Urban Sustainability:
Indicators, Patterns and Systems Dynamics

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Overview

Sustainability Indicators

- Background
- Metrics

Pattern Identification

- Patterns in global road networks
- Patterns in cities

Integration of Metrics

Background

- Sustainable development paradigm is based on a comprehensive view of systems (Shields et al., 2002):
  - open
  - dynamic
  - Integrated
- Current practice of indicator selection is an *ad hoc* and piecemeal approach (Green and Champion, 1991)
- Reductionist approach cannot adequately analyze complex, multidisciplinary, global phenomena

Behavioral Characteristics of Complex Systems

- Counterintuitive
- Insensitive to parameter changes
- Policy-resistant
- Controllable through high-leverage points
- Long-run v. short-run response

Review of Indicator Frameworks

(after Olalla-Tarraga, 2006)

a. Issue-based
   - i.e., energy consumption, employment, etc
   - Does not match indicators with sustainability goals

b. Goal-based
   - Indicators for each sustainability goal
   - Does not capture complex interrelationships among various goals

c. Causal
   - Driving forces-Pressures-State-Impacts-Response (DPSIR)
   - tends to suggest linear cause-effect relations

d. Comparative
   - Common indicators to compare trends across geographic areas
   - Difficult to evaluate specific problems in particular locations

e. Ecosystemic
   - Role of ecological aspects to provide material and functional basis for human activity
   - Lack measures of livability, and focus only on metabolic flows

f. Combination

European Common Indicators

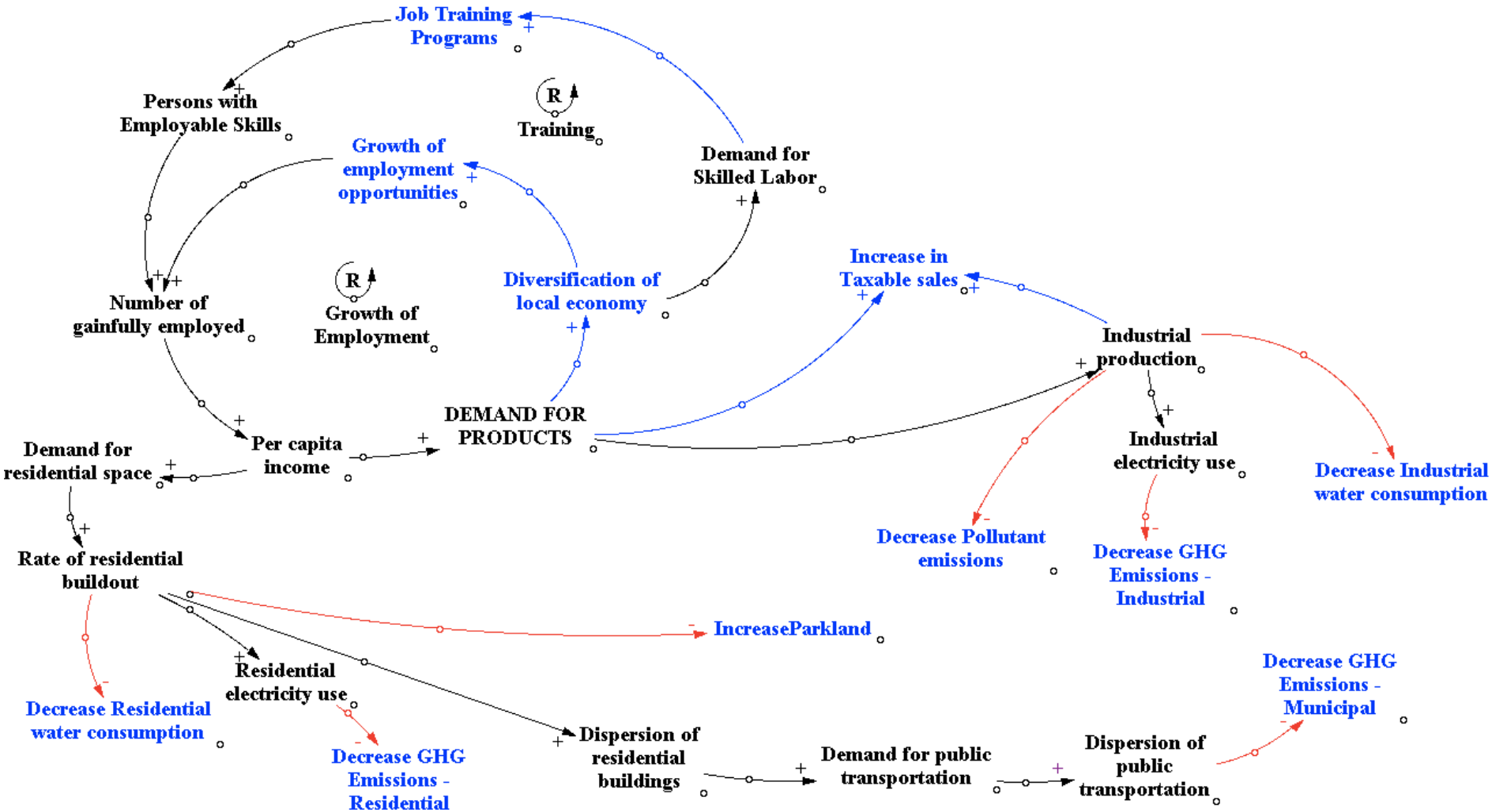
- Framework Type: Comparative
- 10 European Common Indicators
  1. Citizen satisfaction with the local community
  2. Local contribution to global climatic change
  3. Local mobility and passenger transportation
  4. Availability of local public open areas and services
  5. Quality of local ambient air
  6. Children's journeys to and from school
  7. Sustainable management of the local authority and local business
  8. Noise pollution
  9. Sustainable land use
  10. Products promoting sustainability

ICLEI Sustainability Indicators

- Combination: Issue-based, Goal-based
- Topic areas:

Air Quality
Biological Resources
Economy
Energy
Housing
Safety
Transportation
Water
Arts and Recreation
Civic and Political Involvement
Education
Health
Land
Sustainability Initiatives
Waste

ICLEI Indicator Relationships



Control Theory: gain of a feedback loop

- "Gain"
  - strength of the signal returned by the loop, e.g. a gain of 2 means a change in a variable is doubled each cycle

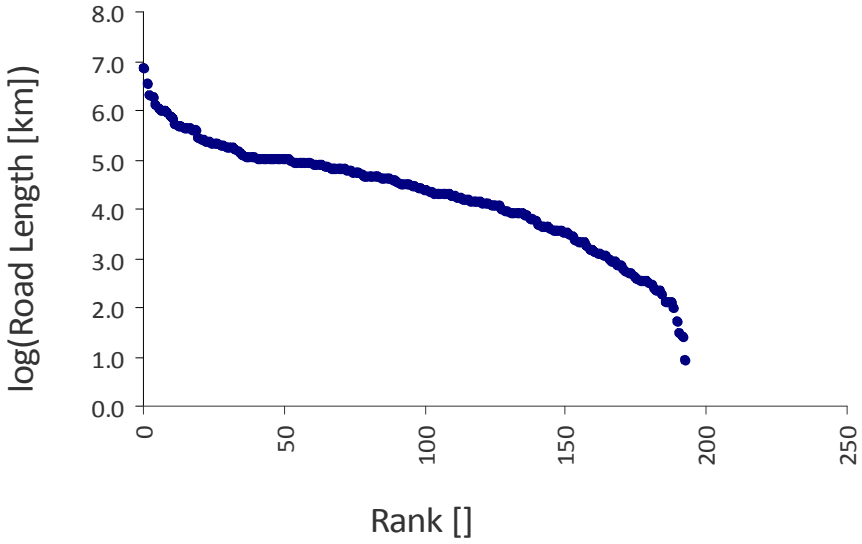
- Open loop gain
  - calculated for just one feedback cycle by breaking the loop at some point
  - partial derivative of x_1^O wrt x_1^I, i.e. the feedback effect of a small change in variable 1 as it returns to itself
  - $\delta x_1^O / \delta x_1^I = (\delta x_1^O / \delta x_n)(\delta x_n / \delta x_{n-1})(\delta x_{n-1} / \delta x_{n-2}) \ldots (\delta x_2 / \delta x_1^I)$

- Furthermore, sign of each partial derivative is the polarity of each "arrow"

