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Estimation of Flooding Disruptions on Interdependent Industry Sectors

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Abstract

These days economic systems and infrastructure are highly interrelated. Natural disasters can cause damage to an infrastructure (e.g. a road). This direct impact of disaster can have an indirect impact on the availability of workforce in an industry. Since workforce acts as a backbone in an industry, unavailability of workforce will result in decreased production and will cause inoperability to the industry. Due to interdependency, inoperability of one industry sector will affect production in other industry sectors and hence the effect will be further exaggerated. This paper seeks to investigate the consequences of workforce absenteeism on the inoperability and economic losses of industry sectors. Inoperability and economic losses are estimated by incorporating economic data in Dynamic Inoperability Input Output Model (DIIM) after a flood in Peshawar, Pakistan. In case study, ten industry sectors that are affected by the flood; are ranked according to economic losses and inoperability. According to inoperability metric, top three sectors that are most affected by the flood are: (1) Electricity supply; (2) Agriculture; and (3) Marble industry.

Keywords: *Natural Disaster, Industry Sectors, Workforce, Inoperability.*

1. Introduction

Disasters usually have a negative effect on infrastructure, economy and lives of people [1]. Disasters are classified into three main types, i.e. natural disasters, manmade disasters and hybrid disasters [2]. Flood causes most of the economic losses in Pakistan [3, 4], also it is the most frequently occurring natural disaster in Pakistan [5].

Flood can cause damage to a building, road, bridge, lives of workers etc. This research focuses on economic losses to industries on the basis of workforce unavailability due to flood. Whenever there is flooding, it causes inoperability of an industry sector. The output of one industry sector is usually the input of other industry sectors, due to which other sectors also become inoperable and all this results in the economic losses of the industries [6]. Different methods are used for finding damages to industries in the form of inoperability and economic losses. In this we use an extension of inoperability in put output model [7, 8] known as dynamic inoperability input output model [9]. We select a local industrial area in Peshawar, which was effected by flood in 2009, as a case study.

2. Aims and Objectives

The aim of this research is to rank the industry sectors on the basis of economic losses and inoperability to identify the critical sectors. Identification of critical sectors will help in allocation of the limited budget to industry sectors in case of a disaster. With this goal in mind this research has the following main objectives.

- To determine the inoperability of different industry sectors.
- To estimate the economic losses of different industry sectors.
- To help the organization to show its status after disruptions.
- To rank the industry sectors on the basis of inoperability and economic losses.
- To help in allocation of the budget by identifying the critical sectors.

3. Literature Review

In early stages some other methods were used for risk assessment. HAZOP [10] is a method which means hazard and operability. It is a qualitative method in which a team of experts identifies the hazards and risks which causes the industry to be inoperable and human injury. Due to their effects on economic system, natural disasters have inspired the researchers to concentrate their work on risk analysis. The actual Input output model [11] which was developed by Leontief has been changed to include effects caused by natural disasters. An extension of Input output model i.e. Inoperability Input output model (IIM) has been used to find inoperability of interrelated sectors. Dynamic Inoperability Input output model (DIIM) is an extension of

IIM to estimate time variant inoperability of different sectors. Olsen et. al., [12] used a method for the risk management in case of flooding. Cho et. al., [13] determined transportation sectors losses due to earthquake by using I-O model. Hsu and Chou [14] combined multi-objective programming technique with the Leontief model in order to evaluate policies for decreasing CO2 emissions in Taiwan. Barker and Santos [15] merged inventories into DIIM to assess resilience of an interrupted system. Okuyama et. al., [16] used other methods for determining economic losses due to disasters. Rose et. al.,[17] used Computable General Equilibrium (CGE) approach for determining economic losses due to water supply disruption. Kujawski [18] compared the Multi-Period Model for Disruptive Events in Interdependent Systems (MPMDEIS) and DIIM to analyze the equilibrium of inter-reliant systems after a disaster. Qin et. al., [19] conducted a study emphasizing the consequences of disasters on workforce availability. Krista et. al., [20] determined inoperability in different sectors due to flooding in Manila. Akhtar et. al., [6] used DIIM for estimating economic losses and inoperability for different intensity hurricanes. Xiao and Renbin [21] deployed a modification of DIIM to optimize supply chain network with time varying disruption.

4. Methodological Background

4.1 Input Output Model

Input output model is a Nobel Prize awarded mode, developed by Leontief. This model describes interdependencies between different industry sectors in an economic region. According to this model output of an industry sector is given by the following equation.

$$x = (I - A)^{-1}c \qquad (1)$$

Where $x = output\ matrix$

$A = Technical\ coefficient\ matrix$

$c = Final\ demand\ matrix$

4.2 Inoperability Input Output Model

Inoperability input-output model (IIM) is an extension of the actual input output model. It is used to find inoperability of an industry sector after a disaster. According to IIM inoperability of an industry sector is given as;

$$q = (I - A^*)^{-1}C^* \qquad (2)$$

Where $q = Inoperability\ matrix$

$A^* = Interdependency\ matrix$

$C^* = Perturbation\ vector$

4.3 Dynamic Inoperability Input Output Model

Dynamic inoperability input output model (DIIM) is an extension of IIM which has the ability to determine inoperability at different durations after a disaster. In IIM inoperability is considered constant but actually inoperability changes with time therefore DIIM is introduced to determine time variant inoperability at different days after a disaster by introducing a resilience matrix K. According to this model inoperability is given as;

$$q(t+1) = q(t) + K[A^*q(t) + c^*(t) - q(t)] \qquad (3)$$

Where $q(t) = Inoperability\ matrix\ at\ time\ t$

$q(t+1) = Inoperability\ matrix\ at\ time\ t+1$

$K = Resillience\ matrix$

$A^* = Interdependence\ matrix$

$c^*(t) = Perturbation\ vector$

5. Case Study

This portion describes the inoperability and economic loss results obtained for different industries along a river system called as “Budni Nallah” [22] in a local area of Peshawar. Peshawar district represents an important industrial zone in Pakistan [23]. Industrial survey of ten different industry sectors in Peshawar, which were disrupted by flood, has been conducted. Survey data combined with local economic data has been used as input to DIIM. After analysis industries are ranked on the basis of inoperability and economic losses.

