Improving Situational Awareness During Early Earthquake Response Using Existing Seismic Risk Models to Rapidly Estimate Damage

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Abstract

In the first several hours following an earthquake, municipalities are often forced to rely upon reports from first responders, reconnaissance along disrupted roadways by emergency personnel, or wait for aerial surveillance and remote sensing. The latter is expected to take at least 12 hours, a crucial period following a major earthquake in which situational awareness can be greatly improved using existing seismic risk modelling tools. This work presents a new initiative to develop a rapid disaster modelling protocol for earthquakes in British Columbia (BC). We explore best practices and the feasibility of using immediately available seismic data in the existing OpenQuake Canada framework to model the impacts to people, the built environment, and the economy from an earthquake in near real-time. The current prototype integrates observed ground motion data from regional strong motion seismometers, like the BC Smart Infrastructure Monitoring System, with physical exposure data from Natural Resources Canada's Human Settlement Layer to report on key metrics for early response: collapsed buildings, entrapment injuries, hospital demand surge, roadway debris which may block response, and immediate mass care needs like shelter requirements. These indicators will be ported to the British Columbia Common Operating Picture Portal, the online situational awareness and mapping platform for authoritative, collaborative and coordinated distribution of emergency management information in the province. These outputs could be made available within tens of minutes of the earthquake occurring, potentially affording emergency managers the opportunity to best direct resources to save lives and reduce suffering.

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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

MOTIVATION

[VIDEO] https://www.youtube.com/embed/y-TBfuZPPVU?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

In the first several hours after an earthquake, situational awareness is a huge challenge. Everyone in the impacted area, regardless of response role, will understandably need to check on loved ones before being able to assist. When they do report for duty, disruptions to road networks and damage to facilities will likely provide significant obstacles to vehicle reconnaissance, and aerial reconnaissance is expected to take hours to tens of hours to initiate. For these reasons, there is almost certainly going to be a period of time following a major earthquake where response efforts are hampered by a lack of knowledge about where exactly the most life-threatening damage has occurred. This same period of time will also be crucial for saving lives by extracting people who are trapped in partially collapsed buildings, and managing hospital resources by ensuring casualties are directed to appropriate medical facilities to meet the expected demand [Goldbaum, 2020].

Fortunately, the Geological Survey of Canada (GSC) has been working on a seismic risk modelling approach, intended for preparedness and risk mitigation, that is fast enough to be applied in a response capacity [Silva & Horspool, 2019]. Through partnerships with the British Columbia (BC) Ministry of Transportation and Infrastructure (MOTI), the Canadian Hazards Information Service (CHIS), and Emergency Management BC (EMBC), a pilot program is being developed for BC. It will respond to the need for situational awareness in the first tens of hours after a major earthquake by leveraging existing instrumentation from MOTI with GSC analysis methodologies, all of which will be communicated by the Province's authoritative source for disaster information, the EMBC GeoBC Common Operating Picture Portal (Fig 1). We are calling this process, by which we deliver earthquake impact estimates directly to emergency managers within tens of minutes of an event, the Rapid Disaster Modelling (RDM) methodology.