Patterns in Global Road Networks

Patterns in Global Road Networks

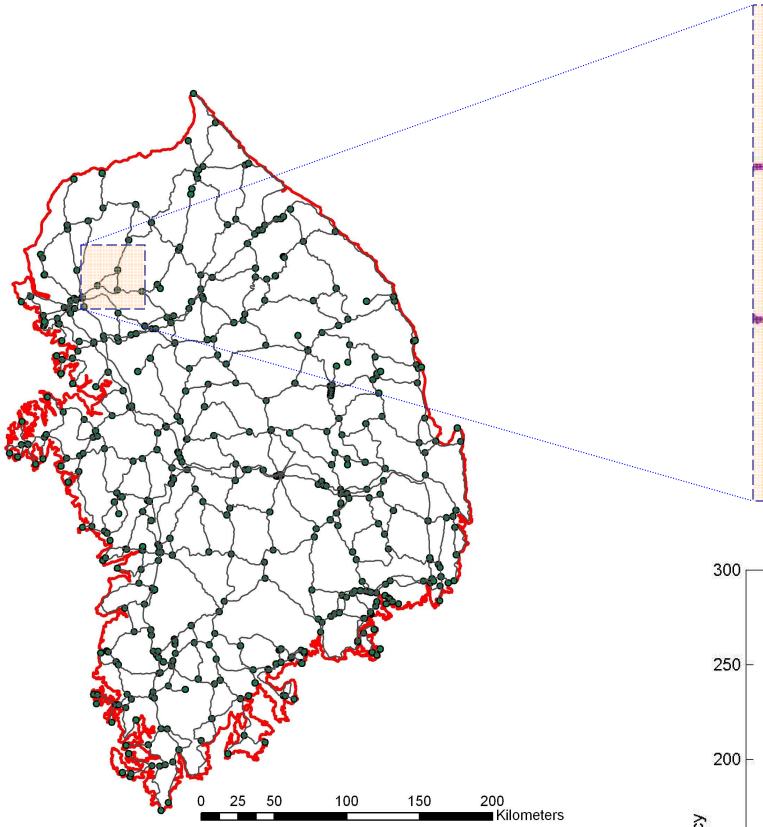
- Approach:
  - Road networks for 54 countries examined
  - Correlations between networks' properties with Gross Domestic Product (GPD), Human Developmen Index (HDI) and resource consumption



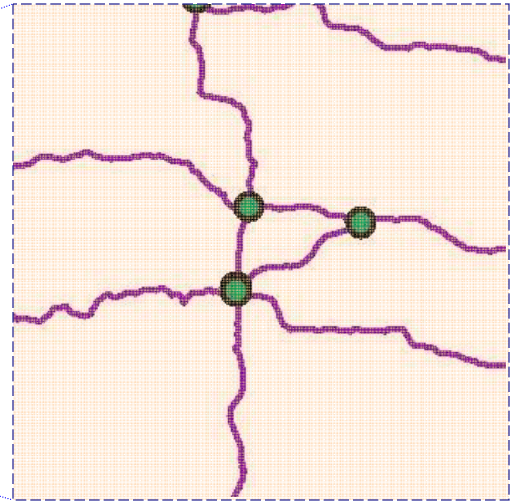
Sources:

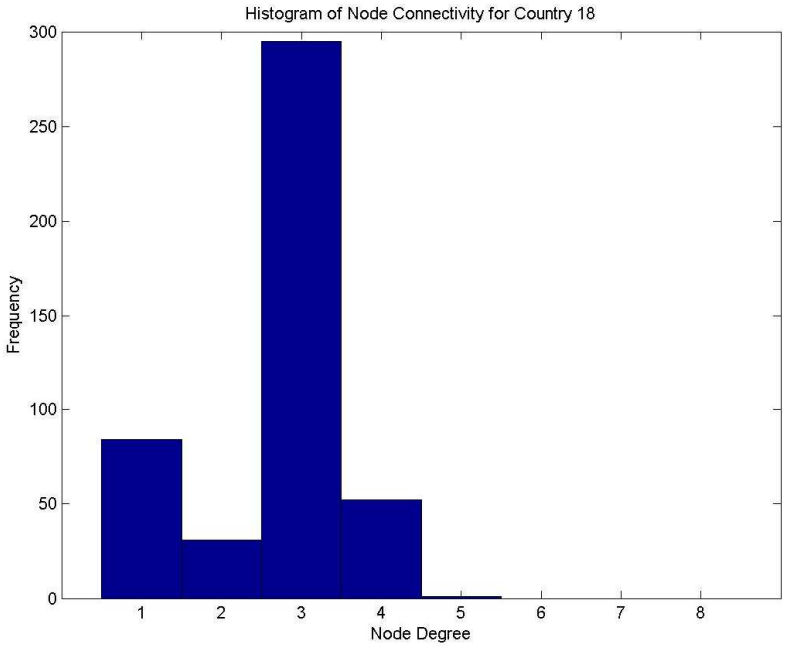
US Census
UN Development Programme
CIA World Factbook
Vector Map (VMap)

