Evaluation of the Economic Impact of Proposed Measures for Non-indigenous Species (NIS) Control on St. Lawrence Seaway Shipping

(Michigan Sea Grant Funded Project, $312k, 1999-2003)

Proposed Research:

Rigorous, Comprehensive Analysis of ANS Proposals for Ballast Water Treatment Using Game Theory

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NIS: Non-indigenous Species

- Zebra Mussel
- Asian Clam
- Green Crab
- Damage to the US: $4 billion annually (Mackey et al., 2000)

Introduction

- Problems due to the introduction of NIS
  - Economic
  - Ecological
- Ballast Water (Vector for the introduction and spreading (within the Great Lakes) of invasive marine organisms)

The Problem

- Introduction of NIS control measures requiring ballast water treatment.
- Capital costs incurred from installation of treatment equipment would increase transportation costs (required freight rates (RFR))
- A possible increase in the (actual, not "required") marine freight rates may cause modal shifts from the marine transportation mode to other transportation modes.
- Modal shifts could produce several negative side-effects that significantly affect society as a whole.

The Goal

Balance the benefits of prevention and control of NIS against overall cost, including the costs of unintended consequences that NIS control may produce, to the economy and to society.

Modeling the Problem

- The decision making process for the legislative body is modeled as a Multi-attribute decision problem (MADP).

AHP-MADP Scenario

- Three NIS control methods are considered:

  A_1 – Heat:

  raising the NIS requirement to a high level (high RFR increase)

  A_2 – Filtration/UV:

  raising the requirement to a higher level than A1 (very high RFR increase)

  A_3 – Ballast Water Exchange:

  raising the requirement to a lower level than A1 (small RFR increase)

AHP-MADP Scenario, Con'd.

- A certain amount of potash moves from Thunder Bay, ON to Toledo, OH.

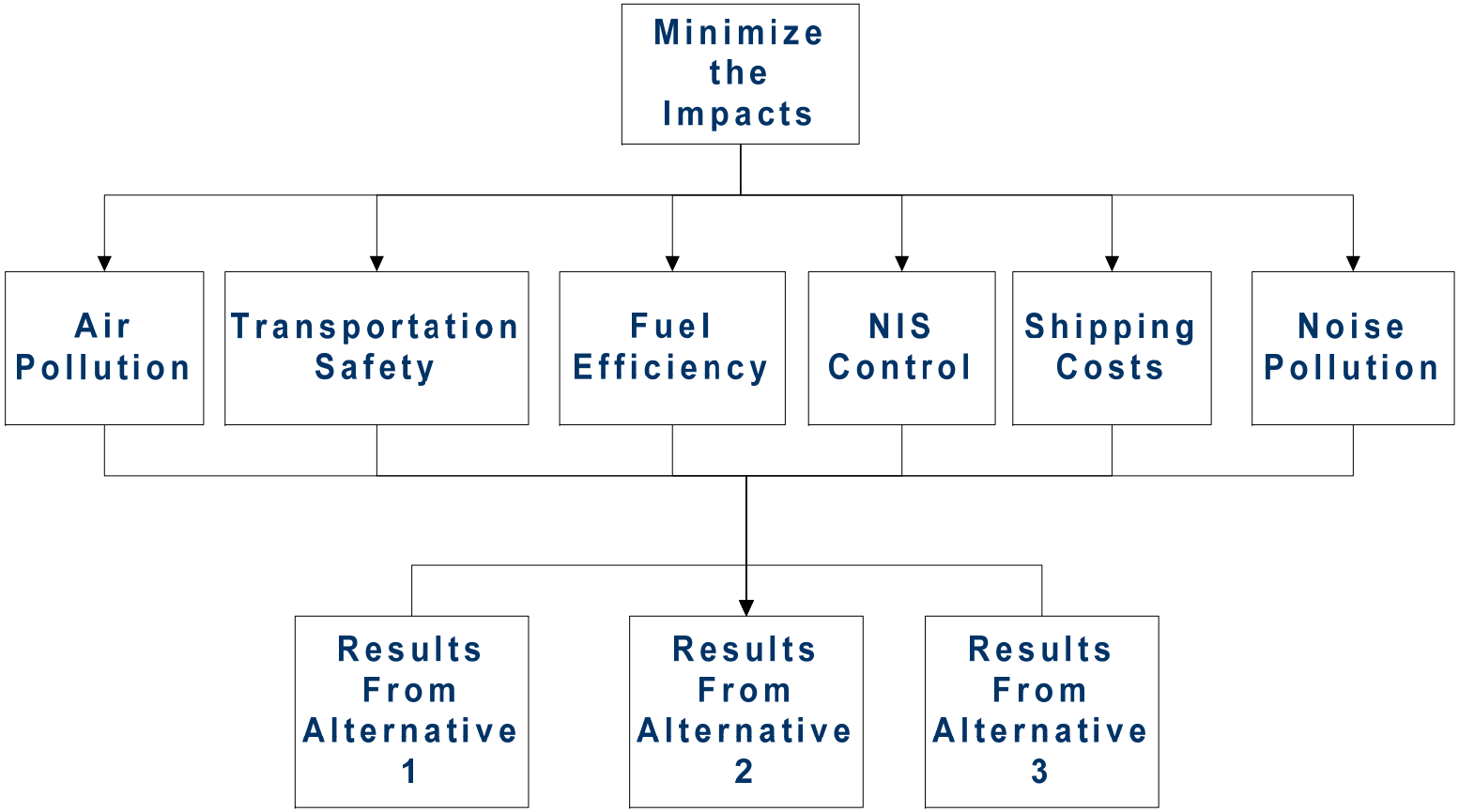
- A modal shift (from ship to rail) in the amount shipped (net tons) for each alternative is assumed:

