한국도로학회 논문집
第11卷1號 2009年 3月
pp. 117 ~ 126

Socio-Economic Impacts of an Unscheduled Event: A Case in Korea

재해발생으로 인한 사회-경제적 영향분석: 우리나라 사례를 중심으로

이성관* 강승림** 김창호***
Seongkwan Mark Lee Seunglim Kang Tschangho John Kim

요지

지진을 기록하기 시작한 후로 우리나라에 발생한 지진은 2000회가 넘는 것으로 집계되고 있으며 그 중 48회는 엄청난 피해를 초래한 것으로 나타난다. 지진으로 인한 생산설비나 주요 관로 등의 시설물피해는 특정 지역에 국한되는 것이 아니라 지역간의 상호 의존적 특성에 의해 경제적으로 볼 때 심각한 피해를 주변에 전달하게 된다. 또한 지진과 같이 예측하지 못하는 사건으로 인해 발생하는 경제적 피해는 단순히 시설붕괴같은 직접적인 손실 뿐만 아니라 당해 시설의 보수나 재건에 소요되는 기간을 통틀어 간접적인 손실이 발생하게 됨을 인지해야 한다. 그런데, 지진 등과 같이 예측하지 못한 사건으로 인한 손실과 피해를 입은 시설 등을 보수보강 하거나 재건하는데 필요한 정부투자나 예산지원 금액을 보다 합리적으로 산정하기 위해서는 피해를 입은 지역내부 뿐만 아니라 그 지역이 관계를 맺고 있는 주변지역과의 직·간접 경제적 손실을 제대로 산출해 낼 필요가 있다. 여기서 직접적인 경제손실이라하면 생산시설이나 공급선의 피해로 인해 발생한 수요-공급관계의 1차적 변화를 의미하며, 간접적인 경제손실은 산업구조상 관계를 맺고 있는 다른 부문에서 나타나는 간접적인 변화를 의미한다. 본 논문에서는 지진발생으로 인한 경제적 영향, 특히 우리나라 교통망이 받는 영향을 분석하고자 하였다. 이를 위해 우리나라의 고속도로, 교량 및 경제 관련 자료를 수집하여 사용하였고, 지진 등 예상하지 못한 사건의 발생으로 인한 최종수요의 손실과 부문별 생산품의 흐름을 예측하였다.

핵심용어 : 의사결정지원체계, 지진, 사회경제적 손실

Abstract

Total number of recorded earthquakes in Korea is more than 2,000 of which 48 were catastrophic. The impacts from infrastructure damage due to an earthquake to production facilities and lifelines may spread across boundaries of several regions via import-export relationships and can bring serious economic impact to other regions. The economic impacts from unscheduled events stem not only from the damage and direct losses, but also from the indirect losses during the recovery and reconstruction periods. To recover and reconstruct the facilities and lifelines damaged by unexpected events through investment or government financial aid, both the direct and the indirect economic impacts from an event, need to be measured in regional and interregional contexts. Direct economic impact is the direct change of production and demand due to the disruption of production facilities and lifelines from an unexpected event, and indirect economic impact is the change in other sectors due to inter-industry relationships. The purpose of the paper is to analyze various economic impacts of an earthquake, especially impacts on transportation networks in Korea. We collected spatial and economic data from Korea, and analyzed and estimated final demand loss and commodity flows from the unscheduled event.

Keywords : decision support system, earthquake, socio-economic loss

---

* Researcher, Expressway & Transportation Research Institute
** Researcher, U-City Project Team in Yonsei University
*** Endowed Professor, University of Illinois at Urbana-Champaign

1. INTRODUCTION

Since the first seismometer was installed in Inchon, Korea in 1905, the total number of 'sensible earthquakes' registering over 3.0 on the Richter scale has been more than 1,700, of which 48 were over 5.0 on the Richter scale. About 37% of 723 earthquakes (264 earthquakes) have been recorded as 'sensible earthquakes' since the end of 1970 (NEIS, 2006). This number is far lower than those recorded in Japan but higher than those occurred in Manchuria. South Korea is a comparatively stronger seismic area than North Korea and Manchuria, and the western half of the Korean Peninsula has shown stronger seismicity than the eastern half.

