Diagnosing Transportation

Developing Key Performance Indicators to Assess Urban Transportation Systems

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Rapid urbanization is putting pressure on transportation agencies to respond to an increasing demand for transportation networks with greater effectiveness and efficiency. In response, policy makers, faced with limited budgets and time constraints, are looking for tools and processes to identify priority problems in a timely and cost-effective manner. Rapid assessments can be performed with diagnostic tools that identify cities' transportation problems within the global context. Using a series of performance indicators that are based on a review of research and practice from around the world, this paper assesses cities' transportation networks. The performance indicators rank cities according to an overall score as well as categories of transportation performance. Such an approach allows planners to identify priority problems in the transportation network to design targeted solutions. The final results benchmark the performance of transportation systems according to the performance of the systems in peer cities with relatively similar sizes. Such a process assists with the benchmarking of performance and accounts for context so that appropriate best practices can be shared between cities around the world.

Transportation planning has multiple economic, environmental, and social goals. Cities often see investment in urban transportation infrastructure to be a means of providing opportunities for increasing competitive economic advantage (*1–3*). In response, the need for tools that can help planning professionals quickly identify priority problems (*4*) and efficiently allocate infrastructure and prioritize investment (*5*) is growing. Additionally, cities are increasingly viewed as logistics centers in a globalized marketplace; their focus on competition and rankings means that their performance relative to that of their peers is more important than their absolute performance (*1, 6*). In any case, before comprehensive solutions to address transportation problems can be identified, a diagnostic study needs to be performed to identify cities' individual problems within the global context.

This paper proposes a diagnostic tool to assist with the formation of an initial review of the state of a city's transportation network. The tool uses a series of performance indicators that are based on research and practice from around the world to assess different cities' transportation networks. The results are ranked to provide a comparison of transportation systems between cities with similar population sizes and gross domestic products (GDPs). The intent of such a comparison is to benchmark the performance of a city's transportation system according to that of peer cities with relatively similar networks. Such an approach helps designate key problems that account for context as well as overcome gaps due to the unavailability of benchmarking data.

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Three questions are addressed to develop the diagnosis: (*a*) What kind of performance indicators must be measured to identify priority problems in urban transportation? (*b*) What kind of readily available data are appropriate for measurement? (*c*) How can results be compared to better account for context?

The final output of this article is an initial diagnosis and ranking of the transport systems of cities around the world as well as a suggested set of measures that can be used to assess transportation performance according to the common goals and objectives of transportation agencies. Alignment of indicators to a broad criterion of goals assists with the harmonization of performance measurements between local, national, and international agencies. Development and planning agencies can use the final set of core performance indicators to evaluate the current state of transportation in cities.

This paper is organized as follows: first, a review of the research on transportation performance indicators is presented to justify the selection of those indicators. Second, transportation plans, policies, and research are analyzed to identify common urban transportation goals and the indicators used to measure progress toward the achievement of these goals. Third, a methodology section frames how the analysis is undertaken and presented. Fourth, the sources of the data are identified and the data used for this study are validated. Finally, a diagnosis is performed according to the composite indicators with the available data, results are presented, and recommendations for further research are made.

LITERATURE

As a result of globalization and the role of transportation in the economy, two major themes govern 21st century transportation planning: sustainable development and global competitiveness (*1*). Measures and scores of competitiveness provide rankings that can serve as benchmarks for policy makers and other interested parties to judge the success or relative position of their nations or cities within a global context (*6*). Sustainable development is becoming an overarching concept behind urban transportation planning as a response to rising rates of motorization and the need to ensure public health while minimizing environmental risks (*1*).

In North America, although various agencies have incorporated sustainable development into their visioning and planning exercises, no comprehensive definition of urban transport sustainability has been identified. However, most plans propose an operational definition that rests on attributes of system efficiency; effectiveness; and impacts on the economy, environment, and society (*7*). Efficiency measures the operational performance of the system, and effectiveness measures a transportation system's progress toward achievement of its policy goals (*8*). Because effectiveness aims to measure progress toward achievement of goals and objectives, potential indicators should be identified and selected after goals and objectives have been formulated (*8*).

The indicators from transport policy documents can then be used to inform how urban transportation is actually measured and evaluated in different cities around the world. Policy-based indicator systems tend to view a sector holistically and intend to foster dialogue between the different stakeholders in urban development (*5*). Use of a holistic approach is important to understand and respond to externalities. Interventions may have unintended consequences. It is therefore important to attempt to identify all potential future effects (*8*).

A number of studies and projects that assess transportation indicators for appropriate use and implementation have been performed. At the corridor level, Tiwari and Jain, analyzing a bus rapid transit route in New Delhi, India, illustrate that traditional indicators favor the free movement of vehicles without taking into account capacities and road usage by other modes (*9*). From an infrastructure investment perspective, Li and Wachs compared light rail transit and bus rapid transit routes in Los Angeles, California, and San Francisco, California, to show that the choice of indicators can have starkly variable results and can affect the identification of key problems (*10*).

On a global level, Westfall and de Villa, in cooperation with the Asian Development Bank, prepared a city performance system that measures urban development and compares results across 18 cities in Asia (*5*). The Economist Intelligence Unit, in partnership with Siemens AG, developed the green city index, an indicators-based evaluation project that looked at the environmental sustainability performance of cities around the world (*11*). Similar to the green city index, Siemens Canada also publishes, as part of the Complete Mobility series, reports that describe research projects that evaluate the transportation infrastructure of cities in Canada through the use of a set of 15 performance indicators and compares the results according to different policy scenarios (*12*). IBM, as part of the Smarter Planet series, conducted a survey on traffic congestion entitled *Frustration Rising: IBM 2011 Commuter Pain Survey* (*13*). The survey attempted to evaluate commuters' levels of satisfaction with the levels of congestion in 20 cities around the world.

