Optimal Resource Allocation During Crisis Conditions

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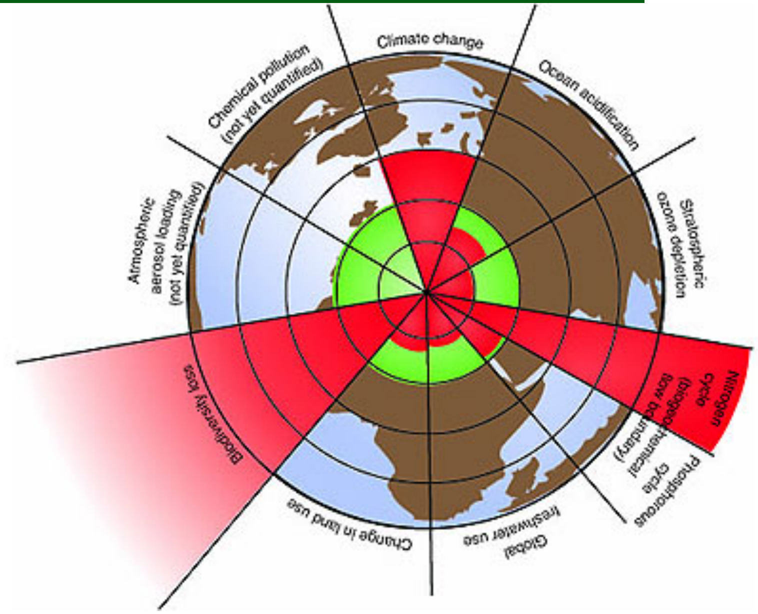
Introduction

- Population growth coupled with climate change are expected to increase the incidence of extreme weather events
- Aftermaths potentially result in serious consequences in human activities which translates to economic losses
- Alternative energy such as hydropower is affected by such climactic changes



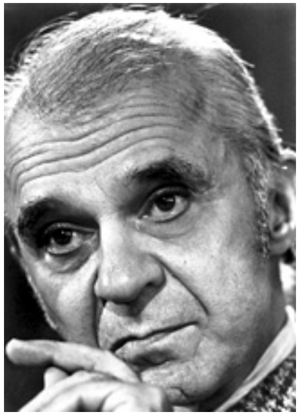
Top 5 Natural Disasters in 2013 (AON Benfield, 2013)

Disaster Event	Location	Economic Loss
Flooding, May/June	Central Europe	USD 22 B
Earthquake, April	China	USD 14 B
Typhoon Haiyan, November	Philippines, Vietnam	USD 13 B
Typhoon, Fitow	China, Japan	USD 10 B
Drought	China	USD 10 B

Example of "Ripple Effects" from Possible Disasters

Triggering Event	Examples of Collateral Damage
Tsunami hits a major tourist spot	➢Job losses due to hotel closures ➢Small businesses go bankrupt
Massive flu outbreak hits major cities	➢Labor shortage across multiple sectors ➢Loss of industrial output across multiple sectors
Ash from volcanic eruption cripples an international airport	➢Manufacturing plant closures ➢Tourism losses
Prolonged drought due to climate change	➢Crop failure ➢Shutdown of hydroelectric facilities ➢Loss of industrial output ➢Reduced investment ➢Loss of livelihood

