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A METHODOLOGICAL FRAMEWORK FOR BENCHMARKING SMART TRANSPORT CITIES

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Abstract

Besides responding to challenges of rapid urbanization and growing traffic congestion, the development of smart transport systems has attracted much attention in recent times. Many promising initiatives have emerged over the years. Despite these initiatives, there is still a lack of understanding about an appropriate definition of smart transport system. As such, it is challenging to identify the appropriate indicators of ‘smartness’. This paper proposes a comprehensive and practical framework to benchmark cities according to the smartness in their transportation systems. The proposed methodology was illustrated using a set of data collected from 26 cities across the world through web search and contacting relevant transport authorities and agencies. Results showed that London, Seattle and Sydney were among the world’s top smart transport cities. In particular, Seattle and Paris ranked high in smart private transport services while London and Singapore scored high on public transport services. London also appeared to be the smartest in terms of emergency transport services. The key value of the proposed innovative framework lies in a comparative analysis among cities, facilitating city-to-city learning.

Keywords: Urban transport, smartness index, smart city, intelligent transport system, city ranking.

INTRODUCTION

The world's urban population has increased from 29% in 1950 to 50% in 2008 and is projected to increase further to 70% by 2050 (UnitedNations, 2008). This rapid growth has increased demand for transportation facilities. While providing more transport services might be an easy option to meet the increased demand, the increase in supply is often associated with undesirable outcomes like traffic congestion. According to a study on 75 US cities in 2000, a total of 3.6 billon vehicle-hours and 5.7 billion US gallons of fuel were wasted due to congestion-related delays, resulting in a congestion cost of $67.5 billion (Shaheen & Finson, 2004). In a parallel vein, Goodwin (2004) has projected that the annual congestion cost in UK would reach GBP30 billion by 2010 and keep increasing thereafter.

Better management of transportation services with controlled increase in supply would be a useful alternative strategy to meet the increased demand. A common strategy is to introduce smart technologies to better manage urban transport systems. The idea of making a transport system smarter is not new. Garcia-Ortiz et al. (1995), for example, has discussed how various cities have developed smarter transport systems by introducing smart technologies. More recently, the Research and Innovation Technology Administration (RITA) has defined an architectural structure for deployment of smart technologies in USA (RITA, 2007). The smart transportation guidebook (NJDOT, 2008) has outlined different policies for making smart transportation systems for New Jersey and Pennsylvania, while IBM (2009) has suggested a number of ways for improving mobility by introducing smart technologies. Debnath et al. (2011) have discussed the smart technology initiatives in Singapore.

Despite various initiatives promoting smartness in urban transport systems, little is known about how these systems and their host cities are performing, and even less, as to which is a model city for smart transportation if one exists. Without a proper concept of smart transport system and specific indicators of smartness, it is difficult to determine if a transport system is becoming smarter or indeed, what needs to be done to make it smarter. Arguably, the lack of proper concepts and indicators could be a reason for not performing comprehensive benchmarking studies on smart transport cities.

Such a benchmarking study would allow comparative studies among cities. The most important aspect of such comparative studies is that cities can learn from each other and take appropriate initiatives to move towards becoming smarter. Notwithstanding criticisms (e.g., raising competitiveness, accuracy of ratings etc.), the ranking of smart transport cities could open opportunities for cities to assess a city's growth potential and to sharpen its profile among other cities. It could be used by transport authorities in public engagement to draw public attention to the major problems and underdeveloped sectors of transport systems, thus, initiating a broad discussion on potential growth issues, helping the authorities to learn what public opinions and desires are. Ranking would also motivate the authorities to make their decisions more transparent and comprehensible.

A review of the extant literature has yielded two regional studies that have attempted to benchmark cities according to the smartness in transport systems. First, Giffinger et al. (2007, 2010) have ranked European medium-sized cities according to the smartness in mobility (transportation and information communication technology) along with five other dimensions (economy, people, governance, environment, and living). Smart transport has been defined and measured by using indicators of local/international accessibility (e.g., public transport network per inhabitant, satisfaction with access and quality of public transport), availability of ICT infrastructure (computers and broadband internet access in households), sustainable, innovative, and safe transport systems (e.g., non-motorized traffic share, use of economical cars). While these indicators could reflect the performance level of a smart transport system, the study fails to identify many true indicators of smartness and hence the question remains how a transport system becomes smart. For example, the indicators of 'local/international accessibility' could measure 'accessibility' of transport facilities, but not for measuring 'smartness' in transport systems. The indicators of ICT infrastructure availability represent how accessible computers and internet are in households, but do not specifically represent how smart a transport system is. True indicators of smart transport systems should be based on transport-related ICT infrastructure (e.g., sensing technology used for tracking vehicles en-route). Moreover, sustainability, safety, and smartness are considered three components of a transport system which support each other (see Haque et al., 2013), but sustainability and safety are not indicators of smartness, rather these are indicators of the performance of a transport system.