Unscheduled events such as an earthquake cause direct damages to transportation networks and have indirect negative impacts on regional and national economies in the long run (Sohn et al., 2004). Recent earthquakes accompanied by catastrophic damages such as Northridge in America (1994), Kobe in Japan (1995), Izmit in Turkey (1999), Chi-Chi in Taiwan (1999), Gujarat in India (2001), Algeria (2003) and southern Iran (2003) suitably demonstrate that the secondary damages to a metropolis caused by a long paralysis of socio-economic activities are far more serious than the direct damages such as disruptions of buildings (Lee and Kim, 2007; Lee, Kim and Kang, 2007).

In the past, scientists and engineers have focused on the analysis of direct damages such as the disruption of bridges and buildings from an unscheduled event (Lee, Lee and Kim, 2006). Consequently, their efforts have been naturally given to the evaluative analysis of the hazards, the minimization of the damages, and the reconstruction strategies for the damaged structures. The indirect impacts such as the long-term economic impacts have not been the focus of such analyses. The purpose of the paper is to analyze and estimate the socio-economic impacts of network vulnerability caused by natural and man-made disasters, especially impacts on transportation networks in Korea.

This paper is composed of four sections. Following the introductory section, Section two describes methods of analysis in detail. In it, the final demand loss function relates the bridge damage to an economic loss in intra- or inter-regional commodity flows. For the estimation of bridge vulnerability, we modified the Hwang's fragility curves (Hwang and Hou, 1996; Hwang, Jernigan and Lin, 1998) as reported in detail in Lee, Kim and Kang (2007). To estimate the final demand loss and commodity flows under an unscheduled event, the Final Demand Loss Function and the Integrated Commodity Flow Model (ICFM) developed by the authors were used (Sohn et al., 2004). Finally, through the hypothetical scenario analysis, we evaluated and verified the performance and applicability of our model. In Section three, we conduct scenario analysis using our model with three different events. A brief conclusion is given in Section four.

2. FINAL DEMAND LOSS AND INTERGRATED COMMODITY FLOW

2.1 Final Demand Loss Function

The following equation is a modified version of the final demand loss function (FDLF) proposed in Rose and Benavides (1998) and Rose et al. (1997):

$$\Delta f = (I - A)\{[D \otimes (1_9 - R)] \circ [(I - A)^{-1} f]\} \qquad (1)$$

Where, Δf = change of the final demand by sector by zone (135×1)

A = 9 sector by sector direct input coefficient by zone (135×135)

D = network disruption ratio by zone (15×1)

$I_9^T = (1, \cdots, 1)$

$I_9^T - R$ = one minus sectoral resiliency factor vector (9×1)

R = sectoral resiliency factor vector (9×1)

f = final demand by sector by zone before the earthquake (135×1)

$\otimes$ = tensor

$\circ$ = defined as $BG = (b_{ij} \times g_{ij})_{m \times n}$ *where* $B = (b_{ij})_{m \times n}$ *and* $G = (g_{ij})_{m \times n}$

Since the focus of the two papers by Rose and Benavides (1998) and Rose et al. (1997) was the earthquake damage on the electricity network, the function has been modified accordingly to fit the transportation network model as follows:

1. The network disruption rates (D) are assumed to depend on the disruption ratios for individual bridges since the disruption of the bridges on the highway generates more serious damages to the commodity flows and bridges are hard to be restored in a short period of time.
2. Even after a bridge has been damaged, most economic sectors in the market economies have ability to respond to change. Resilience is a way of characterizing the economic behavior and is defined here as the ability to adjust to changes due to unscheduled events. Resiliency of economic sectors in terms of the transportation network is defined as the share of production remaining after the complete disruption of transportation network. The following equation shows how to estimate transportation network resiliency (R) of economic sectors in this analysis:

$$r_k = r_k^{IZ}(1 - r_k^{HW}) + r_k^{AD} + \varepsilon_k \tag{2}$$

Where, $r_k^{IZ} = \sum_{m=1}^{15} f_{mm}^k / f^k$ = relative ratio of intrazonal flow of sector k

f_{mm}^k = commodity flow of sector k from m to m (intrazonal flow)

f^k = total commodity flow of sector k

r_k^{HW} = modal share of highway in sector k

r_k^{AD} = standardized inversed average shipment distance of sector k on highway