Input-Output Model

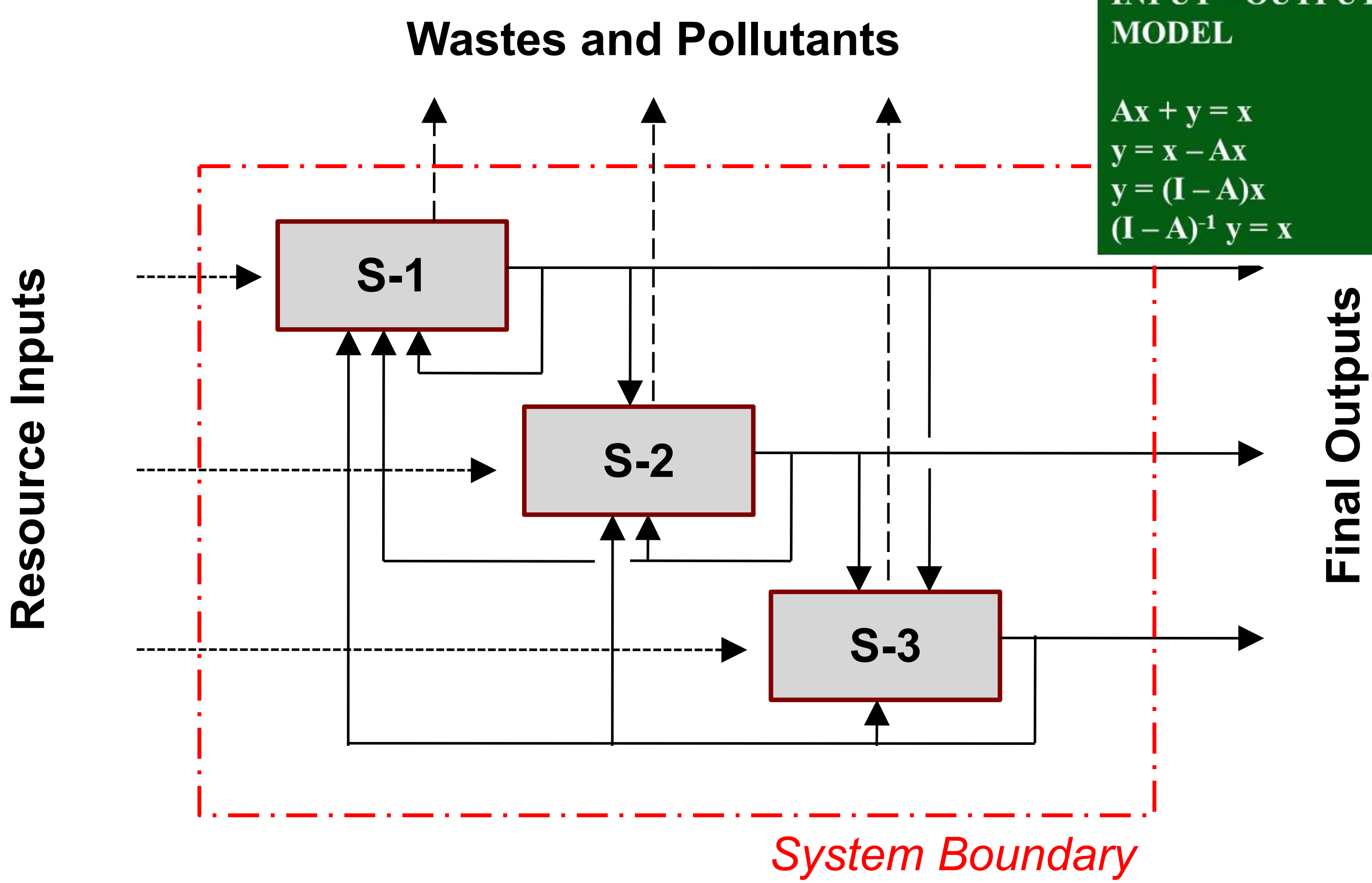


- Developed by Wassily Leontief (1936) for which he won the Nobel Prize in 1973
- IO provides a framework for representing the interdependence between economic sectors
- IO model is a system of linear equations showing the inter-industry relationship of economic sectors
- The impact of disasters ripple through an economy because of the interdependence between sectors

