Evaluation:

Based On

Perspectives on Efficiency in Transportation

and

Identifying Winners and Losers in Transportation

David Levinson

Four Perspectives on Efficiency

Perspective	Profession
Mobility and Safety	Engineers
Utility (Consumer's Surplus)	Economists
Productivity	Managers
Accessibility	Planners

Reason for Multiple Measures

- Planning, investment, regulation, design, operations, management, and assessment.
- Each profession claims to represent traveler.
- Professions take the "*objective*" viewpoint of the omniscient central planner (who may in fact be an engineer, manager, or economist) rather than the "*subjective*" perspective of the travel consumer.

Criteria for Choosing MOE

1. Different measures (e.g. transit and auto level of service) should be collectively complete in that one could combine them to attain an overall measure.
2. Each measure should scale or aggregate well (e.g. it should be possible to combine measures of auto level of service measured on separate links or for separate trips).
3. The measure should align with user experience and be understood by those users.
4. The performance indicator must be measurable, or calculable from available (observable) data.
5. The measure should be predictable, or able to be forecast
6. It must be useful in a regulatory or control context (so that the measure can be used to allow or restrict new development to maintain standards, or to help guide operational traffic engineering decision).

Normative and Positive

- To say that the speed on a link is 50 kilometers per hour tells us nothing about whether that is good or bad, it simply is.
- By comparing the measure to a normative standard (for instance, a speed limit), we can then determine whether we have a speeding problem (the speed limit is 30 kph), a congestion problem (the speed limit is 110 kph), or no problem.

Mobility

- Highway Capacity Manual (segments)
- Texas Transportation Institute (metro areas)
- Quantitative and Qualitative
- Auto and Non-auto
- Scale: Intersection, Link, Subnetwork, Trip, Network
- Basis: Time or Flow

Roadway Mobility Measures

Measurement Scale	Volume and Capacity	Time
Intersection approach	Volume to Capacity Ratio:	Stopped Delay:
	Queue Length	
Total Intersection	Critical Lane Volume:	Average Delay:
Road Segment	Density:	Average Delay:
	Volume to Capacity Ratio:	Average Travel Time:
Road Network	Area Cordon:	Average Travel Time (Distance):
	Area Screenline:	Average Percent Delay:
	Average Congestion Index:	Average Trip Time (Distance) Ratio:
	Average of Area Intersection:	Shoulder Hour Index:
	Distribution Measure:	Distribution Measure:

Qualitative Mobility Measures

Volume &Capacity

- Parking Availability and Cost
- Connectivity
- Conflict with Non-auto System
- Hazard
- Auto Service Stations
- Comfort

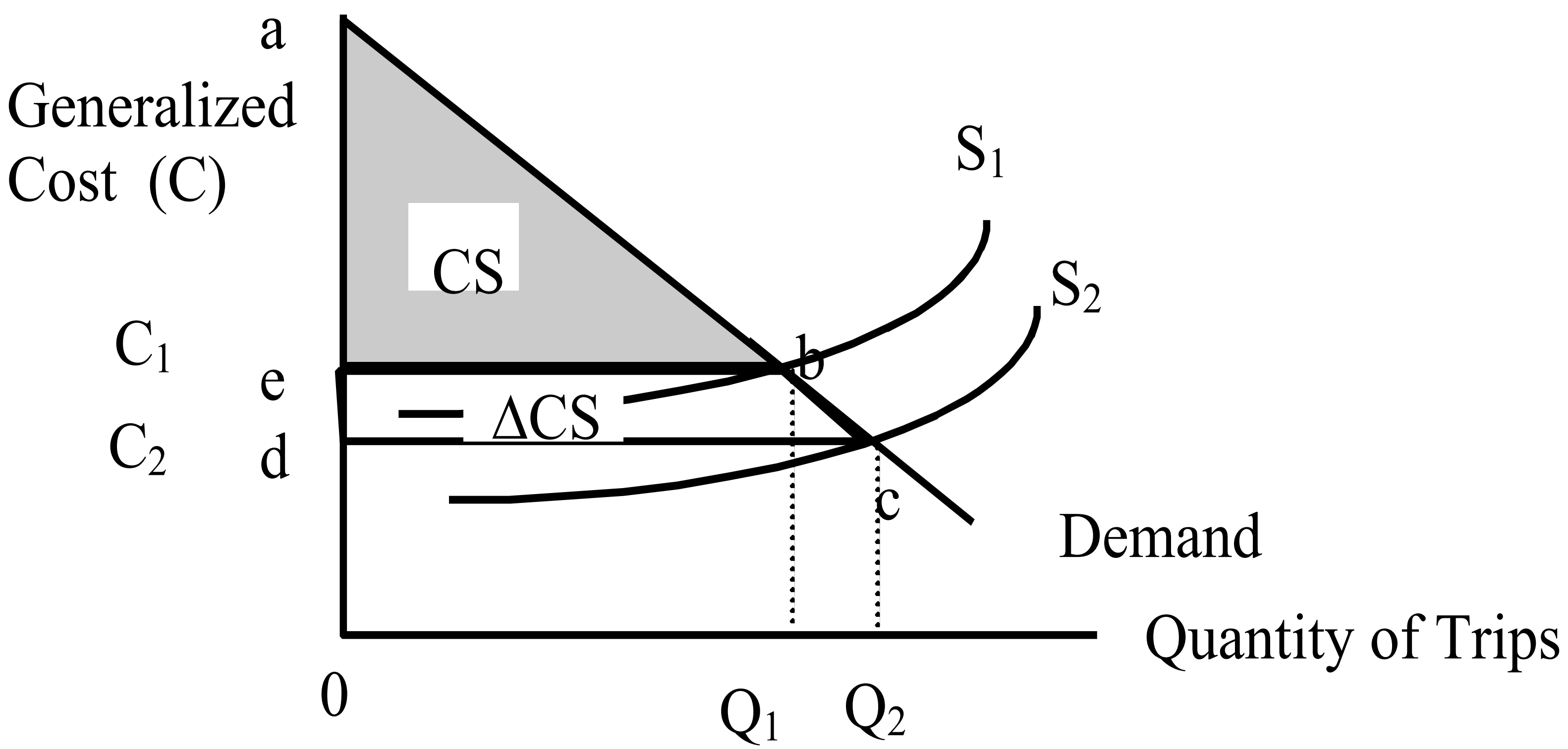
Time

- Coverage
- Aesthetics
- Destination Distribution
- Information System

Non-Auto Mobility Measures

Measurement Stage	Volume and Capacity	Time
Walk (Bike) and Walk Access and Egress to Transit	Sidewalk (Bikeway) Ratio	Coverage
	Connectivity	Circuity
	Hazard	Delay
	Bicycle Parking	Aesthetic
		Travel Time
Auto Access and Egress	Parking Availability and Cost	Park and Ride Access Time
Waiting	Waiting comfort	Frequency
In-Vehicle	Usage	Opportunity
	Service Comfort	Reliability
		Absolute Time
		Relative Time
		Directness

