1. Paper's structure

3. Example demonstration

Comment

One major comment is that this paper could greatly benefit from a holistic illustrative example to apply the framework the author proposed. This example could serve as a powerful tool to demonstrate the practical application of the framework, potentially inspiring the authors to further develop their work.

Figure 2, why does it need a guide design? Why can we not develop criteria from key factors directly? Again, the audience will be more convinced if the paper has an example.

Reply

The structure of this paper is unclear due to the step of "step designing". We suggest combining sections for "key factors identification" and "step designing". Thus, the designed steps, for the "Criteria & Indicators" setting and data analysis, could be presented directly with the identification of key factors (Criteria, indicators, and data). In the new version, the result of section 3 is therefore the development of a guide for building indicator systems. Section 4 shows then a big example for demonstrating the use of the developed guide.
Some example demonstrations are not necessary. Therefore, in the reviewed version, there is only a big example that includes all the steps shown in the developed guide.

Revision 1

Section 2: Research Methodology and Structure

To achieve the objectives of this study, … Therefore, criteria, indicators and data are the indispensable contents of an indicators system. For building an indicator system, the setting of Criteria & Indicators (C&I), and the collection of data are considered basic. This research could start with a presentation of the three basic key factors (criterion, indicator and data). Then, the main research work is designing the steps for C&I setting and data collection (Fig.2). Moreover, for these steps to be better operational in practice, the steps designed in this guide should be clearly described and preferably with the support of schematic diagrams.

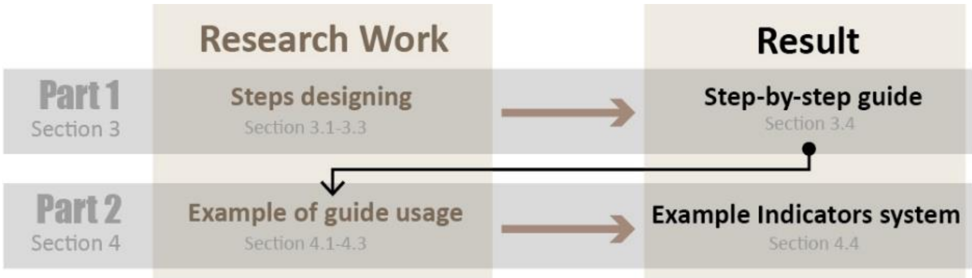

Fig. 2. Methodology and structure of the present study.

In the second part, this study applies the designed steps to a French critical infrastructure to build an indicator system that can assess resilience during urban flooding (Fig.2). The example focuses on the Nantes Ring Road (NRR) network, the investigation of which was assisted by a local management organisation, Direction interdépartementale des routes Ouest (DIRO) that is in charge of the road networks of Nantes City in France. This example involves 62 676 traffic flow data from DIRO, and over 15 000 road infrastructure data from French National Geographic Institute (IGN).

The present paper is divided into several sections. Section 3 will (Fig.2) develop a step-by-step guide that enables CIs managers building indicator systems for their particular studied cases. Section 4 (Fig.2) will illustrate how to use this developed guide to build an indicators system through an example focusing on Nantes Ring Road. Section 5 discusses the contributions, and limitations of this guide, and shows an assessment process (including resilience and indicator assessment phases in Fig.1) in using the built indicator system in Section 4.

Revision 2 **paper's structure**	1 Introduction 2 Research Methodology and Structure 3 Part 1: Guide's Steps Designing 3.1 Specific criteria setting 3.1.1 Direct and indirect damages 3.1.2 Effectiveness and efforts of actions 3.2 Indicators setting and references definition 3.3 Verification of available data 3.4 Result of part 1: Step-by-step guide 4 Example of Guide Usage 4.1 Criteria setting Initial scenario Continuous scenarios 4.2 Possible Indicators setting 4.3 Available data analysis 4.4. an indicator system for studied example case 5. Discussion 5.1 A practical and operational guide 5.2 Assessment demonstration 5.2.1 Criteria & Indicators weighting 5.2.2 Assessment methods and results 5.3 Limitation 6 Conclusion

2. Synonyms	
Comment	Another big issue is that the novelty of this paper is not clear. The word "operationalizing" may not be the most appropriate term. The authors may want to consider using "application" or "implementation". However, without a clear and compelling illustrative example, it becomes challenging to substantiate the novelty of this paper as the authors proposed. This underscores the importance of revising and improving the argumentation to ensure clarity.
Reply	We agree with you about the confused use of "operationalisation", "application" and "implementation". This paper wants to discuss two topics: the application of indicators-based assessment for critical infrastructure resilience; and the implementable actions identified through the Behind the Barriers model. However, the initial paper did not well distinguish these terms. This problem has been resolved in the new version. Since the focus of the paper is on indicator systems built by a developed guide, one discussion refers to the contribution of developed guide and indicator systems to the application of CIs resilience assessment.
Revision 1 **Abstract**	Criteria and indicators are frequently used for assessing the resilience of Critical Infrastructures (CIs). Moreover, to generate precise information on conditions, the assessment designed for CIs resilience could rely on indicator systems. However, few practical tools exist for guiding CIs managers to build specific indicator systems in considering local realities. Therefore, the main objective of this study is to develop a step-by-step guide that contains guidance on operational steps and required resources for Criteria & Indicators setting, references definition, and data collection. This guide enables CIs managers to build systems of indicators adapted to different realities. This guide could assist CIs managers in their decision-making process, as it is structured based on a multi-criteria framework that takes into account the cost-benefits and side effects of implementable actions. This guide could furthermore advance the application of indicator-based CIs resilience assessment in practical management. In addition, this study provides an example to

