MOVING TOWARD A SUSTAINABLE CALIFORNIA

exploring livability, accessibility & prosperity

Susan Shaheen, Ph.D.
Adjunct Professor, Civil and Environmental Engineering, UC Berkeley
Co-Director, Transportation Sustainability Research Center (TSRC), UC Berkeley

Rachel Finson
Research Program Manager, TSRC, UC Berkeley

Abhinav Bhattacharyya
Research Associate, TSRC, UC Berkeley

Mark Jaffee
Undergraduate Student Researcher, TSRC, UC Berkeley

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ABOUT THE TRANSPORTATION SUSTAINABILITY RESEARCH CENTER

The Transportation Sustainability Research Center (TSRC) was formed in 2006. Since TSRC was founded, it has been a leading center in conducting timely research on real-world solutions for a more sustainable transportation future. In addition to performing research informed by a diverse array of perspectives, TSRC also engages in education and outreach to promote its core values of sustainability and equity to ensure that we are able to meet the transportation needs of the present without compromising future generations.

TSRC conducts research on a wide array of transportation-related issues, addressing the needs of individuals as well as the public. Research efforts are primarily concentrated in six main areas:

1. Advanced vehicles and fuels
2. Energy and infrastructure
3. Goods movement
4. Innovative mobility
5. Mobility for special populations
6. Transportation and energy systems analysis.

TSRC uses a wide range of analysis and evaluation tools including: questionnaires, interviews, focus groups, automated data collection systems, and simulation models to collect data and perform analysis and interpretation of the data. The Center then develops impartial findings and recommendations for key issues of interest to aid policymakers in decision-making. TSRC has assisted in developing and implementing major California and federal regulations and initiatives regarding sustainable transportation.

TSRC is managed by the Institute of Transportation Studies of the University of California at Berkeley.

TSRC
408 McLaughlin Hall
University of California, Berkeley
Berkeley, California 94720
Office: (510) 642-9168
http://www.tsrc.berkeley.edu

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Transportation Sustainability Research Center at UC Berkeley conducted a series of tasks to assist the California Department of Transportation (Caltrans) with an understanding of prosperity, accessibility, and livability metrics. Research findings were collected through a combination of literature reviews and expert interviews. Researchers found that prosperity, accessibility, and livability metrics all involve a component of cooperation with partner jurisdictions. A flexible approach that accounts for local and corridor considerations and evolves over time is emphasized. The white paper highlights the importance of equity considerations, data availability, and the scale of measurement.

Prosperity emphasizes long-term or short-term strategies to improve quality of life, focusing on economic indicators, such as income, business, and property values. Prosperity metrics can be used to prioritize transportation projects based on social, environmental, or equity concerns. Accessibility metrics reflect the ability for transportation systems to provide people with access to opportunities. Metrics are centered on travel time and length, land use, mobility, and the availability of public transit. Livability focuses on quality of life improvements with community outcomes and impacts at the local level. Metrics—such as affordability, public health, quality of accessibility, environment, aesthetics, and public participation—all pertain to livability.

INTRODUCTION: PROSPERITY, ACCESSIBILITY & LIVABILITY IN TRANSPORTATION PLANNING

Traditionally, transportation planning has centered on system and road network improvements with a focus on moving vehicles as quickly and efficiently as possible. More recently, some transportation agencies, including the California Department of Transportation (Caltrans), have broadened their scope to include mobility for people (rather than cars), access to goods and services, and quality of life as important planning criteria. Increasingly, state departments of transportation (DOTs) are recognizing the importance of collaboration with local jurisdictions and the use of planning criteria that better meets the needs of all communities, including under-represented populations.

The Caltrans 2015-2020 Strategic Management Plan (SMP) significantly advances the Department's philosophy regarding the important role that transportation plays in all aspects of community and quality of life. The SMP clearly articulates Caltrans' new mission statement to "*Provide a safe, sustainable, integrated, and efficient transportation system to enhance California's economy and livability.*" The SMP is a guide that provides direction to Caltrans to achieve transportation goals and objectives through strategic partnerships. In addition to safety, management, and preservation of infrastructure, the new SMP recognizes Caltrans' role in helping the State reduce greenhouse gas (GHG) emissions and health-based pollutants, while improving quality of life and accessibility to all transportation modes. The SMP calls for performance measures to monitor success.

Many of the five overarching goals outlined in the SMP include aspects of a multi-modal system inclusive of all modes. For example, Goal 3, "Sustainability, Livability and Economy," calls for Caltrans to "make long-lasting, smart mobility decisions that improve the environment, support a vibrant economy, and build communities, not sprawl." Significantly, Goal 1, "Safety and Health," explicitly acknowledges the need to include the safety of all system users including bicyclists, pedestrians, and public transit riders, and reduce negative impacts from GHG emissions, criteria pollutants, and excessive vehicle miles traveled (VMT). Goal 4, "System Performance," also commits Caltrans to collaborate with partners to create an efficient, multi-modal transportation system to increase person throughput, including land-use considerations.

While the SMP outlines five key goals and broad performance measures to meet the goals, the Plan also directs Caltrans to further develop many of the performance measures. Specifically, under Goal 3, Sustainability, Livability and Economy, Caltrans is to develop Accessibility, Livability, and Prosperity Scores that will be adopted by December 2016. The Accessibility Score should consider multi-modal transportation, proximity to jobs, disadvantaged communities, housing services, and transit-oriented communities, among the indices that are developed and adopted. Under Goal 3, Caltrans should increase non-auto modes, reduce VMT, and reduce GHG and criteria pollutants, which are all targets that are anticipated to increase livability. Goal 3 also notes a prosperity goal to increase freight system efficiency 10% by 2020. Goal 4, System Performance, also seeks to improve livability and prosperity by increasing reliability, reducing delays, and providing real-time multi-modal system information on 50% of the top integrated corridors.

By 2020, Caltrans anticipates that transportation and mobility will be a key component toward improved quality of life in California. Caltrans' Goal 3 of the SMP articulates the need to *"make long lasting, smart-mobility decisions that improve the environment, support a vibrant economy, and build communities, not sprawl.*" The California Transportation Plan (CTP) 2040, completed under Senate Bill 391 (California Homes and Jobs Act of 2013), includes a long-term goal to meet mobility needs while lowering environmental impacts. CTP 2040 will become the "interregional equivalent" to Senate Bill 375 (Sustainable Communities Act of 2008). A Sustainable Mobility Program has been implemented in the Division of Transportation Planning to help reorganize Caltrans' efforts in implementing CTP 2040 and Smart Mobility 2010. Smart Mobility 2010 provides the Smart Mobility Framework (SMF) and principles for improving transportation with sustainable outcomes. Specifically, the performance measures of prosperity, accessibility, and livability are the focus of this white paper.

Transportation systems are comprised of diverse interests and issues across a range of invested parties. Considering a broader array of performance metrics enables improved planning, design, and development decisions. **The purpose of this white paper is to provide a stronger understanding of possible metrics that Caltrans might use to measure prosperity, accessibility, and livability, to be used in conjunction with corridor planning, while providing flexibility to meet the needs of regional and local partners.** This white paper presents an overview of the range of metrics that can be used to measure prosperity, accessibility, and livability as developed through a comprehensive literature review, as well as interviews with experts in transportation measurement and planning. This paper includes seven sections: 1) prosperity, accessibility, and prosperity in transportation planning; 2) methodology; 3) cross-cutting themes; 4) prosperity metrics; 5) accessibility metrics; 6) livability metrics; and 7) conclusion. Appendix A provides a glossary of terms.

METHODOLOGY

During the spring and summer of 2016, the Transportation Sustainability Research Center (TSRC) of the University of California, Berkeley completed a comprehensive literature review focused on metrics that have been used to measure prosperity, accessibility, and livability. Sources included academic literature, as well as DOT documents and Internet sources to review planning processes that have considered prosperity, accessibility, and livability. A summary of the metrics identified during the literature review is outlined in Appendix B. Following the literature review, TSRC completed a series of interviews with experts in the areas of prosperity, accessibility, and livability that have experience using these metrics for planning, are working with or evaluating similar efforts with state and regional governments, or both.

