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ESTABLISHING RISK INDICATORS IMPACTING THE FUNCTIONALITY OF CRITICAL INFRASTRUCTURE IN EXTREME WEATHER EVENTS

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Abstract
Urban infrastructure and services are critical to functioning of society, economy and well being, especially in case of disaster, hazard or an extreme weather event. This paper focuses on the Extreme Weather Events and their impact on functionality of the Critical Infrastructure in India. It establishes the need to identify risk indicators that Critical Infrastructure are exposed to, in case of Extreme Weather Events. The study undertaken outlines the methodological approach towards identification of risk indicators. The data for establishing risk indicators is ascribed through comprehensive literature review of post-disaster assessment reports, case studies and Disaster Risk Reduction frameworks in the Indian Context. The final outcome of this paper establishes the risk indicators under the umbrella of the physical, social and economic attributes of the critical infrastructure. The comprehensive list of indicators are sub-categorized and clustered in groups based on critical infrastructure vulnerability, susceptibility and adaptive capacity.

Keywords: *Critical Infrastructure (CI), Indicators, Risk Assessment, Extreme Weather Events (EWE)*

1. Introduction

Climate Change is a global phenomenon which has lead to altering of the weather and climatic events (IPCC, 2001). The effects of these events are witnessed in the form of extreme temperature, humidity, prolonged precipitation for example rain, fog, snow etc. The uncertainty of these weather conditions leads to severe conditions like flooding, drought, avalanche, cyclones, landslides etc. The impact caused by these events are dependent on severity, vulnerability and exposure to the Critical Infrastructure (CI) and services such as transportation, healthcare, energy, telecommunication, water supply etc. (Tagg et. al. 2016)

Risks of Extreme Weather Events (EWE) on the Critical Infrastructure are felt through geographically differentiated locations in India. The Intergovernmental Panel on Climate Change (IPCC) framework, 2011,14 considers the multifaceted impacts on the functionality of the CI upon society, economy and environment. their impact and consequences have often proved inadequate. The probability of occurrence of the EWE is expected to increase (figure 1), thereby measuring the impact on the CI is vital. Hence, there is a need to build climate resilient CI for well functioning of the society and cities in general.

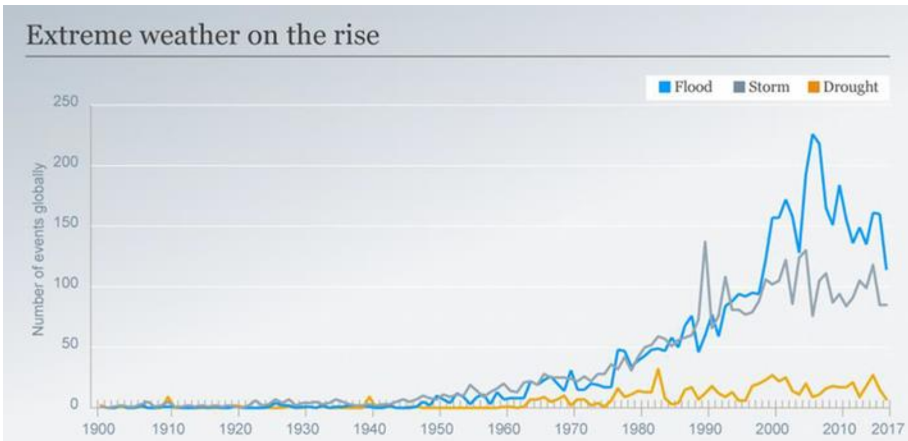

Figure 1 Global Trends of Extreme Weather Events, EM-DAT

In order to measure the impacts on functionality of CI, identification and clustering of risk indicators is essential (Molarius et. al. 2016).

1.1 DEVELOPMENT OF PROBLEM STATEMENT

With the adequate literature it is established that identification of the risk indicators is a pre-requisite to the development of the quantification framework for risk assessment.

This paper reviews various research projects taken up by the European Union, which has contributed vastly in establishing risk assessment methodologies and matrices.

Based on the literature review of the projects, this paper is developed and is broadly divided into 3 sections. The first section is focused on the purpose and need of the identifying risk indicators and risk assessment frameworks adopted for the protection of the critical infrastructure against extreme weather events. The second section describes methodology and literature review of the assessment framework adopted for the identification of risk indicators.

