VAST Challenge 2019
Reviewer Guide: Mini-Challenge 2

This document provides information to support peer review of submissions to VAST Challenge 2019, Mini-Challenge 2. It covers background about the submission structure, the challenge problem, tasks and questions presented to participants, potential answers, and evidence found in the Challenge data supporting these answers. For a full description of the challenge problems and to access the data provided to the participants, please visit https://vast-challenge.github.io/2019/MC2.html.

Submissions

Participants are required to submit their entries on a standard answer form, along with a video explaining how visual analytics were used to help solve the challenges. Please consider both parts of the submission in your review. If you have difficulty reading the answer form or playing the video, please contact us at vast_challenge@ieeevis.org for assistance.

Scenario

VAST Challenge 2019 presents three mini-challenges and a grand challenge for participants to apply visual analytics research and technologies to help a city grapple with the aftermath of an earthquake that damages their nuclear power plant.

Overview

St. Himark is a vibrant community located in the Oceanus Sea. Home to the world-renowned St. Himark Museum, beautiful beaches, and the Wilson Forest Nature Preserve, St. Himark is one of the region's best cities for raising a family and provides employment across a number of industries including the Always Safe Nuclear Power Plant. Well, all that was true before the disastrous earthquake that hits the area during the course of this year's challenge. Mayor Jordan, city officials, and emergency services are overwhelmed and are desperate for assistance in understanding the true situation on the ground and how best to deploy the limited resources available to this relatively small community.

Mini-Challenge 2: Citizen Science to the Rescue

One of St. Himark's largest employers is the Always Safe nuclear power plant. The pride of the city, it produces power for St. Himark's needs and exports the excess to the mainland providing a steady revenue stream. However, the plant was not compliant with international standards when it was constructed and is now aging. As part of its outreach to the broader community, Always Safe agreed to provide funding for a set of carefully calibrated professional radiation monitors at fixed locations throughout the city. Additionally, a group of citizen scientists led by the members of the Himark Science Society started an education initiative to build and deploy lower cost homemade sensors, which people can attach to their cars. The sensors upload data to the web by connecting through the user's cell phone. The goal of the project was to engage the community and demonstrate that the nuclear plant's operations were not significantly changing the region's natural background levels of radiation.

When an earthquake strikes St. Himark, the nuclear power plant suffers damage resulting in a leak of radioactive contamination. Further, a coolant leak sprayed employees' cars and contaminated them at varying levels. Now, the city's government and emergency management officials are trying to understand if there is a risk to the public while also responding to other emerging crises related to the earthquake as well as satisfying the public's concern over radiation.

Data

The data provided to contestants include sensor readings from static and mobile radiation monitors. The two data files span five days that surround the earthquake (12 am on April 6, 2020 to 11:59 pm on April 10, 2020).

The mobile sensor data contains readings from 50 mobile sensors that are attached to cars. Data fields include Timestamp, Sensor ID, Longitude, Latitude, Value, Units, and User ID. The timestamps are reported in 5 second intervals, although poor data connectivity can result in missing data. Each sensor has a unique identifier, which is a number from 1 to 50. Location of the sensor is reported as longitude and latitude values. Radiation measurements were reported with units of counts per minute (cpm). Each measurement is independent and does not represent a summation over the previous minute. Some sensors have a unique user ID while some others have a default name.

The data set contains missing and corrupted data, skipped time steps, and other issues. Both radiation measurements and movements were affected by conditions in the city. The locations of the static sensors and several points of interest, particularly hospitals and the nuclear plant, were provided. Several maps were provided as images and shape files, some with labels and some without. One of the maps indicated major roads but not the full road network.

Ground Truth

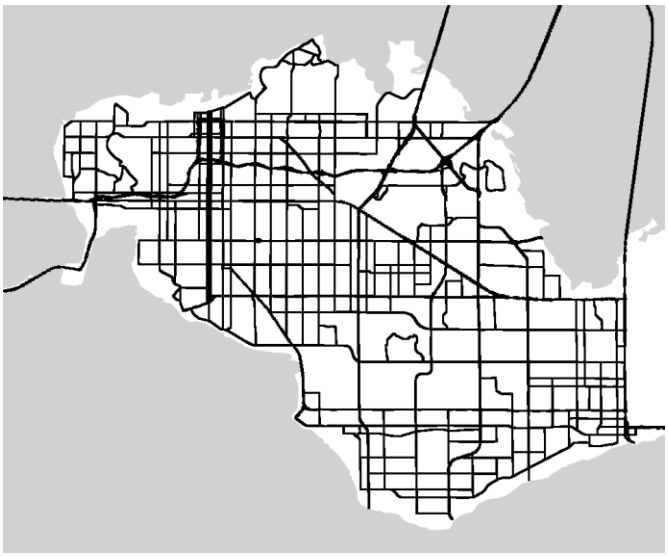


Figure 1. St Himark roads show possible paths of mobile sensors.

Before the quake the road conditions, as reflected by car speeds, are shown in Figure 2. Neighborhoods in the lightest colors had no traffic issues and neighborhoods shaded in darker colors had greater traffic issues. There were no power issues prior to the quake.

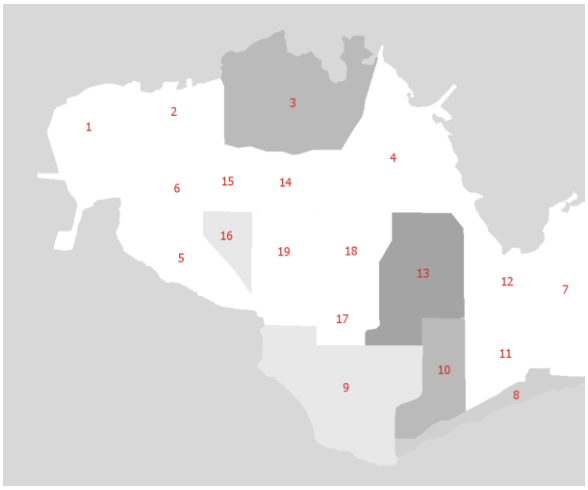


Figure 2. Pre-quake road conditions. Darker shading in the neighborhood indicates greater traffic issues.

