Optimal Resource Allocation During Crisis Conditions

Prof. Kathleen B. Aviso, PhD

De La Salle University, Manila, Philippines

Decoupling Growth and Environmental Impacts

(Rockström et al., 2009. Nature 461: 472)

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FEATURE

A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

SUMMARY

- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

ROAD TO COPENHAGEN

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1–3]. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene[4], in which human actions have become the main driver of global environmental change[5]. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world.

During the Holocene, environmental change occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all stayed within a relatively narrow range. Now, largely because of a rapidly growing reliance on fossil fuels and industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state. The result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development[6]. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[7].

Planetary boundaries

To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries'. These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although Earth's complex systems sometimes respond smoothly to changing pressures, it seems that this will prove to be the exception rather than the rule. Many subsystems of Earth react in a nonlinear, often abrupt, way, and are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans[8,9].

Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (see Fig. 1 and Table).

In general, planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds — for processes with evidence of threshold behaviour — or at dangerous levels — for processes without

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

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- ❑ Economic and demographic trends are pushing the limits of Earth's "safe operating space."
- ❑ Complex interactions exist between resource use and emissions.

Other Emerging Sustainability Issues

CLIMATE CENTRAL

SUSTAINABILITY

Weather Disasters Have Cost the Globe $2.4 Trillion

Factors such as development, population growth and globalization are likely to blame, but the report suggests that we have learned from past disasters

By Brian Kahn, Climate Central on July 17, 2014

You've Heard of the Anthropocene? Welcome to the Hellocene

It sounds like a bad disaster movie, but climate change isn't an abstract threat for our grandchildren. It's here now

By Rob Jackson on November 26, 2018

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BEHAVIOR & SOCIETY
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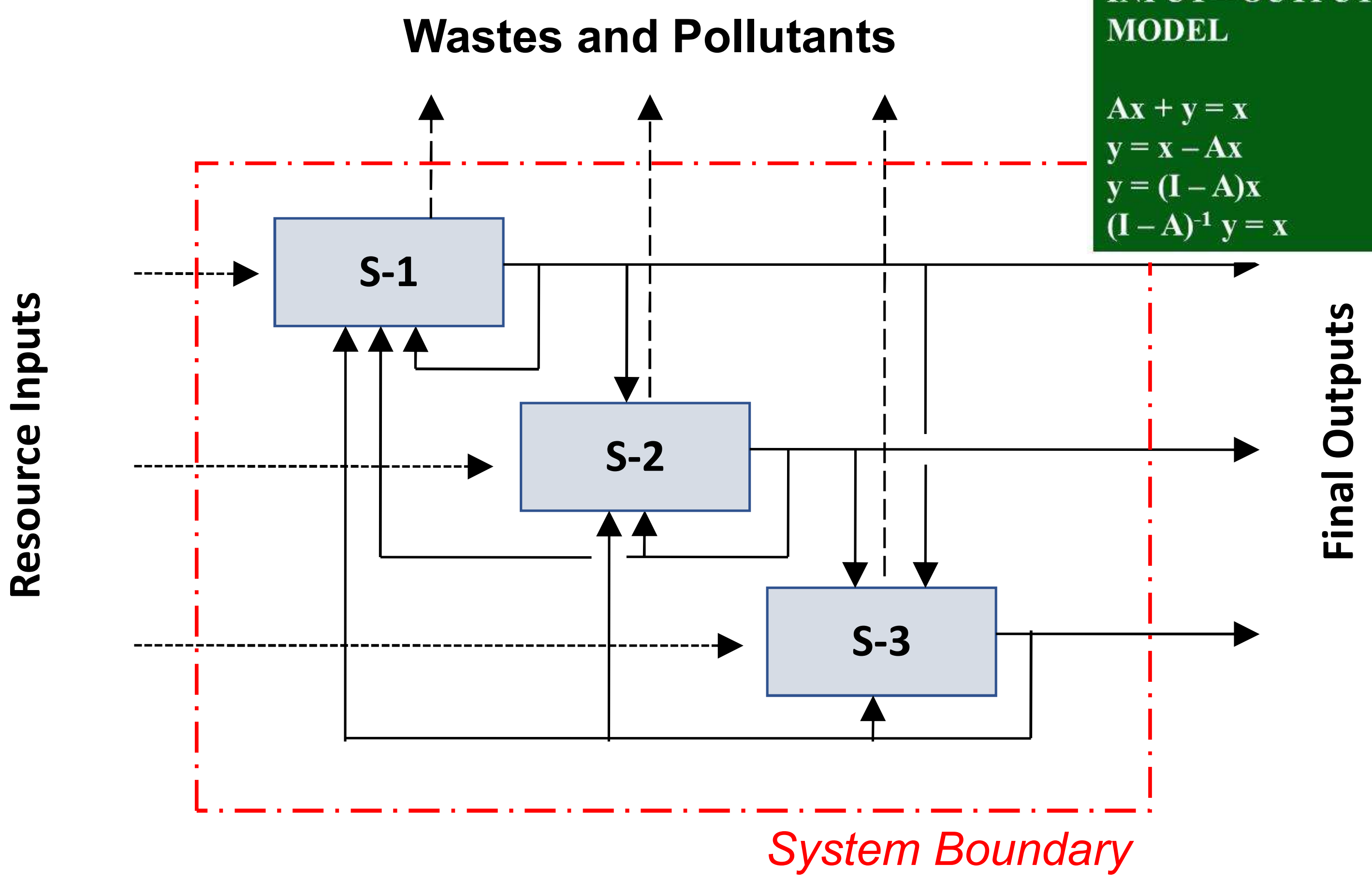
- ❑ Disasters result in economic losses and reduced availability of resources
- ❑ Other emerging sustainability issues may affect options available to industry in the future.

“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

A Three-Sector Input-Output System



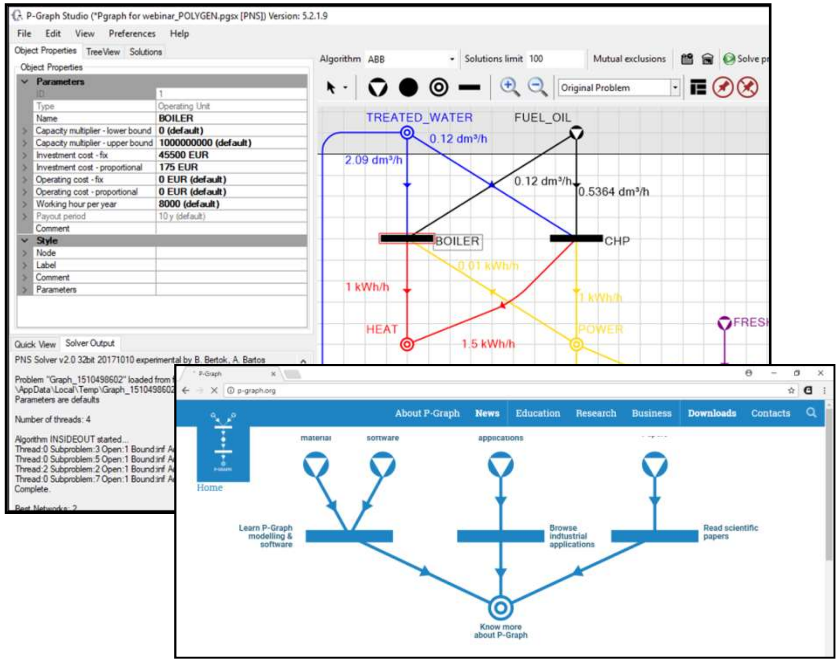
INPUT – OUTPUT MODEL

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

Outline

- ❑P-graph model
- ❑Drought results in electricity shortage in the Philippines
- ❑Human resource allocation during crisis
- ❑Conclusions and Future Work

