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12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public at https://volpeusdot.github.io/RDR-Public.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) Volpe developed the Resilience and Disaster Recovery (RDR) Tool Suite in support of the USDOT Office of Research, Development and Technology in collaboration with the Federal Highway Administration's Office of Natural Environment. The RDR Tool Suite enables transportation practitioners to assess the return-on-investment of resilient infrastructure across a range of potential hazard conditions to help prioritize resilience investments. This Reference Scenario Library guides users through a suite of example RDR scenarios to demonstrate RDR functionality and required input data. It is complemented by the RDR Tool Suite Technical Documentation, User Guide, Quick Start Guide, and Run Checklist.			
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Contents

Reference Scenario Library: Using this Document 5

Reference Scenario 1: Running the RDR ROI Analysis Tool with new hazard data 7

Reference Scenario 2: Expanding the scenario space and using existing core model runs 10

Reference Scenario 3: Running the RDR Benefits Analysis Tool 12

Reference Scenario 4: Incorporating transit 14

Reference Scenario 5: Setting up a transit network from GTFS files 17

Reference Scenario 6: Creating an RDR scenario from public data 19

Figures

Figure 1: RDR Scenarios Folder Structure 6
Figure 2: Regret Dashboard for Reference Scenario 1 8
Figure 3: Map Dashboard for Reference Scenario 1 9
Figure 4: Regret Dashboard for Reference Scenario 2 11
Figure 5: HTML report section on impact of resilience investment for Reference Scenario 3 13
Figure 6: Network for Reference Scenario 4 15
Figure 7: Regret Dashboard for Reference Scenario 4 16
Figure 8: Regret dashboard for Reference Scenario 6 showing outputs for three hazard scenarios of the Fernbridge resilience project. 21

Reference Scenario Library: Using this Document

This document walks through a suite of example analyses using sample data provided with the Resilience and Disaster Recovery (RDR) Tool Suite. Each "reference scenario" provides an example of one way the user can use the RDR Tool Suite. The first five reference scenarios use model transportation networks for demonstration purposes.

1. Reference Scenario 1 runs a return on investment (ROI) analysis with the same Sioux Falls network as Quick Start 1 in the Quick Start Guide and focuses on modeling an earthquake hazard.
2. Reference Scenario 2 also uses the Sioux Falls network and flooding hazards of Quick Start 1 and shows how to use existing core model runs for an ROI analysis on a different scenario space.
3. Reference Scenario 3 shows how to run the Benefits Analysis Tool for the Sioux Falls flooding scenario.
4. Reference Scenario 4 demonstrates how to incorporate a transit network and no-car trip table into an RDR ROI analysis.
5. Reference Scenario 5 demonstrates how to use the Format Network helper tools to construct the combined road and transit network used in Reference Scenario 4.
6. Reference Scenario 6 walks through how to create an RDR scenario primarily from publicly available data sources and models an earthquake hazard near Ferndale, California. The public data methodology can be adapted by the user for their region to supplement any inputs they already have.

All the reference scenarios' input data can be used as templates for custom scenarios the user may wish to run. The sample input files, network data, and batch files for the Reference Scenario examples are included with the code download from the RDR repository on GitHub (https://volpeusdot.github.io/RDR-Public). The RDR Technical Documentation, User Guide, Quick Start Guide, and a Scenario Run Checklist can also be found on GitHub in the "`documentation`" folder.

Installation instructions for the RDR Tool Suite can be found in the Quick Start Guide as well as the User Guide, which also contains documentation on how to configure components of the tool suite to set up new scenarios. For documentation of the models and technical specifications of the RDR Tool Suite, please reference the Technical Documentation. The user is also encouraged to use the Scenario Run Checklist as a final comprehensive list of input data elements to double-check before running a new scenario.

The RDR directory should contain a "`scenarios`" subfolder. Inside the "`scenarios`" subfolder should be a set of six Reference Scenario examples (in addition to the Quick Start example), as seen in Figure 1; each example is detailed in a subsequent section.

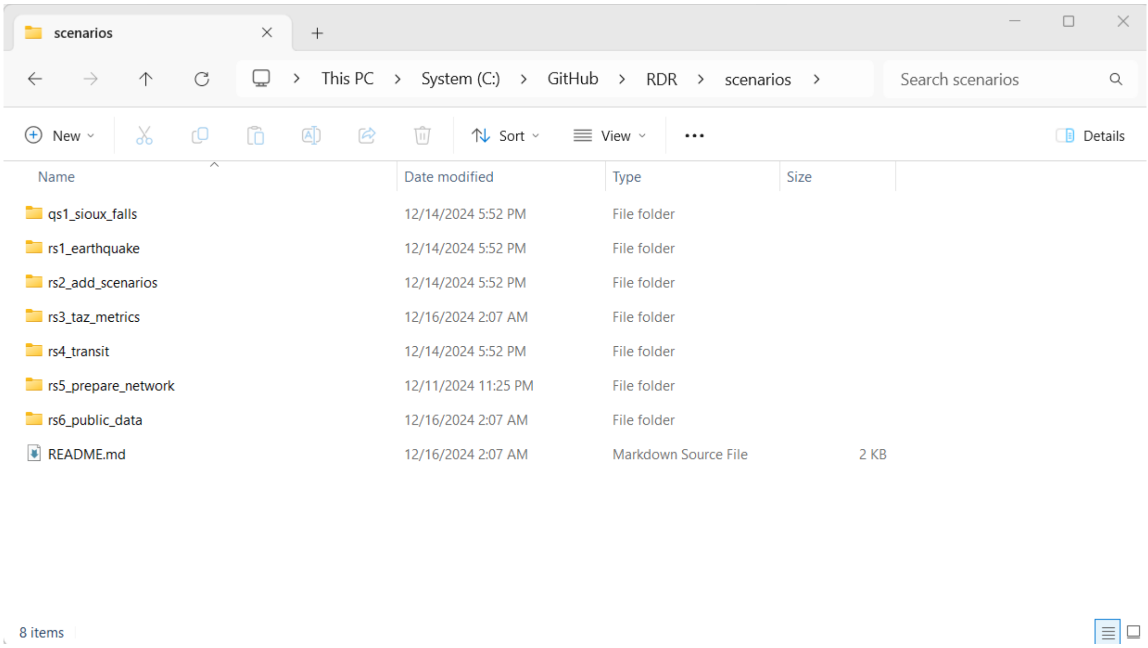

Figure 1: RDR Scenarios Folder Structure

The Reference Scenario examples include batch file(s), configuration file(s), and the required input files to run each analysis. In order to run each Reference Scenario example, the user needs to confirm the configuration file points to the correct input and output folder paths for the Reference Scenario. In addition, the user should confirm the environment variables of the batch file are correct for the user's setup (as described in Section 4 of the User Guide). These sample scenarios can be used to provide examples of input and output files for reference.