<table>
<tr><td></td><td>demonstrate how to use this guide. This example is based on a given scenario for the Nantes Ring Road (NRR) network: when the ring road is flooded and closed, the road network manager suggests alternative roads to the public. An indicator system, consisting of 4 criteria, 7 sub-criteria and 11 indicators, could be built for this scenario through the developed guide. This example relates to criteria and indicators in technical, social, and environmental dimensions, and involves 62 676 data.</td></tr>
<tr><td>Revision 2

Last paragraph of section 1: Introduction</td><td>Indicator systems building involves criteria setting. Criteria serve as characters or signs making a judgment of appreciation. From an operational perspective, multi-criteria analysis allows CIs managers to keep holistic thinking that balances the various advantages and disadvantages (Yang et al., 2023, b). However, many studies about CIs resilience criteria setting have focused on abstract capabilities related to resilience, but have overlooked the fact: the benefits, costs or impacts of implementable actions for every CIs manager are critical. The lack of discussion about the effects of implementable actions causes the application difficulties of CIs resilience assessment in practical management. Therefore, the developed guide for building indicator systems should consider a criteria-setting framework involving implementable actions. The ways for multi-criteria setting involving implementable actions should be added in the objective guide of this present study.</td></tr>
<tr><td>Revision 3

The second and third paragraphs of section 3.1: Specific criteria setting</td><td>Assessments consisting of Criteria & Indicators (C&I) … The aspects of the assessed goal may not be necessary for the assessment process, but they are important for criteria setting. In practical management, the criteria vary between different contexts. The designed criteria-setting steps in the present paper should enable managers to set specific criteria for adapting to different realities.

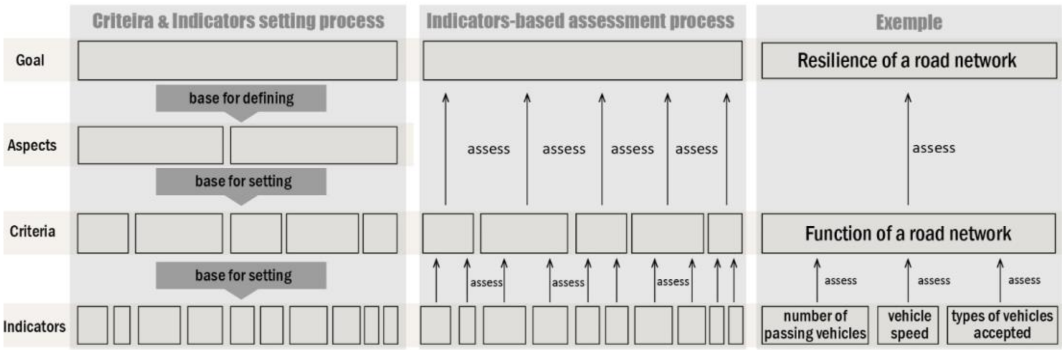

Fig. 3. A hierarchical structure in multi-criteria approaches for C&I-based assessment, adjusted from Yang et al. (2023, b).

The integration of implementable action into assessment criteria is one of the keys to resilience assessment application in practical management (Yang et al., 2023, b). One of the objectives of CIs resilience studies is to help CIs managers find more sustainable and efficient measures or actions to practically deal with increased hazards. A resilient critical infrastructure (CI) should involve diverse implementable actions to improve its different capabilities (Barroca and Serre, 2013). Implementable actions refer to all possible operations that could be taken for optimising CIs resilience, like programs, strategies, projects, measures, or practices for both temporary (short-term) and permanent preventive (long-term) management. Meanwhile, implementable actions aiming at one CI potentially bring unexpected negative effects to itself or externally to its environment, like side effects or over-budget expenses. Therefore, an effective assessment should provide CIs managers with information on the both positive and negative effects of implementable actions. Thinking about the spatial and temporal impacts of implementable actions, across urban systems, helps enhance beneficial strategies and suppress dangerous ones.</td></tr>
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Revision 4 **Section 5.1: A practical guide for building indicator systems** **In section 5: discussion**	The developed guide requires a multi-criteria analysis, a setting of numerous indicators and an investigation of available data. The built indicator systems may be considered complex with a large number of contents, and it may increase the application complexity of indicator systems to a certain extent. Nevertheless, there is no doubt that CIs resilience is a complex object, but not a complicated one. A complicated object, i.e. one with a certain amount of disorder, can be simplified, whereas a complex object should not be simplified. "Complexity varies according to a number of parameters, including the multiple uses to which it is put, the number of participants involved, its geographical dispersion, and the spatial and temporal scales considered" (Barroca et al., 2016). Since CIs resilience is a complex object, complex indicator systems seems inevitable for CIs resilience assessment. The more complex an indicators system, the more it requires detailed knowledge of local realities in diverse dimensions (geographies, socio-economic, environmental, technic, etc.). At the same time, the higher the need to increase the autonomy of local managers, which the developed guide in this study provides. A consideration of the local realities of each case may be one key for advancing CIs resilience application. The realities bring the uniqueness of each case that could be realised by the specificity of sub-criteria and indicators. Just as teaching a man to fish, rather than simply giving him fish. Rather than predefining sub-criteria or indicators for all potential resilience scenarios of CIs resilience, the guide for building indicator systems developed in this study enables CIs to set specific sub-criteria and indicators based on concrete situations. This guide is a tool flexible, adapting itself to different case studies and different kinds of CIs. The developed guide provides a wide margin of autonomy for CIs managers or stakeholders who need support and guidance to build indicator systems. The autonomy also brings the possibility of continuous updating or optimising of building indicator systems. Changes in the external environment may lead to changes in the setting and weighting of criteria, and indicators. For example, the sub-criteria of "Environmental damage" and the indicator of "Additional CO2 emission" has become important in recent years because of the development of environmental concern. In addition, the criteria and indicators relating to implementable actions are another key for advancing the application of CIs resilience assessment. Even though many existing theories or models for CIs resilience assessment are valuable, the discussion about the effects of implementable actions is not sufficient in current studies. The present study insists that, for advancing CIs resilience application, it is necessary to consider the cost-effectiveness and side effects of implementable actions. Meanwhile, the autonomy of this guide can also be interpreted as a weakness. Managers' experience or knowledge may be so limited that they overlook invisible factors. From a holistic perspective, a collaborative exchange between different stakeholders can reduce this shortcoming. The examples in this study demonstrate exactly the kind of cooperation between local operators, university scientists, and local researchers. Whereas a significant investment in human resources at the same time may reduce the cost-benefit of collaborative management. Research in the field of management is therefore needed for better use of built indicator systems. In addition, the developed guide that promotes the practical use of resilience indicators could further contribute to the application of CIs resilience. The current studies of the CIs resilience aim to develop more effective and sustainable infrastructure management strategies for CIs through the concept of "resilience". In other words, one of the desired developments in resilience research is to put resilience-based theories, tools, and models into practice. Thus, CIs resilience studies need to consider the application of the concept of "resilience" in practical risk management. According to Cambridge Dictionary, an application is a way in which something can be used for a particular purpose. A practical application of CIs resilience is therefore a way in which CIs resilience can be used for real risk management. Although CIs resilience has gained considerable attention in the research literature during the last decade, there remain relatively