Research exploring the identification and formulation of indicators for transport is abundant. However, only local corridor-level studies have attempted to evaluate specific indicators. Most global studies reviewed in this research generally provide a list of indicators, arrived at through stakeholder consultations, only recommended for use. Those studies that evaluate the application of the indicators also largely focus on overall city performance and not urban transportation specifically. The *Cities Data Book* and the green city index evaluate a small number of urban transport performance indicators as part of a larger evaluation of urban productivity and sustainable development (*5, 11*). To date, the only projects identified in this research that use indicators for global urban transportation networks are the Complete Mobility series by Siemens Canada, the commuter pain survey by IBM, and a study by Haghshenas and Vaziri (*14*).

The benefits of performance measures have been debated since the 1990s. Nevertheless, their use has steadily risen over the years, especially in larger cities in North America (*15*). Using the lessons learned on the use of performance measures from transportation research, the following section frames a methodology for selection of the indicators to be used for this study.

METHODOLOGY

To select the indicators for this study, a qualitative analysis of the content of transportation plans and policy documents was performed to identify the indicators most commonly used around the world. The Lincoln Institute of Land Policy identifies three principles for the selection of indicators (*16*):

- Validity, which means that the indicator must have a direct link to a relevant policy intervention;
- Availability, which means that the indicator must be quantifiable with easily accessible data; and
- Reliability, which means that the data must have been gathered by a public or a governmental authority.

This list should be considered the minimum requirement for a performance indicator. Other important aspects include whether indicators can be operationalized and scaled properly and are designed to measure accurately that which should be measured. In addition, as a whole, a set of indicators must adequately measure a wide range of benefits and impacts, which include the environmental, economic, efficiency, and social justice impacts of urban transport systems. Many of these concerns, however, are out of the scope of this paper and require further investigation.

The first step is to review the goals of the transportation plans. After goals are identified, they are placed into a set of categories to relate directly goals to indicators. Indicators from three sets of documents are then identified: transportation plans, transportation studies by international agencies and nongovernmental organizations, and articles from published research. The indicators from the three sets of documents are combined to develop an extensive list of indicators, which is then shortened to include only the indicators that are used in more than one plan or study. A final list of policy goals and indicators is then developed on the basis of the availability of data.

After the selection of indicators and the collection of data, the information is compared and evaluated. Previous work in this area has either focused on establishment of a single measure for evaluation (*17*) or used a composite index based on scores determined from weighted averages (*5*). However, to normalize the results so that indicators and scores can be measured and compared across cities, a standardization technique must be applied. The most common approach is to use *z*-scores (which essentially measure the distance of a given value from the sample mean measured in standard deviations) (*18*), the results of which are added by the use of equal weights to derive a final score. This approach is the most widely used because of its simplicity (*19*).

To establish a contextual relationship, cities are grouped according to population size: small (less than 1 million), medium (1 million to 2 million), large (2 million to 5 million), and very large (greater than 5 million). *z*-Scores for each city and individual indicator are first calculated by use of the standardize function in Microsoft Excel software.

Indicators are also assessed on the basis of whether higher-order numbers denote a positive or a negative relationship. For example, longer travel times would be considered an undesirable outcome; therefore, the resulting *z*-score is multiplied by −1 to establish a negative relationship. Likewise, higher speeds denote lower congestion and a more efficient transportation network, so a positive relationship of higher-order z-scores is preserved. The resulting z-scores are added by indicator category to produce cumulative z-scores and are normalized to obtain a score between 0 (for the lowest) and 1 (for the highest) for each category of indicators. Normalized scores for each category are then added to obtain a cumulative score of transportation performance for each city. Although the z-scores are calculated by population group, the normalized scores are calculated for the entire sample. This calculation allows cities to be ranked globally. This helps to answer the third question of this study: How can results be compared to better account for context?

INFORMATION AND DATA SOURCES

To develop a list of indicators that can provide a comprehensive assessment of transportation systems around the world, three sets of documents were reviewed. City plans provided indicators that are commonly used in transportation planning. Measures taken from international development agencies and nongovernmental organizations helped identify indicators used in global transportation policy. Finally, academic research determined indicators that were used for transportation system assessment. Table 1 includes the various documents studied.

Transportation plans were taken from cities in the United States, Canada, the United Kingdom, South Africa, Australia, New Zealand, and Singapore (plans from cities in other English-speaking countries were considered, but plans were either not available or not immediately accessible). The selection of the plans was based on two criteria: first, the city had to have a population in excess of 0.5 million, and second, the plan had to have been published since the year 2000 and to have clear transportation goals and performance indicators.

Because of the difficulty of finding copies of transportation plans in English from developing countries that listed clear performance indicators and data measurements, the list is dominated by plans from cities in developed countries. To tie the indicators to transportation networks in developing countries, goals and indicators from the plans were compared with those from policy documents prepared by international agencies and nongovernmental organizations that had conducted performance evaluations of transportation networks in the developing world. A global outlook can be ensured by evaluation of studies of transportation networks in cities in both developed and developing countries.