Reference Scenario 1: Running the RDR ROI Analysis Tool with new hazard data

Purpose: In this Reference Scenario example, the user can explore an ROI analysis on the same Sioux Falls model network as Quick Start 1 considering a separate set of hazards (e.g., earthquakes). This example shows how the RDR Tool Suite is hazard-agnostic, as long as exposure data is provided in a consistent format (e.g., link-level numerical exposure values). The RDR Tool Suite allows the user to provide custom exposure-disruption and exposure-damage functions for their specific hazard scenarios that relate exposure values to link-level availability and damage based on asset type.

Instructions: To run Reference Scenario 1, execute the batch file '`run_rdr_full.bat`' in the "`scenarios\rs1_earthquake`" subfolder. The run should take <1 minute.

Input Data: The input data for Reference Scenario 1 share several common files with Quick Start 1. The primary changes concern the change in hazards defined in the analysis framework; instead of considering the impact of future flooding hazard scenarios, this example considers the impacts of future earthquake scenarios in the region.

The "`Hazards`" folder contains exposure CSV files for two earthquake hazards ('haz1' and 'haz2'). The hazard 'haz1' represents a moderately strong earthquake, and the hazard 'haz2' represents a slightly stronger earthquake. Each CSV file contains a column representing the damage probability on network links, which are translated to link availability and damage using user-defined exposure-disruption and exposure-damage lookup tables. These lookup tables are referenced in the Reference Scenario 1 configuration file and are located in the "`LookupTables`" folder. See Reference Scenario 6: Creating an RDR scenario from public data for details on how these user-defined relationships were generated.

The parameters of the recovery module have also been changed to reflect earthquake hazards (minimum duration of 1 day, maximum duration of 1 day, 1 hazard recovery case, and hazard recovery period of 0% of initial hazard event duration). The user should also note that they can change parameters for the ROI analysis in the [analysis] subsection of the configuration file in the same manner as recovery parameters were modified in this example. Note that the ROI analysis parameter 'vot_per_hour' does impact link tolls in the AequilibraE core model used to build the regression model, which will require a new run of the RDR Metamodel.

Instead of using the default depth-disruption and depth-damage functions used in Quick Start 1, this example uses user-defined exposure-disruption and exposure-damage calculations ('link_availability_approach' parameter is set to 'Facility_Type_Manual' and 'exposure_damage_approach' parameter is set to 'Manual'). Link availability and damage calculations are defined for each asset type; highway assets and bridge assets in the network are impacted differently. The example continues to use the default repair cost and repair time tables used in Quick Start 1, but the user can modify the configuration file to use a user-defined repair cost table (the user needs to specify the file path using the 'repair_cost_csv' parameter in configuration file, and does not need to specify 'repair_network_type' parameter anymore) and a user-defined repair time table (the user needs to specify the file path using the 'repair_time_csv' parameter) in the same manner.

The example considers three potential resilience projects (a bridge project mitigating hazard exposure on two network links between nodes 1 and 3 labeled 'Bridge1', a highway project mitigating hazard exposure on two network links between nodes 10 and 16 labeled 'Road', and a bridge project mitigating hazard exposure on two network links between nodes 20 and 21 labeled 'Bridge2'), plus the baseline scenario with no resilience investment. All projects partially mitigate the impact of future earthquake hazards to an extent defined in the project link table `'project_table.csv'`, located in the "`LookupTables`" folder. The changes in the scenario space are also reflected in the model parameters XLSX file.

Results: The user should examine the log files in the "`logs`" folder and the output report in the "`Reports`" folder generated by the run to check the run completed successfully.

The main output files are the XLSX file (e.g., `'tableau_input_file_RS1.xlsx'`) and the Tableau workbook `'tableau_dashboard.twbx'` in a timestamped "`tableau_report`" subfolder in the "`Reports`" folder. The uncertainty parameters specified in the `'Model_Parameters.xlsx'` for the ROI analysis lead to 16 total uncertainty scenarios, as seen in the corresponding `'uncertainty_scenarios.csv'` output files. The economic analysis outputs can be seen in Figure 2 in the Regret dashboard of the Tableau data visualization. The overall regret ranking of the three resilience projects shows that resilience project 'Bridge1' ranks first in all four scenarios, with the highest overall regret rank. Note that net benefits and benefit-cost ratios may not exactly match due to the randomness of the Latin hypercube sampling module.