	few resilience studies with application in real-life infrastructure (Hosseini; 2016; Meerow et al., 2016; Hernantes et al., 2019; Heinzlef et al., 2022; Esmalian et al., 2022; de Magalhães et al., 2022; Barroca et al, 2023; Rød, 2020). The obstacle to applying the CIs resilience concerns two major limitations: 1) the absence of applied tools; 2) the lack of an organisational aspect (Weichselgartner and Kelman, 2015; Hernantes et al., 2019 ;Heinzlef et al., 2022; Rød et al., 2020; Yang et al., 2023, b). The guide developed in the present study is firstly a practical tool that can be applied in concrete scenarios, as demonstrated by the example case presented. The fact that the criteria setting is based on organisational perspectives has been also emphasised. The developed guide could contribute to transforming the concept of "resilience" into an object of practical value, in the broader sense of 'use'.
Revision 5 **Section 6: Conclusion**	Focusing on the indicators-based assessment of critical infrastructures resilience, this study develops a step-by-step guide for building indicator systems. The developed guide considers both the positive and negative effects of implementable actions. Three key phases (Fig.9) have been presented in detail for building indicators systems: criteria setting, indicators setting with references definition, and verification of data availability. In addition, this study provides an example to demonstrate how to use this guide. This example is based on a given scenario for the Nantes Ring Road (NRR) network: when the ring road is flooded and closed, the road network manager suggests alternative roads to the public. The results show that this guide enables to building of specific indicator systems adapted to local realities. Built indicator systems could furthermore assist CIs managers in their decision-making process as they involve the various interests of stakeholders.

4. Figures' illustration and description	
Comment	Some figures are not clear. For example, in Figure 1, it would be better if the lines had an arrow pointing from right to left. Some figures need more associated explanations. For example, in Figure 3: Why does it need the layer of aspects?
Reply	Some example demonstrations are not necessary. Therefore, in the reviewed version, there is only a big example that includes all the steps shown in the framework.
Revision 1 **Section 1 introduction Fig. 1**	 **Fig. 1. Indicator-based Resilience Assessment, source: Yang et al. (2023, a).**
Revision 2 **Section 2 Research Methodology and Structure** **Fig. 3**	Assessments consisting of Criteria & Indicators (C&I) could provide a commonly agreed framework for articulating and defining expectations. There is a hierarchical structure for C&I based assessments (Fig. 3), firstly developed for forest sustainability assessment (Prabhu et al.,1996; Lammerts Van Bueren et al., 1997; Mendoza and Prabhu, 2000), today is also used in other disciplines (Montaño et al., 2006; Van Cauwenbergh et al., 2007; Koschke et al., 2012; Feiz and Ammenberg, 2017). This hierarchical structure is a common framework, in which a higher-level "goal" is divided into aspects or themes, which are in turn divided into criteria each with several indicators (Maggino, 2017). The assessment process (Fig3. Indicators-based assessment process) is from "indicators" to "goals", but criteria and indicators (Fig3. Criteria & Inidcators setting process) are set in the opposite direction. This means that the criteria and indicators are set based on certain important aspects of the assessed goal. Important aspects, in turn, are identified in terms of the definition and phenomenon of the assessed goal (Eurostat, 2014; Maggino, 2017). The aspects of the assessed goal may not be necessary for the assessment process, but they are important for criteria setting. In practical management, the criteria vary between different contexts. The designed

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criteria-setting steps in the present paper should enable managers to set specific criteria for adapting to different realities.