Typical Car Behaviors

Every car that has a sensor attached has a home location that it goes to at night. Most cars also have a work location that they go to during the day. Forty-three of the 50 cars go to work locations on the peninsula.

Three cars have work locations off the peninsula, so they appear to use a bridge, have a period during the day where no sensor readings are available and then return later. Cars start driving at about 6 AM. Some cars leave work during the day to go to lunch nearby. Cars start going home from work at about 4 PM. Some cars go home, then go back out to do something for up to 2 hours and then go home again in the evening. A subset of cars acts more like delivery vehicles. They drive to multiple locations in the city, stopping for a while at each location. A subset of cars are science enthusiasts and use their sensors to monitor the nuclear plant. In the morning they drive to a location near the plant and hang out there. In the afternoon, they go home. Some go out again in the evening. Most of these cars also attend a meeting of the Himark Science Society on April 6. This is one event in which sensors from across the city appear at the same location at the same time. A subset of cars at the meeting subsequently also meet at a second location the same night.

Typical Sensor Behaviors

Readings of the mobile sensors are based on data from actual mobile radiation sensors used around the world (visit safecast.org for more information). As a result, the sensor readings have some uneven behavior. Noise levels vary between sensors and over time. There are some unexpected outliers. There are periods without readings. Some sensors appear to have a change in calibration midway through the time period, which shifts measurements by a fixed amount. Two sensors are affected by temperature. The readings rise and fall with this temperature profile, as shown in Figure 3.

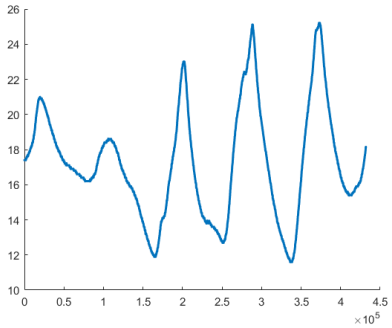


Figure 3. Change in measurements for one sensor based on temperature.

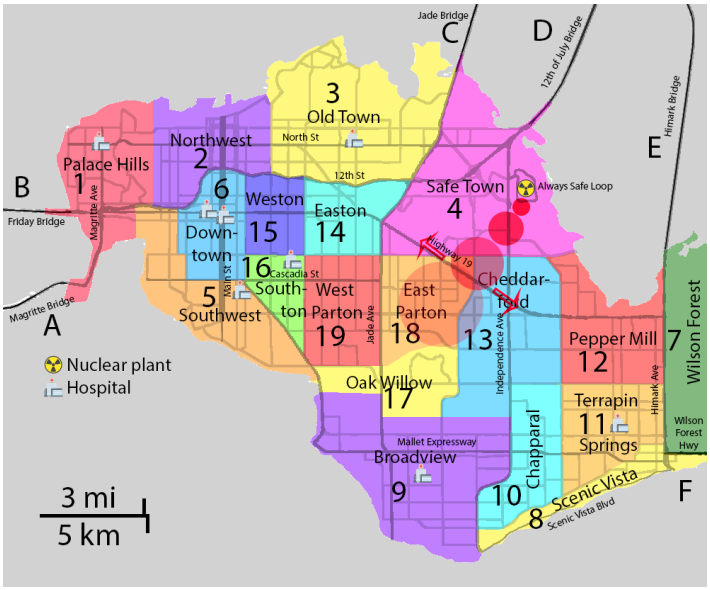
There is also user error. The sensors are designed to run 24/7 but some users turn them off at night. As a result, there is a warm up period in the morning where the sensor has lower readings. Because of where the sensors get placed some get shielded from natural background at either the home or work locations. Some random noise and outliers occurs in the readings, even before the quake.

When the quake happens, everything changes. Two main environmental factors affected cars and the uncertainty of sensor readings after the quake: the state of road damage and power in a neighborhood. Road damage affected car speed and routes as some cars couldn't enter badly damaged areas. The availability of power affects communications networks in the city and results in intermittent connections for the sensors, which have more missing data in areas of poor communication. Damage in the city also impacts the noise levels and rate of outliers for mobile sensors. One sensor stops reporting right after the quake and never turns back on. But many sensors and car behaviors are mostly unaffected. They still get up and go to work and go back home. However, some cars just drive home as soon as the quake happens, and they stay there for the rest of the time. Several cars attempt to leave the peninsula, but if they choose a route that is blocked they have to return home or try another route.

Lastly and most importantly, events at the nuclear plant after the quake also introduce 50 contaminated cars and a contaminated area into the city. These cars are only visible in the data as they pass by other sensors. Like the cars with sensors, each contaminated car has an individual home location. All contaminated cars have a work location at the nuclear plant. Contaminated cars have these general behaviors:

- A few drive to one of the city's hospitals
- Most cars stay until the end of their shift at 4 pm
- Some who leave work try to go home, but if they can't get there then they drive around
- Some try to leave the peninsula and either succeed or hit bridges that are closed
- Some cars that make it home just stay there for the rest of the week
- Others go home and then return to work as normal on the last two days
- Five cars end up getting abandoned at random locations in the city

A non-lethal amount of contamination spreads from the nuclear plant after the earthquake. It starts in the Safe Town neighborhood and spreads to parts of Cheddarford and East Parton as shown by the red circles on the map below. Radiation is a bit higher near the plant. Sensors that drive through this area after the quake will detect elevated radiation levels.