Consumer's Surplus



Consumer's Surplus Criticisms

- Transportation rather than activities as the base for consumer's surplus
- Aggregation error involved.
- No consideration of choice and the existence of non-user benefits in the consumers' surplus metric.
- The costs and benefits associated with spillovers and externalities are often improperly captured

Productivity Measures

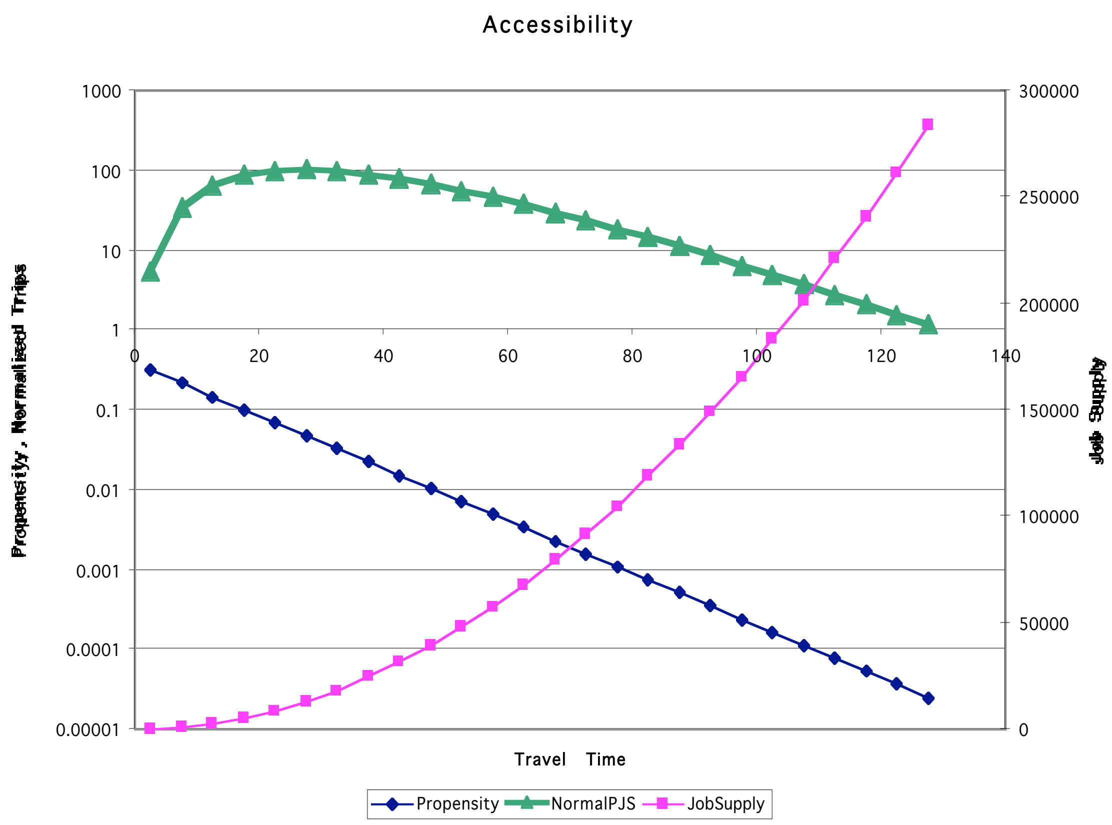
Description	Formula
Productivity of Public Labor (P_{GL})	$P_{GL} = \frac{\sum_l T_l}{\sum_l H_l}$
Productivity of Private Labor (P_{PL})	$P_{PL} = \frac{\sum_l T_l}{\sum_l D_l}$
Productivity of Public Capital (P_{GK})	$P_{GK} = \frac{\sum_l T_l}{\sum_l K_l}$
Productivity of Private Capital (P_{PK})	$P_{PK} = \frac{\sum_l T_l}{\sum_l V_l}$

Where: T = Travel on the system in question (person-km or ton-km), H = Hours of labor by employees of the highway agency (including professional drivers), D = Hours of time by the driver and passengers spent on the network in question (excluding professional drivers), K = Dollars of public capital spent (building and maintaining the infrastructure), V = Dollars of private capital spent (the share of the cost of owning and operating a vehicle, exclusive of taxes to pay for public capital for its use on the network in question), l denotes links in the set of links L under question.

Accessibility Measures

Description	Formula
Accessibility (A) in zone i depends on the opportunities (e.g. jobs P) in zone j and the transportation cost c_{ij} between them	$A_i = \sum_j P_j f(c_{ij})$
Job - Worker Ratio (R) in zone i at radius r (in transportation cost) is the Jobs (P) within radius r divided by Workers (Q) within radius r	$R_i = \frac{\sum_{j=1}^{r} P_j}{\sum_{j=1}^{r} Q_j}$
Density (D) in zone i is the sum of jobs and workers within radius r, divided by the area contained within	$D_i = \frac{\sum_{i=1}^{r} P_i + Q_i}{\pi r^2}$
Difference (Δ) in zone i is the difference between the number of jobs and workers in radius r	$\Delta_i = \sum_{i=1}^{r} P_i - Q_i$
Force (F) between zones i and j is the product of the jobs (P) in zone j and the workers (Q) in zone i and a function of the transportation cost c_{ij} between them	$F_{ij} = Q_i P_j f(c_{ij})$

Accessibility



Travelers and Subjectivity

- Just as Einstein noted that the point of view of the observer shaped the measurement of time, point of view also affects the perception of time as a measure of transportation level of service.
- Moving towards trip-based measures of effectiveness will more closely align with user experience

Motivation

- Welfare comprises *efficiency* and *equity*.
- An allocation is *Pareto Efficient* if there is no other allocation in which some other individual is better off and no individual is worse off.
- Benefit/Cost analysis concerned with net benefits, not distribution.
- Transportation projects and policies create both winners and losers from mobility, accessibility, environmental, and economic standpoints.

Some Terms

- *Horizontal equity:* allocation of benefits and costs among individuals and groups who are similar.
- *Vertical equity:* distribution of benefits and costs across different groups.
- *Process equity*: equal access to the planning and decision making process.
- *Result equity*: examines the outcome.