TABLE 1 Transportation Plans, Policies, and Research

Author	Title	Year
Department of Planning and Infrastructure, New South Wales (*20*)	Metropolitan Plan for Sydney 2036	2010
City of Calgary (*21*)	Calgary Transportation Plan 2009	2009
City of Ottawa (*22*)	Transportation Master Plan	2008
Metrolinx, Government of Ontario (*23*)	The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area	2008
Translink, Metro Vancouver (*24*)	Transport 2040: A Transportation Strategy for Metro Vancouver, Now and in the Future	2008
Ville de Quebec (*25*)	Sustainable Mobility Plan: Transportation for Better Living	2011
Auckland Regional Transport Authority (*26*)	Our World Class City: Auckland Transport Plan 2009	2009
Land Transport Authority, City of Singapore (*27*)	Land Transport Master Plan	2008
City of Johannesburg (*28*)	Integrated Transport Plan 2003/2008	2003
Greater London Authority (*29*)	Mayor's Transport Strategy	2012
Boston Region Metropolitan Planning Organization (*30*)	Journey to 2030—Amendment: Transportation Plan of the Boston Region Metropolitan Planning Organization	2009
City of New York (*31*)	PlaNYC: A Greener, Greater New York	2007
Houston–Galveston Region (*32*)	Bridging Our Communities: The 2035 Houston–Galveston Regional Transportation Plan Update	2011
Los Angeles County (*33*)	2009 Long Range Transportation Plan	2009
Metropolitan Transit Commission of the San Francisco Bay Area (*34*)	Change in Motion: Transportation 2035	2009
East Asian Development Bank (ADB) (*5*)	Cities Data Book: Urban Indicators for Managing Cities	2001
Embarq: The WRI Institute for Sustainable Transport (*35*)	India Transport Indicators	2007
International Association of Public Transport (*36*)	Report on Statistical Indicators of Public Transport Performance in Africa	2010
Lincoln Institute of Land Policy (*16*)	Smart Growth Policies: An Evaluation of Programs and Outcomes	2009
Partnership for Sustainable Urban Transport in Asia (*37*)	Sustainable Urban Transport in Asia: Making the Vision a Reality	2007
Pembina Institute (*38*)	Ontario Community Sustainability Report	2007
United Nations (*39*)	Global Urban Indicators: Selected Statistics	2009
The World Bank (*40*)	Global Cities Indicators Facility	2008
Aftabuzzaman et al. (*41*)	Exploring the Underlying Dimensions of Elements Affecting Traffic Congestion Relief Impact of Transit	2011
Badami and Haider (*42*)	An Analysis of Public Bus Transit Performance in Indian Cities	2007
Gilbert and Tanguay (*17*)	Sustainable Transportation Performance Indicators Project	2000
Haghshenas and Vaziri (*14*)	Urban Sustainable Transportation Indicators for Global Comparison	2012
Li and Wachs (*10*)	A Test of Inter-Modal Performance Measures for Transit Investment Decisions	2000
Litman (*43*)	Developing Indicators for Comprehensive and Sustainable Transport Planning	2007
Nicolas et al. (*44*)	Towards Sustainable Mobility Indicators: Application to the Lyons Conurbation	2003
Tanguay et al. (*45*)	Measuring the Sustainability of Cities: An Analysis of the Use of Local Indicators	2010
Tiwari and Jain (*9*)	Accessibility and Safety Indicators for All Road Users: Case Study Delhi BRT	2012

Finally, indicators were also drawn from transportation research. Although the purpose of the plans and policy documents is to measure systemwide performance, the transportation research gathered looks at both overall systemwide efficiencies and measures that are used at the corridor level.

Statistics for the three sets of indicators were gathered for a number of cities on the basis of readily available data to ascertain what performance measures can be assessed immediately. The set of indicators for which data are available determines the final short list of indicators for comparison, even though they might not be the best for assessment of all aspects of the city transport system. The measures generated were used to help describe the methodology and how it is implemented. Better measures can be generated if the data needed are available.

The majority of data were collected from two sources. The Mobility in Cities Database from the International Association of Public Transport (UITP) supplied statistics for 52 cities, of which 45 had information sufficient for the indicators needed for this project (*46*). Data on 14 cities in Latin America were taken from the report *Observatorio de Movilidad Urbana Para América Latina* [*Latin American Urban Mobility Observatory* (translation by the first author)] by the Corporación Andina de Fomento (Andean Development Corporation) (*47*). Of the 15 cities whose plans were evaluated to select the indicators for this paper, six in total collected data sufficient for inclusion in the study. However, data for two (London and Singapore) are already listed in the UITP database. The remaining four cities—Auckland, New Zealand; New York; Sydney, Australia; and Toronto, Ontario, Canada—were assessed according to information available on the Internet from public-sector and research organizations. The final number of cities assessed for this project on the basis of data availability was 63.

The major constraint to the data was the variability in the time periods of data collection. The UITP database was primarily referenced from 2001, data from the Andean Development Corporation were sourced between 2007 and 2009, and data on the remaining cities sourced from a number of different reports were published by government agencies over a number of years: for Auckland, 2004 to 2011 (*48–57*); for New York, 2007 to 2012 (*58–65*); for Sydney, 2006 to 2012 (*66–72*); and for Toronto, 2006 to 2012 (*23, 73–81*). Even more current reports, however, often contain data that are extrapolations and projections from past data (for example, statistics on many cities in the United States are often in reference to data from the 2000 census).

An additional limitation, also related to the variability of the time of reference, was in the quality of some of the data. Under the indicator category environmental and resource conservation, 19 cities were all missing one indicator each because of gaps in the data from both the Andean Development Corporation and UITP. The reliability of the environmental and resource conservation indicators is questionable because even though greenhouse gas emissions are measured in kilograms and energy use is measured in megajoules, a stark variation between the UITP data and other data exists. This is illustrated by the statistics for the greenhouse gas emissions of transport for Auckland, which, at 3,028 kg/capita, is 32 times as high as that for the lowest-performing city from the UITP database, which was Athens, Greece, with 93 kg/capita. For those cities for which emissions data were not supplied in the Mobility in Cities data set, some statistics were drawn from background information for the media provided by UITP (*82*). The variability in the range of emissions from 2001 to 2009 may be a result of improved techniques for the gathering of greenhouse gas emissions data over the years.

After the necessary data were compiled the next step was to analyze the transportation plans and research to identify indicators to be selected for use for diagnosis. The final list of headline indicators to be used depended on the availability of data.

PLAN, POLICY, AND RESEARCH ANALYSIS

The headline indicators with which to measure progress toward each goal were selected on the basis of two criteria: first, the indicators had a high frequency of use and, second, the indicators were used in both transportation plans and research. However, some of the indicators were available in only one set of documents and were selected because no alternative was available. A different approach was to use a multicriterion analysis approach to select the measures, yet use of this approach was beyond the scope of the study.