STEP 1: FETCH SHAKEMAP FROM MOTI

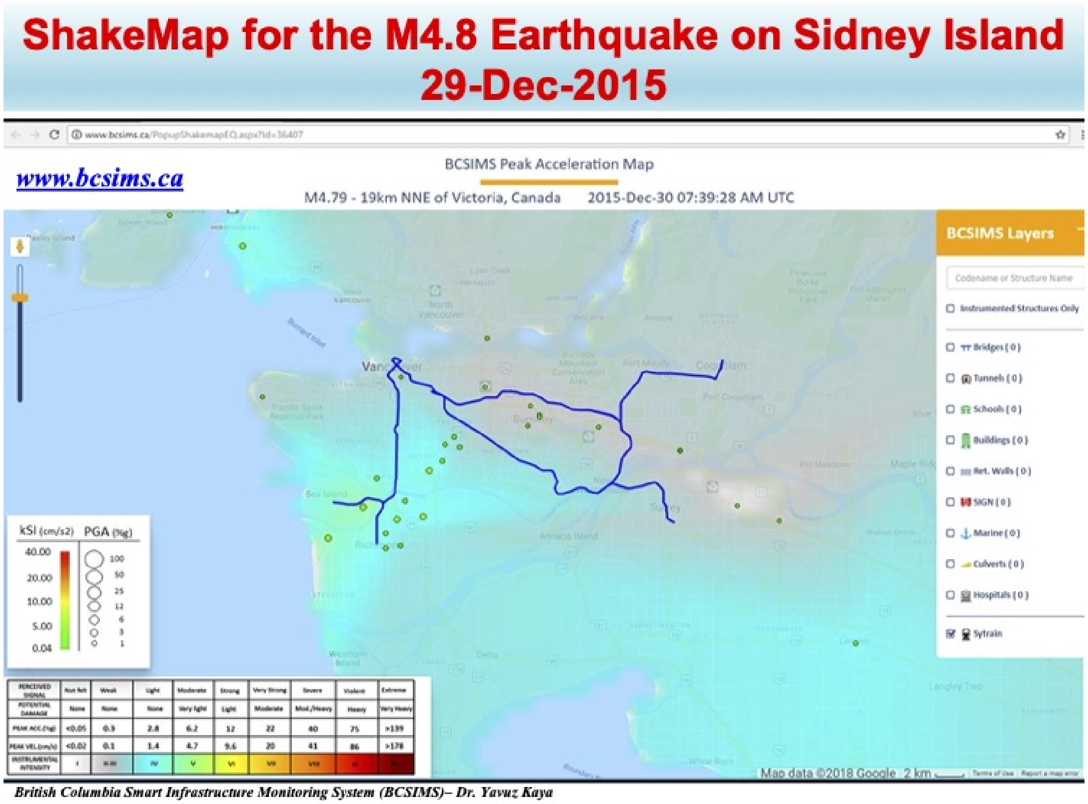


Fig. 3: An example shakemap from MOTI/BCSIMS, showing recorded shaking at sensors (dots, scaled by intensity) and interpolated Modified Mercalli Intensity (shading).

The GSC maintains a network of 120 strong motion seismometers, meanwhile MOTI operates another 40 sensors in addition to their structural monitoring instruments. Through the BC Smart Infrastructure Monitoring System (BCSIMS), all BC earthquakes are automatically reported upon and a shakemap is produced using interpolated observations [Boore & Atkinson, 2008] from the local network (Fig. 3). Amplification is taken into account using local shear wave velocity (vs30) values to account for site effects. Resulting values, in terms of Peak Ground Acceleration, Peak Ground Velocity, and Spectral Acceleration at 0.1, 1.0, and 3.0 seconds, are compiled in a text file in roughly 10-15 minutes and pushed to the BCSIMS website (www.bscims.ca).

STEP 2: RUN OPENQUAKE RISK ANALYSIS

To run the risk analysis, the shakemap must be reformatted for use with the OpenQuake engine [Pagani et al., 2014]. Reformatting the MOTI shakemap involves assigning data points to unique identifiers and splitting the file into 3 files: ground motions, site geometry, and site response. A national building inventory [Journeay et al., 2021] and a standard set of fragility and vulnerability functions [Rao & Silva, 2017] are already available and routinely used by the GSC. From there, the OpenQuake engine is used to calculate the probable damage state at all assets in the exposure database, along with other impacts such as economic losses, casualties, disruptions, and generation of debris. This calculation takes roughly 3-4 minutes, at most, and produces several text files that get pushed to GitHub.

STEP 3: VALIDATE AND CREATE DATABASE

Automatically upon entry of new data to the GitHub repository, scripts will transform the raw earthquake model results into actionable spatial information that can be integrated into a Geospatial Information System (GIS) workflows. This task leverages Python, SQL and PostGIS to:

- Validate underlying data
- Generate Sendai indicator views
- Index the data into an API service

From here, one can access the data via API or through GitHub pages containing GeoJSON and GeoPackage representations, in addition to scenario documentation. API services are aligned to industry standards and leverage caching for low-latency response.

