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RESEARCH ARTICLE

Comparative Flood-Risk Assessment of Different Freight Transport Development Programs

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As most developing countries experience rapid urban growth, the subsequent logistics sprawl increased travel distances, transportation costs, and negative environmental impacts of truck traffic. To address these, many development programs have been proposed to optimize freight transport operations. However, due to limited time and resources, there is a need to develop the optimum development roadmap that takes into consideration possible climate-related risks. The Philippines is at the forefront of the strongest typhoons; the freight transport infrastructure's resilience against flooding is a significant aspect to be examined. In this paper, the dynamic inoperability input-output model (DIIM) is used to assess the overall economic losses resulting from a disruption in the road freight sector (e.g., flooding). By incorporating the resilience performance of various freight transport programs against flood risk, the sustainable development agenda can be integrated with the application of academic frameworks in policy development. Aside from the integration of the DIIM methodology with the resilience metric for the assessment of freight transport development programs, this paper presents how resilience can be quantified, disaggregated, and used to assess potential long-term benefits as well as identify short-term, immediate, and critical needs.

Keywords: Freight, Flooding, Resilience, Input-Output

JEL Classifications: C67, D57, R15

Rapid urban growth has become a serious problem in most developing countries (Tewolde & Cabral, 2011). Not only has it contributed to many urban development challenges including unsustainable land development (Brueckner & Helsey, 2011), it has also affected transportation costs (Young, Tanguay, & Lachapelle, 2016), water demand (Morote & Hernandez, 2016), obesity (Zhao & Kaestner, 2010), ecological connectivity (Dupras et al., 2016), and even local climate (Emadodin, Taravat, & Rajaei, 2016). Along with these, severe land shortage, large urban renewal projects, and the skyrocketing land prices within the city has also resulted in logistics sprawl. This is a phenomenon where logistics and transport companies relocate from inner urban areas to the periphery of the cities (Gupta & Garima, 2017). Aljohani and Thompson (2016) enumerated the mismatch in truck activity level and local road suitability, the extension of urban area boundaries, increased distance traveled by trucks, and negative environmental impacts as some of its effects.

In a survey conducted by Patalinghug et al. (2015) on shippers operating in the Philippine metropolitan region, 16 out of 17 are in the manufacturing business. Within the Greater Capital Region (GCR), over 74% of manufacturing companies operate inside a special economic zone (SEZ). These areas attract manufacturing companies through the exemption from national and local taxes. Compared to an income tax of 30% outside the SEZ (Bureau of Internal Revenue, 1997), business enterprises within the SEZ pay only 5% of their gross income, where 3% goes to the national government while the remaining 2% is remitted to the treasurer's office of the municipality or city where the SEZ is located (The Special Economic Zone Act of 1995, 1994). Table 1 shows the spatial distribution of SEZs within the GCR and how they have sprung outwards to the adjacent regions of Metro Manila over the years. These show that the logistics sprawl phenomenon is also evident in the Philippine metropolitan region.

Under the Philippine Institute for Development Studies, Patalinghug et al. (2015) conducted a system-wide study of the logistics industry in the PGCR, where the assessment of the freight transport modeling scenarios was limited to basic transport metrics (e.g., average travel speed, vehicle-kilometers, vehicle-hours, etc.). However, the geographic location of the Philippines makes it more exposed to natural disasters compared to other countries (Whiteman, 2014). The Philippines is the most exposed to tropical storms in the world, where 19 of the 80 typhoons that annually develop above tropical waters enter the Philippine region; six to nine of which make landfall (Wingard & Brandlin, 2013). The impact has been projected to get worse as noted in the decrease in the number of smaller cyclones (wind speeds of over 118 km/hr) and an increase in the frequency of more hazardous tropical cyclones (wind speeds of over 150 km/hr; Cinco et al., 2016). Thus, in line with the Sustainable Development Goals of the United Nations (2015), freight transport infrastructure's resilience against flooding is a necessary component in the assessment of the optimum

Table 1. *Spatial Distribution of Manufacturing SEZs, Ports, and CBDs*

1975 – 1984	1985 – 1994	1995 – 2004	2005 – 2014

Legend: ■ - Manufacturing SEZs; □ - Ports; ▩ - Central Business Districts; ▬ - Highways

No. of SEZs:	3	No. of SEZs:	12	No. of SEZs:	33	No. of SEZs:	49
Ave. distance to Metro Manila [km]:	26.05	Ave. distance to Metro Manila [km]:	56.31	Ave. distance to Metro Manila [km]:	50.21	Ave. distance to Metro Manila [km]:	91.66

development program. By incorporating the resilience performance of various freight transport programs against flood risk, the sustainable development agenda can be integrated with the application of an academic framework in policy development. It is under this spotlight with which this study assessed different freight transportation projects and roadmaps, in terms of its efficiency and resilience.

Various measures to address logistics sprawl have been proposed in the literature. As the 2014 Manila truck ban forced shippers to find a way to ship their cargo without going through Manila port, it stirred up activity at the Subic and Batangas ports, located at points A and B, respectively, in Figure 1. These ports carry less than 50 thousand- and 11 thousand 20-foot equivalent units (TEUs) (Payumo, 2014), respectively, corresponding to utilization rates of only 6% and 8% of port capacity (Patalinghug et al., 2015). Despite approximately 47% of truck trips coming from and going to areas outside Metro Manila (ALMEC Corporation, 2014), around 76% of the shippers still use the Manila ports, reportedly operating at almost 78% utilization (Patalinghug et al., 2015). Similar with how the Bangkok River Port was limited to carry only one million TEUs while the rest of freight traffic was diverted to Laem Chabang Port to lessen the number of truck trips in the metropolis (Patalinghug et al., 2015), shifting freight traffic to the outer ports could effectively alleviate the traffic congestion attributed to trucks, address the underutilization of the outer ports, and encourage economic activity in the vicinity. With the Metro Manila Skyway Stage 3 (MMSS3) and NLEX-SLEX Connector Road Project (NSCRP) already under construction, the Subic and Batangas ports are soon to become more accessible. With improved capacity, accessibility, and the appropriate incentives, ship calls can be transferred to these ports without significant reproach from shipping companies currently calling in Manila port.

