Premise

The underlying premise is that *the network is the most effective solution to providing sustainable multimodal access and circulation for all users at any scale.* This paper describes characteristics of an effective sustainable transportation network and addresses how the performance measures used in transportation planning and transportation engineering must be reformed to capture the benefits of the network.

Performance measures are a critical part of the transportation planning, transportation engineering, and environmental review processes. The dominant performance measure today at all geographic levels is vehicle delay. At the regional level, vehicle delay is estimated using regional travel demand models and is highlighted in both long-range transportation plans and major project studies. The concept of vehicle delay also is the core of the Texas Transportation Institute's *Travel Time Index*, which is the only transportation performance measure commonly cited in the national press. At the corridor and intersection levels, the dominant performance measure also is vehicle delay. It is often called *level of service,* but this is just another phrase for vehicle delay.

Therefore, the central focus of our current transportation planning efforts today is the unimpeded movement of automobiles. This focus often tramples over other modes. For example, in a major redevelopment plan calling for walkable mixed use development, the engineering study ignored pedestrians and added turning lanes to all of the signalized intersections to reduce vehicle delay – thus overriding the entire premise of the redevelopment initiative. The engineering analyses were wrong even if we only cared about vehicle delay because the computerized analyses of the intersections were done with 0 pedestrians. If pedestrians had been included in the computer analyses, there would have been negative impact of longer pedestrian crossing times on vehicle delay. Unfortunately, this poor level of practice is more the rule than the exception, because the single-minded focus on vehicle delay has dulled the brains of practitioners.

In order to evaluate the network properly, performance measures are needed for all travel modes including walking, biking, transit, auto and freight (and possibly green infrastructure as well), and these measures must properly account for the tradeoffs between the performance of one mode and another. The auto metrics need to shift from moving vehicles to moving people where they want to go. When minimizing vehicle delay, a high-speed circuitous route looks good even if it gets someone to their destination no faster than a more direct, slower route. In reality, the more direct but slower route requires less transportation infrastructure, costs less, is more sustainable, and will cause less disruption of the urban form. However, to provide choice and flexibility to address changing demands and conditions, sustainability requires flexibility and choice in routing as well as mode. Furthermore, performance measures must be comprehensive. Today, billions of dollars are being spent on isolated roadway projects that increase localized capacity, but shift system bottlenecks to a different location without achieving any lasting value.

This reform of transportation performance measures will not be easy. In addition to being entrenched in profession practice, vehicle delay is easy to calculate and is expressed in precise numbers that look accurate to laypeople. In contrast, a full accounting of network performance will necessarily be much more complex, and may include measures that cannot be quantified to several decimal places of precision. Our challenge is to develop a set of performance measures that are comprehensive and accurate, that can be developed efficiently, and that can be communicated effectively to decision makers and the general public.

Discussion Topic

Suggest metrics for the three geographic scales described in the *Charter of the New Urbanism*:

Sustainable Transportation Network Metric Matrix

	Walk	Bike	Transit	Auto	Freight	Emergency	Green	Place
The Region: Metropolis, city, and town								
The neighborhood, the district, and the corridor								
The block, the street, and the building (Takeover Point w/Bluebook)								

Existing Practice

In almost all states, urban transportation planning on a community or regional scale is mainly done by or for metropolitan planning organizations (MPOs), state departments of transportation (DOT's) and municipalities. At the scale of a subarea or development, network planning is done for developers by consulting urban planners, architects, and transportation or civil engineers, then proposed to municipal planning departments by the developers or their agents. Depending on scale, the proposed network additions (or changes) are reviewed and approved by the MPOs as part of the regional plan and by the municipality with jurisdiction. Outside municipalities the county usually serves the local agency role.

At present, the vast majority of transportation planning efforts are corridor or facility-based. That is to say, they focus exclusively on planning, prioritizing and building singular facilities. While such efforts may occur within the context of a system-wide approach, each individual facility must stand on its own merit, without regard to how such facilities might perform in combination with each other (i.e. a network).