WORKFLOW

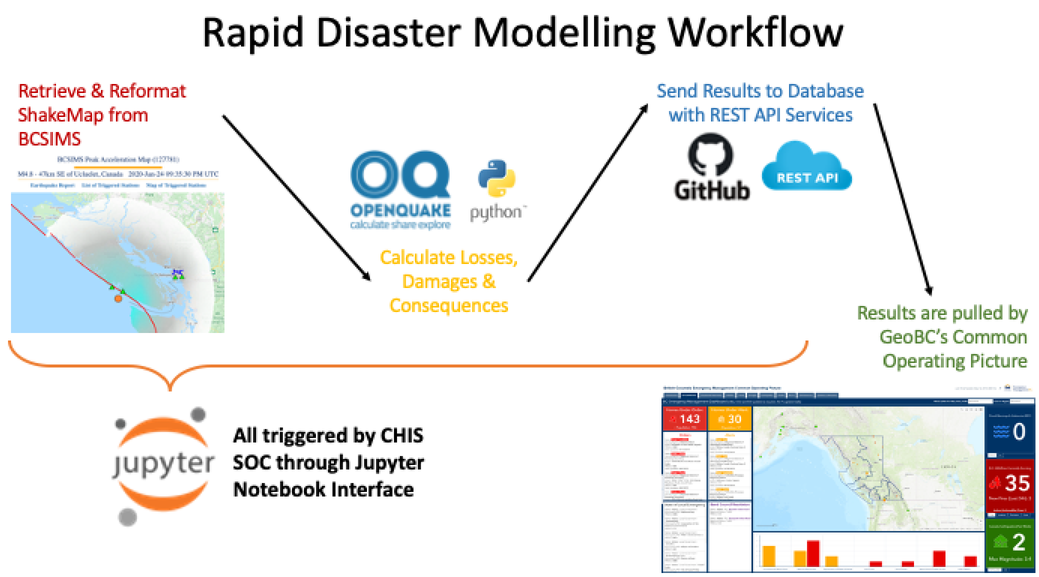
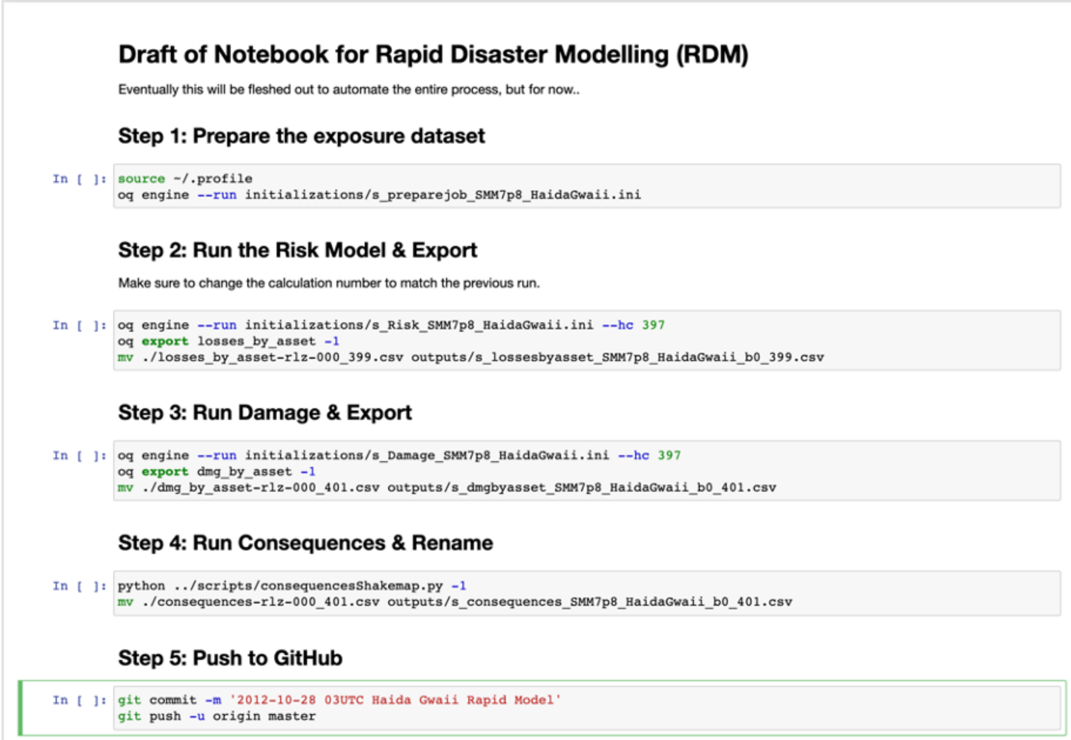


Fig. 1: An overview of the Rapid Disaster Modelling Workflow, from recording of shaking to dissemination of results.