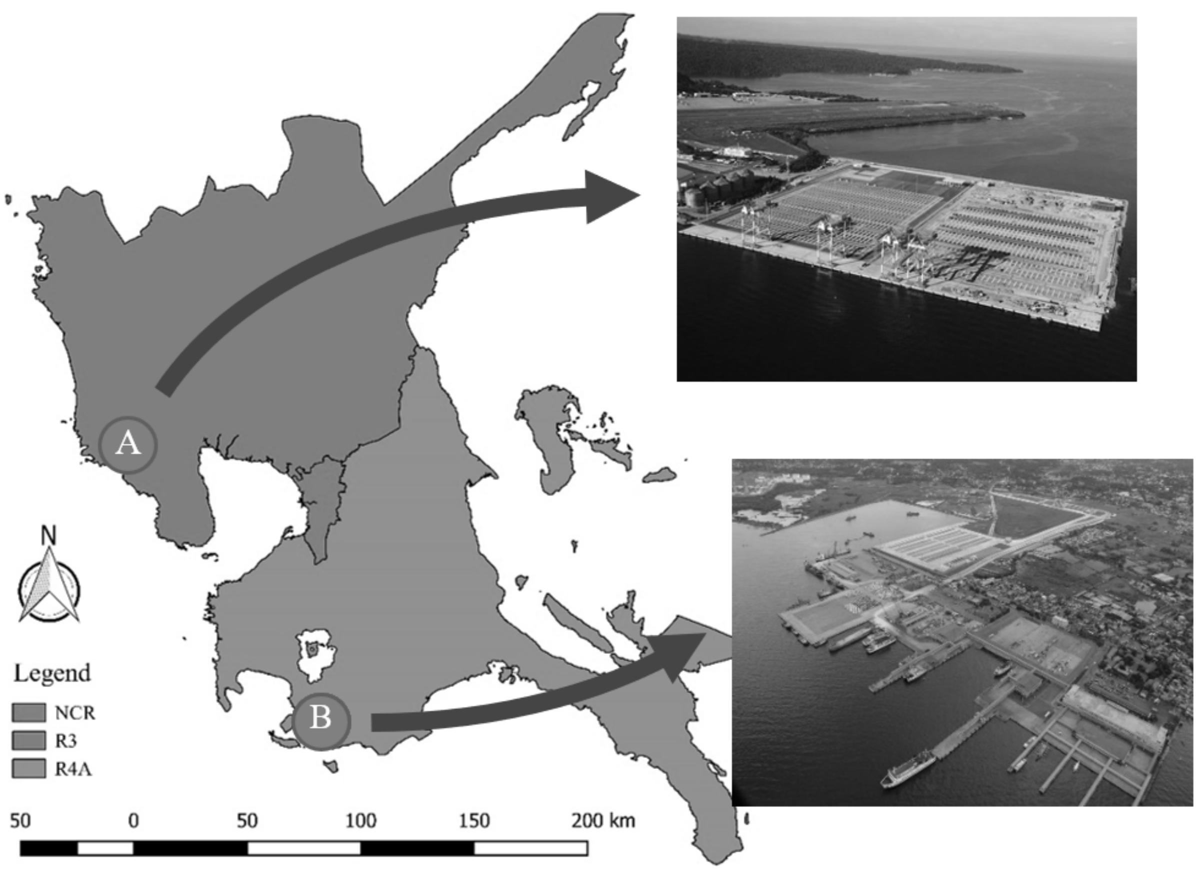
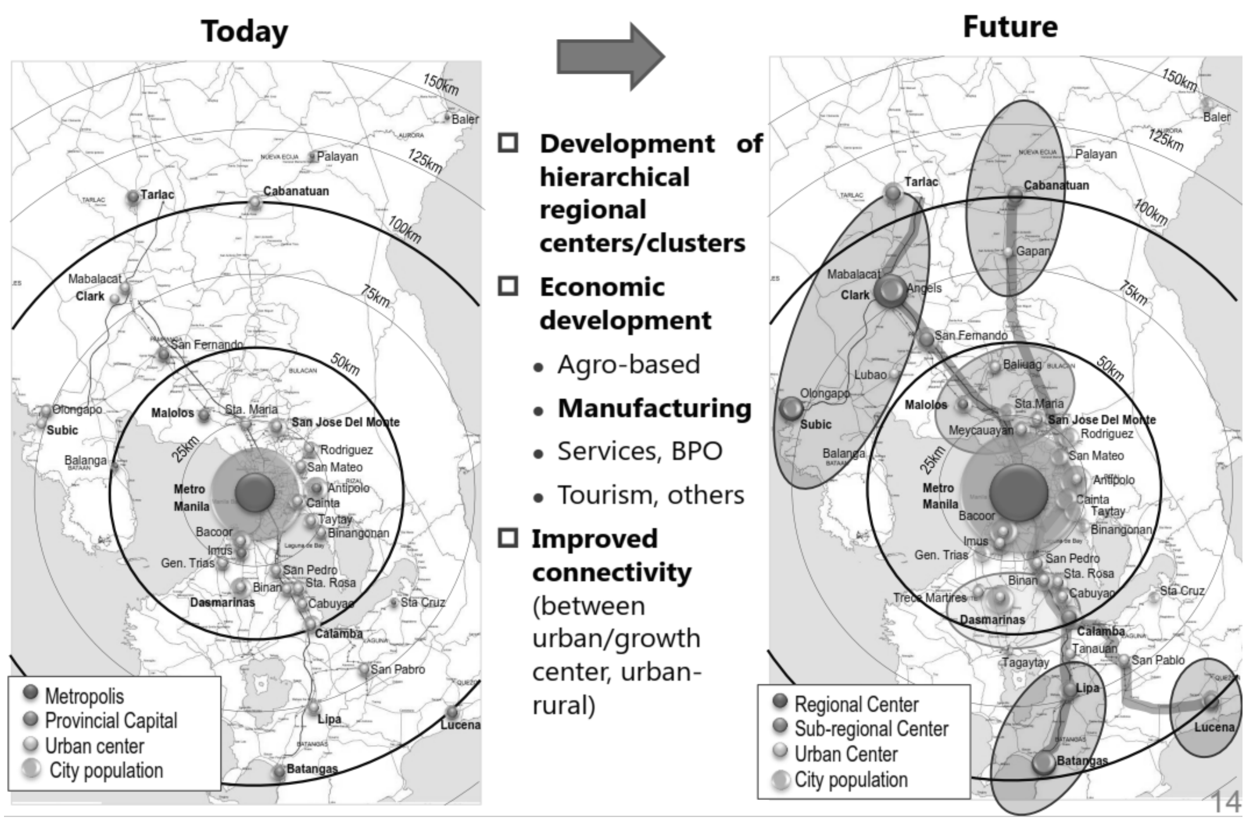


Figure 1. Subic and Batangas ports.

Another development program to optimize freight operations talks about how an increase in average shipment load and efficient spatial distribution of logistics facilities can offset the negative effects of logistics sprawl (Sakai, Kawamura, & Hyodo, 2017). This proposes to combine goods at freight consolidation centers (FCCs), where goods having the same target destinations are combined into one large delivery using high-load vehicles (Olsson & Woxenius, 2014). These facilities are distribution centers situated close to a town center, shopping center, or construction sites, at which part loads are consolidated and from which a lower number of consolidated loads are delivered to the target area (Lewis, Fell, & Palmer, 2010). Scott Wilson Ltd (2010) summarized a consolidation program's objectives into the reduction in congestion, traffic disruption, and vehicle emissions. As congestion is reduced by decreasing the number of vehicles, it also reduces conflicts between vehicles in unloading areas and delivery bays, as well as between delivery vehicles and other road users, especially pedestrians. Throughout this process, air quality is also improved, benefitting the surrounding public. It also allows shippers to reduce costs as they only pay for the space taken up, which results in operational cost savings. For the PGCR, locations of these facilities can be aligned with the proposed development of regional and sub-regional centers as part of the spatial reorganization recommended by JICA (2014).

At first glance, these two development programs seek to improve freight operation efficiency. However, its potential for resilience can also be investigated. Tierney and Bruneau (2007), Rose and Krausmann (2013), and Gilbert, Butry, Helgeson, and Chapman (2015) quantified resilience using the economic loss reduction metric. According to Hasegawa, Tamura, Kuwahara, Yokoki, and Mimura (2009), Okuyama and Santos (2014), and Roquel, Fillone, and Yu (2017), economic loss is estimated using an inoperability input-output model (IIM). The IIM is a tool used to assess the direct and indirect economic impacts of disruptive events throughout the various sectors in a nation's economy (Jung, Santos, & Haimes, 2009). It has been featured in many applications including modeling of



Source: JICA (2014)

Figure 2. Proposed spatial reorganization of regional and sub-regional centers

infrastructure interdependencies and risks of terrorism (Santos & Haimes, 2004; Santos, 2006), multi-state regional electric power blackouts (Anderson, Santos, & Haimes, 2007), extreme weather events (Crowther, Haimes, & Taub, 2007, Haggerty, Santos, & Haimes, 2008; Baghersad & Zobel, 2015; Aviso et al., 2015), international trade disruption (Jung et al., 2009), and other scenarios with supply chain disturbances (Pant, Barker, Grant, & Landers, 2011; Blos & Miyagi, 2015). In this study, an initial perturbation in the road freight sector (e.g., flooding), which in turn leads to operation delays and decreased industry production, was modeled using the IIM to estimate the subsequent economic losses.

The main objective of this study is to assess various freight transport development programs to identify the optimum direction for development. For this paper, a multi-regional IIM for the Philippines was used in resilience assessment of various programs to estimate the potential economic loss savings, which are quantified as the economic losses that would be avoided should the freight transport infrastructures be improved following the different development roadmaps. The shift of freight volume to the other ports and use of freight consolidation centers were modeled as development scenarios using the EMME transport modeling software. The resulting operation degradation values for each region within the GCR, in terms of reduction in assigned trips, were taken as the initial perturbation in modeling the spread of inoperability across the economy and estimating the economic loss incurred by each sector within each region. Aside from the integration of the IIM methodology with the resilience metric for freight transport policy development, this paper presents how resilience can be quantified, disaggregated, and then used to assess potential long-term benefits as well as identify short-term, immediate, and critical needs.