Questions for Participants

Participants were provided the following instructions:

> *"Your task, as supported by visual analytics that you apply, is to help St. Himark's emergency management team combine data from the government-operated stationary monitors with data from citizen-operated mobile sensors to help them better understand conditions in the city and identify likely locations that will require further monitoring, cleanup, or even evacuation. Will data from citizen scientists clarify the situation or make it more uncertain? Use visual analytics to develop responses to the questions below. Novel visualizations of uncertainty are especially interesting for this mini-challenge."*

The following are the questions they were asked to respond to. Following each question is information to support your evaluation of their answers.

As you review the submissions, keep in mind that we are looking for submissions that go above and beyond rudimentary visualization techniques and shallow analyses. We are looking for visual analytics approaches that provide context for the data, support interactive exploration to identify and understand patterns. We encourage creativity. We are also particularly interested in representations of uncertainty in the visualization. Analyses should provide both answers and evidence or rationales, and should demonstrate critical thinking about the data. It is even better if assumptions, multiple competing hypotheses are documented as well.

As you develop your review of the submission, please also consider the following questions.

- If there were hypotheses that remained unresolved, did the submission specify actions to be taken to resolve them?
- Did the team develop an innovative visual analytic tool? Alternatively, did they use an existing tool in an innovative way?
- Did visualizations enable the analysis process? Or did they merely illustrate conclusions? Did the submission rely more heavily on non-visual analytic approaches?

- Did their tool allow useful interactions?
- Did they use all the available data?
- Was the submission clear?

Question 1

1. **Visualize radiation measurements over time from both static and mobile sensors to identify areas where radiation over background is detected. Characterize changes over time.**

   The figure below shows the mobile sensor readings by day. Participants should identify important changes such as the emergence of high readings on April 8-10, the large quantity of missing data on April 9-10, and areas of rising radiation. They should also be able to provide reasonable hypotheses about why these changes occurred, as outlined above.



Figure 4. Mobile sensor readings for April 6-8. Green indicates lower readings, yellow is intermediate, and red is high readings.



Figure 5. Mobile sensor readings for April 9 and 10. Green indicates lower readings, yellow is intermediate, and red is high readings.

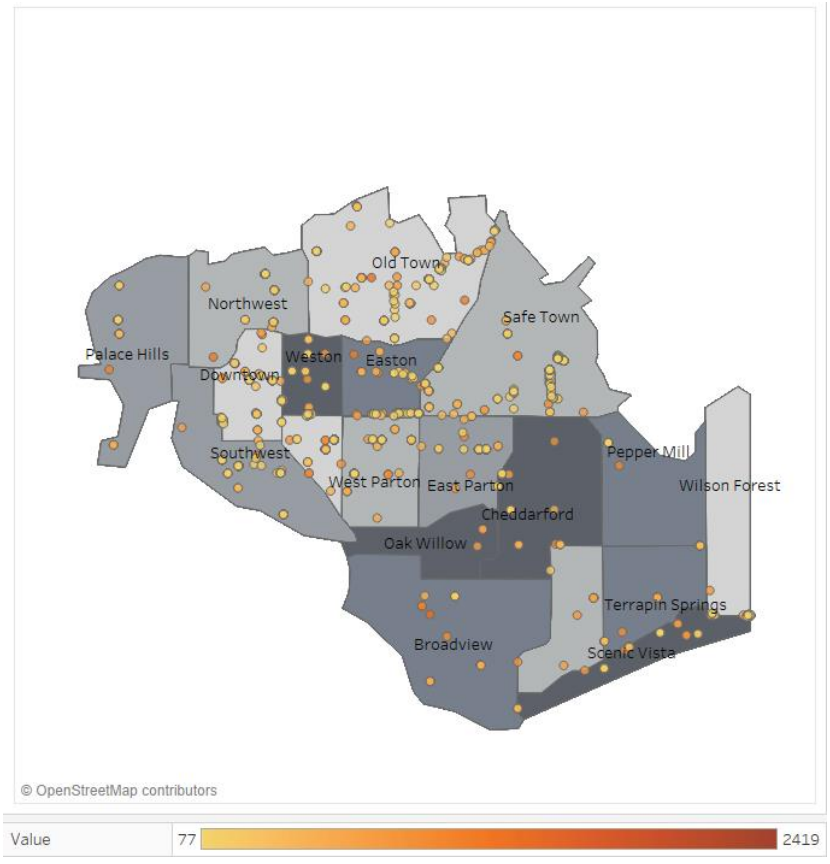


Figure 6. Radiation level outliers measured across the city.

Question 2

2. **Use visual analytics to represent and analyze uncertainty in the measurement of radiation across the city.**

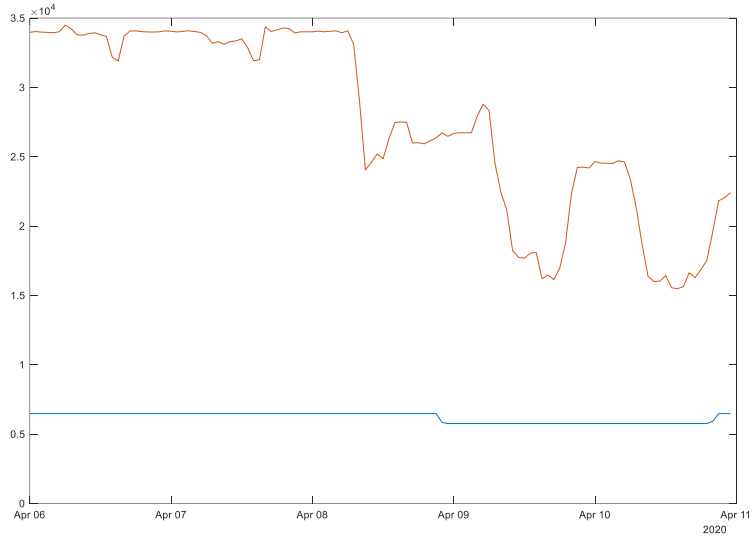


Figure 7. Number of records by day from static (blue) and mobile (red) sensors.