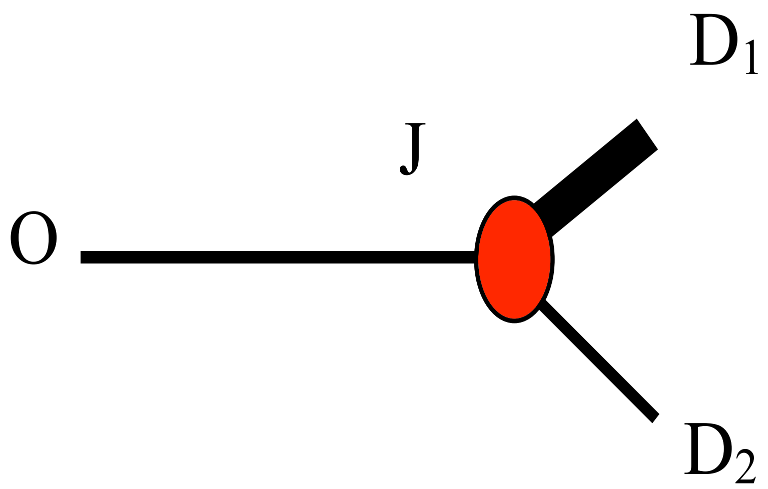
Environmental Costs

Cost Category	Long Run Average Cost ($/vkt)
User	$0.13
Infrastructure	$0.0174
Freeflow Time	$0.15
Congestion	$0.0045
Accidents	$0.031
Noise	$0.006
Air Pollution	$0.0056
Total	$0.34

NIMBY and Equity

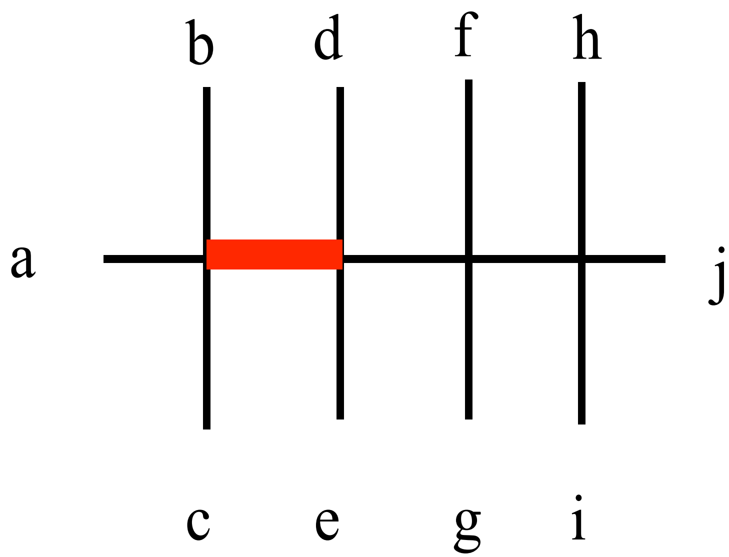
- NIMBYs - Not in My Back Yard 'selfishly' oppose new road projects
- Assumed to be on "property value" grounds.
- May in fact be on "mobility" basis.
- Neighbors do not gain mobility benefits in same way as through trips. Roads often benefit non-locals at expense of locals.
- Most projects create both winners and losers.
- Losers use politics to stop projects which may have an overall net benefit to society.

Example 1: Y-Network



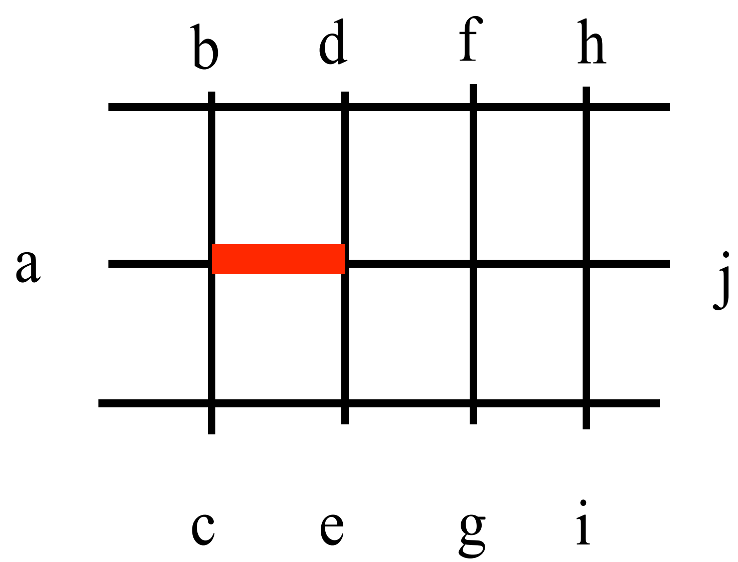
- Inelastic Trip Productions and Attractions
- Inelastic Trip Production, Elastic Trip Attractions
- Elastic Trip Productions and Attractions