CROSS-CUTTING THEMES

Not surprisingly, some metrics identified to measure prosperity, accessibility, and livability can be associated with more than one of these performance measures. While the same metric might be used for more than one application, it is important to note that prosperity, accessibility, and livability are each defined differently. Metrics can be designed to target the specific goals of each metric.

Scale

Understanding the scale at which the performance measurements will be used is helpful to identifying the most useful metrics. The same metric may not be useful at all potential scales of analysis. For example, gross domestic product (GDP) may be at too large of a scale to provide useful information about changes in prosperity at a local level, while percent of shaded sidewalk may be at too granular a level for making regional or state level decisions.

While a discussion of prosperity, accessibility, and livability metrics necessitates collaboration among local, regional, and state partners, deciding the most appropriate scale of measurement (local, corridor, regional, state-wide) is important to selecting the most appropriate metric(s). Fundamentally, quality of life varies based on social, economic, and environmental conditions at the local and regional level. Selecting metrics that capture this variability presents a challenge. In fact, interviewed experts stressed that although standardized metrics have been developed, metrics should be designed to allow for local and corridor variance.

Jurisdiction

Just as there are a wide variety of metrics that might be selected to measure prosperity, accessibility, and livability, there are also a variety of jurisdictions that have authority or planning responsibility that could influence the metric. The experts recommended selecting metrics for which there is some level of control. For example, air quality has been noted as a valuable livability metric; however, a DOT may not have authority over decisions that directly impact air quality. Whereas travel time, a common metric for accessibility, can be impacted by DOT decisions.

Context

The experts noted that identifying the context in which a metric will be used is important to selecting the most appropriate metric. Metrics can be selected to focus on measurement over time to track changes, planning to understand changes associated with different scenarios, or evaluation to track if a project achieved the intended goals. Ultimately, the context in which metrics are used may change over time as data becomes more available and State priorities and policies evolve.

Data (Quantitative and Qualitative)

Both quantitative and qualitative measures can be selected as prosperity, accessibility, and livability metrics. However, qualitative metrics may be challenging to define and track. Other measurements may be needed to represent difficult qualitative goals. For example, data on the quality of public spaces may be readily available, unavailable, or inferred from a collection of data sources, such as percent shade coverage, usage at different times of the day, or both.

Equity

Equity considerations are important for performance metrics. For example, while increasing housing values may signify improving prosperity, the higher costs may be a hardship for persons on limited or fixed incomes. Metrics that can identify distributions of income and race in a region to capture the sub-populations are important. Improvements to quality of life through

increased prosperity, accessibility, and livability are best if they benefit all populations (not a specific sub-population). One expert recommended the use of an affordability index relating transportation costs to per capita income (such as parking and fares compared to income) as a good prosperity metric. The experts also noted that changes to any element of prosperity may affect sub-populations differently. Data aggregated at too high of a level may miss sub-populations. This could adversely affect lower income regions or neighborhoods that are not captured in the aggregate data.

PROSPERITY

Prosperity Metrics in the Literature

Broadly speaking, scores measuring prosperity are based on economic metrics, such as employment, gross regional product (GRP), and freight volume, as reflected in the body of literature.

Variations on jobs and income breakdowns are common metrics for measuring prosperity. The Seven50 Initiative notes the proportion of household income spent on housing and transportation costs (Seven50: SE Florida Prosperity Plan, 2012). Jobs and income/wages are frequently tracked individually (Zietsman et al., 2011) (Weigand, 2008) (Charleston Regional Development Alliance, 2013) and on average (Victoria Transport Policy Institute (VTPI), 2015). The State Smart Transportation Initiative (SSTI) considered short-term employment and employment shifts (SSTI, 2012). The *Workforce Housing Scorecard for Los Angeles* focused on total job growth and the number of new jobs gained or lost, in addition to housing metrics (Los Angeles Business Council, 2008). Job growth, wage and salary growth, and short-term job growth were all tracked in the *2014 Best-Performing Cities* review (DeVol et al., 2015). Jobs, income or value added, as well as high-paying (vs. low-paying) jobs can serve as good prosperity metrics (Roberto, 2008). Of special note are the *TDM Encyclopedia* that tracks employment/unemployment rates in units of Full Time Equivalents (VTPI, 2014) and *San Diego Forward: The Regional Plan*, which monitors the gap between cost of living and wages (SANDAG, 2008).

The composition of GDP, GRP, productivity, and general business success are also recurring themes for measuring prosperity. Relative high-tech GDP growth, high-tech GDP location quotient, and industry concentration in a particular metro area, relative to the national average, was measured by the *2014 Best-Performing Cities* (DeVol et al., 2015). Likewise, a workshop by the National Research Council focused on the contribution of transportation to economic growth (transportation sector value added relative to GDP), logistics (transportation plus inventory) as a fraction of GDP, full-supply-chain distribution cost relative to GDP, growth in transportation infrastructure relative to growth in the economy, and transportation productivity (labor productivity or total-factor productivity) (Norwood and Casey, 2002). GDP and gross national income were both reported as metrics in a report by the RAND Corporation (Ecola and Wachs, 2012).

More directly relating to business, prosperity metrics can include gross business sales volumes and net business profits (VTPI, 2015), as well as additional business growth and attraction

(Weisbrod et al., 2008) and business output (Transportation Research Board (TRB) Circular, 2015).

Prosperity can also be refined as economic gains among population groups of interest. The New Hampshire Secretary of Transportation notes the percentage of discretionary expenditures at small-, women-, and minority-owned businesses in its *2011 Transportation Scorecard*. The Seven50 Initiative was a regional level planning document, which notes the percent of total population that resides in a low-income census tract and more than one mile from a supermarket/large grocery store (Seven50: SE Florida Prosperity Plan, 2012). Another metric of prosperity to consider is the reduction in unemployment rates, poverty rates, or incidence of benefit among selected vulnerable groups (Roberto, 2008). Additionally, comparing housing and transportation costs to the median household income can be useful in gauging the prosperity of a given population (Hickey et al., 2012).

Some agencies use the value of real estate, housing, and related metrics to gauge prosperity. For example, the New York City Department of Transportation specifies retail sales tax filings, commercial leases and rents, real estate transactions, and the number of building permits issued (NYC DoT), while the VTPI notes the value of land and buildings, as well as the value of capital investments (2015). The Seven50 Initiative in southeast Florida tracks the percentage of renter units and owner units affordable to households earning 80% of median family income, affordable housing supply/demand ratios, percent of income spent on housing, percent living in deteriorated or overcrowded housing, population in more/less developed areas, residential valuation in more/less developed areas, and nonresidential valuation in more/less developed areas (2012). Active Living Research also paid special attention to property value impacts (2010), while another group analyzed induced development, among other metrics (SSTI, 2012). Similarly, the *Workforce Housing Scorecard for Los Angeles* focused on total housing growth, the number of new housing units produced, total housing growth as a percentage of the County's housing growth, and changes in housing density, total housing growth, the number of new housing units produced, total housing growth as a percentage of the county's housing growth, and changes in housing density (LA Business Council). Also noted is the increase in land investment, values, and sales in areas affected by projects (Roberto, 2008), as well as building development floor area, direct private investment, property values, and property tax revenue (TRB Circular, 2015).

Freight volume and content are also noted as recurring measurements for prosperity. The New Hampshire Secretary of Transportation considers the number of enplanements, freight through the Port of Virginia, and the Port's market share of East Coast freight volume (2011). Likewise, the State of Washington tracked the amount of freight cargo moving in, out, and within the state as important metrics (2014). Freight transportation costs are also frequently considered (Zietsman et al., 2011). A 2015 report by TRB considered freight cost reduction and commodity flows as important metrics (TRB Circular, 2015).

Occasionally, prosperity is measured in terms of travel times and congestion, as noted in the INVEST Sustainable Highways Self-Evaluation Tool, Version 1.2 (CH2M Hill et al., 2015). Moreover, the *NCHRP Report 708* and the Charleston Regional Development Alliance (CRDA)

have also discussed travel efficiency and congestion (Zietsman et al., 2011) (CRDA, 2013). TRB noted changes in travel time, cost, and level of service (TRB Circular, 2015). Similarly, a workshop also noted transportation capacity use (Norwood and Casey, 2002) and VMT (Ecola and Wachs, 2012), while Weisbrod paid attention to time and cost savings in work-related travel, additional business growth and attraction, logistics-related user cost savings, and the non-work value of personal time saved (2006). Finally, *San Diego Forward: The Regional Plan* focused on "last-mile" access to employment and educational facilities (SANDAG, 2008).