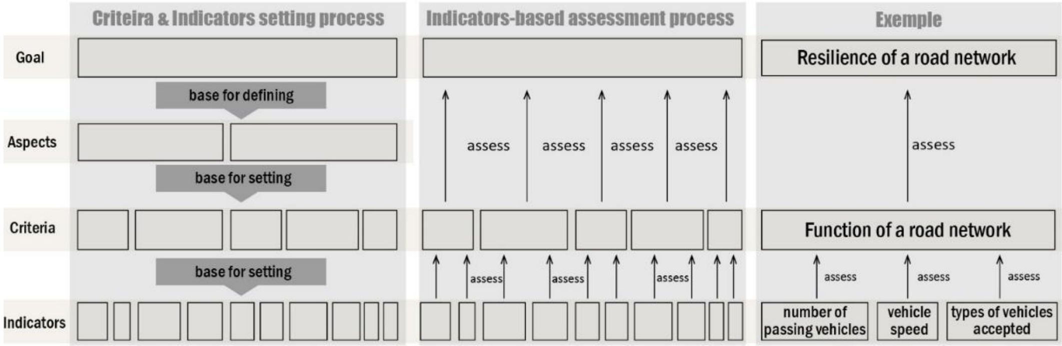

Fig. 3. A hierarchical structure in multi-criteria approaches for C&I-based assessment, adjusted from Yang et al. (2023, b).

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Revision 3

Section 3.1.1 Direct and indirect damages

Fig. 5

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The determination of significant damages is related to two criteria: “damage to internal components” and “damage of actions”. Significant damages could be determined based on Form 1 introduced by Yang et al. (2023, b) (Fig. 5). This Form 1 can be considered as a process of setting specific sub-criteria under these two damage related criteria. According to Form 1, once the target CI (Fig.5. Affected system) has been defined, its four categories of components should be identified: function (seen as a type of component), collective human components, individual human components, and physical non-human components. After that, the damage of the elements considered important should be set as a sub-criterion of resilience assessment.

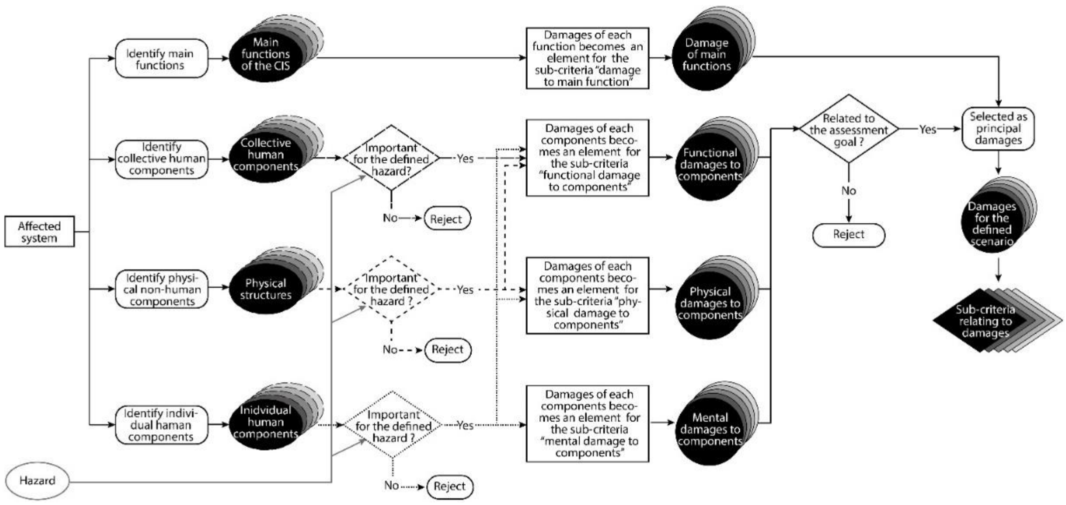

Fig. 5. Form 1 for setting sub-criteria of “Damage to internal components” and “Damage of action” criteria, source: Yang et al. (2023, b).

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Revision 4

Section 3.1.2 Effectiveness and efforts of actions

Fig. 6

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Next, the defined implementable actions allows for describing the desired outcome, which is then treated as a sub-criterion of the ‘effectiveness of action’ criterion. By investigating the components (function, collective human components, individual human components and physical non-human components) related to the defined actions, it is possible to determine the costs of the defined actions in terms of four dimensions: functional, environmental, economic and human or material resources. The costs of the defined actions are considered as sub-criteria of the ‘Effectiveness of actions’ criterion. The process of sub-criteria setting is presented in Form 2 (Fig. 6) and the details could be found in the paper of Yang et al. (2023, b)

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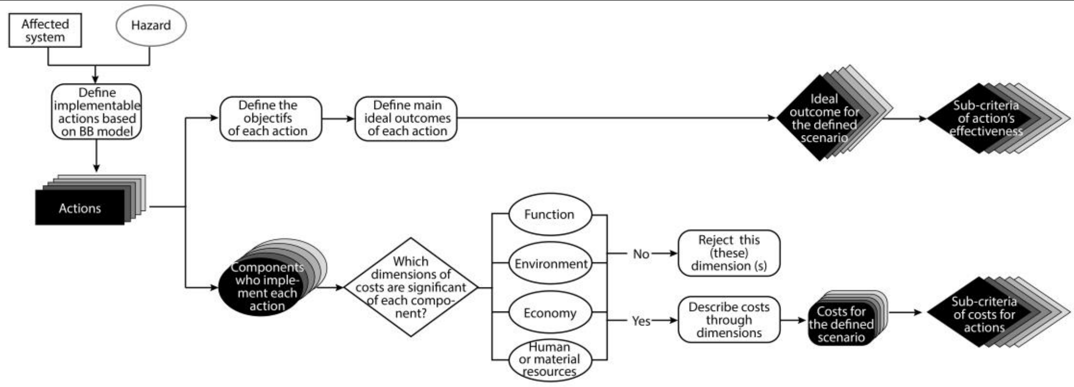