As shown in Figure 7, the number of records over time from static sensors (blue) is more stable than the number of records coming from mobile sensors (red) but there are always fewer records from static sensors. This, combined with their fixed locations, makes it hard to measure radiation across the city with any certainty using only the static sensors. The number of readings is not equally distributed across the city as shown below.

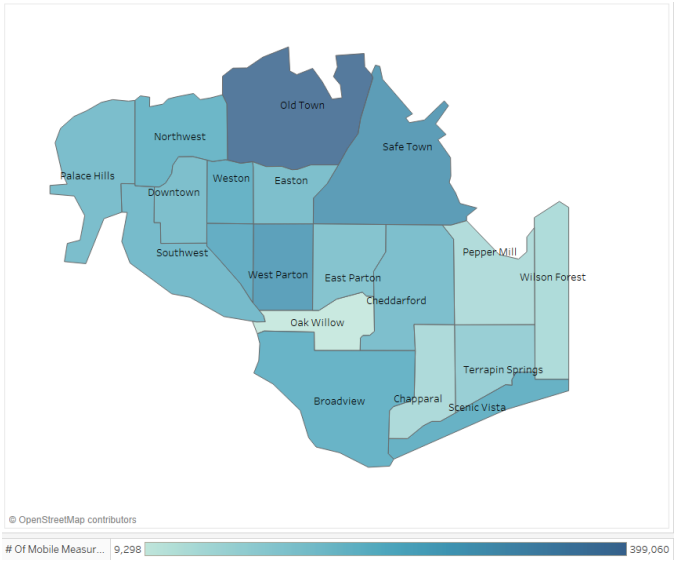


Figure 8.Relative number of mobile sensor readings in each neighborhood. Lighter color represents fewer measurements.

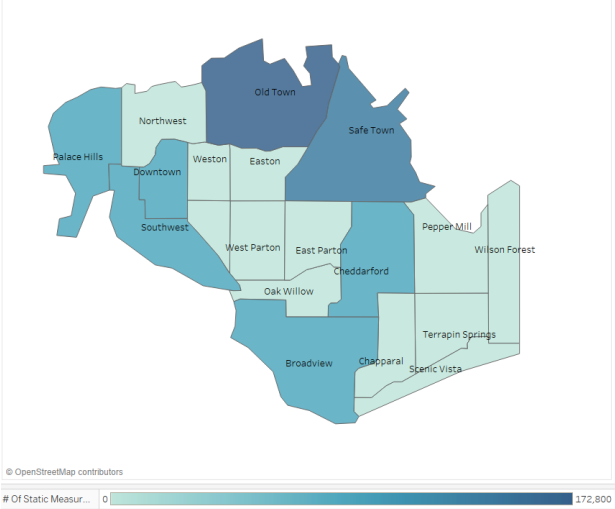
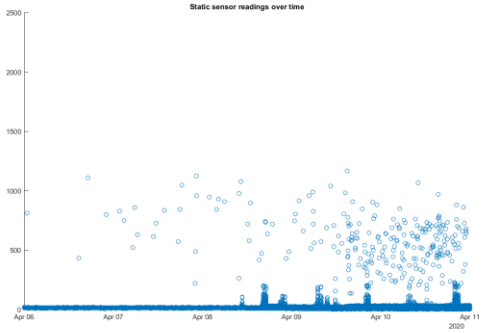
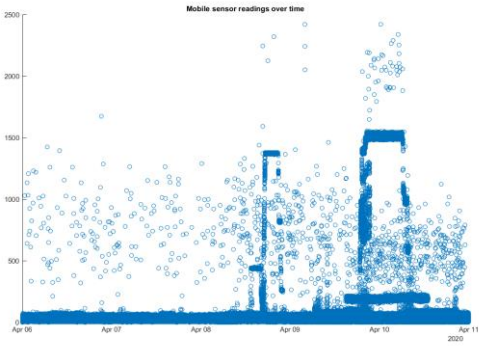


Figure 9. Relative number of static sensor readings in each neighborhood. Lighter color represents fewer measurements.

a. Compare uncertainty of the static sensors to the mobile sensors. What anomalies can you see? Are there sensors that are too uncertain to trust?

The graphs below show sensor readings from static sensors (left) and mobile sensors (right). The number of outliers is much higher for mobile sensors.





A number of anomalous behaviors were built into the mobile sensor readings:

- Sensors 9, 10, 24, 25, 27, 28, 29, and 45 all have unexpected shifts that make them less trustworthy.
- Sensor 34 turns off fairly early and may not have enough data to make a determination of trustworthiness.
- Sensors 1 and 20 drift with the temperature.
- Sensor 2 slowly drifts over time, although this could be corrected.
- Sensors 19 and 23 have readings that are lower while they are moving.
- Sensor 18 is always turned off at home and has artificially low readings after it is turned back on.
- Sensor 37 is shielded at home so its readings are artificially low. This sensor also reports data that is only in intervals of 5 cpm.
- Sensors 5 and 16 are shielded at work, where their readings are artificially low.

There are more than 16000 pairs of measurements where a mobile sensor is reasonably close to a static sensor so it can be used to calibrate. Among these calibration encounters there are about 5000 cases where the mobile sensor differs from the static sensor by more than 10 cpm.

