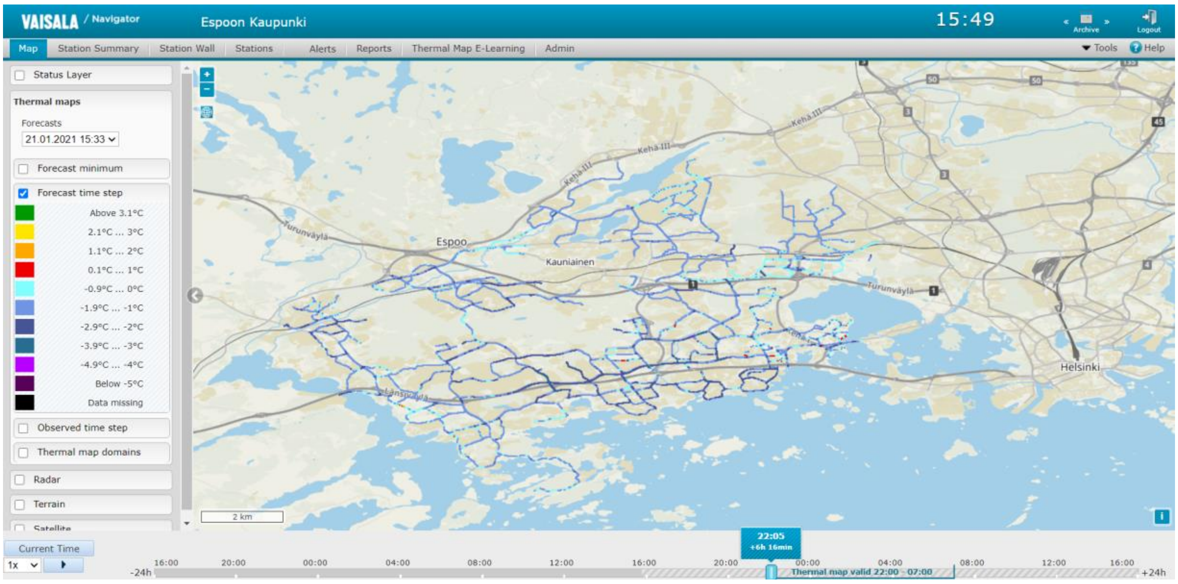


Figure 2.7. RSTs (RoadDSS Vaisala Navigator 2021)

Checking the “Status Layer” box causes weather stations appearance on the map. It’s possible to change values which pop-up windows near each weather station represent (Figure 2.8).

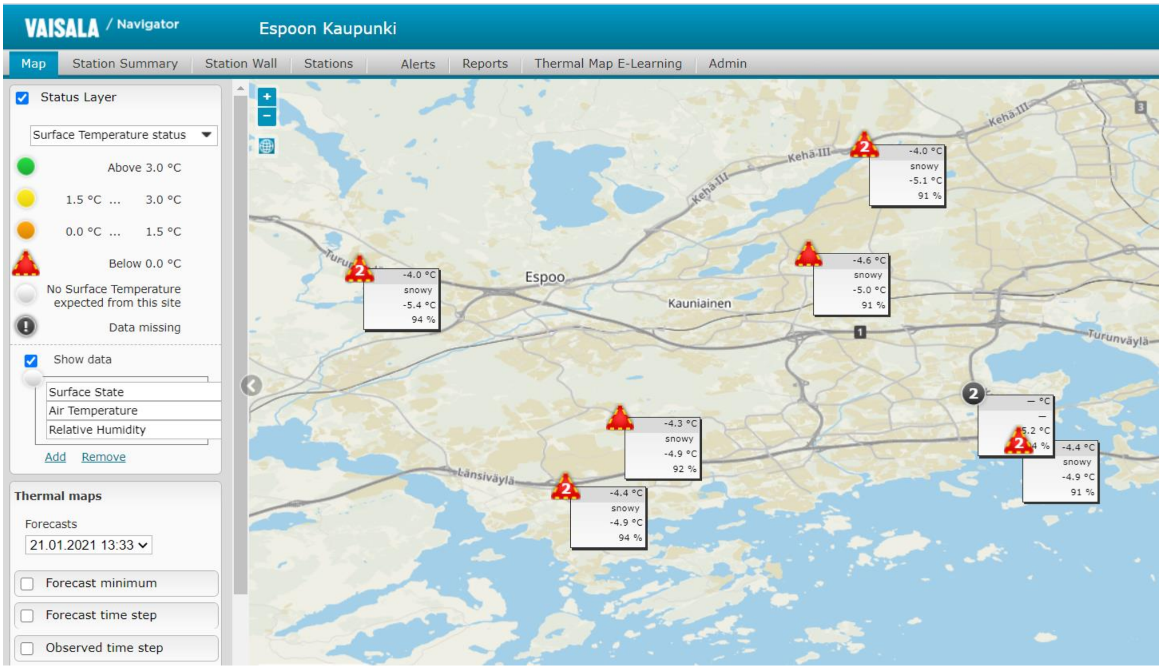


Figure 2.8. Weather stations location (RoadDSS Vaisala Navigator 2021)

On the station page, it's possible to choose any available weather station. Information on this station overview tab includes coordinates, altitude, nearest stations, picture of current conditions and related values of air and surface temperature, dew point, relative humidity, visibility and surface state (Figure 2.9). The camera history tab allows seeing previous 24h camera images.

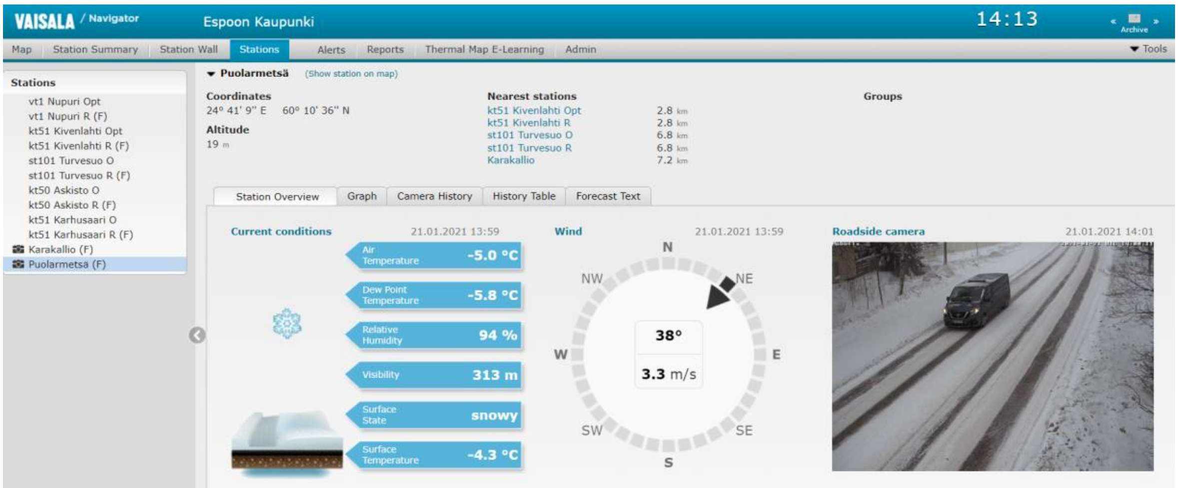


Figure 2.9. Weather stations info (RoadDSS Vaisala Navigator 2021)

For a more detailed overview use the graph tab. There is an option to choose several values and see their changes in time. Dotted lines show forecasting values of the chosen parameter. For, instance, in Figure 2.10 the graph represents changes in time of air and surface temperature. Below the graph road surface state and precipitation state at the weather station location are shown in past, present and future.

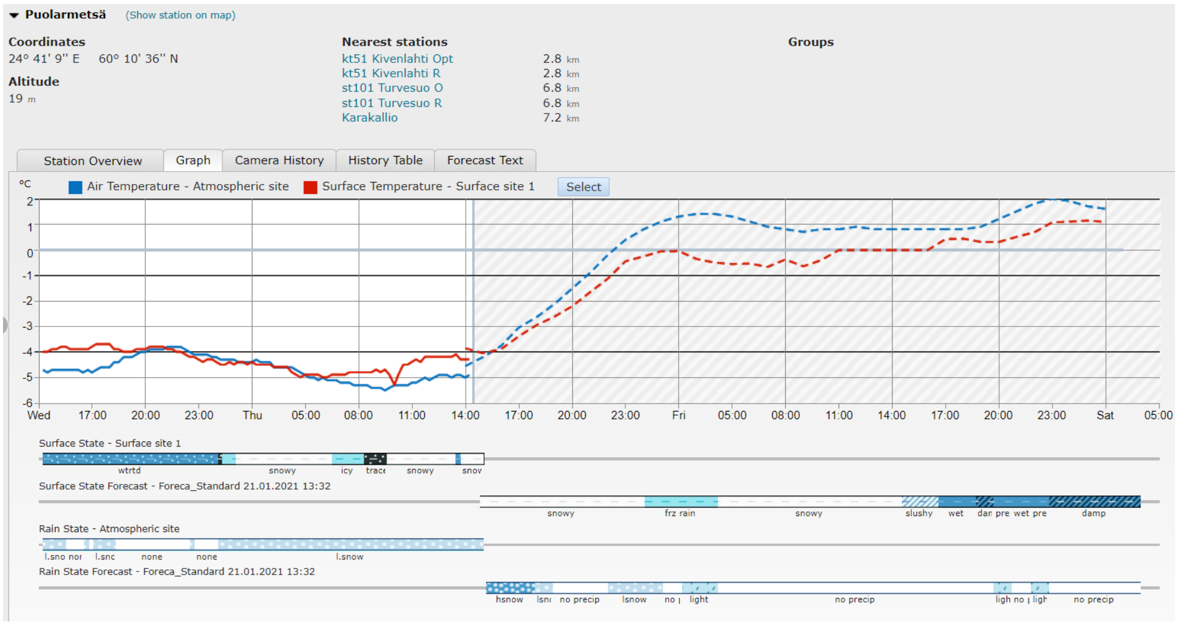


Figure 2.10. Weather stations detailed info (RoadDSS Vaisala Navigator 2021)

3 Car crashes

The data were provided by Natalia Lehtonen, Senior Consultant of Destia Oy. The dataset was uploaded into ArcGIS Pro for subsequent analysis.

Data contain all needed information about car crashes in Espoo for the period 2015 – 2019 (Chart 3.1). Here can be found car accidents for period October – April of each year, because in these months accidents might be caused by ice formation on the road surface, with that poor maintenance of road network (Chart 3.2).

