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## Estimation of Performance Indices for the Planning of Sustainable Transportation Systems

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# **Estimation of Performance Indices for the Planning of Sustainable Transportation Systems**

presented by

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# Introduction

- **What is sustainable transportation system?**
  - ✓ *Fulfill the needs of current generations without compromising the ability of future generations*
  - ✓ *Utilize resources without compromising their health and productivity*
  - ✓ *Leads to development that improves quality of life*
  - ✓ *Assimilate economic, ecological, social, and bio-physical components of resource ecosystems*
  - ✓ *Minimize the use of renewable and non-renewable resources, provide affordability and equity between generations*
- **No consensus is available**

# Literature Review

- ✓ Existing research is associated with the construction, operation, maintenance, and planning of transportation systems.
- ✓ The current planning of transportation systems is limited in terms of the number, accuracy, length, and the approaches used.
- ✓ Fuel consumption, vehicle emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future.
- ✓ **Transportation Level**
  - *Doesn't explicitly includes sustainability considerations*
  - *Multiple performance measures are required*
  - *Composite sustainability index is required*

# Motivation

## Existing Analysis Techniques for considering Multiple Performance Measures

### Multi-criteria Decision Making

- ✓ *Relative importance (weights) of the indicator or criteria*
- ✓ *Aggregation method (linearly weighted)*

### Drawbacks

- ✓ *Expert advise, surveys are done to compute the weights (time consuming)*
- ✓ *Vary from one geographical and spatial location to another*

### Global Level

- ✓ *Multiple interdependent systems are considered*
- ✓ *Combine performance measures using soft technologies such as fuzzy logic*
- ✓ *Dynamic mathematical ecology (predator-prey) techniques*

# Methodology

- Proposed Definitions of Sustainability
- Interdependent Systems
- Performance Indices (PI's)
- Composite Sustainability Index

# Proposed Definition of Sustainability

Sustainability is achieved when the Transportation system, Activity system and Environmental system have all reached minimum and stable levels of quality so that they can continue operating in perpetuity at less than these levels.

# Interdependent Systems

- **Transportation System:** Transportation system is defined as a system that includes all the infrastructure facilities, vehicles, operators, and control strategies used to provide transportation services to people and move products.
- **Activity System:** Activity system is defined as a system which constitutes social, cultural, health-related, and economic/financial aspects that are inherent in our society.
- **Environmental System:** Environmental system is defined as the system that includes the air, water, soil, and all other natural resources as well as all living organisms that are affected and/or used by the transportation and activity systems.



# Performance Indices

## Transportation System

- ✓ Vehicle Miles Travel per Lane Mile (VMT/Lane Mile)
- ✓ Transportation Service Index (TSI)
- ✓ Personal Spending on Transportation

## Activity System

- ✓ Income (GNI/Capita)
- ✓ Education
- ✓ Life Expectancy

## Environmental System

- ✓ Greenhouse Gases (CO<sub>2</sub>)
- ✓ Air Pollutants (CO, NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>, VOC)
- ✓ Water Pollutants (BOD)
- ✓ Energy Consumption