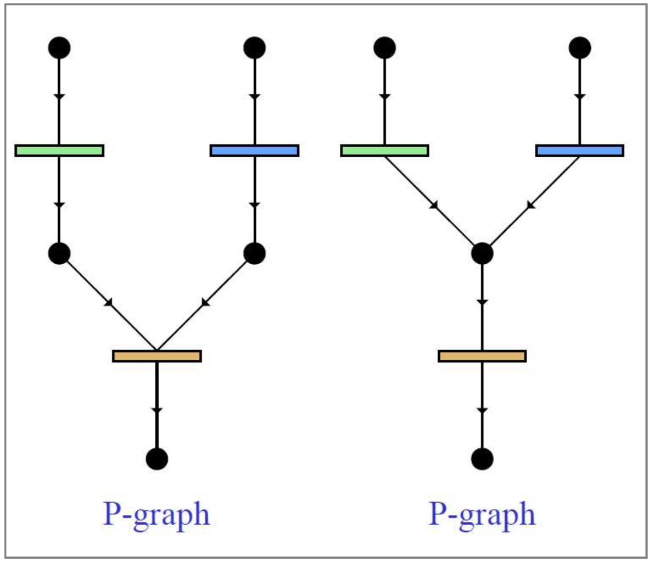
The P-graph Framework



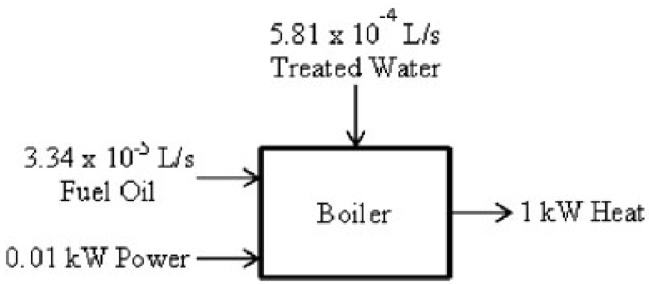
- ❑ Graph-theoretic framework for Process Network Synthesis (PNS) developed by **Ferenc Friedler, Liang-Tseng Fan,** and coworkers.
- ❑ Advantages include computational efficiency and automated generation of alternative structures.

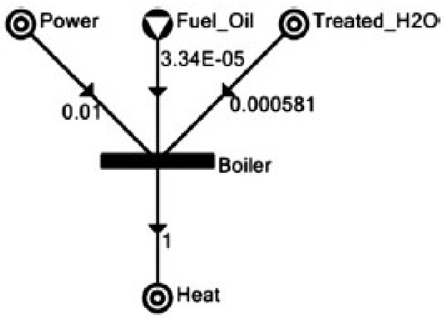
P-graph Fundamentals

(Friedler et al., 1992. CES 47: 1973)



- Bipartite graph consisting of M-type and O-type nodes.
- Capable of unambiguous representation of industrial processes.





P-graph Foundation: Five Axioms

(Friedler et al., 1992. CES 47: 1973)

(S1) Every final product is represented in the structure.

(S2) A material represented in the structure is a raw material if and only if it is not an output from any operating unit represented in the structure.

(S3) Every operating unit represented in the structure is defined in the synthesis problem.

(S4) Any operating unit represented in the structure has at least one path leading to a product.

(S5) If a material belongs to the structure, it must be an input to or output from at least one operating unit represented in the structure.

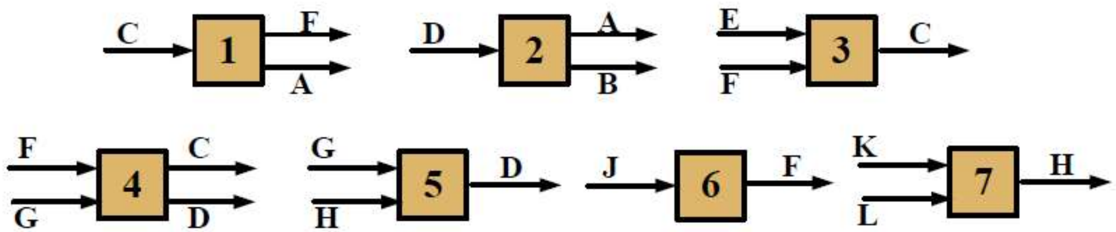
P-graph Component Algorithms

(Friedler et al., 1992. CES 47: 1973; 1993. CACE 17: 929; 1996. In: SOAGO p. 609)

Algorithm	Description
Maximal structure generation (MSG)	Mathematically rigorous generation of a complete, error-free “superstructure”
Solution structure generation (SSG)	Identification of combinatorially feasible subset networks of maximal structure
Accelerated branch-and-bound (ABB)	Efficient branch-and-bound algorithm enhanced with SSG logic to eliminate infeasible and redundant solutions

Illustration of MSG and SSG

(Friedler et al., 1995. CES 50: 1755)