Chart 3.1. Car crashes counts over years

Chart 3.1 shows us decreasing in car crashes by 2019 year, which is a good mark. Keep attention that values in this chart show car crash count for half of each year.

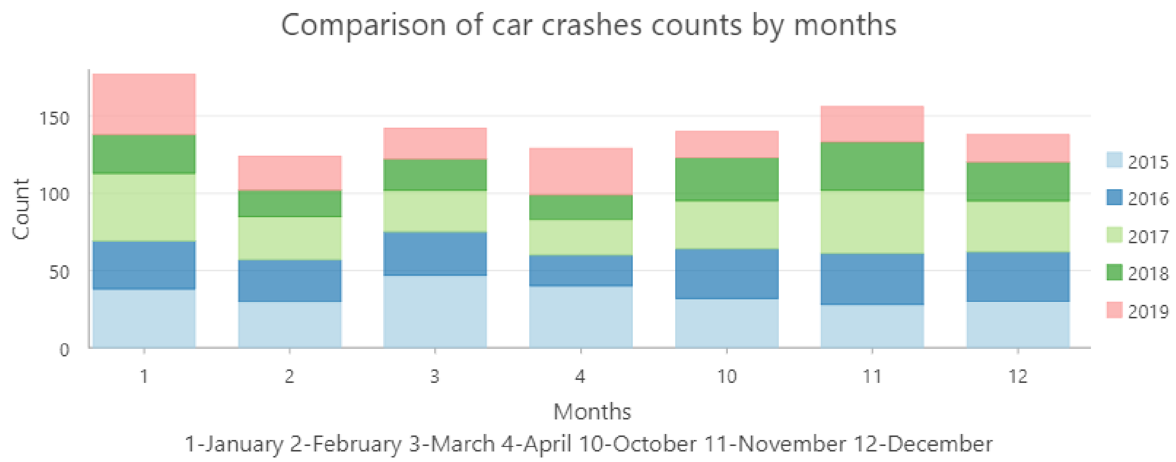
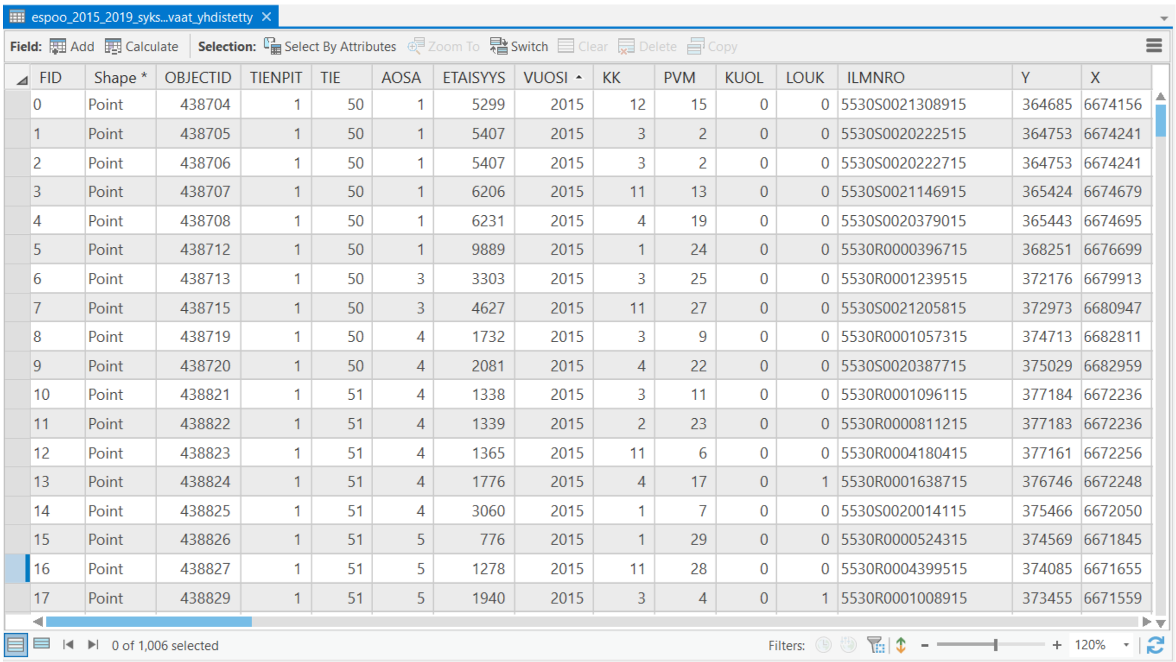


Chart 3.2. Car crash count by months

As you can see in Chart 3.2 most car crashes happen in January and November, less in February and April.

Totally there are 1006 accidents in this dataset (Figure 3.1).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FID	Shape *	OBJECTID	TIENPIT	TIE	AOSA	ETAISYYS	VUOSI	KK	PVM	KUOL	LOUK	ILMNRO	Y	X
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1	Point	438705	1	50	1	5407	2015	3	2	0	0	5530S0020222515	364753	6674241
2	Point	438706	1	50	1	5407	2015	3	2	0	0	5530S0020222715	364753	6674241
3	Point	438707	1	50	1	6206	2015	11	13	0	0	5530S0021146915	365424	6674679
4	Point	438708	1	50	1	6231	2015	4	19	0	0	5530S0020379015	365443	6674695
5	Point	438712	1	50	1	9889	2015	1	24	0	0	5530R0000396715	368251	6676699
6	Point	438713	1	50	3	3303	2015	3	25	0	0	5530R0001239515	372176	6679913
7	Point	438715	1	50	3	4627	2015	11	27	0	0	5530S0021205815	372973	6680947
8	Point	438719	1	50	4	1732	2015	3	9	0	0	5530R0001057315	374713	6682811
9	Point	438720	1	50	4	2081	2015	4	22	0	0	5530S0020387715	375029	6682959
10	Point	438821	1	51	4	1338	2015	3	11	0	0	5530R0001096115	377184	6672236
11	Point	438822	1	51	4	1339	2015	2	23	0	0	5530R0000811215	377183	6672236
12	Point	438823	1	51	4	1365	2015	11	6	0	0	5530R0004180415	377161	6672256
13	Point	438824	1	51	4	1776	2015	4	17	0	1	5530R0001638715	376746	6672248
14	Point	438825	1	51	4	3060	2015	1	7	0	0	5530S0020014115	375466	6672050
15	Point	438826	1	51	5	776	2015	1	29	0	0	5530R0000524315	374569	6671845
16	Point	438827	1	51	5	1278	2015	11	28	0	0	5530R0004399515	374085	6671655
17	Point	438829	1	51	5	1940	2015	3	4	0	1	5530R0001008915	373455	6671559

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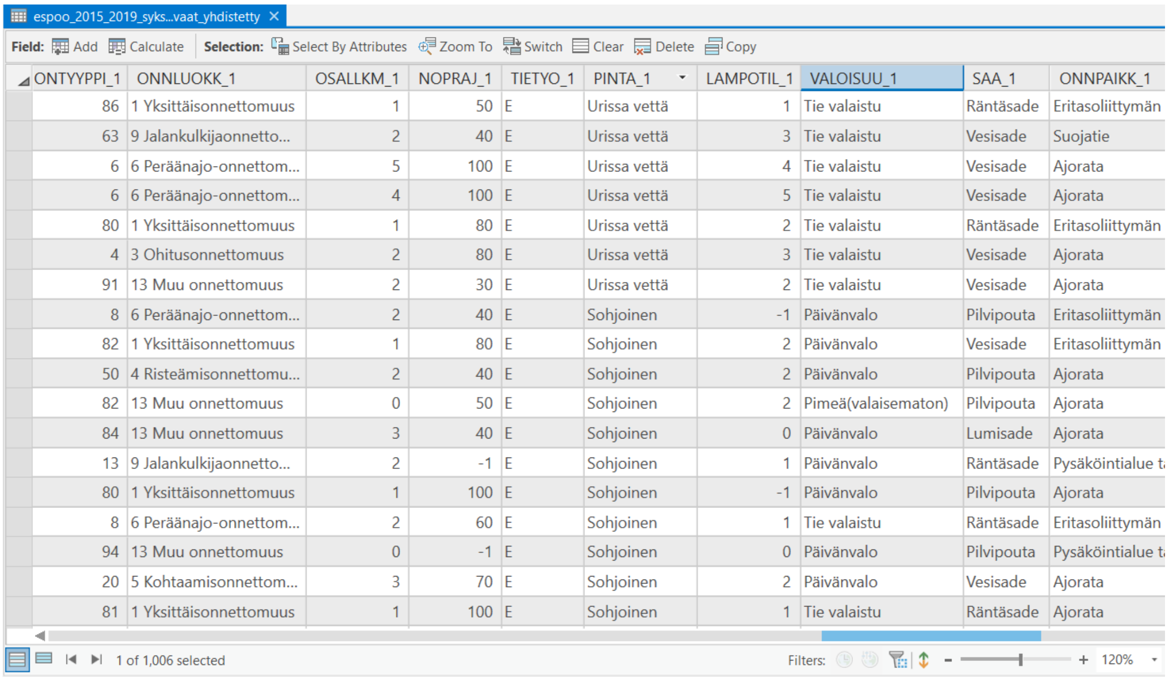

espoo_2015_2019_syks...vaat_yhdistetty

ONTYYPPI_1	ONNLUOKK_1	OSALLKM_1	NOPRAJ_1	TIETYO_1	PINTA_1	LAMPOTIL_1	VALOISUU_1	SAA_1	ONNPAIKK_1
86	1 Yksittäisonnettomuus	1	50	E	Urissa vettä	1	Tie valaistu	Räntäsade	Eritasoliittymän
63	9 Jalankulkijaonnetto...	2	40	E	Urissa vettä	3	Tie valaistu	Vesisade	Suojatie
6	6 Peräänajo-onnettom...	5	100	E	Urissa vettä	4	Tie valaistu	Vesisade	Ajorata
6	6 Peräänajo-onnettom...	4	100	E	Urissa vettä	5	Tie valaistu	Vesisade	Ajorata
80	1 Yksittäisonnettomuus	1	80	E	Urissa vettä	2	Tie valaistu	Räntäsade	Eritasoliittymän
4	3 Ohitusonnettomuus	2	80	E	Urissa vettä	3	Tie valaistu	Vesisade	Ajorata
91	13 Muu onnettomuus	2	30	E	Urissa vettä	2	Tie valaistu	Vesisade	Ajorata
8	6 Peräänajo-onnettom...	2	40	E	Sohjoinen	-1	Päivänvalo	Pilvipouta	Eritasoliittymän
82	1 Yksittäisonnettomuus	1	80	E	Sohjoinen	2	Päivänvalo	Vesisade	Eritasoliittymän
50	4 Risteämisonnettomu...	2	40	E	Sohjoinen	2	Päivänvalo	Pilvipouta	Ajorata
82	13 Muu onnettomuus	0	50	E	Sohjoinen	2	Pimeä(valaisematon)	Pilvipouta	Ajorata
84	13 Muu onnettomuus	3	40	E	Sohjoinen	0	Päivänvalo	Lumisade	Ajorata
13	9 Jalankulkijaonnetto...	2	-1	E	Sohjoinen	1	Päivänvalo	Räntäsade	Pysäköintialue t
80	1 Yksittäisonnettomuus	1	100	E	Sohjoinen	-1	Päivänvalo	Pilvipouta	Ajorata
8	6 Peräänajo-onnettom...	2	60	E	Sohjoinen	1	Tie valaistu	Räntäsade	Eritasoliittymän
94	13 Muu onnettomuus	0	-1	E	Sohjoinen	0	Päivänvalo	Pilvipouta	Pysäköintialue t
20	5 Kohtaamisonnettom...	3	70	E	Sohjoinen	2	Päivänvalo	Vesisade	Ajorata
81	1 Yksittäisonnettomuus	1	100	E	Sohjoinen	1	Tie valaistu	Räntäsade	Ajorata