# Implementation Procedure

- Performance Measures
- Performance Indices
- Composite Sustainability Index

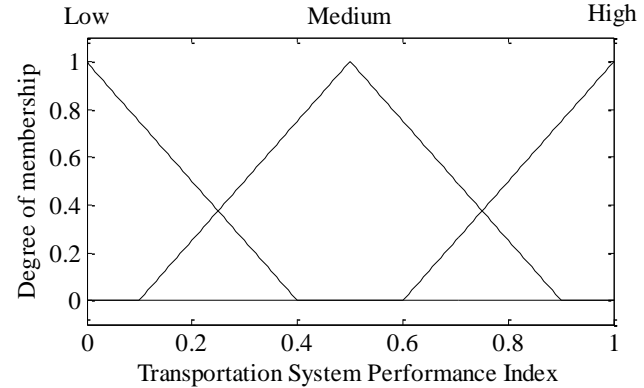
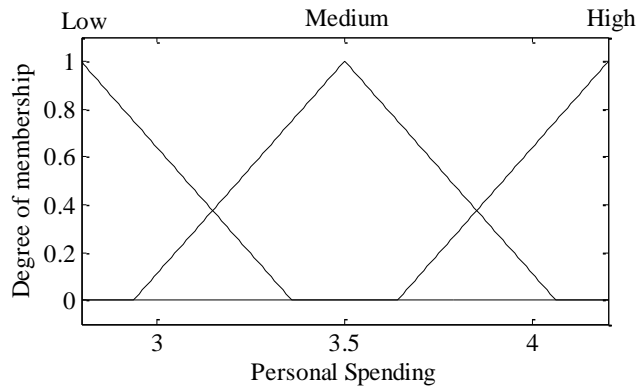
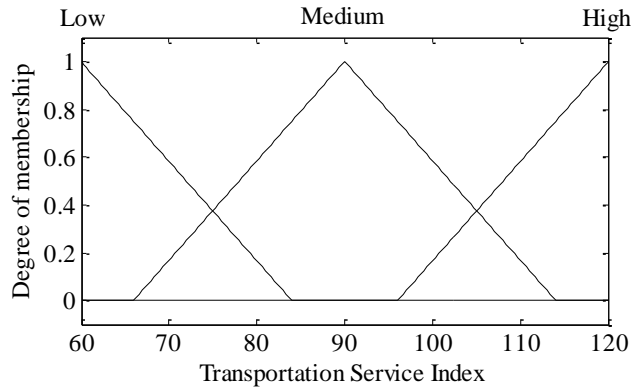
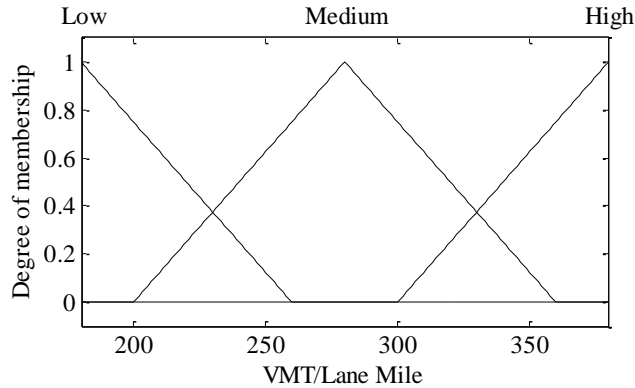
# Fuzzy Logic

- ✓ Combines different data sets with different type of information
- ✓ When linguistic variables are used, the degrees may be managed by specific functions

## **Advantages**

- ✓ *Built on the structures of qualitative description used in everyday language*
- ✓ *Method to define the vague or ambiguous nature of fuzzy set*
- ✓ *Easy to understand, flexible, and intuitive approach*
- ✓ *Based on experience of the people who understands the system*
- ✓ *Easily address certain data set issues: missing values, overlap of common information, complex and nonlinear interdependencies*

# Membership Function for *TSPI*



LHS  
(*if* part)  
antecedent

RHS (*then* part)  
consequent

# If-then Rules for *TSPI*

Rules		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
LHS	<i>v</i>	L	x	x	x	x	x	x	x	x																			
		M										x	x	x	x	x	x	x	x	x									
		H																			x	x	x	x	x	x	x	x	x
	<i>TSI</i>	L	x	x	x							x	x	x							x	x	x						
		M				x	x	x							x	x	x							x	x	x			
		H							x	x	x							x	x	x							x	x	x
	<i>ps</i>	L	x			x			x			x			x			x			x			x			x		
		M		x			x			x			x			x			x			x		x		x		x	
		H			x			x			x			x			x			x			x			x			x
	RHS	<i>TSPI</i>	L	L	L	L	L	L	M	M	M	L	L	L	M	M	M	M	H	H	M	M	M	H	H	H	H	H	H

IF [VMT/lane mile (*v*) is High, *TSI* is Low and Personal Spending (*ps*) is Low]

THEN [Transportation System Performance Index (*TSPI*) is Medium]

# Modeling Approach

*Mamdani max-min composition operator*

$$\delta^\alpha = \max_{z \in Z} \min(\mu_v^\alpha(z), \mu_{TSI}^\alpha(z), \mu_{ps}^\alpha(z))$$