To begin to assess each policy for goals and indicators, a classification system to group the indicators into common themes was established on the basis of the goals of the plans (Table 2). Common themes were identified on the basis of a study by Cambridge Systematics (*83*). The most common goal across all the city plans was the improvement of air quality, followed by congestion reduction and improved mobility and then equal references to improvements to active transport opportunities, the promotion of public health, and reductions in the number of accidents. It can thus be deduced that environmental concerns are the most important to city agencies, followed by mobility and then quality of life and safety.

However, a compilation of the indicators used to measure progress toward goals paints a different picture. As illustrated in Table 2, mobility indicators were the most often cited, followed by safety indicators. Air quality and environmental indicators were used in only seven documents and quality of life was measured in four. The low number of indicators for goals for quality of life might speak to the difficulty of quantitative assessment of quality-of-life measures, but the same cannot be said for air quality indicators.

Additionally, measurements of active transportation were generally cited under mobility improvements rather than air quality or quality-of-life measures. Although air quality concerns topped the list of goals in urban transportation plans, in the research and policy reviewed, less emphasis was placed on the need to take measurements toward improvement. The indicator total population for demand and context helped to determine the contextual basis for comparison. The green city index took a similar approach, establishing socioeconomic clusters within which candidate cities were grouped and compared (*11*).

The indicators in the final list of indicators drawn from research were compared with the indicators in the UITP database. Indicators that matched from one list to another were used for analysis. However, not all the cities were assessed on the basis of the availability of data for 100% of the indicators. Only 13 of the 63 cities had data for 100% of the indicators, 35 had data for 94% of the indicators, and 15 had data for 88% of the indicators.

Data availability also limited the final list of indicators to be used for assessment. Of the final 21 indicators short-listed for assessment, sufficient data were available for only 12. Adequate data were not available for the economic development, quality-of-life, and infrastructure condition and performance indicators. Adequate data were not available for affordability and accessibility measures, as few cities publish data on the population with access to different modes of transport. The report by Cambridge Systematics, however, provides a list of indicators that includes trip travel time (*83*). Therefore, because of the lack of availability of data on access to services or

TABLE 2 Selected Indicators per Goal, Frequency of Use, and Data Availability

Goal	Count	Indicators	No. of Cities	No. of Agencies	No. of Research Studies	Total No.	Data (%)
Demand and context		Total population	3	6	2	11	100
Affordability and accessibility							
Improve access to daily destinations	8	Transit coverage by population (percentage of people who live within 1 or 2 km of rapid transit)	1	2	NA	3	10
		Average length of commute (minutes)	5	NA	1	6	100
Provide affordable mobility	6	Share of household income spent on transport (%)	2	NA	3	5	78
Coordinate transportation and land use plans	4	Length of roads per 1,000 people (km)	1	1	NA	2	97
Mobility							
Reduce congestion, delays, and travel time	10	Average speed of trip (km/h)	4	1	2	7	86
Encourage the use of and improve transit and active transport networks	9	Transport trips by mode (% by mode)	7	6	5	18	100
Provide for efficient freight travel	4	Annual volume of container traffic (tonnes)	3	NA	NA	3	10
Economic development							
Facilitate economic growth through effective management of the transport network	7	Cost of vehicle congestion (in US$)	2	NA	NA	2	6
Quality of life							
Protect and promote public health	9	Number of noise and vibration exceedances per year	1	NA	2	3	5
Respond to public expectations	3	Public transport customer satisfaction (%)	3	NA	1	4	11
Address the mobility needs of the elderly, youth, and persons with special needs	8	Share of transport facilities with step-free access (%)	2	NA	1	3	6
Operational efficiency							
Provide an integrated public transport system	4						
Provide a transportation system that is maintained, reliable, and efficient	7	Public transport capacity (passenger-km)	2	NA	2	4	95
Ensure fiscal sustainability	7	Cost recovery from fares [fare-box recovery ratio (%)]	1	2	1	4	95
Environmental and resource conservation							
Improve air quality	12	Greenhouse gas emissions from passenger travel (kg/capita)	2	3	1	6	71
Advance environmental sustainability	7	Annual energy consumption of transport (MJ)	1	4	NA	5	78
Reduce dependence on nonrenewable resources	2	Biofuel and fossil fuel used per VKT or per capita (L)	1	NA	1	2	2
Safety							
Reduce accidents	9	Road fatalities	3	6	2	11	97
Ensure personal security	5	Crime rates on public transport (%)	1	NA	NA	1	2
Infrastructure condition and performance							
Maintain infrastructure in good condition	3	Percentage of roads in a state of good repair	2	NA	NA	2	8

NOTE: No. = number; NA = not available; MJ = megajoules; VKT = vehicle kilometers traveled.

the transportation network, trip travel time was used as a measure of accessibility by use of the transportation network (*83*).

Data on transportation affordability were limited to the average cost of a trip or the average fare of a public transport service. To calculate the percentage of monthly income spent on transportation, average monthly income was derived from the work of Wellershoff et al. (*84*). The share of income spent on transport was then calculated by use of the transportation affordability index provided by Carruthers et al. (*85*).

Following the short-listing of the final indicators for assessment from the long list in various transportation documents, the next section discusses the analysis and results of the benchmarking exercise.

ANALYSIS AND ASSESSMENT

With the headline indicators selected and the necessary data gathered, a *z*-score analysis was conducted and initial results were normalized by category: affordability and accessibility, mobility, operational efficiency, environmental and resource conservation, and safety. To establish a contextual relationship, the cities were grouped by population. In this way, cities with vastly different population sizes were not directly compared by average travel time, for example. The normalized results were added to derive a cumulative score between 0 (the lowest) and 5 (the highest) for each city. The results are presented in Figure 1.