Product: A

Raw materials: E, G, J, K, L

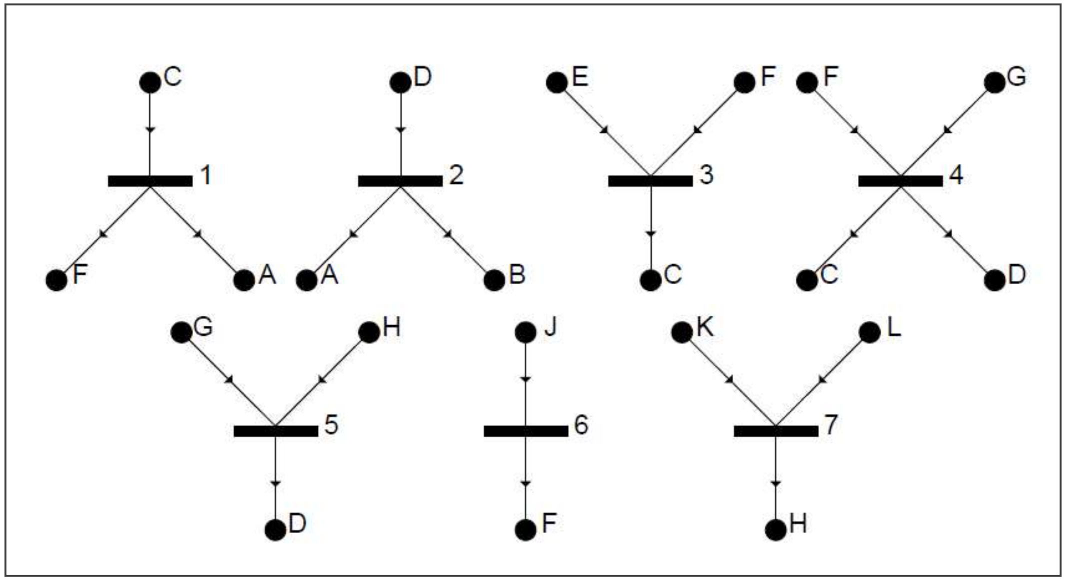
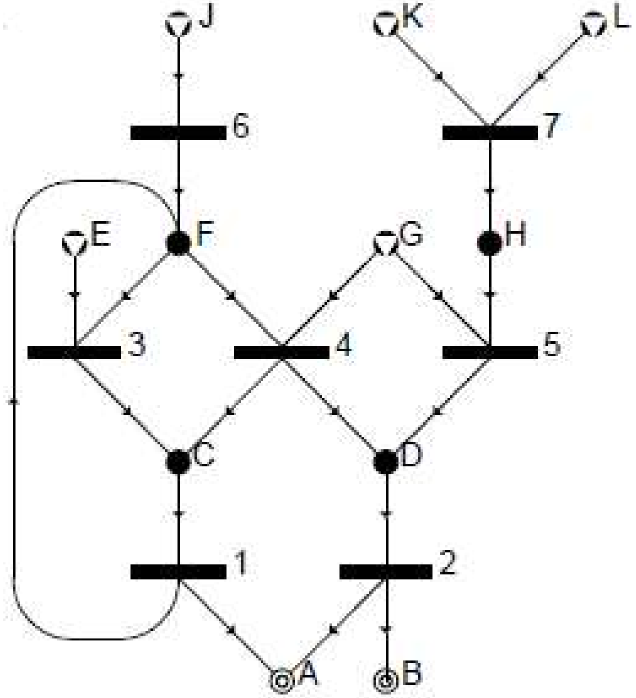


Illustration of MSG and SSG

(Friedler et al., 1993. CACE 16: S313; *Kovacs et al. 2000. CACE 24: 1881)



- MSG algorithm determines the structure that contains all possible networks.
- The result is an error-free superstructure.
- P-graph was shown to have 30% improvement over erroneous MP model*

Impact of Disasters on the Economy
(Aviso et al., 2015)

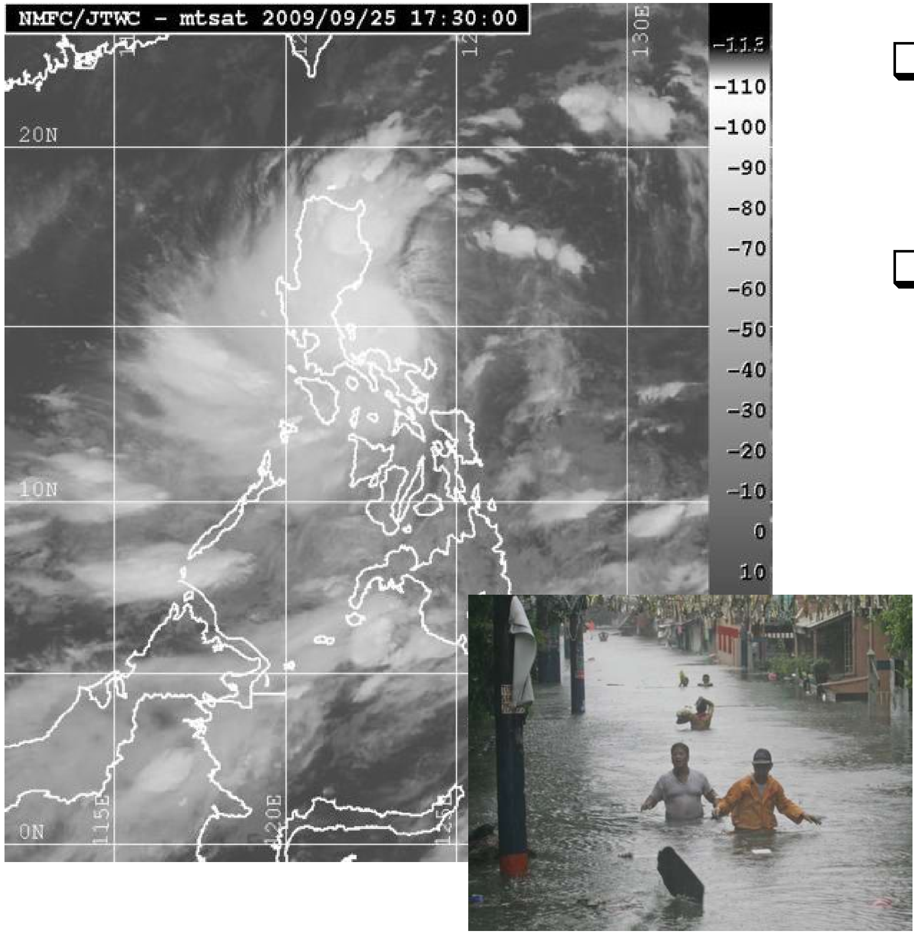
- ❑ Disasters result in shortage of resources and reduction in production capacities
- ❑ Disruptive events result in ripple effects throughout the economy
- ❑ Allocation of resources should be optimized to minimize impacts

Problem statement for economic systems

- 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

Drought causes electricity shortage

(Aviso et al., 2015)