Example 2: Network Bridge



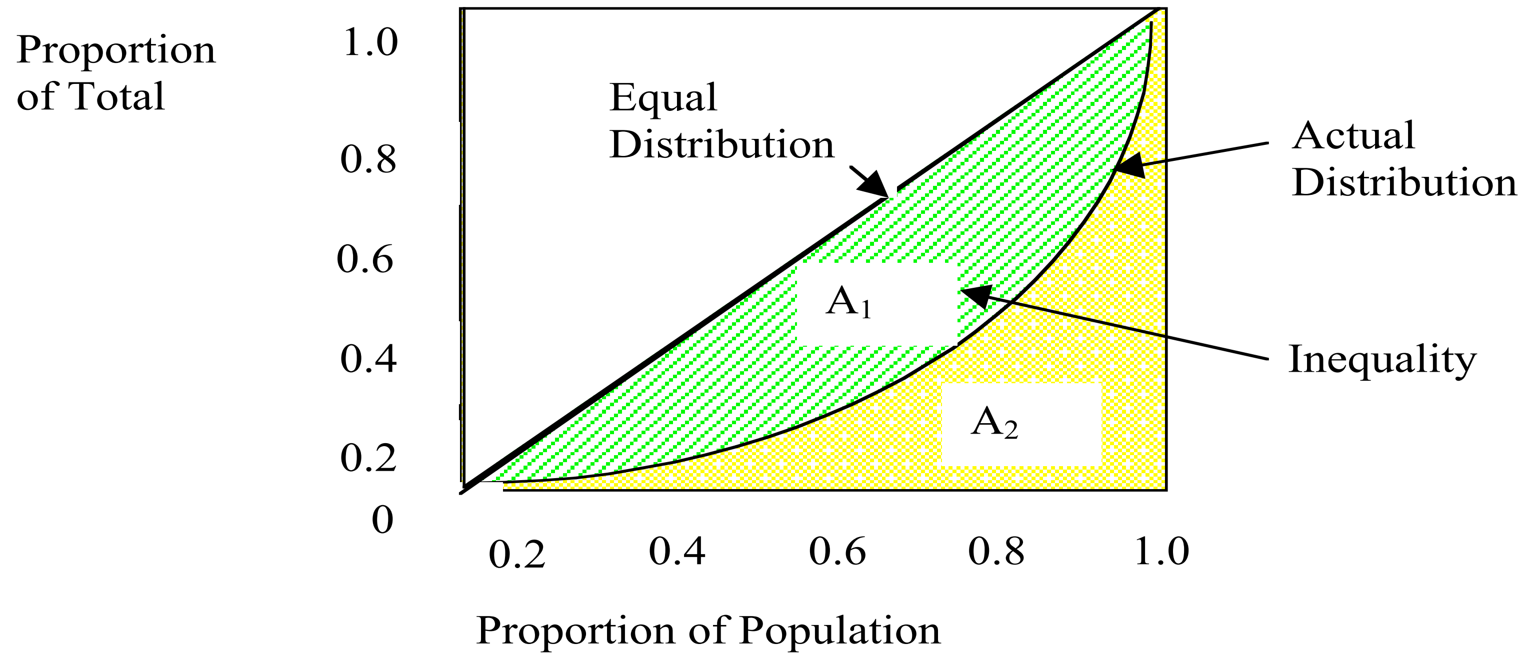
- n=10 origins and destinations
- m=n(n-1)=90 markets
- Elastic demand
- 42 markets using bridge are better off
- 48 markets not using bridge are worse off
- N(Losers) > N(Winners)

Example 3: Network Grid



- Same number of markets.
- Elastic Demand
- Some traffic not using improved link also benefits.
- N(Winners) > N(Losers)

Measuring Equity: Lorenz Curve and Gini Coefficient



Gini Coefficient = $A_1/(A_1+A_2)$

Measuring Equity: Entropy

$$H = -\sum_{j} \left(y_j \bullet \log_k y_j \right)$$

$H =$ the entropy statistic

$y_j =$ the proportion of average net gains to the j^{th} class

$k =$ the log base

To analyze traffic data, we can take:

- y_i = proportion of total delay accrued by each individual

H statistic approaches zero as the distribution approaches complete inequality

Measuring Equity: Redundancy

$$R = 1 - H / H_{\max}$$

$R =$ the measure of redundancy

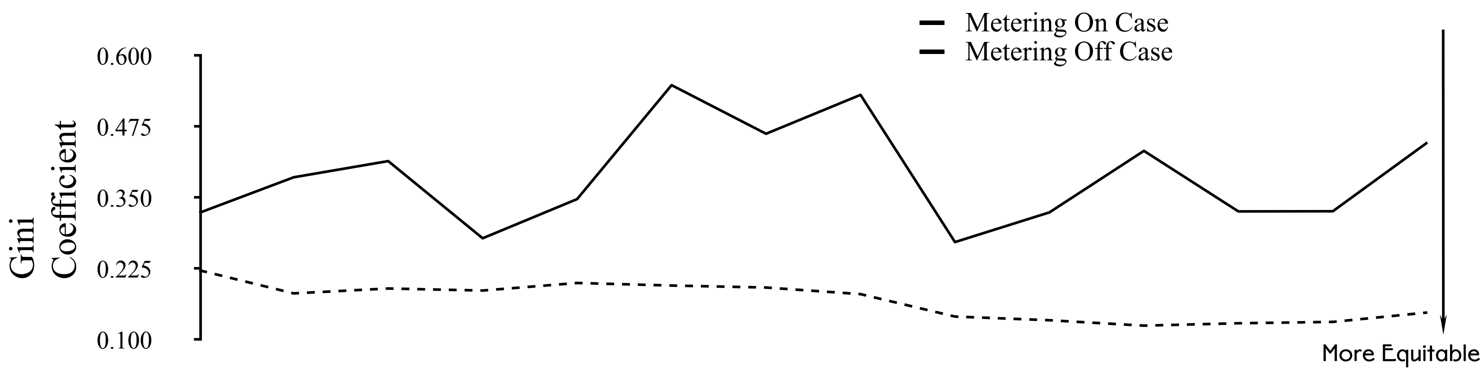
$H =$ the calculated entropy

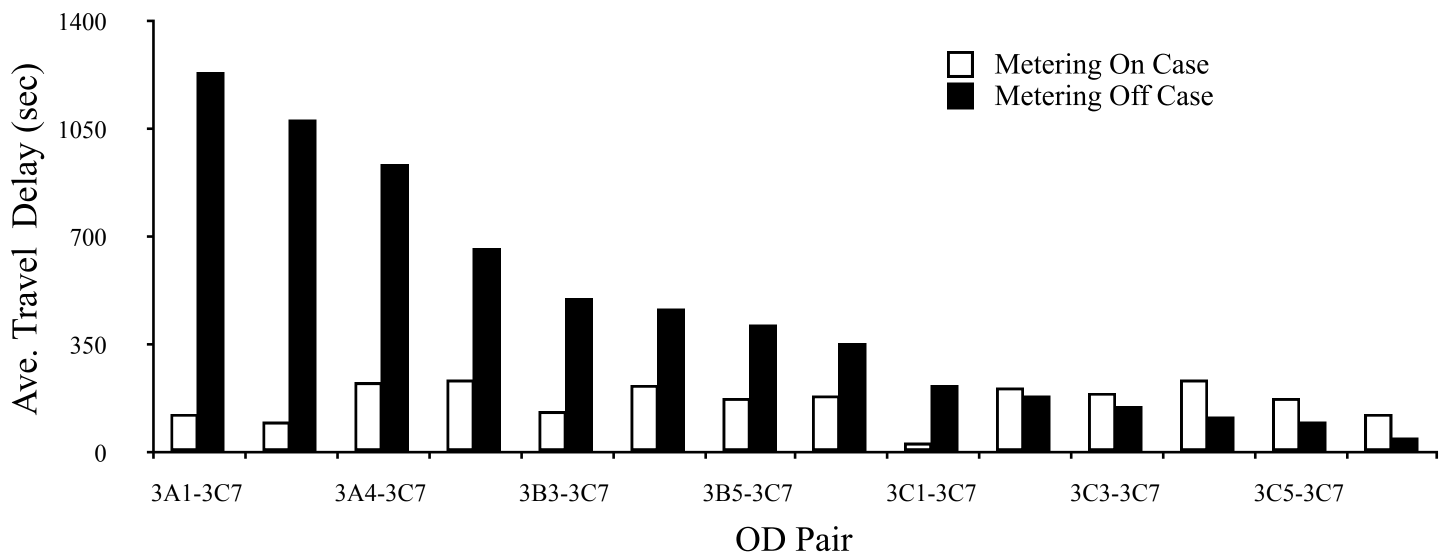
$H_{\max} =$ the maximum possible entropy