Patterns in Global Road Networks

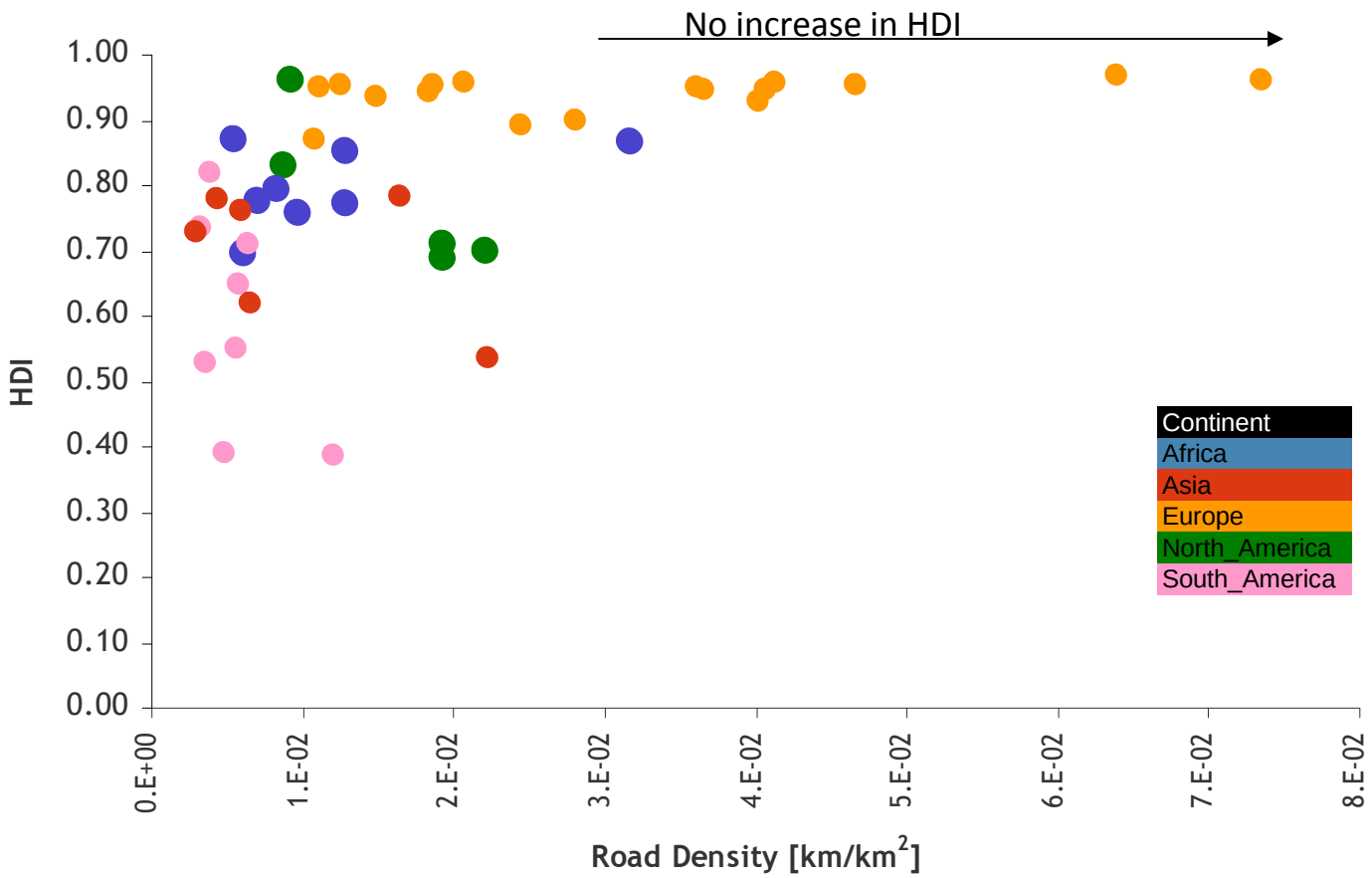


South Korea

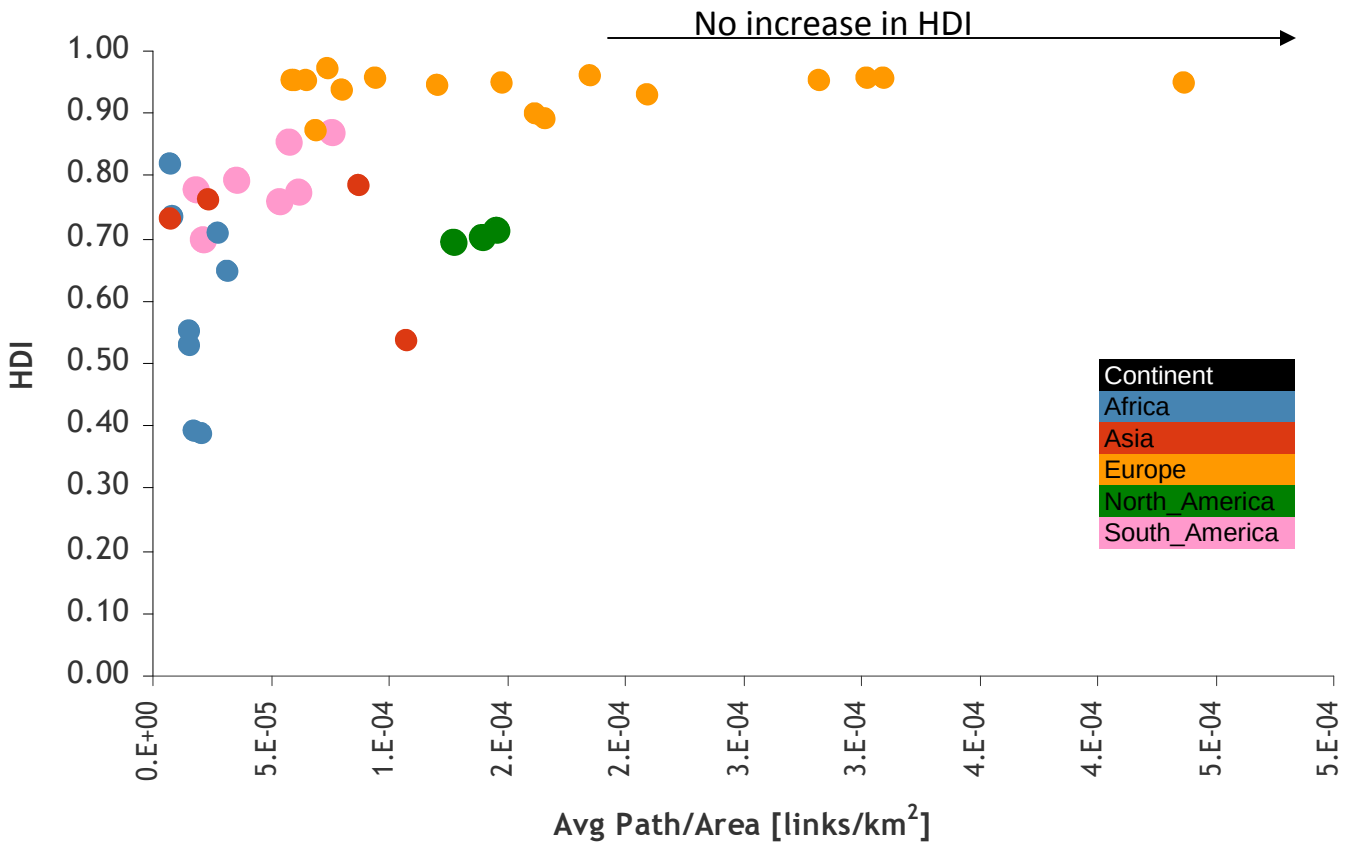




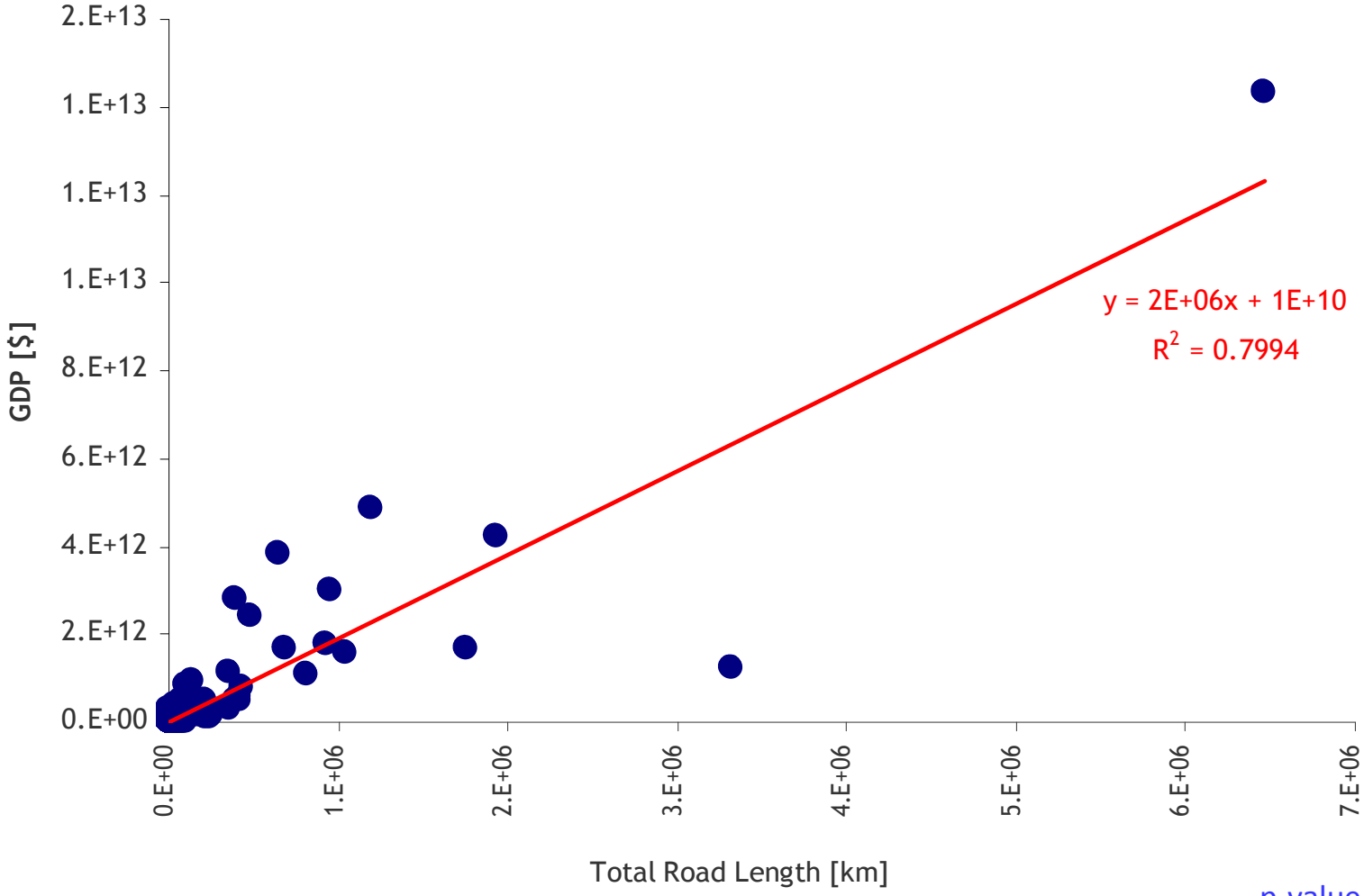
Patterns in Global Road Networks



Patterns in Global Road Networks



Patterns in Global Road Networks