Input-Output Model

The Leontief IO model provides a view of the interaction between different sectors of the economy to estimate the input required for each type of goods or service (Leontief, 1936; Miller & Blair, 2009). One extension of the IO models focuses on the spread of operability degradation in a networked infrastructure system (Haimes & Jiang, 2001). This is called the inoperability input-output model (IIM), where a change in production can be taken as the difference between the planned production and the degraded production, and a change in demand can be taken as the difference between the planned final demand and the degraded final demand. The inability (i.e., as a percentage) of a certain infrastructure to produce and meet the final demand is referred to as inoperability. This is expressed as a ratio with which a sector's production is degraded relative to some ideal or "as-planned" production level (Santos, n.d.).

In the IO model, the production of each unit of the jth commodity requires a_{1j} of the first commodity, a_{2j} of the second, …, and a_{nj} of the nth commodity. However, each sector's output is ultimately produced to satisfy consumers' demand. Hence, a sector's total output is the sum of intermediate demand and final demand, as shown in the following:

$$x_1 = a_{11}x_1 + a_{21}x_2 + ... + a_{n1}x_n + f_1 \quad (1)$$

where x_1 is the total production output needed from industry 1, f_1 denotes the final demand for its output, and $a_{1j}x_j$ is the input demand of the jth industry. Thus, for the entire economy, the system can be written as a matrix equation as follows:

$$x = Ax + f \quad (2)$$

where $\boldsymbol{x}$ is the total output matrix, A is the technical coefficient matrix, and f is the final demand vector. Given the final demand, f, the total production matrix $\boldsymbol{x}$ can be computed using Equation 3. With matrix A consisting of elements a_{ij}, denoting input requirements of sector j from sector i, normalized with respect to the total input requirement of sector j, the model encapsulates the interdependence of different economic sectors. Furthermore, following the linear relationship of matrix equations, the model allows for the analysis of changes in final demands due to external causes, and its system-wide effects on the interconnected network of the economy, shown in Equation 4, where L is known as Leontief inverse or the total requirements matrix.

$$x = (I - A)^{-1} f = L f \quad (3)$$

$$\Delta x = L \Delta f \quad (4)$$

The IIM has a similar structure to the Leontief IO model, as shown in the following equations:

$$q = A^*q + c^* \quad (5)$$

$$q = (I - A^*)^{-1} c^* \quad (6)$$

$$A^* = \hat{x}^{-1}A\hat{x} \quad (7)$$

where q is the sector inoperability, resulting from an initial perturbation c*, and A* is a transformation of the Leontief technical coefficient matrix A called the interdependency matrix. The final demand perturbation, c*, is a vector comprised of the final demand disruptions to each sector, consisting of elements normalized between 0 and 1. It should be noted that a value of 0 denotes that there is no disruption to the sector, and a value of 1 denotes complete failure to operate the sector.

Economic loss is then computed as the product of inoperability and total output of each sector, as shown in the following equation:

$$EL_i = q_i * x_i \quad (8)$$

where EL_i is the economic loss estimate for sector *i*, q_i is the sector inoperability, and x_i is the total output of sector *i*. For this paper, the total output values used were from the year 2017.

Dynamic economic losses, on the other hand, are estimated as the cumulative economic loss estimates starting from the introduction of inoperability to the end of recovery of all sectors. This model is formulated as follows:

$$q(t+1) = q(t) + K[A^*q(t) + c^*(t) - q(t)] \quad (9)$$

where K is a sector resilience coefficient matrix that represents the rates in which sectors recover to their nominal levels of production following a disruption (Lian & Haimes, 2006; Miller & Blair, 2009). Details of the derivation can be found in Santos and Haimes (2004). The sector resilience coefficients are computed as a function of sector inoperability, sector interdependencies, recovery period, and desired level of inoperability reduction for the target recovery period, formulated as follows

$$k_i = \frac{\ln[q_i(0)/q_i(T_i)]}{T_i}\left(\frac{1}{1-a_{ii}^*}\right) = \left(\frac{\lambda}{\tau}\right)_i\left(\frac{1}{1-a_{ii}^*}\right) \quad (10)$$

where T_i is the time it takes for sector *i* to recover from its initial inoperability $q_i(0)$ to a $q_i(T_i)$, τ is the time when inoperability reduces to some value, q_τ, λ is the recovery constant, and a^*_{ii} represents the *i*th diagonal element in the interdependence matrix A*.

For this paper, it is assumed that all sectors will recover at the same time. This was set in the sense that even when only one sector has yet to recover fully, the present inoperability still has an apparent effect on all other sectors. Conversely, only when all sectors have reverted to the original condition will the economy be said to have recovered. For the recovery period, τ, three levels of recovery pace were used to develop a range of values on account of possible developments on flood management and recovery measures, especially in the projection years. Table 2 summarizes the levels used in this study based on what has been done in past literature (Marques, Ceneviva-Bastos, & Casatti, 2013; Francisco, 2015; Asian Infrastructure Investment Bank, 2017).

Regionalization of National Coefficients

Initial data for the inter-sectoral transactions were taken from the 2012 IO Accounts of the Philippines (Philippine Statistics Authority (PSA), 2017), containing annual comprehensive statistics between all sectors of the economy. Originally a 65 x 65 matrix, the IO table was converted into a 19-sector matrix. Detailed discussion on the sectoral disaggregation can be found in Appendix A.

Table 3 shows the sector disaggregation used for this study, where Transportation subsectors Water Transport and Air Transport kept disaggregated, whereas those of Land Transport were further disaggregated into

Table 2. *Recovery Parameters*

Recovery Pace	Description of Resulting Estimates	Recovery Period, τ [days]
Fast	Conservative (floor values)	5
Moderate	Steady	18
Slow	Far-reaching (ceiling values)	30

Table 3. *Sectors Disaggregation*

Sector	Description
1	Agriculture, Hunting, Forestry, and Fishing
2	Mining and Quarrying
3	Manufacturing
4	Construction
5	Electricity, Gas, and Water Supply
6	Bus line operation
7	Jeepney and other land transport services
8	Railway transport
9	Public utility cars and taxicab operation
10	Tourist buses and cars including chartered and rent-a-car
11	Road freight transport
12	Water Transport
13	Air Transport
14	Storage and Communication
15	Trade and Repair of Motor Vehicles, Motorcycles, Personal, and Household Goods
16	Financial Intermediation
17	Real Estate, Renting, and Business Activities
18	Other Services
19	Public Administration and Defense; Compulsory Social Security

Table 4. *Regional Disaggregation*

Region	Description
1	National Capital Region (NCR)
2	Region 3 (R3)
3	Region 4-A (R4A)
4	Rest of Luzon
5	Visayas
6	Mindanao

smaller sections (e.g., Bus line operation, Jeepney and other land transport services, etc.). This was done to introduce a demand perturbation solely on the road freight sector and isolate all the inoperability and subsequent economic losses stemming from it. Value allocations for Land Transport subsections were based on the 240-sector 2006 IO accounts (PSA, 2013), the next latest-published data.

The 2012 IO Account of the Philippines contains values for the entire country. However, the operation disruption across different regions is not homogenous. Thus, the IO table was further disaggregated with respect to regions, to allow the appropriate introduction of the initial perturbation. Detailed discussion on the regional disaggregation can be found in Appendix B.

In the construction of a spatial multi-regional interdependence matrix, the three regions comprising the PGCR were kept separate, while all other regions were aggregated based on island group classification (i.e., Rest of Luzon, Visayas, Mindanao). Table 4 shows the final regional disaggregation used in this study.