The corridor/facility-based approach to contemporary transportation planning has yielded metrics which similarly focus on single corridors or facilities. At the regional or community level, MPOs use travel demand forecasting models to analyze the impacts of 20 and 30 year growth trends on the transportation system. Facility-based metrics – typically volume to capacity ratios – are used to identify 'deficiencies' in the system, the implication being that capacity additions in the form of additional lanes will 'improve' the system. Transit is given nominal attention, while bicycles and pedestrians are virtually ignored.

At the local and sub-area levels, more finite tools are used to measure 'level of service' on road segments and intersections. For the most part, however, capacity issues are still addressed on a facility basis, leading the presiding practitioner to conclude that the best way to mitigate the impacts of a new development or growth in general is to add vehicle lanes to an existing road or to widen an intersection.

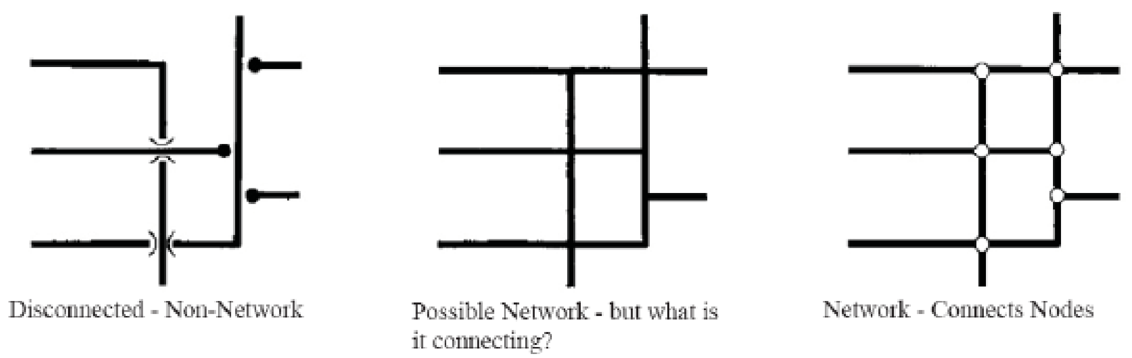
A network-based approach to measuring transportation systems has emerged in some places. For example, the Florida Department of Transportation (FDOT) has developed a process for local agencies that wish to opt out of traditional corridor-based automobile level of service measures by adopting areawide quality of service standards. The areawide approach forgoes automobile measures of LOS altogether in some cases, and in others it takes into consideration the vehicular capacity of an entire interconnected network of streets, rather than a single arterial. The quality of bicycle, pedestrian and transit networks are also taken into account and quantified. This approach to measuring transportation systems, however, is by far the exception and not the rule.

SUSTAINABLE TRANSPORTATION NETWORKS
Desired Practice

Rethinking the conventional methods of transportation network planning requires redefining what is meant by network planning and conceiving a new framework in which to plan to achieve the redefined goals of the network. Furthermore, new measures or metrics must be devised to determine whether or not the goals are being achieved. Finally, the new methods must be examined to determine if they lead to more sustainable results for our networks, our lives and our planet. These subjects are treated separately in the following text and conclude merely with questions to explore rather than answers.

DEFINITION:

What is a network? A network is distinguished from a pattern or grid, a weave or a series of overlays in that it connects things to achieve something. A fishing net is different from burlap in that the crossing fibers are bound together in a knot to ensure the strands do not slide against one another and consequently they are much stronger and maintain their spread. Similarly, having unconnected strands or stray strands do not constitute a network. For a computer network, the strands are typically Ethernet cables that connect computers with the goal of increasing computational capacity. Business networking involves connecting people with information flows with the goal of increasing opportunity. In transportation, the strands are routes and the knots are places and the goal is moving people, goods and services as efficiently and cost-effectively as possible to increase prosperity and opportunity.



(Adapted from W. Lieberman)

Network:
a structure that serves and connects multiple nodes, people, flows and/or functions to achieve a goal.

Discussion Starter – is there agreement on what constitutes a network and what its purpose is?