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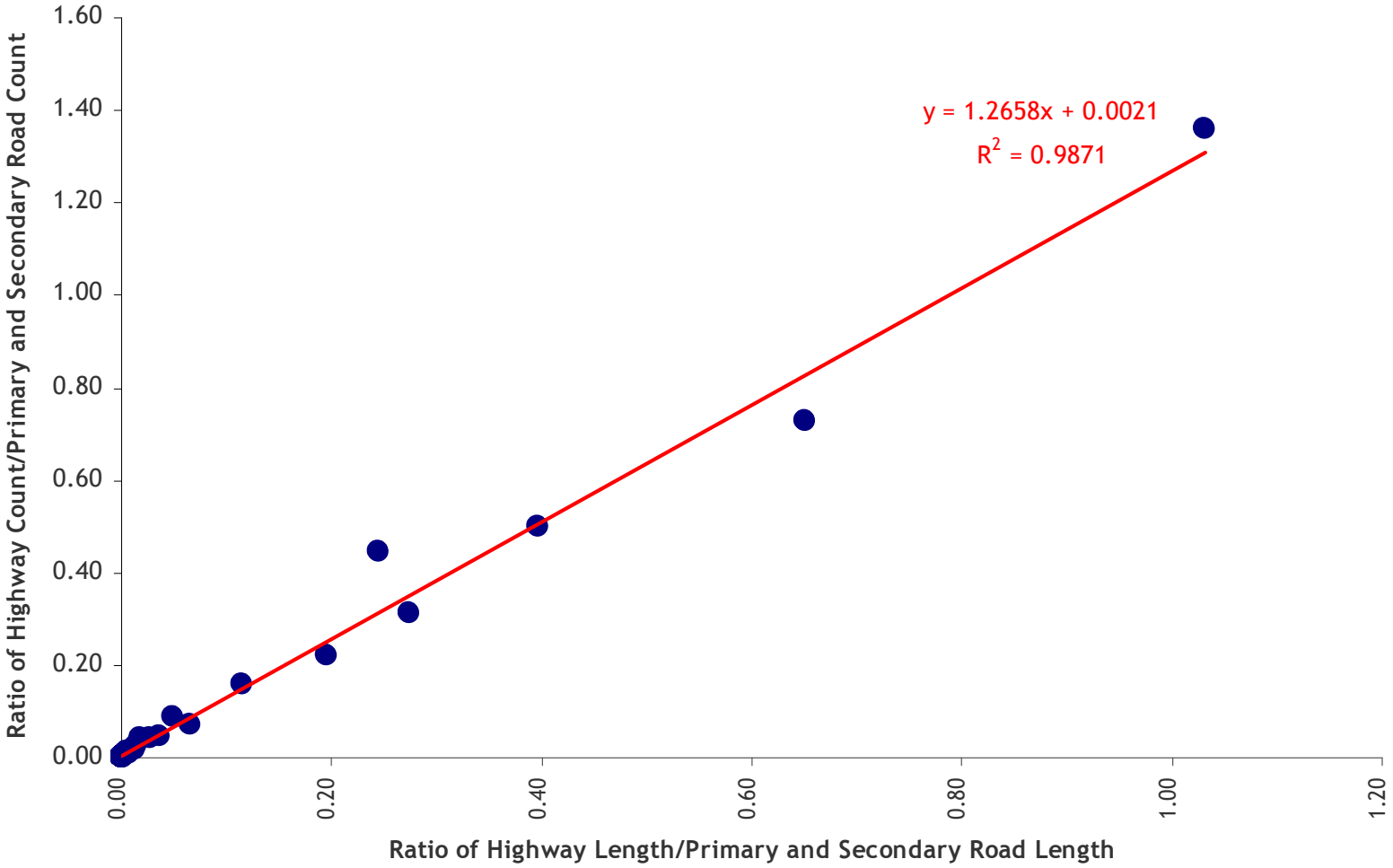
t-value = 28.3021

Patterns in Global Road Networks



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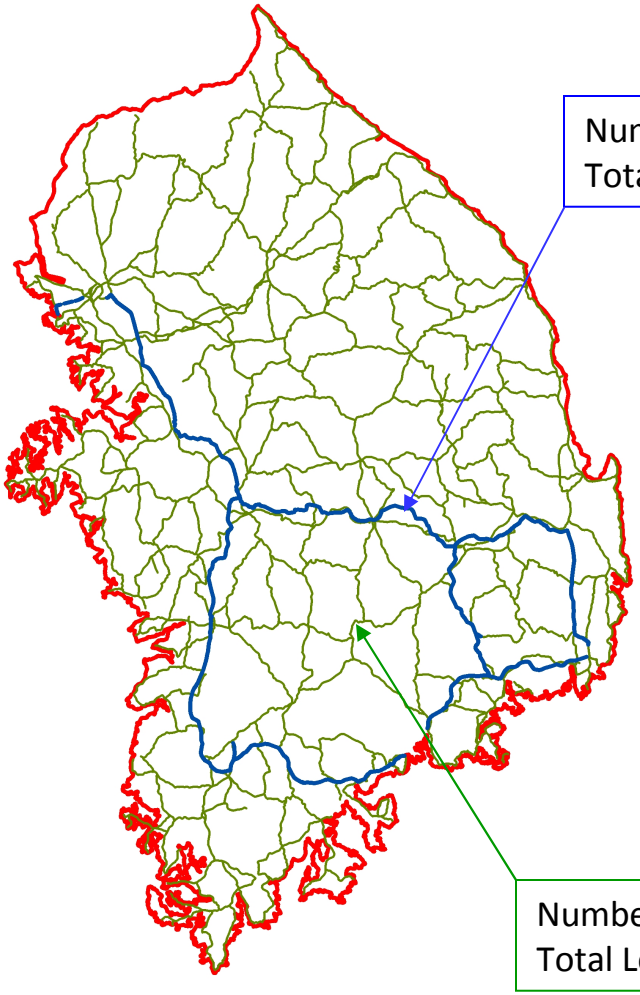
Patterns in Global Road Networks

