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Supply Chain Infrastructure Restoration Calculator Software Tool -- Developer Guide and User Manual

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A. Ojha et al., "Supply Chain Infrastructure Restoration Calculator Software Tool -- Developer Guide and User Manual," *USGS Numbered Series*, U.S. Geological Survey, Jan 2019.
The definitive version is available at https://doi.org/10.3133/ofr20191061

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Supply Chain Infrastructure Restoration Calculator Software Tool—Developer Guide and User Manual

Open-File Report 2019–1061

U.S. Department of the Interior
U.S. Geological Survey

Supply Chain Infrastructure Restoration Calculator Software Tool—Developer Guide and User Manual

By Akhilesh Ojha, Bhanu Kanwar, Suzanna K. Long, Thomas G. Shoberg, and Steven Corns

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

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Suggested citation:
Ojha, A., Kanwar, B., Long, S.K., Shoberg, T.G., and Corns, S., 2019, Supply chain infrastructure restoration calculator software tool—Developer guide and user manual: U.S. Geological Survey Open-File Report 2019–1061, 17 p., https://doi.org/10.3133/ofr20191061.

ISSN 2331-1258 (online)

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
	Power	
kilowatt (kW)	1,000	watt (W)
	Volume	
gallon (gal)	3.785	liter (L)

Abbreviations

SCIRC supply chain infrastructure restoration calculator

XML Extensible Markup Language

Supply Chain Infrastructure Restoration Calculator Software Tool—Developer Guide and User Manual

By Akhilesh Ojha,[1] Bhanu Kanwar,[1] Suzanna K. Long,[1] Thomas G. Shoberg,[2] and Steven Corns[1]

Abstract

This report describes a software tool that calculates costs associated with the reconstruction of supply chain interdependent critical infrastructure in the advent of a catastrophic failure by either outside forces (extreme events) or internal forces (fatigue). This tool fills a gap between search and recover strategies of the Federal Emergency Management Agency (or FEMA) and construction techniques under full recovery. In addition to overall construction costs, the tool calculates reconstruction needs in terms of personnel and their required support. From these estimates, total costs (or the cost of each element to be restored) can be calculated. Estimates are based upon historic reconstruction data, although decision managers do have the choice of entering their own input data to tailor the results to a local area.

Introduction

Supply chain interdependent critical infrastructure has been defined as those elements of the national infrastructure that are so vital that their incapacity or destruction would have a debilitating effect on the defense or economic security of the United States (Executive Order 13010 of July 15, 1996). Modeling supply chain interdependent critical infrastructure restoration is a challenging problem (Ramachandran and others, 2015, 2016). The innate interdependencies between various critical infrastructures add to the complexity of the system. Extreme events such as earthquakes, hurricanes, and the like can disrupt various critical infrastructures, leading to considerable economic losses. Based on the severity of the extreme event, one or more infrastructures can be rendered partially or completely inoperable.

This report presents a developer's guide and a user tutorial for a supply chain infrastructure restoration calculator (SCIRC) tool that estimates the amount of resources required to restore infrastructure networks. This tool was developed as part of a joint effort between the U.S. Geological Survey, Center of Excellence for Geospatial Information Science and the Engineering Management and Systems Engineering Department at Missouri University of Science and Technology. For this report, resources include potable water, gray water, food, sanitation facilities, housing, transportation, and other basic requirements of restoration crews along with the supplies (such as power, fuel, materials, and costs) required for restoring these infrastructures. It is important to estimate the amount of resources required to restore disrupted critical infrastructures to devise efficient disaster restoration and management strategies. This tool can be used by city planners and policy makers to calculate the amount of resources required for restoring one or multiple infrastructures to their normal operating state and for budgeting and prioritizing postdisaster restoration operations.

The SCIRC tool is written as open-source software in the Python programming language and uses a bottom-up cost estimation technique to collect data associated with each infrastructure facility. These data include the amount of resources required to build a unit of each infrastructure element; for example, the amount of power, fuel, potable water, storage area, man-hours, food, materials, gray water, solid waste, and black water required to build 1 square foot (ft^2) of a high school. These data are collected for each of the infrastructure elements represented in the SCIRC tool. The estimation of cost, material, and number of restoration crew necessary for disaster recovery is a unique feature of the SCIRC tool. Once this information is available, policy makers will be able to make more efficient decisions regarding the allocation of the resources for disaster restoration.

Software

The SCIRC tool is written in the Python 2.7 programming language. The SCIRC algorithm (fig. 1) is designed to solve a system of equations to simultaneously determine resource requirements using established methods (Nottage and Corns, 2011). The SCIRC tool application queries the user to input the number of units of an infrastructure element that needs to be restored and then returns the amount of resources required for restoration, or in the advent of a large-scale

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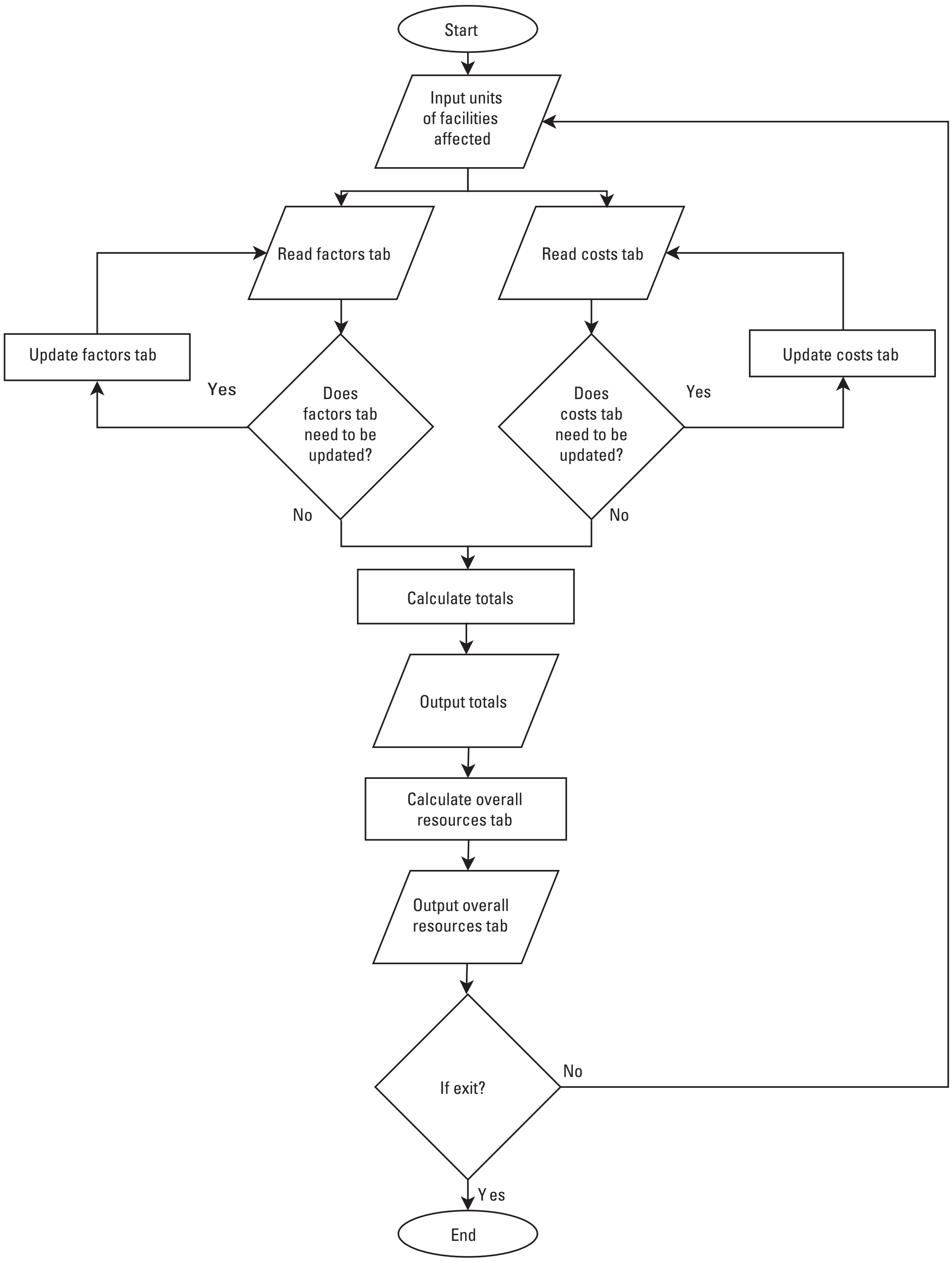