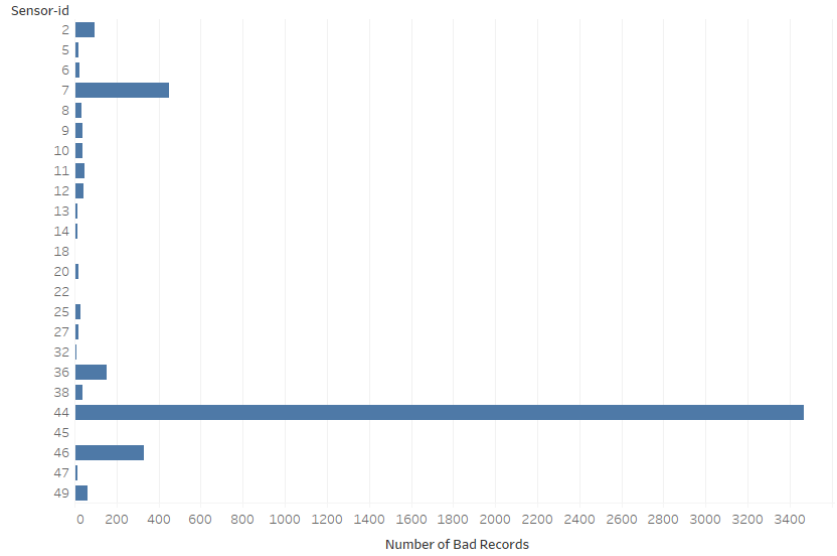


Figure 10 shows that three sensors have a significant number of encounters with static sensors indicating they are not well calibrated. These are sensor 44, 7, and 46. It is likely that these sensors are too uncertain to be trusted.

Figure 10. Counts of bad records, by sensor ID.

b. Which regions of the city have greater uncertainty of radiation measurement? Use visual analytics to explain your rationale.

Prior to the earthquake, uncertainty largely stems from lack of measurements in a given neighborhood as shown below. Darker colors on the map indicate greater uncertainty. Following the earthquake, the sources of uncertainty include lack of data, greater noise in baseline readings, more outlier spikes in readings.

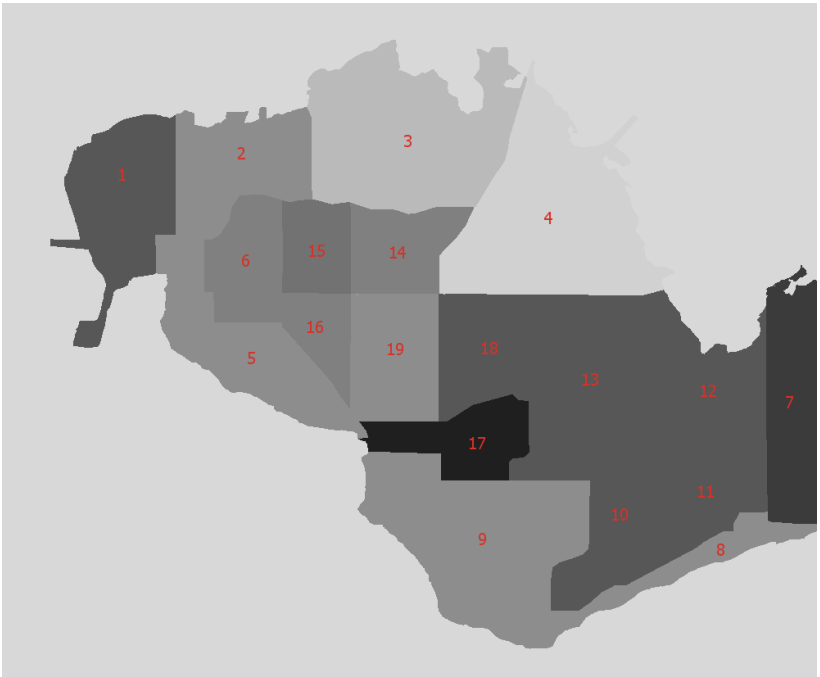


Figure 11. Areas of greatest relative uncertainty prior to the earthquake. Darker colors show greater relative uncertainty.

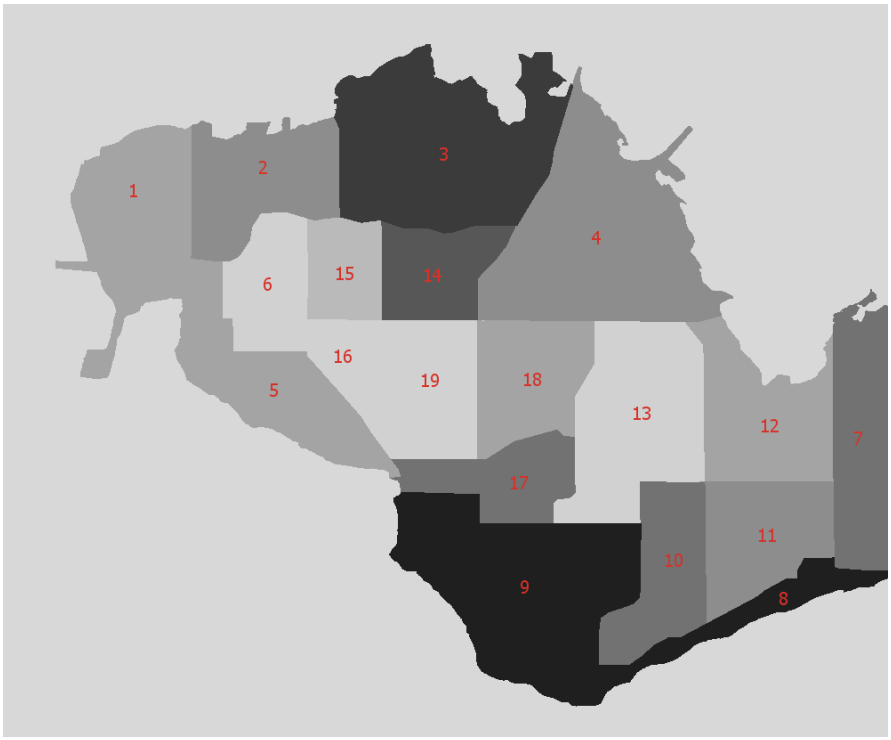


Figure 12. Areas of greatest relative following the April 8 earthquake. Darker colors show greater relative uncertainty.