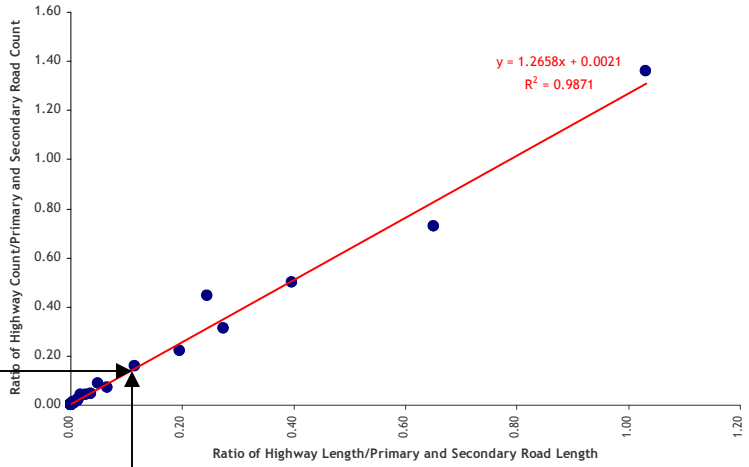


Number of Highways = 133
Total Length = 897.5 km

Number of Roads = 1204
Total Length = 8753.6 km

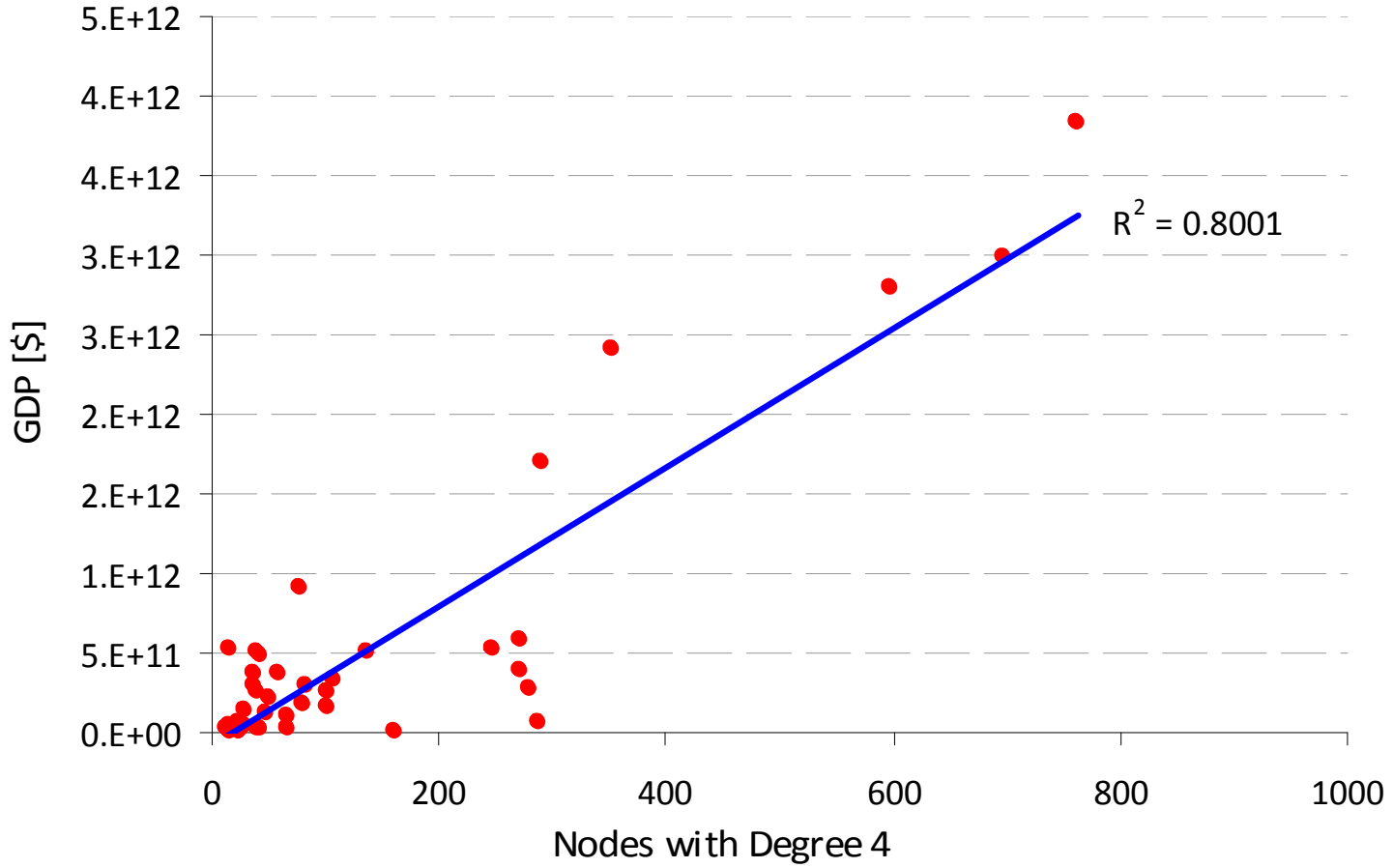
South Korea

133 / 1204



897.5 / 8753.6

Patterns in Global Road Networks



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Patterns in Global Road Networks

Occur globally across many scales

Correlations with resource consumption metrics

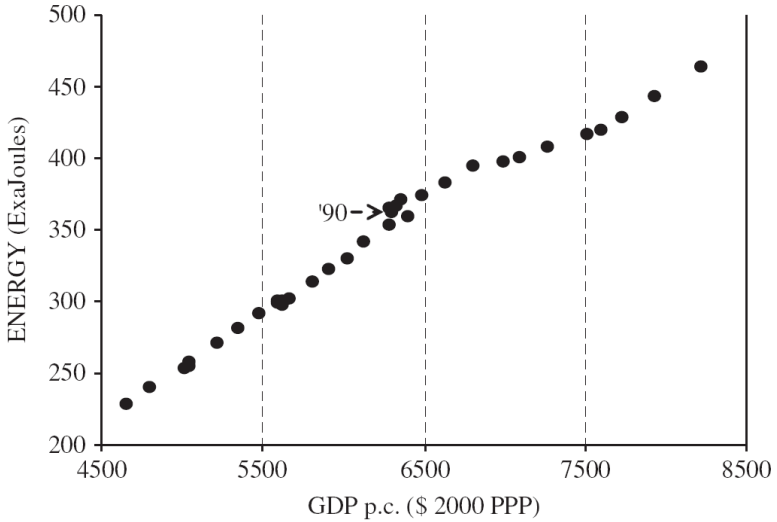
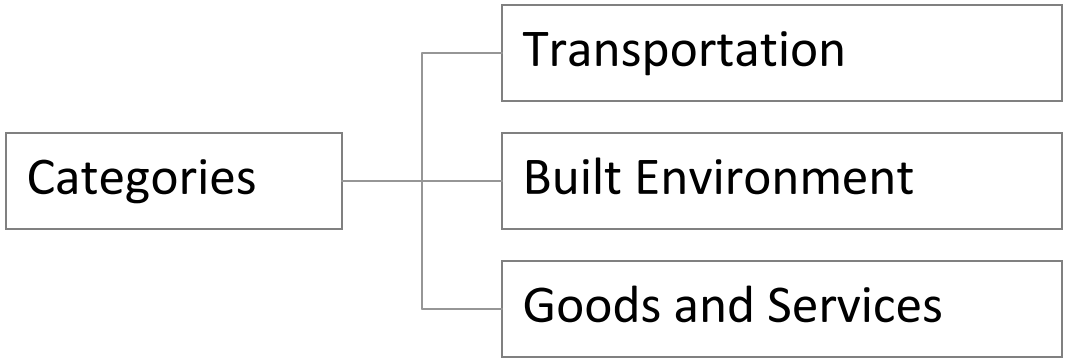


Figure from Luzzati, 2009

Patterns from Cities

Goal: to identify emergent patterns within cities

to understand the causal mechanism of the behavior



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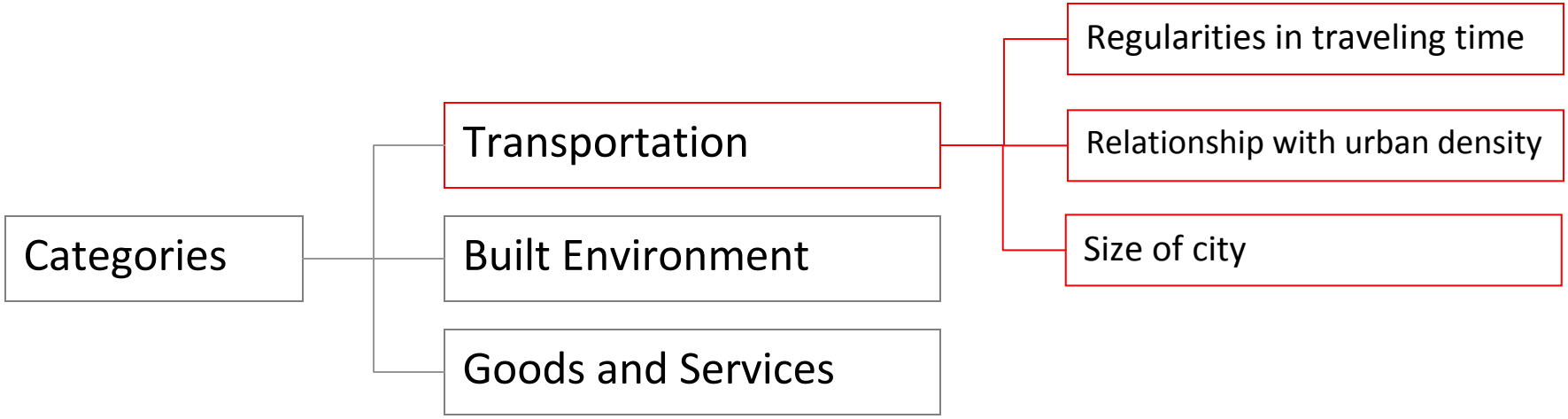
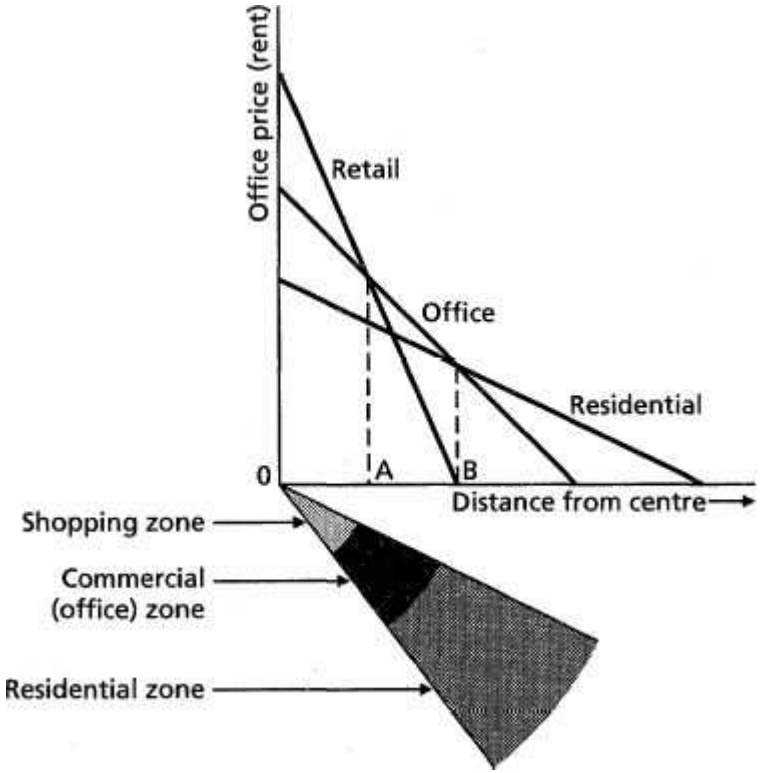