Second, a study by the RITA on 108 cities in the USA, which is more robust than the Giffinger study in terms of using more appropriate indicators of smartness in transportation systems, has conducted a survey on the deployment of intelligent transportation systems in the years 2007 and 2010 (RITA, 2010). While this survey has provided a good opportunity for US cities to learn from others on the use of smart technologies, the concept of smart transport system is not well demonstrated. The deployment statistics have showed the extent of the smart technology usage, but have not explained how smart the technologies are. A comprehensive benchmarking of smart transport cities should not only measure the smartness of an urban transport system but also consider the extent of smart technology usage as well as their levels of smartness.

Review of the two studies reveals two important gaps in literature: (1) inability to utilize true indicators of smartness in transportation systems, and (2) utilizing indicators without considering the smartness levels of the indicators. Arguably, lack of a proper concept of smart transport system, which consequently leads to not obtaining specific indicators of smartness, is the primary source of these gaps in the current literature. Therefore, a comprehensive benchmarking methodology needs to be developed which will address these gaps by developing indicators based on a proper concept of smartness in a transportation system.

This paper proposes a comprehensive and practical framework for benchmarking cities according to the smartness in their transportation systems. The methodology of the framework includes: formulating a proper concept of smartness, generating a generic matrix of indicators of smartness for an urban transport system, measuring smartness indices of different sub-systems of urban transport system, and taking into consideration the usage of smart technologies. The proposed innovative framework, particularly the generic matrix of indicators and the process of developing the matrix by utilizing a proper concept of smartness in urban transport systems, is the key contribution of this paper and mark the advancement in the methodology of benchmarking smart transport systems. In the succeeding sections, the framework, its methodology, assumptions and data sources will be explicated, followed by an illustrative example, which benchmarks 26 major cities across the world. The illustrative example on benchmarking smart transport cities is limited to large cities in terms of population.

FRAMEWORK OF BENCHMARKING

The framework involves three key steps: formulating a proper concept of smartness in the context of urban transport system, generating a generic matrix of indicators of smartness, and measuring smartness indices from scores of the indicators. These three steps are discussed in the following sections.

The Concept of Smartness

The concept of smartness is fundamental to any benchmarking exercise among smart cities. A recent review of the ‘smart city’ concept has revealed diversified ideas and definitions of ‘smart city’ and the associated concept of smartness among service providers, city authorities, governments, and researchers (Chin et al., 2010). In general, a smart city is characterized by its Information and Communication Technology (ICT) infrastructures, facilitating an urban system which is increasingly smart, inter-connected, and sustainable (Giffinger et al., 2007, 2010; Lazaroiu & Roscia, 2012; Lee et al., 2013).

In the context of an urban transport system, several researchers (e.g., Goldman & Gorham, 2006; Santos et al., 2010) have identified the implementation of smart technologies as the central element in achieving smartness and sustainability. Some (e.g., Debnath et al., 2011; Haque et al., 2013) have illustrated how smart technologies can support sustainability by achieving greater economic and environmental efficiency. A smart urban transport system is often viewed as one which utilizes smart technologies in its operation and management. A smart technology is a self-operative and corrective system that requires little or no human intervention. Typically, it has three elements: sensors, command and control unit (CCU), and actuators to provide the basic capabilities: sensing, processing and decision making, acting (control), and communicating (Akhras, 2000).

To have sensing ability, a system should be able to extract information from its sensors and communicate with its CCU or with external systems. Typically, sensors collect information regarding the state of the system, which are transmitted to the CCU for processing. The CCU interprets the information, takes decisions and transmits those to actuators, which execute the decisions into actions. Thereafter, the sensors again collect information and transmit to CCU, reinforcing a closed-loop monitoring and action taking process. The essential idea of a smart system is that it reduces human involvement and makes the system self-operational.

In summary, a smart system should possess the above mentioned basic capabilities. In addition, there could be some other advanced or higher-order capabilities as shown in Figure 1. The higher-order capabilities include: predictability, healing and preventability. Predictability is the advanced level of basic sensing and processing, which refers to how accurately a system can predict a potential problem or scenario. Healing is the advanced level of control, that is, how well a system can heal potential problems to have complete recovery without any human intervention. Preventability, a combination of predictability and healing, is the ultimate level of smartness, which makes a system capable of preventing potential failures by predicting and taking the appropriate preventive measures.

Based on this concept of a smart system and its capabilities, the attributes of a smart urban transport system would have properties that reflect both the basic and advanced levels of smartness.