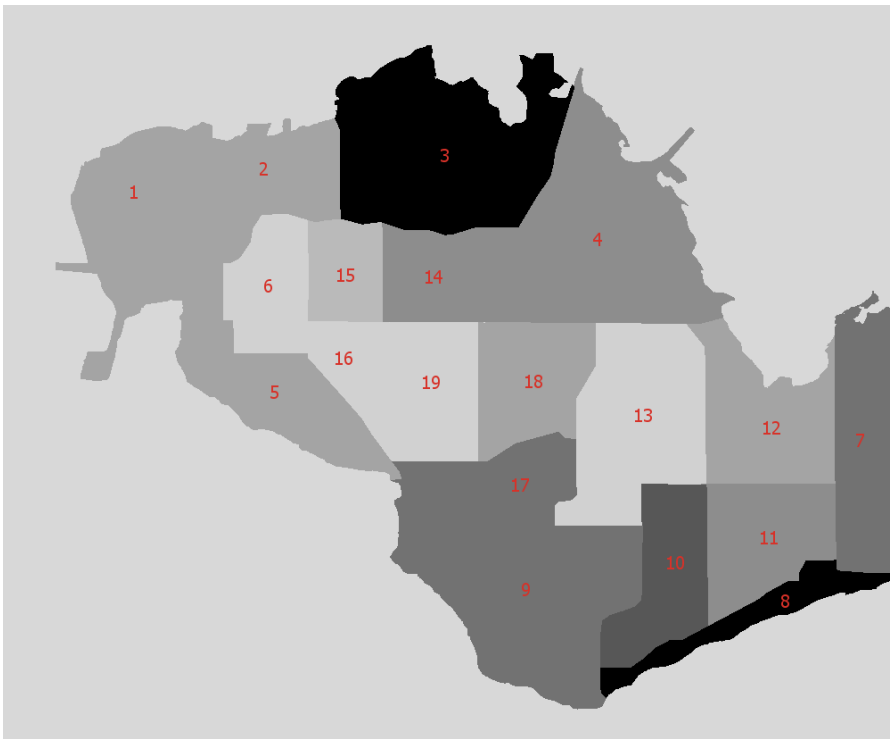


Figure 13. Areas of greatest relative following the April 9 aftershock. Darker colors show greater relative uncertainty.

c. What effects do you see in the sensor readings after the earthquake and other major events? What effect do these events have on uncertainty?

Outliers increase after the earthquake for both mobile sensors (blue) and static sensors (red).

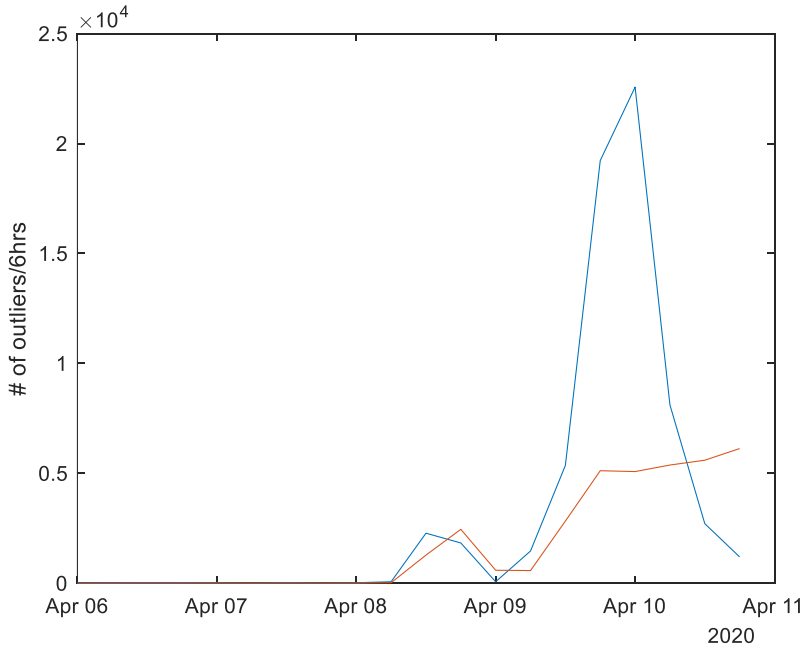


Figure 14. Outlier rates by 6 hour period.

There are 8 time points that change the way sensors behave. Conditions in the city change at these time points and change how sensors report data. Events are:

- 2020-04-08 08:36:00.000 - the major earthquake. Power is lost in much of the city due to automatic safety mechanism. Cars stop moving for several minutes. Some roads become blocked. General damage in each neighborhood affects the quality and number of sensor readings
- 2020-04-08 10:46:35.000 – Power begins to return to areas that did not suffer bad damage
- 2020-04-08 13:23:53.000 – More power is restored, damaged roads/infrastructure begin to improve in areas that were not badly damaged
- 2020-04-09 04:25:30.000 – Crews working overnight restore power and clear roads, even in areas that got hit worse
- 2020-04-09 09:48:42.000 – Further progress is made towards restoring power
- 2020-04-09 15:00:30.000 - The aftershock occurs. Power turns off again for many areas, roads are blocked, and data coming from sensors is affected.

- 2020-04-09 19:29:23.000 – Power and road damage in areas not hit badly by the aftershock is mostly restored.

- 2020-04-10 15:52:06.000 – Further power and damage recovery across the city, except in areas worst hit.

In general, the earthquake and aftershock make uncertainty worse in three ways: less data is available, there are more outliers and there is more baseline noise. In general, uncertainty gets worse right after the quake and the aftershock and then goes down slowly after each event. Uncertainty is exacerbated in the worst affected areas by: lack of sensor movement, slow or non-existent recovery of power and road damage over time.