Figure 1. Algorithm for the supply chain infrastructure restoration calculator tool.

disaster, the user can also calculate the amount of resources required to restore multiple infrastructure elements.

The SCIRC tool includes five tabs:

1. *Facilities affected.*—This tab includes a list of infrastructure elements from which the user can choose one or many to restore. The 30 infrastructure elements that are included in the software, along with their units, are listed in table 1.

2. *Factors.*—This tab delineates the resources required to restore each unit of a selected infrastructure element. The user selects an element from the drop-down menu available in the factors tab to determine the amount of resources required to build a unit of that element. Although standard values for the resources required to restore one unit of an element are default values in the software, the tool does provide the user with an option to change these values in the factors tab based on the user's expertise or locale. Different types of resources, along with their units, are listed in table 2.

3. *Totals.*—This tab lists the amount of each resource required to restore the infrastructure elements specified by the user. The user selects an element from the drop-down menu in the totals tab to calculate the amount of resources needed to restore the specified number of elements. Along with the resources included in the factors tab, the totals tab also includes a total cost estimate, specifically the summation of all costs of the required restoration resources.

4. *Costs.*—This tab lists the unit costs of each resource. The values in the costs tab are preloaded into the software. The software provides the user with an option to update the costs in the application. It is important to note that the costs of resources provided in the costs tab refer to the cost of one unit of each resource, whereas the cost provided in the totals tab refers to the total cost of restoring a specified number of units of an infrastructure element as specified by the user.

5. *Overall resources.*—This tab lists the resources required to restore all the infrastructure elements specified by the user. The tab sums the individual resources required to restore each of the elements and reports the totals. In other words, if the user inputs in the facilities affected tab a request to restore one infrastructure element, the overall resources tab will return the resources required to restore that element, whereas if the user requests restoration of 10 occurrences of a given infrastructure element in the facilities affected tab, the overall resources tab will provide the amount of resources required to restore those 10 elements.

Mathematical Framework for the Application

The user specifies the number of units of one or more infrastructure elements that need to be restored. If the user wanted to restore x units of the element i, the resources are denoted by j, and the SCIRC tool would multiply the number of units, x, with each resource in the factors tab for the element i. In table 3, equations 1–10 give the formula for calculating the total amount of each resource required to restore an element i. In table 3, equation 11 refers to the total cost of restoring x units of element i. Cj in equation 11 denotes the cost of one unit of resource j.

Following the equations described above, totals for multiple elements are calculated. The overall resources are calculated using equation 12.

$$OR_{ij} = \sum_{i=j}^{30} T_{iJ} \quad \forall j = 1, 2, 3, \ldots \ldots ., 11 \qquad (12)$$

where

OR_{ij} is the overall resource for the ith infrastructure element, and

j is the resources included in the overall resources tab.

If there is only a single occurrence of an element to be restored, then the values in the totals tab and overall resources tab remain the same. If multiple occurrences or elements are to be restored, the overall resources tab indicates the total amount of resources required to restore all occurrences for all elements.

Installation

The SCIRC tool is stored as a Python 2.7 executable file for the ease of the user. This application requires minimal effort for installation. The application is provided as an executable file format. The user can download the file from the Geoplatform link (https://communities.geoplatform.gov/disasters/supply-chain-infrastructure-restoration/). Once the file has been downloaded, the user must double-click the saved file and select the run option in the dialog box. The user can now choose the location where the tool will be installed. After the software has been installed, the user can now double-click on the executable file to run the application. The user's computer must meet the minimum system requirements before installing and running the SCIRC application. The system requirements are shown in table 4.

Table 1. List of the facilities included in the software, the description for each facility, and the unit in which each facility is measured.

Facility	Description	Unit
Electrical distribution	Electrical power lines to deliver electricity	Miles.
Coal power plant	Coal-based power plants for electrical generation	Kilowatts.
Nuclear power plant	Nuclear-based power plants for electrical generation	Kilowatts.
Wind farm	Wind turbines-based power plants for electrical generation	Kilowatts.
Natural gas distribution	Steel pipes (10-inch diameter) used for natural gas distribution	Miles.
Water distribution	Network of pipes used to distribute water for domestic and commercial use	Miles.
Water purification	Water treatment plants to purify water	Gallons.
Sewage treatment	Wastewater treatment plants	Gallons.
Warehouse	Warehouse to store goods, supplies, and the like	Square feet.
Wireless towers	Cellular towers in a cellular network	Units.
Wired networks	Optical cable lines for fiber optic internet connection	Miles.
Communication centers	Emergency response centers	Square feet.
Hospital facilities	Super specialty multibed healthcare facility	Square feet.
Fire stations	Facilities with fire engine, fire fighters, fire-retardant materials and equipment, and the like	Square feet.
Police stations	Facilities accommodating police personnel	Square feet.
Railway networks	Railway track lines to transport goods and ferry people	Miles.
Railway bridges	Bridges used by railways to transport goods and passengers over roads, ravines, and the like	Square feet.
Roadway bridges	Bridges used by motor vehicles to transport goods and passengers over roads, rivers, and the like	Square feet.
Elementary schools	From kindergarten through grade 6	Square feet.
Middle schools	From grade 7 through grade 9	Square feet.
High schools	From grade 10 through grade 12	Square feet.
Air freight facilities	Facilities to ship and receive air cargo	Square feet.
Air passenger facilities	Domestic and international airports	Square feet.
Arterial roads	Major and minor roads passing through a town/city	Square feet.
Water freight facilities	Facilities to ship and receive cargo using riverboats and barges	Square feet.
Interstates	Highways connecting two or more States	Square feet.
Traffic signals	Standard traffic signal poles	Units.
Street lights	Standard street lighting poles	Units.
Rail freight facilities	Facilities to ship and receive cargo using railways	Square feet.
Rail passenger facilities	Railway station to transport passengers	Square feet.