A_1: 360,000 A_2: 480,000 A_3: 180,000

AHP-MADP Scenario, Contd.

- Six attributes are considered:
  - Transportation Safety
  - Air Pollution
  - Fuel Consumption
  - Shipping Costs
  - NIS control
  - Noise Pollution

Model of the MADP Problem



Results of AHP-MADP Modeling

Vector of Six Attribute Evaluation Matrices

	Safety	Air Pollution	Fuel Consumption	Shipping Costs	NIS Control	Noise Pollution
A1	0.28	0.31	0.28	0.26	0.35	0.32
A2	0.22	0.31	0.21	0.46	0.35	0.26
A3	0.5	0.38	0.5	0.28	0.29	0.42

Results of AHP-MADP Modeling

- Using the six attribute evaluation matrices, we calculate the decision vector V :

$$V = < 0.31, 0.29, 0.39 >$$

- The three values of V represent the relative priority of alternatives A_1, A_2, and A_3 respectively.

- The third alternative, A_3, has the maximum priority (0.39), and therefore is the most desirable alternative.

Modeling Decision Makers' Preferences Using Utility Theory

- Single attribute utility function
- Mutual utility independence
- Scaling constants
- Multiplicative or additive model
- Multi-attribute utility function
- Evaluation of alternatives using multi-attribute utility function
- Design of questionnaire to evaluate preferences

Comparison of the Four Approaches for MADP Modeling

Approach	Decision Vector	Best Alternative
AHP method	(0.31, 0.29, 0.39)	A_3
Fuzzy set model using interaction approach	(0.329, 0.293, 0.366)	A_3
Fuzzy set model using max-min approach	(0.722, 0.722, 0.681)*	A_1
Multi-attribute utility theory	(0.2761, 0.2543, 0.3038)	A_3

* The second minimum of A_1 is greater than that of A_2.

AHP-MADP Results

- The results from these methods indicate that the most favorable alternative for the Great Lakes economy and ecosystem is the one that produces the least cargo shifted.

Prediction of Modal Shift Amounts

- The modal shifts are calculated using a Multinomial Logit Model (MNL).

- Two Scenarios are considered
  - Canadian Wheat
  - American Wheat

Assumptions of the MNL Model

- The increase of actual marine freight rates will be the same as the increase of required marine freight rates (costs).

- Demand will not change in the case of small fluctuation of freight rates.