The matrix was then balanced using the cross-entropy technique discussed by Fofana, Lemelin, and Cockburn. (2005). With six “regions” having 19 sectors

Table 5. *Multi-Regional IO Table Structure*

MRIO	Region	NCR				Region 3				…	Mindanao			
Region	Sector	1	2	…	19	1	2	…	19	…	1	2	…	19
NCR	1													
	2													
	⋮													
	19													
R3	1													
	2													
	⋮													
	19													
⋮	⋮													
Mindanao	1													
	2													
	⋮													
	19													

each, a 114 x 114 matrix showing the interdependence of various sectors within and outside the regions was constructed. Table 5 shows a simplified illustration of the final multi-regional IO structure used in this paper.

Freight Travel Demand Modeling

This paper uses the truck origin-destination (OD) matrix from the Metro Manila Urban Transportation Integration Study Update and Capacity Enhancement Project (MUCEP) of JICA (2014). This matrix was estimated using OD interview surveys of freight vehicle drivers conducted at 20 survey stations along the outer cordon line set-up at the boundaries of the GCR. Of the estimated 45 thousand truck trips per day, almost 52% is coming from and going to NCR, with Region 3, Region 4-A, and the rest make up 17%, 30%, and 1%, respectively.

Transport networks for base year 2017 and design years 2030, 2040, and 2050 were constructed using the transportation planning software developed by Inro Consultants, Inc., Equilibre Multimodal Multimodal Equilibrium (EMME), where currently-available development plans for transport infrastructure and expected changes in land use based on proclaimed SEZ development were incorporated on all transport baseline models (TBMs), with respect to the indicated expected dates of completion. Then, various freight development programs were integrated with the TBMs to develop the transport scenario models (TSMs) for all projection years for each program. Table 6 summarizes the freight transport development programs modeled in this study, based on proposal resonance and applicability of literature.

For the PVS scenario, in lieu of reducing Manila port freight traffic to only one million TEUs, only the shortest trips accounting for 20% of the original total trips to and from Manila ports were retained while the rest were diverted to Subic or Batangas ports, whichever is nearer. In the FCC scenario, a total of eight consolidation centers were set up at the proposed regional and sub-regional centers specified in the JICA (2014) study and another seven consolidation centers were set up at the periphery of the metropolitan area.

In the travel demand modeling conducted, multi-class traffic assignment was executed to account for different travel demands for various travel modes. For the freight travel demand modeling, peak hour truck

Table 6. *Modeling Scenarios*

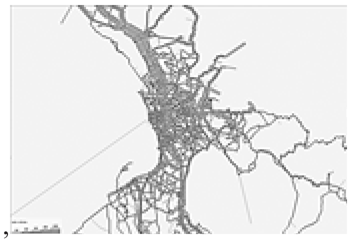
Scenario	Program	Description	Assumptions
BASE	Do Nothing	No freight transport development program introduced	
A	PVS	With Manila ports' 2016 throughput of 4.523 million TEUs (Philippine Ports Authority [PPA], 2017), limiting Manila ports to 1 million TEUs required the diversion of 80% of truck trips going to and coming from Manila ports	Truck trips will be diverted to Subic Port in the North or Batangas Port in the South, whichever is nearer
B	FCC	Truck trips were consolidated into larger deliveries at freight consolidation centers located on the proposed sites for the development of regional and sub-regional centers by JICA (2014)	Truck trips with both origin and destination zones within five km from an FCC will be consolidated
C	Both PVS and FCC	Combination of both development programs	

A) Truck O-D B) Standard Truck Traffic Assignment

C) Mounted on 5-year Flood Hazard Map D) Non-flooded Road Network

Figure 3. Truck traffic modeling.

Table 7. *EMME4 Freight Traffic Modeling Results (Base Year 2017)*

Scenario		**BASE**		**A**	
Flooding		**No**	**Yes**	**No**	**Yes**
Traffic Assignment Model					
Assigned Truck Trips	NCR	23,192	15,098	20,739	13,646
	R3	7,330	6,128	7,593	6,325
	R4A	13,480	11,431	15,670	13,319
TDT [thousand km]		1,411.23	1,187.80	1,554.30	999.04
THT [thousand hr]		275.85	736.38	263.95	143.69
Ave. Speed [km/hr]		34.84	33.20	34.84	33.65

Scenario		B		C	
Flooding		No	Yes	No	Yes
Traffic Assignment Model					
Assigned Truck Trips	NCR	24,279	16,267	31,464	21,301
	R3	7,434	6,178	10,507	8,763
	R4A	13,721	11,759	14,581	12,321
TDT [thousand km]		1,383.82	1,166.61	1,261.61	818.08
THT [thousand hr]		270.98	722.50	252.26	135.21
Ave. Speed [km/hr]		34.90	33.27	35.21	34.04

trips were assigned on top of off-peak public, and private trips as trucks can only ply Metro Manila roads during off-peak periods due to the current truck ban. Standard traffic assignment was performed using the EMME4 transport modeling software to establish base conditions. A short discussion on the traffic assignment procedures can be found in Appendix C.

For the flooded condition, the transport network was overlain onto a 5-year flood hazard map taken from LiDAR Portal for Archiving and Distribution (2017), and the flooded links (i.e., positioned in orange- and red-colored areas, corresponding to 0.5m–1.5m and over 1m flood heights, respectively) were identified and coded accordingly. Disruption was introduced as a reduction in transport infrastructure capacity in flooded areas. Traffic assignment was performed again to show the impact when flooding is introduced into the network. For this study, the operation disruption was modeled as a 24-hour flood. Thus, the characteristics of the modeled flooded condition were assumed to hold throughout the day. Considering that the flood scenario modeled (flood height of over 0.5m) is the kind that persists throughout the day, the authors find this a sound assumption.

From freight travel demand modeling of both normal and flooded conditions, the number of assigned trips was recorded, and the percentage decrease was quantified as the operation disruption. Table 7 shows the summary of the truck distances traveled (TDT), truck hours traveled (THT), and other traffic modeling results for both the normal and flooded conditions in each region within the GCR for the base year 2017.

Resilience Assessment

The assessment measure covered in this paper is the economic loss as flooding is introduced into the road freight sectors of the economy and the corresponding reduction under the different modeling scenarios. Table 8 shows the values used for initial perturbation, c*, which are based on the percentage decrease of trips assigned. Despite incurring losses when trips are diverted to longer but passable routes due to flooding, for this study, operation disruption was limited to only trips that were made impossible in the flooded scenario for a conservative estimate. These values were introduced to the IO model as the initial perturbation, *f**. As such, this paper focuses on the immediate economic loss as inoperability propagates across the economy.

Figure 4 shows the spread of inoperability for the BASE scenario. As shown, the introduction of inoperability in the road freight sector resulted in a spread of inoperability across all other sectors, even in regions without initial perturbation values. This shows the interdependence of sectors, where a disruption in one sector has a corresponding impact to all other sectors. Looking at the distribution, it shows that Sectors 9, 10, and 14 (i.e., the Public utility cars and taxicab operation, Tourist buses and cars including chartered and rent-a-car, and Storage and Communication Sectors, respectively) were estimated to have higher inoperability values among all other sectors. This can be interpreted as the set of most

Table 8. *Initial Perturbation Values (Base Year 2017)*

Region	Flood Condition	Scenario							
		BASE		A		B		C	
		Assigned Trips	c*	Assigned Trips	c*	Assigned Trips	c*	Assigned Trips	c*
NCR	No	23,192	-	20,739	-	24,279	-	31,464	-
	Yes	15,098	0.349	13,646	0.342	16,267	0.330	21,301	0.323
R3	No	7,330	-	7,593	-	7,434	-	10,507	-
	Yes	6,128	0.164	6,325	0.167	6,178	0.169	8,763	0.166
R4A	No	13,480	-	15,670	-	13,721	-	14,581	-
	Yes	11,431	0.152	13,319	0.150	11,759	0.143	12,321	0.155

impacted sectors when Sector 11 was disrupted. This also shows that these sectors, essentially belonging to the same Service sector when using the 11-sector aggregation, are strongly related to each other. It then follows that these same sectors are most vulnerable in terms of inoperability. These are followed by sectors 1, 2, and 3, corresponding to the Agriculture, Mining and Quarrying, and Manufacturing sectors, respectively. This is expected as the cargoes carried by the road freight sector come primarily from these sectors.