The prosperity production of transportation projects is also considered, primarily in regard to the number of jobs created and the revenue generated from construction. The State of Washington considers the number of jobs created by transportation construction (2014). *Infrastructure Investment Creates American Jobs* was especially thorough, measuring impacts to the national economy due to escalating backlog, construction commodity purchases, construction direct employment and labor income, construction labor and proprietor income, administration spending, maintenance commodity purchases, maintenance direct employment and labor income, and maintenance labor and proprietor income (Brun et al., 2014). In a case study, the Progressive Policy Institute noted wages and salaries earned by those working on the project spent on goods and services, the number of workers immediately involved in construction, as well as the jobs required to support those workers (such as architects, engineers, and on-site food and sanitation providers) (Carew and Mandel, 2014).

Some researchers, including the VTPI, are careful to pay attention to transportation prices and their impacts on individuals. Specifically, they have noted the price of parking and fares (Litman, 2014), as well as transport costs relative to income and transport expenditures by income class (VTPI, 2015). This is corroborated by the National Research Council, which has suggested tracking transportation prices as an index of the aggregate price of transportation services, possibly divisible by mode or commodity (Norwood and Casey, 2002).

A few other metrics that were not recurring but were noted in the literature include:

- General local government debt-to-revenue ratio in southeast Florida (Seven50: SE Florida Prosperity Plan, 2012);
- The value of tourism (Weigand, 2008);
- Air quality (CRDA, 2013);
- Improvement in market opportunities, scheduling/logistics productivity, and other cost efficiencies for businesses and residents in the affected area (Roberto, 2008);
- Value of taxes paid; education, health, longevity, crime rates, housing quality, public services, etc.; and changes in self-reported life-satisfaction ratings (Litman, 2015);
- Broadband speeds (Carew and Mandel, 2014); and
- Additional miscellaneous prosperity metrics include cost efficiency and economic vitality (retail sales, building vacancies, and visitors) (VTPI, 2014).

A potentially useful tool that can be used for the development of prosperity indicators for other DOTs is the *Opportunity Score*, developed by Redfin. This program ranks 350 U.S. cities based on the number of jobs that can be accessed within a 30-minute walk or public transit ride. Users can input an address where locations are assigned an opportunity score based on walk score data, real estate information, percent of jobs available by public transit or walking (Redfin, N. d.).

Prosperity Metrics Expert Discussion

As a concept, prosperity was broadly defined in the interviews in terms of economic benefits that also improve social equity and the environment. According to the experts, prosperity is often divided between direct measures of prosperity, drivers that cause increased prosperity, and outcomes that result from prosperity. When assessing prosperity, the experts noted there are challenges associated with representing the multifaceted interests of prosperity while not creating contradictions when prioritizing design and planning decisions. One strategy suggested by the experts to address this concern is to set up a scoring system before projects are prioritized so that interests are weighted on a system-wide basis rather than project-by-project. Another expert indicated that a guiding principle for selecting economic metrics should be increased access and a better quality of life for the community. From this perspective, metrics that focus on improving cost savings for individuals are important. Prosperity strategies are commonly based on per capita income improvements and opportunities for increased standard of living.

Experts emphasized that prosperity metrics and interests are dynamic and change over time. Since prosperity metrics are likely to vary by situation and location, experts thought prosperity metrics are best defined at the local and regional level. One expert recommended the need to accurately align criteria to prioritize transportation projects with current prosperity interests, which can require the re-evaluation of existing prosperity metrics. For example, local prosperity interests may prefer infrastructure efficiency improvements over capacity expansion projects at a time when transportation networks do not meet transportation demand. Another expert noted that DOTs could use prosperity metrics to determine the priority for repairing or maintaining existing infrastructure assets that would contribute toward increased system efficiency.

One expert suggested jurisdictions could compare themselves with similar regions to establish a standard of prosperity performance on a comparative basis for prosperity metric development. Records can be maintained and compared over time to monitor progress toward prosperity interests. Since DOTs should be responsive to changing interests pertaining to prosperity, DOTs might find it necessary to introduce new prosperity metrics over time.

One expert defined prosperity as the culmination of GDP growth from an economic point of view and the creation of stable, high-paying jobs from a societal point of view.

Another expert suggested real estate, rents, housing and commercial leases as indicators of prosperity for a population. Increasing property values signifies growth, as long as affordability

of housing is taken into account. State DOTs can prioritize equity concerns, especially across minority and economically weaker demographics for overall economic prosperity.

According to experts, freight volume is another important indicator of prosperity, but the effectiveness of the indicator depends on how the metric is measured. Total and aggregate measurements of freight can be misleading, since a significant amount of freight travel may be to destinations outside the region or empty vehicles returning to a point of origin. Thus, percent of freight retention may be a more effective metric to accurately measure freight volume. One expert thought special attention should be given to high- and low-priority freight corridors. Prosperity metrics for freight projects could be weighted by the number of jobs and income impacted. Goods movement travel time has an effect on job accessibility and therefore impacts economic development models. Same-day delivery for perishable products and the radius of employability are all indicators closely tied to prosperity.

Travel time and congestion were noted by experts as related metrics that may indicate prosperity and growth. However, one expert suggested minimizing travel time and congestion in relation to prosperity. Another expert focused on congestion as a dependent variable for business reliability. Congestion has an adverse effect on productivity whereas a swift, efficient transportation system can boost the productivity of individuals. Reliability, congestion, and economic prosperity are very closely tied together.

Some experts valued the temporary jobs and revenue created from transportation infrastructure construction projects while others considered the travel efficiency improvements over the useful life of infrastructure more important than the jobs and revenue created by construction projects. Experts also drew attention to improvements in tourism as a way to increase state-wide income by making the state more competitive and productive. However, the tourism industry may create lower income jobs, limiting the potential for improved quality of life. The experts noted that prosperity should focus on long-term, economic improvements, not transfers of wealth.

Experts supported the use of economic output, employment, and productivity metrics that could be used to directly measure prosperity. One expert specifically mentioned a benefit-cost analysis as a useful tool to assess user benefits, such as wealth savings, increased public safety, and improved environment across a region. Economic-centered metrics can link the prosperity of a region to competitiveness among states. Experts recommended reliability, market access, expansion of delivery markets, and intermodal connectivity as metrics. In addition, the economic prosperity of the population at large can be determined by the presence of out-of-state investments of private equity. Experts had mixed opinions on whether GDP and GRP were useful economic indicators; GDP and GRP may be useful when compared, but certain economic indicators may require a broad GDP measurement or a more specific GRP measurement.

Among non-economic prosperity metrics, experts mentioned quality of life, pollution levels, air quality, and quality of intermodal connectivity as potential, prosperity metrics that are closely connected with livability.

Experts stressed that determining how data are compared with goals and objectives to monitor progress is especially important. DOTs can choose to contrast previously implemented performance metrics with current metrics or examine the differences between current metric design with future goals and objectives. Two experts recommended learning from the successes of other transportation agencies at the state and regional level.

One expert suggested the prosperity metric with the largest potential for economic change, before and after implementation in a transportation planning model, indicates the most important opportunity for improvement. As economic benefits are defined at different jurisdiction levels, systems can be designed to weigh benefits differently in order to better prioritize prosperity interests. One expert recalled a "points system" where projects earned points for supporting both state or state and regional goals, but lost points if the project only benefited regional goals. Another expert described an effort made by regional and local DOTs to convene with partners in business meetings to update strategic goals and objectives.