1 of 1,006 selected

Figure 3.1. Attribute table of car crashes layer in ArcGIS

As you can see in Figure 3.1 the attribute table contains lots of information such as the day of a car accident, accurate location, the type of car crash, number of participants in the accident, casualties, the weather and road surface conditions etc.

To start analysis car accidents on the state roads, such as Turunväylä, Länsiväylä, Kehä I, Kehä II, Kehä III were excluded, these roads aren't maintained by the City of Espoo. New total amount is 740 accidents that should be analyzed (Figure 3.2).

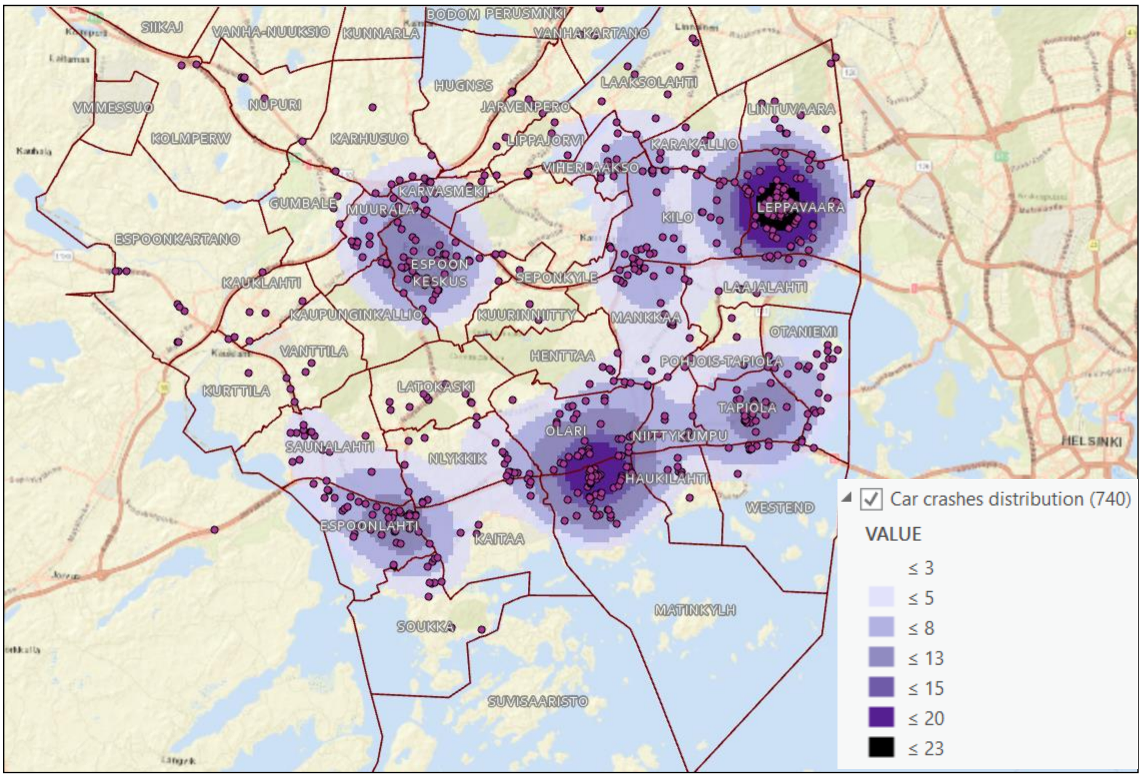


Figure 3.2. Kernel density. Car crashes layer (ArcGIS Pro)

Figure 3.2 shows car accidents distribution within Espoo. The darkest parts have the highest density. Generally, car crashes concentrate in 5 local centres of Espoo. Leppavaara (Sello) and Olari-Matinkylä intersection (Iso Omena) are areas with the highest car crashes density.

The values represent the kernel density value per unit area for each cell (100*100m). The equation that calculates the density values from the counts is Density = Count / Area. Area units – square kilometres.

For identifying a connection with inappropriate winter road maintenance, firstly, it's necessary to understand the origin of a car crash and the circumstances in which it happened. There is certain information about car crash type and category for each case in the dataset.

Each accident category is forming based on the number of participants, the type of participants and the type of car accident. Totally there are 13 car accident categories (Onnettomuusrekisterin koodit, 4):

1. Individual accident
2. Turning accident
3. Overtaking accident
4. Crossing accident

5. Collision accident
6. Rear-end accident
7. Motorcycle accident
8. Bicycle accident
9. Pedestrian accident
10. Moose accident
11. Deer accident
12. Other animal accident
13. Other accident.

To find out the most common car accident categories the Chart 3.3 was made.

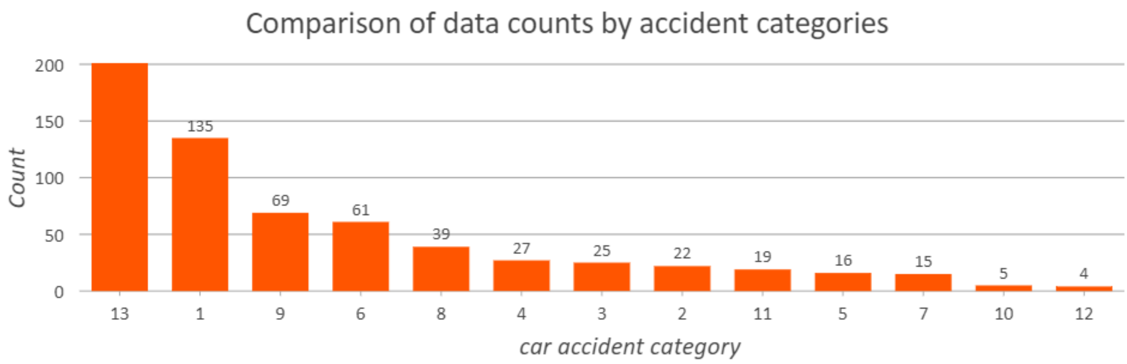


Chart 3.3. Car crash count by categories

As you can see in Chart 3.3 the most common car accidents are classified as individual accidents (135 cases), pedestrian accidents (69 cases), rear-end accidents (61 cases). The last listed type of accidents occurs most often while one vehicle is stationary and the other is moving at high speed and as the result, the vehicle crashes into the one in front of it.

The recent known rear-end collision involving tens of vehicles cars and trucks was happened in Espoo on Finnish national road 1 (Turunväylä) on 9 March 2021 (Figure 3.3). The motorway is the main route between Helsinki and Turku. The driving weather was bad due to heavy snowfall and slippery roads. (Finland Today News 2021).

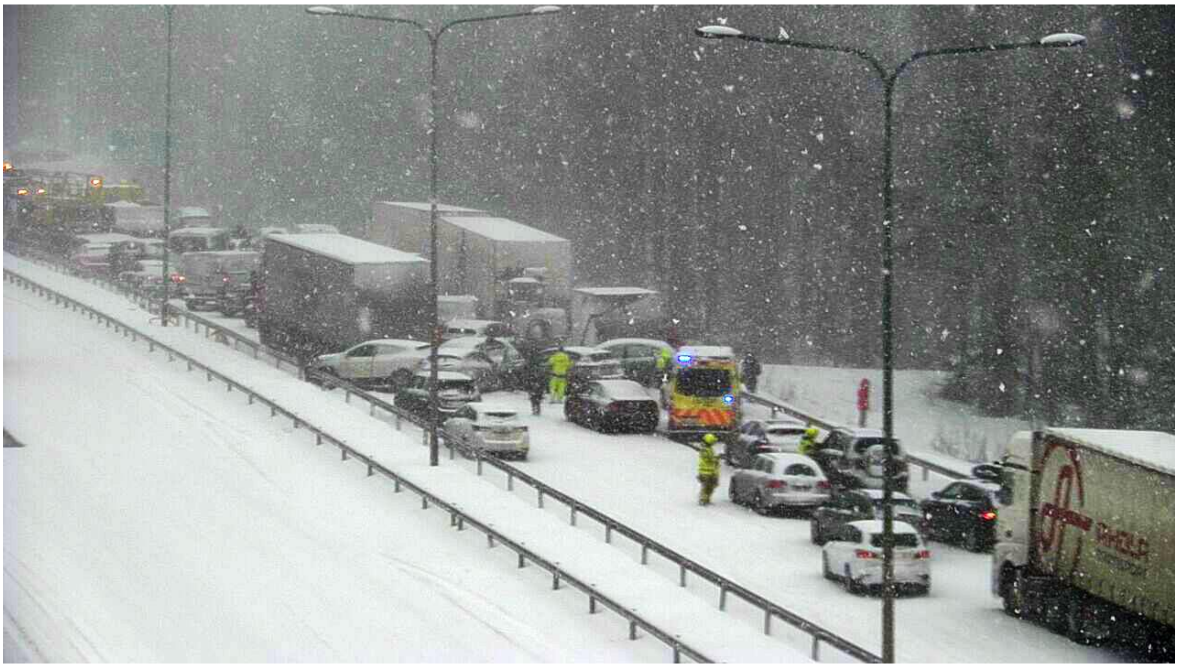


Figure 3.3. Road camera picture of the site of the accident at Kirkkojärvi on Finnish national road 1 (Finland Today News 2021)

Due to the car accident type catalog, there are about 80 different types. The first index of type is based on the following (Liikenneonnettomuustyyppikuvasto, 1-2):

0 Same directions (none of the vehicles were turning)

1 Same driving directions (one of the vehicles was turning)

2 Opposite driving directions (collision accident)

3 Opposite directions (one of the vehicles was turning)

4 Intersecting directions

5 Intersecting directions (one of the vehicles was turning)

6 Pedestrian accident (on a guardrail)

7 Pedestrian accident (off-road)

8 Derailment – car runs off the roadway

9 Other accident.

To find out the most common car accident types the Chart 3.4 was made. Types with more than 10 car crashes are represented here.