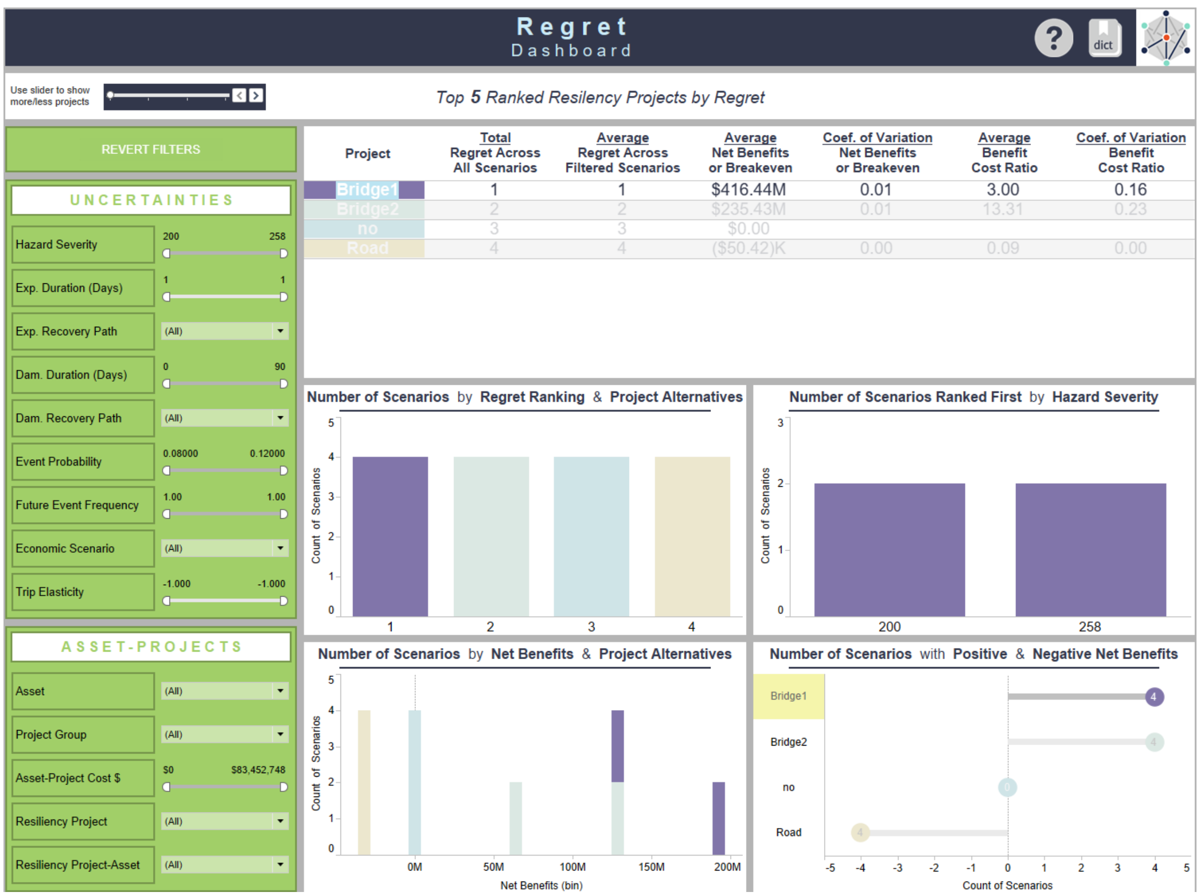

Figure 2: Regret Dashboard for Reference Scenario 1

The 'Bridge1' resilience project on the network link between nodes 1 and 3 had the lowest overall regret rank when considering its impact on network performance, including vehicle safety metrics, across all uncertainty scenarios. While the project has the highest cost, its mitigation of 0.2 MMI of earthquake hazard impact on link capacity and damage on a critical link in the network provides greater future benefits. The 'Bridge2' project also shows positive net benefits, just at a lower magnitude. On the other hand, the 'Road' project mitigates hazard exposure on a network road segment that does not have a loss of capacity during the earthquake hazards (as defined by the exposure-disruption lookup table), so the project costs outweigh the potential benefits. The Map dashboard provides a geospatial representation of these project outcomes (Figure 3).

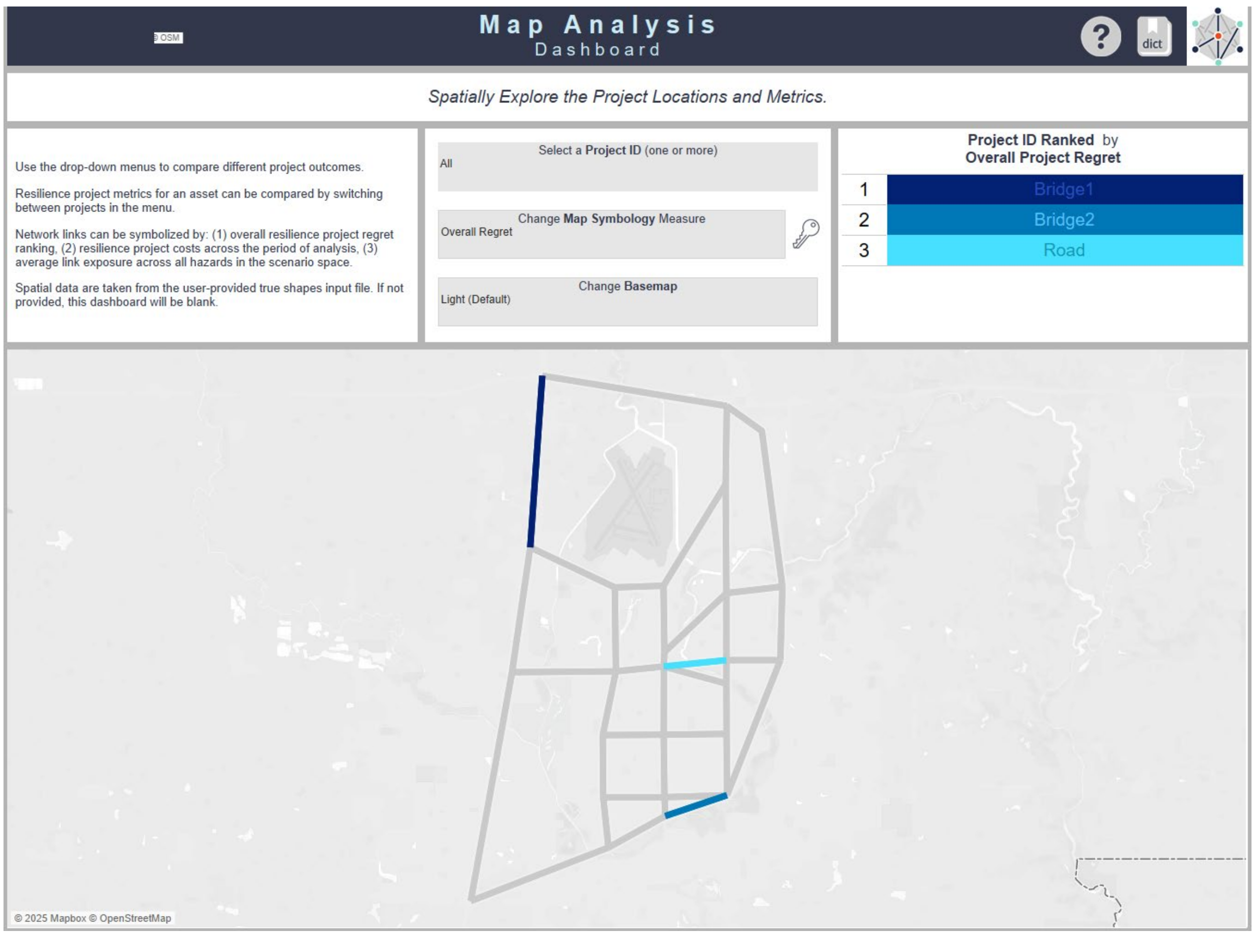

Figure 3: Map Dashboard for Reference Scenario 1

Reference Scenario 2: Expanding the scenario space and using existing core model runs

Purpose: This example completes a full run of the RDR Tool Suite in order to run an ROI analysis with a modified scenario space, as compared to Quick Start 1. Modifying the scenario space requires several additional core model runs for comprehensive coverage, which entails re-running the RDR Metamodel in order to build a new regression model incorporating the new scenario space (e.g., given updated inputs). In addition, this example details how previously run core model runs can be reused for new RDR scenario runs, in the interest of reducing runtime and improving regression fit.