Based on the ascribed methodology in the second section, the final section of the paper outlines the cause-consequence diagram method to strategically identify the components of risk indicators. Indicators are selected based on their relevance and measurability, under the umbrella of social, physical and economic indicators.

The scope of the study is limited to establishment of cause-effect relation with Extreme Weather Events and critical Infrastructure. It does not take natural disaster or man-made hazard into account. In order to measure the vulnerability and risk of critical infrastructure, indicators are identified through literature review. The risk indicators are thereby categorized as per exposure, susceptibility and adaptive capacity of the critical infrastructure when exposed to extreme weather condition.

The outcome of the paper forms a basis for carrying out risk assessment studies for infrastructure projects in case of EWEs. In addition, this paper will help CI operators and Policy makers to re-evaluate the functional aspects of CI in case of EWEs.

2.1 DEFINITIONS

2.1.1 Critical Infrastructure

Critical Infrastructure (CI) definition differs amongst countries, depending upon the officially recognized infrastructure components and regional differentiation. (Claudia Bach et. al. 2013). Few of the definitions are enlisted below for reference.

UNIDSR, 2017 defines Critical Infrastructure as *'The physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society'.*

Council Directive-European Union defines Critical infrastructure as *"an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social wellbeing of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions."*

CPNI, UK defines Critical National Infrastructure as *"those facilities, systems, sites, information, people, networks and processes, necessary for a country to function and upon which daily life depends."*

CI including power, transportation, telecommunications, financial services, information and communications technology (ICT), etc needs to be protected from cyber or other attacks along with Extreme Weather events or natural disasters (Singh et. al, 2014).

Table 1 indicates the global scenario for recognition of the CIs by different countries. It is established that the categories of CI varies from country to country.

Table 1 Country wise list of differentiated Critical Infrastructure
Source: Author

	Transport	Energy	ICT	Food and Agriculture	Health	Financial Services	Public Safety	Industry/manufacturing	Environment	Defense Base	Water Supply and Sanitation	Public Buildings	Government	Social Infrastructure	Emergency services	Chemical industries	Dams	commercial facilities	nuclear	monuments	Telecommunication	Space
India	✔	✔	✔	✔	✔	✔					✔	✔	✔	✔								
Canada	✔	✔	✔	✔	✔	✔	✔	✔			✔		✔									
USA	✔	✔	✔	✔	✔	✔		✔		✔	✔	✔			✔	✔	✔	✔	✔			
UK	✔	✔		✔	✔	✔				✔	✔		✔		✔	✔			✔		✔	✔
Australia	✔	✔	✔	✔	✔	✔																
EU	✔	✔	✔	✔	✔	✔			✔													
China	✔	✔	✔		✔	✔																

As suggested in the table, UK enlists 13 type of CI whereas USA enlists 16 type of CI. Based on the Critical Infrastructure protection priority list actions are thereby taken by both government and other agencies. Refer to table 1 for country wise listing of CI. The CI are divided into 22 categories based on the literature review of the critical infrastructure list and components. The countries from where the literature has been referred to area India, Canada, USA, UK, European Union, Australia and China.

Singh et. al, 2012 identifies 9 types of CI for India, as reflected in table 1. The selection is based on evaluation of all the CI definitions and 22 categories of the CIs.

2.1.2 Extreme Weather Events

IPCC, 2011 report defines Extreme Events as *'the occurrence of a value of a weather variable above or below a threshold value near the upper or lower ends of the range of its observed values in a specific region'.*

In other words, unforeseen weather events which has occurred in a specific region affecting the society, economy and physical infrastructure of the city. As defined by the oxford dictionary; Extreme: Reaching a high or the highest degree; Not usual and Event: a thing that happens or takes place, especially one of importance.

David B. Stephenson in 2008 gives various other terms similar to extreme events such as severe events, high-impact events, rare events etc. He also marks the attributes associated with EWEs such as probability of occurrence, magnitude, spatial-temporal duration, multi-variate dependencies etc.

Understanding the patters of the EWEs in order to identify risk indicators is vital to this study. With the increase in occurrence of the EWEs, the impact on CI also increases. The first step towards risk assessment of the CI is to identify the hazards caused by the extreme weather events (EWENT, 2012). Hence understanding of the EWEs and its attributes is vital in order to conduct the risk assessment studies.