FRAMEWORK:

As mentioned above, conventional tranportation network metrics focus on cars. Sustainable transportation network design attempts to transform the conventional approach to one based on connecting PEOPLE to places, allowing places to become more intense centers of economic development.

SUSTAINABLE TRANSPORTION NETWORK*	CONVENTIONAL NETWORK
About places and getting to them	About moving cars at speed
Connected	Not
Multimodal	Auto-dependent
Accessible destination	Indirect routes
More public streets	Fewer public streets
Detailed streetscape	Few streetscape elements
Welcoming for pedestrians	Dangerous and unpleasant for pedestrians
More route choices / redundant down	Fewer route choices / prone to break-
Smaller (narrower ?) streets	Wider streets
Finer grained	Coarser grained
Lower speeds but faster trips	Higher speeds but slower trips
Focus on quality of place	Focus on speed of vehicles
Less delay at intersections	More delay at intersections
Simpler turns	More complicated turns
Supports activity on sidewalks / adj to streets	More arterials that are not vcomfortable to be next to

Table courtesy of Brian Bochner
*(N.B. these are not absolute values but divergent tendencies or directions along a continuum ranging from one extreme to the other)

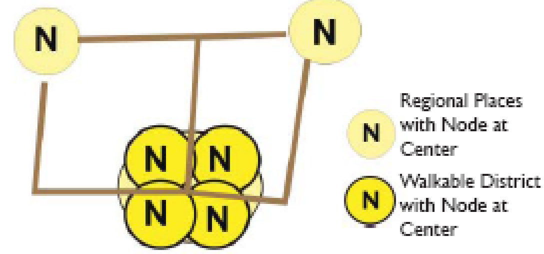
We can call these new networks, "Sustainable Transportation Networks".

Just as sophisticated netting has multiple layers of connecting strands (e.g. netframe, mesh and submesh), so do most networks operate on multiple levels. In the case of transportation, network levels can include inter-regional travel, regional travel, district travel, and corridor travel (cf. CNU canons). In this presentation of sustainable transportation networks, three levels will constitute the focus: the region, the neighborhood and the corridor.

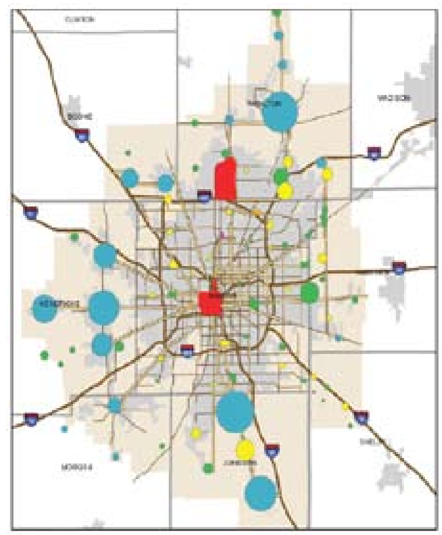
Regional Places:

In Sustainable Transportation Network planning, the first step is to identify the places and connect those places throughout the region with multimodal corridors (cf. Link and Place, S. Marshall), as well as the proper scale of those connections. The Places themselves must be walkable. If the Place is too big to be walkable, it should be broken into neighborhoods, i.e. walkable districts (cf. schematic at right).

Regional Places Diagram
Courtesy of Storrow Kinsella Associates



In Central Indiana, for example,the MPO undertook this planning in partnership with its eight constituent counties and numerous communities. They identified 98 places to connect and also what kind of walkable districts each place constituted ranging from CBD to Village Mixed Use to Village Residential and more (cf. map at right, the district colors designating different pedestrian district types). Each of the connections designated multimodal alignments showing that a corridor or series of corridors were to become paths for transit, bicycle, pedestrian travel as well as automobile. Similar procedures were reportedly undertaken in Denver and Portland. For more information on multimodal regional connections refer to Network and Mode..