A Three-Sector Input-Output System

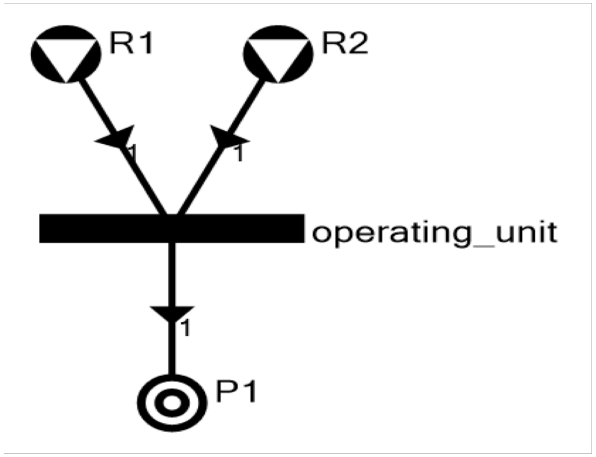
INPUT – OUTPUT MODEL

$$Ax + y = x$$
$$y = x - Ax$$
$$y = (I - A)x$$
$$(I - A)^{-1} y = x$$



P-graph Model

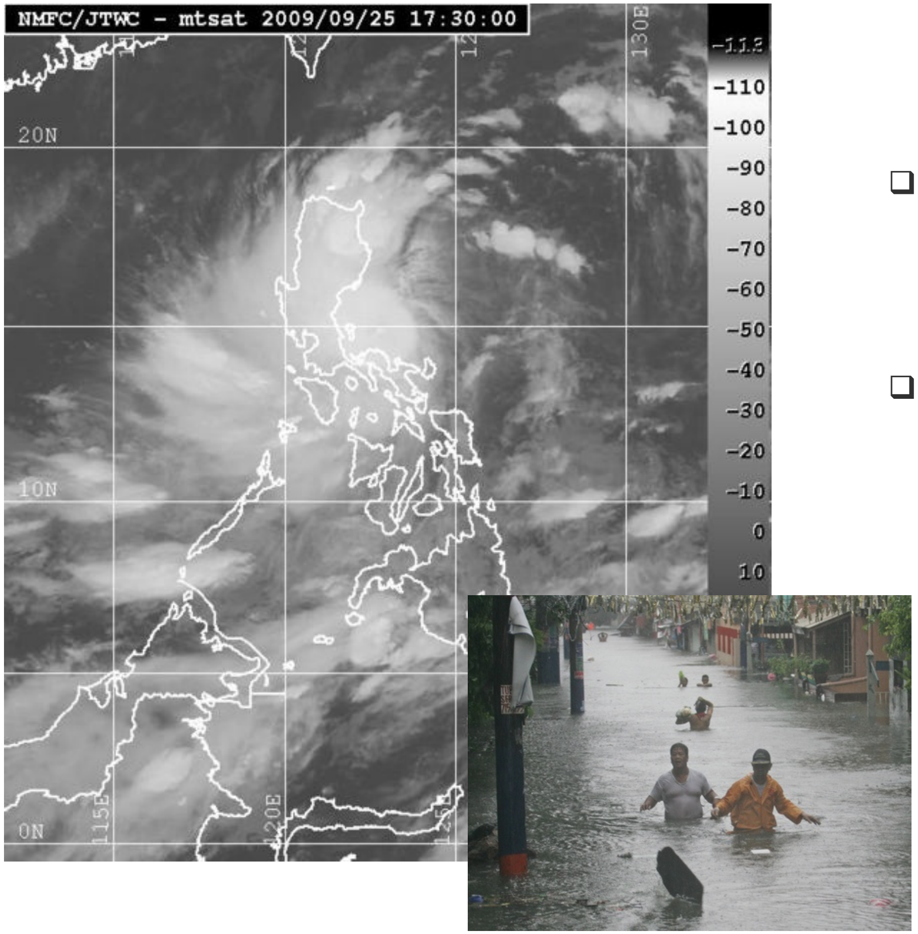
- Process graph or p-graph is a graph theoretic method developed for process network synthesis
- P-graph utilizes 3 algorithms to identify the optimal network structure
  - MSG – maximal structure generation
  - SSG – solution structure generation
  - ABB – advanced branch and bound
- P-graph is a graphical representation of matrix calculations such as MILP and MINLP



Problem Statement

- Given an economic system with *n* sectors, *n* commodities
- Given a crisis event that results in the reduction in availability of the *kth* commodity
- The problem is to determine the optimal allocation of the scarce commodity in order to maximize economic productivity even during a crisis

Case Study: The Philippines (Aviso et al., 2015)



- The Philippines is one of the most disaster-prone countries in the world
- Research that contributes to **weakening the vicious cycle of disaster vulnerability** is essential

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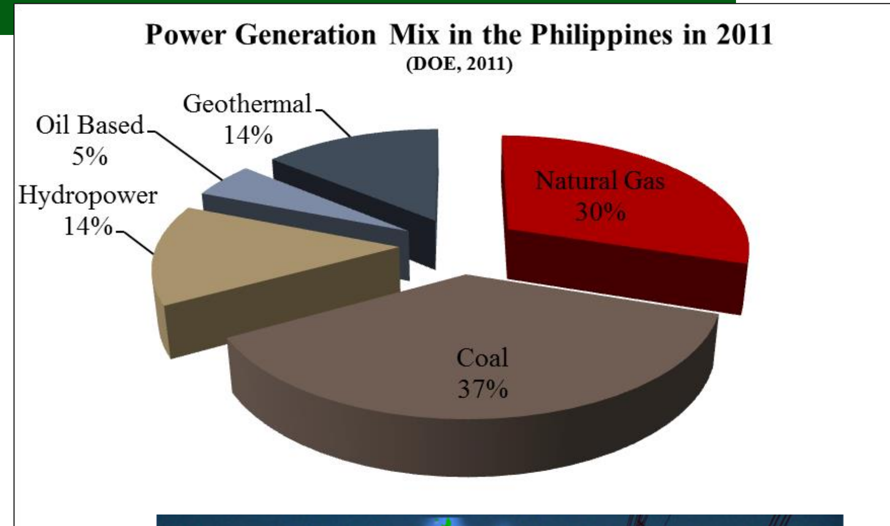
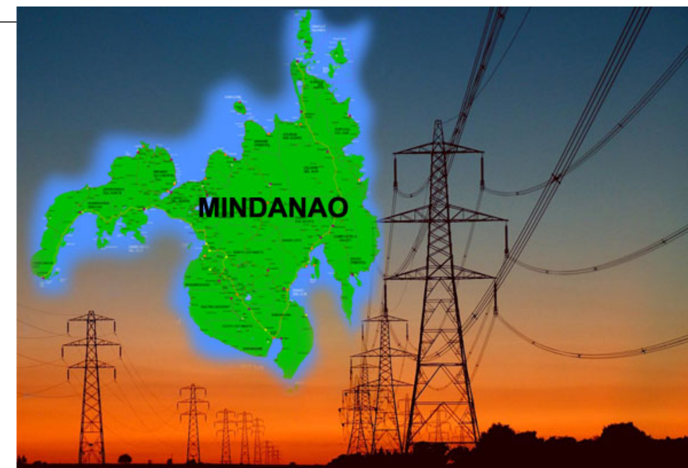
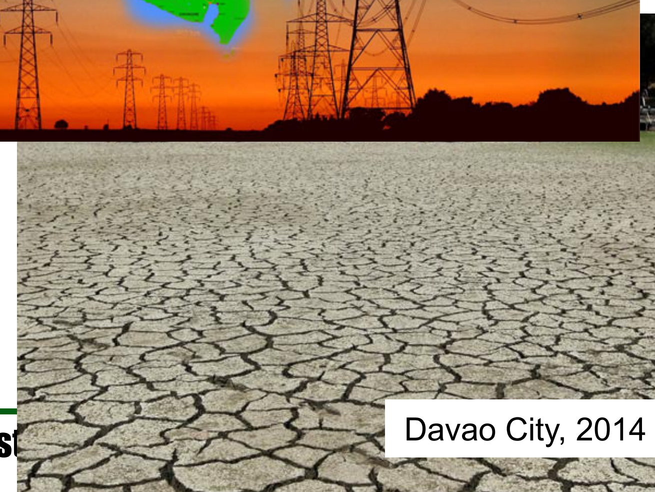
Case Study 1:
The Philippines