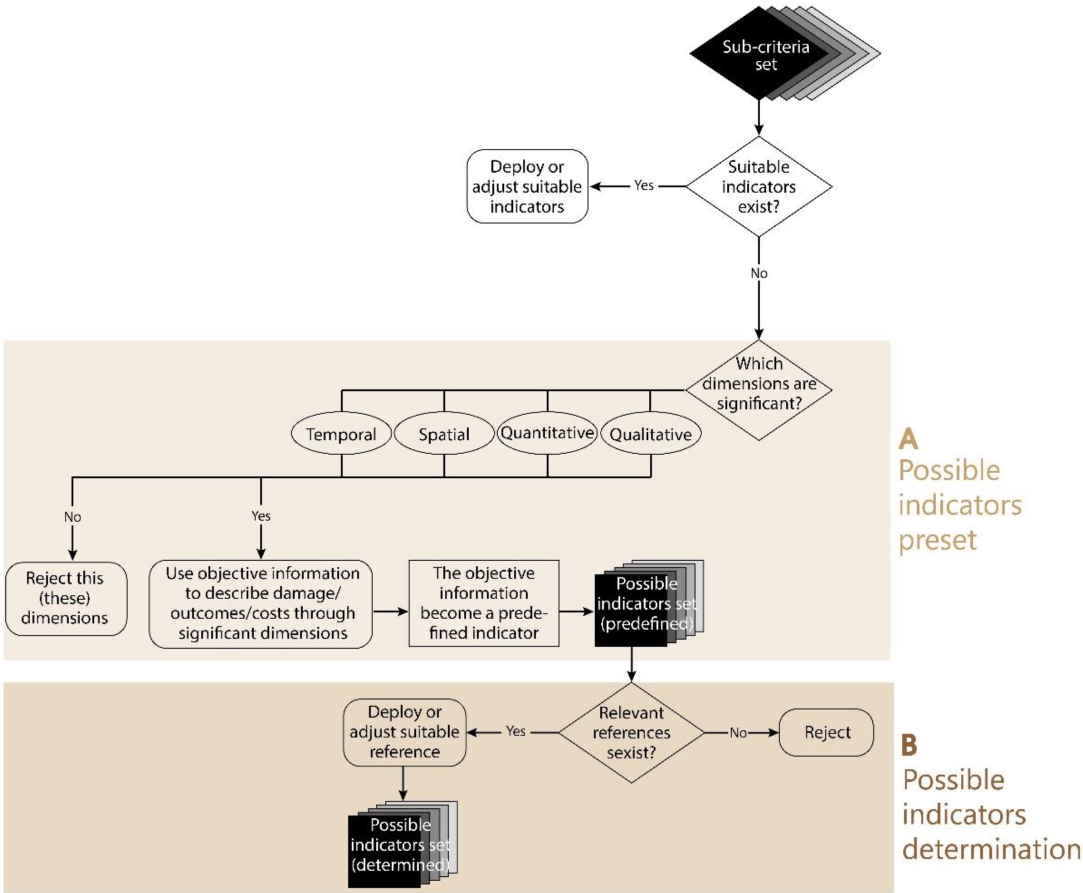
Fig. 6. Form 2 for setting sub-criteria of "Effectiveness of action" and "Effort for action" criteria, source: Yang et al. (2023, b).

The indicators created based on these four dimensions could be called pre-set indicators (Fig.7, part A) because they are not usable without reference definitions. Therefore, once possible indicators have been pre-set, reference definitions for these indicators should be established (Fig.7, part B). Since indicators references are extremely pertinent to the object in particular studies, they should rely on the documents, laws, regulations, policies, guidelines, plans, and other information sources provided by relevant institutions or stakeholders. Finding references sometimes requires considering the sources not publicly available. The indicators with reference definitions could be called determined indicators (Fig.7, part B). However, they are only possibly used for CIs resilience assessment, as their data resources have not been verified. The setting of possible indicators is shown in Fig.7. To make sure the use of determined indicators, the verification of their available data is required.

Revision 5

Section 3.2 Indicators setting and references definition

Fig. 7



<table>
<tr><td></td><td>Fig.7. Form 3: Possible Indicators predefinition and determination associated with indicator references definition, following Form 1 and Form 2, created by authors.</td></tr>
<tr><td>Revision 6