ε_k = universal random variable or error term that satisfies $N(0, \sigma^2)$

The multiregional input-output coefficient matrix (A) was estimated by the column coefficient model. The column coefficient model assumes the identical regional supply pattern, in which regional composition of any given input is identical among all purchasers in a region. The 9 by 9 sector national input-output table of Korea is used as the basis for each of the 15 regional input-output tables, thus assuming identical technical interindustry linkages across regions. Trade coefficients are obtained from the estimated commodity flows among 15 earthquake analysis zones (EQAZs) for 9 economic sectors. Figure 1 shows the delineation of 15 EQAZs in

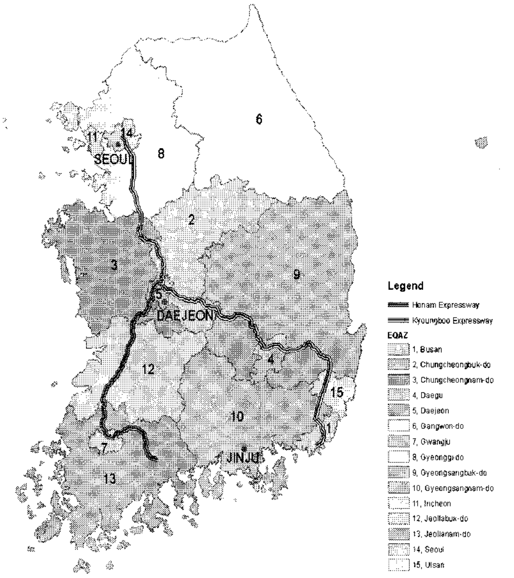

Fig. 1. Fifteen Earthquake Analysis Zones and Map of Korea

Table 1. Key variables and inputs used in Model

Variable	Input	Source
Input-output table (A)	Input-output coefficient	2000 National Input-Output Table (Bank of Korea)
	Trade coefficient	2001 Freight Flow Survey (Korea Transport Database)
Disruption ratio (D)	Moment magnitude	Scenario (Assumed)
	Epicentral distance	Scenario (Assumed)
Resiliency factor (R)	Sectoral intrazonal flow	2001 Freight Flow Survey (Korea Transport Database)
	Highway model share	
	Average shipping distance	
Interregional commodity flow model	Input-output coefficient	2000 National Input-Output Table (Bank of Korea)
	Ton-won conversion ratio	Conversion ratio adopted from Kim, Ham and Boyce (2002) and 2001 Freight Flow Survey (Korea Transport Database)
	Total interzonal flow	
	Intrazonal travel cost	Adopted from Kim, Ham and Boyce (2002)
	Highway link length	2002 Highway Geographic Information Systems (Korea Highway Corporation)
Initial final demand (f)		2000 National I-O Table (Bank of Korea)

Korea for this analysis. Construction sector is assumed to have intrazonal flow only and thus treated here as the identity matrix. The result is the 135 (15 EQAZs by 9 sectors) by 135 multiregional input-output matrix from which a Leontief inverse matrix can be derived.

The output (Δf) of the final demand loss function is change of the final demand by sector by zone (135×1) due to the amount of final demand loss induced by an earthquake. Table 1 summarizes the variables used in estimating final demand loss and inputs used in estimating those variables. The notable contribution of this analysis related to assessing final demand loss is threefold:

(1) Derivation of function to assess final demand loss induced by transportation network disruption;

(2) Translation of bridge disruption into capacity loss of links on the network and accessibility loss of zones; and

(3) Derivation of resiliency factors of economic sectors on network disruption.