- R-value of 0% represents complete equality

Twin Cities Ramp Meters

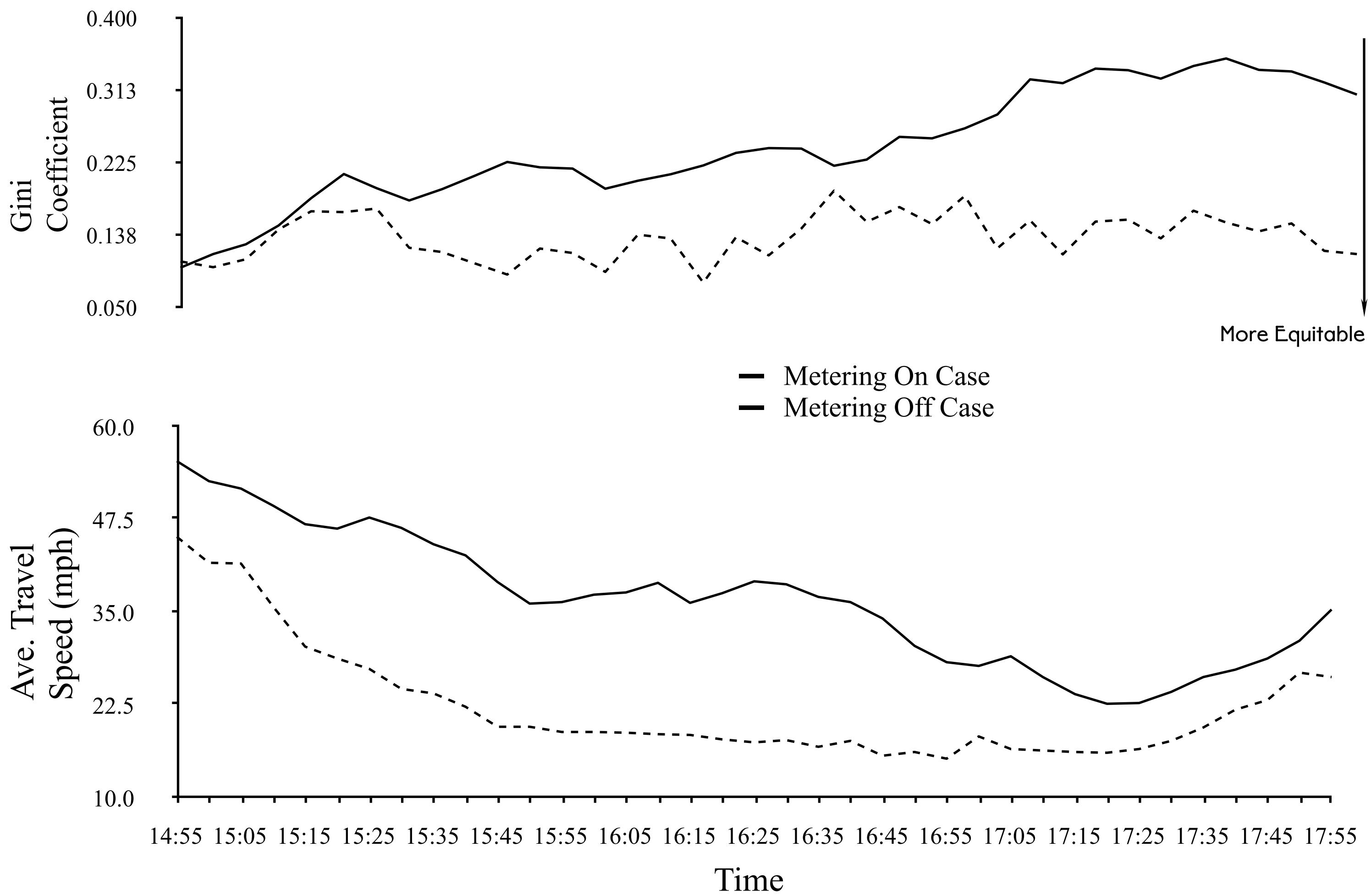
TH169 mobility vs. temporal equity





Twin Cities Ramp Meters 2

TH169 mobility vs. spatial equity



Environmental Justice

- Environmental Justice considers "fair treatment for people of all races, cultures, and incomes (Executive Order 12898)" regarding the development of environmental laws and policies.
- Considers only environment.
- Considers only a few groups.
- Only a partial consideration of equity.

Equity Impact Statement

	Process	Outcomes				
Stratification	Opportunity to Engage in Decision-Making	Mobility	Economic	Environmental	Health	Other
Population Spatial Temporal Modal Generational Gender Racial Cultural Ability Income						