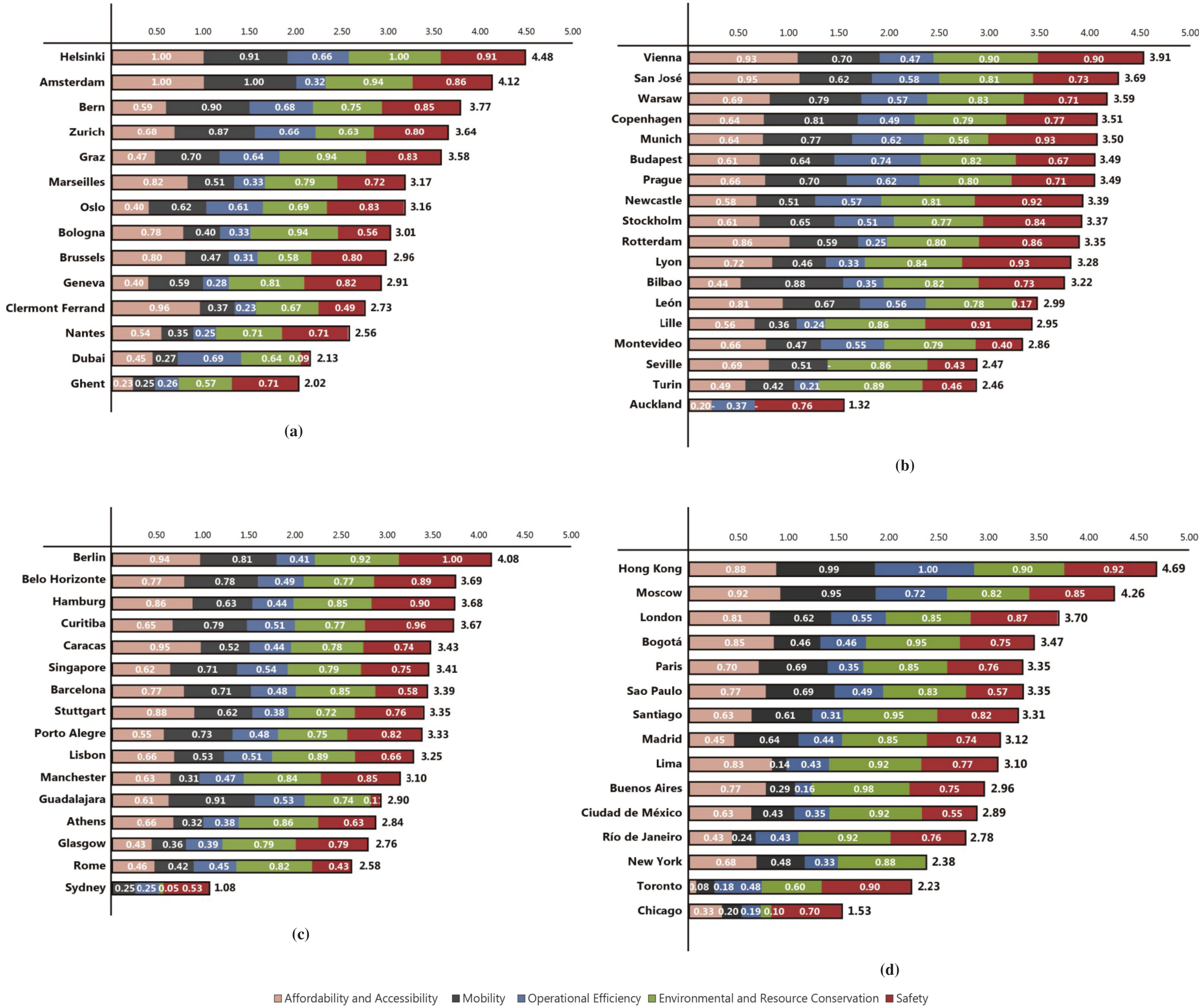

FIGURE 1 City rankings by population group: (*a*) less than 1 million, (*b*) between 1 million and 2 million, (*c*) between 2 million and 5 million, and (*d*) 5 million and greater.

Under the small cities group, Helsinki, Finland, scored the best (highest), scoring above average in every category (Figure 1*a*). Amsterdam, Netherlands, followed, scoring the strongest in affordability and accessibility and mobility performance. The highest score for operational efficiency was not observed in the highest-ranking cities. Rather, Dubai, United Arab Emirates, scored very well in operational efficiency because of a fare box recovery ratio that exceeded 100%, which indicates that the city's public transport services operate at a profit. The city of Ghent, Belgium, scored the lowest in total because of scores that were lower than average across the board. This may be because data on the share of income spent on transportation and the number of fatalities on the transportation network were missing. Ghent's ranking may change with further information. However, other cities in the group that were missing points of data included Amsterdam; Zurich, Switzerland; and Graz, Austria. These three cities rank in the top five for this population group.

In the medium population group, Vienna, Austria, scored the highest overall. However, in the individual categories, Vienna ranked at the top only in environmental and resource conservation because of very low transport greenhouse gas emissions (Figure 1*b*). San José, Costa Rica, took the top score for affordability and accessibility because of very low transportation costs per capita. The city of Bilbao, Spain, ranked the highest in the mobility category because of a very high mode share for walking and cycling (49%). Budapest, Hungary, excelled in operational efficiency because of a combination of high public transport capacity use and fare recovery (although the cities of San José and Montevideo, Uruguay, both boasted 100% fare recovery). Lyon, France, and Munich, Germany, tied for the lowest fatality rates on the transportation network, thereby scoring the best for the safety category. Auckland scored the lowest overall, with very low scores in affordability and accessibility as well as extremely low scores for mobility and environmental and resource conservation. Auckland's affordability and accessibility data indicate that the Auckland transportation network has long travel times to reach services, a higher-than-average cost of travel, and a very low road network density. It also has the highest private vehicle mode share of this population group (80%). Furthermore, Auckland has some of the highest emissions and energy use for transport in the entire sample of 63 cities.