2.2 Transportation Network Model

For the calculation of the transportation system network cost, the integrated commodity flow model (ICFM) developed by Kim, Ham and Boyce (2002) is used for the scenario analysis. The model consists of interregional commodity flows to meet each region's final and intermediate demand and assesses the direct and indirect damages that an earthquake could cause (Ham, Kim and Boyce 2005b). Lee and Kim (2007) modified the original ICFM model in a spatio-temporal framework, but the original static ICFM model has been used in this paper.

2.2.1 Model formulation.

On the assumption that shippers collectively desire to minimize their total shipment distances, in the absence of shipment cost information, and that other factors causing the dispersion of shipments across origins and destinations and modes can be represented by interregional and modal dispersion (entropy) functions, the objective function is defined as follows:

$$\min_{h,x} \; Z(h,x) = \sum_{aw} \int_0^{f_a^w} d_a^w(\omega)d\omega + \sum_{mjw} \left(\frac{x_{jj}^{mw}}{g^m}\right) d_{jj}^w +$$

$$\sum_m \frac{1}{\alpha^m g^m} \sum_{ijw} x_{ij}^{mw} \ln\left(\frac{x_{ij}^{mw}}{x_{ij}^m}\right) + \sum_m \frac{1}{\beta^m g^m} \sum_{ij} x_{ij}^{mw} \ln\left(\frac{x_{ij}^m}{\overline{X}_i^m}\right) \quad (3)$$

Where, the exogenous variables are:

α^m = the modal distance sensitivity parameter for sector m

β^m = the interregional distance sensitivity parameter for sector m

g^m = the ratio of monetary shipment value to weight used to convert the output of sector m from won to tons (won/ton)

d_a^w = cost function of total flow on link a by mode w (km)

x_{ij}^m = the flow (won) of sector m from subregion i to subregion j per year

$\overline{X}_i^m$ = the total output of sector m in region i (won) in a prior year, a measure of its size, which is proportional to the a priori shipment before the consideration of shipment distances and other constraints

The total distance to be minimized is represented by the sum of the link flows times link distances by mode plus intraregional shipments times intraregional modal shipment distances. The model solution determines the interregional and intraregional commodity shipments by mode, and the freight flows by routes and links within modes. Not all of these commodity shipments and flows, however, are uniquely determined by the solution.

2.2.2 Solution algorithm

A generalization of the algorithm proposed by Evans (1976) was used to solve the optimization problem. In this case each iteration of the algorithm uses Wilson's (1970) iterative balancing method to generate the subproblem interregional commodity shipments, and the all-or-nothing assignment method to find the subproblem network link flows.

The convergence of Wilson's iterative balancing method can be judged by the relative error between the observed and calculated final demands for each sector and each region, or the relative change of balancing factors (Ham, Kim and Boyce 2005a). The former convergence criterion was used successfully with 0.001 as the stopping value. Unlike the experience of Rho, Boyce and Kim(1989), convergence was satisfactory. Note that Table 1 shows the input data for ICFM.

2.2.3 Calculation of the network cost

Once the value of the objective function is obtained, sectoral system-wide transportation cost is calculated by the following equation:

$$\Delta TC_i = \frac{\Delta TC \times (DM_1^i - DM_0^i)}{\sum_{i=1}^{9} (DM_1^i - DM_0^i)} \qquad (4)$$

Where, $\Delta TC = 830{,}578{,}975 \times (Z_1 - Z_0) / Z_0$ = system transportation cost change (million won)

830,578,975 = total commodity flow in Korea in 2000 (million won)

Z_1 = objective function value of ICFM after the earthquake

Z_0 = objective function value of ICFM before the earthquake

ΔTC_i = sectoral system transportation cost change

DM_1^i = total won-Km for sector i commodity after the earthquake

DM_0^i = total won-Km for sector i commodity before the earthquake

3. SCENARIO ANALYSIS

In this scenario analysis, we use an earthquake as an unscheduled event. For a spatial dataset, we obtained spatial date for each of the 15 EQAZs; 19 expressways with a total of 322 links, 19 railroads which had a total of 691 links as network data; and 1008 bridge data. Thirty-two sectors of original economic data were aggregated to 9 sectors as shown in Table 2, and zonal input-output flows of the 9 sectors were calculated in advance. The basis of all spatial data was the end of 2002.