2.1.3 Concept of Risk

Estimating the severity of the event, expected long term loss is calculated in terms of risks, in order to measure the impact on any infrastructure facility.

For risk quantification probability of occurrence of EWEs is taken into account, until recently product of hazard and vulnerability was identified for optimal calculation of the risks. EWENT, 2012 defines vulnerability of a particular mode in a particular country is a function of exposure (indicated by transport or freight volumes and population density), susceptibility (infrastructure quality index, indicating overall resilience) and coping capacity (measured by GDP per capita). Hence, we define the extreme weather risk as

$$\begin{aligned} \text{Risk} &= \text{hazard} \times \text{vulnerability} \\ &= \text{P(negative consequences)} \times \text{V[f(exposure, susceptibility, coping capacity)]} \end{aligned}$$

In order to quantify the vulnerability and thereby risks, indicators for the same is identified for regionally differentiated EWEs.

3. Impact on CI due to EWEs

Various studies and projects have been conducted on measuring the impact on CI in case of natural hazard or extreme weather events. Few of the studies are enlisted in the table 2 below for reference.

Table 2 Research Projects measuring the impact of EWE on CI

Name of Project	Title	Year	Description
Impact of extreme weather on critical infrastructure – Capability Project	INTACT	2014-2017	• Offers a Decision Support to CI operators & policy makers regarding Critical Infrastructure Protection (CIP) against changing EWE risks caused by climate change. • The decision support will enhance the aspect of business continuity, or, sustained resilience, in order to allow societies and economies to function unimpaired.
Risk Analysis of Infrastructure Networks in response to extreme weather	RAIN	2015-2018	• The principal objective of the RAIN (Risk Analysis of Infrastructure Networks in response to extreme weather) projectis to provide an operational analysis framework to minimize the impact of major weather events on land based transportation and energy and telecommunication (E&TC) CI in the EU. • RAIN aims to quantify the complex interaction of existing infrastructure systems and their interrelated damage potential in the event of specific EWE's.
Critical Infrastructure Preparedness and Resilience Research Network	CIPRNET	2013-2017	• The CIPR Net Joint Programme of Activities (JPA) integrates and makes complementary use of CIP and related knowledge, expertise, and resources (e.g., tools, methods, top experts and other staff) of the partners.
Extreme Weather Risk Indicators	EWRI	2012	• The methodological approach of EWENT is based on the generic risk management standard (IEC 60300-3-9) and starts with the identification of hazardous extreme weather phenomena, followed by an impact assessment

Name of Project	Title	Year	Description
			and concluded by mitigation and risk control measures.
Extreme Weather Impacts on European Network of Transport	EWENT	2010-2012	• The framework is specific to the transport systems in the EU framework. It gives a methodological approach towards risk assessment. A probabilistic approach is adopted in the assessment methods.

The framework adopted for most of the projects mentioned in the table 2 reflects risk assessment methodology used in the INTACT project under the 7th European Framework for boosting resilience of the CI against EWEs.

The assessment is performed with a focus on post-construction performance of the CI along with the recommendation of alternative measures adopted on ad-hoc basis for the CI.

In India, National Disaster Management Authority, Government of India sets the rules, regulations and policy guidelines for the regionally differentiated natural disasters, hazards and extreme events across India. In the Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR), 2016 the measurement of impact on CI in case of EWE was recommended. The impact on the CI can be either direct, indirect or intermediate when exposed to an extreme event.

Direct impact is set to have a causal linkage of the complete or partial destruction of the immovable assets whereas indirect impact is referred to as hindered flow of goods and services and social loss. The intermediate or wider impact is on the macro level wherein the long term impact on production is to be measured.

Based on the post-disaster reports and case studies of the occurrence of extreme events in past 10 years in India, physical,
impact on the CI was cross analyzed as represented in table 3.