Instructions: To reuse the existing core model runs from Quick Start 1 in this quick start, the user first needs to **manually copy the entire output data folder of Quick Start 1** (e.g., "`C:\GitHub\RDR\scenarios\qs1_sioux_falls\Data\generated_files`") **from the** "`qs1_sioux_falls`" **folder to the** "`rs2_add_scenarios`" **folder to use as the starting output data folder for Reference Scenario 2** (e.g., "`C:\GitHub\RDR\scenarios\rs2_add_scenarios\Data\generated_files`"). In particular, this will pre-populate the core model runs subfolder ("`generated_files\aeq_runs`") with the previously run core model runs. The RDR Tool Suite will automatically add these existing core model runs into the new RDR scenario run. Note that the run ID provided in the Reference Scenario 2 configuration file is 'QS1', not 'RS2', in order to use the Quick Start 1 core model runs; to use existing runs, the RDR scenarios must have the same run ID.

To run the Reference Scenario 2 scenario, execute the batch file '`run_rdr_full.bat`' in the "`scenarios\rs2_add_scenarios`" subfolder. Note that the environment variables in the .bat file may need to be edited to reference the user's paths to the corresponding Python and RDR code files, as noted in Section 4 of the User Guide. The run should take between 1-2 minutes. The command prompt window will ask the user to confirm that they would like to use prior core model runs in the current RDR run; press 'r' to confirm.

Input Data: The modified scenario space can be seen in the model parameters file across all three tabs. In addition, a new hazard exposure file for the new hazard event is included in the "`Hazards`" subfolder of the input data folder, and a new network attribute file for the new project group is included in the "`Networks`" subfolder of the input data folder. Expansions to the scenario space compared to Quick Start 1 include 1 additional project group (given the arbitrary value '00') with 1 potential resilience project (a highway project completely mitigating hazard exposure on 2 network links labeled 'L20-21'), 1 additional hazard event (given the label 'haz3'), and 1 additional recovery stage (possible recovery stages are 0, 1, and 2). As seen in the configuration file, 16 AequilibraE core model runs are specified by the 'lhs_sample_target' parameter to be chosen by the 'lhs' module. The 8 existing core model runs from Quick Start 1 are supplemented by 8 new core model runs to cover the expanded scenario space. The RDR Tool Suite will automatically use the pre-existing core model runs since the output folder and run ID are the same.

Results: The user should examine the log files in the "`logs`" folder and the output report in the "`Reports`" folder generated by the analysis run to check the run completed successfully.

The main output files are the XLSX file '`tableau_input_file_QS1.xlsx`' (in the output data folder for Reference Scenario 2, not Quick Start 1) and the Tableau workbook '`tableau_dashboard.twbx`' in a timestamped “tableau_report” subfolder of the “Reports” folder. The uncertainty parameters specified in the `‘Model_Parameters.xlsx’` for the ROI analysis lead to 72 total uncertainty scenarios, as seen in the `‘uncertainty_scenarios_QS1.csv’` output file. The economic analysis output for these uncertainty scenarios can be seen in Figure 4 in the Regret dashboard for the Tableau data visualization. Note that net benefits and benefit-cost ratios may not exactly match due to the randomness of the Latin hypercube sampling module.

Figure 4: Regret Dashboard for Reference Scenario 2

The new resilience project added in Reference Scenario 2, ‘L20-21’, ends up with the third-best overall regret ranking among projects. Project ‘L2-7’ remains the best-ranked project overall, with the top regret ranking in all 12 scenarios analyzed.

Reference Scenario 3: Running the RDR Benefits Analysis Tool

Purpose: Reference Scenario 3 presents a simple benefits analysis for the Sioux Falls model network, demonstrating use of the Benefits Analysis Tool to analyze the impact of a single resilience project during a single flooding hazard scenario on three categories of transportation analysis zones (TAZs). The scenario space is built upon Quick Start 1 and considers a disaggregate benefits analysis of resilience project 'L15-19'.

Instructions: To run Reference Scenario 3, execute the batch file `'run_TAZ_metrics.bat'` in the `"scenarios\rs3_taz_metrics"` subfolder. The run will complete a benefits analysis and should take less than 1 minute.

The `'run_TAZ_metrics.bat'` file may need to be edited to reference the user's paths to the corresponding Python executable and TAZ metrics code file, as noted in Section 4 of the User Guide. A full description of the analysis is below, including the expected results.

Input Data: As seen in the `'RS3_TAZ_metrics.config'` and `'TAZ_Mapping.csv'` input files, Reference Scenario 3 executes a benefits analysis considering one potential resilience project ('L15-19') and one hazard scenario ('haz1'), with a categorical classification of TAZs associated with the Sioux Falls network. The TAZ categorization is based on the U.S. Census estimates of the percentage of the population in poverty, which are the default classification used by the Benefits Analysis Tool.

Note that a second configuration file (`'RS3.config'`) is included in the input data folder; this is a configuration file for the RDR Metamodel (and is essentially identical to the configuration file for Quick Start 1). Because the Benefits Analysis Tool relies on core model runs to quantify the impacts of the resilience project on different TAZ categories, this configuration file is required and referenced in the `'RS3_TAZ_metrics.config'` file.

Results: The user should examine the log files in the `"logs"` folder to check the run completed successfully.

The main output files of the Benefits Analysis Tool are the HTML report `'MetricsByTAZ_RS3BenefitsAnalysis.html'` and several CSV files generated in the output folder. The HTML report provides a narrative of the analysis steps, along with questions driving the analysis. The disaggregate impact for the TAZ categories is broken down by baseline network performance statistics, relevance and impact of the hazard scenario, and project impact of the resilience project. A series of bar charts (for continuous TAZ categorizations, scatterplots are shown) compare different network performance metrics for the three TAZ categories. Figure 5 provides a selection of the results, showing the impact on number of trips taken, average travel time, and average trip distance for TAZs of each category (where 0 represents a location with less than 10 percent of the population in poverty, 1 represents a location with 10 - 19.99 percent of the population in poverty, and 2 represents a location with 20 or more percent of the population in poverty).[1]

[1] https://www.census.gov/data/experimental-data-products/model-based-estimates-of-2021-persons-in-poverty.html and https://mtgis-portal.geo.census.gov/arcgis/apps/experiencebuilder/experience/?id=ad8ad0751e474f938fc98345462cdfbf&page=EDA-Census-Poverty-Status-Viewer&views=Modeled-Tract-Area-Poverty