*Mamdani min implication operator*

$$\mu_{TSPI^{\alpha^*}} = \min(\delta^\alpha, \mu_{TSPI^\alpha})$$

*Aggregation*

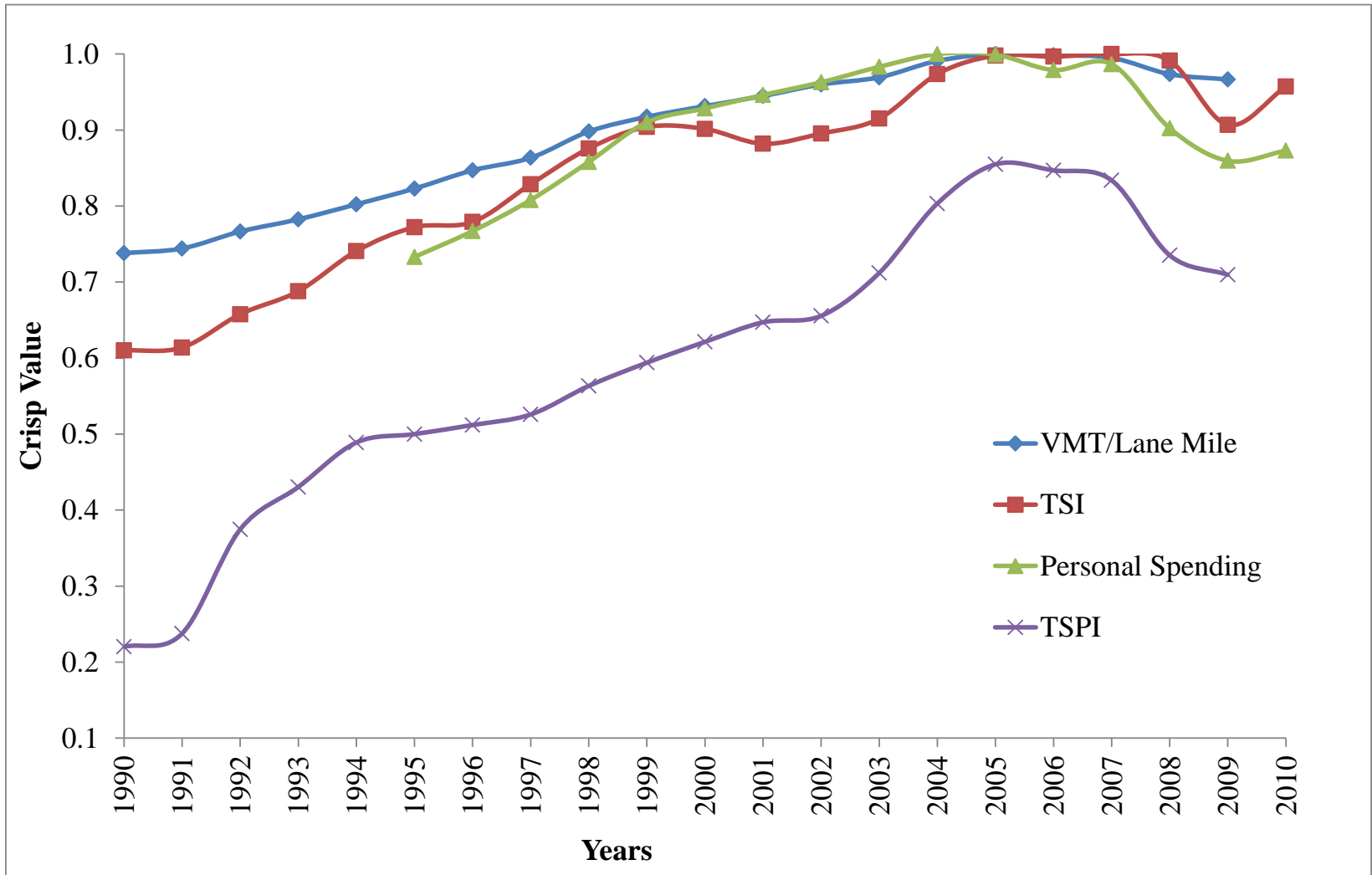
$$\mu_{TSPI^*} = \sum_{\alpha=1}^R \mu_{TSPI^{\alpha^*}}$$