Table 3 Impact on the CI due to EWE
Source: Author

Extreme Weather Event	Cause/ Impact	Types of Critical Infrastructure										
		Transport	Water Supply	Emergency	Financial Services	Hospitals	Agriculture and Food	Defense Base	Government	ICT	Public Safety	Electricity
Extreme Precipitation	Floods											
	Flash Floods											
	Landslides											
Wind	Cyclone											
	Dust Storm											
	Tornado											
Lack of Precipitation	Drought											

High temperature	Heat Waves											
Low temperature	Snow/Blizzards											

Indirect Impact
Intermediate Impact
Direct Impact

From the cross-matrix formed for measuring the impact on the CI, it can be concluded that sectors like healthcare and agriculture and food suffers from the maximum direct loss when exposed to the events like floods, landslides, cyclones, drought etc.

In addition, sectors like defence, government, ICT, safety etc. endures the maximum indirect impact. Utility and services type of supportive infrastructure, which is set to be most vital for the functioning of the infrastructure like healthcare, public buildings etc. encounters the most wide range of impact. The wider or intermediate range of the impact abides by the adaptive and coping capacity under the umbrella of the risk assessment framework ascribed the EU framework, referred in the following chapters.

4. Methodology to establish risk indicators

Risk indicators varies with the category of infrastructure and The concept of risk indicators for CI against the EWEs is derived from the World Risk Report (WRR), 2016 where in UNISDR, 2004; Wisner et al., 2004; Birkmann, 2006; IDEA, 2005; IPCC, 2012 has also been referred to be using the same Risk measurement index (Refer figure2).

The indicators for the risk has been categorized as per their exposure, susceptibility, coping capacity and adaptability against the EWEs.

In this paper, the broad level methodology is adopted from the WRR, 2016 however the indicators are established under the umbrella of the physical, social and economic attributes of the CI.

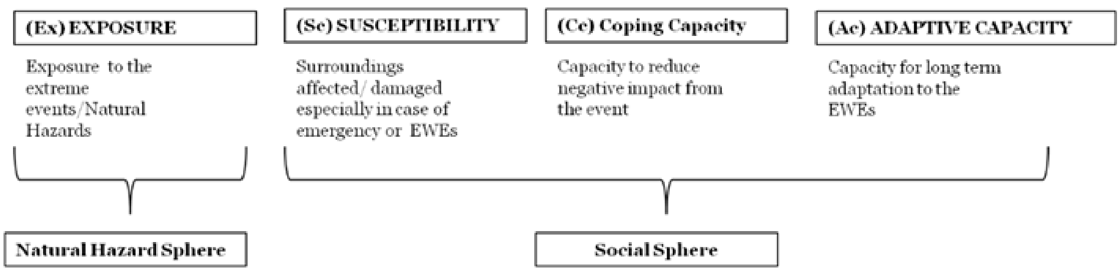

Figure 2 Disaster Risk Indicators
Source: World Risk Index, 2016

5. Risk Indicators and its components

In accordance to identification of the risk indicators, understanding of the CI interdependencies is vital (BOARU et.al 2008). Identification of the physical, social and economic impacts on the CI when exposed to a EWEs is illustrated through a fish bone diagram in the figure 3.

Various literature reveals that the impact assessment of the CI can also be taken into account by the attributes like Infrastructure characteristics, types of CI failure in order to measure the resilience, operational scenario and response mechanism of the infrastructure type. The components describing the interdependencies of the CI is established through the case studies presented by the report on Disaster Risk Reduction by the National Institute of Disaster Management (NIDM), 2013.