In Canada, two federal seismologists are on call at all times to respond to earthquakes greater than Mw 4.0 across the country. Therefore, this methodology hinges upon one of those seismologists initiating this process, described below, using a simple Jupyter Notebook interface (Fig 2).

1. Obtain shakemap in text format from the MOTI website, and convert format
2. Run the risk analysis, and push results to GitHub
3. Automatically, raw outputs are validated, indexed and entered into a searchable database
4. Results are pulled by EMBC via API, and displayed in a user-friendly dashboard



Draft of Notebook for Rapid Disaster Modelling (RDM)

Eventually this will be fleshed out to automate the entire process, but for now..

Step 1: Prepare the exposure dataset

In [ ]:
```
source ~/.profile
oq engine --run initializations/s_preparejob_SMM7p8_HaidaGwaii.ini
```

Step 2: Run the Risk Model & Export

Make sure to change the calculation number to match the previous run.

In [ ]:
```
oq engine --run initializations/s_Risk_SMM7p8_HaidaGwaii.ini --hc 397
oq export losses_by_asset -1
mv ./losses_by_asset-rlz-000_399.csv outputs/s_lossesbyasset_SMM7p8_HaidaGwaii_b0_399.csv
```

Step 3: Run Damage & Export

In [ ]:
```
oq engine --run initializations/s_Damage_SMM7p8_HaidaGwaii.ini --hc 397
oq export dmg_by_asset -1
mv ./dmg_by_asset-rlz-000_401.csv outputs/s_dmgbyasset_SMM7p8_HaidaGwaii_b0_401.csv
```

Step 4: Run Consequences & Rename

In [ ]:
```
python ../scripts/consequencesShakemap.py -1
mv ./consequences-rlz-000_401.csv outputs/s_consequences_SMM7p8_HaidaGwaii_b0_401.csv
```

Step 5: Push to GitHub

In [ ]:
```
git commit -m '2012-10-28 03UTC Haida Gwaii Rapid Model'
git push -u origin master
```

Fig. 2: A draft of what the Jupyter Notebook might look like, to be used by the GSC seismologist on call in initiating the Rapid Disaster Modelling methodology.