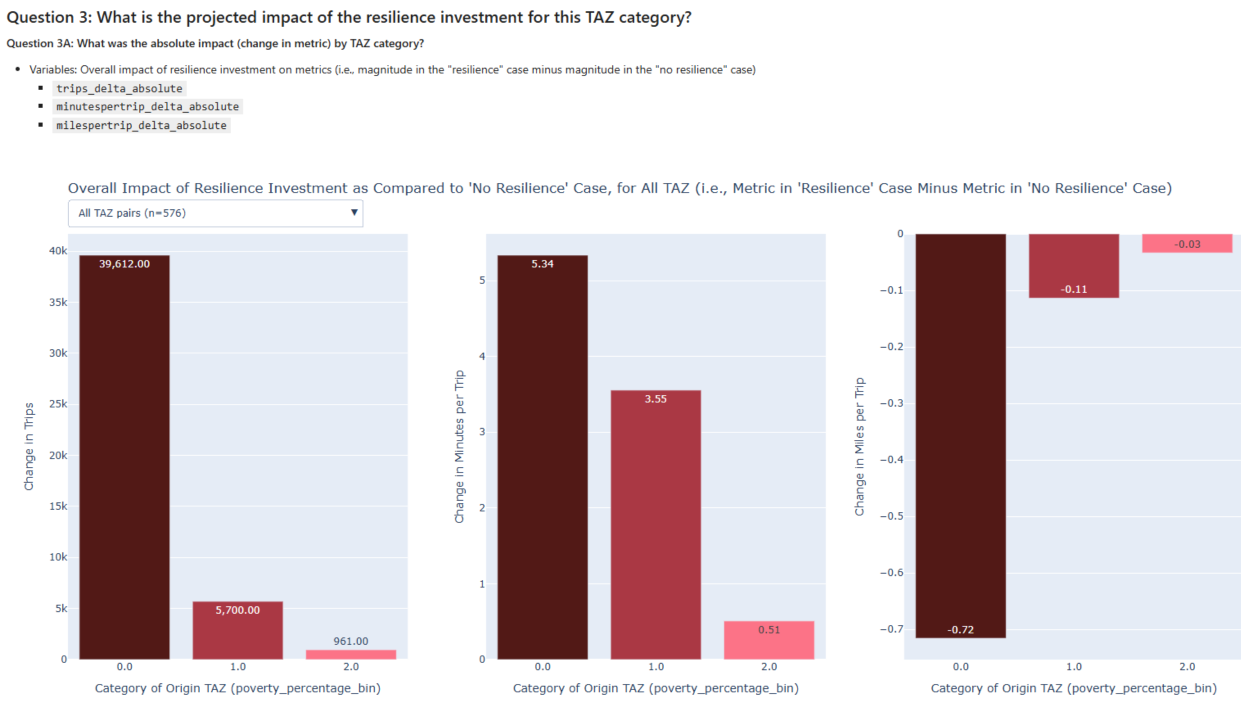

Figure 5: HTML report section on impact of resilience investment for Reference Scenario 3

Reference Scenario 4: Incorporating transit

Purpose: Reference Scenario 4 presents a simple analysis with a small scenario space that includes both a road and transit network. Performance metrics disaggregated by car and transit mode are calculated in the analysis to provide the RDR ROI Analysis Tool with metrics (e.g., transit wait time, transit passenger miles traveled, among others) required for transit-specific calculations of benefits and disbenefits. In addition, this example demonstrates the use of two distinct trip table inputs, one for households owning vehicles and one for no-car households, with corresponding differences in travel time and cost on the road network. Similar to Quick Start 1, it demonstrates how to run a resilience return on investment run with the RDR Tool Suite, including the RDR Metamodel and the RDR ROI Analysis Tool.

Instructions: To run the Reference Scenario 4 scenario, execute the batch file `'run_rdr_full.bat'` in the `"scenarios\rs4_transit"` subfolder. The run will complete a full run of the RDR Metamodel and RDR ROI Analysis Tool, including 6 runs of AequilibraE, and should take about 1 minute.

The `'run_rdr_full.bat'` file may need to be edited to reference the user's paths to the corresponding Python and RDR code files, as noted in Section 4 of the User Guide. A full description of the analysis is below, including the expected results.

Input Data: As seen in the `'Model_Parameters.xlsx'` input file, Reference Scenario 4 executes an ROI analysis considering two potential resilience projects (a road project, labeled 'Road', completely mitigating hazard exposure on network links 9 and 10 connecting nodes 13 and 14, and a subway project, labeled 'Rail', completely mitigating hazard exposure on network links 20 and 21 connecting nodes 23 and 27), plus the baseline scenario with no resilience investment, all within one project group. See Figure 6 for a schematic of the transportation network under disruption.

Note that the input OMX file, located in the `"scenarios\rs4_transit\Data\inputs\AEMaster\matrices"` subfolder, contains two trip table matrices, named 'matrix' and 'nocar', denoting the trips for households owning vehicles and households without vehicles, respectively.

The input network, `'base01.csv'`, contains two sets of tolls and travel times, because the tolls and travel times experienced by 1+ car and 0 car households are different.

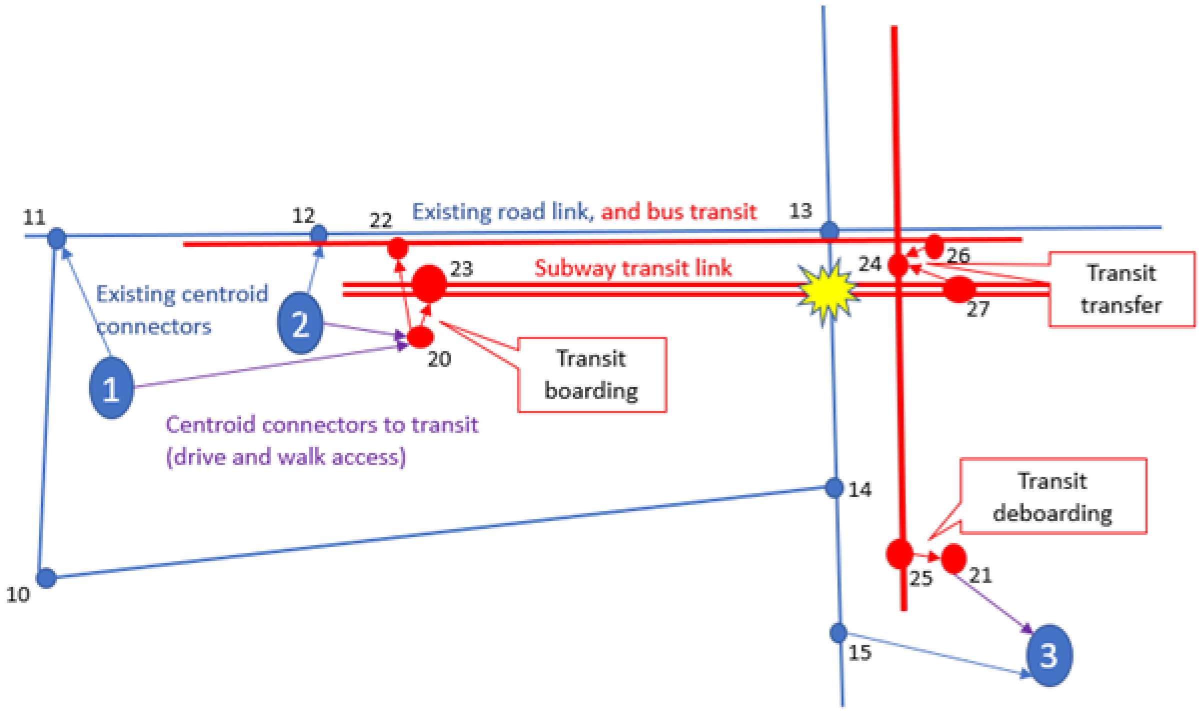

Figure 6: Network for Reference Scenario 4

There is one hazard event ('haz' represents a 10-year river flooding event) and two recovery stages for each hazard event (labeled 0 for the initial hazard severity and 1 for an intermediate hazard recession stage). There is only one possible future economic scenario (labeled 'base') and one possible trip loss elasticity (-1) to consider.