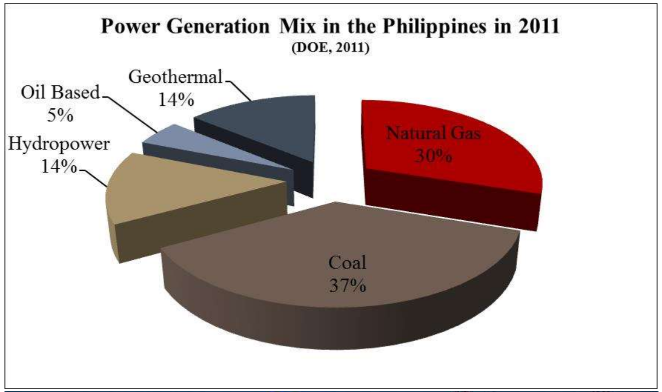


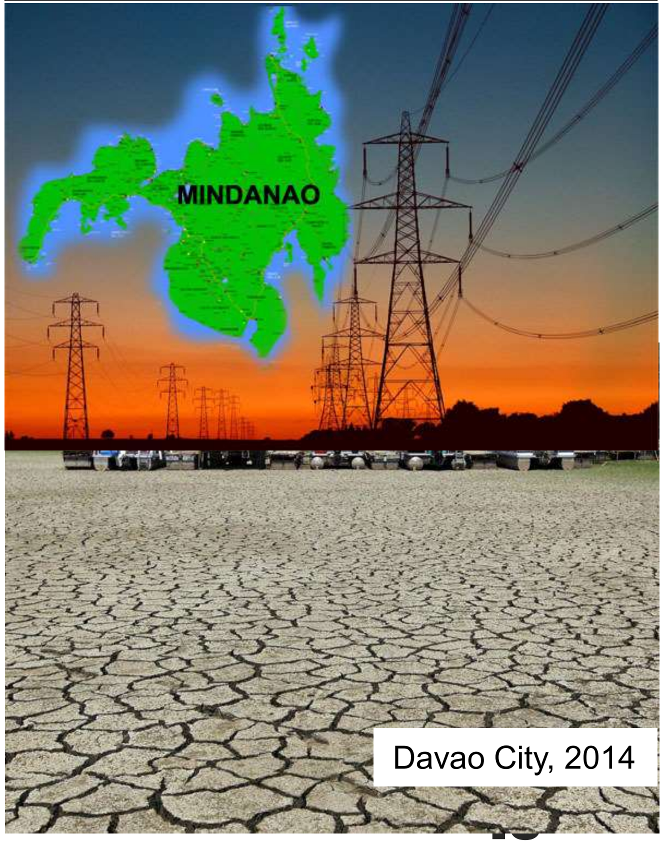
- The Philippines is one of the most disaster-prone countries in the world
- Research that contributes to **weakening the vicious cycle of disaster vulnerability** is essential

http://commons.wikimedia.org

Drought causes electricity shortage

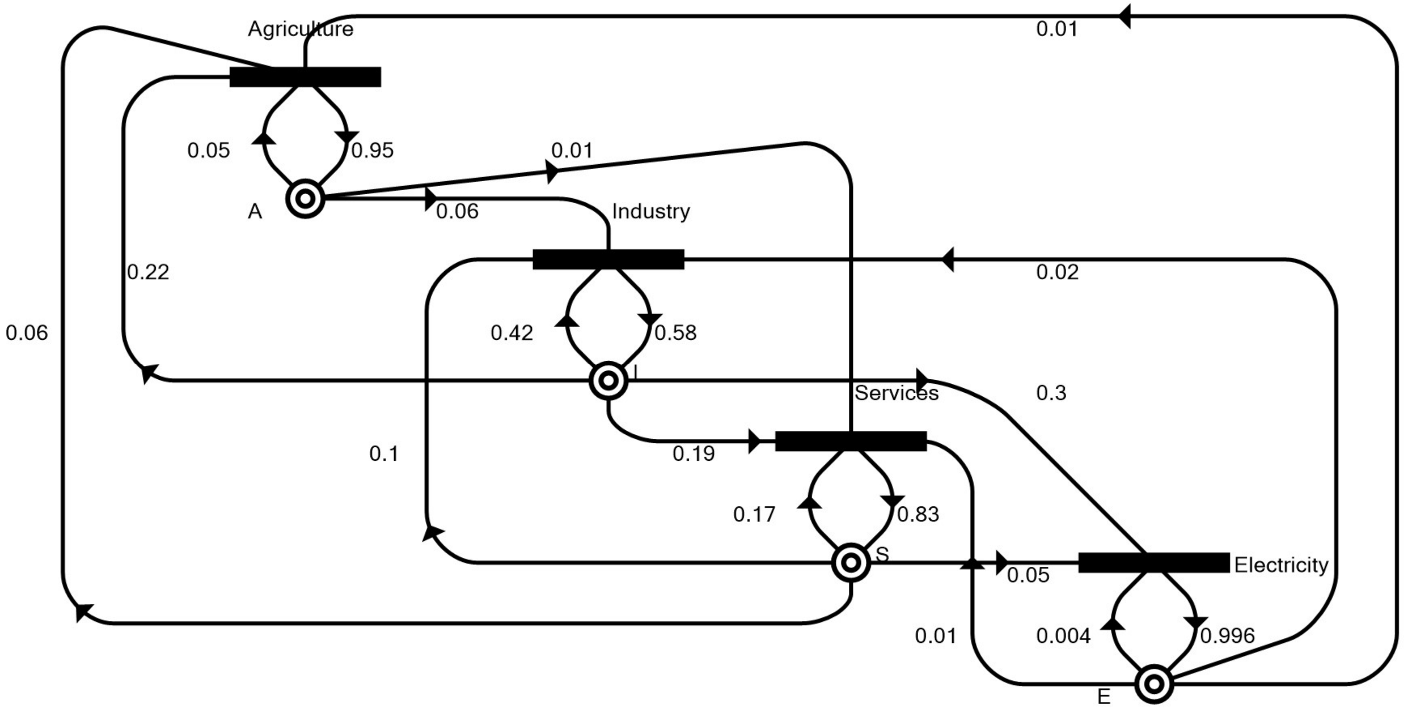
- Mindanao is the southern most major island of the Philippines
- Alternative energy is encouraged to mitigate greenhouse gas emissions
- Chronic electricity shortages are due to over-dependence on hydroelectric power
- A 4-sector low resolution Regional IO is used to demonstrate the implications of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