It is also meaningful to express the resulting impact in terms of monetary values. These may result in a separate set of most affected sectors. To estimate the economic loss, inoperability values are multiplied with the average daily ideal production output (total output divided by 360 days) of each respective sector, where the product can be taken as a loss in terms of production output. For this paper, the total output values used were that of the year 2017. Figure 5 shows the distribution of estimated losses across the economy for the BASE

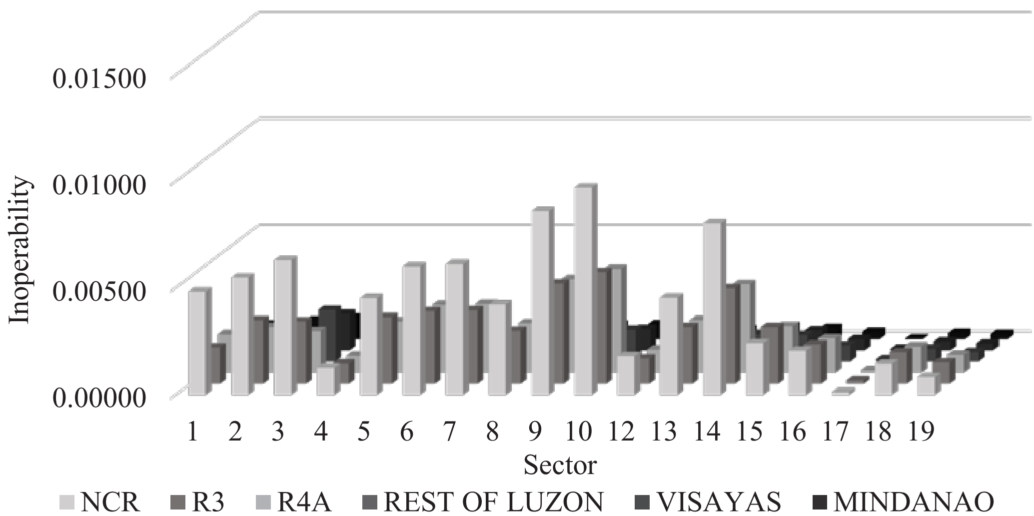


Figure 4. Spread of inoperability – BASE scenario (base year 2017).

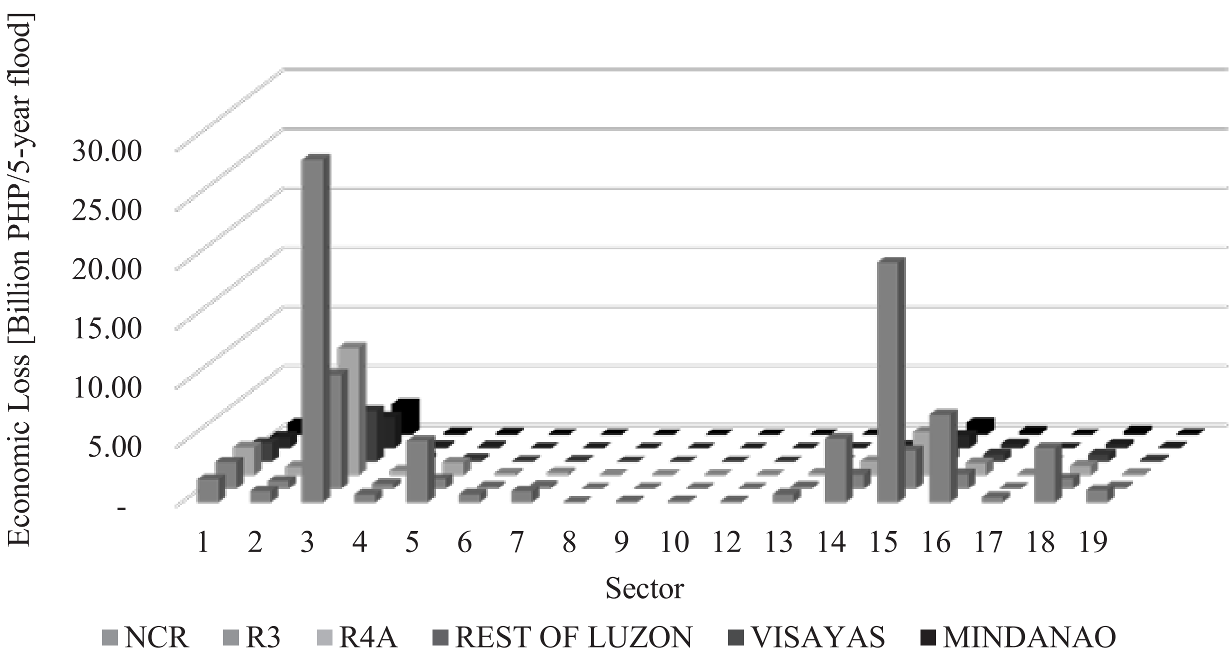


Figure 5. Spread of economic losses – BASE scenario (base year 2017).

scenario in 2017, excluding Sector 11 for illustration purposes, where a separate set of most affected sectors could be identified. This is attributed to the fact that different sectors produce outputs having different monetary values per unit.

The Manufacturing sector stands out for incurring the biggest loss, distantly followed by Sector 15 (i.e., Trade and Repair of Motor Vehicles, Personal and Household Goods Sector). This shows that the most affected sectors based on inoperability are not necessarily the most affected in terms of monetary losses. As an example, for the BASE Scenario in 2017, over PHP30 billion in losses was estimated for the Manufacturing Sector in NCR. Moreover, for the Manufacturing Sector as a whole, a total of PHP60.57 billion was estimated in losses. At the regional level, NCR was estimated to incur over PHP191 billion in economic losses. All these numbers were estimated as a loss in production output every time a 5-year flood occurs. With an estimated loss amounting to PHP297 billion for the entire economy, with an annual probability of occurrence of 20%, it fittingly needs to be taken into consideration. With this knowledge, a change in one sector's operation, or perhaps, in its capacity to withstand disruption and minimize the initial perturbation, can be used to model the overall impact of various development scenarios to the rest of the economy.

The IO estimates involve uncertainties, such as the magnitude of the flood event, and therefore, its

Table 9. *BASE Scenario Economic Loss Estimates in 2017 Prices (BASE Scenario in 2017) [Billion PHP/5-year flood]*

Sector	Description	NCR	REG3	REG4A	Rest of Luzon	Visayas	Mindanao	Subtotal
1	Agriculture, Fishery, and Forestry	1.382	0.558	1.372	0.624	0.413	0.424	4.773
2	Mining and Quarrying	0.874	0.184	0.606	0.213	0.14	0.141	2.159
3	Manufacturing	19.185	2.219	9.716	2.132	1.477	1.429	36.158
4	Construction	0.07	0.043	0.058	0.076	0.039	0.039	0.325
5	Electricity, Gas, and Water	0.751	0.098	0.407	0.132	0.082	0.077	1.548
6	Bus line operation	0.06	0.036	0.043	0.06	0.032	0.033	0.264
7	Jeepney and other land transport services	0.071	0.037	0.047	0.062	0.033	0.034	0.284
8	Railway transport	0.038	0.035	0.042	0.053	0.027	0.032	0.227
9	Public utility cars and taxicab operation	0.04	0.035	0.043	0.053	0.027	0.032	0.229
10	Tourist buses and cars including chartered and rent-a-car	0.04	0.035	0.043	0.053	0.027	0.032	0.23
11	Road freight transport	37.329	1.443	14.728	0.056	0.033	0.033	53.622
12	Water Transport	0.114	0.03	0.049	0.048	0.03	0.03	0.3
13	Air Transport	0.138	0.031	0.046	0.046	0.026	0.026	0.313
14	Communications and Storage	0.37	0.076	0.161	0.106	0.063	0.062	0.838
15	Trade	2.299	0.266	0.833	0.284	0.225	0.223	4.129
16	Finance	1.812	0.158	0.479	0.188	0.113	0.103	2.853
17	Real Estate and Ownership of Dwellings	0.234	0.042	0.082	0.071	0.04	0.037	0.506
18	Private Services	0.969	0.125	0.252	0.208	0.126	0.113	1.792
19	Government Services	0	0	0	0	0	0	0
	Subtotal	65.777	5.45	29.007	4.466	2.952	2.897	110.548

actual impact on the road freight network, are also uncertain, on top of the inherent uncertainties in economic activities during the flood, warning time and response, velocity of floodwaters, as well as recovery. Furthermore, with the modeled flood event itself having been estimated from a limited number of observations of past flood occurrences, there is also an innate variability in the likelihood of equaling or exceeding the modeled flood event in any year. As such, a way to quantify the flood risk away from point estimates of scenario economic loss savings was required.