In the large cities group, Berlin scored the highest overall, as well as in the environmental and resource conservation and safety categories (Figure 1*c*). Caracas, Venezuela, had the best affordability and accessibility ranking because of the very low costs of transportation in the city and a low road network density. For mobility, Guadalajara, Mexico, scored the highest because of a high active transportation mode share and a low personal motor vehicle mode share. Singapore scored the highest for operational efficiency. Although the city has the lowest fare box recovery ratio, Singapore's public transport capacity use was significantly higher than that of any other city in the group (1.5 times the runner up, Rome). Sydney scored the lowest in this population group because of a very low road network density, which ties into travel times that are roughly twice the average for the group. This was not necessarily due to congestion, as, even with a very high private vehicle mode share (68%), average travel speeds are not far below average.

Hong Kong scored the highest in the very large population group because of its strong performance in mobility, operational efficiency, and safety, followed by environmental and resource conservation and affordability and accessibility (Figure 1*d*). The affordability and accessibility scores for Hong Kong were not as high because the cost of travel in the city is only slightly below average. The overall highest score for affordability and accessibility was awarded to Moscow, where, perhaps because of a very low road network density, residents can travel relatively shorter distances to reach services. The city with the highest performance in environmental and resource conservation was Buenos Aires, Argentina. However, the city is missing data on the energy use of transport, so its performance in this category could possibly change, should these data become available. Chicago, Illinois, scored the lowest overall. The city suffered from a low road network density and a high cost of travel per capita. However, average travel speeds were higher than the mean for the group, and the private vehicle mode share was also very high, findings that mean that congestion may not be the primary factor in the low affordability and accessibility score. Chicago had the highest private vehicle mode share (88%) as well as the highest emissions and transportation energy use for this population group.

Although the scores establish a ranking, they are not meant to be interpreted as a final judgment of each city's transportation infrastructure. As an example, although Hong Kong had the highest mobility, operational efficiency, safety, and cumulative scores for its group, it did not rank among the highest in affordability and accessibility and environmental and resource conservation. In such a situation, clustering according to socioeconomic characteristics of the cities would be useful, so that Hong Kong may want to look to a city with a similar socioeconomic profile for inspiration on how best to tackle its problems in affordability and accessibility and environmental and resource conservation.

Although population groups provide one way to cluster the results according to context, another means of organization of the results is by GDP per capita (*12*). Figure 2 ranks the scores by per capita GDP and accounts for the population group (indicated by the size of each circle). When the GDP data were not available in the UITP data set, they were obtained from the work of Hawksworth et al. (*86*).

The results in Figure 2 show that transportation systems in cities with high average incomes are not necessarily more efficient or effective, as a wide variety of incomes are distributed across the spectrum. In the very large population group, Hong Kong, with a GDP per capita that stands a little above the average for the sample [€27,600, with a sample average of €22,803 (€1 = $1.35 in 2005)], ranks the highest, followed by Moscow, which holds one of the lowest per capita GDP rates. Likewise, in the large cities group, Curitiba, Brazil, ranks higher than Singapore, even though the GDP per capita in Curitiba is less than half that of Singapore. The lack of a strong relationship between high earnings and high cumulative scores may indicate that a city does not need to have high GDP rates to maintain an efficient and functional transportation network. Furthermore, the lack of a strong relationship may also bring into question the premise that an efficient transportation network affects a city's economic advantage. However, further study is required to establish an exact relationship.

Figure 3 shows the distribution of city rankings geographically, with colors representing the range of scores and the size of circles representing the population group (*87, 88*). Scores were distributed by use of the equal interval attribute in geographic information system software. As illustrated, most of the cities were distributed over the range of scores of from 2.52 to 3.97, with a few apparent outliers (Hong Kong, Moscow, etc.). Although cities in Europe take up the majority of the sample size, none of them ranked in the lowest category. The addition of cities in Asia, Australasia, and North America may help balance the overall sample and provide a greater variation in scores.

City administrators and policy makers who wish to use this data set to benchmark their transportation networks can do so using the