As seen in the configuration file, this analysis specifies 6 AequilibraE core model runs ('lhs_sample_target' parameter is set to 6 in the configuration file). The minimum number of core model runs is three since that is the maximum number of possible values for an uncertainty parameter (there are three possible values for 'Resiliency Projects' including the baseline scenario). AequilibraE is set to use the routing algorithm ('RT') to create core model outputs, which is necessary as well to calculate disaggregate performance measures by mode. The RDR Metamodel is set to use a simple regression model ('base') to expand the core model runs to cover the entire scenario space.

Additional parameters for the recovery module specify a minimum initial hazard event duration of four days and a maximum duration of eight days, with two hazard recovery cases (four days and eight days) and a hazard recession period specified to be four days.

The ROI analysis is run for an analysis period of 2020 to 2045, with base year core model runs specified for 2017, a future year indicated as 2045, and costs all in 2023 dollars. Other parameters are found in the configuration file (discounting factor, vehicle occupancy rate, etc.) and the user inputs file (1 and 1.001 event frequency factors).

Results: The user should examine the log files in the "`logs`" folder and the output report in the "`Reports`" folder generated by the analysis run to check the run completed successfully.

The main output files are the XLSX file `'tableau_input_file_RS4.xlsx'` (in the output data folder for Reference Scenario 4) and the Tableau workbook `'tableau_dashboard.twbx'` in a timestamped "tableau_report" subfolder of the "Reports" folder. The uncertainty parameters specified in the `'Model_Parameters.xlsx'` for the ROI analysis lead to 12 total uncertainty scenarios, as seen in the `'uncertainty_scenarios_RS4.csv'` output file. The economic analysis output for these uncertainty scenarios can be seen in Figure 7 in the Regret dashboard for the Tableau data visualization. Note that net benefits and benefit-cost ratios may not exactly match due to the randomness of the Latin hypercube sampling module.

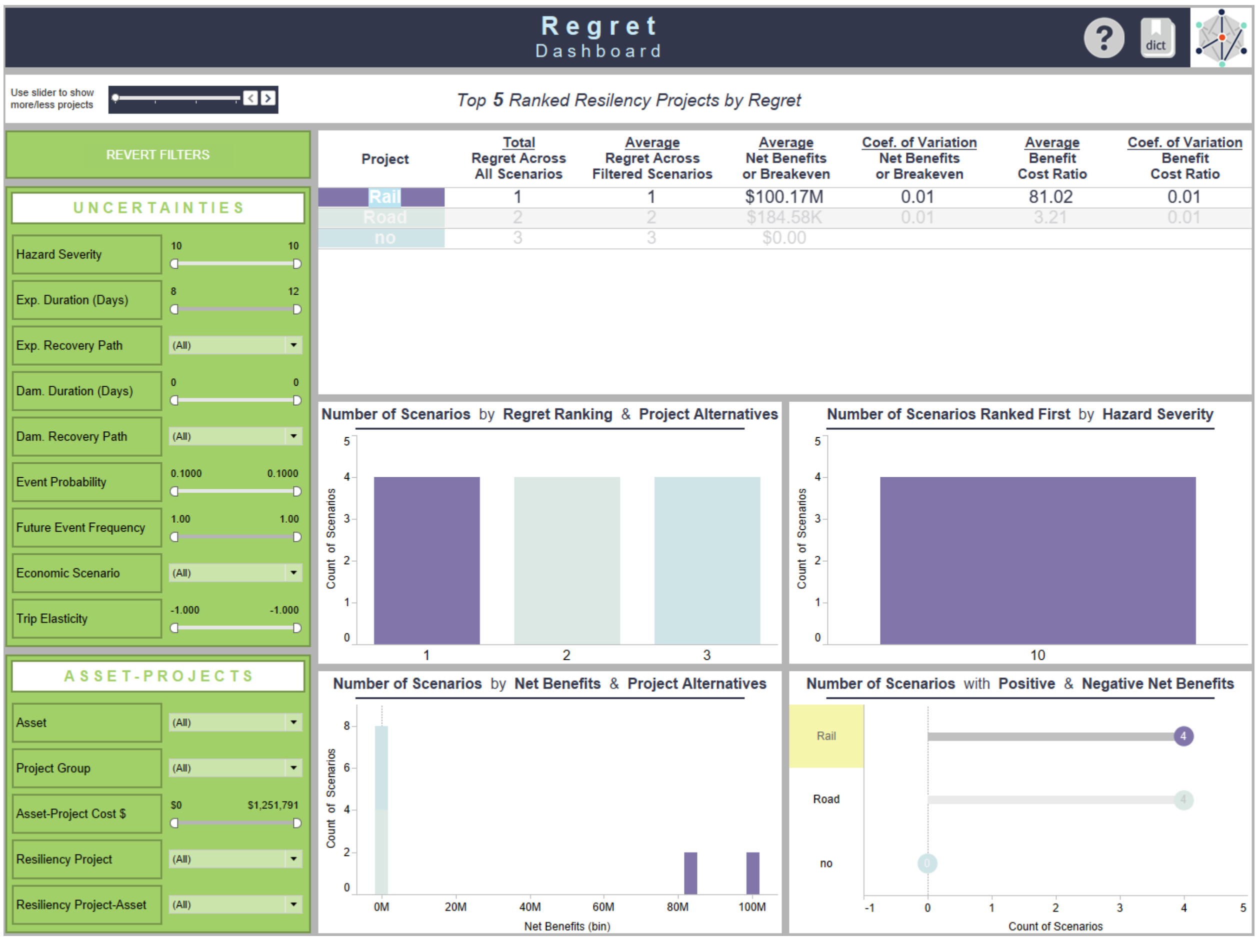

Figure 7: Regret Dashboard for Reference Scenario 4

The resilience project for the transit network, 'Rail' has the best overall regret ranking, with a positive average net benefits, followed by the resilience project for the road network, 'Road', followed by the no-action baseline.