Indicators of Smartness

The corresponding indicators of smartness in an urban transport system could be identified through the smart capabilities in its sub-systems. Typically, an urban transportation system is composed of sub-systems like private transport, public transport, commercial transport and emergency transport services. In this study, a generic matrix of smartness indicators was formulated where the columns represent the sub-systems (i.e., Private, Public, and Commercial and Emergency transport) and the rows represent the smart capabilities (i.e., Sensing, Processing and control, Communicating, Predicting, Healing, and Preventing).

Under every smart capability, each sub-system could have multiple items, each of which is presented in a single cell. For example, the 'sensing' capability of the private transport sub-system includes detection of a private vehicle at a number of points including parking facilities, traffic intersections, enforcement facilities, and while vehicles are on the way. It also includes detection of occupancy (i.e., number of passengers in a vehicle). Essentially, each cell of the matrix contains two components: (1) a description of smart Capability that a technology should possess (marked as 'C' in Table 1), and (2) the Extent to which a smart technology is available (i.e., indicators of the smart capability, marked as 'E'). In summary, 'C' describes the particular capability of a technology and 'E' measures the availability of that technology. The complete generic matrix is presented in summary form in Table 1. The detailed matrix containing the whole set of sub-systems and smart capabilities is enormous and not included in this paper, but can be found in Chin et al. (2011).

Extents of availability or indicators are gauged in four categories: 1) Not available, 2) Trial phase, 3) Partial coverage, and 4) Full coverage. The first category (not available) refers to the state that a particular technology is unavailable in a city, including the situation where city authorities may have started planning for the technology but have not taken any initiatives to implement. The second category (trial phase) indicates a state where city authorities have started to study the feasibility of implementing a technology including pilot testing. The third category (partial coverage) refers to a state where a technology either at system or individual level is deployed partially in selected places. An example of partial usage at system level includes a city that has implemented network coordinated traffic signal system at a few traffic intersections and the rest are equipped with fixed-time controllers. Similarly, an example of partial usage of a technology at individual level (e.g., the 'e-call' system) includes a city where a portion of people has started to use this technology while the rest are yet to decide on its use. The last category (full coverage) indicates a scenario where a technology is available in a city in full extent. A system level technology is considered in the category of full coverage if the technology is implemented almost everywhere in a city while an individual level technology is considered as full coverage if it is being used by most of the inhabitants of a city.

The primary reason for developing a smartness indicators matrix is that it has the potential of identifying relative smartness of the sub-systems across categories of the smart capabilities. A proper categorization of the sub-systems of an urban transport system will allow identification of the extent of available technologies that make these sub-systems smart. In addition, the matrix format has the advantage of capturing every possible smart technology for all sub-systems.

Developing a generic matrix with complete lists of smartness indicators requires identification of the technologies that possess the smart capabilities in their applications. For this study, this information is drawn from three major sources - existing technologies listed on websites and publications of city authorities, mining websites of service providers for technologies that are being commercialized and under design stage, and potential future technologies obtained from city's master plans, service provider's future plans and research organization's publications. A total of 66 indicators have been identified.

Measurement of Smartness Indices

To benchmark smart transport cities, a composite scoring system is developed to measure the smartness index (*SI*) of a city's transportation system. *SI* utilizes the scores of each component of the smartness indicators matrix to calculate a composite score using the following equation

$$SI = \frac{\sum_{j=1}^{J}\sum_{i=1}^{I} s_{ij}}{\sum_{j=1}^{J} I_j} \times 100\% \qquad (1)$$

where S_{ij} is the smartness score for indicator i in each sub-system j, J is the total number of sub-systems, and I_j is the total number of indicators in each sub-system.

Similarly, smartness index can be computed separately for each sub-system as,

$$SI_j = \frac{\sum_{i=1}^{I} s_i}{I_j} \times 100\% \qquad (2)$$

where SI_j is the smartness index of sub-systems j.

To assign scores (S_{ij}) to the indicators, the extent of their availability could be considered with a maximum value of 1 for each indicator. Scores for each category of the extent of availability could be chosen based on the rationale of the benchmarking exercise and the level of availability of detailed data. While the simpler form would be to use an ordered scale with uniform scores (where the four categories Not available, Trial phase, Partial coverage, and Full coverage has scores of: 0, 0.33, 0.67, and 1), a more sophisticated form would be to use a continuous scale where the ordered categories could further be disintegrated. For example, instead of using a single score for the category 'Trail phase', scores can be assigned based on the progress of the trial phase. A higher score can be assigned if the trial is nearing completion, or on the other hand, if it is at the beginning stage, a smaller score can be assigned. A simple ordered scale is adopted in this study mainly due to lack of detailed data on various indicators of smart transport system across the cities around the world.