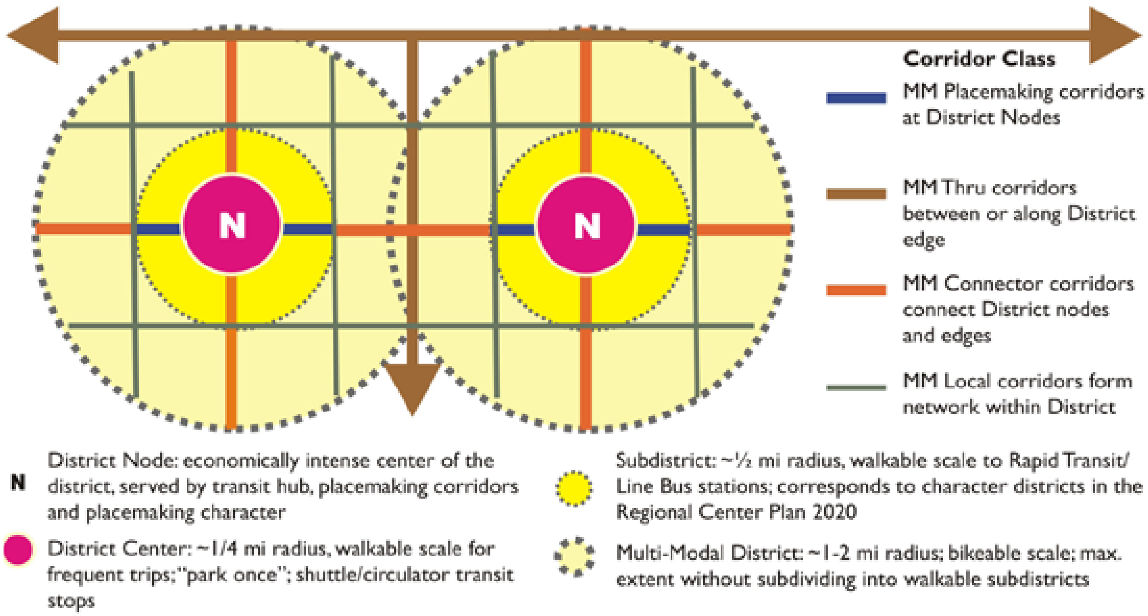


Neighborhoods and Walkable Districts :

Once the location of neighborhoods, basically walkable districts, have been identified, then the next task is determining their centers and edges (cf. Sustainable Urbanism – D. Farr). The district node, a site with a higher intensity of activity preferably near the center of the district and preferred location for a transit hub, should also be determined. Corridors with higher speed travel should be located along the edge of the district, not through. The node is located along a placemaking street at the heart of the district and connected to thru corridors by multimodal corridors, placemaking and connector corridors should be slower moving, but with high people capacity (see diagram below).

Walkable District Diagram

Courtesy of Storrow Kinsella Associates and the Indianapolis MPO



Corridor:

Corridors are places, too. For them to work well, it is critical to focus on multimodal capacity and having the appropriate multimodal corridor at the right place (cf. diagram below), rather than on LOS or vehicle speed. These latter tend to promote wider, faster corridors that destroy places and create sprawl. Transitions between these different corridors and districts should be demarcated clearly. For more information on walkable district and corridor networks, please refer to Network and Place.

STN Functional Class	**Street Types**	**Speed Regime**	**Landuse Intensity & Cross-Traffic**
Thru	Highway, Parkway	35-65 mph	Low & low
Connector	Commuter, Boulevards	25-35 mph	Med & high
Placemaking	Avenues, Mainstreets	15-25 mph	High & high
Local	Local, Links, Quiet	Bike, ped, transit determine speed, not autos	High & low-med

Discussion Starters

Is this framework the right one in principle?
Do we agree with a different functional classification?
Is the 10 minute or ½ mile radius the right place-basis or district size?

METRICS:

Metrics apply on different levels, including optimizing, assessing and verifying (*to attain a certain* *ultimate level of performance or outcome, we call it optimizing, but could be a filtering/winnowing of choices based on threshold values or characteristics, or a weighting, balancing and/or prioritization*):

Optimizing:

First, the metrics must help define or organize the network - the first level of optimizing. Are we serving the places we need to serve? Are we supplying service or too much service where it is not warranted? Are we providing service via all pertinent modes and at the pertinent scale?