Reference Scenario 5: Setting up a transit network from GTFS files

Purpose: Reference Scenario 5 shows how a transit network suitable for RDR can be built from General Transit Feed Specification (GTFS) files. This example is built from an already-constructed road network, TAZ zones provided as a shapefile, and GTFS files for Reference Scenario 4. It demonstrates the use of the `format_network` helper tools.

Instructions and Input Data: The Format Network helper tools are comprised of three separate batch files, which run through the steps of (1) translating GTFS files for a transit network into the General Modeling Network Specification (GMNS) format, (2) creating transit centroid connectors and combining the transit and road networks, (3) calculating transit-specific tolls and travel times consist with boarding, service, and transfer links, along with separate attributes for households with no vehicles if needed. To run the first step, another GitHub repository is needed as well: https://github.com/VolpeUSDOT/GTFS2GMNS.

1. Download the Volpe GTFS2GMNS repository and unzip the file into the `C:\GitHub` folder on your local machine. The `C:\GitHub\GTFS2GMNS` folder should contain subfolders "`dataset`", "`doc`", "`src`", and "`test`".

2. Navigate to the folder `C:\GitHub\RDR\scenarios\rs5_prepare_network` (assuming you have installed RDR in `C:\GitHub\RDR`).

Three batch files then need to be run:

3. The first executes the GTFS2GMNS code, located in `C:\GitHub\GTFS2GMNS`. Run the `run_gtfs2gmns.bat` batch file. Its inputs are located in `C:\GitHub\RDR\scenarios\rs5_prepare_network\Data\inputs\GTFS_data`, and include the following GTFS files: agency.txt, routes.txt, stop_times.txt, stops.txt, trips.txt. (It does not use shapes.txt). Its output is the GMNS representation of the transit network and is placed in the same directory as the inputs. The two output files are `node.csv` and `link.csv`.

4. The second runs the Prepare RDR Transit Network method, which adds transit centroid connectors and concatenates the road and transit networks. Run the `prepare_rdr_transit_network.bat` batch file. It uses functions from ArcGIS Pro and the `RS5_format_network.config` file for parameters and file locations. Other inputs are located in `C:\GitHub\RDR\scenarios\rs5_prepare_network\Data\inputs` (including the `GTFS_data` and `TAZ_shapes` subdirectories). They are:
    a. `road_node.csv` – nodes of the road network
    b. `road_link.csv` – links of the road network
    c. `GTFS_data\node.csv` – transit nodes generated in the previous step
    d. `GTFS_data\link.csv` – transit links generated in the previous step
    e. `TAZ_shapes\zones.shp` – shapefile of the transportation analysis zones (TAZs)
    f. `GTFS_data\shapes.txt` – shapefile of the transit routes (optional)

    Its output is the combined road and transit links and nodes. Outputs are placed in `C:\GitHub\RDR\scenarios\rs5_prepare_network\Data\generated_files`, and include the following files: `combined_node.csv`, `combined_link.csv`, `gtfs_gis.gdb`. The last file is a geodatabase of transit route shape information that can be used by the Exposure Analysis Tool. Several other intermediate files are also generated.

5. The third runs the Calculate Transit Network Metrics method, which calculates travel times and costs for links in the combined road and transit network. Run the `calculate_transit_network_metrics.bat` batch file. This program adds costs and wait times to the appropriate links, using parameters in `RS5_format_network.config`. Its inputs are the CSV files generated in the previous step: `combined_node.csv`, `combined_link.csv`. Its output is `link_final.csv`. The `link_final.csv` and `combined_node.csv` files can then be used as input to the main RDR process.

Results: The final files should match the network node and link CSV files found in the "`Networks`" folder of Reference Scenario 4.

Reference Scenario 6: Creating an RDR scenario from public data

Purpose: Reference Scenario 6 demonstrates how users can build an RDR scenario from a publicly available road network, travel information, and hazard information. The specific scenario demonstrated uses an example from an earthquake in Ferndale, California, in 2022.

The 2022 Ferndale earthquake damaged roadways in northern California, with several fatalities related to medical emergencies during the quake event.[2] This 6.4 magnitude earthquake occurred near the city of Fortuna, California, with a population of approximately 12,000.

A user of RDR could take this specific historical incident as a scenario, along with a hypothetical even stronger earthquake, and ask how resilience investments could minimize disruption to travel and even save lives.

Details on the processes for how data are generated for this scenario are largely in the User Guide. See the following sections:

Table 1: Index of User Guide sections detailing public data workflows

Public Data Type	User Guide Section
Network Data	3.1.3 RDR Road Network Generation from Public Data
Trip Data	3.2.3 Generating Trip Tables from Public Data Sources
Hazard Data	5.5.1 Ferndale Earthquake Example

This section supplements the information provided in the User Guide with specific directions for how to run this scenario.

In this scenario, there are three hazards, represented in the hazard CSV files in `inputs/Hazards`:

- haz0.csv: This represents a scenario where the 2022 earthquake shaking damaged only the Fernbridge roadway links.
- haz1.csv: This represents a scenario where the 2022 earthquake shaking damaged all bridges identified by the National Bridge Inventory in this area that had potential to be damaged. In this scenario, there are 172 roadway bridge links which have 0 link availability following the earthquake hazard.
- haz2.csv: This represents a scenario where a hypothetical quake stronger than the 2022 earthquake shaking damaged all bridges identified by the National Bridge Inventory in this area that had potential to be damaged. In this scenario, there are 197 bridge roadway links which have 0 link availability following the earthquake hazard.

Instructions: To run Reference Scenario 6, execute the batch file ‘`run_rdr_full.bat`’ in the “`scenarios\rs6_public_data`” subfolder. The run should take <1 minute.

Input Data:

[2] https://en.wikipedia.org/wiki/2022_Ferndale_earthquake

The input data for the 2022 Ferndale Earthquake have been prepared following the Network Data, Trip Data, and Hazard Data steps detailed in the User Guide. The primary public data sources were:

- OpenStreetMap (OSM) for the road network
- the EPA Smart Location Database for trip tables
- the United States Geological Survey (USGS) Earthquake Catalog for hazard data

To modify the earthquake hazard, users can follow steps in `rs6_Public_Data_Prep.ipynb` inside `scenarios\rs6_public_data`. This notebook guides users through the steps of how to use the National Bridge Inventory (NBI) to associate bridges with the road network and determine hazard impact based on bridge attributes.

As in Reference Scenario 1, there are hazard exposure files representing earthquake hazards ('haz0', 'haz1', and 'haz2'). Each CSV file contains a column representing the damage probability value on network links, which are translated to link availability and damage using user-defined exposure-disruption and exposure-damage lookup tables. These lookup tables are located in the "LookupTables" folder.