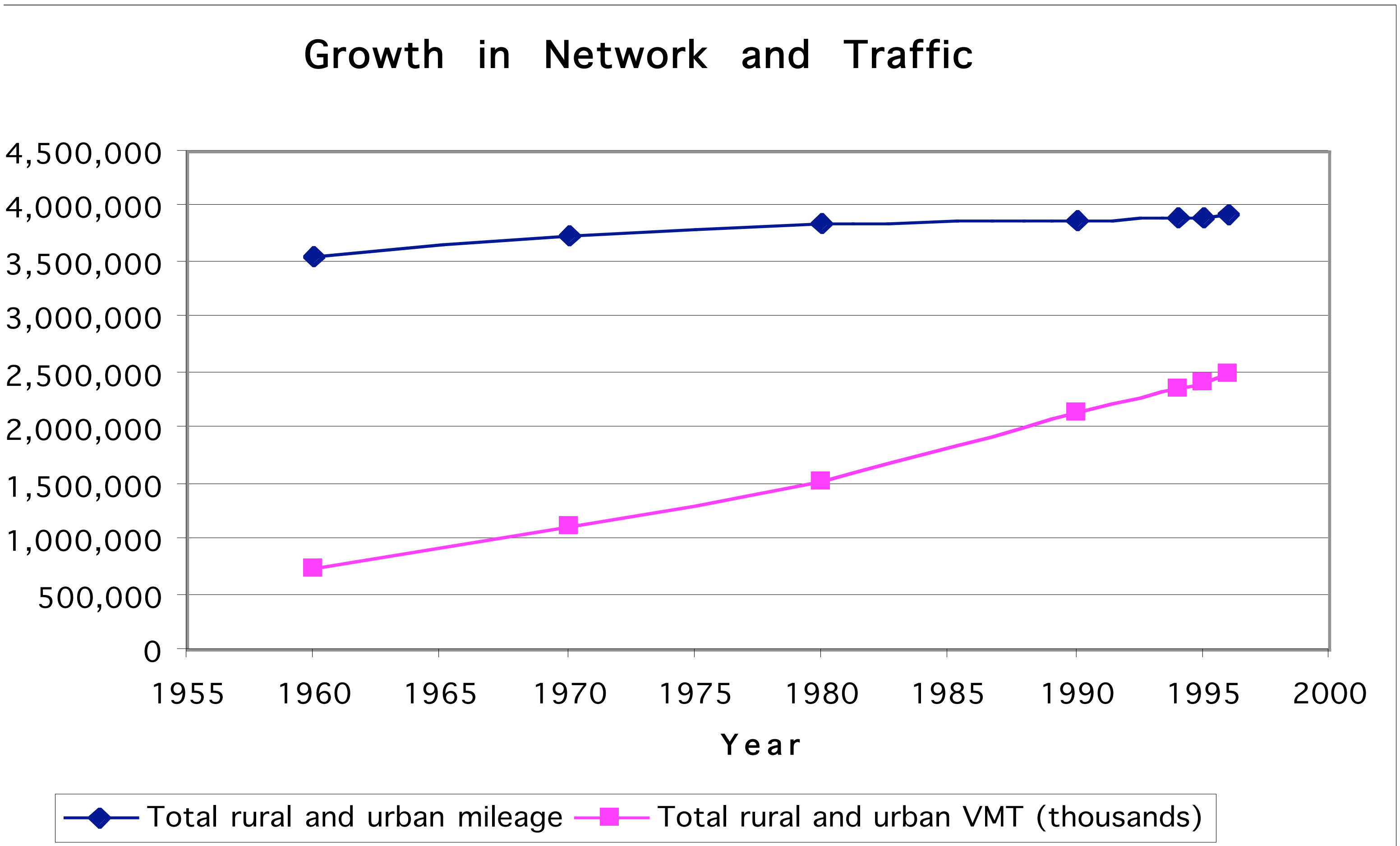
Conclusions

- Four Classes of Efficiency Measures: Mobility, Utility, Productivity, Accessiblity.
- Each is a gauge, none should be exclusive.
- None captures the subjective perspective of travelers.
- New measures must be developed which do reflect the customer.

Conclusions: Equity is Efficient

- Equity a central issue for transportation, not just because it is 'right' but also because it is efficient if we actually want to implement projects. (An un-implemented project serves no one).
- Need to think beyond single project: Develop means for compensation of losers from gains of winners. Side payments, bargains, and bundles of projects may accomplish this.
- Danger of log-rolling turning into pork barrel.
- Equity must be broadly considered.
- Things need not be strictly fair, but the unfairness inherent should not be unknown.

Growth in Traffic and Network



Engineering Systems: Notes from the MIT ESD Symposium, March 2004

David Levinson

Engineering Systems

- We are interested in systems with the following characteristics:
  - Technologically Enabled
  - Large Scale (large number of interconnections and components)
  - Complex
  - Dynamic, involving multiple time scales and uncertainty
  - Social and natural interactions with technology
  - May have Emergent Properties

ES Requires

- An Interdisciplinary Perspective—technology, management science and social science
- The incorporation of system properties, such as sustainability, safety and flexibility in the design process. (These are lifecycle properties rather than first use properties.)
- An Enterprise Perspective
- The incorporation of different stakeholder perspectives

ES Examples

- Military Aircraft Production & Maintenance Systems
- Commercial & Military Satellite Constellations
- Megacity Surface Transportation Systems
- The Worldwide Air Transportation & Air Traffic Control System
- The World Wide Web & the Underlying Internet
- Automobile Production & Recycling Systems
- Consumer Supply Logistics Networks
- Electricity Generation & Transmission Systems

Hierarchy of Knowledge

- 1. Observation
- 2. Classification
- 3. Abstraction
- 4. Quantification and Measurement
- 5. Symbolic Representation
- 6. Symbolic Manipulation
- 7. Prediction

Disciplines with ES

- Systems Engineering
- Operations Research
- Engineering Management
- Technology Policy

Systems Architecture

- an abstract description of the entities of a system and the relationships between those entities.
- System engineering theory works most smoothly when the product can be broken into modules that are relatively independent - Modular.
- When products cannot be decomposed simply, or when their behaviors interact, they are called integral.

Examples of Desirable and Undesirable Anticipated and Emergent System Properties Influenced by Architecture

	Anticipated	Emergent
Desirable	Electric power networks share the load. Hub-spokes airline routes shorten the length of trips.	Blackouts are associated with increased births. Hub-spokes plus waiting time creates a business opportunity in airport malls.
Undesirable	Power networks can propagate blackouts. Hub-spokes causes huge swings in workload and resource utilization at airports.	Blackouts are associated with increased births. Airport operators become dependent on mall rental income, making it difficult to modify airline route structures.