Once we have decided what the network is to serve, then we determine the second level of optimization. How do we get the best service within our means for the places we want to serve? Possible metrics include the following: concepts like time to destination, directness, connectivity/ spacing and coverage...

1. Time to Destination, Directness and Circulation patterns

We have now defined places that have a node at the center of a district that is accessible (~ 10 minutes, but varies by district) from anywhere within the district on foot. These measurements can thus be defined between nodes. There should be adequate circulation opportunities which would involve the following:

- Connections should be as direct as possible to prevent circuitous travel, at least as important with respect to time as distance.
- Block lengths should be fairly short (preferably less than 600 feet)
- The transportation system should be focused on the various centers
- The transportation system should be designed as an integrated multimodal system

2. Connectivity and Spacing

There should be adequate connectivity generally between most nodes and more particularly for the following conditions:

- Within and between walkable districts (i.e. neighborhoods) and especially to district centers (i.e nodes).
- From one node to another.
- From one regional center to another and from urban centers to regional transportation facilities
- Connections should be at the proper spacing, too close and the efficiency goes down.

3. Continuity and Convergence

There should be an opportunity for continuous movement for all modes and in particular in the following situations:

- Within districts (neighborhoods can be residential or part of a mixed use development) and in particular converging on the nodes
- Between the nodes (neighborhood centers, town centers, and urban centers)
- Between major facilities (inter regional)

4. Street Hierarchy and Types

The functional classification of streets should address place and moving traffic TO places. The purpose of the corridor and its location relative to the district is of utmost importance. Intensity can change over time, but the corridor's purpose to the network is difficult to change once determined (cf. S. Marshall). These are more characteristics or metrics in the sense of, "do the streets have a functional place-based hierarchy"? (Answer: yes/no or to what degree). Streets in the hierarchy toward the center of the district should have more accessibility, more cross-traffic and more kinds of services and activity.

5. Street Intensity, and Mode Accessibility

Street intensity is a function of this activity intensity and street types. Higher activity intensity results in high traffic demand, which requires more street capacity. In high intensity areas, street types with high capacity should be placed at a higher density to maintain the required capacity. Furthermore, the capacity should be in terms of people capacity, NOT automobile. Thus, if capacity cannot be adequately served by automobiles, all the more reason to serve the needs with transit or other modes. With increasing intensity, more modes should be accessible.

6. Cost and Efficiency

All elements should tie back to cost, what is the cost/person to travel and serve the districts (neighborhoods). {The cost of moving each of us by car everywhere is the problem with the way we do things afterall, isn't it? The classic mobility vs. accessibility curve ignores the element of cost – you can have both, BUT it WILL cost you}

Assessing:

At this point, a tentative network should be proposed, against which we assess its performance. The performance of transportation networks is typically measured along very few dimensions, few of which are meaningful in urban contexts – vehicle congestion, "level of service", and average speeds dominate most performance studies, note that here they are to determine how well the network is working NOT what the network should be designed to. For instance, An LOS D for a placemaking corridor is a mark of success, not failure. A thru corridor should perform more toward a B – if you have an A, the network is probably wasting its capacity. Urban networks require performance for all users, over a wide range of conditions. A broad range of research is underway to compare the performance of alternative networks, including conventional dendritic systems, traditional grids, and some networks approximating the Sustainable Transportation Network (STN). The research ranges from neighborhood to regional scale, from theoretical to empirical, and evaluates alternative networks including traditional connected urban, conventional dendritic suburban, and STN. Results indicate that urban and new urban networks provide equal or superior performance on a number of conventional and broader performance measures.

Clearly, the comparison of alternative networks requires the ability to distinguish among the characteristics of networks as built. However, as indicated in Optimizing above, the range of design criteria in use has conventionally been quite limited. A more robust range, including other than (minimum) speed, supports the design of the STN. Specifically, multimodal connectivity, continuity, circulation, and accessibility measures can contribute to the design of better networks.