The experts noted that prosperity indicators should be viewed through a perspective that incorporates equity, where no population is disadvantaged by prosperity improvements to another population. Income equity is a key component to prosperity where low-income equity and job opportunity serve as indicators for prosperity. Social equity ensures that the beneficiaries of policy and economic decisions include the average traveler and not specific populations. Although income distribution is available to connect accessibility with income, it is difficult to obtain accurately. Income gains should therefore vary with population and income distribution to ensure prosperity benefits are appropriately distributed throughout an area. Common metrics include average wages, rate of yearly appointment, and wage distribution across industries and location. Experts also considered affordability as a key component of equity and transportation costs. One expert thought that a benefit-cost analysis that connects affordability with transportation would be helpful. Another expert suggested that using an affordability index relating to transportation (such as parking and fares compared to income) could also be a good prosperity metric.

ACCESSIBILITY

Accessibility Metrics in the Literature

The literature often characterized accessibility as a person's overall ability to reach services and activities. In broad terms, the current literature has focused on accessibility metrics concerning motor vehicle travel time and delay, using indicators such as roadway level-of-service, the travel time index (an indicator of congestion intensity), and average commute duration. Until recently, most accessibility indicators focused on automobile travel, but in recent years indicators of walking, bicycling, and public transport (including air travel) access have been developed. Access to jobs, in addition to other destinations such as schools and essential services (medical services and shopping), was also noted in the literature. Accessibility is one of the most quantifiable ways to measure the development and inclusiveness of a region, and a number of metrics are used to quantify accessibility.

Travel time is the time required for someone to get from point A to point B. Travel time is most commonly calculated as the time taken by individuals to travel from their place of residence to their workplace. In relation to travel time, the measurement is often how many jobs or places are reachable within a specific timeframe from one's residence. The University of Minnesota measured how many jobs were reachable via public transit within 30 minutes during morning commute hours (Owen and Kasziolka, 2015) and how many destinations were reachable among given travel times via automobile (Levinson, 2013). Another study by the University determined the number of jobs that were reachable in 46 of the 50 largest metropolitan areas in the United States during morning commute hours (Owen and Levinson, 2014). Similarly, the VTPI also measured how many jobs were reachable by an automobile within certain time periods (Litman, 2016). The Hubert H. Humphrey Institute of Public Affairs calculated how many low-, medium-, and high-wage jobs were reachable given predetermined travel times (Fan et al., 2010). Under its Smart Scale project prioritization process, the Virginia Department of Transportation scored projects based on the number of jobs reachable by automobile within 45 minutes and by public transit within 60 minutes for the general population and for disadvantaged populations. Their measurements included a decay function, which assigns a higher value to nearer jobs (Virginia, 2016). Among the various factors influencing travel time, the literature takes into account travel modes and time of day. Shin et al. (1994) discusses travel times both during free flow conditions and peak-hour congested conditions, as well as walking times to the nearest subway station.

The University of Minnesota's Center for Transportation Studies explains in *Access Across America: Transit 2014* that accessibility is commonly measured in terms of travel time to points of interest, yet job trip indicators are more significant from an accessibility standpoint. The study measures how many jobs could be reached from different points in space weighted by the number of workers residing in each census block and averaged them across the entire metropolitan area (Owen and Levinson, 2014). The calculations include all components of a public transit journey, including "last mile" access and egress walking segments and transfers. The University of Michigan also measured reachable destinations by zones, but researchers weighted them negatively by the difficulty in reaching them (Grengs et al., 2010). Along the same lines, Grengs (2010) measured jobs that were reachable from a zone or neighborhood, adjusted for travel difficulty, and observed the spatial difference in the demand for jobs.

While many accessibility measures evaluate access to jobs, several consider access to other types of non-work destinations. Grengs et al. (2010) developed gravity-based accessibility measures (meaning the weight of each destination is inversely proportional to the travel time required to reach each destination squared) for work and non-work destinations by automobile and public transit. Measurements were used to compare the relative accessibility between San Francisco and Washington D.C. Merlin (2014) developed gravity-based accessibility measures for jobs, retail and service sector jobs, and non-work destinations. The study finds that a balance of work and non-work activity accessibility needs to be measured at the local and regional level for complete communities (Merlin, 2014). Pyrialakou, Gkritza, and Fricker (2016) measured accessibility to hospitals, schools, and other destinations in transportation-

disadvantaged urban communities or rural areas where opportunity and population density may be lower than high-populated areas. Walk Score, available online, provides a measure of accessibility to education, retail, food, recreational, and entertainment destinations by walking.

Factors that can further influence accessibility are the road networks and infrastructure. Reilly et al. (2009) observed the distance to a region's Central Business District via the nearest highway with more than two traffic lanes. Another study by Chen et al. (2007) discusses link speeds in a network to reach employees within a time threshold. Bocarejo and Oviedo (2012) focused on level of service and supply of infrastructure to help classify access levels. These levels of access were further weighted based on types of activities available and number of activities feasible under the time threshold. The University of California, Davis further explored street connectivity and street patterns (Sciara, 2015).

In addition to the standard metrics of accessibility, the literature also considers how accessibility can be affected when the routine transportation network is hindered or changed. Chen et al. (2011) adopted a combined travel demand model to evaluate the long-term equilibrium network condition due to network disruptions. The study presents measures for assessing vulnerability of degradable transportation networks, as well as examining link failures and the behavioral responses. The National Cooperative Highway Research Program released a guidebook for sustainability performance measurement for transportation agencies in which it discusses how network disruptions result in increases in travel times and lowers accessibility significantly (Zietsman et al., 2011).

Mobility was mentioned as a component of accessibility in the literature and in the *Access to Destinations* study, by the University of Minnesota's *Center for Transportation Studies*, explores this concept. The interdisciplinary research program develops tools and data sets to quantify overall accessibility at the Twin Cities regional level by taking into account multiple modes (walking, cycling, public transit and automobile) and land use development patterns. Subsequent research analyzed accessibility by mode (automobile and public transit) and purpose (work and non-work trips) for about 30 US metropolitan areas (Levine, et al. 2012). The analysis indicates that although denser urban development tends to reduce vehicle travel speeds, it increases geographic accessibility, which is about ten times more influential than travel speed in determining a metropolitan area's overall accessibility.

Access to public transit is a major component of accessibility. Much of the literature covers the extent of the public transit network in terms of travel time while using public transit. However, an often-overlooked measure is one's distance from the station to home or work, commonly described as the 'first mile-last mile'. The VTPI discusses, in addition to jobs relative to a regional urban center, the quality of public transit serving a location and its ease of access via walking, cycling, and automobile (Litman and Steele, 2016). The United States Environmental Protection Agency (US EPA, 2011) also observed the distance to public transit stops. Trips within a quarter mile of transit stops were measured, as well as population and household counts close to public transit stops. The US EPA (2016) also studied the locations of home and

work locations within a 45-minute trip incorporating both public transit and the walking distance from transit to the desired location.

Increasingly, equity is considered as it greatly affects accessibility. Many mid- and high-income households have different options and opportunities to increase their own accessibility. The demographic that has the least opportunity to increase their own accessibility are low-income households and the physically challenged. Low-income households have their options limited because their neighborhoods are usually farthest away from popular attractions, job centers, and reliable public transit. Physically challenged populations have more obstacles when traveling, even from the most basic transportation mode, i.e., walking. Georgia State University and North Carolina State University studied disadvantaged populations and their travel times via public transit, as well as pedestrian safety and access (Lane et al., 2015). The United States Department of Transportation (2015) looked at the number of low-income jobs accessible by public transit, as well as the number of transit corridors and their walkability.

Another commonly overlooked metric in terms of job accessibility relates to the negative perceptions of public transit riders compared to car users in many urban job markets. There is a clear connection between transportation accessibility and economic opportunity, which has been analyzed by the Mineta National Transit Research Consortium (Smart and Klein, 2015). This research examined the relationship between economic outcomes and transportation access over a 14-year period. It compared two forms of transportation access: public transit accessibility and car ownership. Eight waves of panel data were used from the Panel Study of Income Dynamics to assess how public transit accessibility and car ownership shape future employment outcomes and earnings. Further, the same panel dataset was used to estimate the costs of car ownership to examine if the increased earnings from access to cars outweighs the financial burdens of car ownership. This research found that improving automobile access is associated with a decreased probability of future unemployment and also with greater income gains. However, the analysis suggested that the costs of owning and maintaining a car may be greater than the income gains associated with increased car ownership. The relationship between public transit and improved economic outcomes was less clear. The authors suspect that public transit accessibility is a proxy for other aspects of the neighborhood or residents that were unable to be included in their model.