Question 3

3. Given the uncertainty you observed in question 2, are the radiation measurements reliable enough to locate areas of concern?

a. Highlight potential locations of contamination, including the locations of contaminated cars. Should St. Himark officials be worried about contaminated cars moving around the city?



Figure 15. Movements around the city April 8.



Figure 16. Movements around the city April 9 and 10.

Movements on April 8 clearly show an area of contamination spreading out from the nuclear plant. But the lack of mobile sensor movement in the contaminated area on April 9 and 10 make it hard to say whether it is a danger.

b. Estimate how many cars may have been contaminated when coolant leaked from the Always Safe plant. Use visual analysis of radiation measurements to determine if any have left the area.

50 total cars were contaminated. The contamination levels ranged from 100 to 10000. However, radiation declines with distance so most sensors will not detect contamination levels this high if they are even a short distance away. Many of the cars with contamination levels of 500 or less may not be detectable. The graph below shows how many cars had each of the possible contamination levels. A

total of 18 cars had contamination levels of 5000 or 10000 and these are much more easily detected. The map at right indicates the locations of outlier measurements, each of which may be an encounter with a contaminated car.

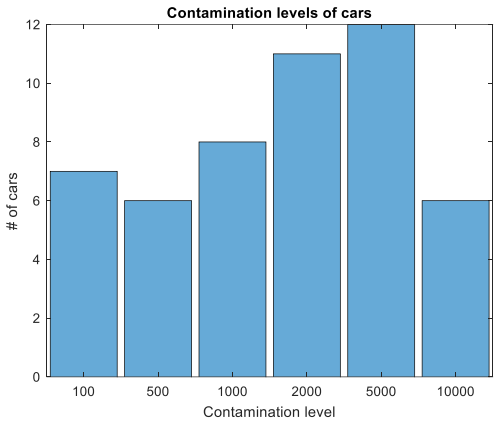


Figure 17. Contamination level of cars.

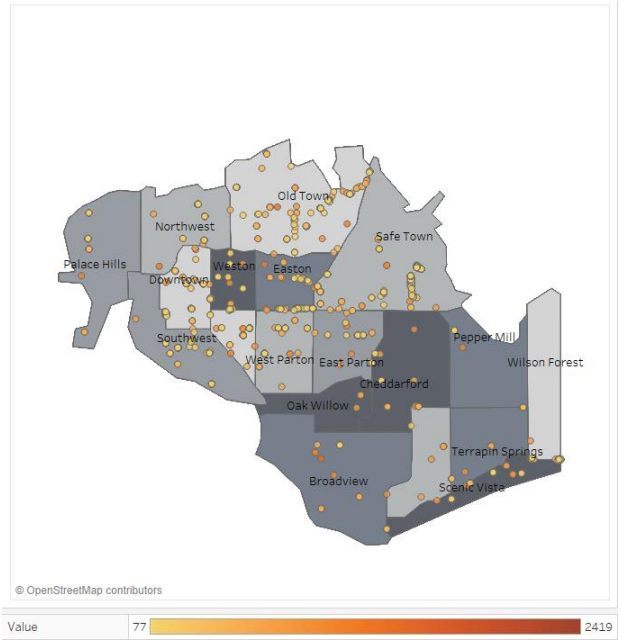


Figure 18. Locations of anomalous readings.

c. Indicate where you would deploy more sensors to improve radiation monitoring in the city. Would you recommend more static sensors or more mobile sensors or both? Use your visualization of radiation measurement uncertainty to justify your recommendation.

Responses may vary. Respondents should indicate areas of the map that:

- Have low sensor coverage
- Have high radiation measurement uncertainty
- Have higher potential contamination as a result of the quake.

These answers should be supported by their responses to earlier questions.

Question 4

4. Summarize the state of radiation measurements at the end of the available period. Use your novel visualizations and analysis approaches to suggest a course of action for the city. Use visual analytics to compare the static sensor network to the mobile sensor network. What are the strengths and weaknesses of each approach? How do they support each other?

Respondents should show the spread of contamination across the city in both the area contaminated by the plume and by the contaminated cars driving around. The maps below show radiation measurements in the last twelve hours of the data. The first map shows all mobile sensor readings and reveals a significant number of locations with high radiation (large red circles). Respondents may refer to calibration events where mobile sensors pass by static sensors so you can tell whether they are measuring accurately. The calibrations reveal a set of sensors that measure well. Filtering to only include well-calibrated sensors shows radiation contained to three main areas: Safe Town, Old Town, and the 12th of July Bridge. There are also areas of concern in Scenic Vista and Palace Hills.