A large number of specific measures were examined in current practice and research, with the goal of selecting a small number to carry forward as 1) capable of differentiating between network designs, 2) operationalizable and measurable, and 3) proven or potentially meaningful in predicting performance.

1. Network grain – measured as intersection density or average block size. The former, intersection density, offers the most examples in practice. It should be calculated without including "intersections" with dead-end facilities in the calculation, as they do not contribute to route choice.

2. Pedestrian route directness – includes both vehicle thoroughfares with sidewalks and ped/bike-only thoroughfares.

3. Pedestrian environmental quality, including public realm amenities, character and vitality – operationalized in many ways, but it is critical to include a measure of the quality of the pedestrian experience and not just its "quantity" as reflected in route directness, but can also reflect a balance in the street hierarchy since "every street cannot be an "A" street (Duany)". Would include measures of street-frontage quality and not just sidewalks. This does not need to incorporate crossing if a measure like (4) below is included, but some efforts have combined ped quality and crossing quality into a single measure.

4. Width of thoroughfares – operationalized in different ways, including average pavement width, % of streets with more than four lanes, etc. Can indicate both ease of pedestrian crossing, and complexity of intersections/signals for vehicles.

5. Accessibility – combines multimodal transportation with land-use, most promisingly in measures like "% of jobs within 45 minutes by 3 or more travel modes" and the like, although these are origin or point-specific.

With a set of measures incorporating all five of these key areas, we can begin to distinguish between alternative transportation networks. As the land-use/thoroughfares compatibility sections are more fully developed, it may be possible to measure the share of thoroughfares with designs that accompany appropriate land uses and designs.

Verifying:

This is the evaluation level often consisting of indicators that may or may not be directly related to the optimizing or assessing parameters, including street safety, environmental performance, quality of life, etc. These are difficult to distinguish from the sustainability metrics, so they will be covered in the next section.

Discussion Starters

Which metrics are best for optimizing and assessing networks?
Do they work together in a framework or methodology?

Whereas there are many definitions of sustainability, sustainability is unquestionably about time. These networks should continue to perform well over time. In Australia, they do not have "sustainability" specialists as the triple bottom line is a part of everything ALL practitioners must respect. These networks should probably also take this into consideration. How to implement over time is perhaps the most critical part. For a more complete understanding of this, please refer to Network and Implementation.

Many possible "sustainability" parameters and networks could include: green infrastructure, triple bottom line (social, environmental and economic well-being) measures, adaptability of networks over time – there are more networks than those of cars and people or even modes. Other measures could include cooling streets, stormwater impact and CO2 capture, healthy and safe streets, diversity, opportunity, AND of course economics, including cost of living based upon the quality of network designed. Ultimately if the triple bottom line can be tied to the optimization of the network, this will help not only Transportation Planning, but funding and network implementation, too. Networks may be designed for today, but it is perhaps more important what the network does over time, which may include possibly preparing for DE-construction of corridors that do not serve (cf. Rick Hall). If land use is tied to transportation, does this make for more metrics?

Finally, what best describes the performance of an overall network structure (i.e. the ultimate, overall metric)? Is there a better metric or driver that subsumes all the other components of sustainable transportation planning? One has been proposed:

Generative capacity - the best network is the one that best serves the function for which it was created. Generative capacity describes the "return on investment" or ROI for public infrastructure, i.e. the return to a community for a given investment in infrastructure. **It can be estimated simply by an increase in tax-base/cost of additional infrastructure investment**. The direct linkage is admittedly more complex. Tax base can be roughly linked to land-use intensity and infrastructure is related to transportation and utility infrastructural capacity – co-locating resources diminishing investment costs . Transportation and modes serve places enabling them to become growth poles for economic and quality of life potential, generating more than the input investment alone. This usually can be broken down into cost of service, degree of service (NOT level of service, but how much service and how many ways is the service provided), and efficiency of service (incorporating time into cost). The parameters discussed in this paper can be related to Generative Capacity.

Discussion Starters

What are the best indicators for the network, especially over time?
Which ones best describe the sustainability of a given network?
Is Generative Capacity a good overall metric for evaluating a STN?