Section 3.3 Verification of available data

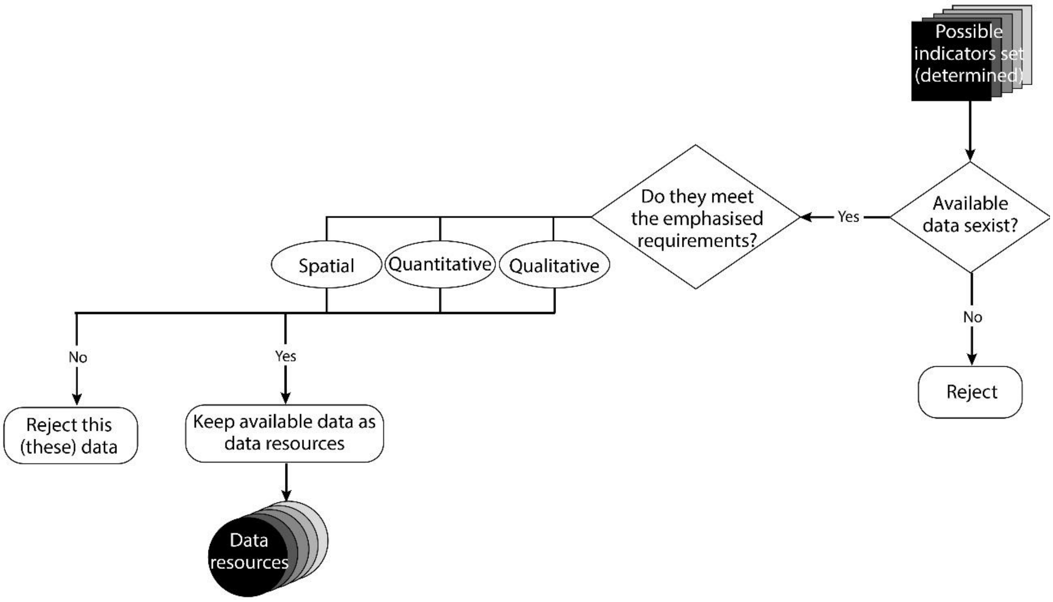
Fig. 8</td><td>Indicators could be assessed by historical data or modelling data. Each country has national databases for different areas and various documents for diverse infrastructures and hazards, which are potential resources for indicators assessments. …The indicators without available data should be rejected (Fig. 8). For the indicators with available data, three points are emphasised for available data analysis (Fig. 8) :
- Relevance. The data must be relevant to set indicators and criteria. For example, in studying flood hazard, flood-related institutions, websites or documents should be the focus of data collection.
- Adaptability. The studied scenarios are related to specific hazards and types of CI, and the information obtained should be adapted to them.
- Usability. Managers should confirm their authority over obtained data before using them. The duration of data availability should be also verified to ensure continuous assessment.
Although modern data is diverse, databases and information technology have systematically evolved from primitive file processing to complex and powerful database systems since the 1960s. Therefore, if the research involves databases with huge numbers of data, the data mining techniques proposed by Han et al. (2011) are suggested to collect valuable data.


Fig. 8. Form 4: Verification of available data, following Form 3, created by authors.</td></tr>
<tr><td>Revision 7

Section 3.4 Result of part 1: Step-by-step guide

Fig. 9</td><td>A step-by-step guide for building an indicator system for CIs resilience assessment is developed in this section. This guide has three phases: 1) specific criteria setting; 2) possible indicators setting and references definition; 3) Verification of available data. This guide combines Forms 1, 2, 3 et 4 (Fig.5, Fig.6, Fig.7 and Fig.8) and is summarised in Fig. 9. The process of indicators setting, incorporating reference definitions, is based on set sub-criteria (Fig.9. phase 2). Final indicators set is determined after the verification of available data (Fig.9. phase 3), as indicator assessment needs reliable data. All steps require …Next section will illustrate how to use this developed guide to build an indicators system for an example case.</td></tr>
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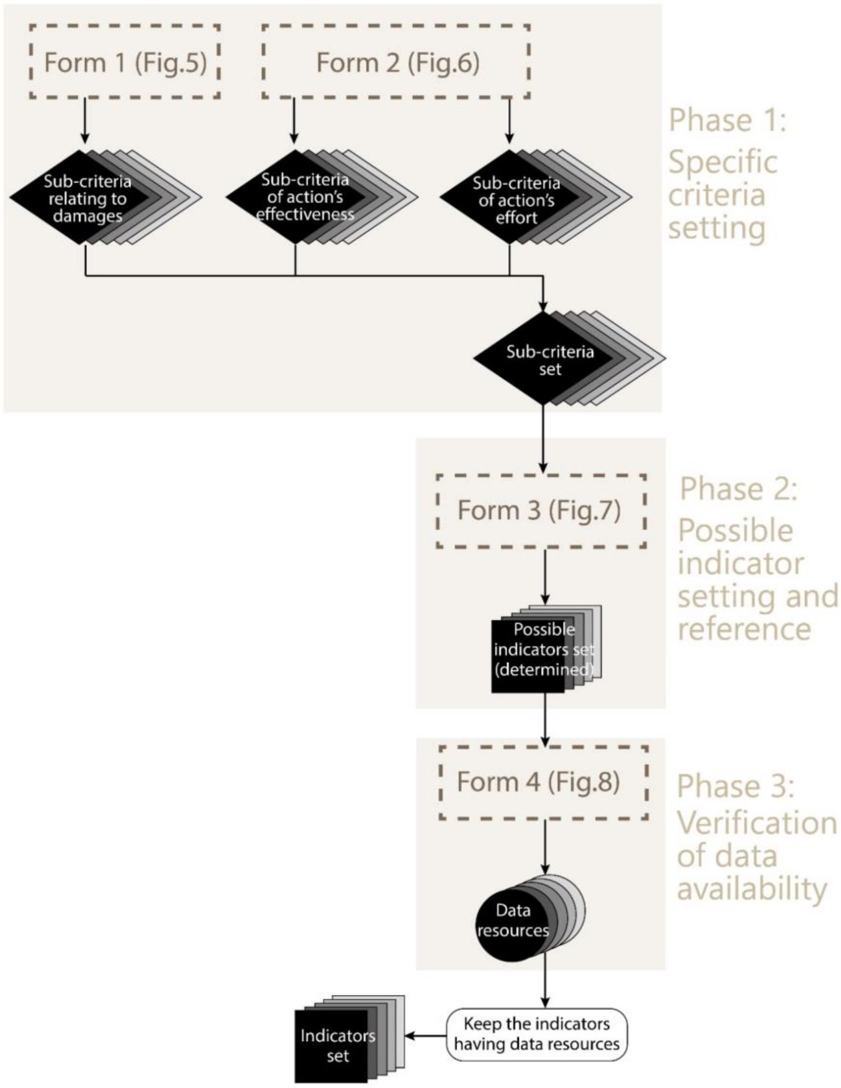