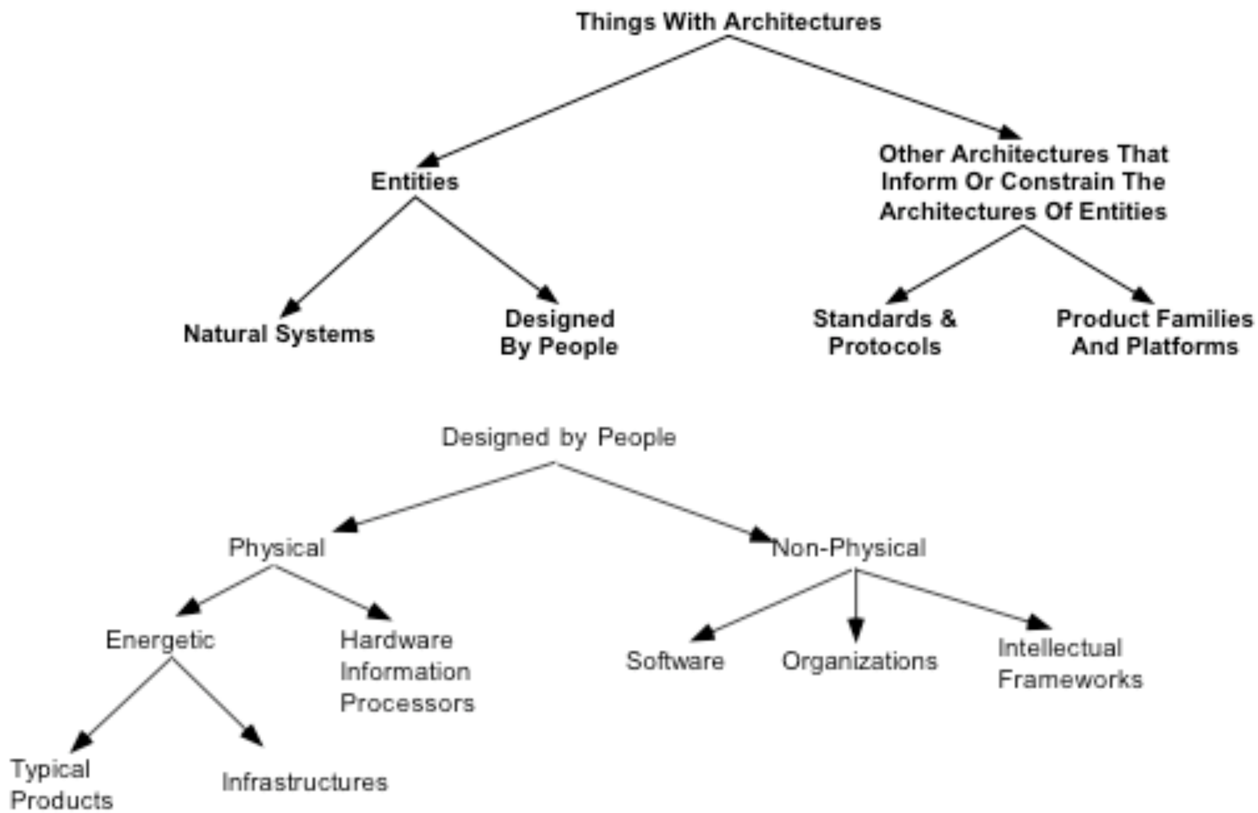
4 Types of Architectures

- The functional architecture (a partially ordered list of activities or functions that are needed to accomplish the system's requirements)
- The physical architecture (at minimum a node-arc representation of physical resources and their interconnections)
- The technical architecture (an elaboration of the physical architecture that comprises a minimal set of rules governing the arrangement, interconnections, and interdependence of the elements, such that the system will achieve the requirements)
- The dynamic operational architecture (a description of how the elements operate and interact over time while achieving the goals)

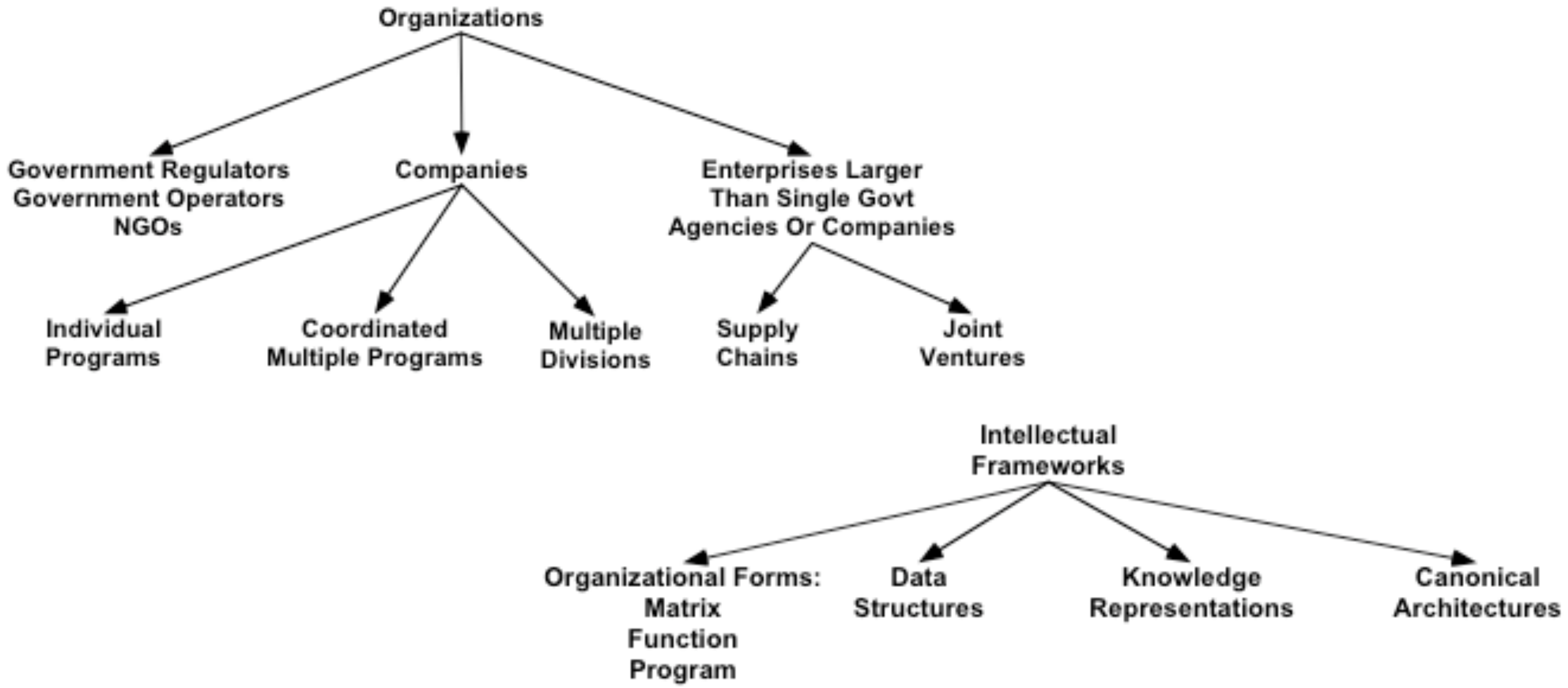
Why is System Architecture Important?