*Defuzzification*

$$TSPI = \frac{\sum_{\alpha=1}^R \bar{\theta}^\alpha \cdot S(\mu_{TSPI^{\alpha^*}})}{\sum_{\alpha=1}^R S(\mu_{TSPI^{\alpha^*}})}$$

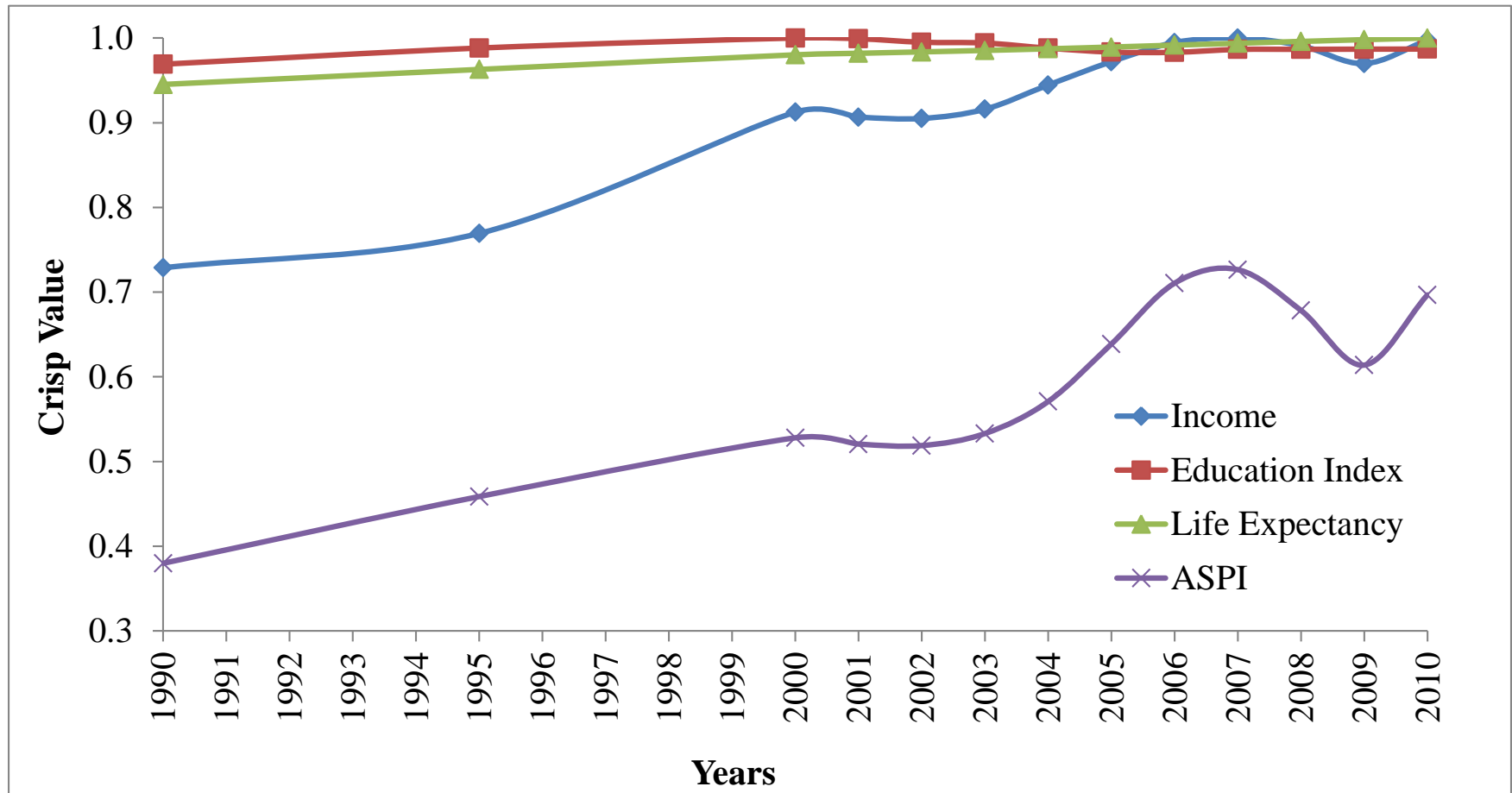
# Analysis and Results

## Normalized