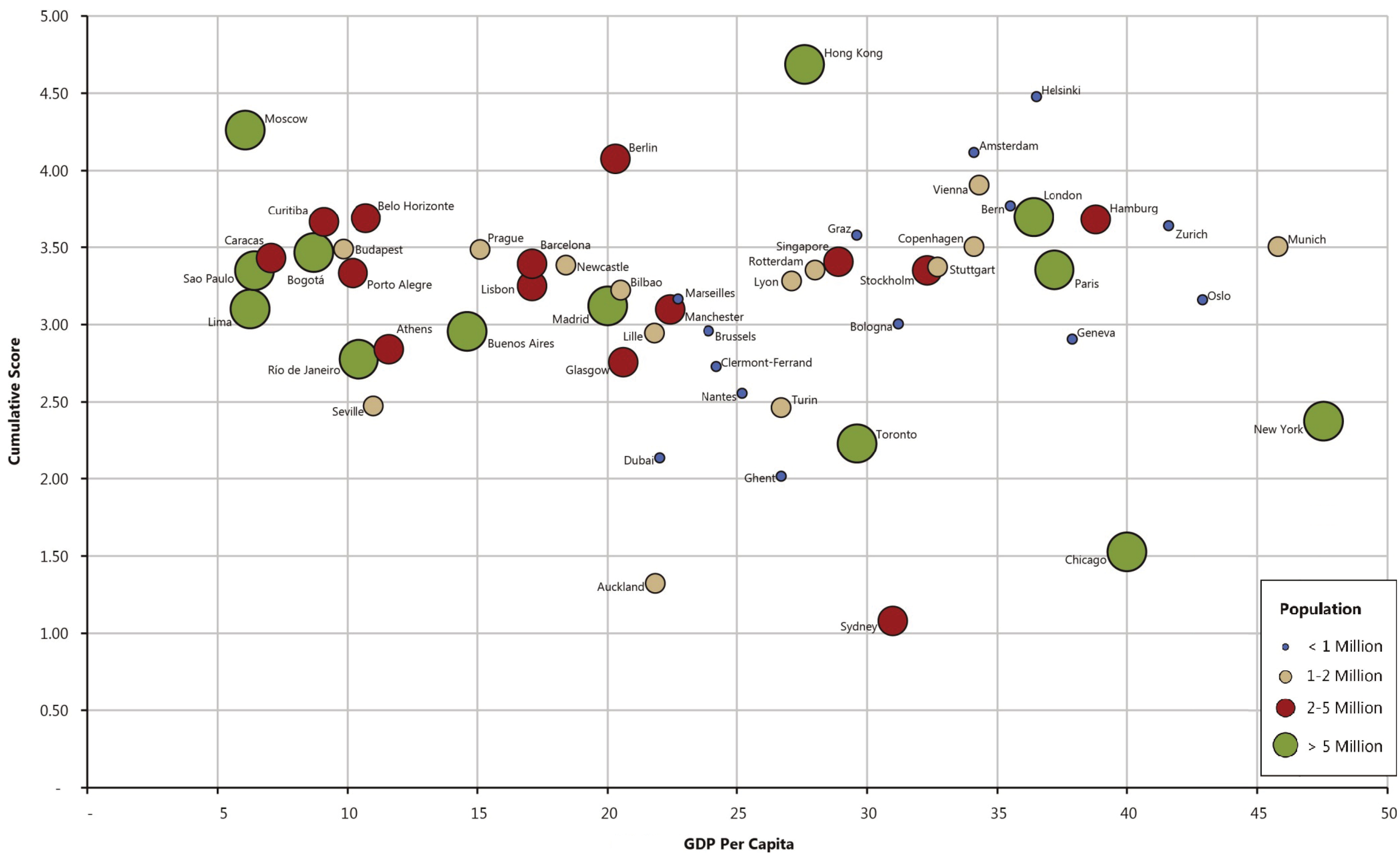

FIGURE 2 City rankings by GDP per capita (in thousands of euros) and cumulative scores.

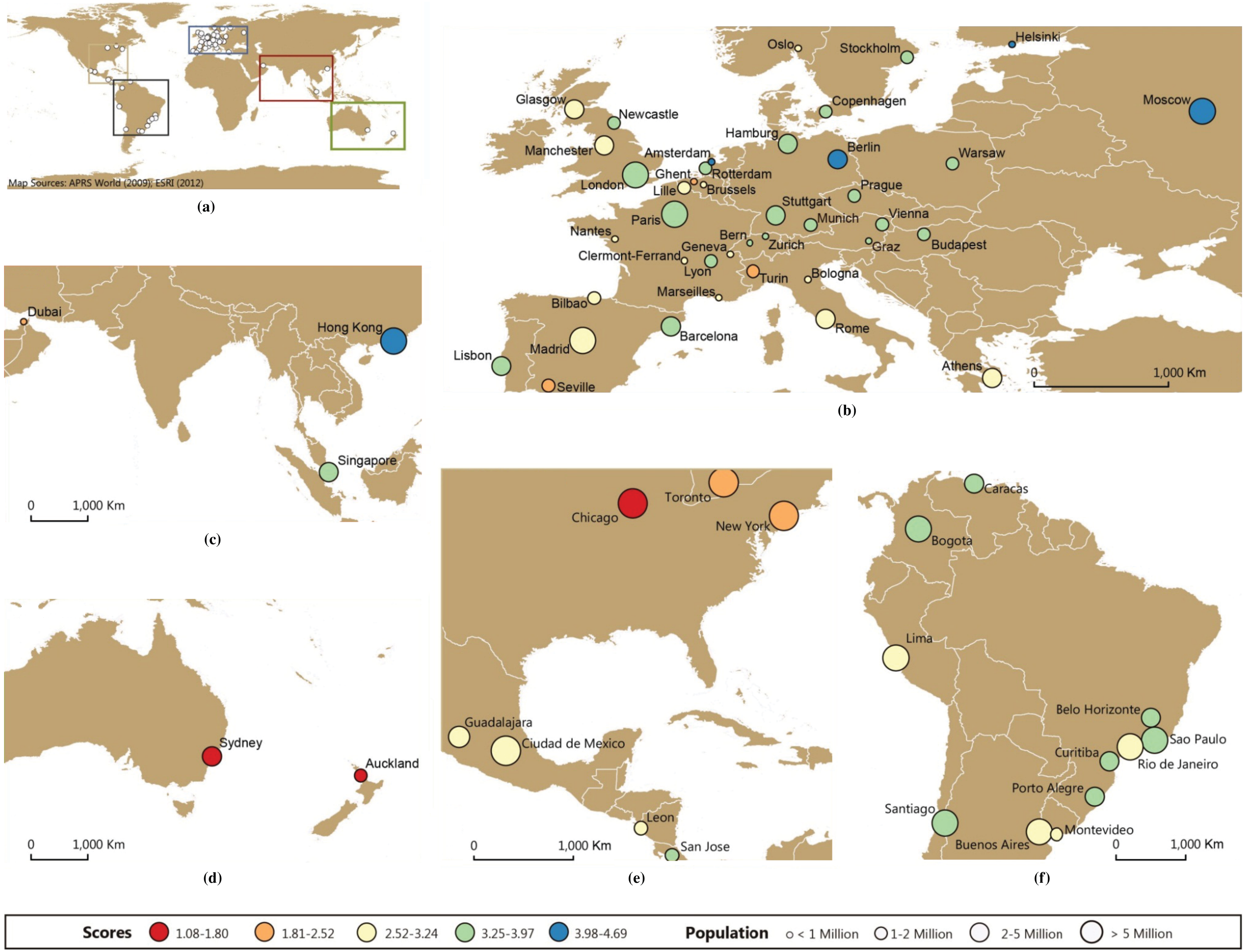

FIGURE 3 City rankings by geographic distribution: (*a*) context map, (*b*) Europe, (*c*) Asia, (*d*) Australasia, (*e*) North America, and (*f*) South America.