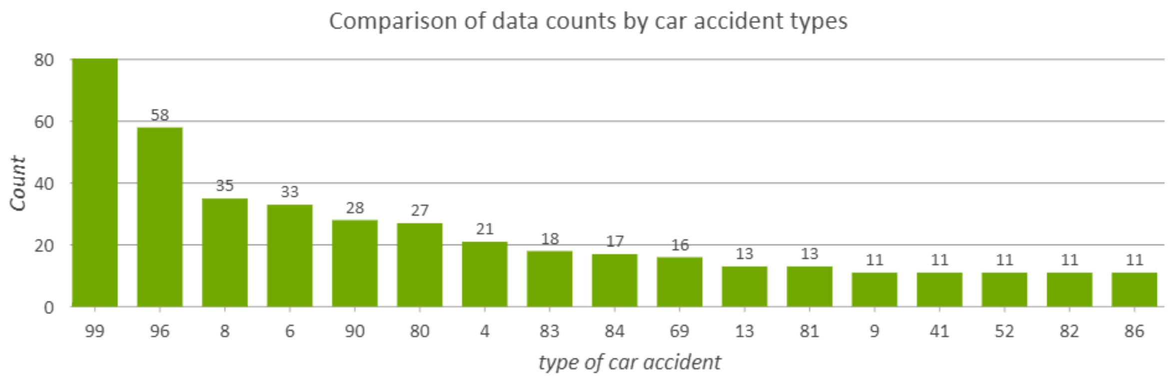


Chart 3.4. Car crash count by different types

As you can see in Chart 3.4 the most common types of car accidents are 96 - accident while reversing, 8 - rear-end collision when the car in front has stopped for an obstacle, 6 - rear-end collision when the vehicle in front is braking, 90 - accident with an animal, 80 - deviation to the right on a straight line, (99 – uncertain type).

The next step for accurate analysis is to restrict the number of car crashes one more time. With the Select by Location tool car crashes are intersecting with the thermal mapping network were selected (with a deviation of 15 m in case of inaccurate location data). Car crash count was decreased from 740 to 359 (Figure 3.4).

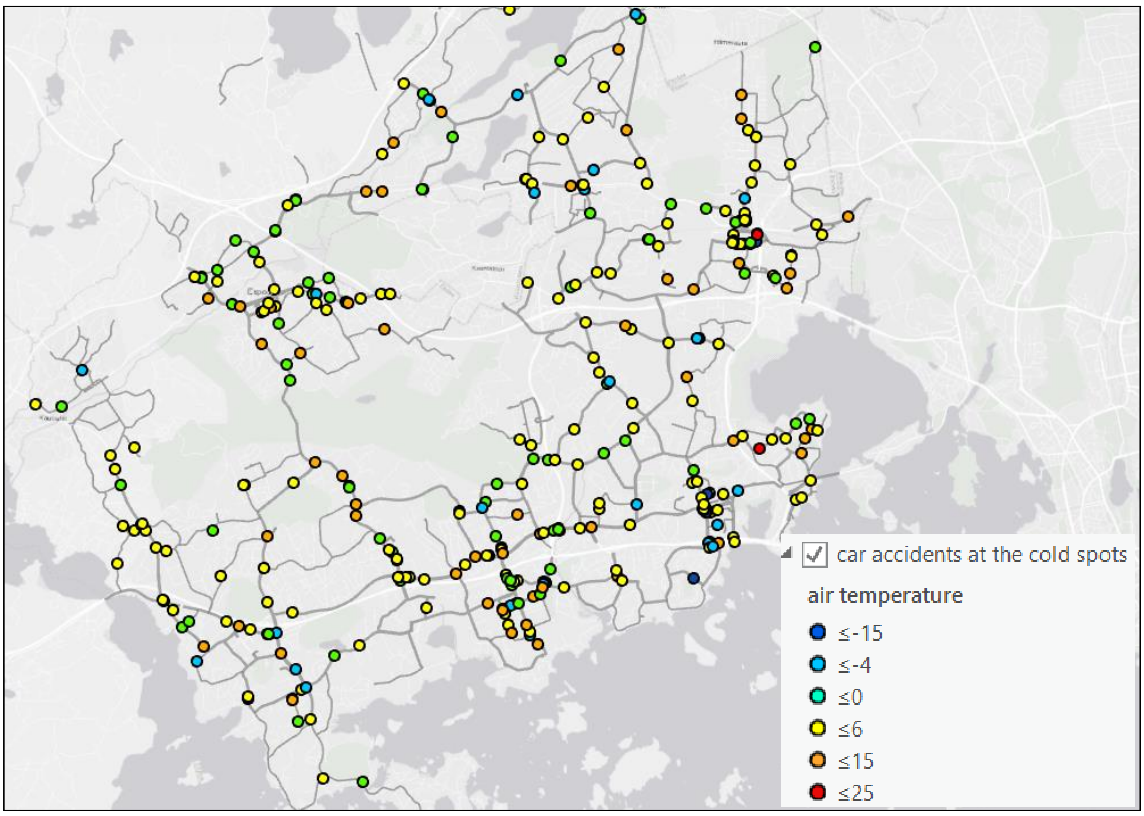


Figure 3.4. Car accidents on surveyed road network (ArcGIS Pro)

Figure 3.4 shows car crashes points that have graduated symbology by air temperature at the moment of the accident. Here you can see mostly accidents happened when the air temperature was from 0 to +6 °C (173 cases), and 116 cases with the air temperature is below 0.

Then with the Definition Query tool, weather and road surface conditions were taken into account. Figure 3.5 shows expressions that were created for the selection of those car crashes that can relate to inappropriate winter road maintenance. Now there are 106 car accidents in the attribute table.

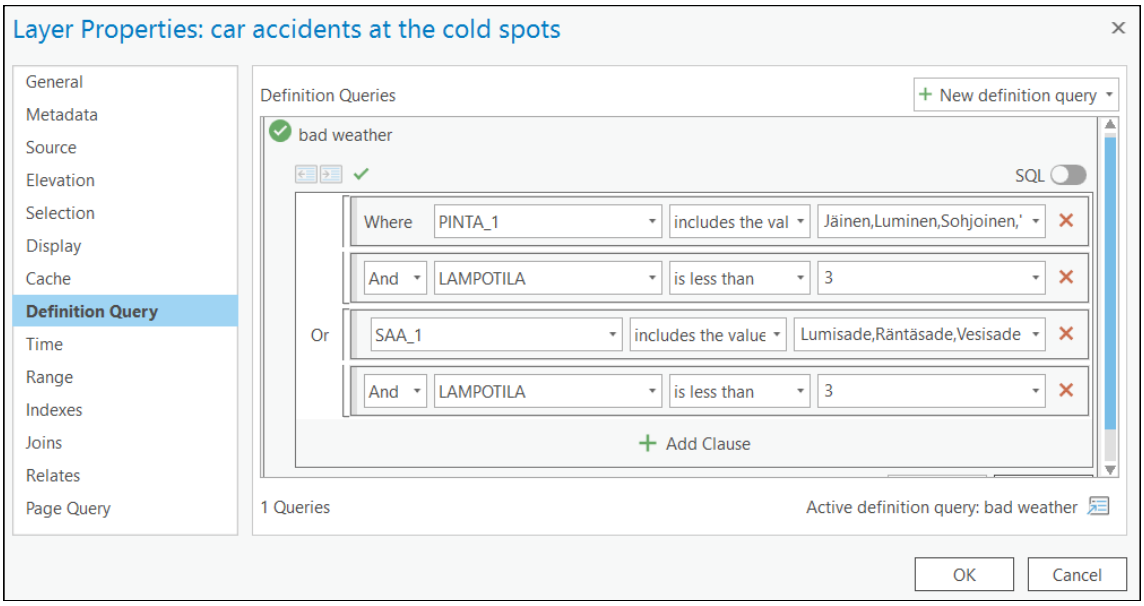


Figure 3.5. Definition Query (ArcGIS Pro)

In Figure 3.5 you can see two conditions. The first one is finding out car accidents with the wet, icy or snowy road surface, and the second one is to figure out accidents that happened under bad weather conditions (rain, snowfall, sleet storm). To both expressions, the string with air temperature was added to provide the condition of ice formation. The value is less than 3 °C was chosen because in the dataset there are cases where icy road surface exists at 2 °C.

Around these 106 cases, the buffer was made to visualize potentially dangerous zones that need more winter maintenance treatment (Figure 3.6).