Locational access to air transportation in the United States was analyzed by the University of Missouri and Drexel University (Matisziwa and Grubesic, 2010). The researchers proposed a new metric to incorporate measures of access to air transport, as well as accessibility within air transportation networks. Using a comprehensive dataset on scheduled airline service, the developed approach was then applied to the US domestic commercial passenger air transportation network to explore geographic differentials in accessibility. The results suggest marked differences among core-based statistical areas throughout the US.

Some tools created for the development of accessibility indicators for other DOTs include:

- Citilabs' *Sugar Access*: an integrated Geographic Information Systems (GIS) software program that communities can use to quantify the access (time and financial costs) of accessing various types of services and work/non-work activities (healthcare, shops, schools, jobs, parks, etc.) by various travel modes in a particular area. Accessibility scores can evaluate accessibility within a certain area and scenario planning tools can be implemented (Citilabs, 2016).

- The Metropolitan Chicago *Urban Accessibility Explorer:* a mapping system that measures the number of activities, including various types of jobs, schools, parks, stores and libraries, that can be reached by residents of a specified neighborhood within a given amount of travel time by a particular mode and time of day in the Chicago Metropolitan area. The Accessibility Explorer was developed by the Department of Urban Planning and Policy at the University of Illinois at Chicago to help policymakers, planners, and the general public easily evaluate how transportation system and land use changes could alter accessibility (Tilahun, N. D.). The results are displayed on maps that can be adjusted by scale and area.

- *20-Minute Neighborhoods* by the City of Portland: uses GIS mapping to evaluate the number of commonly-used services that can be accessed within a 20-minute walk of residences. The tool also can take into account the infrastructure that exists for pedestrians and cyclists to reach those destinations (2012).

Accessibility Metrics Expert Discussion

Accessibility describes the ability for transportation systems to provide people with access to opportunities*.* Accessibility metrics usually measure the total number of job opportunities available within a certain amount of travel time at peak periods of traffic to accurately reflect road and public transit conditions. Travel time is defined as the total amount of time a traveler spends commuting to public transit stops (first-mile and last-mile), waiting for transit, and time in transit to destination. Accessibility metrics that measure time proximity to opportunities relate places and time in an aggregate, cumulative data set. This metric strategy is beneficial for analysis, but other indicators can be used in addition to work-home trip pairings. Work and non-work trips should not be bundled together when evaluating accessibility. Experts identified cumulative and weighted metrics as two primary types of accessibility metric strategies that could be used at a state DOT level. Cumulative accessibility metrics identify a total capacity proxy for all destinations that can be reached in a certain amount of travel time. This method measures the travel time between arbitrary origins and destinations, so some accuracy and detail is lost. Weighted accessibility metrics evaluate the weight of destinations with time to determine accessibility. Closer destinations possess a greater weight than farther away destinations. Weighted metrics allow for a more transparent analysis when comparing travel time and destinations.

Accessibility metrics serve as a way to measure how transportation creates new opportunities. However, these opportunities are difficult to measure. Experts noted that implementing a standardized set of accessibility metrics at the state DOT level may not be helpful, since there are unique regional and local land use situations where standardized metrics may not be

appropriate. States, regions, and local jurisdictions have been at the forefront of accessibility metric development with many active programs to measure accessibility. Some states have formalized accessibility as an important aspect of their city and regional planning processes. Some experts expressed concern that the data to support metric development across public transit modes was unreliable. Transportation networks were so large that data collection required information on the costs, types of destinations, and other details about populations and their origin that may not apply to accessibility measures at the local level. Other experts believed there is no longer an issue with the availability of General Transit Feed Specification (GTFS), HERE and INTRIX (roadway and travel speed data), LHED Origin-Destination Employment Statistics (LODES), InfoUSA, and tools like Sugar Access by Citilabs.

All of the experts thought of equity as an important aspect of accessibility. Equity analyses can be used as a tool to identify public transit need for low-income populations in areas where problematic transit connections are known to occur. The same can be true for physically disadvantaged populations. However, physically disadvantaged populations are not as geographically centered. If the physical abilities of a traveler changes, then the ability to access travel modes may also change. Metrics to measure transportation equality should reflect a system-level understanding, such as percent of handicapped accessible intersections. Metrics should be disaggregated enough to capture which populations are exposed to different modes and levels of accessibility. Transportation equity is a subset of accessibility, ensuring that any person with any level of physical ability or income can access destinations that allow for increased access to opportunities and quality of life.

In the long term, travel infrastructure and modal planning should aim to decrease travel time, enabling people to travel farther distances to gain access to more opportunities. Experts thought that focused efforts on creating sustained job opportunities for future residents may result in a more desirable place to live over time. In the short term, accessibility metrics should focus on improving current commute conditions by capturing the travel behavior of residents in an area and reducing travel costs.

Since a large part of accessibility is closely linked with land use, DOTs may want to consider how to best include land use when considering accessibility. As land use is a local concern, state DOTs can work at different levels of aggregation with their partners to coordinate accessibility improvements. Experts encouraged state DOTs to separate road and public transit accessibility as much as possible to develop better indicators and improve results. Public transit corridors, network, and land use data reliability all create challenges for state DOTs to determine where accessibility improvements are needed most. One expert mentioned analyzing connection networks from state DOT facilities to regional and industrial points as a way to identify opportunities for improved accessibility. Each region and industry has different land use criteria that can help to identify system availability and accessibility issues. Travel time data can be collected from local sources where land use improvements can be tied to accessibility benefits.

Accessibility closely relates to mobility, as this metric indicates what transportation development needs to happen. Mobility evaluates transportation systems based on three core

criteria: usage, destination, and ease. Analyzing the properties of the transportation modes and networks people use to connect from one location to another allows time considerations and transportation network efficiencies to be taken into account. Transit disconnections can cause significant changes in travel time that impact accessibility, as access to opportunities can be significantly altered if routine transportation networks are hindered or changed. Accurately representing public transit networks is key to accessibility measurements: models can be adjusted for expected speed versus attainable speed, or schedule/service interruptions that could negatively affect accessibility. Using proximity to transit systems and destinations ties land use with accessibility. By using readily available data, such as census data to know trip origins and destinations, DOTs can better recognize points of interest to ensure facilities, infrastructure, and connections between public transit options exist for reaching those destinations. One expert identified accessibility as the potential for ease and engagement. Since accessibility looks at the capacity and ability for people to engage with a public transit system, travel time can be used to quantify the degree of ease and engagement. Factors, such as changes in elevation and percent sidewalk cover, can be built into accessibility scores on an as needed basis to more closely correlate ease of travel with accessibility. Another expert identified safety and risk as factors that are not commonly considered when evaluating accessibility. Decreased overall safety of a travel mode may negatively affect the ease of using the system and therefore lower the number of people willing to use that particular mode to access opportunities.

Availability and accessibility are interconnected. Availability of transportation modes and the presence of infrastructure to get to a desired location are major components of accessibility that can greatly impact travel time and access to job opportunities and other key locations. Maximizing availability of transportation modes and the presence of necessary infrastructure to get to a desired location can lower travel time and improve accessibility.

Some of the leading research groups / programs that develop accessibility indicators and were mentioned by experts include:

- The Accessibility Observatory, within the Center for Transportation Studies at the University of Minnesota, is a leading resource for the research and application of accessibility-based transportation system evaluation (Center, n.d.).

- European Cooperation in Science and Technology (COST) is a coalition of private industry and professional researchers who are developing practical tools and implementing strategies for accessibility planning (European, n.d.).

- The Brookings Institution and their *Moving to Access (MTA) Initiative* that aims to inform and promote a more socially focused, access-first approach to urban transportation policy, planning, investment, and services (Tomer, 2016).