STEP 4: DISSEMINATE RESULTS TO EMERGENCY MANAGERS

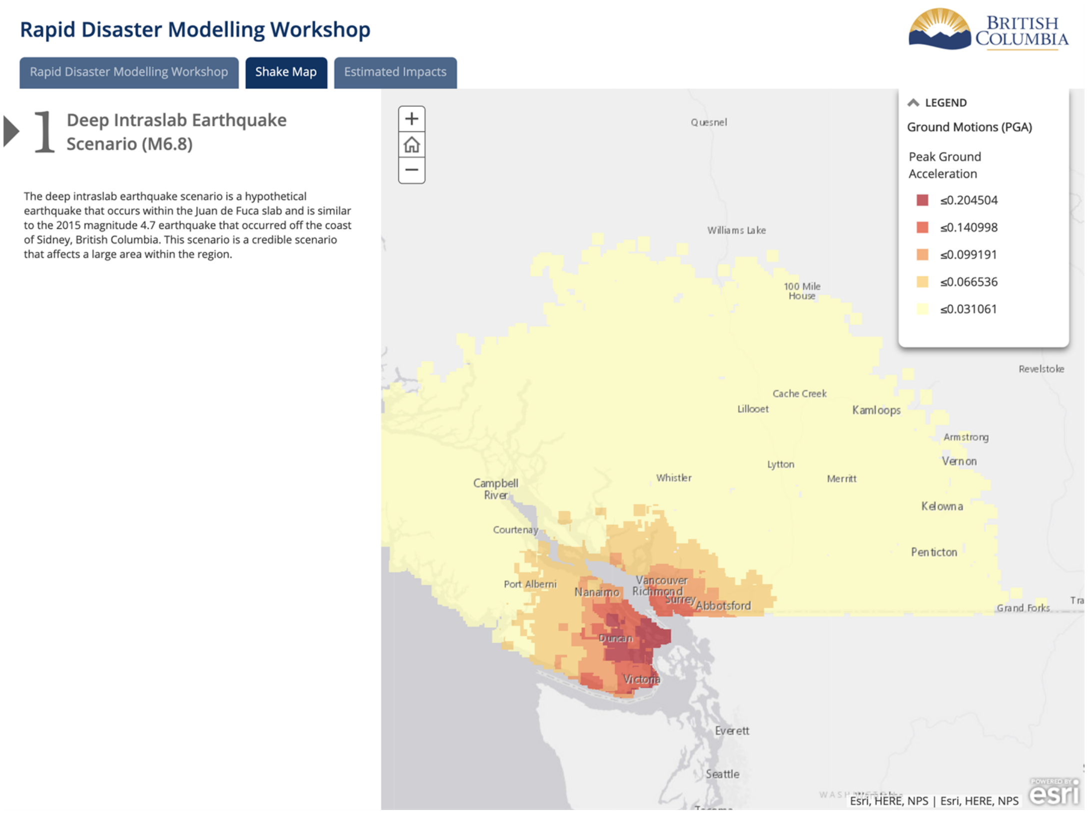


Fig. 4: A screen capture of the current RDM prototype in the COP. This view shows anticipated shaking, in percentage of g, for the Peak Ground Acceleration from a deep Mw 6.8 earthquake scenario off the coast of Vancouver.

The results will then be pulled into GeoBC's online situational awareness platform, the Common Operating Picture (COP). The COP is the single, authoritative source for information during disasters in British Columbia and is used by emergency operations personnel only. Using REST API services with pre-formatted spatial queries, the COP can pull results for the entire suite of Sendai Indicators [Aitsi-Selmi et al., 2015] or just a small set of the most relevant indicators for the event in question:

- Critical entrapment casualties requiring extrication
- Non-critical casualties requiring hospitalization
- Mass care needs (displaced population)
- Roadway disruptions (debris)
- Extent of economic impact

A simplified dashboard will include information about the shaking, before leading into impacts. The user has the option to overlay critical infrastructure or jurisdictional information such as locations of hospitals, roadways, gas pipelines, etc. This is critical for contextualizing and problem solving. These services are built into the ESRI-based COP so municipalities can understand spatial data even if they do not have a robust GIS program in place.