Many city ranking studies (e.g., Castillo and Pitfield, 2010; Giffinger et al., 2007) have weighted the scores of indicators based on their importance in the context of the study. Expert opinions or judgments of professionals on the importance and relevance of the indicators have also been used to assign the weights (see Lazaroiu and Roscia, 2012). To assign weights to the scores, authorities who conduct the ranking exercise may commission experts for identification of relative importance and relevance of the indicators. The composite indices of the sub-systems could further be weighted depending on the relative importance of the sub-systems in the overall transportation system (e.g., different cities may have different priorities for the sub-systems). In order to assign similar weights to the indicators of this study, it might be necessary to have expert opinions regarding the importance of each indicator in each of the cities studied, which will require extensive amount of data collection and resources. To simplify the data collection process, all indicators and sub-systems are assumed to carry equal weight in this study. However, the effects of different weights on the indicators and sub-systems are explored by conducting a simulated sensitivity analysis. In particular, sensitivities are simulated for four weight cases: 1) equal weights for all sub-systems, 2) 0.5 for private transport and 0.25 for others, 3) 0.5 for public transport and 0.25 for others, and 4) 0.5 for emergency transport and 0.25 for others. It is noteworthy to mention that these weights are assigned for illustration purpose only. As mentioned earlier, the weights may vary from city to city based on their relative preferences to each of the sub-systems.

The smartness indices in Equation 1 and 2 are expressed in percentage values. This allows one to evaluate a transport system's smartness in comparison with the model smart transport system. The model system would incorporate all of the technologies and their usage would be in full scale. Thus, the model system would obtain smartness indices of 100% for all sub-systems and the system itself.

AN ILLUSTRATIVE EXAMPLE OF BENCHMARKING SMART TRANSPORT CITIES

Preliminary Selection of Cities

A benchmarking exercise was conducted to illustrate the proposed framework. A total of 26 cities, as shown in Table 2, were selected for this exercise based on two criteria. First, a city must have a good level of infrastructure. Availability of a good level of infrastructure would indicate that the city has the potential to deploy smart technologies. The basic postulation is that utilization of smart technologies can only be possible if a city has a good level of basic infrastructure for its main sectors, such as transportation, electricity distribution, water supply, telecommunication, etc. Second, a city should be large in population size as the scope of this illustrative example was limited to large cities only. A threshold of two million populations was selected to keep the data collection process within the available resources of this study.

The results of MERCER (2009), a global benchmarking study on cities according to the levels of infrastructure available in six categories (electricity supply, water availability, telephone and mail services, public transport provision, traffic congestion, and the range of international flights from local airports), were utilized in the city selection process. The top 50 cities from that survey were selected in the first instance and then filtered according to the population size threshold.

Data Collection

Due to resource constraints, the benchmarking exercise of this study mainly relied on secondary information. Since information about the indicators (both the level of smartness and extent of availability) were unlikely to be available in any single database, information was collected from several sources over 2010-11 including publicly available information (e.g., webpages, reports and publications), and through contacting transport authorities and agencies.

In the first instance, webpages of city authorities, service providers and related research and news agencies were mined using Google search with keywords of the indicators and city names. Since the indicators describe the deployment of smart technologies, it is reasonable to anticipate that news of their deployment and usage statistics would be documented on webpages of city authorities and service providers, or in media reports. To ensure accuracy and robustness in the collected information, the websearch was repeated by two researchers independently. Information collected by both researchers was later combined and cross-checked for errors and omissions. A more comprehensive way of collecting such information would be to conduct surveys among candidate cities, which unfortunately was not possible in this study because of resource constraints. Since the main aim of this study is to demonstrate a new benchmarking methodology using the proposed smartness indicators matrix that take into account both the level of smartness and the extent of availability, a dataset with secondary information might serve the purpose of benchmarking exercise here.

Following the web search, those indicators with no information were isolated and the relevant transport authorities and agencies were then approached through emails to provide further information. It is worth noting that even though every effort was made to collect the most up-to-date information, with technology and information change, the collected data might be valid for a short time period only. On completion of the data collection, the indicators were again cross-checked to ensure that valid data for each indicator were available for every city. Only those indicators with all available information were selected for the benchmarking exercise, leaving a final set of 21 indicators for comparing across cities (Table 3).

Results

Results showed that London was the smartest among the 26 studied cities for its transportation system (SI = 67.1%), followed by Seattle (SI = 59.2%), Sydney (SI= 57.2%), New York (SI= 56.9%) and Melbourne (SI=56.5%). The top cities in smart private transport services were Seattle (SI = 56.6%), New York (SI = 54.8%), and Paris (SI = 54.8%), whereas London (SI = 88.4%), Singapore (SI = 71.7%) and Paris (SI = 63.4%) ranked highest in terms of public transport services. London was also found to be the smartest (SI = 100%) among all cities for emergency transportation services. Figure 2 shows the benchmarking results of the 26 cities' transportation system as a whole as well as their sub-systems of private, public, and emergency transport services. The relative global rankings of the cities are indicated next to the city names.