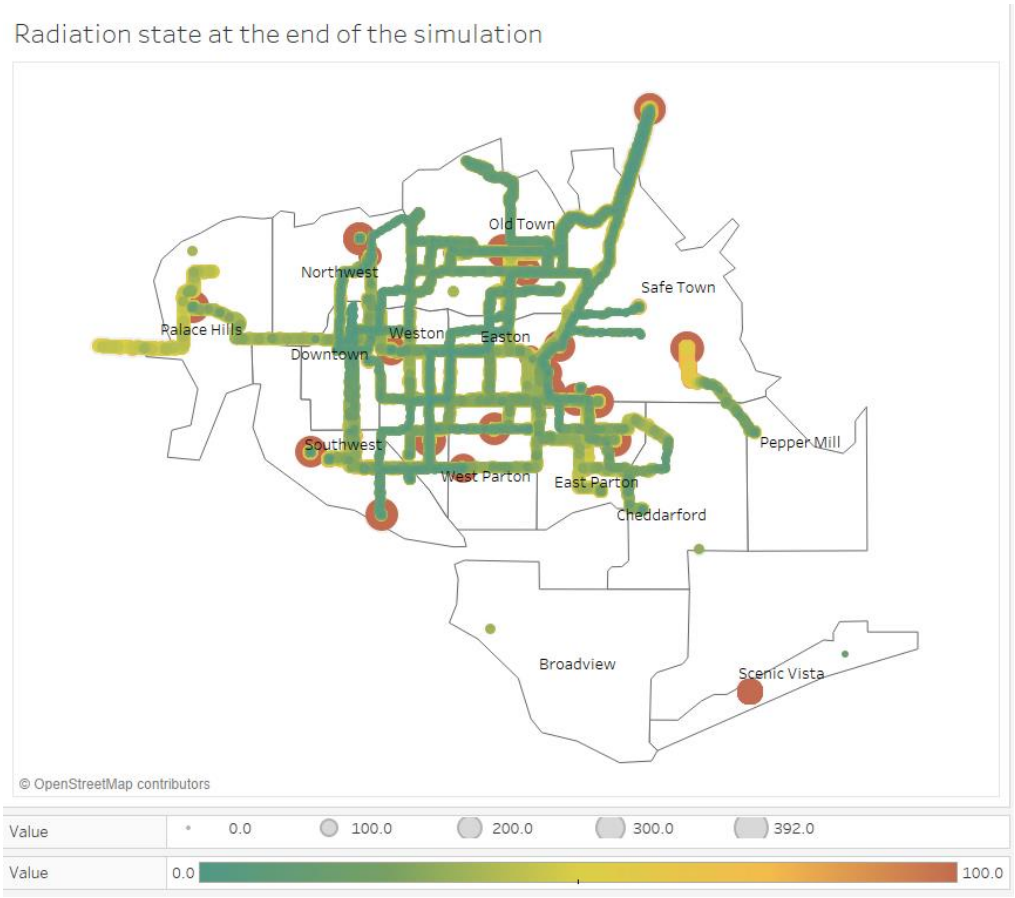


Figure 19. Locations of high radiation at the end of the data, if all data is considered.

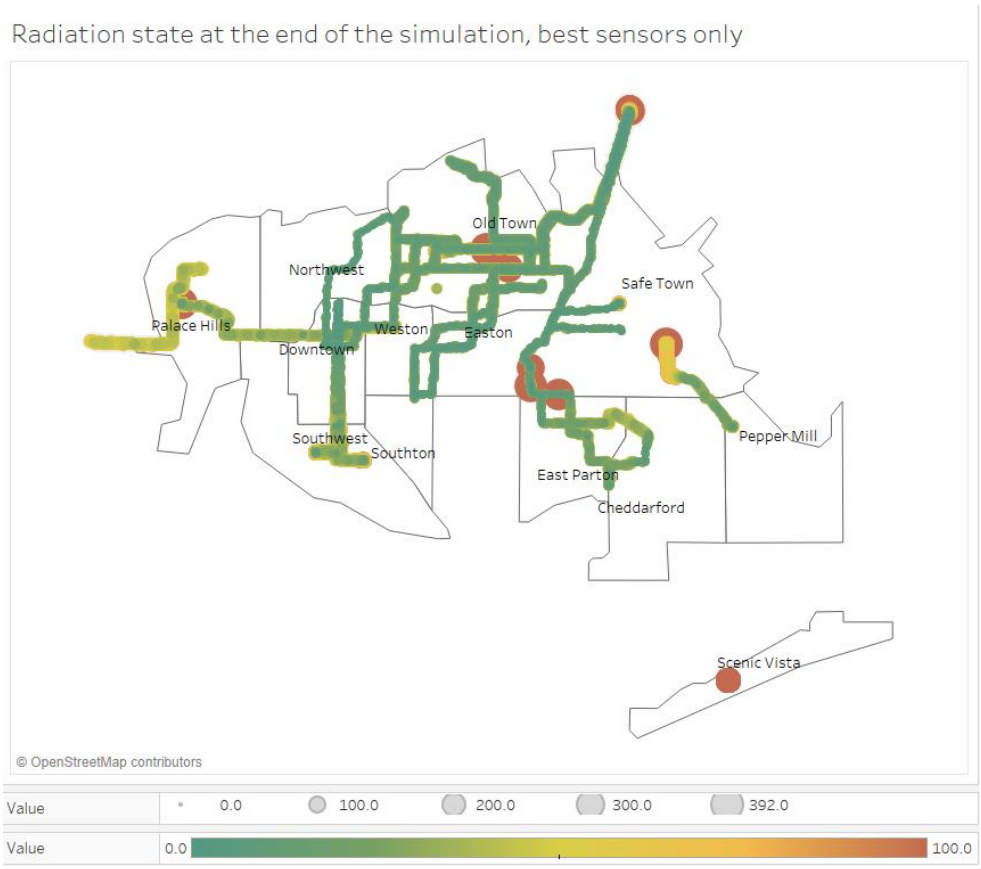


Figure 20. Locations of high radiation at the end of the data, if only the most reliable sensors are considered.

Question 5

5. **The data for this challenge can be analyzed either as a static collection or as a dynamic stream of data, as it would occur in a real emergency. Describe how you analyzed the data - as a static collection or a stream. How do you think this choice affected your analysis?**

Responses may vary. We are looking for thoughtful answers regarding how the form of the data may affect their insights. Do they assert that patterns may be easier to identify in streaming or static data? Do they provide rationale for their assertion?

This question also invites reflection on how data processing decisions impact the answers produced. Things you might see addressed include:

1. How was sequence of events used in the answers?
2. How do they think sequence impacted the answers?
3. Does answer confidence/accuracy change over time?
4. How many passes over the data were required to get their answer?
5. If they used machine learning techniques, did they use time in setting up training data?

Our concern is that they are introspective about their own process and recognize the impact of the choices that they made.