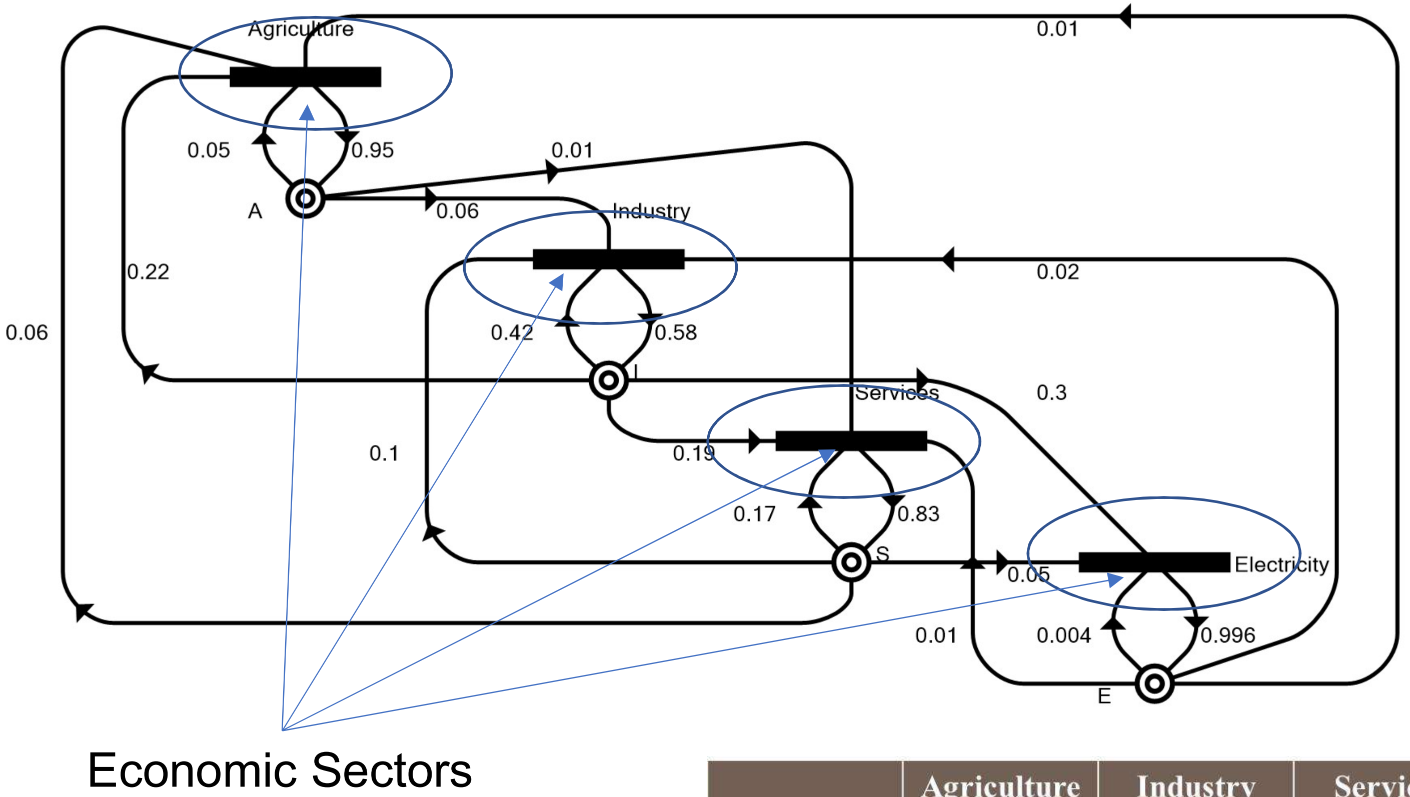
Davao City, 2014

P-graph model of a four sector economy



	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

P-graph model of a four sector economy



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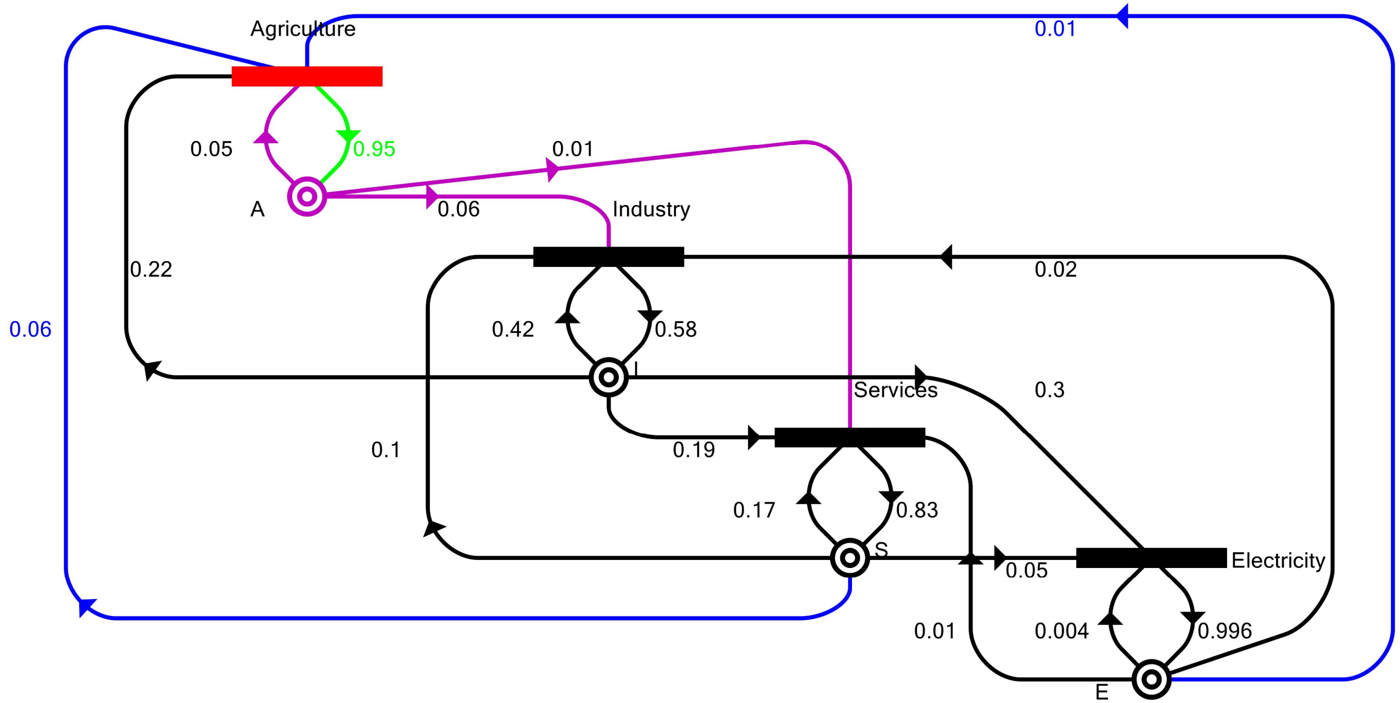