As explained in the methodology section, information about the extent of availability of smart technologies was used in this benchmarking exercise. However, information about the effects of the technologies (e.g., amount of congestion reduced due to installation of a smart congestion pricing technology) was not collected, primarily because the effects are not clearly identifiable and often non-distinguishable from the effects of transport policies, which are supported by the smart technologies (Debnath et al., 2011). The benchmarking results of the top 5 smart transport cities along with their key smart technologies (i.e., extent of their availability) are discussed next according to the order of their global ranks.

Rank #1. London

The transportation system of London was found to be the smartest among all studied cities (SI = 67.1%) with the highest ratings for its public (SI = 88.4%) and emergency (SI = 100%) transport systems.

London has a wide range of smart technology in its public transport system. For example, all buses are equipped with Automatic Vehicle Location Systems (AVLS) and on-board passenger information display and announcement system. The AVLS enable providing passengers with real-time information on bus arrival timings at most bus stops and through text messaging and online channels. Using text messaging, most taxis can also be booked in real-time. The other notable smart services include: intermodal and electronic fare collection system including contactless payment technology, bus rapid transit system, driverless control of transit vehicles, bus lane enforcement system, and whole corridor traffic signal priority system for buses. London also has the state-of-the-art personal rapid transit (PRT) system at Heathrow international airport.

London’s smart private transport services (SI = 36.2%, rank = 14) include a network coordinated traffic signal system, variable speed limit control system, and metered ramps. Since 2003, London has introduced congestion charging, using automatic number plate recognition system (ANPR) for processing the payments of congestion pricing (Transport-for-London, 2011).

For emergency vehicle routing, London is using a computer-aided-dispatch system for its entire fleet, which also gets priority at traffic signals. Several initiatives have been taken to further improve the dispatch system. For example, the London Fire Authority has awarded a GBP7 million contract to replace and enhance its command and control emergency response system (PRNewswire, 2010).

Rank #2. Seattle

Seattle’s transportation system was the second smartest (SI = 59.2%) with the highest (SI = 56.6%) and fourth highest ratings (SI = 60.1%) for its private transport and public transport services respectively.

Among the smart private transport services, Seattle has a real-time adaptive and synchronized traffic signal system. ANPR systems are used to reduce red-light violations at some intersections. Freeways have metered ramps (148 ramps in 2007) and variable speed limit control system (10 freeway miles in 2007) (RITA, 2010). A smart parking guidance system (e-Park) provides parking space availability information for selected garages through roadside display panels and web portals. Electronic toll collection (ETC) facilities have been implemented on the SR167 HOT lanes, and two bridges (WSDOT, 2010).

Highlights of smart public transport systems include: AVLS for all buses, intermodal and electronic fare collection, transit signal priority at selected intersections, and real-time transit arrival timing sharing on mobile platform. Many of Seattle’s traffic signals are being updated for its future Rapid Ride Transit Corridors to support the signal priority system. Public transport users get real-time bus arrival timings on mobile platform for all bus stops. One of the taxi companies also provides SMS-based booking service.

Rank #3. Sydney

Sydney's transportation system achieved the third highest ratings (SI = 57.2%) with fourth ranking (SI = 50.1%) for private transport, sixth (SI = 58.3%) for public transport, and second (SI = 83.5%) for emergency transport services.

Smart technologies, such as variable speed limit control systems, ramp metering in some motorways, automated parking systems, and ETC systems have been implemented. For coordinating traffic signals, Sydney is using the Sydney Coordinated Adaptive Traffic System (SCATS), which coordinates and controls by continually adjusting the phasing of traffic lights so that they respond to traffic flow and traffic incidents.

For managing public transport services, Sydney has committed A$235 million to improving bus priority on strategic bus corridors and Sydney-wide implementation of the Public Transport Information and Priority System (TransportNSW, 2010). The AVLS, bus rapid transit systems, real-time next bus arrival information sharing for selected routes (on trial) are the other notable examples. To enforce bus lanes, Sydney has deployed bus lane cameras. SMS-based taxi booking service is available for all taxi companies. Similar to the bus priority signals, Sydney has deployed signal priority system for emergency vehicles, which also have the facility of computer-aided dispatching.

Rank #4. New York

New York scored a SI of 56.9% to obtain an overall fourth rank with second highest rating (SI = 54.8%) in private transport, whereas for public transport and emergency transport services, it ranked seventh (SI = 53.4%) and second (SI = 83.5%) respectively.

The highlights of New York's smart technology in private transport services include: an adaptive signal control system, variable speed limit technology, covering 152 freeway miles in 2007 (RITA, 2010), ETC system for all toll points, automated parking system, and real-time system for broadcasting parking space availability in selected areas.