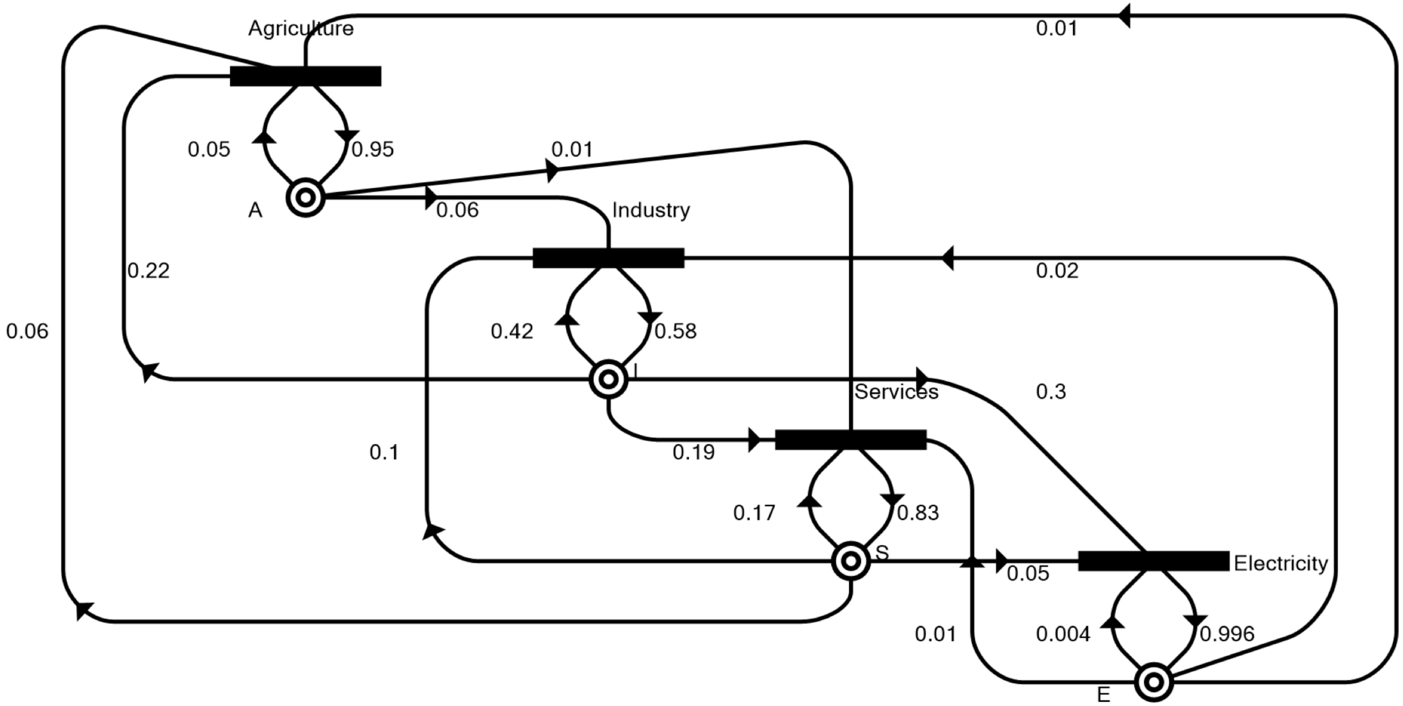


- Mindanao is the southern most major island of the Philippines
- Alternative energy is encouraged to mitigate greenhouse gas emissions
- Chronic electricity shortages are experienced in the region during the dry season due to over-dependence on hydroelectric power
- A 4 sector low resolution Regional IO is used to demonstrate the implications of a 10% electricity shortage in Mindanao





