PEOPLES: indicator based tool to compute community resilience

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PEOPLES: INDICATOR-BASED TOOL TO COMPUTE COMMUNITY RESILIENCE

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ABSTRACT

This paper introduces a new methodology to evaluate the resilience of communities. The methodology is based on the PEOPLES framework and it makes use of resilience indicators to evaluate community resilience. The methodology requires data for the indicators as input and returns a resilience function as an output. The resilience function shows the serviceability of the community for a given period of time following the disaster. This methodology has been implemented in the form of two software tools. The first one is a web app that is accessible at http://www.resiltronics.org/PEOPLES/login.php or http://borispio.ddns.net/PEOPLES/login.php while the other is a desktop software. The output quality provided by the tools is not compromised with their usage simplicity. Both softwares are meant to assist the user to use the introduced resilience framework by offering a user-friendly interface. As a case study, the resilience of the city of San Francisco city has been evaluated using both tools.

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This paper introduces a new methodology to evaluate the resilience of communities. The methodology is based on the PEOPLES framework and it makes use of resilience indicators to evaluate community resilience. The methodology requires data for the indicators as input and returns a resilience function as an output. The resilience function shows the serviceability of the community for a given period of time following the disaster. This methodology has been implemented in the form of two software tools. The first one is a web app that is accessible at http://www.resiltronics.org/PEOPLES/login.php or http://borispio.ddns.net/PEOPLES/login.php while the other is a desktop software. The output quality provided by the tools is not compromised with their usage simplicity. Both softwares are meant to assist the user to use the introduced resilience framework by offering a user-friendly interface. As a case study, the resilience of the city of San Francisco city has been evaluated using both tools.

Introduction

Resilience assessment provides a measure of a system's ability to cope with external factors. According to Bruneau et al. (2003), the resilience of a system depends on its serviceability performance [1]. The serviceability performance (Q) ranges from 0 % to 100 %, where 100% and 0% imply full availability and non-availability of services, respectively. The occurrence of a disaster at time t_0 causes damage to the system and this produces an instant drop in the system's serviceability (ΔQ). Afterward, the system is restored to its initial state over the recovery period (t_0-t_1). The loss in resilience is considered equivalent to the service degradation of the system over the recovery period. This concept is mathematically defined as:

$$LOR = \int_{t_0}^{t_1} \left[100 - Q(t)\right] dt \tag{1}$$

where LOR is the loss-of-resilience measure, t_0 is the time at which a disastrous event occurs, t_1 is the time at which the system recovers to 100% of its initial serviceability, $Q(t)$ is the serviceability of the system at a given time t.

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Several solutions for measuring resilience are available in the literature [2-4]. Liu et al. (2017) introduced a method that combines dynamic modelling with resilience analysis [5]. Interdependent critical infrastructures have been analyzed in terms of design, operation, and control using this method by performing a numerical analysis. Kammouh et al. (2017) have introduced a quantitative method to assess the resilience at the state level based on the Hyogo Framework for Action [6; 7]. The approach introduced was an evolution of the risk assessment concept. The resilience of 37 countries has been evaluated and a resilience score between 0 and 100 has been assigned to each of them [6; 8]. Cutter et al. (2014) reported that research on measuring community resilience is still in the early stages of development [9]. Although many attempts have been made to consolidate research on community resilience (e.g. [10-12]), no accepted method exists so far and there are still difficulties in developing concrete assessment approaches and reliable indicators [13].

While simulation-based approaches are considered non-affordable to measure the resilience of a system because of the modelling complexity, the use of indicators is usually preferred, and therefore it is herein adopted. This paper introduces two software tools to measure the resilience of communities. The first is implemented in the form of web application that is accessible from all platforms while the second is presented in the form of a desktop software. An indicator-based approach based on the PEOPLES framework is adopted as an engine for the tools. The methodology allows decision makers to take proper actions under emergencies because it provides a visual interpretation of the community performance. As a case study, the methodology has been applied to the city of San Francisco city using the introduced tools.