performance measures and Transportation System Performance Index (TSPI)



# Analysis and Results-contd.

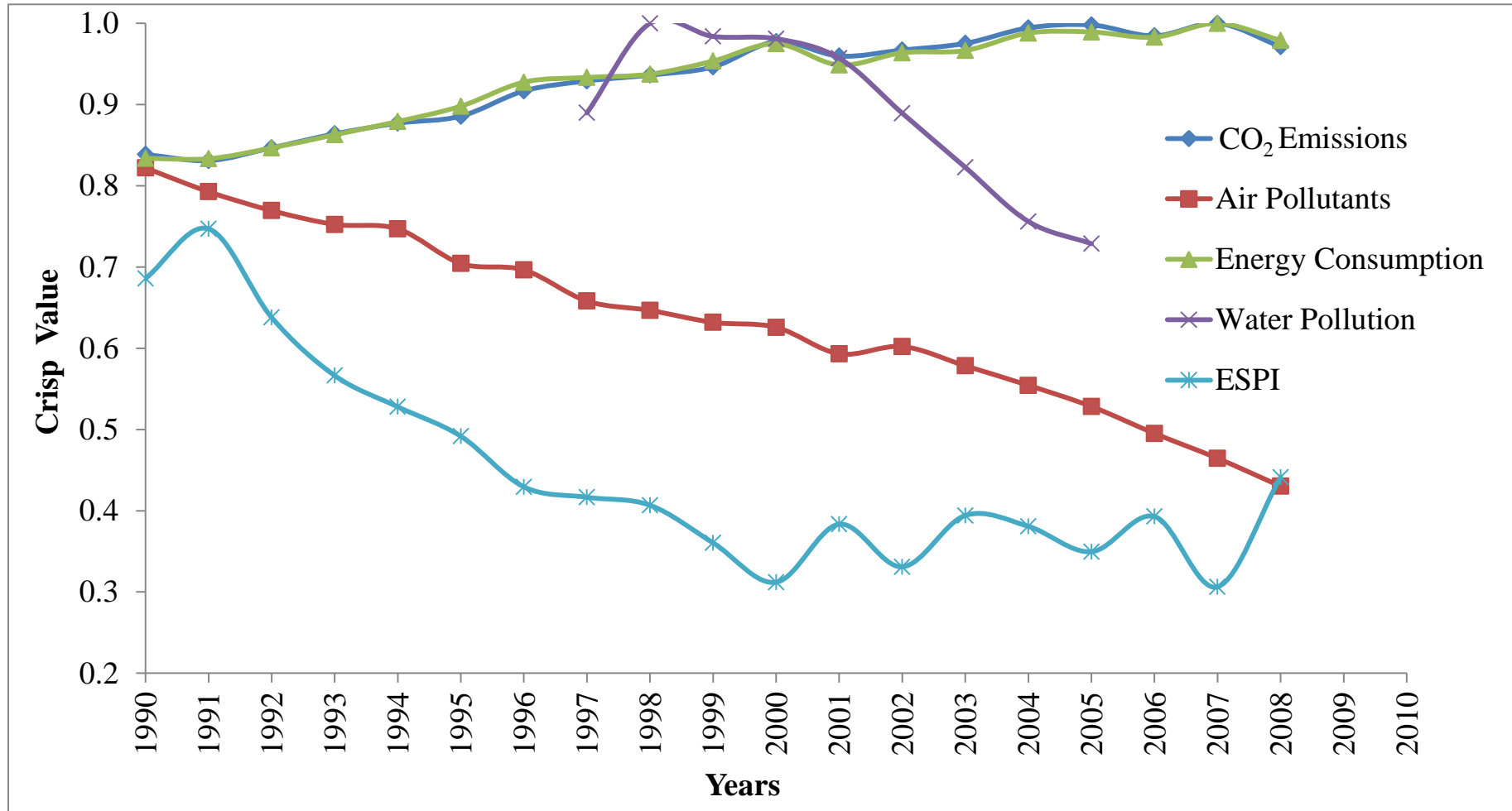
## Normalized performance measures and Activity System Performance Index (ASPI)