Table 2. List of resources, a description for each resource, and the unit in which the resource is measured.

[The table includes a description for each resource and the unit in which the resource is measured; *F*, factor; *i*, element]

Factor	Description	Unit
Power (F_{i1})	Electric power needed for restoration tools and operations	Kilowatts per unit of the facility.
Fuel (F_{i2})	Amount of gas needed to run power generator, tools, and construction equipment	Gallons per unit of the facility.
Potable water (F_{i3})	Amount of clean drinking water needed by the restoration crew	Gallons per unit of the facility.
Storage area (F_{i4})	Storage space used by restoration crew to store goods, tools, and the like	Square feet per unit of the facility.
Man-hours (F_{i5})	Labor hours spent by personnel working on restoration activities	Hours per unit of the facility.
Gray water (F_{i6})	Water used for restoration and construction activities	Gallons per unit of the facility.
Black water (F_{i7})	Wastewater containing fecal matter	Gallons per unit of the facility.
Solid waste (F_{i8})	Garbage, construction waste, and the like	Pounds per unit of the facility.
Food (F_{i9})	Amount of food items needed by the restoration crew	Pounds per unit of the facility.
Materials (F_{i10})	Construction material required to construct respective facilities	U.S. dollars per unit of the facility.

Table 3. Mathematical equations for the totals tab.

[*T*, total; *i*, element; *x*, number of units; *F*, factor; *j*, resource; C_j, cost of one unit of resource *j*]

Definition	Equation
T_{i1} refers to the amount of power required to restore *x* units of facility *i*	$T_{i1}=x \times F_{i1}$ (eq. 1).
T_{i2} refers to the amount of fuel required to restore *x* units of facility *i*	$T_{i2}=x \times F_{i2}$ (eq. 2).
T_{i3} refers to the amount of potable water required to restore *x* units of facility *i*	$T_{i3}=x \times F_{i3}$ (eq. 3).
T_{i4} refers to the amount of storage area required to restore *x* units of facility *i*	$T_{i4}=x \times F_{i4}$ (eq. 4).
T_{i5} refers to the amount of man-hours required to restore *x* units of facility *i*	$T_{i5}=x \times F_{i5}$ (eq. 5).
T_{i6} refers to the amount of gray water required to restore *x* units of facility *i*	$T_{i6}=x \times F_{i6}$ (eq. 6).
T_{i7} refers to the amount of black water generated while restoring *x* units of facility *i*	$T_{i7}=x \times F_{i7}$ (eq. 7)
T_{i8} refers to the amount of solid waste generated while restoring *x* units of facility *i*	$T_{i8}=x \times F_{i8}$ (eq. 8).
T_{i9} refers to the amount of food required to restore *x* units of facility *i*	$T_{i9}=x \times F_{i9}$ (eq. 9).
T_{i10} refers to the amount of materials required to restore *x* units of facility *i*	$T_{i10}=x \times F_{i10}$ (eq. 10).
T_{i11} refers to the total cost incurred to restore *x* units of facility *i*	$T_{i11} = \sum_{j=1}^{10} (T_{ij} \times C_j)$ (eq. 11).

Table 4. System requirements to run the supply chain infrastructure restoration calculator application.

System type	System requirements
Central processing unit (CPU)	1 gigahertz (GHz) or 32-bit (×86) or 64-bit (×64) processor.
Random access memory (RAM)	1 gigabyte (GB, 32 bit) or 2 GB (64 bit).
Disk space	60 megabytes (MB).
Operating system	Microsoft Windows version 7 or newer.

Tutorial

Launching the application.—To launch the application, double-click on the SCIRC executable file (SCIRC.bat).

User interface.—Once the application is launched, the user will see the main interface page of the software (fig. 2). The facilities affected, factors, costs, and totals tabs are accessible as the top field of the table, whereas the overall resources tab is accessible in the horizontal bar positioned after the first bank of input/output boxes.

Input.—The user can input values for the desired infrastructure element in the box adjacent to that element (fig. 3); for example, to calculate the amount of resources required to restore 487,000 ft^2 of a high school, the user should complete the following steps:

1. Click on the box adjacent to the high schools label.
2. Input the value 487,000 in the box and press the enter key on the keyboard.

The user can also input values for multiple facilities using the above steps. The user can click on the reset button at any time to make all the values in the facilities affected tab zero.

Output.—Once the user has input the values in the facilities affected tab, the output can be seen in the overall resources and totals tabs (figs. 4 and 5, respectively). The user accesses the amount of resources required to restore an individual element as follows:

1. Click on the totals tab.
2. Click on the select facility drop-down menu.
3. Click on the element that the user wants to select from the drop-down menu. The amount of resources required to restore the user-specified units of the select facility can be viewed now (fig. 5).