PEOPLES Framework: Indicator-Based Approach for Community Resilience

PEOPLES is a framework for identifying the different resilience aspects of a community and for providing new ways through which the decision makers can take actions under emergency. The framework comprises seven *dimensions* that represent the different community aspects, summarized under the acronym "PEOPLES". Each of the dimensions is the collection of more specific *components*, and each of the components is divided into a set of *indicators* collected from a wide range of literature. Each indicator is accompanied with a *measure* to allow the analytical computation of the indicator's performance. The measures are presented in the form of continuous functions instead of scalar values (crisp values). This allows identifying the performance of the indicator during an interval of time (i.e. the period following the disaster) rather than at a specific instance of time. Finally, the indicators are weighted and their performance functions are aggregated into a single serviceability function that represents the performance of the community after the disastrous event. The hierarchal logic of the methodology is shown in Fig. 1. More details about the methodology can be found in [14].

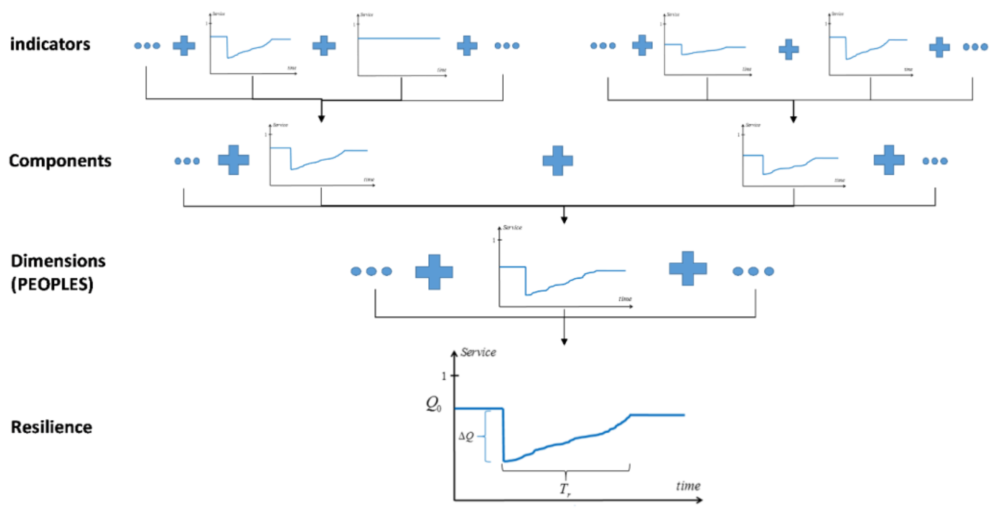


Figure 1. Hierarchical scheme of the adopted indicator-based resilience methodology.

Software Tools for PEOPLES Framework

This section introduces two software tools in which the community resilience approach described above is implemented. The first tool is an online software that is accessible at: http://www.resiltronics.org/PEOPLES/login.php or http://borispio.ddns.net/PEOPLES/login.php, while the other is a portable desktop software (*Note: contact the author if the webpages are unreachable or to request the desktop software)*. Both tools require the same input and return the same output. As an input, the user is asked to insert information about specific community resilience indicators before and after a disaster event. The output is presented in the form of a resilience curve for the whole community. In the following, the use of each tool is described in details.

PEOPLES Web-App

The use of the online software is illustrated here. A Login/Register window appears when accessing the website (Fig. 2a). The user must register prior to using the tool. Once registered, the user can start a new scenario for which the resilience is to be evaluated (Fig. 2b). The scenario is composed of two main ingredients: (1) the analyzed community (i.e. city, country, etc.), and (2) the hazard considered (e.g. earthquake, tsunami, fire, etc.).

Figure 2. (a) Registration/login page, (b) new scenario definition/load scenario.