Canadian Wheat Scenario

- From Winnipeg, Manitoba to Rotterdam, Holland
  - Alternative 1: Train (Thunder Bay) – Lakers (Montreal) – Oceangoing Ships (Rotterdam)
  - Alternative 2: Train (Thunder Bay) – Oceangoing Ships (Rotterdam)
  - Alternative 3: Train (Montreal) – Oceangoing Ships (Rotterdam)

MNL Prediction of Canadian Wheat Modal Shifts

- Three Treatment Options:
  - Ballast Water Exchange (BWE)
  - Filtration/UV (F/UV)
  - Heat (H)

Predicted Modal Shifts in Canadian Wheat Scenario

Modal Shifts Due to Three Treatment Methods For Alternative 3

(Unit: tons)

	BWE	F/UV	H
Modal Shifts	**440** **0.06%**	**7,964** **1.04%**	**1,042** **0.14%**

American Wheat Scenario

- From Bottineau, North Dakota to Rotterdam, Holland
  - Alternative 1: Train (Duluth, MN) – Lakers (Montreal, QC) – Oceangoing Ships (Rotterdam)
  - Alternative 2: Train (Duluth, MN) – Oceangoing Ships (Rotterdam)
  - Alternative 3: Train (Montreal, QC) – Oceangoing Ships (Rotterdam)

American Wheat Scenario

- Two Treatment Options:
  - ❑Filtration / UV
  - ❑Chemical

Predicted Modal Shifts in American Wheat Scenario

Modal Shifts Due to Two Treatment Methods For Alternative 3

(Unit: tons)

	Chemical	F/UV
Modal shifts	**9,361** **1.96%**	**254** **0.05%**

Prediction of Decrease in Demand

- For a significant increase in freight rates, a decrease in demand may occur.
- Modified Multinomial logit model is needed to reflect the decrease in demand for transportation.

Sensitivity to Ballast Water Treatment Costs and Freight Rates

- Cases used for sensitivity analysis
  - Ballast treatment costs
  - Marine freight rates
  - Rail freight rates

Results of Modal Shift Amount and Sensitivity Analysis

- Small Amounts Shifted (less than 1%)
- In the grain market, the economic impact will not be significant.
- Output values are not very sensitive to the input values.

Extreme Cases

1. Zero ships entering Great Lakes ports from overseas, due to very high ballast water treatment costs, or

2. Zero modal shifts due to low treatment costs and low standards.

Extreme Cases, Contd.

- A ban on ships entering GL ports from overseas may produce significant modal shifts and decreases in demand, resulting in higher rates of:
  - Transportation fatalities and injuries
  - Fuel consumption
  - Air pollution
  - Shipping costs
  - Noise pollution
- Lower ballast water treatment requirements and standards would damage the GL ecosystem, and further NIS introduction would have a significant economic impact.

Conclusions

- Currently, no ballast water treatment is 100% effective. Ballast water exchange, filtration/UV, and heat are the most attractive options.
- Modal shifts would happen if the ballast water treatment methods are mandated without financial incentives.
- These amounts will most likely be quite small though (less than 1%)
- Sensitivity analysis indicates that the outputs of the models are not very sensitive to their inputs. The predicted shift amount is always very small compared to the total amount.
- It is advisable to apply mandatory ballast water treatment requirements for the ships entering the Great Lakes from overseas.