Technical Coefficients of the 4-Sector IO Model



	Agriculture	Industry	Services	Electricity Generation
Agriculture	0.05	0.06	0.01	0.000
Industry	0.22	0.42	0.19	0.300
Services	0.06	0.10	0.17	0.050
Electricity Generation	0.01	0.02	0.01	0.004

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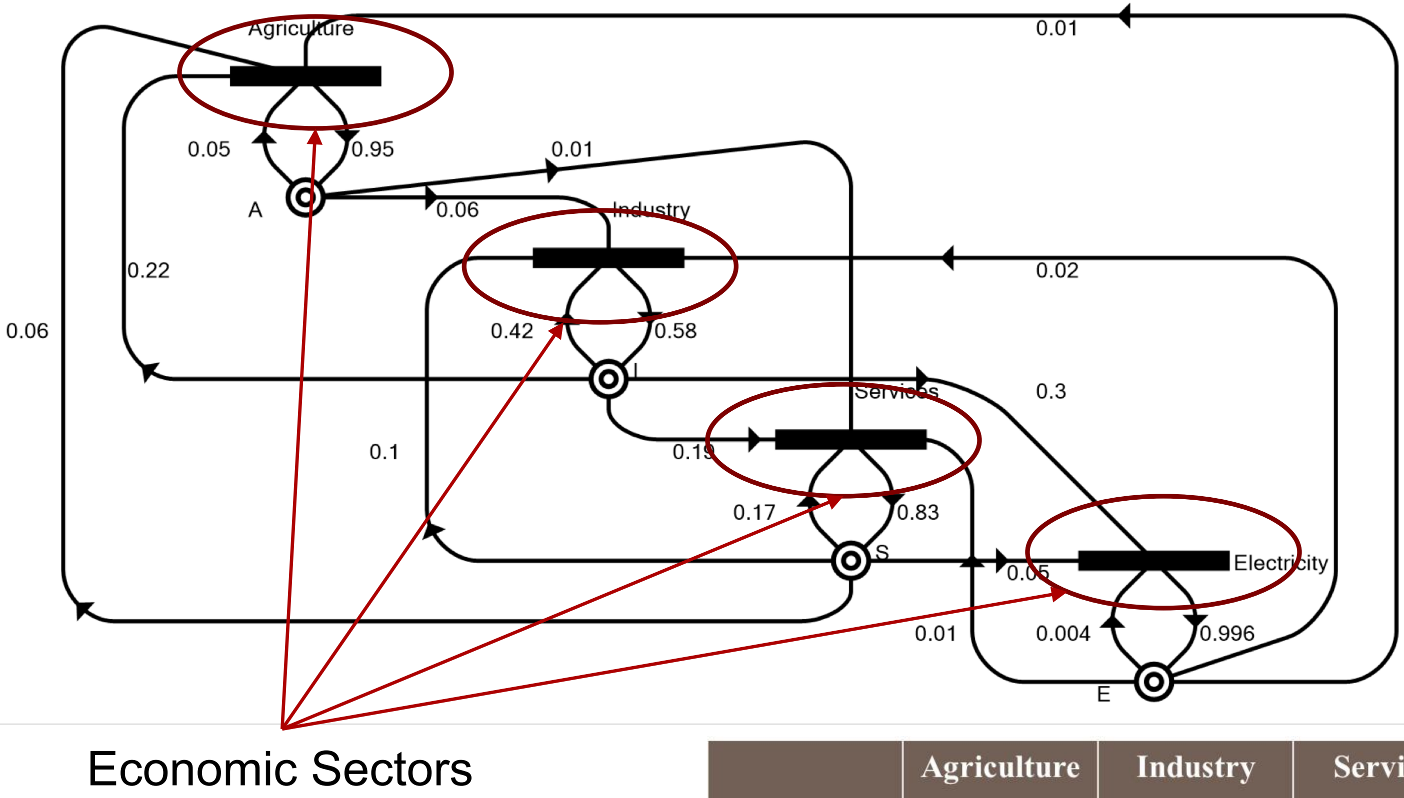