Patterns from Cities



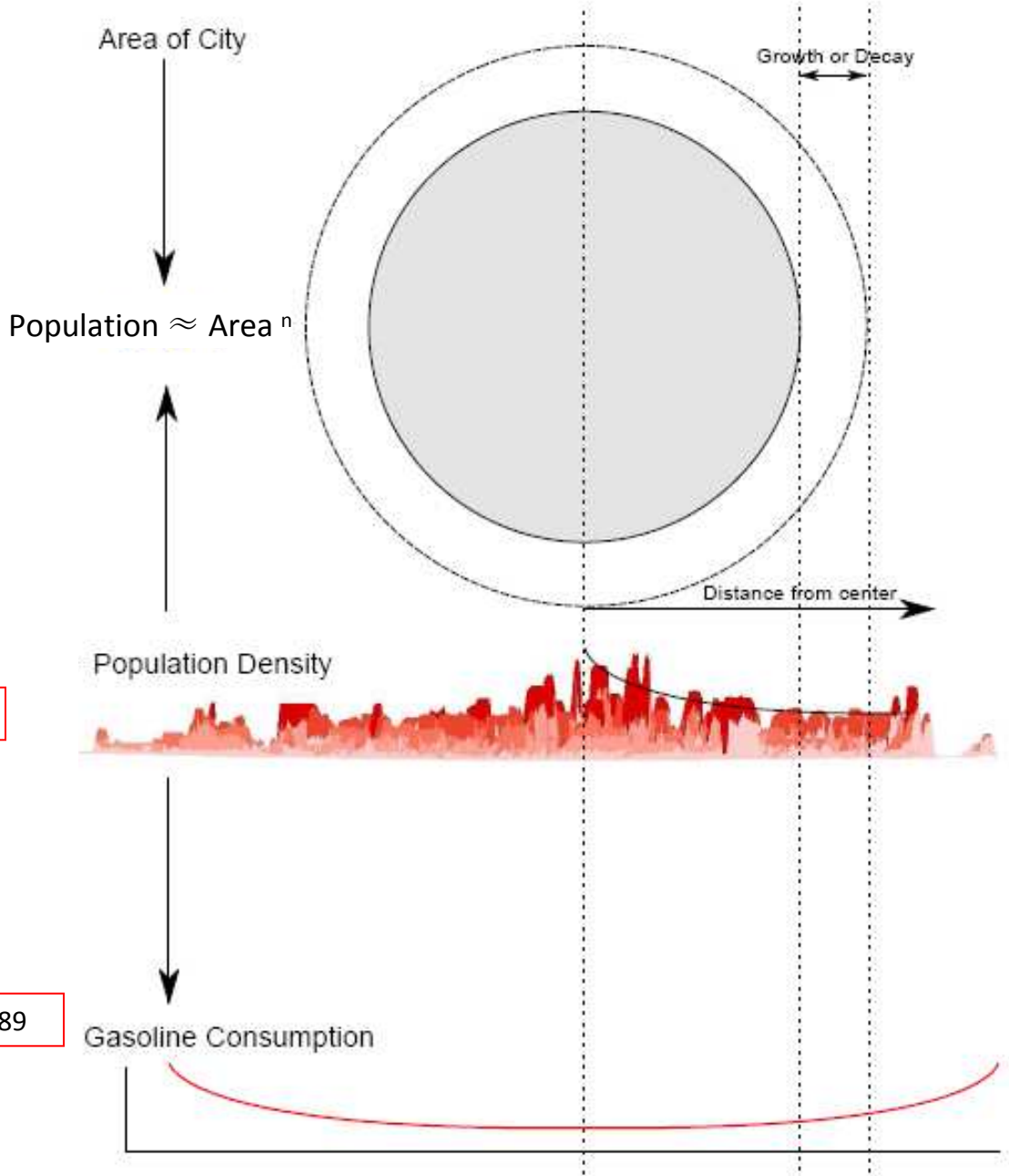
Source: http://content.answers.com/main/content/img/oxford/Oxford_Geography/0198606737.bid-rent-theory.1.jpg