TABLE 3 Data for Calculating *z*-Scores and Normalized Scores

Indicator	Unit	Under 1 Million		1–2 Million		2–5 Million		5 Million and More		Normalization	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Min.	Max.
Affordability and accessibility										–4.66	2.49
Average duration of trip	min	25	3	25	6	28	12	36	13		
Monthly income spent on transport	%	9	2	11	5	15	8	12	5		
Length of road per thousand inhabitants	m	3,828	1,351	2,961	1,028	2,376	1,621	2,205	1,392		
Mobility										–6.45	4.55
Average speed of trip	km/h	31	8	29	7	30	6	27	6		
Daily trips on foot and by bicycle	%	31	8	31	9	27	10	24	12		
Daily trips by private motorized modes	%	54	11	47	13	50	13	48	17		
Daily trips by public transport	%	15	6	23	14	22	9	27	13		
Operational efficiency										–3.13	3.89
Annual public transport passenger-km per inhabitant	km	1,272	762	1,730	1,219	1,337	992	1,768	1,418		
Recovery rate of public transport operating expenditure by fare box revenue	%	52	23	58	28	67	31	75	32		
Environmental and resource conservation										–6.19	1.93
Annual polluting emissions due to passenger transport per inhabitant	kg	63	21	459	894	333	604	627	786		
Annual energy consumption for passenger transport per inhabitant	MJ	15,321	2,844	14,255	8,883	15,613	6,123	14,443	11,897		
Safety: passenger transport fatalities per million inhabitants	Unit count	65	49	57	36	64	35	77	50	–3.19	1.29

NOTE: SD = standard deviation; min. = minimum; max. = maximum.

averages and standard deviations for each population group in this study. The averages provided are the mean of means, because many of the original data were already averaged. Likewise, the standard deviations provided were the standard deviations from the mean of means. Table 3 provides the data. By using the mean and standard deviation for each population group provided in Table 3, transportation planners in any city around the world can participate in this exercise. Use of the minimum and maximum normalization scores provided for each category will allow any city to be ranked within the results tables so that planners can best identify areas in which weaknesses in their local transportation networks exist and what cities they may look to for best practices.

The comparison of the results of key indicators helps to establish a level of context among the transportation networks in cities around the world. Analysis of the variables that lead to high scores opens up the discussion on what constitutes the characteristics of an efficient and effective transportation network. The study intends to provide a framework for discussions that can lead to more targeted and resourceful approaches to identifying problems and devising solutions. By comparing the results of the rankings with contextual indicators, such as demographic data (population, density, GDP, etc.), policy makers can better decide how to interpret the results and determine from which cities to draw inspiration for solutions.

CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

This paper began by posing three questions for the development of a diagnosis for a transportation network: What needs to be measured? What kind of data should be used? How should the results be compared to better account for context? The responses to these questions were found through an analysis of policy and research to identify key performance indicators with which to assess urban transportation at the global level. These indicators make up a diagnostic tool that is based on a framework of rapid assessment processes, providing policy makers and planners with a way to identify weaknesses in transportation networks quickly and develop targeted solutions. The diagnostic tool measures transportation performance according to a number of categories identified through an analysis of urban transportation goals around the world: affordability and accessibility, mobility, operational efficiency, environmental and resource conservation, and safety. The plan and policy analysis also identified the following additional categories: economic development, quality of life, and infrastructure condition and performance. However, indicators measuring performance in these categories were not selected because of a lack of data. The final result is a set of 12 indicators measuring the performance of the transportation networks of 63 cities.

This study has revealed that by use of a combination of transportation policy and research, transportation agencies have sufficient information to begin developing a benchmarking process. However, the weakness lies in the availability of secondary data that can be used to develop a comprehensive database. With available and reliable data, the development of a number of analytical tools is possible, and the simplest of these tools was demonstrated for the project described here. Armed with such tools, transportation planners around the world can conduct rapid assessments of transportation systems to identify areas in which major weaknesses lie and areas in which to look for best practices. By centralizing the information and making it publicly available, it is possible for policy makers, community organizers, and interested citizens to participate in the exercise and provide input into the process. Such initiatives are already under way, with national-level data provided by the World Bank and the United Nations (among other organizations), and cities around the world are launching open data platforms. Improved access to more reliable data will expand this tool and make it an effective means of continuous improvement for urban transportation networks around the world.

To both deepen and broaden this analysis, the following recommendations are made:

1. Data. The current number of indicators helps provide a sufficient performance benchmark on the basis of currently available data. However, as illustrated by the initial policy and research analysis, to create a holistic picture of a transportation network, additional data in the areas listed below are needed. Statistics are needed for the remaining indicators to enhance the data set.
   – Accessibility. Access to jobs and services is becoming a key driver in improving the interplay between transportation networks and land development. Progress in the accessibility category can be a good indicator of the integration of transportation and land use.
   – Economic development. Data on economic development provide a means to better frame the costs of congestion (in many cases, the costs of business as usual) as well as potential benefits from system improvements.
   – Quality of life. Data on quality of life will help to integrate universal design principles into the transportation network.
   – Infrastructure condition and performance. Infrastructure condition and performance are tied to operational efficiency and account for the state of the physical assets. Data in this area will help to ensure that the system infrastructure is maintained.
2. Sample size. Data from a geographically wider sample of cities will balance the indicators, which are currently more in line with statistics for European cities. As cities around the world improve their data-gathering techniques and expand their databases, a greater number of cities will, perhaps, be able to be assessed.
3. Contextual research. The historical, geographical, cultural, and socioeconomic backgrounds of the sample cities must be considered to deepen the analysis.

The process developed in the project described here can be used immediately to form an initial and rapid assessment of a city's transportation system. However, additional research and analysis are required to develop a fully implementable tool. In the meantime, transportation planners can use this framework to identify priority problems and place the performance of their city's transportation network in the right context. Increased use of tools and processes such as the one presented in this paper can help harmonize available data around the world, thereby allowing anyone with access to the Internet to partake in this exercise and help expand the data set.

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