The process for developing the relationships first depends on the relationships in the FEMA Hazus[3] for translating earthquake shaking to the probability of moderate damage, extensive damage, or collapse for a bridge, given the specific characteristics of each bridge. Bridge characteristics come from the NBI. These FEMA Hazus relationships are referred to as bridge fragility curves. These are summarized to a single damage probability value, assuming that the probability of collapse is a more significant attribute than the probability of moderate or extensive damage, for example. The damage value is then converted into the availability of a bridge link using a conservative estimate for link availability. For example, at even a moderate degree of damage, the availability of a bridge is considered to be very limited because a bridge will likely be closed for inspection at least.

The Ferndale network trip table, constructed from the EPA Smart Location Database as described in the User Guide, is located in the `scenarios\rs6_public_data\Data\inputs\AEMaster\matrices` folder. Note that it is provided in a CSV file instead of an OMX file format to demonstrate RDR's ability to read trip table inputs in either format. RDR will automatically first create an OMX trip table file from the trip table CSV file and the nodes CSV file before running the scenario. For more information on trip table file format specifications, see the User Guide.

In this scenario, a breakeven analysis is conducted by setting the Fernbridge project cost to zero. This allows the user to evaluate a "breakeven" point for consideration of resilience project cost; given the set of future hazard scenarios the region may encounter, with user-provided hazard event probabilities, the net benefits calculated represent the highest cost that will be considered worth investing in the resilience project.

Results:

The Ferndale earthquake example demonstrated in this scenario showcases both the impact of transportation resilience projects on economic benefits as well as potential health and safety benefits. In the Ferndale earthquake, the damage to one major bridge, the Fernbridge, was noted as a factor in

[3] https://www.fema.gov/flood-maps/tools-resources/flood-map-products/hazus/software

delayed medical response, leading to two fatalities. The RDR ROI Analysis Tool focuses on the economic benefits included in US DOT BCA guidance, which includes potential benefits of improved safety and decreased noise and air pollution. Though not covered in this scenario example, the RDR Exposure Analysis Tool can also be used to evaluate emergency service routes for life-saving transportation of people experiencing medical emergencies.

The scenario produces a `generated_files` directory as other RDR runs do. The Tableau dashboard in `generated_files/Reports` shows the results of the breakeven analysis for a resilience project on the Fernbridge when three hazard events are considered. The Fernbridge is the major bridge connecting Ferndale on the south and Fortuna on the north side of the Eel River in California; this is the bridge which was damaged in the 2022 earthquake. A view of the Tableau report is shown in Figure 8.

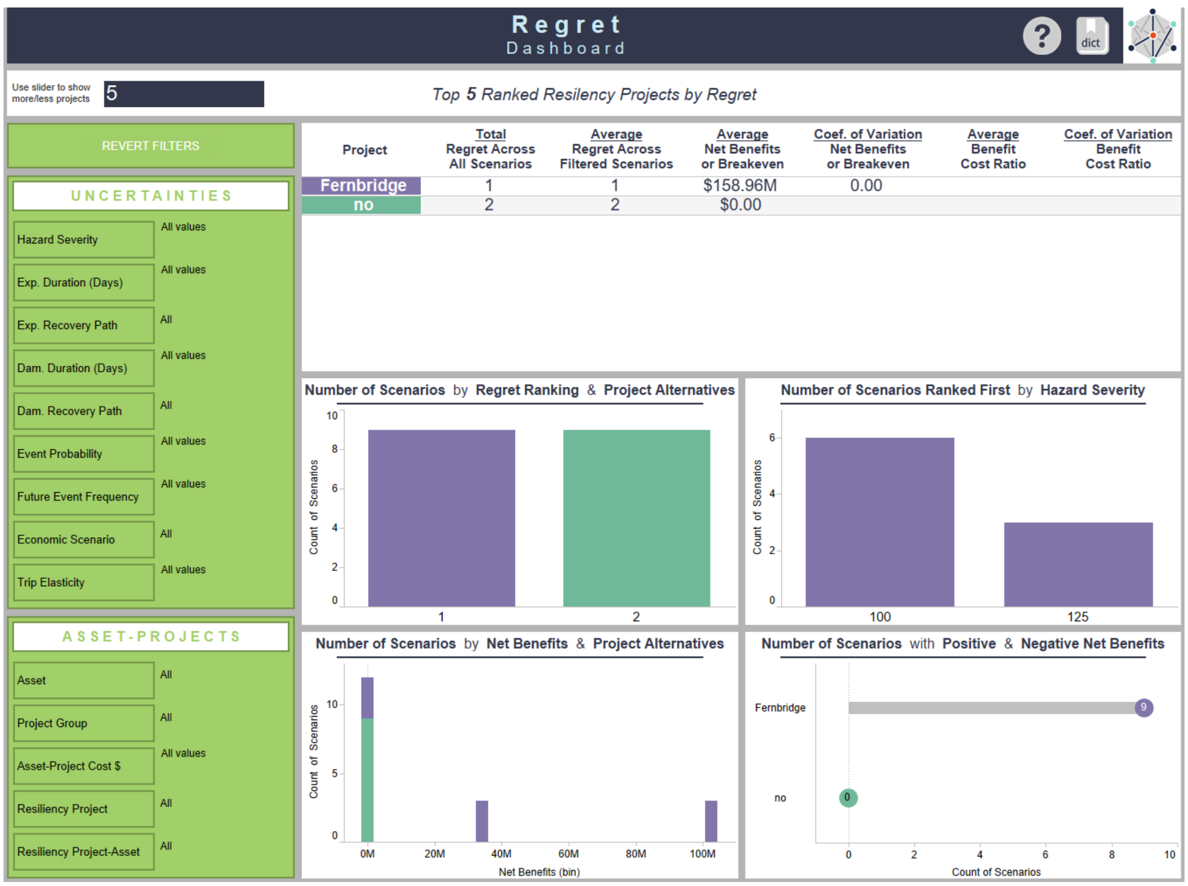

Figure 8: Regret dashboard for Reference Scenario 6 showing outputs for three hazard scenarios of the Fernbridge resilience project.

The Regret dashboard shows the performance of the potential resilience project on the Fernbridge across all nine uncertainty scenarios. As expected, since the project cost is zero, the project outperforms the no-action baseline in every scenario, though the distribution of net benefits (as seen in the lower lefthand panel) varies widely across hazard scenarios. For the most severe hazards, the net benefits of the projects are large. Making Fernbridge resilient to extreme earthquake hazards can lead to significant network performance benefits in the low likelihood of a severe earthquake occurring. Based on this set of future hazard events, a resilience project costing up to $158.96M can be considered worth the investment.