After defining the scenario, a data-entry page that displays the various variables of the

PEOPLES framework appears (Fig. 3). On the left side of the webpage, the seven dimensions of PEOPLES are listed. A separate page for each dimension can be accessed by clicking on the dimension. For each dimension, a list of components and indicators is shown with blank spaces to insert the data of the parameters required for the resilience evaluation. A pop-up description is triggered when hoovering the mouse over a parameter in the window. This is to get extra information that helps the user identify what kind of information they should insert. The parameters involved in the resilience evaluation are:

- Importance factor (*I*): each indicator is associated with an importance factor between 1 and 3 representing the weight of the indicator towards the resilience output.
- Indicator nature (*Nat*): the indicators are classified according to their nature: "Static (*S*)", assigned to the measures that are not affected by the disastrous event, and "Dynamic (*D*)" or event-sensitive measures, assigned to the measures whose values change after a hazard takes place;
- Un-normalized serviceability before the event (q_{0u}): is the unnormalized initial serviceability of the measure;
- Standard value (*SV*): represents the optimal quantity for the indicator in order to be considered as fully resilient;
- Normalized serviceability before the event (q_0): is the normalized initial serviceability of the measure. It is obtained automatically by the software by dividing the unnormalized serviceability q_{0u} over the standard value *SV*;
- Serviceability after the event (q_1): The residual serviceability after the disaster. This quantity should be normalized by the user with respect to *SV*;
- Serviceability after recovery (q_r): it is the recovered serviceability, which can be equal, higher, or lower than the initial serviceability (q_0). In this paper. The recovered serviceability q_r is assumed equal to the initial serviceability q_0;
- Restoration time (T_r): it is the time needed to finish the recovery process. This value is usually determined using probabilistic or statistical approaches.

A list of importance factors (*I*) has been set as default in the software; however, the user can change the numerical values in the list according to their preference. The importance factors can be set all to "1" in case the user finds no justification to assign weights to the indicators; in this case, the indicators will be equally weighted. The nature of the indicator "*Nat*" can also be changed by the user because this parameter depends on the type of hazard and type of community considered in the analysis. If the indicator is *Static 'S'*, it is enough for the user to insert data about the initial serviceability of the system q_{0u}, and the standard value *SV*. If otherwise the indicator is *Dynamic 'D'*, the user should proceed and insert data about the post-event damage q_1, serviceability level after restoration q_r, and restoration time T_r. The parameter q_{0u} is inserted as unnormalized value while the other serviceability parameters q_1 and q_r have to be normalized by the user with respect to *SV* (divide over *SV*). A serviceability curve for each component is shown at the bottom of the page after inserting the indicators' data. The serviceability curve of the analyzed dimension, which is the weighted average of all serviceability functions of the components, is also shown on the same graph.

After inserting the required data for all PEOPLES seven dimensions, the user will be able to see the serviceability curve of the community by clicking on the 'The community resilience curve' on the left side of the screen. For each of the serviceability curves, the software automatically evaluates the *LOR*, which is an indicator for the serviceability loss incurred during the event.