Table 2. Nine Aggregated Sectors used in Scenario Analysis

Number	Sector
1	Agriculture and Fishing
2	Mining
3	Consuming Goods Manufacturing
4	Basic Materials Manufacturing
5	Manufacture of Machinery and Equipment
6	Manufacture of Electrical and Electronic Machinery and precision products
7	Manufacture of Transport Equipment
8	Construction
9	Utilities, Services and Others

3.1 Development of User-Friendly Analysis Tool

In order to perform socio-economic impacts analyses of any scenario under any unscheduled events including earthquake, we developed a user-friendly tool with graphic user-interface (GUI). We hope that the tool would be helpful for anyone who wants to know how much all of the bridges would be disrupted by an earthquake with certain maginitude, how much the bridge damage would influence the final demand loss via network and zonal demand loss, and how much the total commodity and transportation loss would be. A frame of the application is given in Figure 2. Simple explanations for each part of the application are as follows:

① Map Control
② Layer Control
③ Parameters for Fragility Curve
④ Flow of Operations
⑤ FDLF and ICFM results

Figure 3 describes how this system visualizes the analysis results. As shown on the left side of Figure 3, bridge vulnerabilities, which were calculated using fragility curves, are displayed as gradated color from yellow to red. The system exposed the estimated total

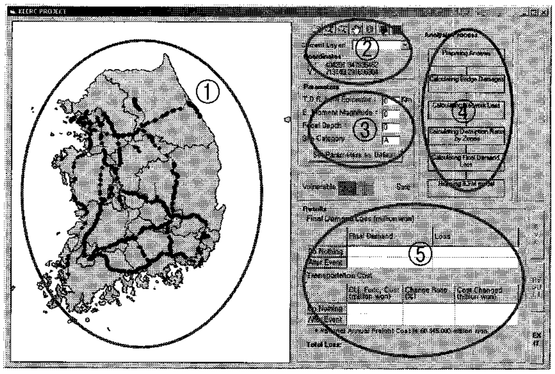

Fig. 2. Decision Support System

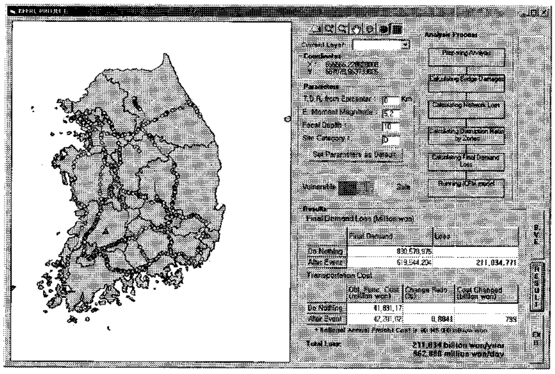

Fig. 3. Visualization of Analysis Results

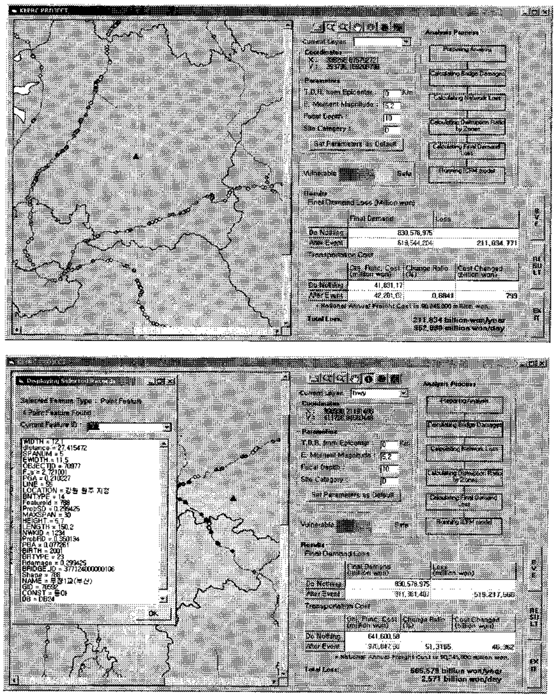

Fig. 4. Zoom in Features and Identify Features

economic loss after running the FDLF and ICFM at the lower right of the frame, as shown in Figure 3. This system can give us zoomed-in features and information about the features, as shown in Figure 4.

3.2 Three Scenario Analyses

With the user-friendly analysis tool, we analyzed three scenarios with different epicenters, magnitudes of moment, focal depths, and site categories.

3.2.1 Scenario I: An earthquake near Seoul