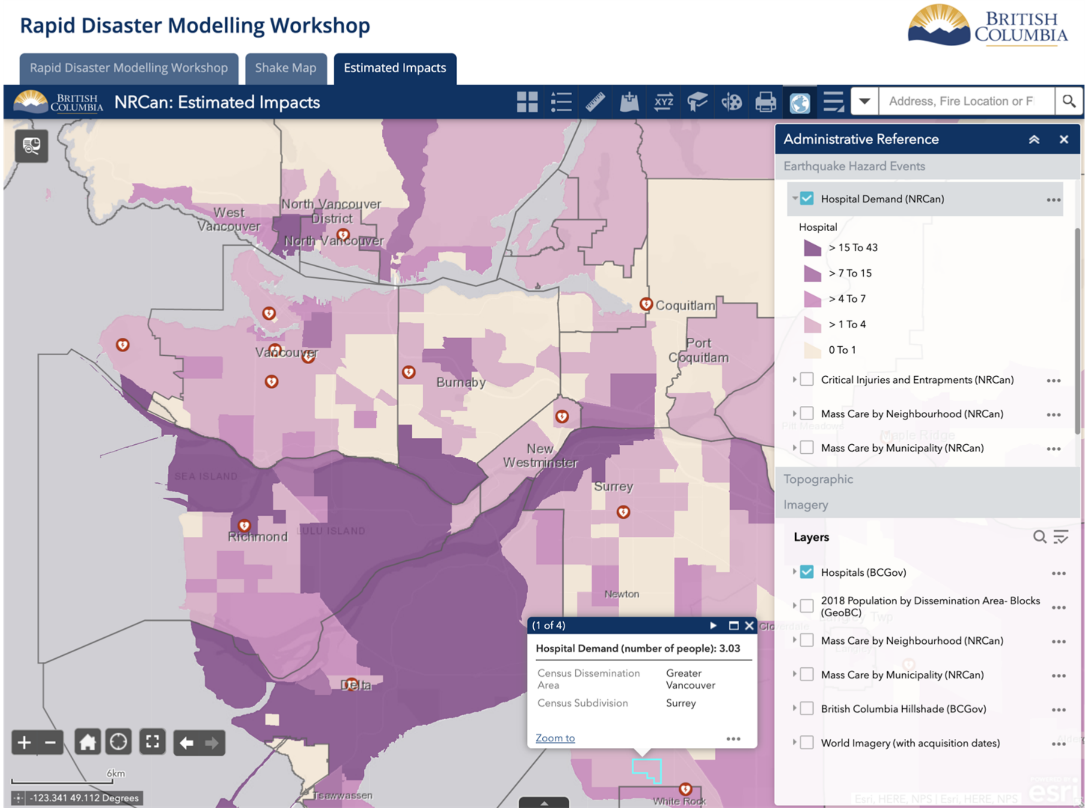


Fig. 5: A screen capture of the current RDM prototype in the COP. This page shows the anticipated impacts of the earthquake, in this case hospital demand in units of people, associated to the Census Aggregated Dissemination Area geometry. Overlain are locations of hospitals. This map would likely signal to an emergency manager the need to try to direct injuries from Delta and Richmond to other hospital facilities such as Vancouver or Coquitlam where possible.

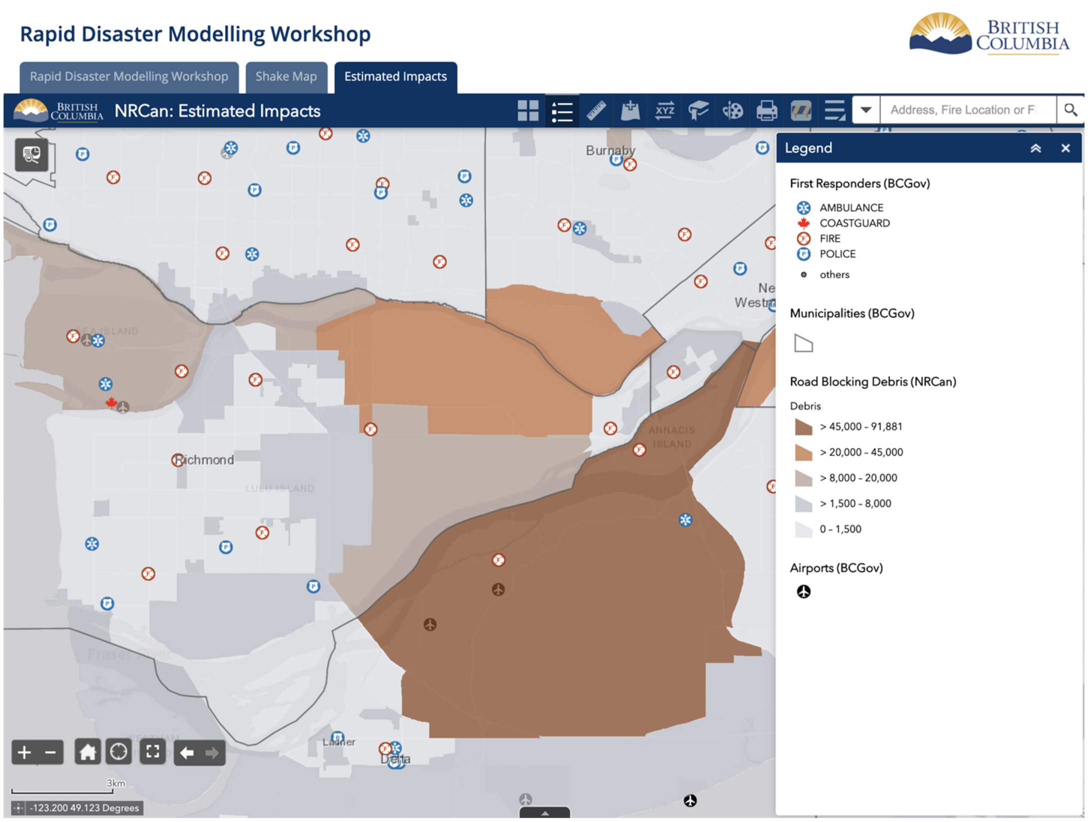


Fig. 6: A screen capture of the current RDM prototype in the COP. This page shows the anticipated impacts of the earthquake, in this case the debris generated in units of tonnes, associated to the Census Dissemination Area geometry. Overlain are the locations of First Responder facilities, Airports, and Helipads. This map would be very useful for understanding how people and aid will be able to move through the disaster zone. It would be expected that Vancouver International