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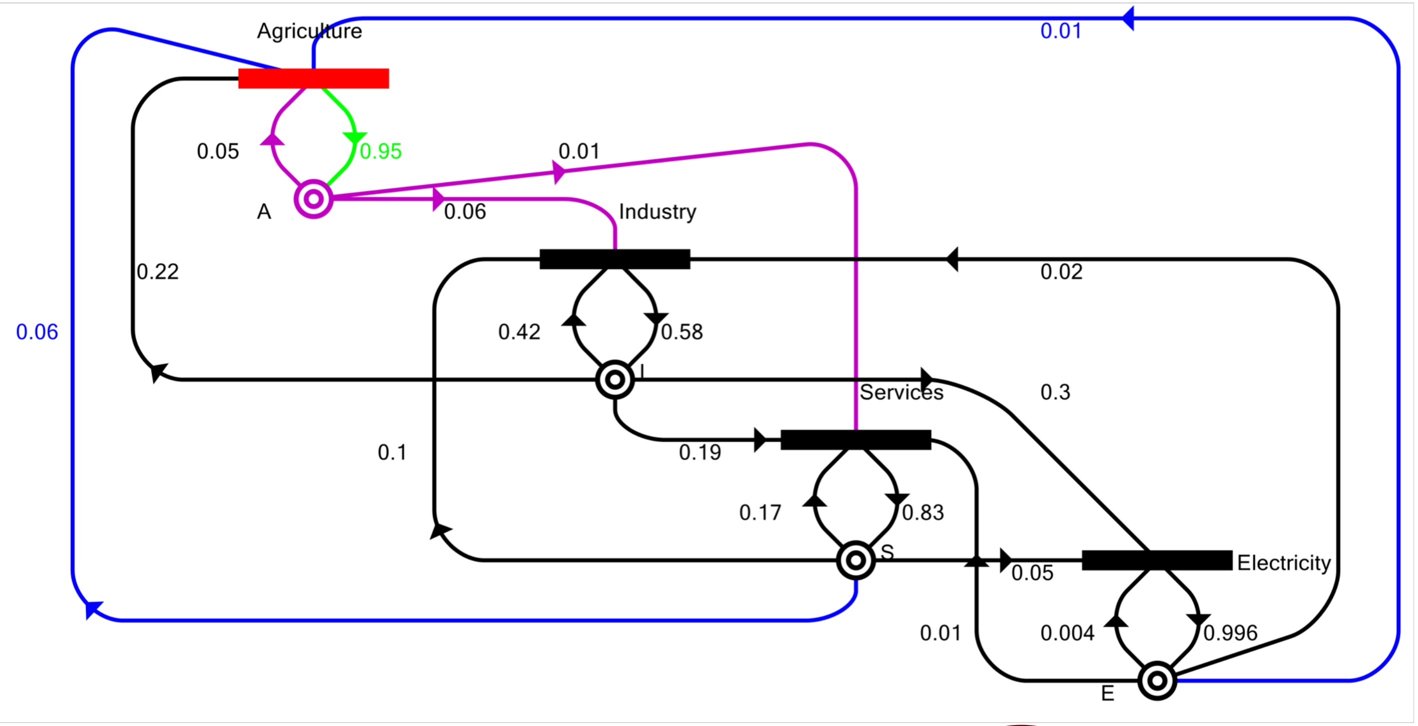

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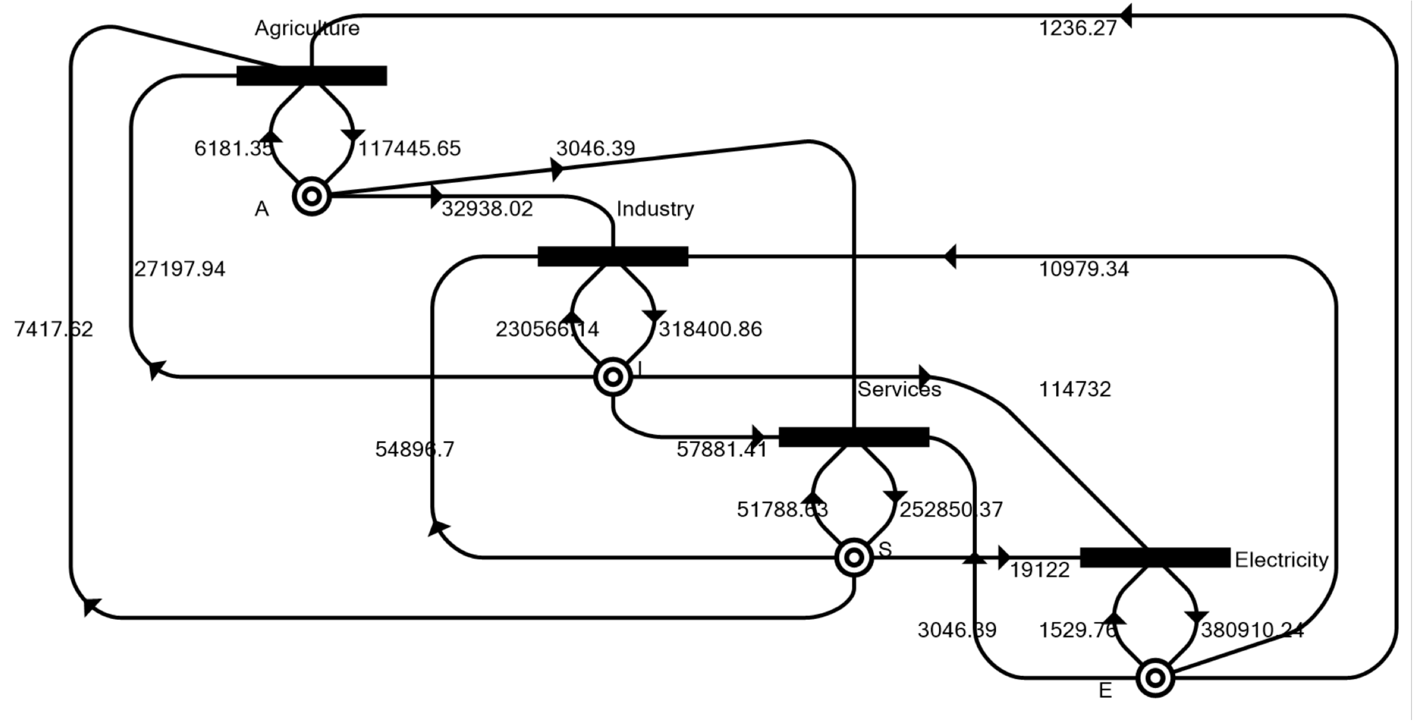
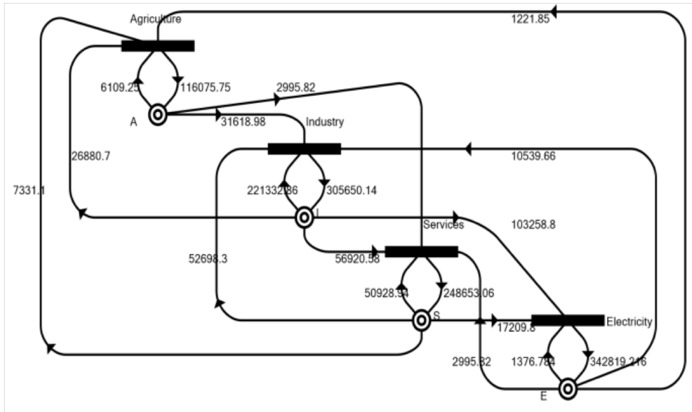
Economic transactions of the unperturbed system