Future Work

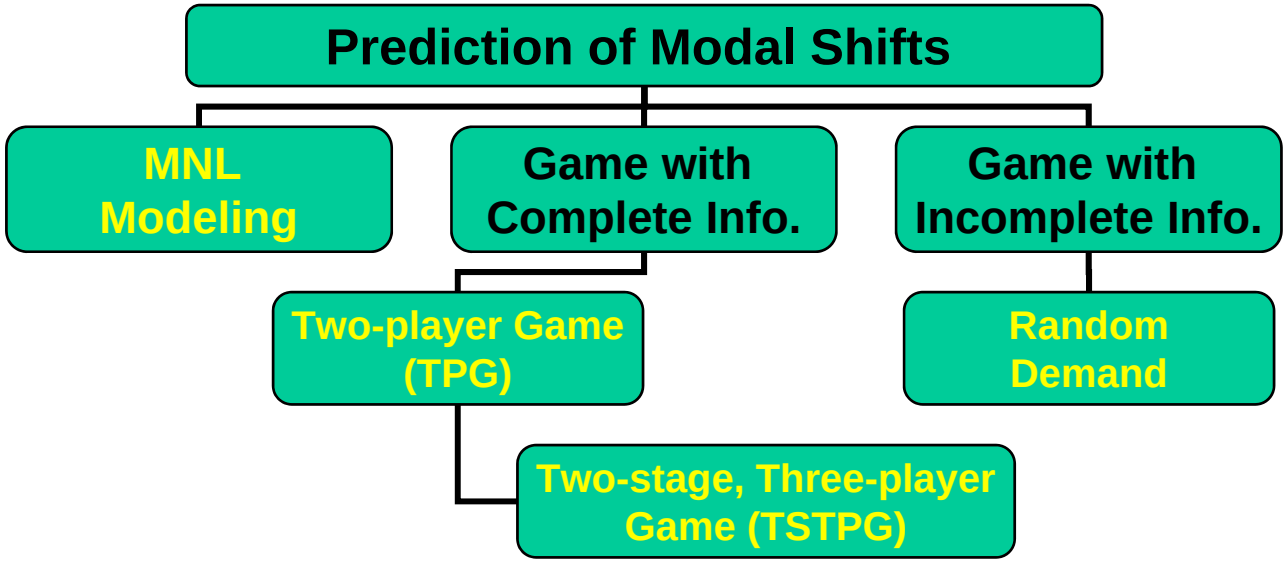
- Investigating modal shifts involving other cargoes (iron ore, coal).
- Developing a model studying the change of supply location.
- Far more accurate modeling of the multi-attribute decision problem can be achieved using game theory techniques.

Advantages of Game Theory

- **In real life, there are several different decision makers (DM):**
  - **Cargo owners**
  - **Rail companies**
  - **Marine shipping companies**
  - **Legislators!**
- **Our previous MNL models do not allow for these DMs to make non-cooperative decisions**
- **Game theory allows us to realistically model several different DMs and their interactions**

Proposed Game Theoretic Models

- Two – player game (TPG)
- Two stage, three player game (TSTPG)



Using Game Theory to Estimate Demand Decrease

Canadian Wheat Scenario Modal Shifts Prediction

Using the Two-stage Three-Player Game Model

(Unit: Tons)

Alternatives	1 (BWE)	2 (F/UV)	3 (H)
Increase of Marine RFR ($ per ton cargo)	0.0053	0.0964	0.0126
Decrease of Total Demand	1,200	8,500	4,000
Modal Shifts to Rail	3,700	4,300	2,700

Comparison of the Three Models

Predicted Modal Shift From the Marine to Rail

(Unit: Tons)

Alternative	1 (BWE)	2 (F/UV)	3 (H)
MNL	440 0.015 %	7,964 0.27%	1,042 0.035%
TPG	200 0.007%	3,800 0.127%	500 0.017%
TSTPG	3,700 0.123%	4,300 0.143%	2,700 0.090%

Further Research

- Two–stage N–player Game
- Infinite Repeated Game
- More Scenarios

Acknowledgements

Thanks to the National and Michigan Sea Grant Program for funding the research project

"Aquatic Nuisance Species Research and Outreach: Economic Impact of Measures to Limit the Introduction of Non-Indigenous Species on St. Lawrence Seaway Shipping," National and Michigan Sea Grant Programs, $312,000, October 1, 1999-September 30, 2001.

Thanks to our Subcontractor (Great Lakes Commission, Dr Donahue, Steve Thorp)

And to the LCA (Glenn Nekvasil, Rick Harkins) for volunteering helpful info during the project.

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and the following two invited talks (PPTS)

A.N. Perakis, "Evaluation of the Economic Impact of Proposed Measures for Non-indigenous Species Control on St. Lawrence Seaway", Presentation at the Great Lakes and Great Rivers Section, The Society of Naval Architects and Marine Engineers, October 15, 2004.

A.N. Perakis, "Economic Impact of Measures to Limit the Introduction of Non-indigenous Species on St. Lawrence Seaway Shipping", Presented to the Committee on the St. Lawrence Seaway," Invited and presented at the NAS workshop "Options to Eliminate Introductions of NIS into the Great Lakes", The National Academies, Transportation Research Board/ Water Science and Technology Board, Washington, D.C., June 22, 2004.