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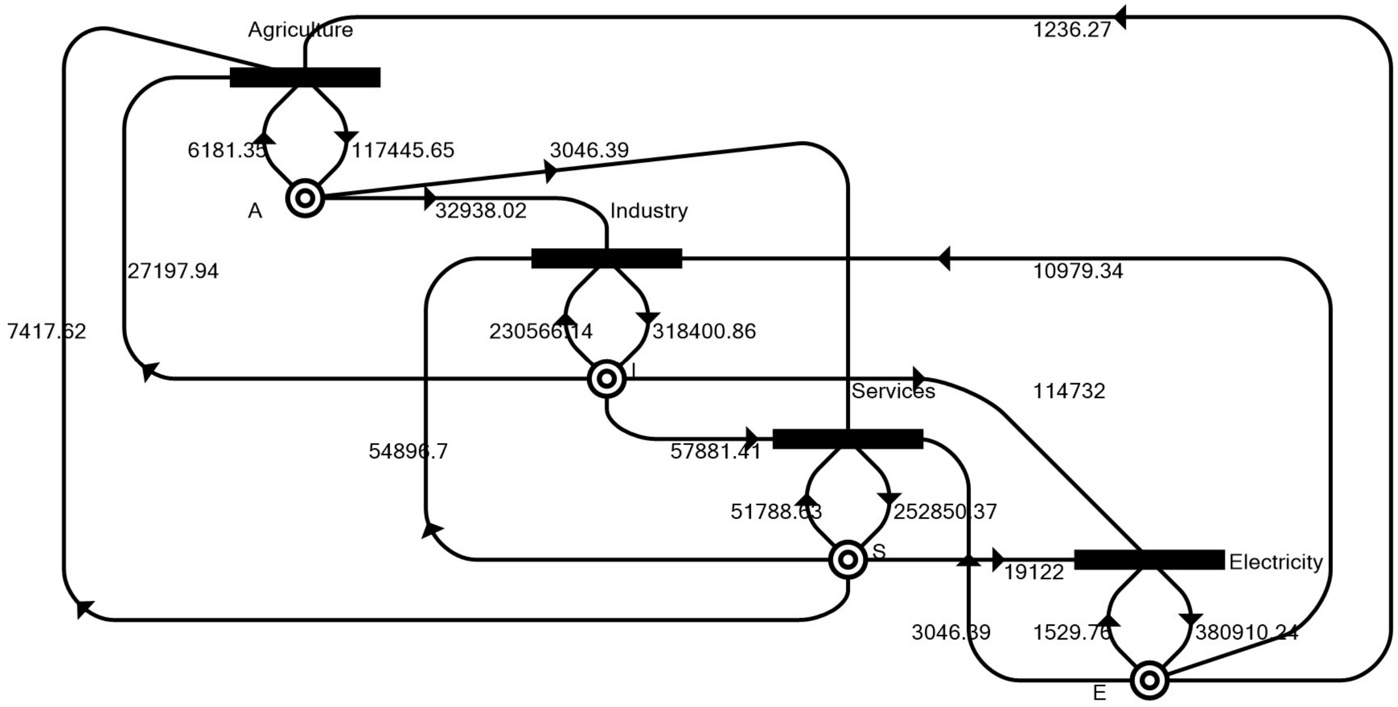
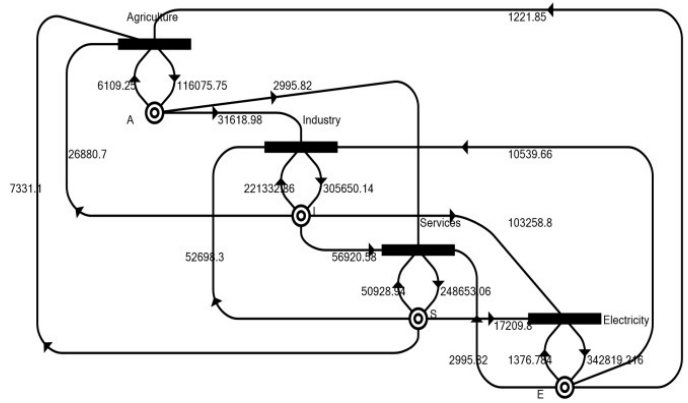
Normal economic transactions (Baseline)



	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

10% Reduction in electricity

- How should electricity be allocated to maximize economic productivity?



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
- Reduction in the total output of the Electricity sector results in reduced final output of other sectors
- **Final Demand is prioritized**

Human Resource Allocation in Crisis

(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 infrastructure

Problem statement for human resource allocation

- 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

Organizational IO Model
(Correa and Craft, 1999)

$$\text{Minimize } \mathbf{p}^{\mathrm{T}}\mathbf{t}_{\mathrm{f}}$$

$$\mathbf{At_f} + \mathbf{e_f} = \mathbf{t_f}$$

$$\mathbf{e_f} \geq \mathbf{e_f^{LL}}$$

$$\mathbf{t^{LL}} \leq \mathbf{t_f} \leq \mathbf{t^{UL}}$$

Parameters

$\mathbf{A}$ – Interaction matrix

$\mathbf{e}_{\mathrm{f}}^{\mathrm{LL}}$ - minimum demand output

$\mathbf{p}^{\mathrm{t}}$ - price vector

$\mathbf{t}^{\mathrm{LL}}$ - lower limit of personnel

$\mathbf{t}^{\mathrm{UL}}$ - upper limit of personnel

Variables

$\mathbf{e}_{\mathrm{f}}$ - Net final demand output

$\mathbf{t}_{\mathrm{f}}$ - total number of personnel

Objective is to minimize total costs

Organizational IO Model
(Correa and Craft, 1999)

$$\text{Minimize } \mathbf{p}^{\mathrm{T}}\mathbf{t}_{\mathrm{f}}$$

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

$$\mathbf{e}_{\mathbf{f}} \geq \mathbf{e}_{\mathbf{f}}^{\mathbf{LL}}$$

$$\mathbf{t}^{\mathbf{LL}} \leq \mathbf{t}_{\mathbf{f}} \leq \mathbf{t}^{\mathbf{UL}}$$

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Variables

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Organizational IO Model
(Correa and Craft, 1999)

Work interaction balance

$$\text{Minimize } \mathbf{p}^{\mathrm{T}}\mathbf{t}_{\mathrm{f}}$$

$$\boxed{\mathbf{A}\mathbf{t}_{\mathrm{f}} + \mathbf{e}_{\mathrm{f}} = \mathbf{t}_{\mathrm{f}}}$$

$$\mathbf{e}_{\mathrm{f}} \geq \mathbf{e}_{\mathrm{f}}^{\mathrm{LL}}$$

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Organizational IO Model
(Correa and Craft, 1999)

Net work output requirements

$$\text{Minimize } \mathbf{p}^{\mathrm{T}}\mathbf{t}_{\mathrm{f}}$$

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

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Variables

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$\mathbf{t}_{\mathrm{f}}$ - total number of personnel

Organizational IO Model
(Correa and Craft, 1999)

Workforce availability conditions

$$\text{Minimize } \mathbf{p}^{\mathrm{T}}\mathbf{t}_{\mathrm{f}}$$

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

$$\mathbf{e}_{\mathbf{f}} \geq \mathbf{e}_{\mathbf{f}}^{\mathbf{LL}}$$

$$\boxed{\mathbf{t}^{\mathbf{LL}} \leq \mathbf{t}_{\mathbf{f}} \leq \mathbf{t}^{\mathbf{UL}}}$$

Parameters

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$\mathbf{e}_{\mathrm{f}}^{\mathrm{LL}}$ - minimum demand output

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$\mathbf{t}^{\mathrm{UL}}$ - upper limit of personnel

Variables

$\mathbf{e}_{\mathrm{f}}$ - Net final demand output

$\mathbf{t}_{\mathrm{f}}$ - total number of personnel

The Business Processing Outsourcing (BPO)

	Department
OD	Operations
TQ	Quality Assurance
RWD	Resource and Workforce
IT	Information Technology
MD	Marketing
CSD	Client Services
FD	Finance

BPO workforce interaction matrix (man-days/day)