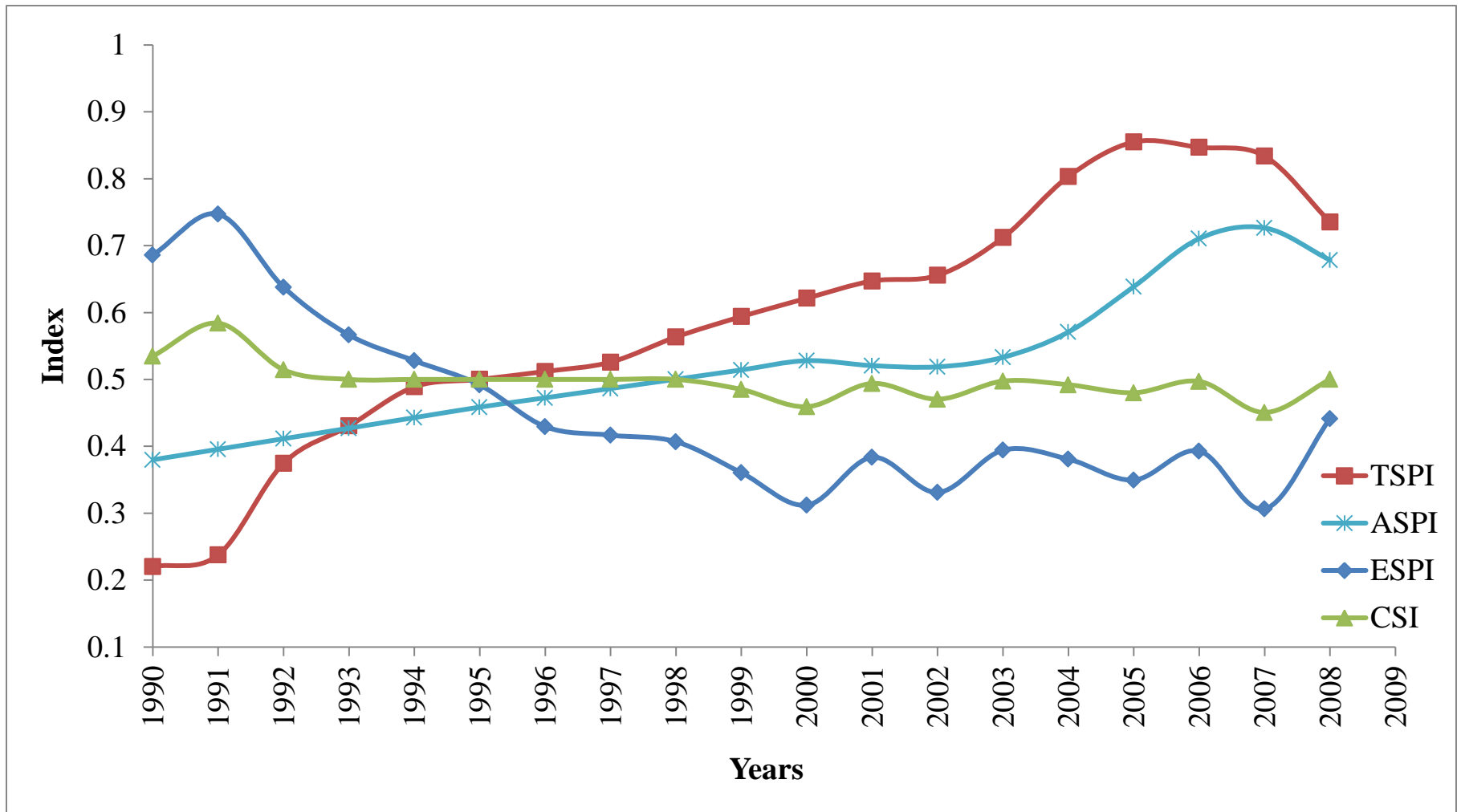
# Analysis and Results-contd.