Urban Economics and Consumption

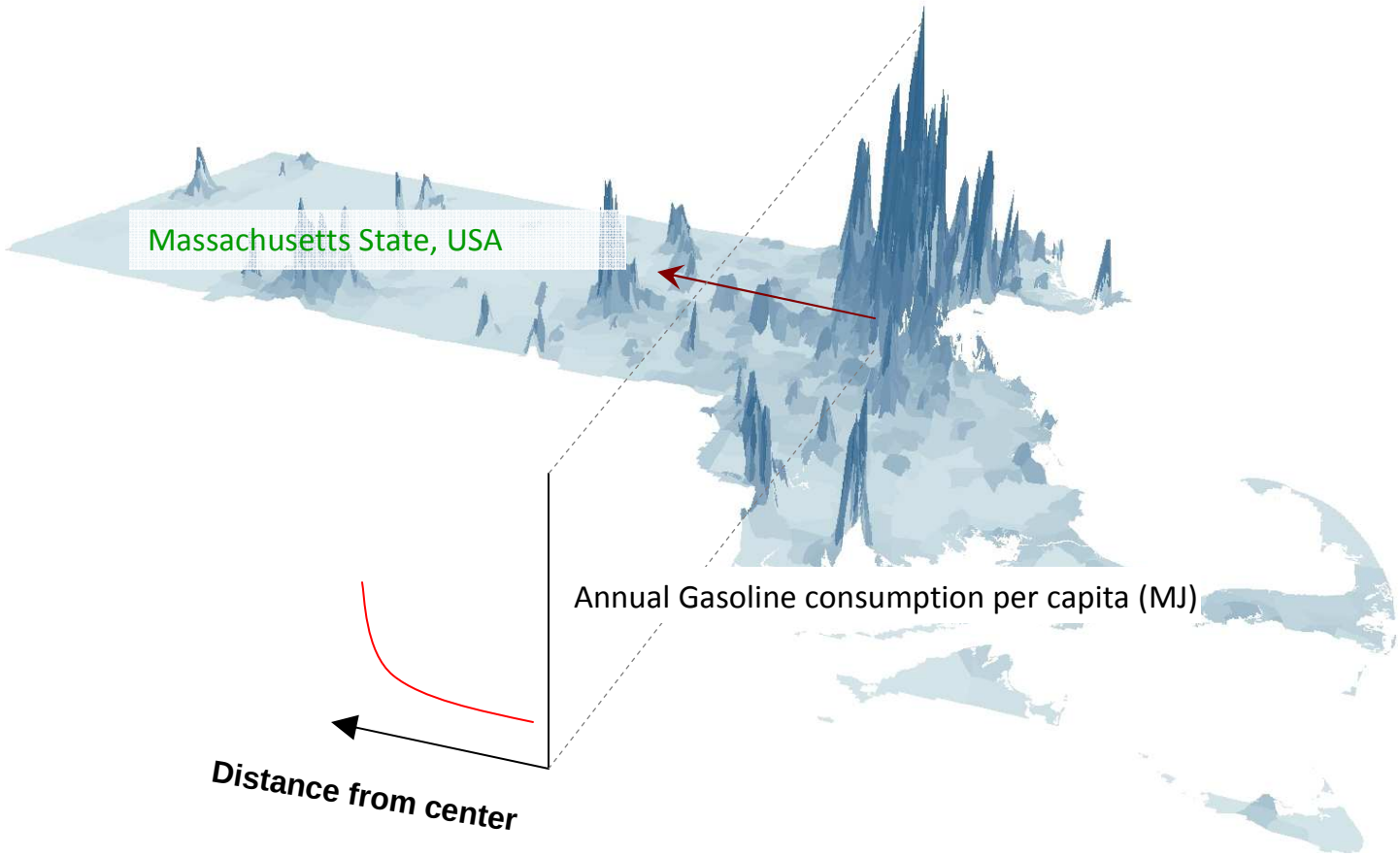
Marshall, 2004

Batty 1992, Clark 1951

Newman and Kenworthy, 1989



Population Density of Boston, USA



- Examine if patterns are true for other cities
- Develop explanations of causality

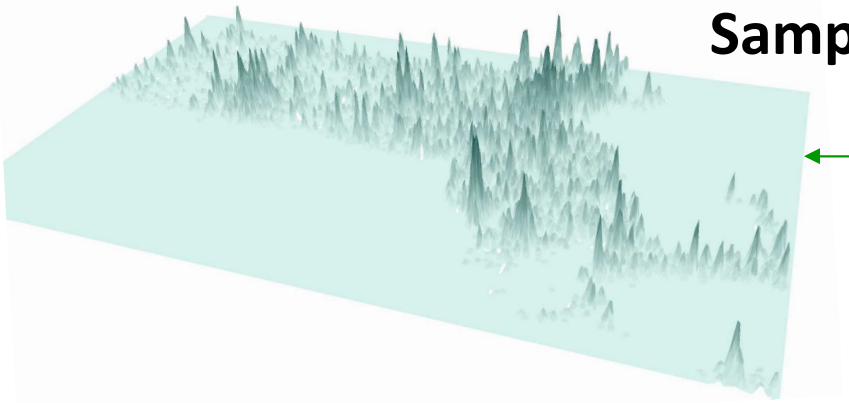
Future Work: Proposed approach for aggregation of metrics

Overlay Analysis

Combining multiple factors for ecological analysis (McHarg, 1981)

Proposed as an approach for examining multiple urban measures of sustainability

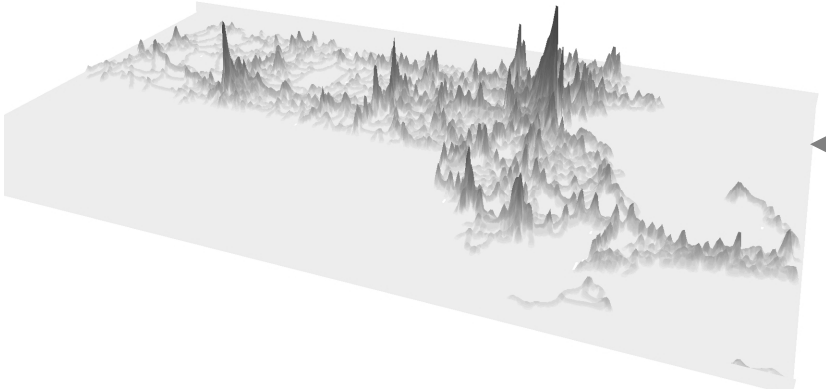
Sample Metrics



Distance from Urban Green Space

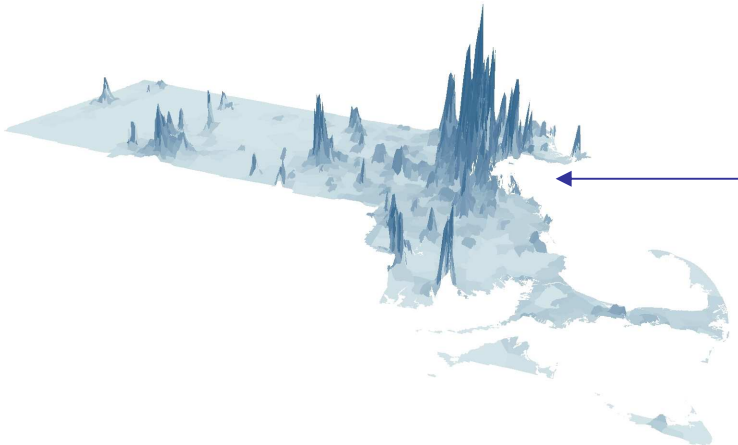
Air Quality

Vegetation

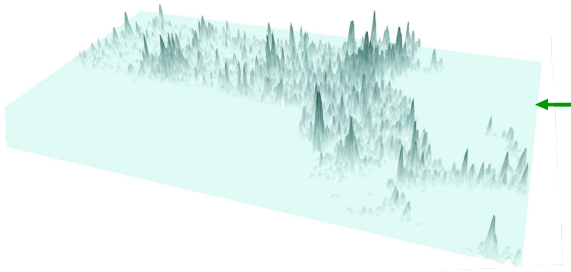


Road Density

Rail Density



Population Density



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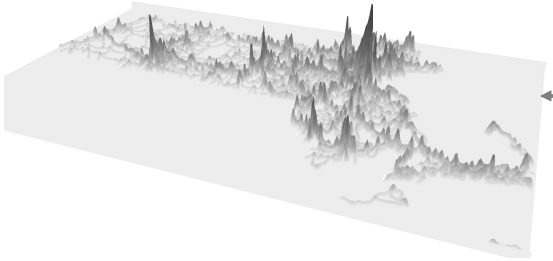

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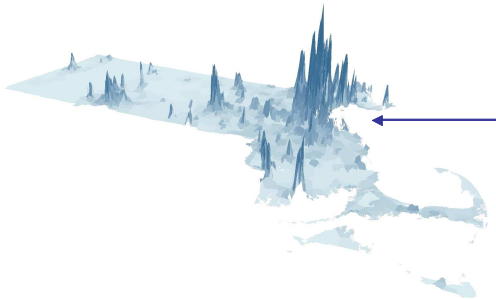
Rail Density