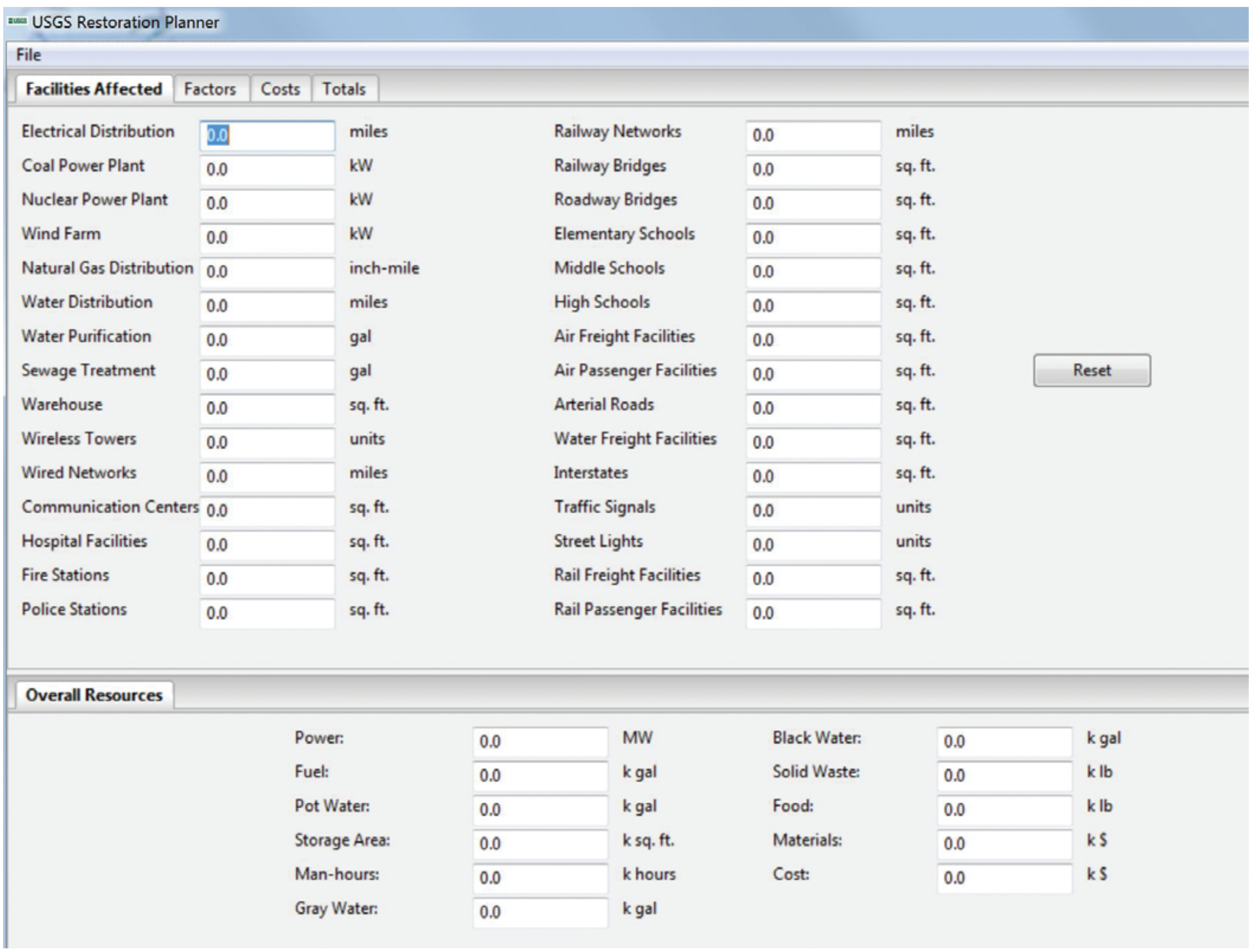

Figure 2. User interface as seen when the application is launched.

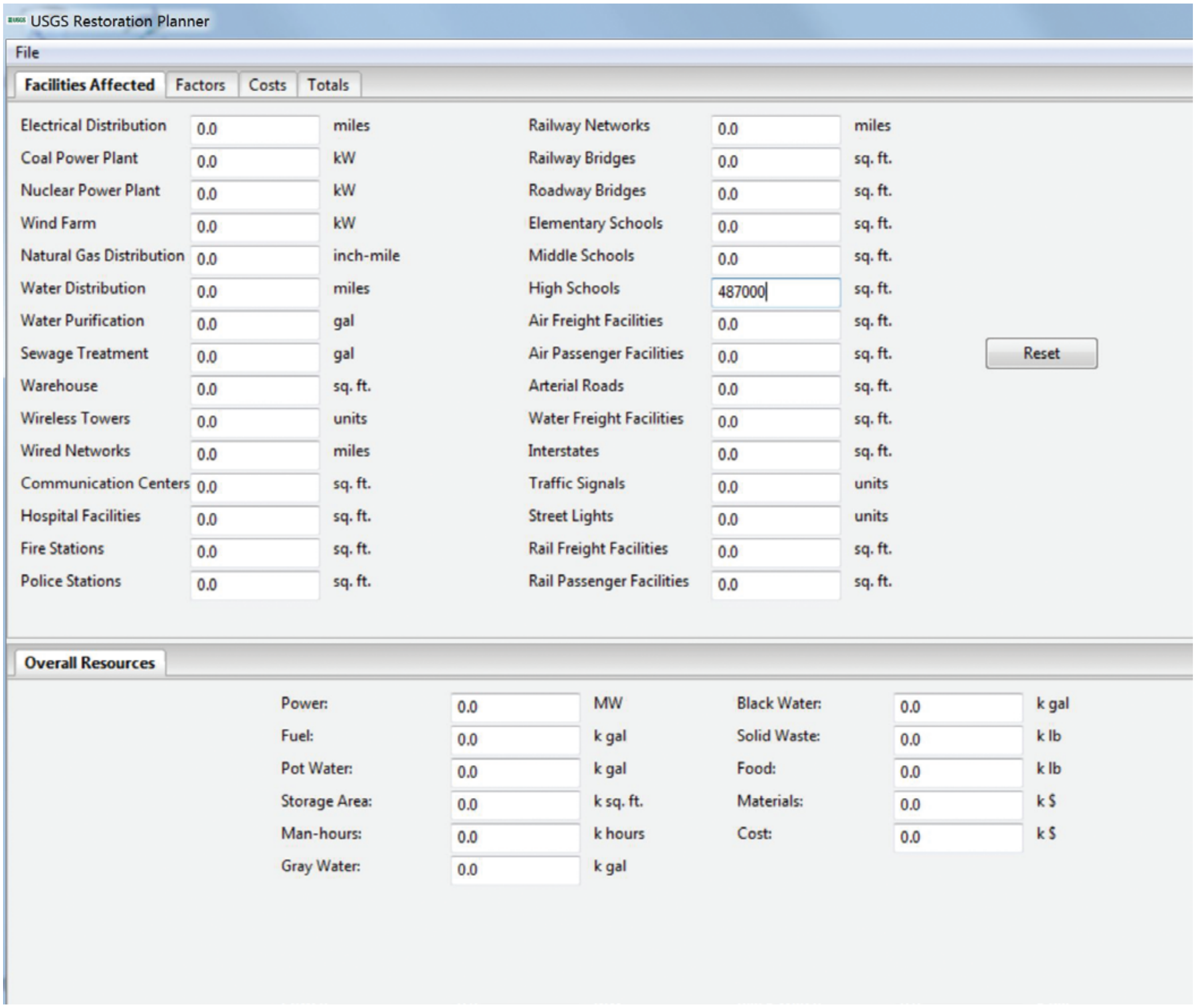

Figure 3. The user entering the value in the box adjacent to the high schools label.

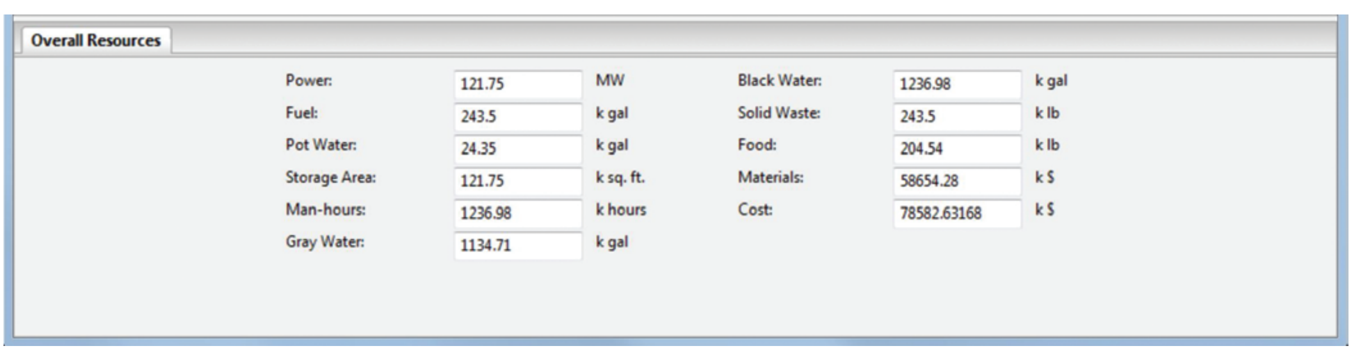

Figure 4. Overall resources tab where the user can view the amount of resources required to restore one or more facilities.