New York has introduced smart public transport technologies for automatic vehicle tracking, electronic fare collection for all public transport services, providing transit signal priority at some intersections, automated enforcement of bus lanes, and sharing real-time bus arrival timings through web, mobile phones, and display panels at selected bus stops. Computer-aided dispatch systems are available for all emergency vehicles, which also get priorities at traffic signals.

Rank #5. Melbourne

The fifth smartest city (SI = 56.5%) was Melbourne, which got the fourth highest ratings for both the private (SI = 50.1%) and public (SI = 60.1%) transport services.

Similar to Sydney, Melbourne is using the SCATS system at more than 3,200 traffic intersections for coordinating traffic signals. It has also deployed ANPR for identifying unauthorized drivers and vehicles, automated parking systems, ramp meters at selected expressway entry points, ETC, and variable speed limit control systems. For example, the Western Ring Road is able to vary its speed limit between 60 km/h and 100 km/h depending on traffic conditions.

Public transport services utilize a good number of smart technologies, such as the AVLS, intermodal and electronic fare collection system, express transit services, and transit signal priority at over 500 intersections. A real-time transit arrival information system is available on mobile platform. Text-message based service is also available for booking Silvertop taxis in real-time.

Sensitivity Analyses

The foregoing shows results for the case in which equal weights were assigned to the sub-systems. Results from the simulation exercise of exploring sensitivities of the results are presented in Figure 3. With respect to a reference case (Case 1: equal weights), deviations in smartness indices for each weight case are plotted against the cities studied. The abscissa at zero deviation stands for the reference case (Case 1) where equal weights were assigned. A positive deviation from this line indicates that the weighted smartness index has increased by the deviation amount from the smartness index of the reference case and vice versa. In Case 2, the weights of private, public and emergency transport vehicles are respectively 0.5, 0.25 and 0.25. For Case 2, eight cities' smartness indices deviated outside of a 4% band around the reference case. Smartness indices of six cities were reduced and of two cities increased when the weight case was applied. In terms of absolute deviation, London had the highest deviation (-9.3) followed by Montreal (-6.0) and Boston (-5.3). These three cities ranked poorly under Case 1 for their smart private transport services (14th, 24th, and 26th respectively), therefore, the larger weight of private transport reduced the aggregate smartness indices of these cities in greater amounts than those of others. For Case 3 (public transport is weighted by 0.5 and others by 0.25), smartness indices noticeably deviated towards the positive side for four cities and negatively for one city, indicating a major thrust towards positive side. Again, the maximum deviation was seen for London (6.9), followed by Singapore (5.3) and Madrid (-4.6). London and Singapore were among the top ranked cities mainly for their smart public transport services under Case 1. Assigning larger weights to public transport services boosted their smartness indices, whereas it was reduced for Madrid (which ranked 25th under Case 1). Smartness indices of only two cities (Paris and Houston) deviated outside the 4% band for Case 4 (Emergency transport is weighted by 0.5 and others by 0.25).

From the above discussion, it is clear that assigning weights to the sub-systems influences the results significantly. Cities, where there are varying priorities and preferences for the sub-systems, should incorporate weights to their sub-systems based on appropriate theoretical grounds and justifications.

Common Trends and Issues

The benchmarking exercise has identified several trends among the top 5 smart cities in terms of the implementation of technologies and their usage for smarter management of transport systems.

All 5 cities have deployed technologies for tracking public transit vehicles and emergency vehicles en-route and at terminals/stations though the extent of usage differs from 'partial' to 'full' among the cities. Automatic Vehicle Location System (AVLS) is used on board public buses and trains to continuously track transit vehicles for providing a wide range of services: managing headway, providing real-time travel information to passengers, allocating prioritized signal at intersections, incident management etc. These smart services would help improve accessibility, reduce travel time, and promote enhanced efficiency of transit operations (e.g. ensuring smoother and balanced flow of transit vehicles). Additionally, these services would help encourage public transport as a viable alternative mode to private transport, reducing travel time for passengers by allowing them to choose the best route (e.g. fastest, cheapest) before starting a journey.

However, the AVLS technology has the potential for better utilization of existing prioritized transit signals. These signals are mostly operated based on loops/optical detection technology through detecting buses before approaching an intersection and correspondingly allocating green times for quicker and early discharge at intersections (e.g., New York, Melbourne). A smarter utilization of AVLS technology is to provide signal priority through a corridor instead of the commonly practiced intersection based approach. An example is Route 43 of London (DFT, 2011).