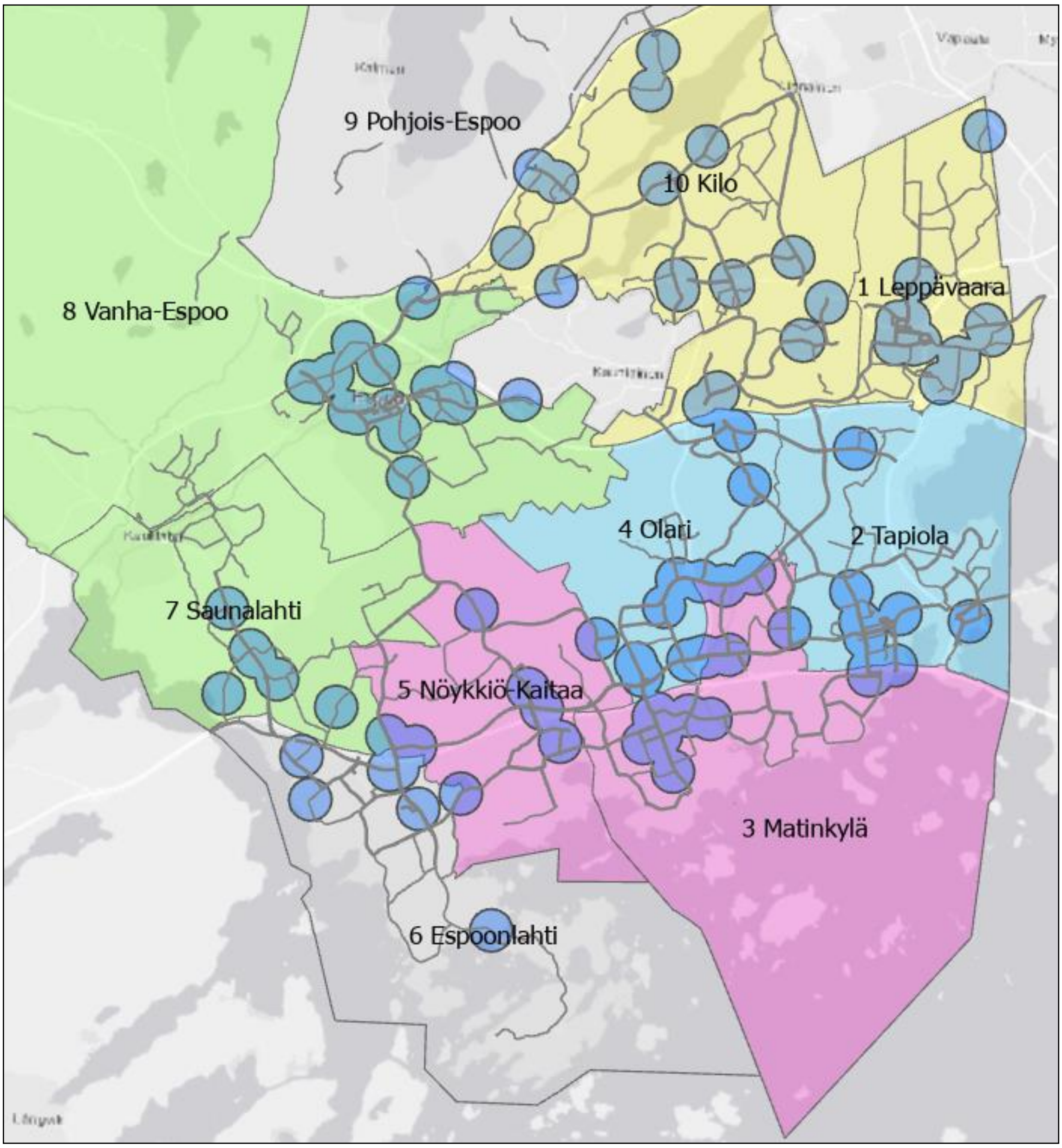


Figure 3.6. Potentially dangerous zones (ArcGIS Pro)

In Figure 3.6 you can see 10 maintenance areas, the main road network and buffer zones that show road parts where car accidents happened due to ice formation on the road surface or bad weather conditions.

4 Interview with drivers

For this analysis two workers from the City of Espoo, snow-plowing operators, were interviewed on 11 November 2020. The experience of drivers can be very useful to find out the most problem parts of the network during winter. Table 4.1 was made based on questions from the interview.

Name	*Erno Lantiainen*	*Hannu Suominen*
Maintained area	*Matinkylä*	*Nöykkiö*
Experience in years	*16 years (since 2004)*	*30 years (since 1990)*
How many drivers in your team?	*20-25 people*	
Salary per hour	*about 15 euros per hour*	
Type of snow plowing machine (car brand)	*SISU R500*	*Mercedes Actros*
Route: km, street names	*10 km of bus-lines; Suomenlahdentie, Kalastajantie, Nuottaniementie, Matinkyläntie, Matinkatu etc.*	*17,5 km of bus-lines; Nöykkiönkatu, Finnoontie, Eestinmalmintie, Puolarintie, Martinsillantie etc.*
Problem parts of roads (much more ice formation)	*Nuottaniementie, Nelikkotie and Matinkartanontie intersection.*	*Nöykkiönkatu, Puolarintie-Friisinkalliontie.*
How much salt do you use? Do you control it?	*Normally 8-16 g/m^3, Yes, we try to regulate spreading based on snow depth and ice thickness.*	
Shift duration, How much time the whole route takes?	*Usually we clean roads at night, salt spreading takes 2 hours and snow plowing takes 6 hours, so totally 8 hours is our normal shift to maintain our own route.*	
How many breaks for one trip/workday do you have? Break duration?	*We have breaks every 2 hours, break duration – 15 min.*	
What speed do you usually drive?	*The average speed of snow plowing is 30 km/h, for salt spreading the speed is a little higher.*	
How often do you refuel?	*Every 300 km of snow plowing, 200-220 liters of diesel, we have all receipts in Neste app.*	

Years with the strongest snowfalls after 2000	*2008-2012 period had the heaviest snowfalls.*
Snowy period of winter	*Usually most of snow we have at the end of January and the first half of February.*
Maximum snow depth	*The maximum was 35 cm in 2004, and for last years 3 cm snow on the road surface is the maximum for winter.*
Where is the snow storage site?	*Now we don't have any special sites for snow storage, just accumulate it on roadsides.*
What applications do you use for work?	*Only Paikannin to see our location, speed and stops.*
What do you do in summer?	*Keep the city's streets clean.*

Table 4.1. Drivers' answers

After the interview drivers' routes were drawn in ArcGIS Pro (Figure 4.1 and 4.2).

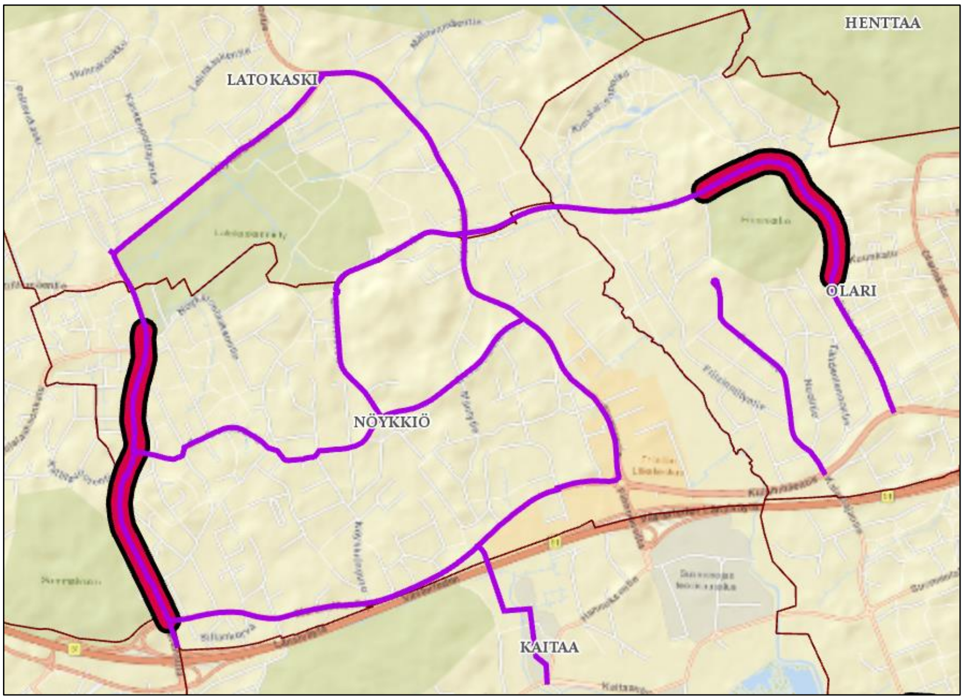


Figure 4.1. Hannu's route (ArcGIS Pro)

In Figure 4.1 you can see on which roads Hannu spreads salt in winter, shown roads are bus lines. All road network inside the area bounded by these bus lines is just cleaned from snow without spreading the salt. Red areas are problem parts needed more treatment in winter by the driver's opinion.

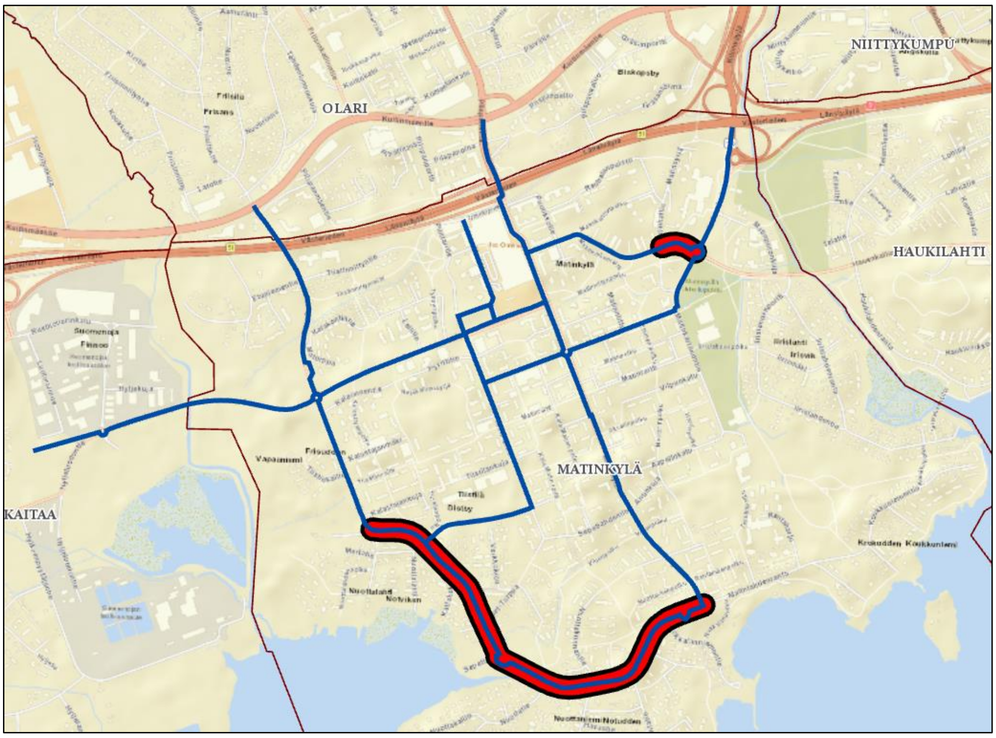


Figure 4.2. Erno’s route (ArcGIS Pro)

In Figure 4.2 you can see main roads maintained by Erno in winter, snow plowing includes the road network inside and around these bus lines too. Red areas are problem parts needed more treatment in winter in his opinion.

In the order to get more information based on experience in winter maintenance two street masters were asked to set out their opinion. They were Aho Ari (who is in charge of Nöykkiö-Kaitaa and Matinkylä maintenance areas) and Mika Vepsäläinen (Olari and Tapiola).