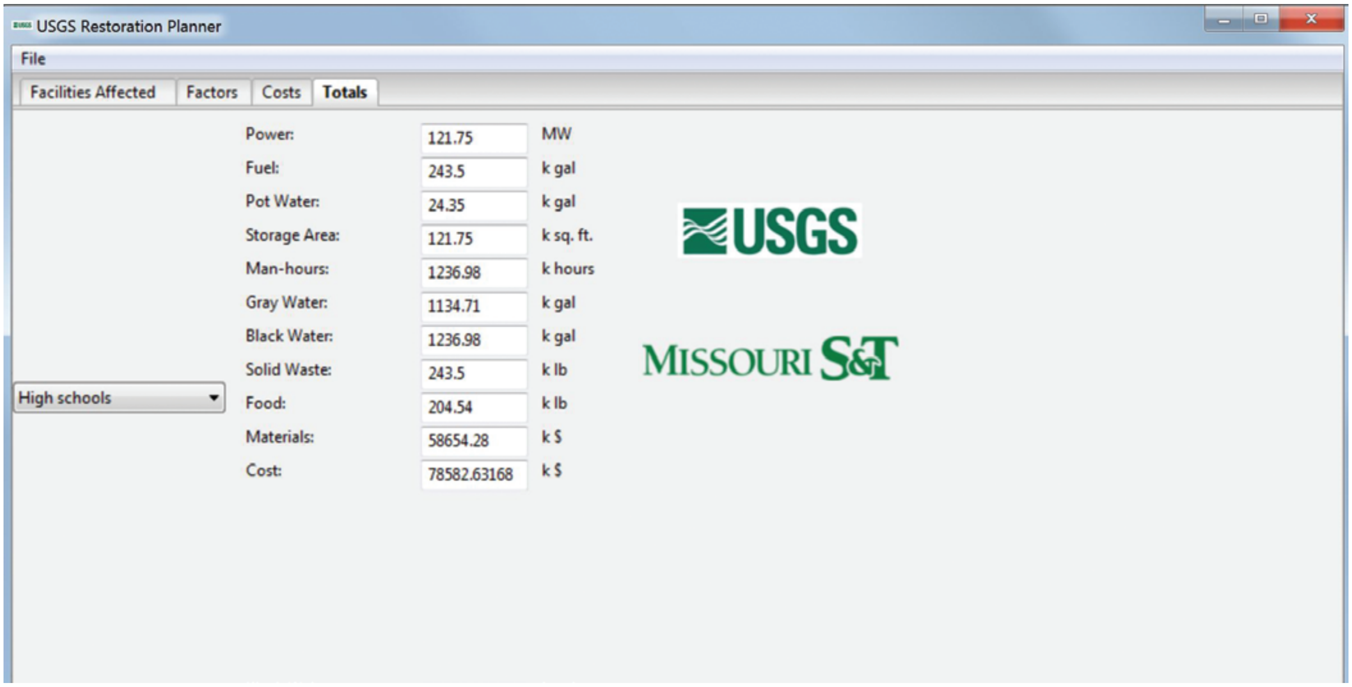

Figure 5. Totals tab where the user can select a facility from the drop-down menu and view the amount of resources required to restore an individual facility.

Flexibility of the application.—Based on the need and (or) expertise of the user, the user may want to change the values in the factors and costs tabs. The factors tab gives the amount of resources required to restore one occurrence of an individual infrastructure element. The costs tab provides the restoration cost of one occurrence of each necessary resource. To modify the values in the factors tab, follow the steps below:

1. Click on the factors tab and select an infrastructure element from the drop-down menu (fig. 6) for which the value should be modified (for example, high schools).
2. Click on the box adjacent to the resource for which the value needs to be modified (for example, man-hours).
3. Delete the value in the box by pressing the backspace or delete key on the keyboard.
4. Enter the value in the text box using the keyboard and press the enter key.

To modify the values in the costs tab, follow the steps below:

1. Click on the costs tab.
2. Click on the box adjacent to the resource for which the cost needs to be modified (for example, man-hours).
3. Delete the value in the box by pressing the backspace or delete key on the keyboard.
4. Enter the value in the box using the keyboard and press the enter key.

Saving and opening a file.—The user can save the results in an Extensible Markup Language (XML) formatted file. The saved XML file can be opened in the application.
To save a file, follow the steps listed below:

1. Click on the file menu.
2. Click on the “save as” option and type the file name in the “save file as” dialog box. Note that the file must be saved in an XML format.
3. Click on “save” to save the file.

To open a saved file, use the following steps:

1. Click on the file menu.
2. Click on the “open” option to view the “choose a file” dialog box.
3. Select the file and click on “open.” The selected file will be opened in the application.

Results

The SCIRC tool calculates the resources required for restoring multiple facilities after catastrophic failure. Unlike traditional commercial software, this application also calculates the amount of resources required for the restoration crew while they complete the restoration operations. The total cost provided by this software does not include overhead expenses such as accounting fees, advertising, legal fees, and profits;