This was done by expressing the uncertainties on simulation results in the form of confidence limits to capture the natural variability of flood impact factors. With the hazard map showing the maximum, not the mean, flood heights with an annual exceedance probability of 1/5, the ranges of values were estimated from the varying recovery periods. Proceeding with the introduction of inoperability values from Table 8 to the IO model, with varying recovery periods taken from Table 2, the dynamic economic loss savings for all scenarios were estimated, as summarized in Table 10. Different recovery periods were used to provide a range of floor and ceiling estimates when the modeled disruption occurs.

As shown in the previous table, varying the recovery period greatly affects how much the total economic losses will be. As an example, plotting the recovery path of NCR – Sector 11 (i.e., road freight transport sector in NCR), and taking the area below the recovery path to represent the cumulative inoperability, a longer recovery path (i.e., 30 days) can be recognized to accumulate more losses than a shorter one (i.e., 5 days), as economic losses are computed as a reduction in production for each day, until the economy has recovered back to the original conditions. With this, it follows that one way to minimize economic losses will be to pave the way for a fast recovery.

However, also shown is the possibility of the model to overshoot the mark and result in negative inoperability values when a short recovery period was used. This can be attributed to the short amount of time allotted for it to revert to 0 (i.e., fully-functioning state), which effectively forces the model to take bigger steps to do so. These instances where negative inoperability values were acquired, however, cannot be interpreted as the sector producing more than the production demand. We would rather take this as an indication for a need for a more stable recovery period. As such, Figure 7 was constructed to show the recovery paths of fast recovery periods, where seven was identified to be the smallest number of days required for a stable recovery.

Updating the values presented in Table 10, as shown in Table 11, the range of floor and ceiling estimates now involve stable recovery paths all throughout. The values presented are the estimated economic loss savings against the BASE Scenario (i.e., Scenario economic loss estimates subtracted from that of the BASE Scenario), which represent the economic losses that would have been incurred without the

Table 10. *Dynamic Economic Loss Savings in 2017 Prices*

Recovery Period [days]	Year	Scenario		
		A	B	C
5	2017	6.02	18.53	18.32
	2030	15.97	21.12	20.89
	2040	19.76	23.28	23.03
	2050	22.90	24.79	24.52
18	2017	21.52	66.25	66.93
	2030	57.11	75.52	76.30
	2040	70.65	83.25	84.10
	2050	81.89	88.65	89.55
30	2017	35.63	109.73	113.04
	2030	94.58	125.08	128.85
	2040	117.02	137.88	142.03
	2050	135.61	146.83	151.25

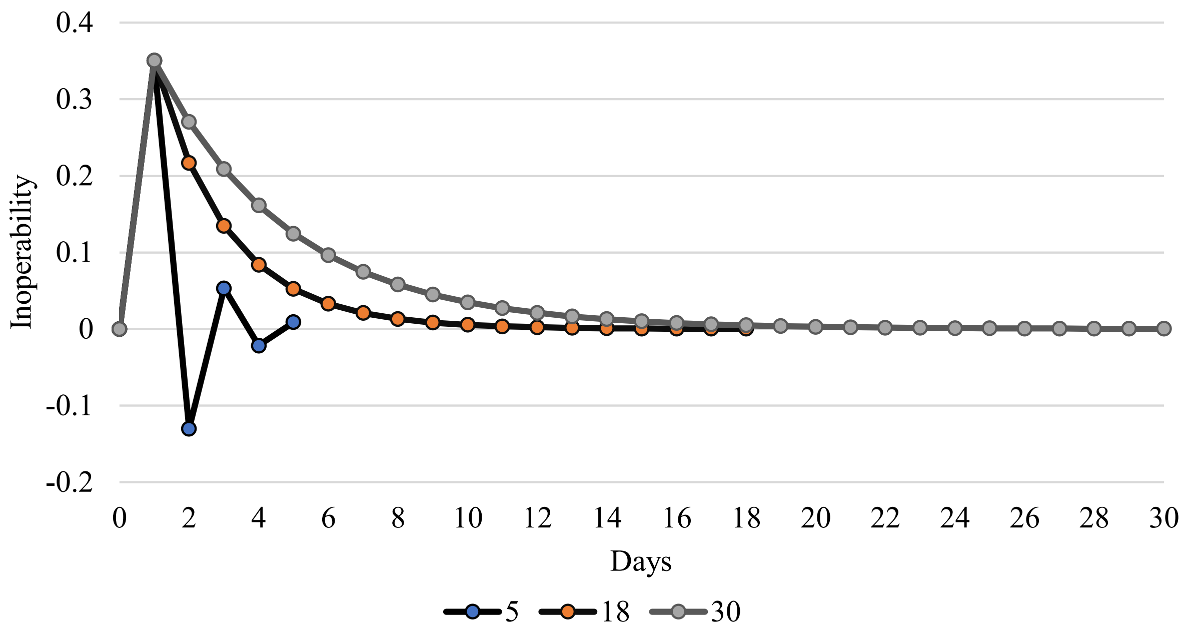


Figure 6. Recovery path of NCR – Sector 11 in Scenario A in 2017.

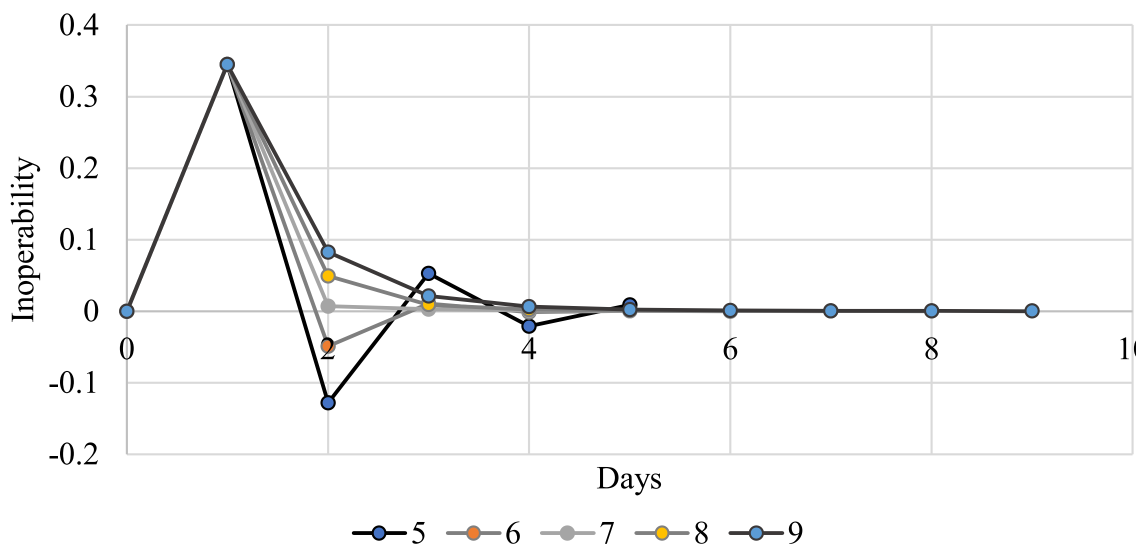


Figure 7. Paths of fast recovery periods.