Our difficult areas correlate quite well with your findings, but I also want to highlight one zone of Finnoontie. This part of Finnoontie gets quite slippery since damp air gathers and freezes on the road surface, which usually is a bit colder than average. Also this part is dangerous due to the road curves relatively sharply. (Aho Ari 2020. Street master. City of Espoo. Interview on 18 November 2020).

I want to highlight Mankkaanlaaksontie in a particular. This part is one of the first ones to freeze in winter, so it correlates very well with your findings. Also we tested the use of light-weight Leca-gravel when building the foundations and this part of the road network will be rebuilt in 2021-2022. (Mika Vepsäläinen 2020. Street master. City of Espoo. Interview on 18 November 2020).

5 Results

After all needed data were derived, the final map combining all feature layers was made (Figure 5.1). The full map you can check in Appendix 2.

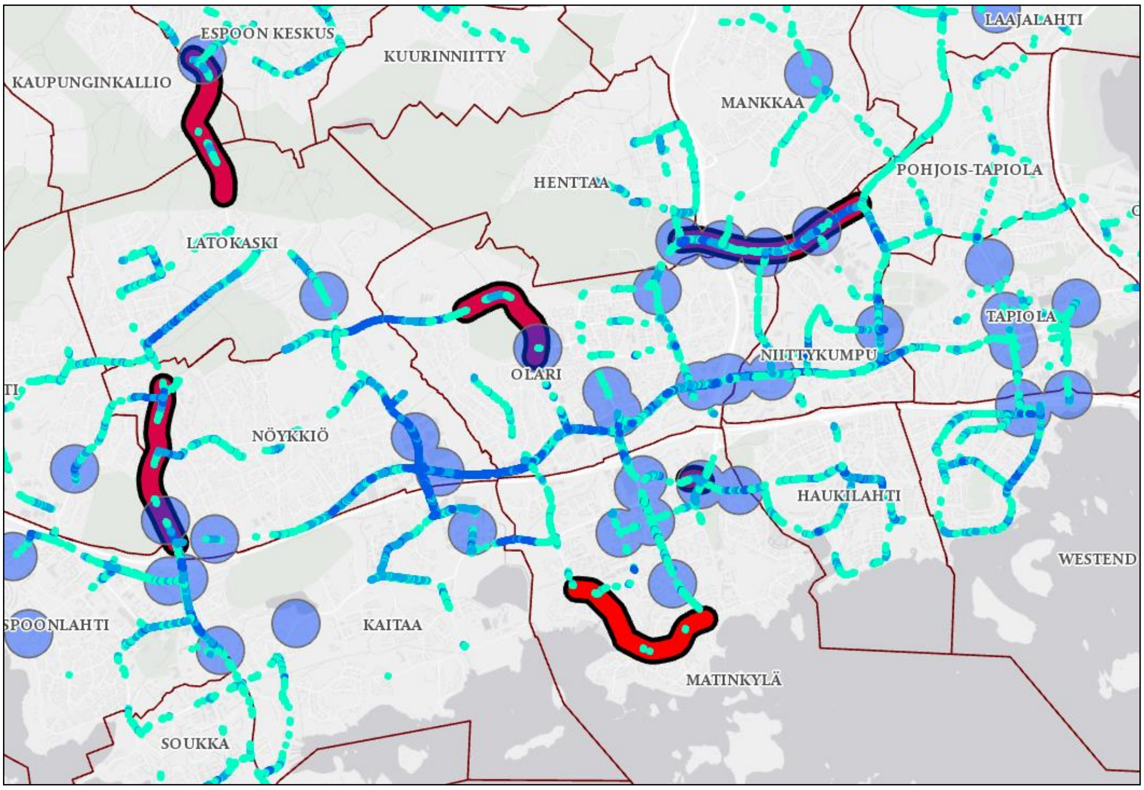


Figure 5.1. Final map (ArcGIS Pro)

In Figure 5.1 you can see the following layers: thermal map (spots with lower than average RST), red problem road parts by drivers' opinion and blue circles – dangerous zones according to car crashes analysis.

Then the correlation between all these datasets can be estimated.

Findings:

1. Dangerous zones according to car crashes analysis have a strong positive correlation with cold spots and therefore approve the accuracy of thermal mapping calculation. These zones locate mostly in city centres and need to be taken into consideration as priority zones for winter maintenance actions.
2. Drivers' and street masters' opinion has a weak positive correlation with cold spots, it means that all problem parts mentioned by street maintenance workers need to be checked individually.

As Mankkaanlaaksontie (Olari-Mankkaa-Nittykumpu intersection) it can be a dangerous part of the road network according to both car accidents analysis and drivers' opinion.

At the same time one of the red zones, Nuottaniementie (Matinkylä), mentioned by drivers doesn't have any cold spots, RSTs here are higher than average with about 1°C according to the thermal map. But this street locates in a shoreline zone and sea proximity may cause high humidity and therefore more often ice formation.

3. Cold doesn't mean ice. Since measurements for thermal mapping are carried out once and there aren't fixed factors affecting humidity of the road surface, RoadDSS Navigator doesn't calculate relative humidity and dew point at any point of the road. Such data is shown only where road weather stations are located. It means we can't get all needed information from the thermal map to estimate and highlight cold spots that tend to be slippery in winter surely and need treatment as in Nuottaniementie case.
4. The coldest intersection (Figures 5.2 – 5.4).

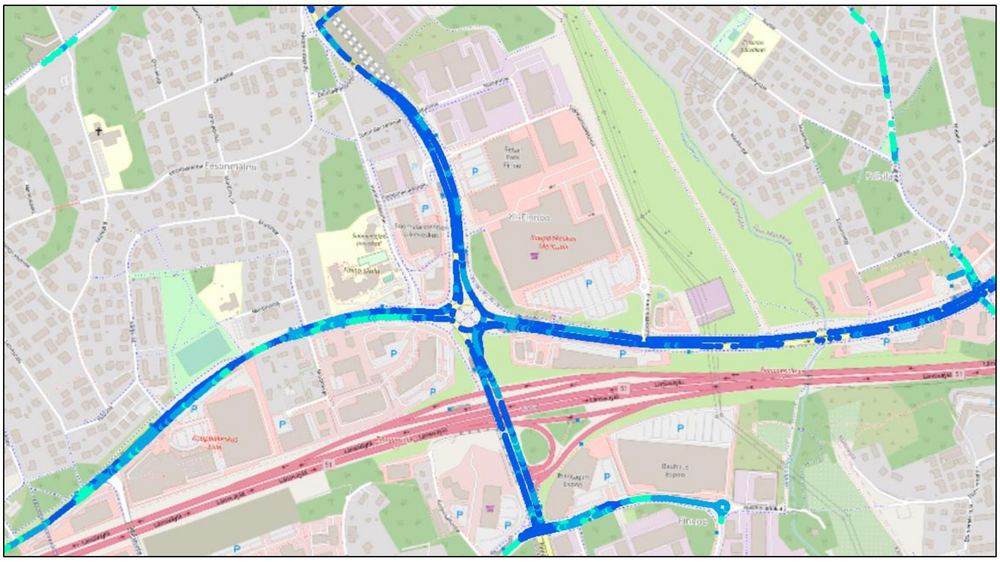


Figure 5.2. Finnoontie-Kuitinmäentie intersection. Thermal map layer (ArcGIS Pro)

In Figure 5.2 you can see the thermal map fragment of Finnoontie-Kuitinmäentie intersection (more famous as Suomenojan liikenneympyrä). This part of the road network stays the coldest under any weather conditions.

Figure 5.3. Finnoontie-Kuitinmäentie intersection. Satellite view (Google 2021)

This phenomenon can be caused by high sky view factor which is equal to 1. It means that the roadside of this road network part isn’t covered by trees or high buildings as you can see in Figure 5.3, then heat will disappear rapidly from this road surface at night.

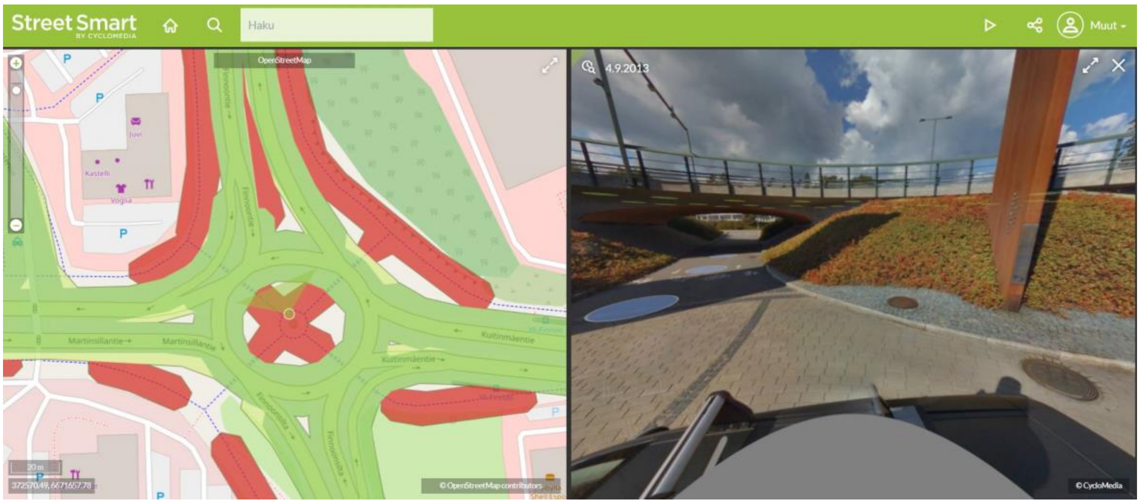


Figure 5.4. Finnoontie-Kuitinmäentie intersection. 3D view (Street Smart 2021)

The second reason is the presence of bridge decks in this roundabout construction as shown in Figure 5.4. Any stored heat escapes from both above and below the structure, that’s why the bridge deck is colder than other parts of the road.

Recommendations:

- To get out drivers' opinion about problem parts of the road network during winter at every of 10 maintenance area.
- To install extra road sensors near the shoreline and the coldest intersection to measure surface state (Figure 5.5). It's needed to fill up the lack of humidity data that directly influence ice formation.

Figure 5.5. DSC111 Remote Surface State Sensor (Vaisala 2021)

In Figure 5.5 you can see DSC111 Remote Surface State Sensor which uses proven laser technology to identify water, ice, slush, snow, frost, and determine grip. There is no need to install the whole road weather stations because road surface temperatures are estimated with the thermal map.