	OD	TQ	RWD	IT	MD	CSD	FD	e	t
OD	12.50	0.188	0.094	0.094	0.031	0.188	0.094	186.8	200
TQ	0.188	1.250	0.188	0.188	0.031	0.188	0.094	17.87	20
RWD	0.094	0.019	0.938	0.019	0.031	0.375	0.019	8.505	10
IT	0.188	0.188	0.094	0.250	0.031	0.019	0.019	9.211	10
MD	0.031	0.031	0.031	0.031	0.375	0.031	0.031	7.439	8
CSD	0.019	0.019	0.019	0.019	0.031	0.313	0.019	4.561	5
FD	0.094	0.375	0.375	0.188	0.031	0.019	0.438	5.761	7

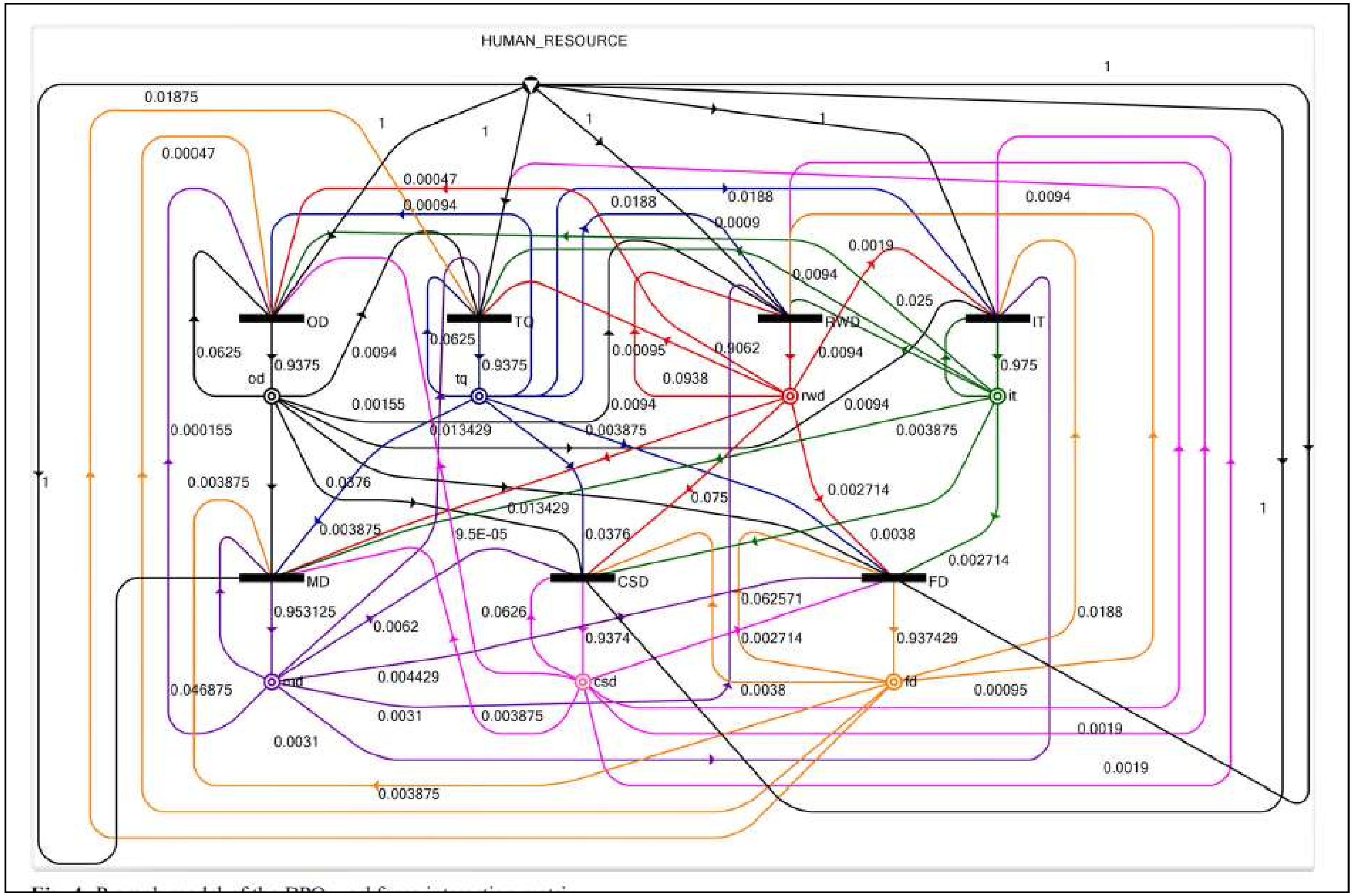
BPO workforce interaction matrix (man-days/day)

	OD	TQ	RWD	IT	MD	CSD	FD	e	t
OD	12.50	0.188	0.094	0.094	0.031	0.188	0.094	186.8	200
TQ	0.188	1.250	0.188	0.188	0.031	0.188	0.094	17.87	20
RWD	0.094	0.019	0.938	0.019	0.031	0.375	0.019	8.505	10
IT	0.188	0.188	0.094	0.250	0.031	0.019	0.019	9.211	10
MD	0.031	0.031	0.031	0.031	0.375	0.031	0.031	7.439	8
CSD	0.019	0.019	0.019	0.019	0.031	0.313	0.019	4.561	5
FD	0.094	0.375	0.375	0.188	0.031	0.019	0.438	5.761	7

Workforce Interaction Matrix

	OD	TQ	RWD	IT	MD	CSD	FD
OD	6.25	0.94	0.94	0.94	0.39	3.75	1.34
TQ	0.09	6.25	1.88	1.88	0.39	3.75	1.34
RWD	0.05	0.09	9.38	0.19	0.39	7.50	0.27
IT	0.09	0.94	0.94	2.50	0.39	0.38	0.27
MD	0.02	0.16	0.31	0.31	4.69	0.63	0.45
CSD	0.01	0.09	0.19	0.19	0.39	6.25	0.27
FD	0.05	1.88	3.75	1.88	0.39	0.38	6.25

P-graph model of BPO case



Reductions in workforce

Department	Initial Reduction (%)	Max. allowable reduction (%)
OD	2.00	5.00
TQ	5.00	10.00
RWD	5.00	10.00
IT	2.00	3.00
MD	10.00	30.00
CSD	10.00	30.00
FD	10.00	3.00

Optimal solution

	OD	TQ	RWD	IT	MD	CSD	FD	e	t	tavail
OD	12.25	0.179	0.089	0.092	0.028	0.169	0.085	183.1	196	196
TQ	0.184	1.188	0.179	0.184	0.028	0.169	0.085	16.98	19.0	19.0
RWD	0.092	0.018	0.891	0.019	0.028	0.338	0.017	8.098	9.50	9.50
IT	0.184	0.179	0.089	0.245	0.028	0.017	0.017	9.049	9.81	9.81
MD	0.030	0.029	0.029	0.030	0.338	0.028	0.028	6.687	7.20	7.20
CSD	0.019	0.018	0.019	0.018	0.028	0.282	0.017	4.100	4.50	4.50
FD	0.092	0.356	0.089	0.184	0.028	0.017	0.394	5.139	6.30	6.30