Fig. 9. Guide for building an indicators system for critical infrastructures resilience assessment (in combining Form 1, Form 2, Form 3 and Form 4), created by authors.
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<td>Revision 8

Section 4 Example of Guide Usage

Fig. 10</td>
<td>For demonstrating how to build an indicator system through the developed guide, this study targets a specific circumstance, in which Nantes Ring Road (NRR) is affected by urban flooding. With a length of 42 kilometers, the NRR has services extending beyond the local level and is attractive in the region and even in the nation. However, the section (Fig. 10, lines in red) between the "Porte de la Chapelle" (Fig. 10, point B) and the "Porte de la Beaujoire" (Fig. 10, point C) is frequently closed due to the flooding of the Gesvres River. This study takes the flood event in February 2020 as an example, during which this section was closed on both sides for 56h (Cerema, 2023). During the closure of this section, local road management DIRO suggests alternative roads (Fig. 10, lines in green). These alternative roads contain a part of another highway, Cofiroute network (Fig. 10, lines in bleu). The data from 6 stations, Bonjoire, Bastignolles, Carquefou, Anjou, Bel and Vignoble (Fig. 10), provide important information on the traffic of the sections that connect the frequently flooded section (Fig. 10, lines in orange) of the Nantes ring road. These stations monitor the traffic flows per six minutes on the NRR. Furthermore, in decision-making process for risks management, the consideration of experts' opinions is undeniable because of their professional knowledge (Merad, 2010). Therefore, during the whole study process, the research team, including university scientists, researchers in Cerema (Centre for Studies and expertise on risks, the environment, mobility, and development), and the practicing managers DIRO, make collective decisions based on the content of their meeting discussions.</td>
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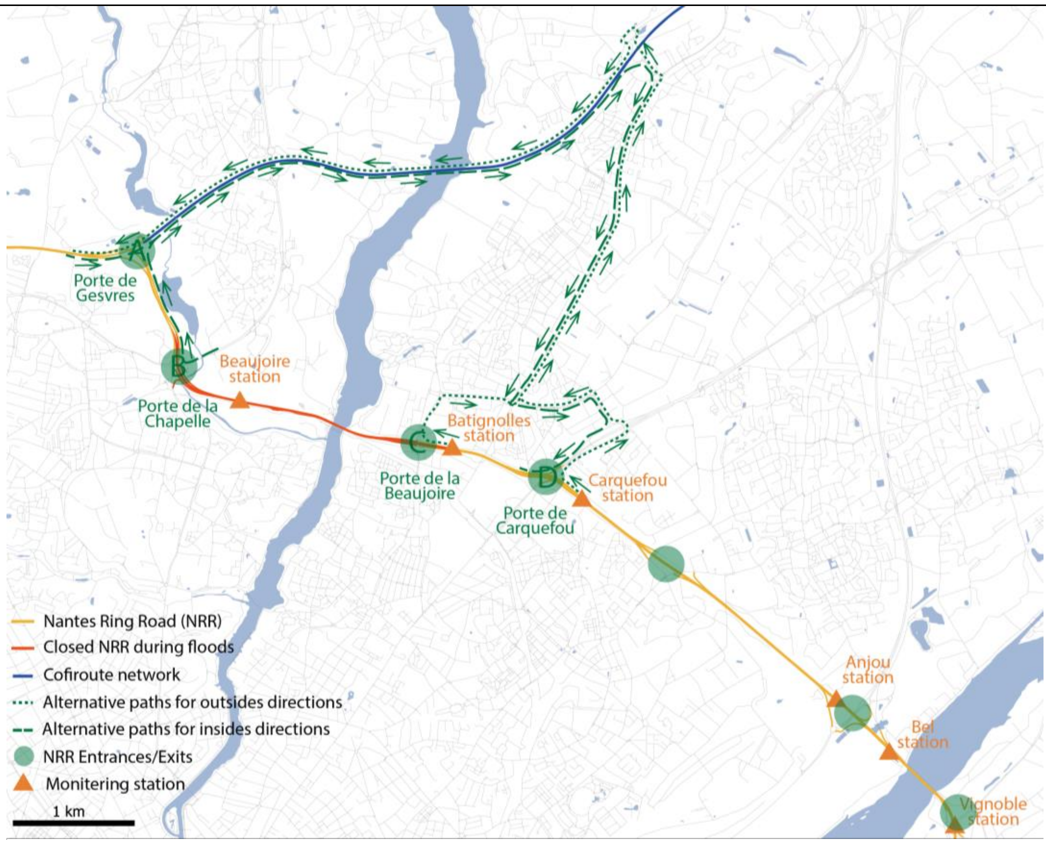

Fig. 10. Road networks in presented example, adjusted from Cerema (2023).