LIVABILITY

Livability Metrics in the Literature

Livability is defined in the Caltrans SMP as a sustainability strategy that supports quality of life improvements, efficient land use, livable public spaces, social engagement, natural systems, local businesses, long-term community outcomes and opportunities for improved environmental conditions. The metric for livability that appears most consistently in the literature pertains to accidents and injuries. The American Association for Retired Persons (AARP) tracked pedestrian fatalities and injuries (Farber et al., 2011), while researchers at the University of Colorado Denver reported the fatal or injurious crashes annually per 100,000 residents (Marshall, 2013). In a similar vein, the VTPI noted per capita traffic casualty rates (injury and death) (Litman, 2011). A report by the Federal Highway Administration (FHWA) focused more on the types of accidents, specifically rear-end conflict crashes during turning movements at signalized intersections, in addition to crash rates in general (Grant et al., 2012).

Crime, or the lack thereof, is also a strong indicator of livability. Wesley Marshall of the University of Colorado Denver referred to violent crimes annually per 100,000 residents as a measure of livability (2013). Similarly, the VTPI noted specifically traveler assault and crime rates (Litman, 2011).

Accessibility to facilities, services, and recreation is also strongly tied to the measurement of livability. *Aging in Place*, by the AARP, gauged access to intercity transportation (Farber et al., 2011), while Marshall (2013) considered the number of jobs within one mile of a transit oriented development (TOD). Likewise, 'Creating Livable Communities' chose to consider jobs within one mile of public transit, as well as the percent of workforce living within a 30 minute or less commute from primary job centers (Rue et al., 2011). Finally, researchers at the Mineta Transportation Institute used the metric of personal mobility, which they defined as person miles traveled, person hours traveled, and person hours of delay (Fabish and Haas, 2013).

Analysis of modal share is also common in relation to livability, specifically with regard to the use of personal vehicles compared to bikes, public transit, and walking. *Aging in Place* again noted the percentage of trips two miles or less made by car as a specific measurement of commuter modal share (Farber et al., 2011). The VTPI defined commuter mode share as the "portion of travel by walking and cycling" (Litman, 2011), while the University of Colorado Denver used the percentage of survey respondents walking or biking to work (Marshall, 2013). An analysis of the implementation of pedestrian factors into the SF CHained Activity Modeling Process (SF-CHAMP) model by the San Francisco Country Transportation Authority (SFCTA) and the Alameda County Transportation Commission (ACTC) used travel diary and modal shift data (Bomberg et al., 2012). Finally, a meta-analysis of livability at five metropolitan transit organizations (MTOs) found precedence for the proximity and quality of public transit, pedestrian, and bike options as well as the mix and balance among the modes as metrics (Fabish and Haas, 2013).

Following modal share, the utility of public transit appears frequently in reports pertaining to livability. A University of Colorado Denver report tracked the ridership of public transit, transit

score, and pedestrian shed, or percent of half-mile "as-the-crow-flies" walkable zones accessible via the network (Marshall, 2013). Similarly, the Mineta Transportation Institute considered the proximity and quality of transit, pedestrian, and bike options as notable metrics for livability (Fabish and Haas, 2013). Ducas (2011) from the Massachusetts Institute of Technology (MIT) emphasizes how public transit stops are sited in relation to destinations, such as parks, schools, and employment.

In addition, pedestrians and walkability is the focus of a subset of livability metrics focused on accessibility. In *Active Transportation, Citizen Engagement and Livability*, the authors aggregated the length and location of pedestrian networks (sidewalks), as well as the volume of pedestrians (Schlossberg et al., 2012). The University of Colorado Denver tracked a walk score and the walkability of various areas (Marshall, 2013), and the Mineta Transportation Institute found pedestrian volume and diversity to be influential (Fabish and Haas, 2013).

Congestion and delay, another metric class more typically associated with accessibility, also appears in livability reports. A report sponsored by the FHWA noted travel delay as a livability metric (Rue et. al, 2011), while travel time is noted by the SFCTA and ACTC (Bomberg et al., 2012). Fuel use, delay cost, vehicle speed, and traffic cost also appeared in the five MTOs analysis (Fabish and Haas, 2013).

Collecting metrics on demographics is a way to measure livability through social equity. A report by the University of Colorado Denver used area-by-area measures of mixed income (degree of evenness ranging from 0 to 1), mixed race (degree of evenness ranging from 0 to 1), and the creation of affordable housing (Marshall, 2013). *Towards Livability Ethics* focused on the presence of affordable housing and transportation choices as important metrics (Appleyard, 2013). In a broadly social context, a paper from MIT seeks the prevalence of community, particularly volunteerism, social networks, and diversity of ages and ethnic groups (Ducas, 2011). Home ownership in general is also considered, as the Mineta Transportation Institute found the job–housing balance, density of housing and jobs, home ownership rates, and the range of housing ownership and financing types to have all been used to measure livability (Fabish and Haas, 2013).

The Promise of Rural Roads, prepared for the TRB 'Low-Volume Roads Committee', outlines a variety of unique metrics based on its subject of analysis, much of which translates into this present report. Access to jobs and economic opportunity, durable housing resistant to natural disasters, provision of potable water, electricity, information and communication technology, quality schools, and reliable health services all fall under its purview. Aesthetics are also considered, specifically the environmental and social quality of an area as perceived by residents, employees, customers, and visitors. Finally, safety and health (traffic safety, personal security, and public health); local environmental conditions (cleanliness, noise, dust, air quality, and water quality); quality of social interactions (neighborliness, fairness, respect, community identity and pride); and opportunities for recreation and entertainment, aesthetics, and the existence of unique cultural and environmental resources capture additional aspects of what it means for a community or region to be "livable" (Faiz, 2012).

The VTPI placed special emphasis on metrics of air quality and pollution. A large part of their report was based on these metrics, including per capita emissions of global air pollutants such as carbon dioxide (CO_2), chlorofluorocarbon (CFC), methane (CH_4), etc., and local air pollutants including particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxide (NOx), carbon monoxide (CO), etc., and general exposure to harmful pollutants. This report also included noise pollution as a tangentially-related metric (Litman, 2011). Similarly, the five MTO analysis produced the metric of emissions, specifically pounds of CO, CH_4, NOx, and CO_2 (Fabish and Haas, 2013). Associating air pollutant emissions and air quality with livability was also a feature of *The Role of Transportation Systems Management & Operations in Supporting Livability and Sustainability* (Grant et. al, 2012).

Zoning, density, and land use also seem to influence the definition of livability, often in relation to recreation and aesthetic metrics. The five MTO study noted the mix and balance of uses, open space, social infrastructure, and the density of stationary activities (Fabish and Haas, 2013). A MIT report suggests the metrics of land use patterns, green space, local business ownership, and cultural amenities as well as aesthetics, cleanliness, safety, availability of seating, availability of shade, and building conditions (Ducas, 2011).

Cost is a recurring metric for livability. The cost of transportation and housing is included in a report by the University of Colorado, Denver (Marshall, 2013). The FHWA tracks both cost of housing and the percent of housing located in walkable neighborhoods with mixed use destinations located nearby, as well as the efficiency and use of existing transportation facilities (Grant et al., 2012). *Transport Infrastructure and Global Competitiveness* considers land prices and rent to be important considerations for livability (Cervero, 2009).

Michael Fein (2014) emphasizes that "we should not insist on a fixed, crystallized definition of livability," while there is a need to "remain sensitive to the difficulties imposed by these ambiguities". He cites examples of some of the more common metrics, such as crime rates, access to public services and infrastructure, and levels of employment in addition to some less common metrics, such as pollen levels, public art, and green spaces to exemplify the changing definition of livability as transport modes change.

Some tools created for the development of livability indicators for other DOTs include:

- *Revision*: A regional mapping, analysis, and visualization program, created by UCLA's Lewis Center for Regional Policy Studies, that integrates a range of public and private data and performance indicators suitable for sustainable community evaluation. Developed for the greater Los Angeles area, livability, land use, and mobility/accessibility can be mapped. Filters can also be applied to the map by public transit mode or job accessibility (UCLA, 2016).

- *Smart Location Mapping:* A program by the Environmental Protection Agency that identifies more than 90 infrastructure variables and indicators that contribute toward interactive maps and data for measuring location efficiency, including the effects of the built environment on per capita vehicle travel and methods for measuring access to jobs and workers by public transportation (United, July 2016).