- Architecture Is A Way To Understand Complex Systems
- Architecture Is A Way To Design Complex Systems
- Architecture Is A Way To Design Standards And Protocols To Guide The Evolution Of Long-lived Systems
- Architecture Is A Way To Manage Complex Systems

Decomposition of Architecture



Further Decomposition



Properties

- Delivery of Basic Function: Performance & Cost
- Illities: Flexibility Robustness Scalability Safety Durability Sustainability Reliability Recyclability Maintainability Quality
- Characteristics: Complexity, Emergence, Systems Architecture, Uncertainty

Robustness

- Robustness is defined as "the demonstrated or promised ability of a system to perform under a variety of circumstances, including the ability to deliver desired functions in spite of changes in the environment, uses, or internal variations that are either built-in or emergent" (ESD 2002).

Adaptability

- Adaptability is defined as "the ability of a system to change internally to fit changes in its environment," usually by self-modification to the system itself (ESD 2002).

Flexibility

- Flexibility is defined as "the property of a system that is capable of undergoing classes of changes with relative ease. Such changes can occur in several ways: a system of roads is flexible if it permits a driver to go from one point to another using several paths. Flexibility may indicate the ease of 'programming' the system to achieve a variety of functions. Flexibility may indicate the ease of changing the syscomplexity and rework" (ESD 2002).

Safety

- Safety is defined as "the property of being free from accidents or unacceptable losses." Associated with this definition are several others: An accident is "an undesired and unplanned (but not necessarily unanticipated) event that results in a specified level of loss" (human, economic, etc). A hazard is "a state or sets of conditions that, together with worst-case external conditions, can lead to an accident." Risk is "the level of hazard combined with the likelihood of the hazard leading to an accident, and the duration of exposure to the hazard" (Leveson 1995).

Scalability

- Scalability is defined as "the ability of a system to maintain its performance and function, and retain all its desired properties when its scale is increased greatly, without causing a corresponding increase in the system's complexity" (ESD 2002).

Complexity is Complex

- 1. Behavioral complexity—A system is deemed behaviorally complex if its external behavior is difficult to predict. Unfortunately, it does not take much to achieve this state of affairs. Chaotic and thus unpredictable behavior can be achieved with a relatively simple mechanical arm.
- 2. Interface complexity—A system has a complex interface if it has numerous components, such as knobs and dials, in its interface to humans or to other technical systems. Systems with complex interfaces are usually difficult for humans to operate or successfully integrate with other systems. George Miller wrote a famous paper in psychology called The Magical Number 7±2 (1956). An interpretation of the paper is that humans are limited in their processing ability to dealing with no more than 7±2 different things at any one time.
- 3. Structural complexity—A system is structurally complex if it has numerous components whose interconnection, interaction or interdependence is difficult to describe or understand. Our discussion below will emphasize structural complexity. It is hoped that systems whose structural complexity is reasonably limited will meet the traditional, and some non-traditional, properties and goals without too much difficulty.

Sustainable Transportation

Environment	Economy	Equity	Institutional	
Ability to Recycle; Assimilative Capacity; Avoidance of Irreversibility; Precautionary; Preventive; Regenerative; Stewardship; Substitutability; Use of Energy	Affordability; Cost-effectiveness; Cost Internalization; Economic Growth; Economic Well-being; Effective Use of Innovation; Quality of Life	Access & Choice; Equitable Economic Growth (Share the Gains) Environmental Justice; Poverty Reduction; Social Well-being; Social Responsibility	Appropriate Use of Land & Resources; Comprehensive & Long-term Planning; Goals, Performance, and Outcomes; Improvement in Efficiency; Integration; International Cooperation	Protection of Health & Safety; Participation & Education; Reduction of Automobile Dependency; Technological Innovation; Transparency & Accountability

E E E

The Three E's of Sustainable Transportation

"I/C"

"I/C" for System Innovation/Change

Twin Cities Transit & Land Use

- Questions:
- Consider Light Rail Transit in Minneapolis and the "Illities" … Does the system exhibit properties that are desirable, undesirable? What are they?

Sussman's Key Points

As relayed by
David Levinson

People and organizations alter behavior based on transportation system expectations.

Transportation service is part of a broader system - economic, social, and political in nature.

Competition, or its absence, for customers by operators is a critical determinant of the availability of quality transportation service.

Analyzing the flow of vehicles on transportation networks, and defining and measuring their cycle is a basic element of transportation systems analysis.

Queueing for service and customers and storage for vehicles/ freight/travelers are fundamental elements of transportation systems

Intermodal and intramodal transfers are key determinants of service quality and cost.

Operating policy affects level of service

Capacity is a complex system characteristics affected by: infrastructure, vehicles, technology, labor, institutional factors, operating policy, external factors (e.g. clean air, safety, regulation).

Level of service = f(volume); transportation supply. As volume approaches capacity, level of service deteriorates dramatically - the "hockey stick" phenomenon.

The availability of information (or the lack thereof) drives system operations and investment and customer choices

The shape of transportation infrastructure impacts the fabric of geo-economic structures.

The cost of providing a specific service, the price charged for that service, and the level-of-service provided may not be consistent.

The computation of cost for providing specific services is complex, and often ambiguous.

Cost level of service tradeoffs are a fundamental tension for the transportation provider and the transportation customer, as well as between them.

Consolidation of like demands is often used as a cost minimizing strategy.

Investments in capacity are often lumpy (e.g. infrastructure).

The linkages between Capacity, Cost, and Level of Service - the lumpiness of investment juxtaposed with the hockey stick level of service function as volume approaches capacity - is the central challenge of transportation systems design.

Temporal peaking in demand: a fundamental issue is design capacity - how often do we not satisfy demand.

Volume = f(level of service); transportation demand.

Level of service is usually multidimensional. For analysis purposes, we often need to reduce it to a single dimension, which we call utility.

Different transportation system components and relevant external systems operate and change at different time scales (e.g. short run - operating policy; medium run - auto ownership; long run infrastructure, land use).

Equilibration of supply and demand for transportation service to predict volume is a fundamental network analysis methodology.

Pricing of transportation services to entice different behavior is a mechanism for lowering the negative externalities caused by transportation users on other transportation users and society-at-large.

Geographical and temporal imbalances of flow are characteristic in transportation systems.

Network behavior and network capacity, derived from link and node capacities and readjustment of flows on redundant paths, are important elements in transportation systems analysis.

Stochasticity in supply and demand is characteristics of transportation systems.

The relationship among transportation, economic development, and location of activities - the transportation/land use connection - is fundamental.

Performance Measures shape transportation operations and investment.

Balancing centralized control with decisions made by managers of system components (e.g. terminals) is an important operating challenge.

The Integrality of vehicle/ infrastructure/ control systems investment, design, and operating decisions is basic to transportation system design.