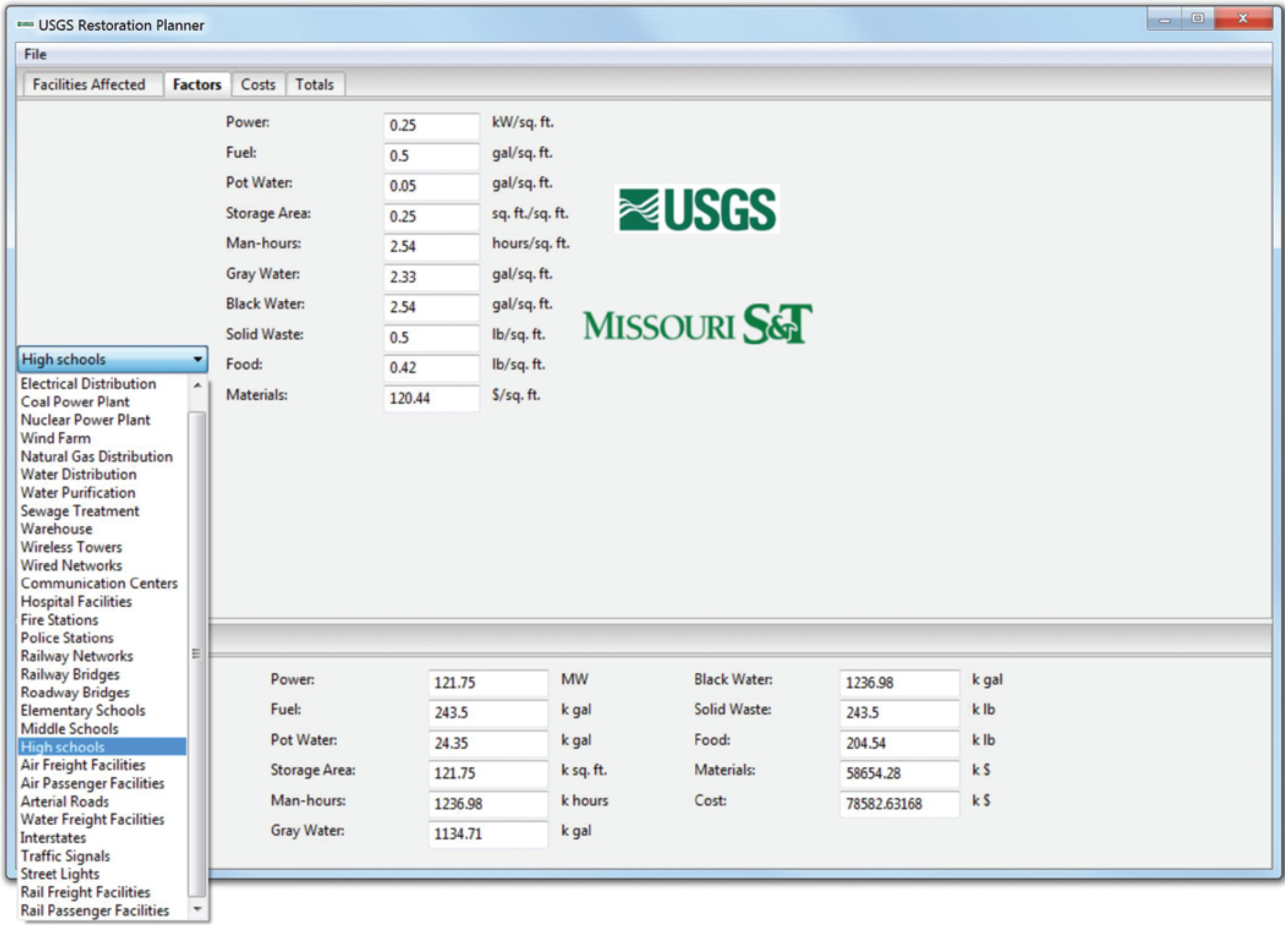

Figure 6. Factors tab where the user can select an infrastructure element from the drop-down menu and modify the value of one or more resources for that facility.

however, the cost and amount of supplies required by the restoration crew are calculated. A detailed comparison between the actual cost (the actual cost of restoring elements using data from reconstruction after a tornadic event) and the cost of restoring a facility using the SCIRC tool, along with the percentage difference between the actual and calculated cost for restoring a facility, is provided in table 5. A list of facilities that have been validated using these data is presented in table 5.

The actual and SCIRC costs for fire stations, warehouses, police stations, and railway networks are compared in figure 7. Because the cost estimates from the SCIRC tool do not include contractor fee, architectural fee, and profit, these costs are excluded from the actual costs of restoring different infrastructure elements for validation purposes.

The actual and SCIRC costs for hospitals, high schools, elementary schools, and middle schools are given in figure 8. Note that the cost used for validation does not include the cost of equipment used within these facilities. For instance, the cost of restoring a hospital does not include the cost of equipping it with x-ray, computed tomography scan, magnetic resonance imaging, and similar medical equipment. Also, the costs of furniture, computers, gym equipment, and similar products required for day-to-day operation of the facility are not included in the total cost. Because the hourly wage for a restoration crew member varies with the nature of work, an average hourly wage of $30 is assumed across all facilities for the restoration crew member.

The actual and SCIRC cost values of wired networks, traffic signals, and street lights are given in figure 9. For wired networks, the cost of optical fiber cables as well as their installation are included in the cost used for validating the results obtained from the SCIRC tool. The cost used to validate a traffic signal includes the cost of replacing one signalized post and mast arm, the cost of the controller cabinet, and the cost of installing the traffic signal. For street lights, the cost includes the cost of the light poles, bracket arms, controller, sensor, high-pressure sodium lamp, and wiring and installation of the street light.

Table 5. Percentage cost difference between the actual and calculated costs for restoring a given facility.

[SCIRC, supply chain infrastructure restoration calculator]

Facilities affected	Unit of facilities affected	Actual cost, in U.S. dollars	SCIRC cost, in U.S. dollars	Percentage cost difference
Hospital	900,000 square feet	168,000,000	168,531,674	−0.16
High school	487,000 square feet	89,740,786	97,137,331	8.24
Elementary school	66,500 square feet	10,800,000	11,251,868	4.18
Middle school	125,800 square feet	24,320,000	24,381,387	0.25
Fire station	7,500 square feet	755,108	786,838	4.20
Warehouse	10,000 square feet	880,000	852,924	−3.08
Police station	5,000 square feet	567,286	674,264	18.86
Wired networks	1 mile	16,632	16,695	0.38
Railway networks	1 mile	1,585,000	1,318,523	−16.81
Traffic signals	1 each	32,760	36,181	10.44
Street lights	1 each	5,200	5,342	2.73

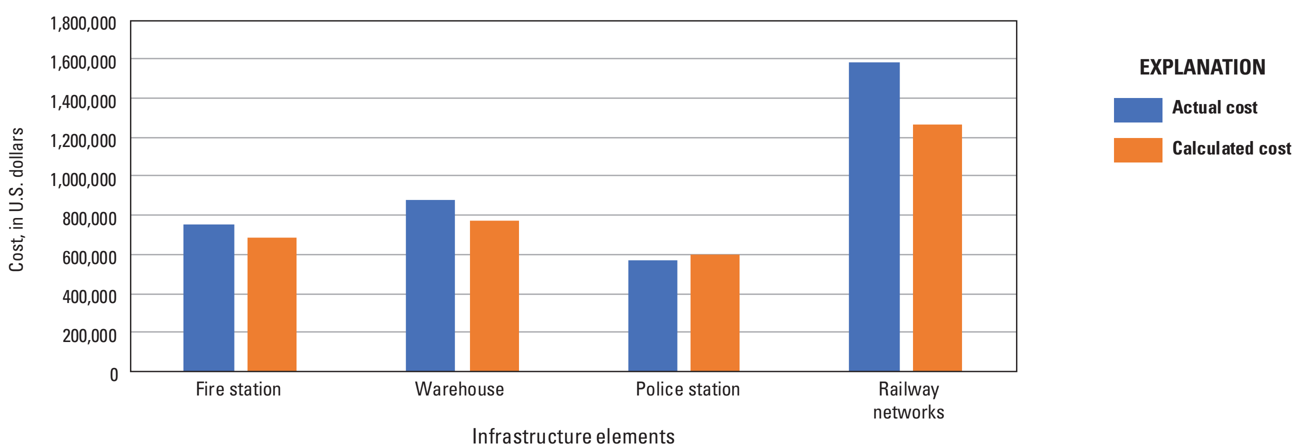

Figure 7. Actual cost versus supply chain infrastructure restoration calculator cost for fire station, warehouse, police station, and railway networks.