- *Toolbox for Regional Policy Analysis*: An analysis tool by the United States Federal Highway Administration that describes analytical methods for evaluating regional economic, social, and environmental impacts of various transportation and land use policies. The tool box contains examples, case studies, and other references (Federal, 2012).

Livability Metrics Expert Discussion

Experts broadly defined livability as set of opportunities that enable people to improve their quality of life. If livability is defined in terms of community outcomes, metrics could include public health, community safety, community involvement, community capital, or community equality. Livability is best defined at the local level, where values, interests, and community outcomes change by geographic location. One expert noted that community concerns and geography determine livability from neighborhood to neighborhood.

Livability metrics can help determine where development should happen, yet there are no standardized livability metrics for state, regional, and local use. Priority among social, economic, and environmental livability metrics is determined by community values and interests on a neighborhood-by-neighborhood basis. Since livability is oriented toward local impact, metric implementation is guided by the ultimate vision for the community. Experts stressed that metrics must be allowed to vary along a corridor and that no complete set of metrics can apply to all areas. Common livability metrics include: visual quality, amount of green space, air and noise pollution levels, physical activity and fitness, quality of accessibility for disadvantaged people, and affordability.

Efforts to standardize livability metrics may inadvertently include some overlap with accessibility, prosperity, and other sustainability-oriented metrics. Metrics focused on affordability, environment, public health and safety, diversity, proximity to entertainment and culture, population density, and amount of green space may specifically be good livability indicators. Livability metrics use subjective, qualitative data that can be challenging to define and measure due to limited data.

A transportation equity analysis is an important tool for identifying where livability has the greatest potential for improvement. Experts considered social and income equity as important components for livability metrics. When applying transportation equity to livability, aggregate data should not be used if disadvantaged groups may be harmed. Equity in accessibility means that any person regardless of income should be able to live in a public transit rich neighborhood. Quality of life improvements should be spread equally across all residents in a particular area.

Most experts agreed that injuries and accidents extend to metrics for livability, but they could not agree on a way to measure the data. One metric suggested by an expert counted the total number of injuries and deaths measured on a risk per capita (100,000 people) versus a miles traveled basis to allow for a measure that reflects improved safety and internal capture (a measurement of the number of trips that begin and end within a corridor) rates. Improved corridor health opportunities can potentially benefit quality of life and livability. Perception of

safety and public comfort collected through perception surveys can help to identify opportunities for livability improvements. Metrics, such as street ecology, number of lanes, width of lanes, travel speed, frequency of stopping, traffic volume, street geometry, tire index, and increased walking activity, all affect perceptions of safety. The prevalence of crime in an area can also be a strong indicator of livability and safety, as crime is highly impacted by street ecology. Metrics should be adapted for per capita crime rates and normalized by income to better reflect crime activity and street ecology.

Although livability and accessibility are tied closely together, livability examines the quality of accessibility for physically, economically, or other disadvantaged populations and their necessary mobility for a basic quality of life. Two experts explicitly defined physical and social accessibility: physical accessibility ensures that accessibility is maintained in the quality of infrastructure (environmental cleanliness, public health, etc.), while social accessibility ensures disadvantaged groups maintain their basic mobility to locations deemed necessary for a good quality of life. Regional and local accessibility are the two strategies most prominent for use in livability metrics. If used separately, regional accessibility locates where to concentrate funds/activities for development, while considering land use and other factors. Local accessibility centers on the quality of accessibility at the local level. Opportunities that improve livability for some should not come at the cost of other individuals.

One expert referred to affordability as the most significant blind spot in current performance indicators. Combined expenses for housing and transportation are often included in a cost of living assessment and can be a good metric for livability and social equity. In particular, accessibility helps to identify problematic public transit disconnections that may adversely affect affordability by requiring vehicle ownership or access. The fixed costs of owning a car raises the cost of living and can lower the livability of a particular area. Some metrics that emphasize affordability may not fall explicitly under DOT control, but experts believed that DOT decisions have a significant impact on the ability for families to reduce their vehicle ownership.

Green infrastructure overlaps with other metrics related to livability and environmental outcomes. Since green infrastructure can be implemented on state rights-of-way or adjacent property, three experts suggested state DOTs work with their local partners to understand the land use decisions and impacts on transportation. For example, green infrastructure built to relieve congestion may temporarily improve public transit affordability and increase vehicle throughput but adversely affect livability with higher VMT and GHG numbers. Consistent green infrastructure data may also be an issue, so DOTs should consider readily available data or proxies that can be used to indicate green infrastructure benefits. One expert mentioned that tree canopy coverage and access to green spaces could be used as a livability metric.

Air quality and noise pollution are byproducts of modern transportation systems that indirectly influence the health and livability of people living near pollution sources, such as roads or highways. Experts considered air quality as a factor of livability, but they noted this might not be under DOT control. Two experts recommended that DOTs pursue livability metrics that

measure the effect of DOT facilities on local air quality and noise pollution on nearby neighborhoods.

Public participation has the ability to contribute or hint at new ways to improve livability at the local level. However, public participation is difficult to measure accurately. State DOTs can consider and identify all interests and concerns, avoid aggregating data, ensure people in attendance are representative of the full community, and incorporate other context-sensitive processes to ensure equitable representation in the planning phase.

Understanding how new facilities affect the surrounding neighborhood is important. Local residents may fear the negative impacts of a proposed public transit system constructed in their neighborhood, although the facility may provide a regional transportation benefit. Thus, a balance between satisfying local needs and meeting regional performance indicators is important. A variety of methods can be used to evaluate regional and local projects including: adjusting predictive models properly to reflect regional progress, placing more weight on regional impact, encouraging multi-modal transportation development across local jurisdictions, employing a context-sensitive process and engagement to improve the ecology of the urban experience (prescriptive livability), and determining if public transit initiatives advance sustainability goals.

Most experts were unable to cite specific objectives or indicators that measure the livability of public spaces or other direct community cohesion indicators. Public cohesion is difficult to measure and can be simplified by carefully considering different measurement strategies. Complex and hard to measure metrics can be inferred from simple design measurements, such as walkability, walking proximity to traffic, volume and speed of nearby traffic, and frequency of protected crossings.

CONCLUSION

As Caltrans and its partners expand their sustainability goals and objectives, performance metrics that align with livability, accessibility, and prosperity provide a unique way to improve engagement at the municipal and regional level. Flexible metrics that capture these values can reflect the importance of local and corridor level planning. Equity and scale are themes that were noted for all of the scores in the literature and among the experts. In addition, context and jurisdiction are important considerations for selecting specific metrics. Finally, data availability and priorities are likely to change over time, so metrics should be reviewed and updated periodically.

Livability, accessibility, and prosperity metrics are dynamic and can be used in conjunction with the changing transportation landscape at the planning phase. Connected/automated vehicles, shared mobility services, and smartphone-based mobility (e.g., apps) all have the potential to provide significantly more data about how both vehicles and individuals travel. The standard for the industry for decades has been VMT. With increased modes, sharing, and sensing devices, it is possible to begin looking at person miles traveled.

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APPENDICIES

Appendix A: Glossary of Terms

Term	Definition
Accessibility (From Caltrans SMP)	A property of transportation systems and subset of mobility that focuses on the ability for users to reach destinations and points of interest. Accessibility also reflects the degree to which people, goods, and services can travel through a transportation system. Accessibility measurements are usually destination based on time or proximity to opportunities.
Community Design (From Caltrans Smart Mobility Framework)	Characteristics of development use, form, and location that combine with the multi-modal transportation system to support convenience, non-motorized travel, and efficient vehicle trips at the neighborhood and area scale.
Core Based Statistical Areas (CBSA)	A term coined by the U.S. Office of Management and Budget (OMB) to identify an urbanized area and surrounding counties with a high degree of economic and social integration. The core areas in "core based statistical areas" must have a population greater than 10,000 people.
First mile – last mile	A general term referencing the distance from a home or work location to facilities that connect them with the public transit system.
Livability (From Caltrans SMP)	A sustainability strategy that supports quality of life improvements, efficient land use, livable public spaces, social engagement, natural systems, local businesses, and opportunities for improved environmental conditions. Livability is oriented toward long-term community outcomes.
Location Efficiency (From Caltrans Smart Mobility Framework)	Location efficiency is defined by the California Department of Transportation as a characteristic of the physical environment and its transportation systems and services. Community design and regional accessibility together contribute to reduced VMT and shorter average trip length, increased non-motorized and public transit use, and encouraged multi-modal mobility.
Modal Split	The percentage or number of trips travelers use for a particular type of transportation.
Prosperity (From Caltrans SMP)	A focus on promoting economic development that improves State and local economies through investments in transportation projects that support local businesses and increases competitiveness through a resilient and integrated transportation system.