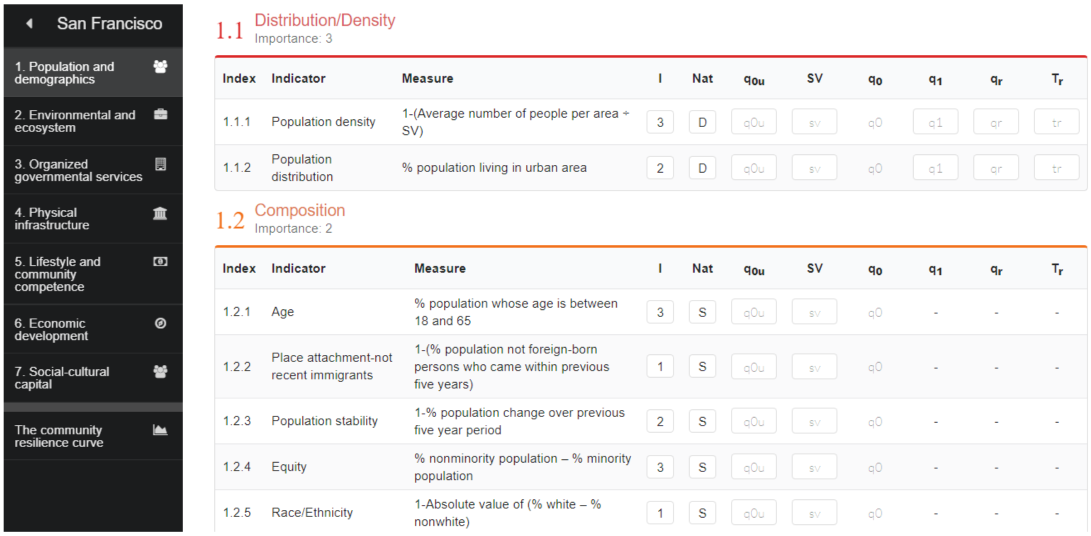
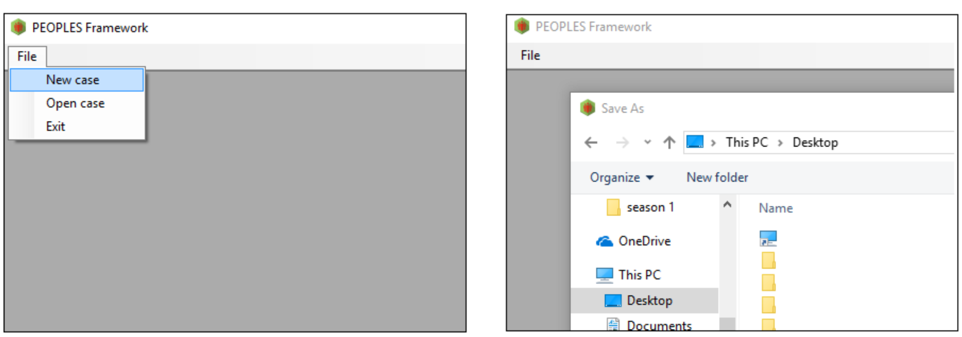


Figure 3. User interface and data entry environment.

Desktop Software

The software introduced in this section is a portable version that does not require installation. To run the software, only one file containing the indicators database is required. This file comes preloaded in the software package. The user cannot modify the indicators and the results accumulation hierarchy of the methodology as these are fixed according to the PEOPLES framework. When the software is run, the user will be required to choose whether they want to start a new scenario "New case" or to load a saved one "Open case" (Fig. 4a). If the user chooses to start a new scenario, a new window, shown in Fig. 4(b), asking the user to define the directory to which the scenario is saved will pop up.



(a) (b)

Figure 4. (a) starting a new scenario "New case" or loading a saved scenario "Open case", (b) saving the scenario if the option "New case" is chosen.

After saving the new scenario, a new blank page with only three functions "Add", “Remove”, and “Edit” will display (Fig. 5a). At this stage, the user needs to insert the database specific to the analyzed case study. To do that, the user should click on the “Add” function, which triggers a window containing all the indicators of the PEOPLES framework (Fig. 5b). The user can delete and modify the indicators using the functions “Remove” and “Edit”. Each of the indicators is accessed independently to insert the data required for its evaluation.

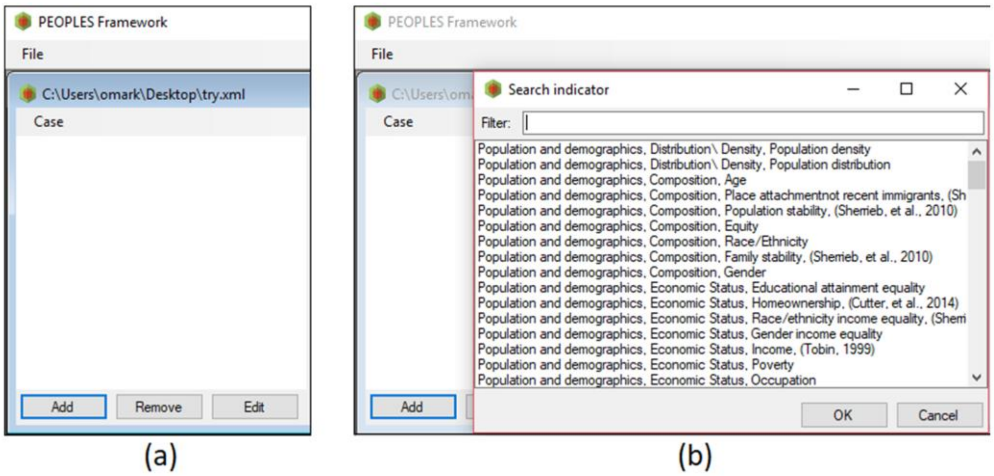


Figure 5. Indicators database

The number of inputs required depends on the nature of the indicator. Static indicators require only two parameters for their evaluation (q_0 and I) (Fig. 6a) whereas dynamic indicators need five inputs (q_0, q_1, q_f, T_r, and I) (figure 6(b)). It is very important to note that unlike the web app software introduced in the previous section, all the serviceability parameters q_0, q_1 and q_r MUST be normalized by the user (i.e., the user has to divide these quantities over SV).