Revision 9

Section 4.1 Criteria setting

Fig. 11

Studied scenarios should be defined before criteria setting. The first studied scenario refers to the NRR affected by flooding, for which DIRO suggests alternative roads when affected sections are closed (Fig. 11, Initial scenario). The suggestion of alternative roads is thus the implementable action for the first scenario. For studying the side effects of the implemented action, it necessitates defining continuous scenarios, in which the implementable action affects NRR or its environment. In this example, since part of the Cofiroute network (Figure 10, lines in blue) is alternative roads, Cofiroute network could be treated as an external system affected by the implementable action. The increase in traffic on the Cofiroute network due to the closure of NRR could have negative impacts, such as congestion, noise pollution, etc. (Cerema, 2023). Cofiroute network is an affected system in a continuous scenario (Fig. 11, 1st continuous scenario). Moreover, the alternative pathways, which are longer than the initial pathways, produce more air pollution. The air environment in Nantes could be treated as another external system affected by the implementable action. Then, the air environment in Nantes is also an affected system in another continuous scenario (Fig. 11, 2nd continuous scenario).

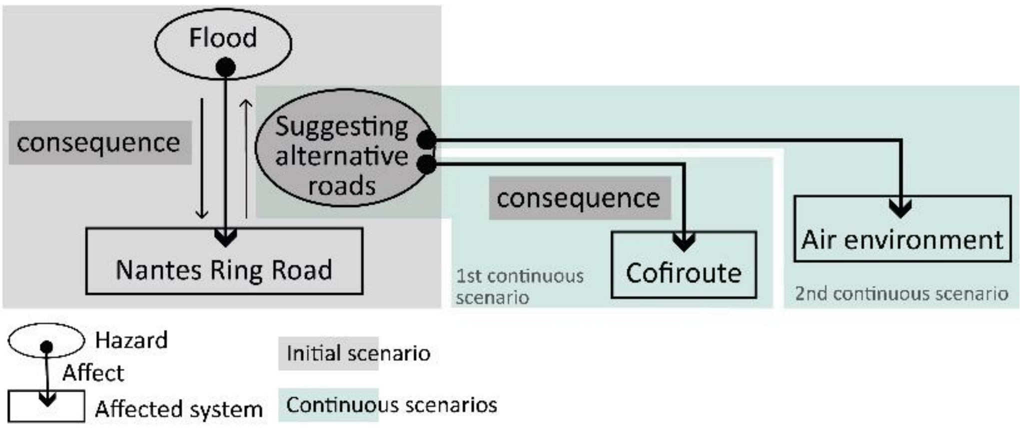

Fig. 11: Initial and continuous scenarios of presented example, adjusted from Yang et al. (2023, b).

Revision 10

Section 4.4. Result of part 3: an indicator system for studied example case

Table 11
Fig. 12

4.4. Result of part 3: an indicator system for studied example case

4.5.

As shown in Fig. 2, an indicators system contains criteria, indicators and data. After Criteria & Indicators setting, and data selection, the indicators system for the studied CI, Nantes Ring Road network, is built as show in Table 12 and Fig.12. The sub-criteria in this indicator system are set based on four general criteria. The indicators in this system are set in terms of sub-criteria and the availability of data resources.

Table 11. Criteria, sub-criteria, indicators and data resources for studied example, created by authors.

Criteria	Sub-criteria	Indicators	Data resources
Damage to internal components	functional damage of transport function	Duration of the NRR close	DIRO
		Traffic flow on the affected NRR sections	DIRO
		Importance of closed road sections	IGN
	Physical damage of individual users	Number of injured users	Local news
		Number of killed users	Local news
		Injury grade of injured passengers	Local news
	Physical damage of road structures	Duration of NRR flooding	DIRO
Effectivenes s of action	Increased transport function of alternative roads	Percentage of traffic being restored on alternative roads	DIRO
Efforts for action	Resources costs of individual users	Additional time costs	IGN
Damage of actions	Functional damage of transport of Cofiroute Network	Additional co2 emission	IGN
	Environmental damage	Traffic state on the alternative roads	Nantes metropole

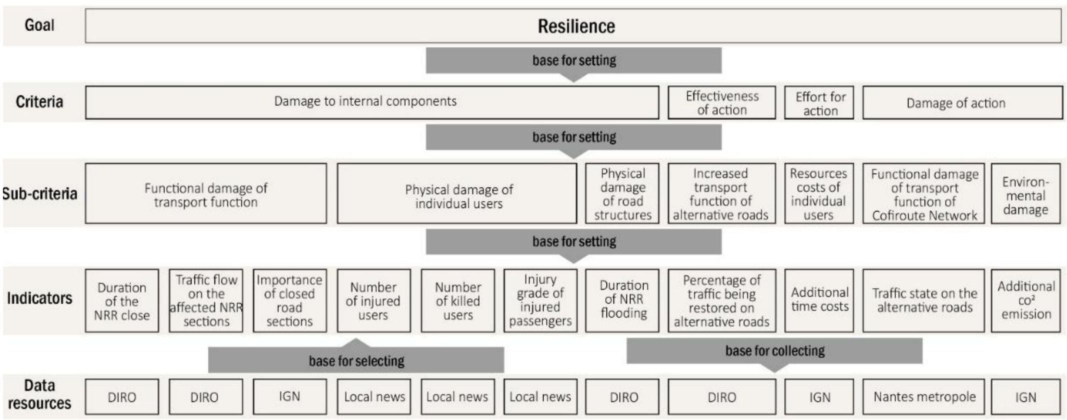

Fig. 12. Indicators systems for studied example built based on the developed guide (Fig. 9), created by authors.