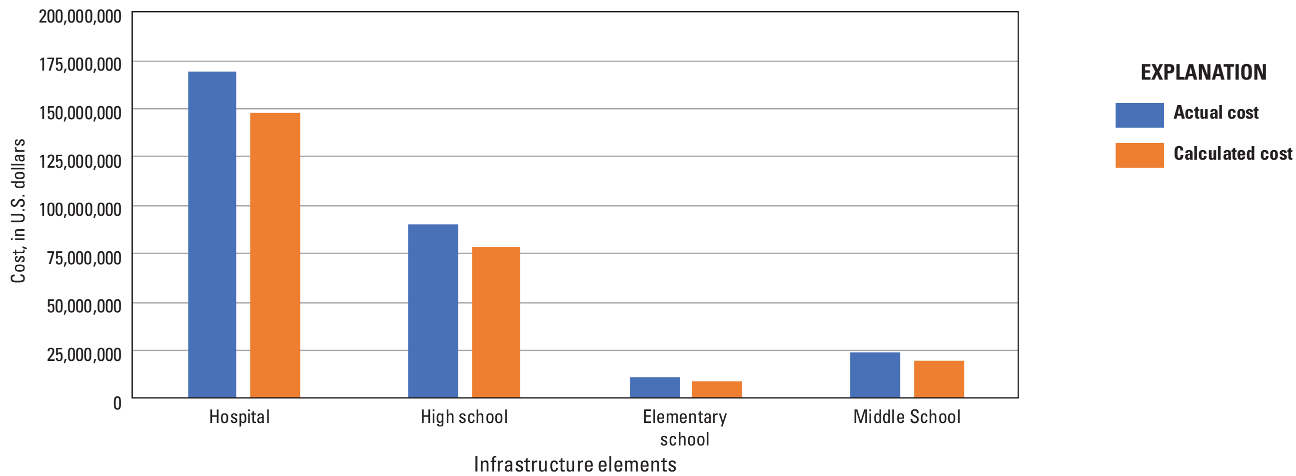

Figure 8. Actual cost versus supply chain infrastructure restoration calculator cost for hospital, high school, elementary school, and middle school.

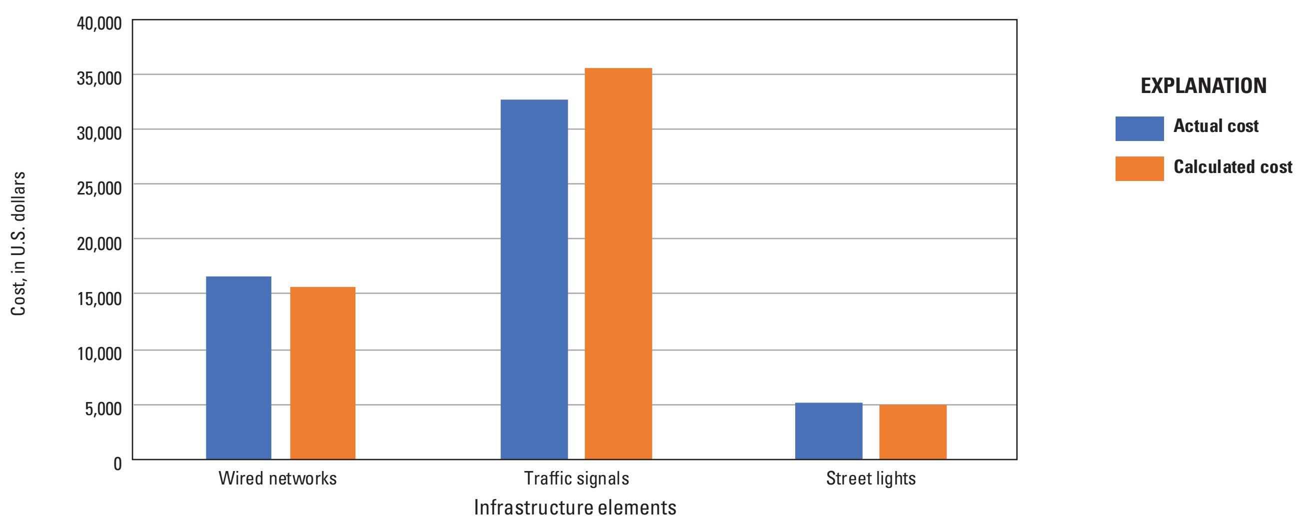

Figure 9. Actual cost versus supply chain infrastructure restoration calculator cost for wired networks, traffic signals, and street lights.

Validation Parameters

The default values used by the SCIRC tool to calculate resource costs were gathered from government and industry sources indicative for the midwestern United States (U.S. Energy Information Administration, 2017; U.S. Environmental Protection Agency, 2018; Michigan Water Environment Association, 2018; Boesler, 2013; Jiang, 2011). Some default data (presented in appendix 1) were derived from a combination of cost estimates from other projected resource needs. In areas of the country where costs differ substantially from the midwestern values, the user can and should substitute local prices for the default values in the costs tab.

Calculated results from the SCIRC tool are validated against real-world data published in after action reports after the F–5 tornado that devastated Joplin, Missouri, on May 22, 2011 (table 6). Facility costs were generally taken directly from published project reports, although some of the infrastructure elements available in the SCIRC tool are distinct from cost categories in the published reports. In these cases, cost data are either derived or taken from State or Federal reports for labor costs or from alternate published sources, such as construction bids and agency websites. The facilities and the references from which the data have been extracted for validation are listed in table 6. Standard construction bids include a 20-percent cost overrun in their cost markup. Because of this standard, a relative error range of plus or minus 20 percent is used as the acceptable error range. This goodness of fit incorporates industry practice and existing protocols for cost analysis (U.S. Government Accountability Office, 2009).

Discussion

The SCIRC tool extends industry cost estimating tools in several ways. It is specifically designed to consider interdependencies and includes ratios that calculate how changes in one system or subsystem result in changes in other systems. The SCIRC tool provides a holistic analytical capability to map the level of resources and manpower required to restore damaged systems. This integrated approach allows a unique mechanism for considering the cost benefit analysis of full restoration, this can be used to best discriminate between restoration of older damaged facilities or replacing these with new infrastructure elements.

The SCIRC tool provides the user with information about the amount of resources required to restore one or multiple facilities. The user can input the number of occurrences of each infrastructure element that needs to be restored after an extreme event, and the software calculates the amount of resources required for restoration. Quantifying the extent of damage caused by a disaster is crucial to restoration planning. This tool can be applied to a region affected by a disaster. Based on the severity of the disaster, the extent of damage to various infrastructure elements can be analyzed. If 100,000 ft^2 of a hospital, 5 miles of an interstate, and 100 traffic signals are destroyed because of a tornado, the user can input the values for these destroyed infrastructures in the SCIRC tool and calculate the amount of resources that will be required to restore these infrastructures. The SCIRC tool provides a macrolevel view of the amount of resources required to restore an infrastructure network. The tool also provides information regarding the number of man-hours required to carry out

Table 6. A list of references used to validate different infrastructure elements.