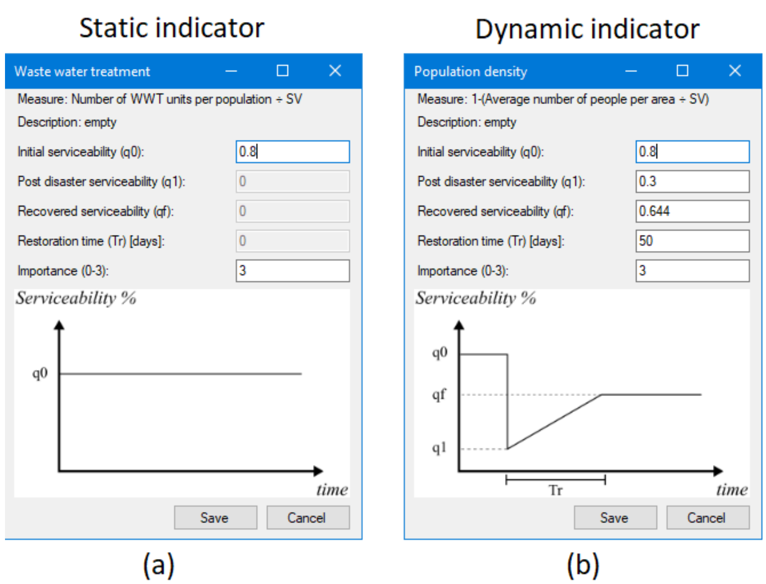


Figure 6. use interface and data entry sheet for the indicators.

Case Study

The resilience of the city of San Francisco is evaluated using the introduced resilience assessment tools. The case study intends to show the applicability of the proposed methodology and not the actual evaluation of the resilience of San Francisco. The 1989 Loma Prieta earthquake, with a moment magnitude of 6.9, has been considered as the disaster event. Only one of the PEOPLES dimenskamions 'Physical Infrastructure' has been considered for the sake of simplification. Table 1 shows the extended list of the components and indicators within the dimension 'Physical Infrastructure' along with the data associated with each indicator. In this study, damage data was determined using open database sources (see notes under Table 1), which offer data for all cities across the US. Restoration fragility curves recently developed in [15;16] have been used to determine the restoration time for the different indicators. The case study can be replicated in the software tools by inserting the data of Table1 in their corresponding fields in the web app and desktop software as explained earlier in the paper.

Table 1. Serviceability parameters of the indicators within the Physical Infrastructure dimension for the city of San Francisco after the Loma Prieta earthquake.

4- Physical infrastructure (I=3)									
Component /indicator	**Measure**	**w**	**Nat**	q_{0u}	***TV***	q_0	q_1	q_r	T_r (days)
4.1 Facilities	-		-						
4.1.1 Sturdy (robust) housing types	% housing units that are not manufactured homes	3	D	1	1	1	0.599	0.998	120
4.1.2 Temporary housing availability	% vacant units that are for rent	3	D	2.68	5	0.536	0.050	0.536	620
4.1.3 Housing stock construction quality	100-% housing units built prior to 1970	3	D	0.241	1	0.241	0.145	0.241	700
4.1.4 Community services	%Area of community services (recreational facilities, parks, historic sites, libraries, museums) total area ÷ TV	2	D	0.16	0.2	0.800	0.480	0.800	430
4.1.5 Economic infrastructure exposure	% commercial establishments outside of high hazard zones ÷ total commercial establishment	2	S	0.85	1	0.850	-	-	-
4.1.6 Distribution commercial facilities	%Commercial infrastructure area per area ÷ TV	3	D	0.13	0.15	0.867	0.520	0.867	160
4.1.7 Hotels and accommodations	Number of hotels per total area ÷ TV	3	D	102	128	0.797	0.478	0.797	130
4.1.8 Schools	Schools area (primary and secondary education) per population ÷ TV	3	D	134	140	0.957	0.574	0.957	90
4.2 Lifelines									
4.2.1 Telecommunication	Average number of Internet, television, radio, telephone, and telecommunications broadcasters per household ÷ TV	3	D	5	6	0.833	0.500	0.833	90
4.2.2 Mental health support	number of beds per 100 000 population ÷ TV	2	D	69	75	0.920	0.644	0.920	35
4.2.3 Physician access	Number of physicians per population ÷ TV	2	S	2.5	3	0.833	-	-	-
4.2.4 Medical care	Number of available hospital	3	D	544	600	0.907	0.635	0.907	35