Figure 5 is the result of an earthquake scenario for an earthquake occurred near Seoul with the magnitude of moment 3.5, focal depth 15 km and site category E. Setting the magnitude of moment at 3.5, there was not much significant damage to the bridges. Although the damage was not significant, annual commodity flows were affected by the event. The final demand loss reached almost 38,000 billion won (about 38 billion dollars), and transportation costs arising from the damage was about 14,000 billion won (about 14 billion dollars).

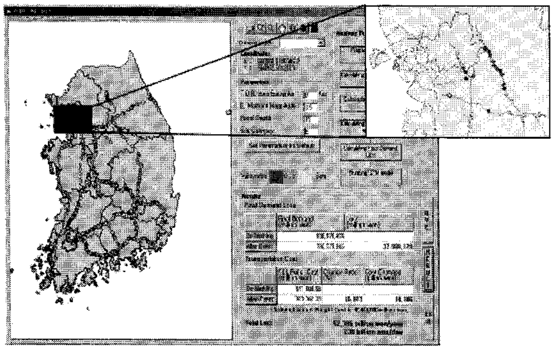

Fig. 5. Result of Scenario I

The total loss of 52,385 billion won/year was the sum of those two losses. Since Seoul is the capital of Korea and almost 43% of the population of Korea lives around Seoul, we cannot help but suspect that the result is an underestimate. However, the damage, which was not significant and limited to the edge of the network, explains the relatively small amount of economic loss.

3.2.2 Scenario II: An earthquake near Daejeon

Figure 6 shows the result of an assumed earthquake near Daejeon with magnitude of moment 5.2, focal depth 10 km and site category D. In contrast to Scenario I, we set the magnitude of moment at 5.2, which is the magnitude of the largest earthquake ever to have occurred in Korea. Many bridges were significantly damaged, as seen in Figure 6. This damage was directly reflected in the annual commodity flows, and both final demand loss and transportation loss increased sharply. The final demand loss reached almost 593,000 billion won (about 593 billion dollars), and the transportation cost arising from the damage was about 46,500 billion won (about 46 billion dollars).

Total loss was as high as 639,134 billion won/year. When compared to Scenario I, which revealed damage in the flange of network, great damage in the middle of the network seemed to aggravate the economic losses. Actually, the region that is colored reddish is a key position in Korea because some main expressways, including Kyoungboo Expressway and Honam Expressway, cross within the region.