## Normalized performance measures and Environmental System Performance Index (ESPI)



# Analysis and Results-contd.

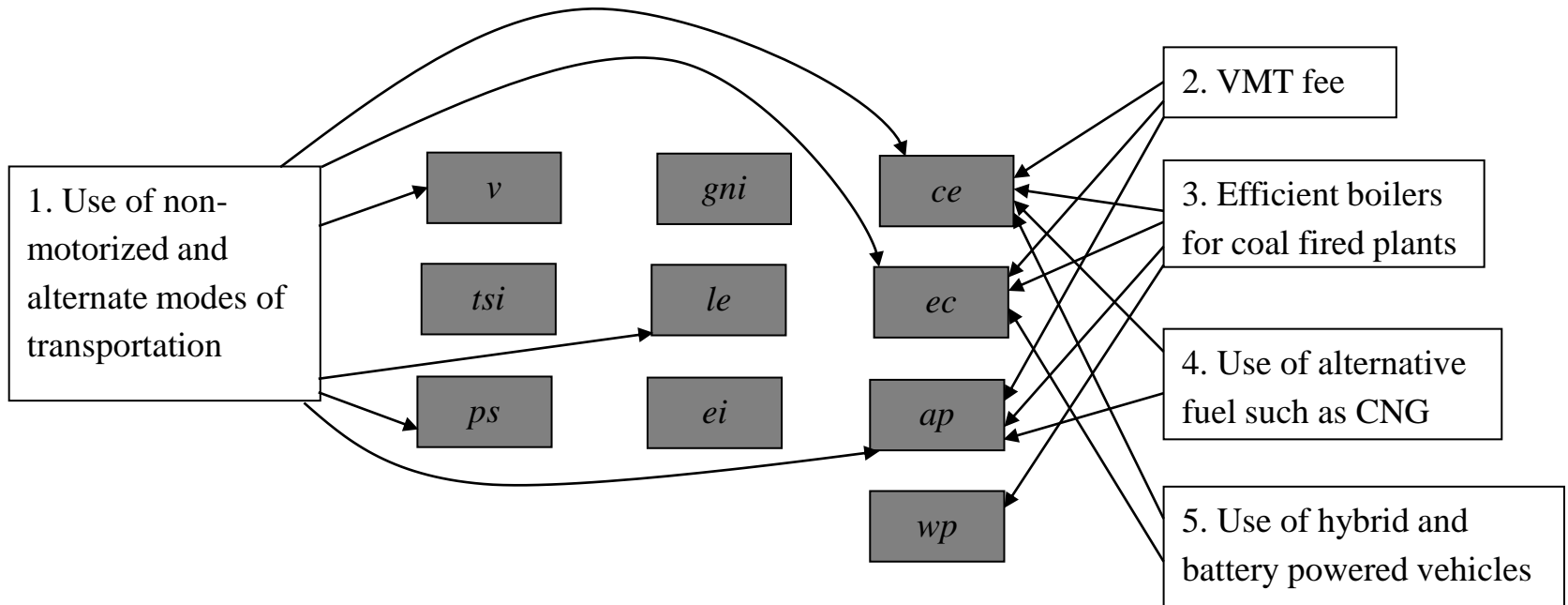
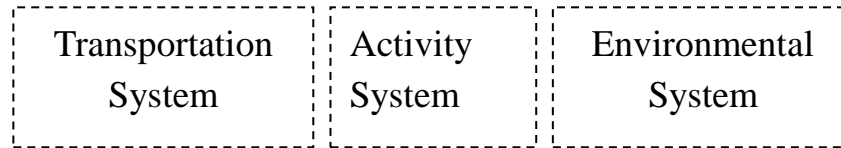
## Composite Sustainability Index (CSI)



# Axioms of Sustainability

- The system of systems is sustainable when the overall slopes for the *TSPI*, *ASPI* and *ESPI* have a positive trend
- The system of systems is unsustainable when the slopes of *TSPI* and *ASPI* have a positive trend but the slope of *ESPI* has a negative trend
- The system of systems is sustainable when the overall slopes for the *TSPI*, *ASPI* and *ESPI* have a nonnegative trend

# Policy Options



# Conclusions and Recommendations

- This study computes performance indices for a system of systems including the Transportation, Activity, and Environmental systems
- Additional performance measures can be incorporated based on spatial and demographic characteristics
- The framework used in this study is currently being extended to enable the analysis of regional systems
- A simulation-based framework is being developed to estimate multiple performance measures required to estimate the desired performance indices
- Analyze the interactions between multiple systems using mathematical modeling (predator-prey techniques)

# Acknowledgements

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# Questions!!