project, where positive values account for losses that were avoided due to the improvement of the TSM configuration. Summarizing the ranges of IO estimates for each scenario and the respective average annual expansion (AAE), Scenario B was found to have the highest maximum value, but also the widest range of estimates. Scenario A, on the other hand, was found to have more stable estimates, with a particularly consistent range of values. Lastly, Scenario C was found to have the biggest relative change over the years, with an increasing range of values towards the future. From the plot of AAEs, shown in Figure 8, the trends show that by the year 2070, the IO estimates of Scenario A will overtake those of Scenario B. Scenarios A and C were also found to have higher possible IO estimates towards the future. From the

Table 11. *Updated Ranges of IO Estimates in 2017 Prices [Billion PHP]*

Year	Scenario								
	A			B			C		
	Min	Max	AAE	Min	Max	AAE	Min	Max	AAE
2017	8.42	35.63	-	25.91	109.73	-	25.71	113.04	-
2030	22.34	94.58	5.56	29.54	125.08	7.35	29.31	128.85	7.66
2040	27.63	117.02	8.94	32.56	137.88	10.53	32.31	142.03	10.97
2050	32.03	135.61	10.36	34.67	146.83	11.22	34.40	151.25	11.69

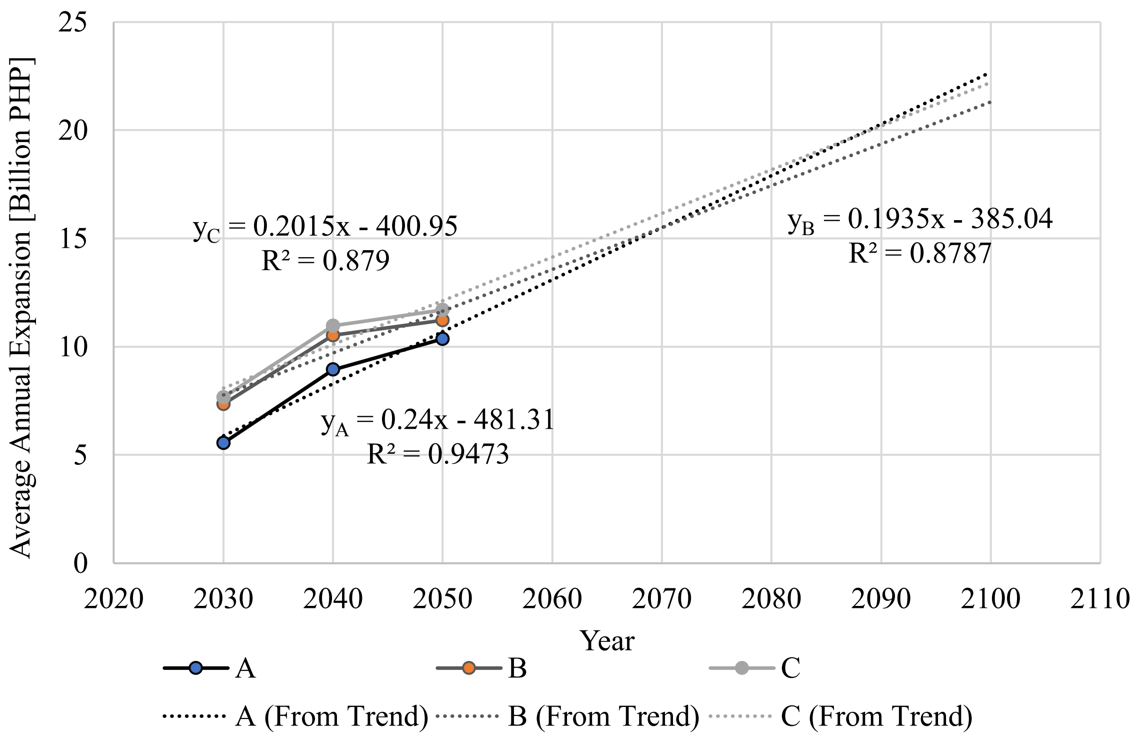


Figure 8. Average annual expansion of ranges of IO estimates in 2017 prices.

plot of AAEs, shown in Figure 8, the trends show that by the year 2070, the IO estimates of Scenario A will overtake those of Scenario B. Scenarios A and C are also expected to continue to have higher possible IO estimates towards the future.

Disaggregated Freight Infrastructure Resilience

This paper looks into the systemic response of the economy against the disruptions introduced. Scenario configurations are external shocks to the system, which makes it useful to look into the values of the initial perturbation and the corresponding IO estimates. From Table 12, it can be seen that an inoperability value of 0.15 applied to the road freight sector in NCR will result in a minimum of PHP136.49 billion in economic losses in the same region, to a maximum of PHP580.67 billion. Moreover, the same inoperability value applied in NCR can also be seen to result in economic losses amounting to a minimum of PHP8.41 billion to a maximum of PHP35.10 billion in R3, a minimum of PHP8.57 billion to a maximum of PHP35.81 billion in R4A, and a minimum of PHP27.83 billion to a maximum of PHP 16.16 billion for the rest of Luzon, Visayas, and Mindanao.

Table 12. *Inoperability Values and Corresponding IO Estimates in 2017 Prices [Billion PHP]*

Region	Inoperability	NCR		R3		R4A		Rest of Luzon, Visayas, and Mindanao	
		Min	Max	Min	Max	Min	Max	Min	Max
NCR	0.15	136.49	580.67	8.41	35.10	8.57	35.81	27.83	116.16
	0.30	272.97	1,161.33	16.82	70.20	17.15	71.61	55.66	232.32
	0.45	409.46	1,742.00	25.22	105.30	25.72	107.42	83.50	348.49
	0.60	545.94	2,322.67	33.63	140.39	34.30	143.23	111.33	464.65
R3	0.15	1.41	5.87	47.43	201.58	1.45	6.01	5.48	22.81
	0.30	2.82	11.74	94.86	403.16	2.89	12.03	10.97	45.61
	0.45	4.23	17.61	142.29	604.75	4.34	18.04	16.46	68.41
	0.60	5.64	23.48	189.72	806.33	5.78	24.06	21.94	91.22
R4A	0.15	2.45	10.21	2.61	10.86	65.45	278.34	9.59	39.90
	0.30	4.90	20.41	5.22	21.73	130.90	556.69	19.17	79.82
	0.45	7.35	30.62	7.83	32.59	196.35	835.03	28.77	119.71
	0.60	9.80	40.83	10.44	43.45	261.80	1113.38	38.35	159.63

Table 13. *Summary of Inoperability Values and Corresponding IO Estimates in 2017 Prices [Billion PHP]*

Region	Inoperability	Overall IO Estimates		Percentage of GDP	
		Min	**Max**	**Min**	**Max**
NCR	0.15	181.30	767.74	1.15	4.86
	0.30	362.60	1535.46	2.29	9.71
	0.45	543.90	2303.21	3.44	14.57
	0.60	725.20	3070.94	4.59	19.43
R3	0.15	55.77	236.27	0.35	1.49
	0.30	111.54	472.54	0.71	2.99
	0.45	167.32	708.81	1.06	4.48
	0.60	223.08	945.09	1.41	5.98
R4A	0.15	80.10	339.31	0.51	2.15
	0.30	160.19	678.65	1.01	4.29
	0.45	240.30	1017.95	1.52	6.44
	0.60	320.39	1357.29	2.03	8.59

Table 13 summarizes the overall economic losses stemming from various inoperability values applied to the road freight sectors of various regions, in terms of the GDP. As shown, an inoperability value of 0.15 applied to the road freight sector in NCR resulted in a minimum overall IO estimate of PHP181.30 billion and a maximum of PHP767.74 billion, or approximately 1.15% and 4.86% of the GDP, respectively. On the other hand, an inoperability value of 0.30 in the road freight sector in R3 resulted in a minimum of PHP111.54 billion and a maximum of PHP472.54 billion, or approximately 0.71% and 2.99% of the GDP, respectively.