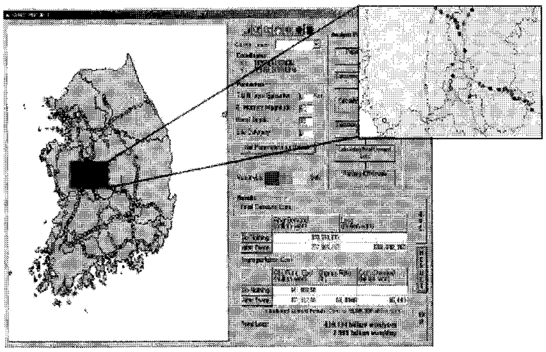

Fig. 6. Result of Scenario II

3.2.3 Scenario III: An earthquake near Jinju

With assumed magnitude of moment 4.1, focal depth 10 km and site category C occurred near Jinju. Unlike Scenario II but just like Scenario I, Figure 7 shows few damaged bridges. However, it was a little worse than Scenario I. Although it is difficult to discern in the figure, some bridges showed significant damage. The damage was expressed in terms of final demand loss and transportation loss. The final demand loss was almost 125,000 billion won (about 125 billion dollars), and the transportation cost was about 28,000 billion won (about 28 billion dollars). The total loss was about 153,000 billion won/year. Compared to Scenario I and Scenario II, this seems to be similar to Scenario I. Bridge damage, which was also limited to the flange of the network, did not cause as much loss as in Scenario II.

Table 3 summarizes the results that we derived from the above three scenario analyses. From this table, we can infer that the economic losses depend on the severity of the earthquake.

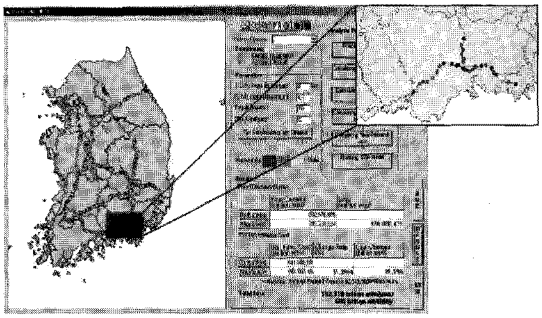

Fig. 7. Result of Scenario III

Table 3. Summary of Results derived from Scenario Analysis

Scenarios	I	II	III
Region	Seoul	Daejeon	Jnju
Moment Magnitude	3.5	5.2	4.1
Focal Depth(km)	15	10	10
Site Category	E	D	C
Final Demand Loss	37,999	592,693	124,820
Transportation Cost(billion won)	14,386	46,441	28,090
Total Loss(billion won)	52,385	639,134	152,910

4. CONCLUSIONS

The scenario analyses have revealed that any local damage can be directly related to the socio-economic impact on the nation as a whole. While the economic losses depend on the severity of the earthquake, disruptions in the middle of the country's transportation network caused more total economic loss than did those on the edge of network. The results indicate that transportation infrastructure located in the middle of country such as in the Daejeon region is vital for the national economic activities, even more than that of in the Capital region of Seoul. It seems counterintuitive at first, but the fact that the majority of commodity flows either heading to the Capital region or to the second largest region of Busan pass through the Daejeon region, indicates that the role of the transportation network in the Daejeon region is vital to the nation's economic activities. The results, in fact, shed light on the issue of setting locational priorities for retrofitting and recovering from damages due to any unscheduled events (Sohn et al. 2003).

One of the future directions of the research is to find a logical and rational basis for transforming the structural disruption ratio of a bridge directly to its functional disruption ratio. An improved version of the model should be developed and tested to work in a flexible way with a different number of zones at different spatial scales. This will also provide an opportunity to assess the economic significance at a local scale, so that policy makers in local government are able to access such information to finalize their decisions. In addition, considering that the current model is data-demanding, an improved model should be able to either incorporate a filter that is able to screen some erroneous inputs and maintain a certain level of data quality, or reduce the dependence on data.

The input-output coefficients, the final demands, and the total outputs used in estimating the interregional and transportation network commodity flows are based on 2002 data. To estimate the current or future economic impacts of an unexpected event, those commodity flow data sets need to be updated. Moreover, it will be a challenge to incorporate the system presented in this research into a more formal cost-benefit analysis.

One of the primary contributions of this research is its interdisciplinary nature, which incorporates the areas of civil engineering, transportation planning, regional economics, and disaster geography. The methodology adopted in the research was used to construct a decision support system for policy makers on formulating various strategies from ex-ante retrofitting strategies to ex-post strategies for setting recovery priorities. Through the approach that calculates total system-wide economic loss, the model could provide bases for establishing the retrofit priority and/or repair priorities that is the most efficient from the national economic point of view.