	In Thousand Pesos	
	Final Demand	Total Output
Agriculture	81, 646	123, 678
Industry	117, 565	547, 260
Services	168, 693	301, 291
Electricity Generation	367, 904	384, 637

Perturbed System
10% Electricity shortage



Economic Sector	% Reduction in Final Demand	% Reduction in Total Output
Agriculture	0.00	1.17
Industry	0.00	4.04
Services	0.00	1.69
Electricity Generation	9.83	10.00
Over-all	2.79	4.95

Results

- The Agriculture, Industry and Services sectors experience no reduction in final demand
- The perturbation in the total output of the Electricity sector translates as a reduction in final output of the other sectors due to interdependence
- **Priority is given towards satisfying the final demand** in comparison to satisfying intermediate consumption between sectors

Case Study 2: Human Resource Allocation in Organizations (Aviso et al., 2016)

- Organizations have to be prepared to deal with climatic impacts that threaten operational continuity
- Models for dealing with workforce shortage during climatic disruptions should also be developed.
- Human resources are vital for the continuous operation of critical infrastracture

Problem Statement

- Given N departments in an organization with each department providing service
- There is a fixed ratio of personnel interaction required
- At normal conditions, the total number of personnel required for each department is known
- A disruption reduces the total number of personnel available

Model Formulation

$$\max \lambda + \frac{1}{m}\sum_{i}^{N} \lambda_i$$

$$t_f \leq \alpha t_0$$

$$\mathbf{t} = \mathbf{A}\mathbf{t} + \mathbf{e}$$

$$(\mathbf{I} - \mathbf{A})\mathbf{t} = \mathbf{e}$$

$$\left(\frac{e_{if} - e_i^L}{e_{i0} - e_i^L}\right) = \lambda_i$$

λ – degree of satisfaction
α - fraction of available workforce
A – interaction matrix
e – net output of work
e^L – lower limit of work output
t – total workload vector

Model Formulation

Objective Function

$$\max \lambda + \frac{1}{m}\sum_{i}^{N} \lambda_i$$

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Human resource available during disruption/crisis

$$\mathbf{t} = \mathbf{A}\mathbf{t} + \mathbf{e}$$

$$(\mathbf{I} - \mathbf{A})\mathbf{t} = \mathbf{e}$$

$$\left(\frac{e_{if} - e_i^L}{e_{i0} - e_i^L}\right) = \lambda_i$$

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Balance equations according to interaction matrix

λ – degree of satisfaction
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Model Formulation

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$$\left(\frac{e_{if} - e_i^L}{e_{i0} - e_i^L}\right) = \lambda_i$$

Workforce reduction limits

λ – degree of satisfaction

α - fraction of available workforce

A – interaction matrix

e – net output of work

e^L – lower limit of work output

t – total workload vector

Case Study for a hypothetical Acute Care Hospital

List of departments in ACH.