- Another actual recommendation for winter maintenance improvement is to create a web app showing real-time vehicle location data and progress of snow plowing and de-icing in each maintenance area of Espoo. ArcGIS Velocity can help to deal with such big real-time data processing and analysis (Figure 5.6).

Figure 5.6. ArcGIS Velocity in the ArcGIS platform (Esri 2021)

This tool enables to assimilate, visualize, analyze, store, and act upon data from IoT(Internet of Things) sensors. High-velocity event data can be filtered, processed, and transmit to multiple destinations, permitting to connect virtually any type of streaming data and when certain conditions occur automatically alert personnel. It's also possible to design analytic models to process high-volume historical data and gain insights into patterns, anomalies and trends. (Esri 2021).

And with ArcGIS Dashboards this real-time dataset can be shared with all employees of the Public Works Department (Figure 5.7).

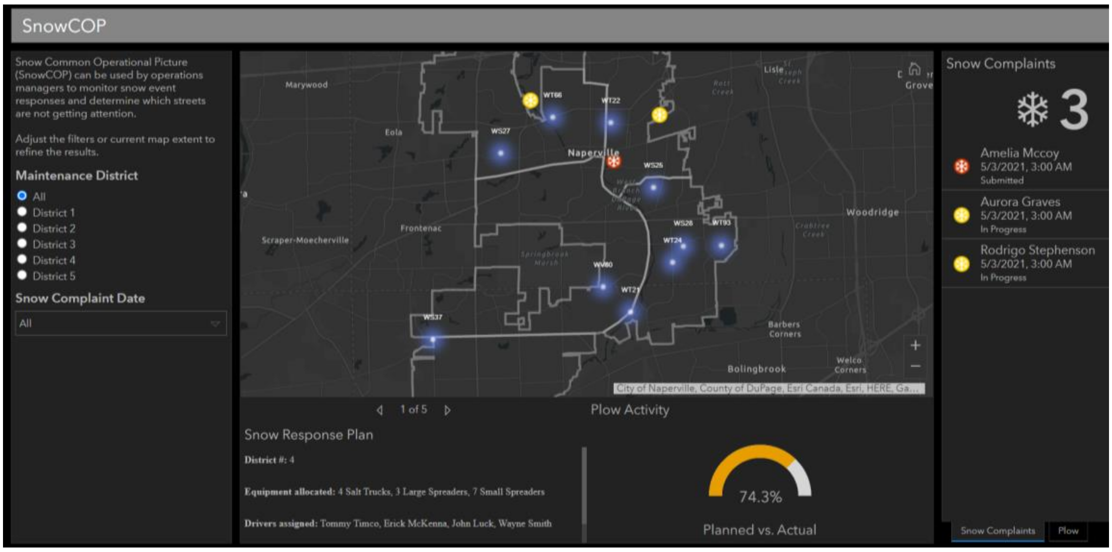


Figure 5.7. SnowCOP (ArcGIS Solutions 2021)

In Figure 5.7 you can see one of the examples of using ArcGIS Dashboards. This Snow Common Operational Picture (SnowCOP) can be used by operations managers to monitor snow event responses and determine which streets require attention. The dashboard leverages visualize real-time locations of vehicles and assets (ArcGIS Solutions 2021).

6 Route optimization

For more efficient usage of analysis results, route optimization should be done according to the findings – the most problem parts of road network in wintertime. One solution is ArcGIS Network Analyst.

Routes represent the quickest or shortest path along roads to visit stops or point locations. They can be basic point-to-point routes visited in the order you specify or in the order that minimizes overall travel time or distance (Esri 2021).

For instance, a street master can easily do route optimization in ArcGIS Pro following the next steps and then share results with his drivers using an online map or personally:

1. Add the road network layer (Figure 6.1). Then click Network Analysis and choose Route.

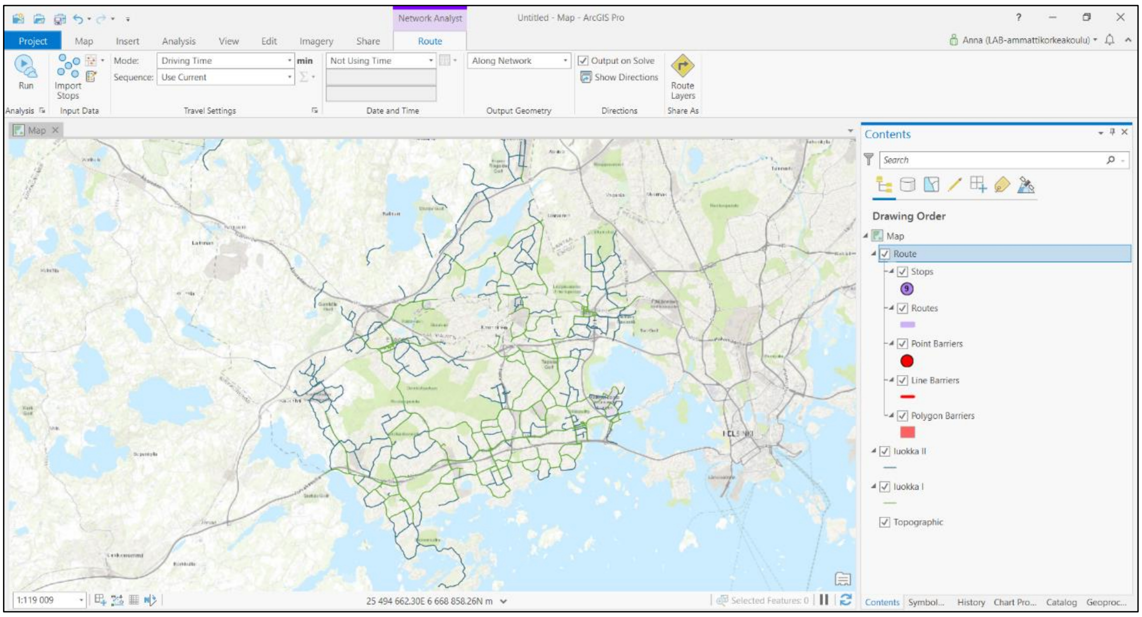


Figure 6.1. Network Analisys. Base layer (ArcGIS Pro)

You can see in Figure 6.1 the road network consists of 1 and 2 road classes (you must add the whole Espoo network for accurate route calculation). In the right Contents tab, you can find all needed layers: stops, routes, point/line/polygon barriers that you're able to upload as existing datasets or draw on the map by yourself.

2. Add critical road parts according to the findings (cold spots) as stops, where winter treatment needed.

3. Now that you have imported the stops, you are ready to create routes. The numbering is inherited from the data source, and it represents the order in which the

stops were imported into the point feature class or the order of drawing. On the Route tab, in the Travel Settings group, you can choose Driving Time as Mode and Sequence set to Find Best. In the Analysis group, click Run (Figure 6.2).

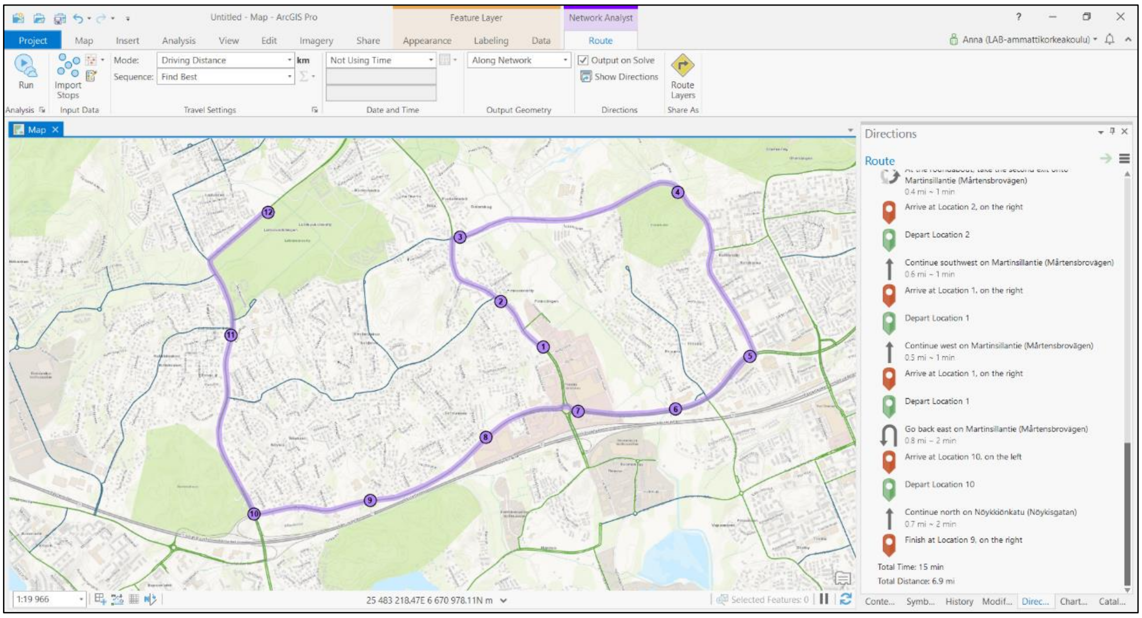


Figure 6.2. Network Analysis. Route creation (ArcGIS Pro)

After the analysis run as shown in Figure 6.2 stops are marked in the order according to the best route, also you can click Show Direction that can be used as a navigator.

You can apply this analysis for example when you get citizen complaints. Add them as stops, mark snow-plowing machine location as stop 1. On the Route tab, in the Travel Settings group, choose Driving Time as Mode and Sequence set to Preserve First Stop and run all process again.

7 Summary

Thanks to cooperation with Vaisala, Destia and interviews with drivers of snow-plowing machines all needed data were derived and then these datasets were analyzed and visualized using ArcGIS Pro.

According to the goal of thesis work the final map was created for a visual representation of the correlation between thermal map, winter maintenance workers' experience and car accidents. The findings of analysis allowed to figure out the benefits of Thermal Mapping, issues that must be considered in the future, and offer some recommendations for winter maintenance improvement.

Certainly, Thermal Mapping is a good start for developing the winter maintenance field. Thermal Mapping has the following benefits:

- identification of potentially dangerous parts by the road surface temperature relationship across the whole road network;
- possibility to use forecasting data for anti-icing strategies;
- identification of the best location and number of road weather stations and other sensors;
- providing key input data for Route Optimization.

But it doesn't have all needed data for appropriate winter maintenance treatment actions.