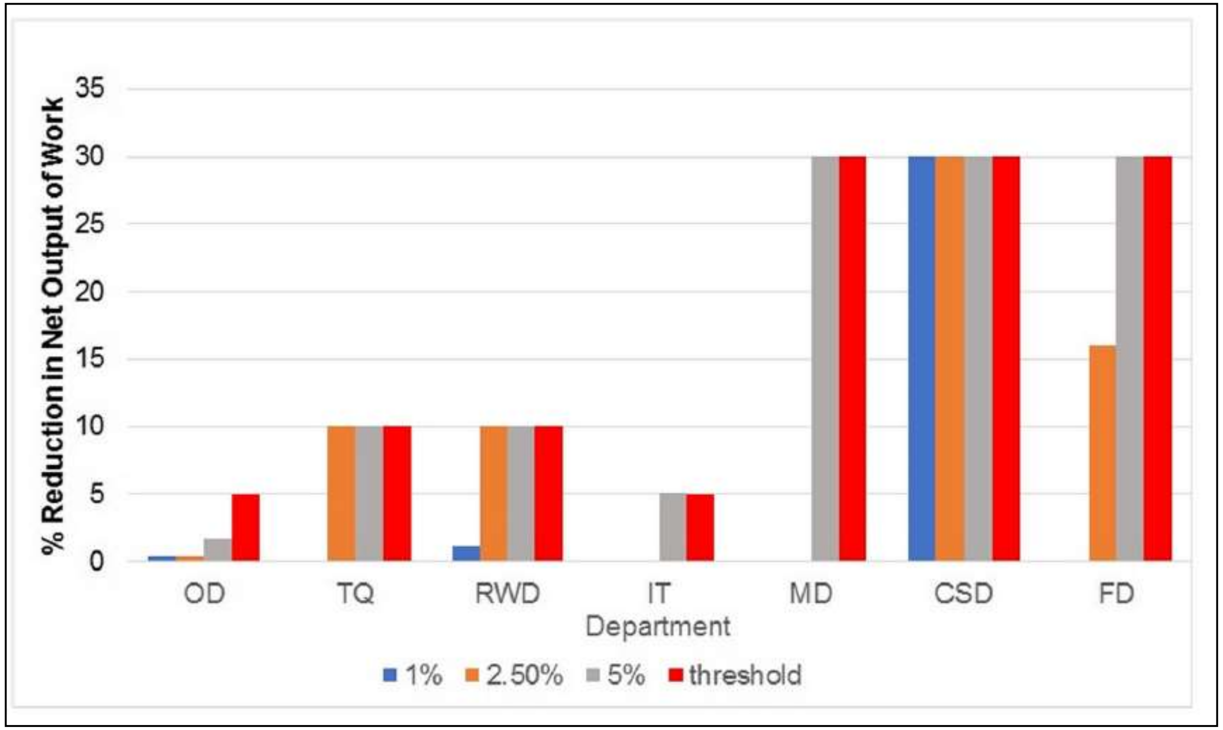
- All departments are within the threshold level of workforce reduction
- A reduction of 2.96% in total workforce but total reduction in output is only 2.92%

Solution for 1% workforce reduction

	OD	TQ	RWD	IT	MD	CSD	FD	e	tnew	told
OD	12.45	0.187	0.092	0.094	0.031	0.133	0.094	186.1	199.2	200
TQ	0.188	1.246	0.184	0.188	0.031	0.133	0.094	17.87	19.94	20
RWD	0.094	0.019	0.917	0.019	0.031	0.266	0.019	8.408	9.773	10
IT	0.187	0.187	0.092	0.250	0.031	0.013	0.019	9.203	9.982	10
MD	0.031	0.031	0.030	0.031	0.375	0.022	0.031	7.439	7.990	8
CSD	0.019	0.019	0.019	0.019	0.031	0.222	0.019	3.194	3.542	5
FD	0.094	0.374	0.092	0.188	0.031	0.013	0.437	5.761	6.990	7

- Workforce is allocated to departments with low tolerance for workforce reduction

Sensitivity Analysis on Workforce Disruption



- ❑Impact on department given varying workforce disruptions
- ❑Some departments are more prioritized than others

Conclusions and Future Work

- A P-graph approach for the IO model has been developed
- Model can be used for the allocation of various types of resource has been presented
- P-graph and IO can be used for analyzing impact of disruptions on the system
- Model can be implemented at various levels of implementation (e.g. economic systems, organizations, supply chains)
- Future work can focus on integrating this approach within a comprehensive decision analysis framework

Other Areas of Application

- Human resource planning in universities
- Crisis operations in Industrial complexes
- Inoperability in energy systems

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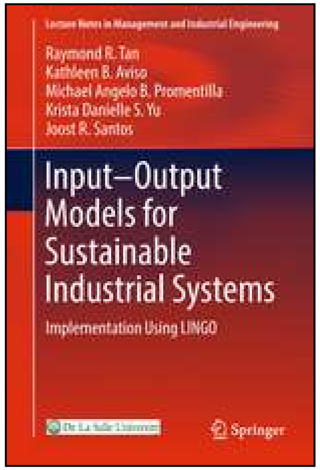
Kathleen B. Aviso, Ph.D.

Professor, Chemical Engineering Department
Assistant Dean for Research and Advanced Studies
Gokongwei College of Engineering
De La Salle University



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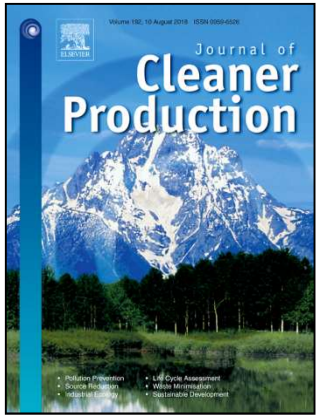
Input-Output Models for Sustainable Industrial Systems: Implementation using LINGO



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Thank you

For comments and suggestions you may also contact me at:

Tel. No.: + 632 – 5244611 loc 127

Email: kathleen.aviso@dlsu.edu.ph

BPO workforce transaction matrix (man-days/day)

	OD	TQ	RWD	IT	MD	CSD	FD
OD	6.25	0.94	0.94	0.94	0.39	3.75	1.34
TQ	0.09	6.25	1.88	1.88	0.39	3.75	1.34
RWD	0.05	0.09	9.38	0.19	0.39	7.50	0.27
IT	0.09	0.94	0.94	2.50	0.39	0.38	0.27
MD	0.02	0.16	0.31	0.31	4.69	0.63	0.45
CSD	0.01	0.09	0.19	0.19	0.39	6.25	0.27
FD	0.05	1.88	3.75	1.88	0.39	0.38	6.25

Workforce Interaction Matrix

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