Airport (YVR) on Sea Island (top left) would sustain significant damage and be unable to operate until debris is cleared.

FEEDBACK

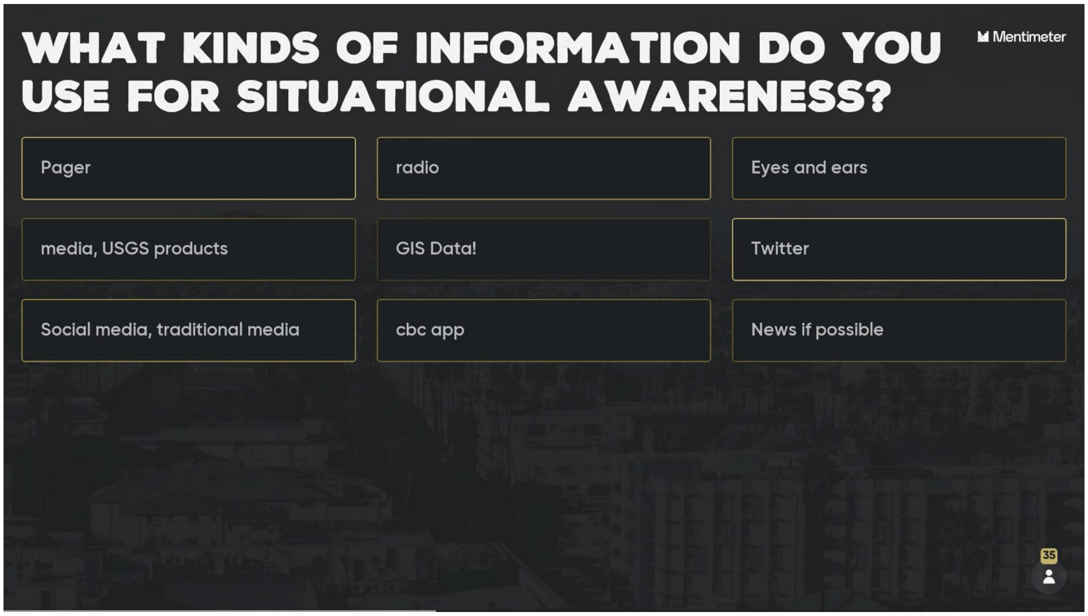


Fig. 7: Results from feedback poll at workshop presentation, where participants were asked what sources they use for situational awareness currently.

A workshop was convened in November 2020 to gather information about current practices, present the prototype to stakeholders, and solicit feedback, as part of the Understanding Risk BC symposium series. Attendees listed the following for situational awareness resources they are currently planning to use (pre-RDM):

- News
- Social Media
- Emails and posts from trusted sources (Earthquakes Canada, response agencies)
- Personal observations such as blocked roads and power outages
- Amateur Radio
- Situation Reports as they become available

When asked what information they or their organization would have access to in the first 1-2 hours, the responses favoured ‘reconnaissance by foot’, ‘monitoring instruments’, and ‘reports from first responders’. These results confirm the motivation expressed above.

Attendees were then shown the prototype, including the scientific and technical underpinnings. Among the feedback collected, attendees recommended (1) expanding this program to include a public facing component, (2) featuring information about social vulnerability or demographics, (3) creating some kind of education program to train users ahead of a disaster, (4) finding a way to blend these results with real observations as they become available, and (5) adding aftershocks to the dashboard. In the future, we will incorporate these recommendations, where possible, as well as continue to refine our visualization approach. For example, heat maps may be a more impactful way to convey extent of damage without compromising privacy of building owners – a concern which was raised by several of the focus groups.

AUTHOR INFORMATION

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