capacity	beds per 100000 population ÷ TV								
4.2.5 Evacuation routes	Major road egress points per building ÷ TV	2	S	0.67	1	0.670	-	-	-
4.2.6 Industrial re-supply potential	Rail miles per total area ÷ TV	3	D	5412	6000	0.902	0.631	0.902	45
4.2.7 High-speed internet infrastructure	% population with access to broadband internet service	3	D	0.9	1	0.900	0.450	0.900	300
4.2.8 Efficient energy use	Ratio of Megawatt power production to demand	3	D	0.8	1	0.800	0.160	0.800	25
4.2.9 Efficient Water Use	Ratio of water available to water demand	3	D	1	1	1.000	0.240	1.000	60
4.2.10 Gas	Ratio of gas production to gas demand	3	D	0.1	1	0.100	0.050	0.100	70
4.2.11 Access and evacuation	Principal arterial miles per total area ÷ TV	3	D	172138	200000	0.861	0.602	0.861	45
4.2.12 Transportation	Number of rail miles per area ÷ TV	3	D	5412	6000	0.902	0.631	0.902	72
4.2.13 Waste water treatment	Number of WWT units per population ÷ TV	3	D	3	4	0.750	0.300	0.750	65

* q_{0u} = the initial serviceability; *TV* = the target value; q_0 = the initial normalized serviceability; q_1 = post disaster serviceability; q_r= the recovered serviceability; T_r = the restoration time.
* Source: City Data, Census Data, This Study, City Assessor's Data, Dept of Numbers, SF Indicator Project, Data World Bank, Dot Ca, SF Bos, Arcadis, SF Wáter, Energy Ca.

Data collection was the most difficult part of the analysis since data about the serviceability of community systems is scares and not shareable with the public. However, this does not imply that data is not available but rather is not accessible. Interested parties, such as decision makers and authorities, can use the framework with its full potential since data is usually available to them.

The software combines the serviceability functions of the group of indicators under a component point by point into a single serviceability function, taking into account their weighting factors. This curve represents the serviceability function of the underlying component. Similarly, the serviceability function of the dimension (i.e. Physical Infrastructure) is derived by computing the weighted average of serviceability functions of the corresponding components (i.e. facilities and lifelines). The tool evaluates the loss of resilience of the physical infrastructure using Eq. (1). The time interval for calculation of resilience is considered from the time that the event occurs (t_0=0) until the end of full recovery (i.e. the time corresponding to the instance where the curve reaches its pre-disaster level, which coincides with the maximum restoration time among all indicators; t_r=700 days). The control time T_c is determined based on the user's period of interest so it can take any value. In this example, T_c is set equal to t_r automatically by the software. Fig. 7, 8 show the resilience curve of the case study obtained using the online and the desktop software tools, respectively. The obtained *LOR* value (25.6%) corresponds only to the physical infrastructure dimension of the community. In order to have a resilience index for the whole community, the serviceability functions of other dimensions have to be similarly evaluated and combined in the same way. It is also interesting to compare the resilience of the two components *facilities* and *lifelines* shown in Fig. 7. It is clear that the city of San Francisco has more problems in facilities (*LOR*=31.29%) than lifelines (*LOR*=21.85%); therefore, it is suggested that the authority focuses more on enhancing their facilities.