Facilities affected	Reference
Hospital facilities	Mercy, 2018.
High schools	DLR Group, 2018.
Elementary schools	Hollis Miller, 2018a.
Middle schools	Hollis Miller, 2018b.
Fire stations	Building Journal, 2018.
Warehouse	Compass International, Inc., 2016.
Police stations	Building Journal, 2018.
Wired networks	U.S. Department of Transportation, 2018.
Railway networks	Compass International, Inc., 2017.
Traffic signals	J. Harper, Missouri Department of Transportation, written commun., July 18, 2018.
Street lights	Lindon City, 2008.

restoration activities. This information can be used to calculate the number of personnel required for carrying out restoration operations and is useful in quantifying the amount of resources that would be required by the restoration crews while completing restoration operations. City planners and policy makers can use this tool for budgeting and prioritizing postdisaster operations. Organizations overseeing restoration efforts and budget planning can use this tool to devise efficient disaster restoration strategies. Although the SCIRC tool can be used to calculate the direct costs associated with restoring different infrastructure elements, it is not helpful for calculating the indirect costs accrued after one or multiple infrastructures are damaged because of an extreme event.

The software is flexible; it can be used to calculate the amount of resources required to restore multiple infrastructure elements and can be applied to different regions. Whereas most tools are specific to a single infrastructure, the SCIRC tool calculates the resources required for construction of multiple infrastructure elements of multiple types as required by a restoration scenario. A limitation of this software is that additional infrastructure elements cannot be added to the tool. Also, this tool lacks a feature to automatically update the value of costs based on different regions; however, the factors and costs can be manually updated by a user based on the user's expertise and knowledge. Future work will allow the user to automatically update the value of costs by selecting the geographic region. Ultimately, it would be possible to link the SCIRC tool with a geographic information system framework such as The National Map to calculate the amount of resources required to restore infrastructure elements by selecting a specific area on the map on a near-real-time basis.

Summary

The supply chain infrastructure restoration calculator (SCIRC) tool calculates the amount of resources required to restore one or more infrastructure elements after failure. The software calculates the total amount of resources required to restore one or more occurrences for each selected infrastructure element along with the cost of each resource. The SCIRC tool calculates results for 30 different infrastructure elements. The SCIRC tool also calculates costs based upon a standardized average base for the country, but the user can tailor cost to a specific region by inputting the cost data manually. A unique contribution of the SCIRC tool is the ability to account for the resources required by restoration crews as well as the material resources necessary to restore the infrastructure network. The output from this software can be used by city planners and policy makers to devise efficient strategies for postdisaster restoration operations.

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Appendix 1

Table 1.1. Default parameters for facility factors (per unit of restoration metric).

Facility	Power, in kilowatts per unit	Fuel, in gallons per unit	Potable water, in gallons per unit	Storage, in square feet per unit	Man-hours, in hours per unit	Gray water, in gallons per unit	Black water, in gallons per unit	Solid waste, in pounds per unit	Food, in pounds per unit	Materials, in U.S. dollars per unit
Electric distribution	250	1,500	72.92	15,000	3,500	3,208.33	3,500	700	583.33	145,000
Coal power plant	5	2.25	0.0375	9.5	1.8	1.65	1.8	0.36	0.3	3,200
Nuclear power plant	9	4.7	0.048	10	2.3	2.11	2.3	0.46	0.38	3,800
Wind farm	5	3.5	0.42	9	2	1.83	2	0.4	0.33	1,500
Natural gas distribution	200	500	8.33	12,500	400	366.67	400	80	66.67	70,000
Water distribution	100	200	8.33	5,000	400	366.67	400	80	66.67	5,000
Water purification	0.2	0.2	0.002	1	0.1	0.092	0.1	0.02	0.017	2
Sewage treatment	0.3	0.15	0.002	1.2	0.1	0.092	0.1	0.02	0.017	2
Warehouse	0.5	0.05	0.012	0.1	0.6	0.55	0.6	0.12	0.11	66.72
Wireless towers	2,300	600	1.67	500	80	73.33	80	16	13.33	184,000
Wired networks	2,400	250	1.44	6,000	68.92	63.18	68.92	13.78	11.49	10,665.23
Communication centers	0.25	0.5	0.019	0.5	0.9	0.825	0.9	0.18	0.15	92.97
Hospital facilities	0.25	0.5	0.03	0.5	1.54	1.41	1.54	0.308	0.26	138.6
Fire stations	0.25	0.5	0.02	0.5	0.86	0.79	0.86	0.17	0.14	77.02
Police stations	0.25	0.5	0.02	0.5	0.98	0.9	0.98	0.19	0.16	103.3
Railway networks	750	1,500	80	15,000	3,500	3,200	3,500	715	580	1,200,000
Railway bridges	0.104	0.34	0.009	1.319	0.469	0.429	0.469	0.094	0.078	972.22
Roadway bridges	0.022	0.063	0.003	0.546	0.148	0.136	0.148	0.029	0.025	156.14
Elementary schools	0.25	0.5	0.05	0.25	2.59	2.37	2.59	0.51	0.43	88.65
Middle schools	0.25	0.5	0.05	0.25	2.55	2.33	2.55	0.51	0.42	114.49
High schools	0.25	0.5	0.05	0.25	2.54	2.33	2.54	0.5	0.42	120.44
Air transportation facility	2	7.5	0.042	1	2	1.83	2	0.4	0.33	75
Air passenger facilities	2.5	12.5	0.62	1.5	3	2.75	3	0.6	0.5	155
Arterial roads	0.003	0.014	0.001	0.114	0.024	0.022	0.024	0.005	0.004	7.58
Water freight facilities	2	7	0.42	0.5	2	1.83	2	0.4	0.33	75
Interstates	0.003	0.012	0.001	0.094	0.02	0.018	0.02	0.004	0.003	14.04
Traffic signals	25	50	0.94	75	45	41.25	45	9	7.5	34,630
Street lights	5	10	0.49	50	23.49	21.53	23.49	4.7	3.92	4,572.3
Rail freight facilities	2	7	0.042	0.5	2	1.83	2	0.4	0.33	75
Rail passenger facilities	2.4	12	0.625	1	3	2.75	3	0.6	0.5	130

Table 1.2. Default costs (Midwestern scale) for restoration activities.

Facility	Unit	Cost
Power	Dollars per kilowatt	0.097
Fuel	Dollars per gallon	2.781
Potable water	Dollars per gallon	0.004
Storage area	Dollars per square foot	0.5
Man-hours	Dollars per hour	30.0
Gray water	Dollars per gallon	0.003
Black water	Dollars per gallon	0.005
Solid waste	Dollars per pound	0.002
Food	Dollars per pound	3.0

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Publishing support provided by the
Rolla Publishing Service Center

Ojha and others—**Supply Chain Infrastructure Restoration Calculator Software Tool—Developer Guide and User Manual**—Open-File Report 2019–1061

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20191061