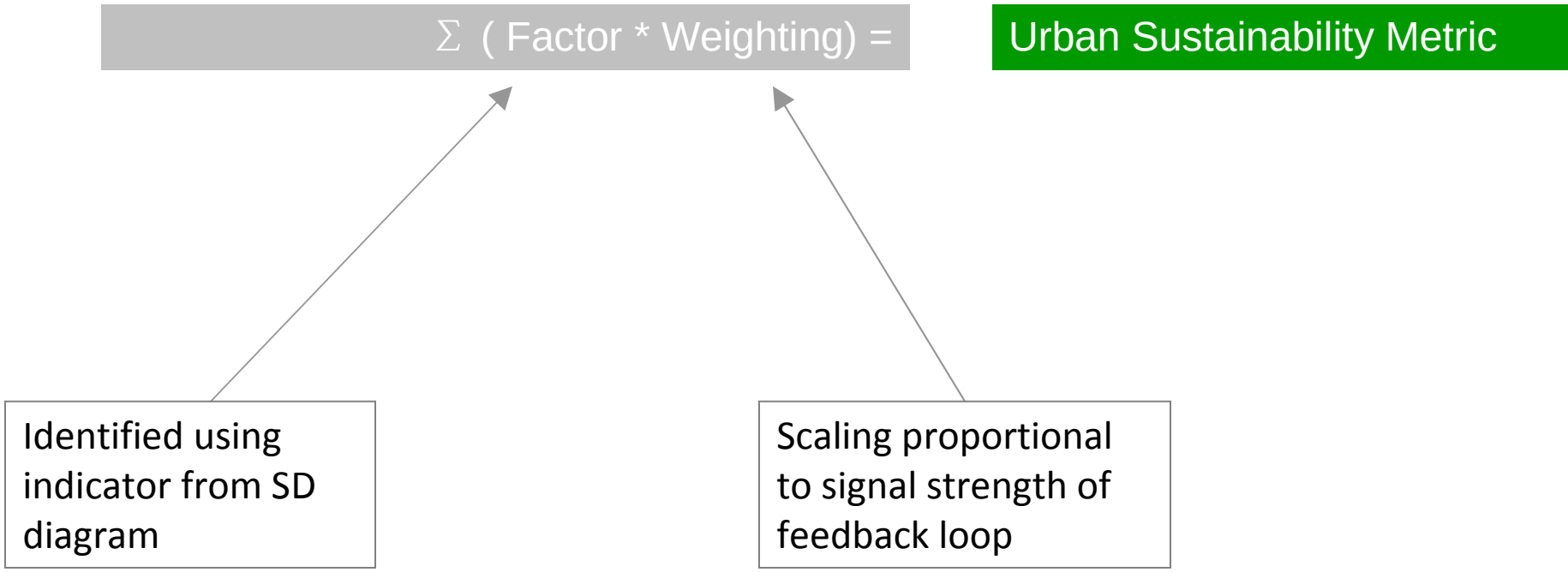


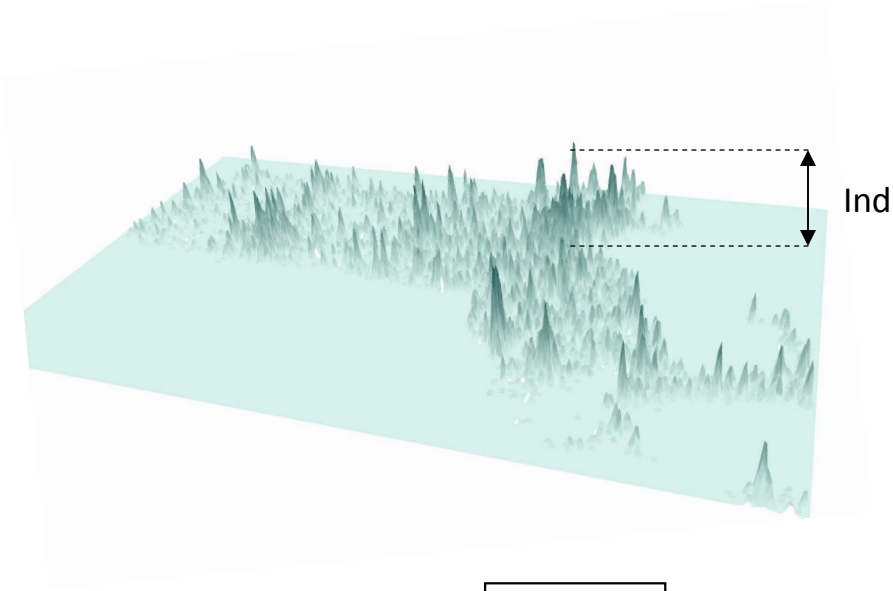
Population Density

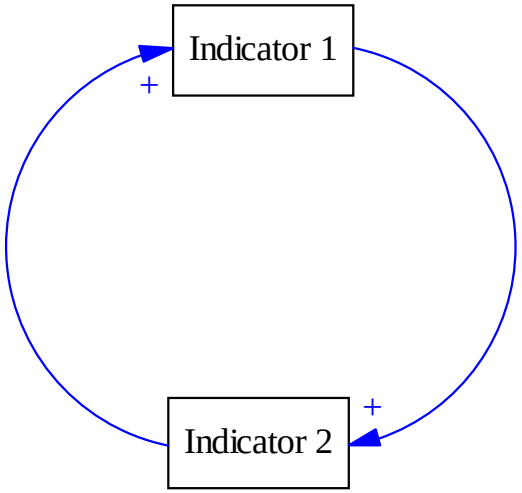
Urban Sustainability Metric

Σ (Factor * Weighting) =

Urban Sustainability Metric

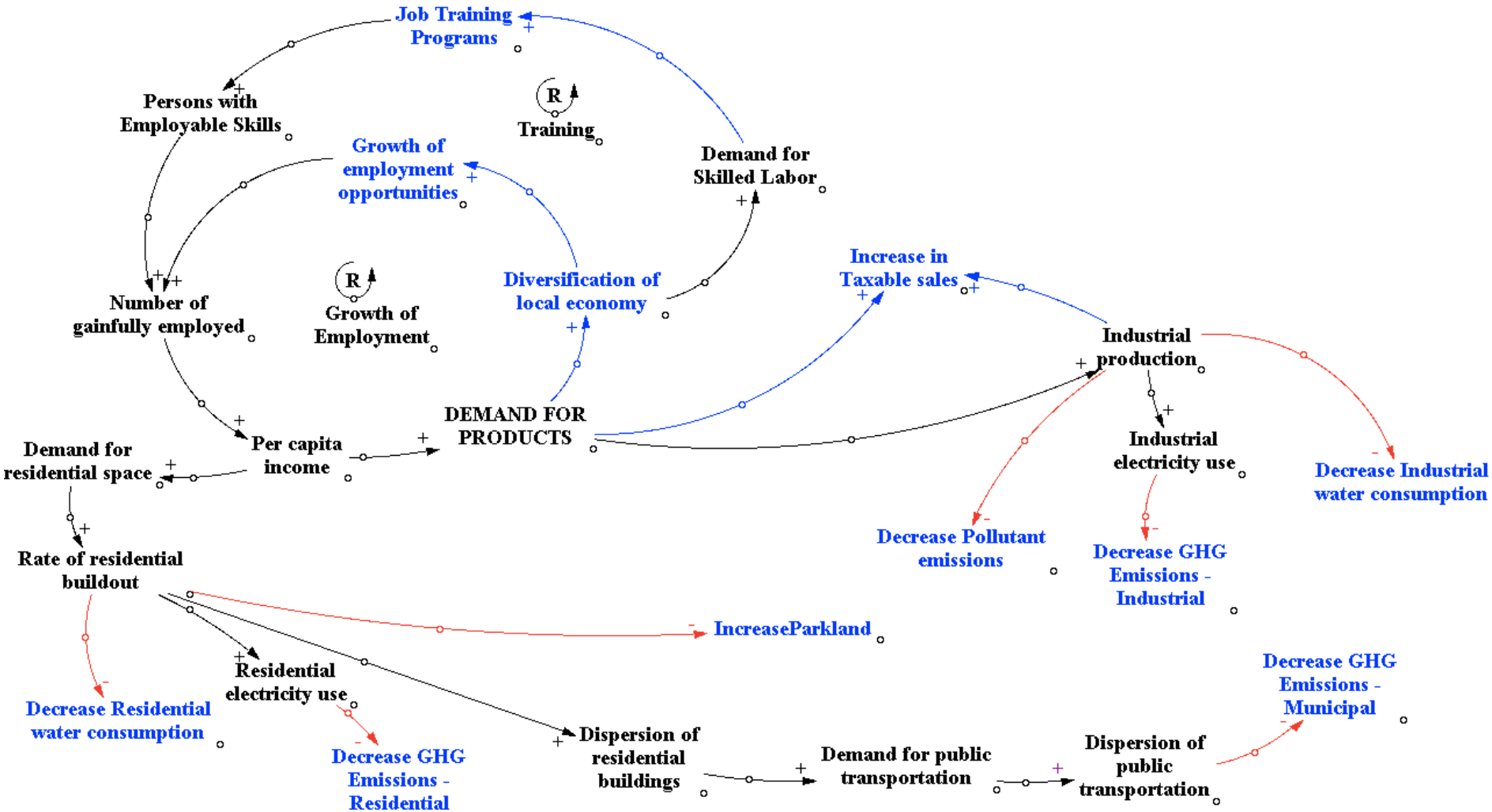

Σ (Factor * Weighting) =
Urban Sustainability Metric
Identified using indicator from SD diagram
Scaling proportional to signal strength of feedback loop





System Dynamics model examines effect on examine the feedbacks effects of changing Indicator 1 on Indicator 2

ICLEI Indicator Relationships



Conclusions

Reductionist approach not appropriate for complex systems

Feedback analysis necessary to consider the effects of changes throughout the system

Patterns illustrate spatial variation in indicator of performance

Patterns and feedback loops result in a holistic approach

References:

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