The tracking of private vehicles has not attracted as much attention as in the case of transit vehicles in most cities, probably because of privacy issues. However, many of these cities are using APNR technologies for identifying vehicles at toll collection points or at locations of enforcement cameras (e.g., red light, speed cameras). The use of smart tags for paying tolls or congestion charges have gained popularity in many cities. However, their capabilities have yet to be exploited efficiently. These tags could be used for smarter traffic flow management and safety improvement.

Detection of passengers on transit vehicles though utilization of smart card fare payment systems is another popular sensing technology used in many public transport systems. As a transition to smart cards from cash based payments, most cities are currently using both transaction systems. However, often a higher fare is imposed for cash based payments to encourage passengers to use smart cards. A smart card only system would be able to track all passenger movements and correspondingly manage the balance between transit vehicle supply and demand. Cities (e.g., London, Seattle, New York) are also moving towards an intermodal and seamless fare collection system, where a single smart card can be used in all services and modes, highlighting the potential of using passenger movement information for better utilization of resources.

Providing traffic and travel related information to travelers have been found common in many cities. Public transport users are able to get real-time transit arrival information on their mobile phones. Some cities (e.g., New York, Seattle) have deployed smart technologies to disseminate information on parking spaces to private transport users in order to achieve better usage of parking facilities and reduce travel and search time for a parking space. Automated parking facilities are also gradually being deployed in many cities for better utilization of parking spaces and improved efficiency.

However, to bridge the gap between private and public transport services, most of the cities are providing high-end personalized services by using smart para-transit technologies like real-time taxi booking through phone call and messaging. While personalized rapid transit systems (PRT) have attracted much attention of researchers in recent years, the only commercial implementation is London’s Heathrow airport PRT. The 3.8 km long PRT has become the world's first true commercial PRT system (ULTRA, 2011), and its successful implementation could trigger plans to deploy it in other cities.

For smarter and safer management of traffic flow, all 5 cities are utilizing smart technologies like coordinated traffic signal system, variable speed limit control, and metered expressway entry control. Adaptive and coordinated traffic signal systems continuously collect traffic information (detection of vehicles and pedestrians) and adjust signal timing accordingly based on real-time demand. By coordinating traffic signals at adjacent intersections, the systems are able to optimize travel time by minimizing the number of stops at intersections so that greater efficiency in traffic flow and reduced travel time and fuel consumption are achieved. While many cities (e.g., London, Melbourne, New York) have most of their intersections under the coordinated signal systems, Singapore has all of its intersections under the system. Arguably, the intersections at major corridors are of most importance to be included in the system and for larger cities it might be impractical to have all intersections under the system.

While the studied cities have deployed impressive numbers of smart technologies, most of the technologies have only basic level of abilities like sensing, processing, control, and communicating. Availability of higher-order smart abilities, such as predicting, healing, and preventing, are unavailable in most cities. However, there is a trend towards utilizing higher-order smart systems. To ensure smoother traffic flow, cities (e.g., Singapore, London, New York) are trialing/studying traffic prediction tools in order to predict traffic flow and speed. Prediction of traffic conditions, passenger movement patterns, etc. would allow cities to provide responsive supply by predicting real-time demands.

While currently available surveillance and enforcement systems are able to detect incidents and allow cities to act promptly, there is much to be done to achieve automated healing and preventing abilities. Arguably, more research in these smart systems would encourage cities to implement technologies with higher-order smart abilities. This also provides opportunities for the less smart cities as they learn from other smarter cities and gradually move towards being smart by utilizing technologies of basic smart abilities.

Smart transport systems are anticipated to be an important growth area in the next 10-15 years. Pike Research has estimated that $22.4 billion will be invested worldwide on smart transport (Bodhani, 2012). Development of structured frameworks for planning, developing, and integrating smart transport technologies (e.g., the National ITS Architecture in the US, the FRAME Architecture in the EU) further reflect the positive intention of transport authorities in developing and deploying smart technologies. These frameworks could identify and assess the potential of individual smart transport technologies, as well as of integration of the technologies.

The benchmarking framework proposed in this paper allows comparative studies among smart transport cities. From the illustrative example, several cities (e.g., London, Seattle, Sydney, New York, Melbourne) have emerged among the world's top transport smart cities. A close examination of these cities' urban transport systems and smart technologies application could yield good practices and useful lessons for other cities wishing to pursue similar development. That is, the benchmarking has the potential to allow the less smart cities to identify gaps in the use of smart technologies in their transport systems by comparing their development against those of the top cities. It also allows these cities to learn from the smarter cities, particularly the kinds of smart technologies that have been implemented and their success/failure stories.