Regional Accessibility (From Caltrans Smart Mobility Framework)	Characteristics of development use, form, and location that combine with the multi-modal transportation system to make destinations available through non-single occupancy vehicle travel and efficient vehicle trips at the regional, interstate, and international scales.
Reliable Mobility (From Caltrans Smart Mobility Framework)	Manage, reduce, and avoid congestion by emphasizing multi-modal options and network management. Provide predictability and capacity increases that are focused on travel that support economic activity.
Robust Economy (From Caltrans Smart Mobility Framework)	Invest in transportation improvements that support the economic health of the State and local governments, the competitiveness of California's businesses, and the welfare of California residents.
Sustainability (From Caltrans Strategic Management Plan)	The California Department of Transportation defines sustainability as a combination of people, planet, and prosperity principles that improve the quality of life for California residents. People foster community health and vitality while prosperity promotes economic development abroad. Lastly, preserving and restoring environmental and ecological systems is important to both planet and people alike.
Social Equity (From Caltrans Smart Mobility Framework)	Provide mobility for people who are economically, socially, or physically disadvantaged to support their full participation in society. Design and manage the transportation system to equitably distribute its benefits and burdens.

Appendix B: Scores Metric Table

PROSPERITY	
Housing	Housing and transportation costs vs. incomes for the median-income household
	Percentage of renter units and owner units affordable to households earning 80% of median family income
	Percent living in deteriorated or overcrowded housing
	Increase in land investment, values, and sales in the affected area
	Population in more/less developed areas
	The number of new housing units produced and total housing growth as a percentage of the county's housing growth
Income/Jobs	Reduction in unemployment rates, poverty rates or incidence of benefit among selected vulnerable groups
	Proportion of household income spent on housing and transportation costs
	The number of new jobs gained or lost
	Gap between cost of living and wages
	Employment in more/less developed areas; Income in more/less developed areas
Others	Wage and salary growth
	Gross domestic product (GDP), Gross regional product (GRP), and Gross state product (GSP)
	General local government debt-to-revenue ratio
	Percentage of discretionary expenditures at small-, women-, and minority-owned businesses
	Nonresidential valuation in more/less developed areas
	Transportation productivity (labor productivity or total-factor productivity)
	Commodity flows and freight cost reduction
	Business output, building development floor area, direct private investment, property values, and property tax revenue
	Improvement in market opportunities, scheduling/logistics productivity, and other cost efficiencies for businesses and residents
	Poverty rates, differences in outcomes between advantaged and disadvantaged groups
	"Last-mile" access to employment and educational facilities
	Social welfare and changes in self-reported life-satisfaction ratings
	Direct user and agency costs and benefits, including operating costs, travel time costs, and often other impacts, such as crash accident and pollution costs

	Change in the composition of the area's economic base (high-paying (vs. low-paying) jobs, high-growth (vs. low-growth) industries or business growth targets (e.g., tourism, technology industries, etc.))
	Amount of freight cargo moving in, out and within an area
	Value of land and buildings; Value of capital investments; Value of taxes paid
	Induced impacts, which occur from increased household spending due to higher regional wages
	Travel time or other costs/benefits, as well as indirect and induced impacts on business growth
	Induced development, value capture and its fiscal impacts
	Work-related travel: time + cost savings
	Transport costs relative to income; Transport expenditures by income class
	Education, health, longevity, crime rates, housing quality, public services, etc.

ACCESSIBILITY	
Job accessibility	Number of jobs that can be reached by public transit within 30 minutes of travel during the 7 AM to 9 AM period
	Number of jobs that are reachable, on average, within a given travel time threshold between 7 AM and 9 AM
	Jobs reachable from a zone or neighborhood, adjusted according to the relative difficulty of travel
	Number of jobs that could be reached by automobiles within certain time periods
	Cost to move between origin and destination for various opportunities
	Number of low-, medium-, and high-wage jobs that can be reached within a predetermined travel time
	Number of destinations reachable within a given travel time
	Jobs reachable within X minutes, especially low-income jobs
	Percent of the population within X minutes of Y percent of employment sites
	Jobs within a 45-minute transit commute; Working-age population within a 45-minute public transit commute
	Jobs within a 45-minute drive; Working-age population within a 45-minute drive
	Number of households within a 30-minute public transit ride of major employment centers
	Regionally-standardized measure of job accessibility by public transit, with the most accessible tract in the region scored as 1.0, and tracts with access to one-half as many jobs scored as 0.5
	Average travel time to jobs for disadvantaged populations via public transit
	Percentage of workforce that can reach their workplace by public transit within one hour with no more than one transfer
Cost Aspects	Sum of generalized costs of the shortest path from one centroid to all the other centroids

	Cost of travel to an airport; Available alternative airports; Frequency of flights
	Travel time by income group
Others	Destinations that can be reached from that zone, negatively weighted by the difficulty in reaching them (gravity approach)
	Walking time to the nearest subway station
	Average travel time under both free-flow conditions and peak-hour congested conditions
	Distance to the nearest highway with more than two traffic lanes
	Distance to each region's premier Central Business District (CBD)
	Roadway network and link speeds
	Number of transit stops within a certain travel time
	Location of development relative to regional urban center
	Accessible roadway segment length
	Percentage of people within X-minutes of major need-based activity (shops, medical, etc.)
	Pedestrian safety and access
	Congestion delays due to induced demand (jobs, commute hours, etc.)
	Median length of cul-de-sacs
	Late-night transit frequency for residential locations
	Percent of daily/peak period trips (origins and destinations) starting or ending within ¼ mile of a public transit stop
	Number of public transit corridors; Number of transit stations walkability; Number of obligated Transportation Improvement Program (TIP) projects with bike/pedestrian elements
	Quality of public transit serving a location and the ease of accessing that service by walking, cycling, and automobile
	Whether special populations, such as the elderly, are able to use transportation; Whether services are Americans with Disabilities Act (ADA) compliant

LIVABILITY	
Travel	Vehicle miles traveled and ridership
	Walk score and Walkability index
	Traffic congestion
	Person mobility (i.e., person miles traveled)
	Per capita traffic casualty (injury and death) rates

	Traveler assault (crime) rates
	Travel diary data, travel time, and modal shift
	Traffic noise levels
	Access to intercity transportation
	Portion of travel by walking and cycling
	Traffic volume, pedestrian volume, and diversity
Neighborhood/ Community	Durable housing resistant to natural disasters; Provision of potable water, electricity, information and communication technologies (ICT); Quality schools; Reliable health services
	Land use patterns, green space, local business ownership, and cultural amenities
	Quality of social interactions (neighborliness, fairness, respect, community identity, and pride)
	Volunteerism, social networks, and diversity of ages and ethnic groups
	Opportunities for recreation and entertainment, aesthetics, and existence of unique cultural and environmental resources
	Location of public transit stops are in relation to destinations, such as parks, schools, and employment
	Pedestrian shed (% of half-mile “as-the-crow-flies” walkable zone accessible via the network)
	Violent crimes per year per 100,000 residents
Others	Percent of workforce living within a 30 minute or less commute from primary job centers
	Per capita emissions of global air pollutants (CO_2, CFCs, CH_4, etc.)
	Per capita emissions of local air pollutants (PM, VOCs, NOx, CO, etc.)
	Mixed income (degree of evenness ranging from 0 to 1); Mixed race (degree of evenness ranging from 0 to 1)
	Affordable housing and transportation choices
	Air quality standards and management plans
	Cleanliness, safety, availability of seating, availability of shade, and building conditions
	Range of housing ownership and financing types
	Job–housing balance