Table 1 shows the ranking of ten industries according to inoperability while Table 2 describes the classification of ten industry sectors according to economic losses. The values given for inoperability in Table 1 are of effective average inoperability.

Sectors having high average inoperability as well as economic losses are agriculture sector, electricity supply and marble industry sector. The reason for high inoperability and economic losses of these industry sectors are their higher dependency on labors relative to other industry sectors in this particular area. Top three industry sectors according to inoperability are: (i) electricity supply sector; (ii) agriculture sector; and (iii) marble sector. Both construction and telecom industries have low inoperability as these industry sectors are more resilient (less workforce disruptions) in case of flooding. In this region telecom sector has low economic losses and inoperability because of its less dependency on employees. Construction sector is not suffering from high inoperability because the labors of this particular sector have their residence on the working site and flood is not causing a major disruption of its workforce. Top three industry sectors according to economic losses are: (i) agriculture sector; (ii) marble sector; and (iii) electricity supply sector.

Table 1: Inoperability ranking

Sector	***Rank***	***Inoperability value (%)***
Electricity sector	1	9.01
Agriculture	2	8.33
Marble	3	7.21
Flour mill	4	5.24
Health	5	4.81
Education	6	4.62
Storage	7	4.58
Wood industry	8	2.81
Telecom	9	2.25
Construction	10	1.75

Table: 2 Economic loss ranking

Sector	***Rank***	***Economic loss (Million PKR)***
Agriculture	1	1.01
Marble	2	0.98
Electricity	3	0.81
Flour mill	4	0.66
Wood industry	5	0.59
Education	6	0.34
Health	7	0.28
Telecom	8	0.27
Construction	9	0.25
Storage	10	0.13

Figure 2 describes the recovery behavior of inoperability while figure 3 predicts cumulative economic losses for ten industry sectors. It is clear from figure 2 that inoperability of industry sectors decreases with time as the sectors are coming to their normal positions after the flood. Highest value of inoperability is almost 72% which is the inoperability value of marble industry. This value shows initial inoperability of marble industry just after the flood. Effective inoperability value for marble industry is 7.21% as clear from table1.The minimum initial inoperability value is for telecom sector i.e.15%. Effective inoperability of telecom sector is 2.25%. Inoperability of almost all industry sectors becomes negligible after five days which shows after to five days industry sectors are almost near to their normal positions.

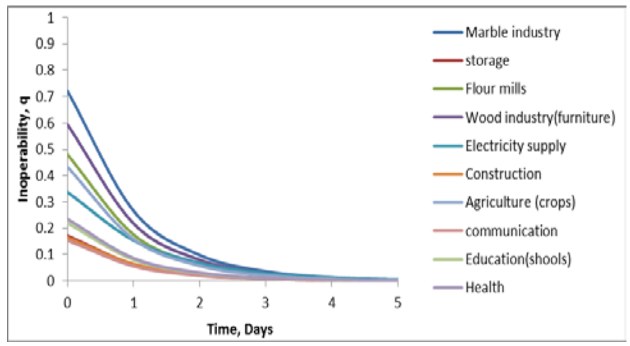

Fig.1 Inoperability with respect to time

Figure 3 describes cumulative economic losses separately for ten industry sectors. Maximum economic loss is for agriculture sector which is almost 1 million PKR. Minimum economic loss is 0.13 million PKR, which is for storage industry. Collective economic losses of all industry sectors are almost 5.32 million PKR, among which top three industry sectors (agriculture, marble and electricity supply) have economic losses of 2.80 million PKR. These top three sectors represent 52.63% of total economic losses in this particular area.

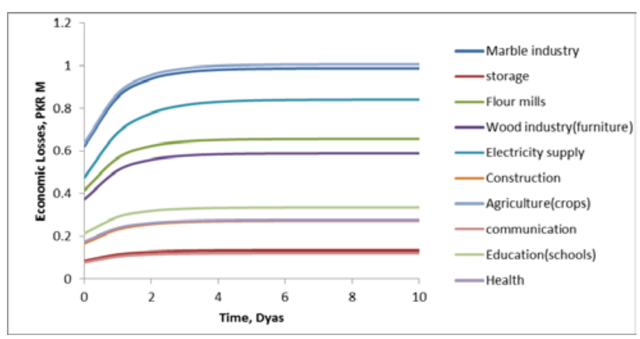

Fig.2 Economic loss with respect to time

6. Conclusion

In this research, initial inoperability was determined on the basis of workforce absenteeism for industry sectors after flooding. After that DIIM was used to estimate time variant inoperability and economic losses. Industry sectors were ordered on the basis of inoperability and economic losses to help policy makers in the process of resource allocation. Ten different industry sectors were selected for research purpose. Next time this research can be prolonged by including more industry sectors. Furthermore, this methodology can also be applied to determine impacts due to other disasters.

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