References

Ham, Heejoo, Tschangho John Kim and David E. Boyce (2005a). "Implementation and estimation of a combined model of interregional, multimodal commodity shipments and transportation network flows," *Transportation Research Part B*, Volume 39, Issue 1, pp.65-79.

Ham, Heejoo, Tschangho John Kim and David E. Boyce (2005b). "Assessment of Economic Impacts from Unexpected Events Using an Interregional Commodity Flow and Network Model," *Transportation Research Part A*. Vol 39/10, pp. 849-860.

Hwang, H., and J. R. Hou (1996). "Simulation of earthquake acceleration time histories." *Technical Report*, Center for Earthquake Research and Information, The University of Memphis, Memphis, TN.

Hwang, H., J. B. Jernigan, and Y. Lin (1998). "Evaluation of seismic damage to brides and highway systems in Shelby county, Tennessee." *Technical Report*, Center for Earthquake Research and Information, The University of Memphis, Memphis, TN.

Kim, T. J., H. Ham, and D. E. Boyce (2002). "Economic impacts of transportation network changes: Implementation of a combined transportation network and input-output model." *Papers Reg. Sci., 81*, pp. 223-246.

Lee, Jong Sung and Tschangho John Kim (2007). "Spatio-Temporal Models for Network Economic Loss Analysis under Unscheduled Events: A Conceptual Design." in A. Murray and T. Grubesic (eds)." *Reliability and Vulnerability in Critical Infrastructure: A Quantitative Geographic Perspective*, Springer.

Lee, S. M., J. Lee and T. J. Kim (2006). "Socio-economic impacts of an unscheduled event: a case in Korea." *the 53rd Annual North American Meetings of the Regional Science Association International*, Toronto, Canada.

Lee, S. M., T. J. Kim and S. L. Kang (2007). "Development of fragility curves for bridges in Korea." *KSCE Journal of Civil Engineering*, Vol. 11(3), pp.165-174.

Moses, L. N. (1955). "The stability of interregional trading patterns and input-output analysis." *Am. Econ. Rev., 45(5)*, pp.803-832.

National Earthquake Information System (NEIS) (2006). "Korea Meteorological Administration." http://kmaneis.go.kr/, accessed.

Rho, J.H., David E. Boyce and T.J. Kim. (1989). "Comparison of Solution Methods for Wilson's Interregional Commodity Flow Model." *Journal of Geographical Analysis*, 21(3), pp.259-267.

Rose, A., Benavides, J., Chang, S.E., Szczesniak, P., and Lim, D. (1997). "The regional economic impact of an earthquake: Direct and indirect effects of electricity lifeline disruptions." *J. Regional Sci.*, 37(3), pp.437-458.

Rose, A., and Benavides, J. (1998). "Regional economic impacts. Engineering and socioeconomic impacts of earthquakes: An analysis of electricity lifeline disruptions in the New Madrid area." M. Shinozuka, A. Rose, and R. T. Eguch, eds., Multidisciplinary Center for Earthquake

Engineering Research, Buffalo, N.Y., pp.95-123.

Sohn, J., Kim, T. J., Hewings, G. J. D., Lee, J. S., and Jang, S. G., (2003). "Retrofit priority of transport network links under an earthquake." J. *Urban Planning & Development,* Vol. 129(4), pp.195-210.

Sohn, Jungyul, Geoffrey J.D. Hewings, Tschangho John Kim, Jong Sung Lee and Sung-Gheel Jang (2004). "Analysis of Economic Impacts of an Earthquake on Transportation Network." in Y Okuyama and S.E. Chang (eds). *Modeling Spatial and Economic Impacts of Disasters*, Springer, Berlin.

접 수 일 : 2008. 11. 14
심 사 일 : 2008. 11. 20
심사완료일 : 2008. 12. 8