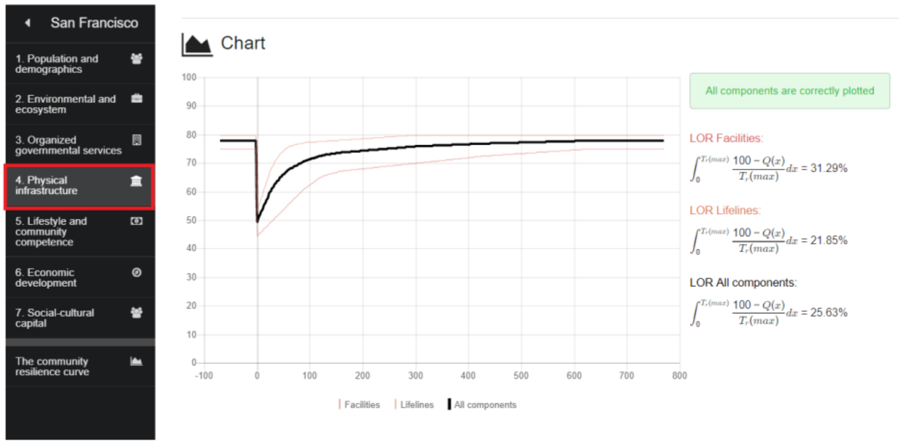


Figure 7. Serviceability curves of the components “Facilities” and “Lifelines” and the dimension “Physical Infrastructure”.

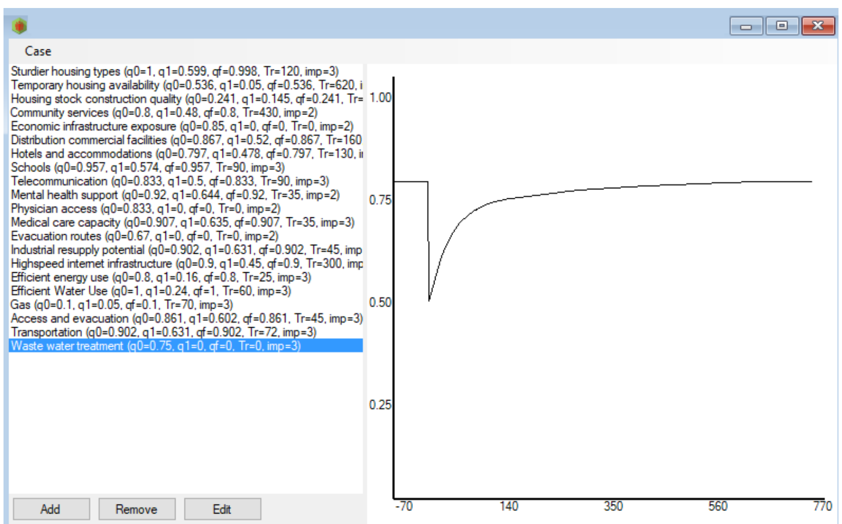


Figure 8. Serviceability curve the dimension “Physical Infrastructure”.

Conclusions

Previous work on resilience evaluation provided several theoretical frameworks that have not been put in practice because no actual tool has been associated to them [17]. This makes it difficult for the user to apply those resilience methods. In this paper, two software tools to compute the resilience of communities are developed. The first is a web app while the second is a portable desktop software. An indicator-based method based on the PEOPLES framework has been implemented as an engine for the tools. This method has been chosen as it has the potential to indicate in details whether the resilience deficiency is caused by the system’s lack of robustness or by the slow restoration process. It also identifies where exactly resources should be applied to efficiently improve resilience.

The softwares can serve as an initial tool for decision makers to evaluate the disaster resilience of their communities. The significance of the introduced tools lies in their graphical representation that helps decision makers take proper actions under emergency. The output quality provided by these tools is not compromised by their simple algorithm. Future research is aimed at studying the interdependency between indicators to define better weighting factors for the indicators. The softwares will be improved to contain additional features that allow the user to select the type of hazard and the type of analysis they want to perform.

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