Qualifying the GDP percentage losses below 5%, 5–10%, and above 10% to signify mild, significant, and critical impacts on the economy, respectively,

Table 14. *Qualification of Inoperability Values*

Range	Description	NCR	R3	R4A
Below 5%	Mild	0.00–0.25	0.00–0.81	0.00–0.57
5–10%	Significant	0.25 -– 0.50	Above 0.81	Above 0.57
Above 10%	Critical	Above 0.50		

inoperability values in each region was classified as shown in Table 14. From this table, mild impacts on the economy can be expected from inoperability values up to 0.25 in NCR. For R3 and R4A, that value was found to be at 0.81 and 0.57, respectively. Moreover, a significant impact on the economy can be expected from inoperability values up to 0.50, but any value beyond that corresponds to a critical impact on the economy. For R3 and R4A, even a value of 1.00 (i.e., total failure) was found to fall within the range covering significant impact to the economy. This shows that the impacts of the road freight sectors in R3 and R4A to the rest of the economy are not as significant as that of NCR.

With this, assessment of various development programs can be redirected to focus on how it can minimize the disruptions at the critical locations. Although the need to consider the overall impact remains, it is also wise to target areas that promise bigger returns, especially in consideration with the limited resources. For example, despite showing Scenario A to having the highest estimates towards the future, the high investment costs of equipping the outer ports to be able to accommodate the diverted freight traffic demand understandably result in some reservations against it. As such, without diminishing the potential benefits of shifting freight traffic outside of the metropolis, a way to minimize the risk of disruptions within the metropolis can prove to be a more viable option to start with. One of which is by consolidating truck trips, especially in the metropolitan area, which not only reduces operating costs, energy consumption, and emissions but also improves operation efficiency and disruption risk reduction.

Conclusion and Recommendations

This paper shows that the IO framework can be employed in the assessment of freight transport programs against the impact of an operational disruption of one sector to the entire economy. As presented, the overall economic loss originating from an initial demand perturbation can be estimated as it propagates throughout the economy. With this, the resulting economic loss estimates, isolated to have strictly originated from the introduced disruption in the road freight sectors, can then be used to assess how different development programs hold up against operation disruptions. With resilience becoming more relevant in program assessment and policy evaluation research, the economic loss reduction metric is a welcome addition to the factors to be considered and is one that can be easily integrated, owing to the simple structure of the IO model. With flooding incidents being probabilistic in nature, the program assessment procedure employed is a novel approach that is useful in considering the long-term effects of different transport development programs and policies.

Furthermore, as the effects of operation disruptions caused by flooding usually persist even after the day of impact, it follows that programs that shorten the recovery period should also be investigated. By looking at ways to minimize the disruption, or the time it takes to recover from the disruption, or both, the assessment will be able to identify programs that cover efficiency and resilience. Thus, it is recommended for other programs that fit into these criteria be also considered for further studies.

References

Aljohani, K., & Thompson, R. (2016). Impacts of logistics sprawl on the urban environment and logistics: Taxonomy and review of literature. *Journal of Transport Geography, 57*, 255–263.

ALMEC Corporation. (2014). *Roadmap for transport infrastructure development for Metro Manila and its surrounding areas (Region III and Region IV-A)*. Retrieved from http://www.neda.gov.ph/wp-content/uploads/2015/03/FR-SUMMARY.-12149597.pdf

Anderson, C., Santos, J., & Haimes, Y. (2007). A risk-based input-output methodology for measuring the effects of the August 2003 northeast blackout. *Economic Systems Research, 19*(2), 183–204.

Asian Infrastructure Investment Bank. (2017). *Republic of the Philippines Metro Manila flood management project*. Retrieved from https://www.aiib.org/en/projects/approved/2017/_download/Philippines/summary/MetroManilaFloodProject-PDBoard.pdf

Aviso, K., Amalin, D., Promentilla, M., Santos, J., Yu, K., & Tan, R. (2015). Risk assessment of the economic impacts of climate change on the implementation of mandatory biodiesel blending programs: A fuzzy inoperability input-output modeling (IIM) approach. *Biomass and Bioenergy, 83*, 436–447.

Baghersad, M., & Zobel, C. (2015). Economic impact of production bottlenecks caused by disasters impacting interdependent industry sectors. *International Journal of Production Economics, 168*, 71–80.

Blos, M., & Miyagi, P. (2015). Modeling the supply chain disruptions: A study based on the supply chain interdependencies. *IFAC Papers Online, 48*(3), 2053–2058.

Brueckner, J. K., & Helsey, R. W. (2011). Sprawl and blight. *Journal of Urban Economics, 69*(2), 205–213.

Bureau of Internal Revenue. (1997). *National internal revenue code*. Retrieved from https://www.bir.gov.ph/index.php/tax-code.html

Cinco, T., De Guzman, R., Ortiz, A., Delfino, R., Lasco, R., Hilario, F., . . . Ares, E. (2016). Observed trends and impacts of tropical cyclones in the Philippines. *International Journal of Climatology, 36*(14), 4638–4650.

Crowther, K., Haimes, Y., & Taub, G. (2007). Systemic valuation of strategic preparedness through application of the inoperability input-output model with lessons learned from Hurricane Katrina. *Risk Analysis, 27*(5), 1345–1364.

Dupras, J., Marull, J., Parcerisas, L., Coll, F., Gonzalez, A., Girard, M., & Tello, E. (2016). The impacts of urban sprawl on ecological connectivity in the Montreal metropolitan region. *Environmental Science and Policy, 58*, 61–73.

Emadodin, I., Taravat, A., & Rajaei, M. (2016). Effects of urban sprawl on local climate: A case study, north central Iran. *Urban Climate, 17*, 230–247.

Fofana, I., Lemelin, A., & Cockburn, J. (2005). Balancing a social accounting matrix: Theory and application. Retrieved from http://www.pep-net.org/sites/pep-net.org/files/typo3doc/pdf/sambal.pdf

Francisco, J. (2015). *Property damage recovery and coping behavior of households affected by an extreme flood event in Marikina City, Metro Manila, Philippines* (Discussion Paper No. 2015-40). Retrieved from https://dirp3.pids.gov.ph/webportal/CDN/PUBLICATIONS/pidsdps1540.pdf

Gilbert, S., Butry, D., Helgeson, J., & Chapman, R. (2015). *Community resilience economic decision guide for buildings and infrastructure systems* (National Institute of Standards and Technology Special Publication No. 1197). http://dx.doi.org/10.6028/NIST.SP.1197

Gupta, S., & Garima. (2017). Logistics sprawl in timber markets and its impact on freight distribution patterns in metropolitan city of Delhi, India. *Transportation Research Procedia, 25*, 965–977.

Haggerty, M., Santos, J., & Haimes, Y. (2008). A transportation-based framework for deriving perturbations to the inoperability input-output model. *Journal of Infrastructure Systems, 14*(4), 293–304.

Haimes, Y., & Jiang, P. (2001). Leontief-based model of risk in complex interconnected infrastructures. *Journal of Infrastructure Systems, 7*(1), 1–12.

Hasegawa, R., Tamura, M., Kuwahara, Y., Yokoki, H., & Mimura, N. (2009). *An input-output analysis for economic losses of flood caused by global warming: A case study of Japan at the river basin's level*. Retrieved from https://www.iioa.org/conferences/17th/papers/276323009_090612_072807_HASEGAWAETAL.(2009).pdf

Jung, J., Santos, J., & Haimes, Y. (2009). International trade inoperability input-output model (IT-IIM): Theory and application. *Risk Analysis, 29*(1), 137–154.

Leontief, W. (1936). Quantitative input and output relations in the economic system of the United States. *Review of Economics and Statistics, 18*(3), 105–125.

Lewis, A., Fell, M., & Palmer, D. (2010). *Freight consolidation centre study*. Transport and Travel Research Ltd. Retrieved from http://archive.northsearegion.eu/files/repository/20130719151509_SEStran_FreightConsolidationCentreStudy-FinalReport.pdf

Lian, C., & Haimes, Y. (2006). Managing the risk of terrorism to interdependent infrastructure systems through the dynamic inoperability input-output model. *Systems Engineering, 9*(3), 241–258.

LiDAR Portal for Archiving and Distribution. (2017). *5-year flood hazard map*. Retrieved from https://lipad-fmc.dream.upd.edu.ph/layers/?limit=100&offset=0&keywords__slug__in=flood-hazard-map&exte