After the estimation of the results, few problems were figured out and the solutions were offered. These recommendations include an obligatory interview with street masters and drivers to add their findings over all 10 maintenance areas to the final map and the installation of extra sensors to monitor the road surface state near the shoreline and the coldest intersection of the road network.

During data analysis, great ArcGIS products capabilities have been identified. To begin with MapInfo Professional I could say that ArcGIS Pro is more user-friendly and easy to study. This product has a higher price but the capabilities of this program, an enormous choice of ready-to-use analysis tools, minimum time spent and high-quality visualization, in the end, pay off the price. ArcGIS implementation can help the City of Espoo to develop in the winter maintenance field.

References

ArcGIS Velocity. Esri 2021. Retrieved on 5 May 2021. Available at https://doc.arcgis.com/en/iot/get-started/what-is-arcgis-velocity.htm

Find the shortest path and generate directions with Route. Network Analyst Tutorials. Esri 2021. Retrieved on 18 December 2020. Available at https://pro.arcgis.com/en/pro-app/latest/help/analysis/networks/route-tutorial.htm

Liikenneonnettomuustyyppikuvasto (Car accident type catalog).

Onnettomuusrekisterin koodit (Accident register codes).

Rachel Adams 2018. Using road surface temperature relationship to benefit winter maintenance actions. Vaisala.

Rear-End Collision on Natioinal road 1. Finland Today News. Retrieved on 30 April 2021. Available at https://finlandtoday.fi/rear-end-collision-involving-cars-and-trucks-cuts-off-traffic-on-national-road-1/

Remote Surface State Sensor DSC111. Weather stations and sensors. Vaisala 2021. Retrieved on 20 January 2021. Available at https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/weather-stations-and-sensors/dsc111

RoadDSS Vaisala Navigator 2021. Retrieved on 23 January 2021. Available at https://www.vaisala.com/en/roaddss

RWS200 Product Catalog 2019. Vaisala.

SnowCOP. ArcGIS Solutions. Esri 2021. Retrieved on 5 May 2021. Available at https://solutions.arcgis.com/local-government/help/snow-cop/

Street maintenance. City of Espoo 2021. Retrieved on 15 January 2021. Available at https://www.espoo.fi/en-US/Housing_and_environment/Streets_and_Transport/Street_Maintenance

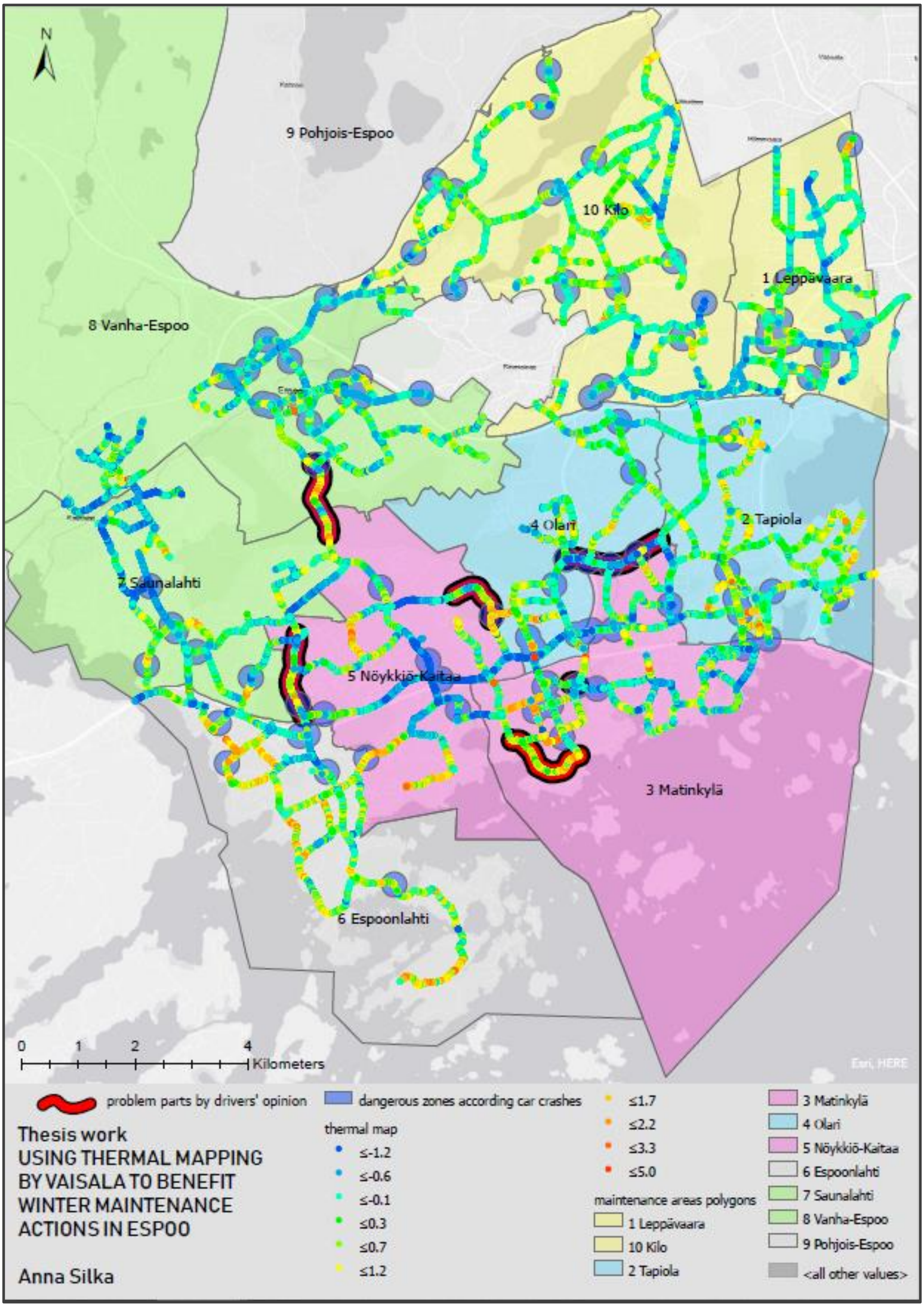
Surface Patrol Pavement Temperature Sensor Series DSP100. Weather stations and sensors. Vaisala 2021. Retrieved on 15 January 2021. Available at https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/weather-stations-and-sensors/dsp111

Thermal Mapping Module. E-learning by Vaisala 2021. Retrieved on 6 August 2020. Available at http://thermal.training.vaicld.com/

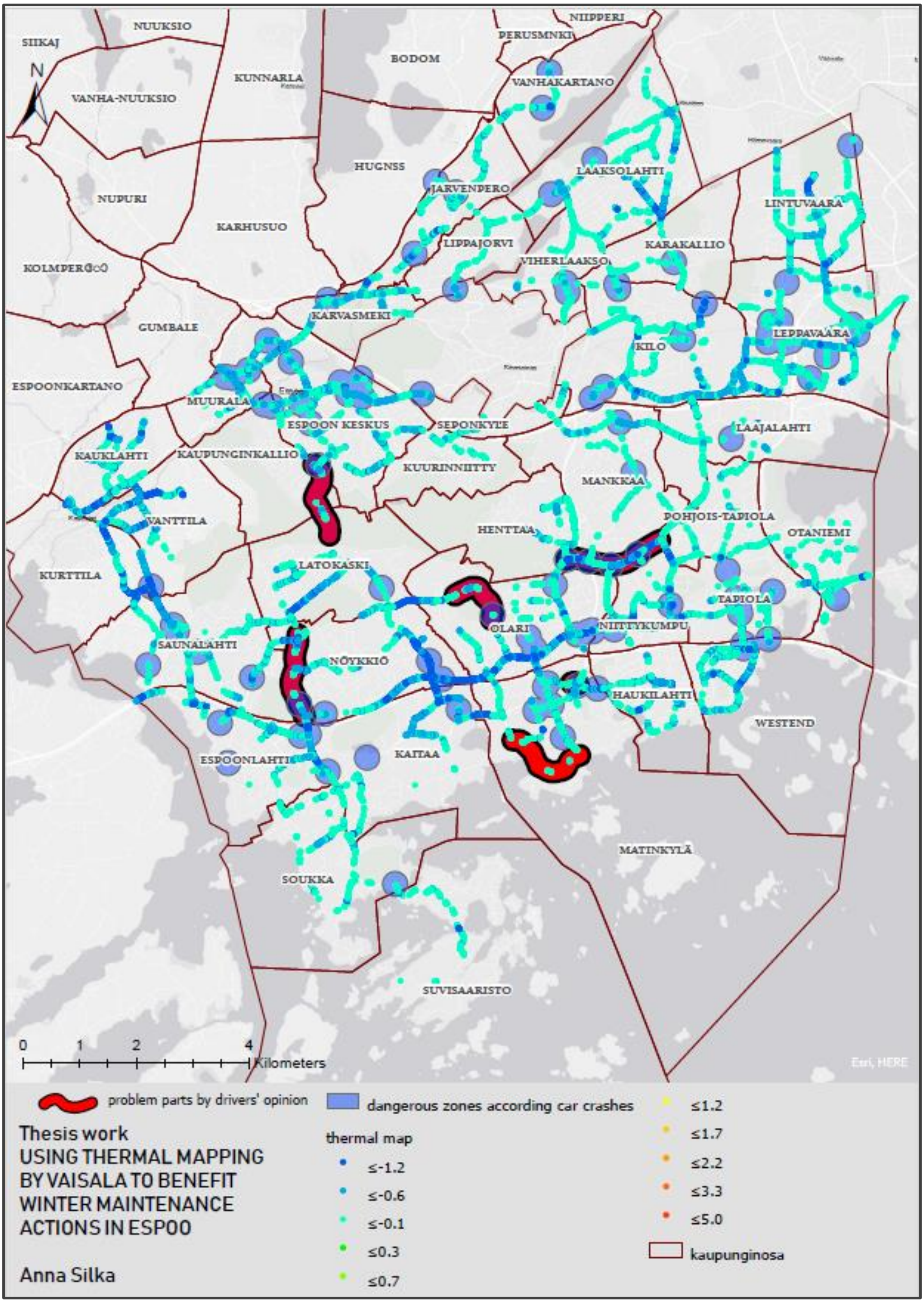
Thermal Mapping Report 2020. Vaisala Transportation Weather Services.

Vaisala in brief. Vaisala 2021. Retrieved on 6 August 2020. Available at https://www.vaisala.com/en/about-vaisala/vaisala-company/vaisala-brief

Appendix 1. Final map with 10 maintenance areas base layer



Appendix 2. Final map showing cold-spots



Appendix 3. Customer satisfaction with winter maintenance