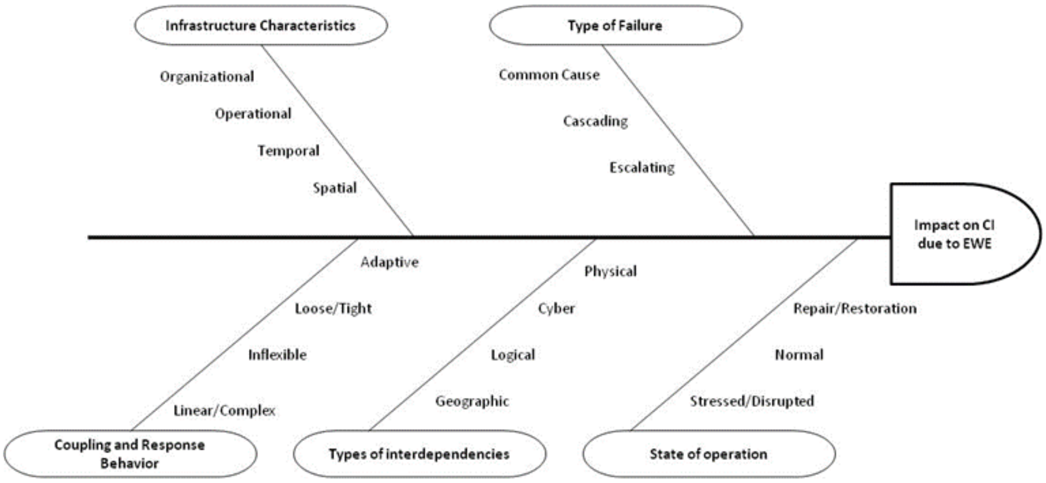

Figure 3 CI Interdependencies and Impact on CI due to EWE
Source: Author

These above mentioned attributes have sub-attributes responding to the typology of the infrastructure. For instance, according to nature of CI interdependencies varies with the geographical locations, physical networks and linear relationships with the other infrastructure (Aaron Clark-Ginsberg et.al, 2018).

5.1 CAUSE-CONSEQUENCE ANALYSIS OF THE RISK INDICATORS

Andrews et. al., 2018 describes cause consequence analysis methods as an extension to the fish bone diagram for system risks. The methods outlines the logic behind the system failure by identification and branching out the indicators established.

A fault tree tool is used to follow up on the cause and consequence analysis. It takes into account the event that has occurred and cause of the incident in order to establish risks.

The author in the figure 4 has adopted this method to initiate the 27 indicators under the umbrella of the physical, social and economic indicators as per their individualistic exposure, susceptibility and adaptive capacity as discussed in the section 3 of the paper.

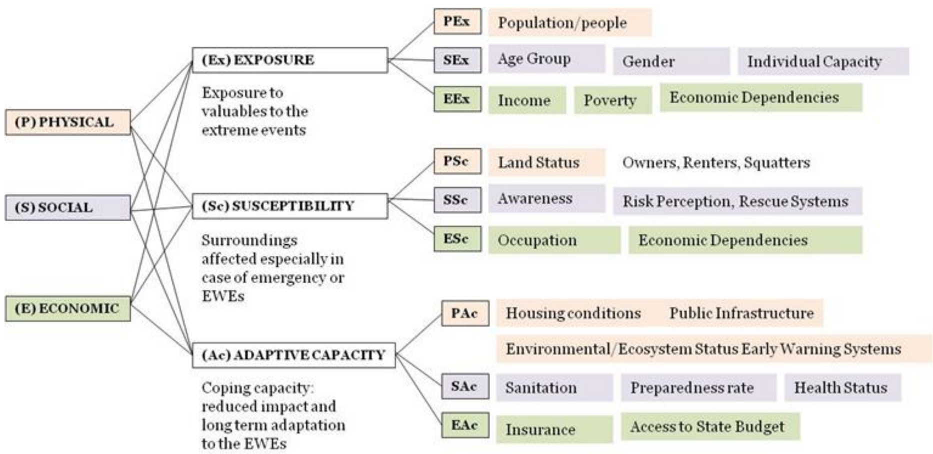

Figure 4 cause- Consequence Diagram for identification of risk indicators
Source: Author

5. Conclusion

With the increased facets of the development activities interdependencies of the utility and services have also increased. A holistic approach towards measuring resilience of CI is adopted through this paper.

As with the first section, defining the CI in the global scenarios and importance of CI protection is highlighted. As a result of variations in the climatic events, measuring the impact on the CI has become vital. The impact assessment carried out in the paper showcases the direct, indirect and intermediate impact on the CI when exposed to extreme weather conditions. Projected increase in the EWEs has also set an impact on educed life expectancy with the increased exposure to the individual capacity and population.

The study also exhibits projects and academic studies across global especially by the Government of the UK, US and European Union for CI protection and risk assessment methodologies adopted by the specific countries.

Hence, significant risk assessment studies are proved to be a vital asset in increasing the coping capacity of the large scale infrastructure projects. While understanding of the risk is vital to the society with the current government engagements in India, assessment and management of the CI and its impact due to EWEs are to be promoted. Hence outlining the future area of work.

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