	Departments
D1	High-level Management
D2	Middle-level Management
D3	General Administration
D4	Support Administration
D5	Finance Administration
D6	Human Services
D7	Information Services
D8	Medical Staff
D9	Nursing Staff
D10	Ancillary Staff

Transaction matrix (**P**), net output of work ($\mathbf{e}_0$) and initial total work load ($\mathbf{t}_0$) for case study 1 (in man-days per day).

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	$\mathbf{e}_0$	$\mathbf{t}_0$
D1	0.80	1.40	0.04	0.04	0.04	0.04	0.20	0.04	0.40	0.20	0.80	4
D2	3.60	2.40	1.50	0.30	1.50	2.40	1.50	4.80	4.50	4.50	3.00	30
D3	0.83	20.75	24.90	0.83	4.15	4.15	1.66	5.81	1.66	12.45	5.81	83
D4	0.12	0.12	0.00	1.20	0.12	0.36	0.60	1.20	2.40	3.60	2.28	12
D5	4.32	6.24	0.96	0.96	19.20	0.96	3.84	2.40	0.96	0.96	7.20	48
D6	0.60	1.20	0.60	0.60	0.60	2.40	0.60	0.60	0.60	1.80	2.40	12
D7	5.55	11.10	5.55	1.11	16.65	5.55	33.30	16.65	5.55	7.77	2.22	111
D8	0.45	0.45	0.45	0.45	0.45	0.45	0.45	1.35	4.50	13.50	22.50	45
D9	1.98	1.98	1.98	1.98	1.98	1.98	1.98	3.96	29.70	19.80	130.68	198
D10	0.20	1.00	1.40	0.20	0.80	1.00	1.40	6.60	1.00	2.40	4.00	20

Workforce interaction matrix (**A**) for case study 1.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
D1	0.200	0.047	0.000	0.003	0.001	0.003	0.002	0.001	0.002	0.010
D2	0.900	0.080	0.018	0.025	0.031	0.200	0.014	0.107	0.023	0.225
D3	0.208	0.692	0.300	0.069	0.086	0.346	0.015	0.129	0.008	0.623
D4	0.030	0.004	0.000	0.100	0.003	0.030	0.005	0.027	0.012	0.180
D5	1.080	0.208	0.012	0.080	0.400	0.080	0.035	0.053	0.005	0.048
D6	0.150	0.040	0.007	0.050	0.013	0.200	0.005	0.013	0.003	0.090
D7	1.388	0.370	0.067	0.093	0.347	0.463	0.300	0.370	0.028	0.389
D8	0.113	0.015	0.005	0.038	0.009	0.038	0.004	0.030	0.023	0.675
D9	0.495	0.066	0.024	0.165	0.041	0.165	0.018	0.088	0.150	0.990
D10	0.050	0.033	0.017	0.017	0.017	0.083	0.013	0.147	0.005	0.120

Data Limits

Initial and optimized reduction in workforce available for case study 1.

Departments		Initial reduction in available workforce $\left(1-\alpha_j\right)*100$	Maximum level of reduction in net output of work $100*\beta_i$
D1	High-level Management	10%	25%
D2	Middle-level Management	10%	25%
D3	General Administration	10%	25%
D4	Support Administration	10%	25%
D5	Finance Administration	10%	25%
D6	Human Services	10%	25%
D7	Information Services	10%	25%
D8	Medical Staff	12%	15%
D9	Nursing Staff	12%	15%
D10	Ancillary Staff	10%	40%

- Reduction in available resources upon disruption
- Each department suffers an initial loss in workforce

Optimized Results

Table 8
Comparison of total workforce available during normal and crisis conditions and total workforce needed for case study 1.

Departments	(t_0)	Initial total workforce available (αt_0)	Available workforce during crisis condition (t_f)	Total workforce needed during crisis condition
D1	High-level Management	4	3.60	3.37
D2	Middle-level Management	30	27.00	25.43
D3	General Administration	83	74.70	69.87
D4	Support Administration	12	10.80	10.12
D5	Finance Administration	48	43.20	40.41
D6	Human Services	12	10.80	10.07
D7	Information Services	111	99.90	94.17
D8	Medical Staff	45	39.60	39.01
D9	Nursing Staff	198	174.24	174.24
D10	Ancillary Staff	20	18.00	16.50

- Optimized results indicate the amount of workforce needed to meet demand for net output of work
- Total workforce needed may be less than available workforce
- Nursing staff was maximized

Conclusions and Future Work

- A P-graph approach for the allocation of various types of resource has been presented
- A graphical approach using the P-graph framework was presented.
- A fuzzy optimization model has been used to simultaneously account the demand for each department
- This framework can be utilized for developing disaster and risk management strategies
- Future work can focus on integrating this approach within a comprehensive decision analysis framework

Acknowledgments

- The authors would like to thank the Commission on Higher Education Philippine Higher Education Research Network (CHED-PHERNet) which funded this work through the Sustainability Studies Program

THANK YOU

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