While the proposed framework is illustrated to benchmark 26 selected cities according to smartness in their transportation systems, the framework could be used to rank other cities in the world. For example, if a transport authority or a city administration or a researcher group is interested to find the smartness indices of a city's transport system and its sub-systems, the generic matrix of indicators developed in this study could directly be applied. Decision of weights to the indicators and sub-systems of the transportation system could be made based on the interests of the city and availability of required information and resources (e.g., expert opinions on the relative importance of the indicators). However, if the sector to be studied is different from 'urban transportation system' (e.g., healthcare system) or the focus of the study is something else than smartness (e.g., user acceptability), then appropriate indicators for user acceptability of the city's healthcare system need to be developed. To do so, the process of developing a generic matrix of indicators described in this study could be adopted.

CONCLUSIONS

This paper presented a comprehensive framework for benchmarking smart transport cities, which was illustrated using the data of 26 large cities around the world. Unlike earlier benchmarking activities, this framework is grounded on the development of a proper concept of smartness and identification of appropriate indicators. Sixty-six indicators of smartness were identified in the form of a generic matrix through a rigorous and systematic search process from literature survey and secondary sources. The matrix format has the potential of identifying relative smartness - in every category of smart abilities of every possible smart technology in urban transportation sub-systems. The generic matrix of indicators and the process of developing the matrix by utilizing a proper concept of smartness in urban transport systems is the key contribution of this paper.

It should be noted that benchmarking is necessarily a dynamic activity where the scores of the indicators may change over time. The emergence of new technologies could create new dimensions to the generic list of indicators. As such, since the information about the indicators analyzed in this paper were collected during 2010-11 and these information are likely to change with new developments in the cities, proper care need to be taken when comparing the cities.

Thus said, it is important that these dynamic changes be considered as far as are possible. To take account of these dynamic changes, the proposed framework may be extended by modifying the generic list of indicators to match changing societal needs. This is an area for further research development. Also, more comprehensive data collection methods, such as conducting surveys among candidate cities, might be additionally employed for better validity of benchmarking results. Inclusion of more indicators, possibly all of those in the generic matrix, could further enrich the reliability and robustness of the benchmarking exercise. Weighting the indicators and the sub-systems based on appropriate theoretical grounds and justifications could further enhance the validity of the benchmarking results. Evaluating the uncertainties in smartness indices for different weighting schemes could be an interesting extension of this research. Examining the effectiveness of the smart technologies is another important area of future research.

DISCLAIMERS

This paper does not reflect the views of any organizations/agencies mentioned in the paper. The authors are solely responsible for the views of this paper.

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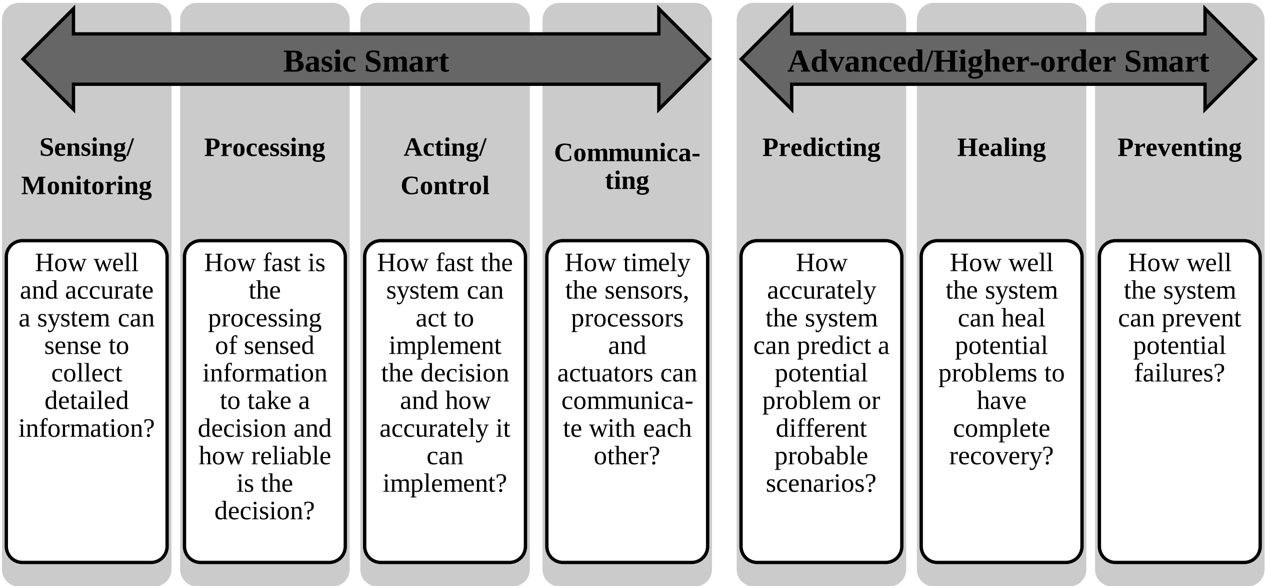

Figure 1 Capabilities of a Smart System

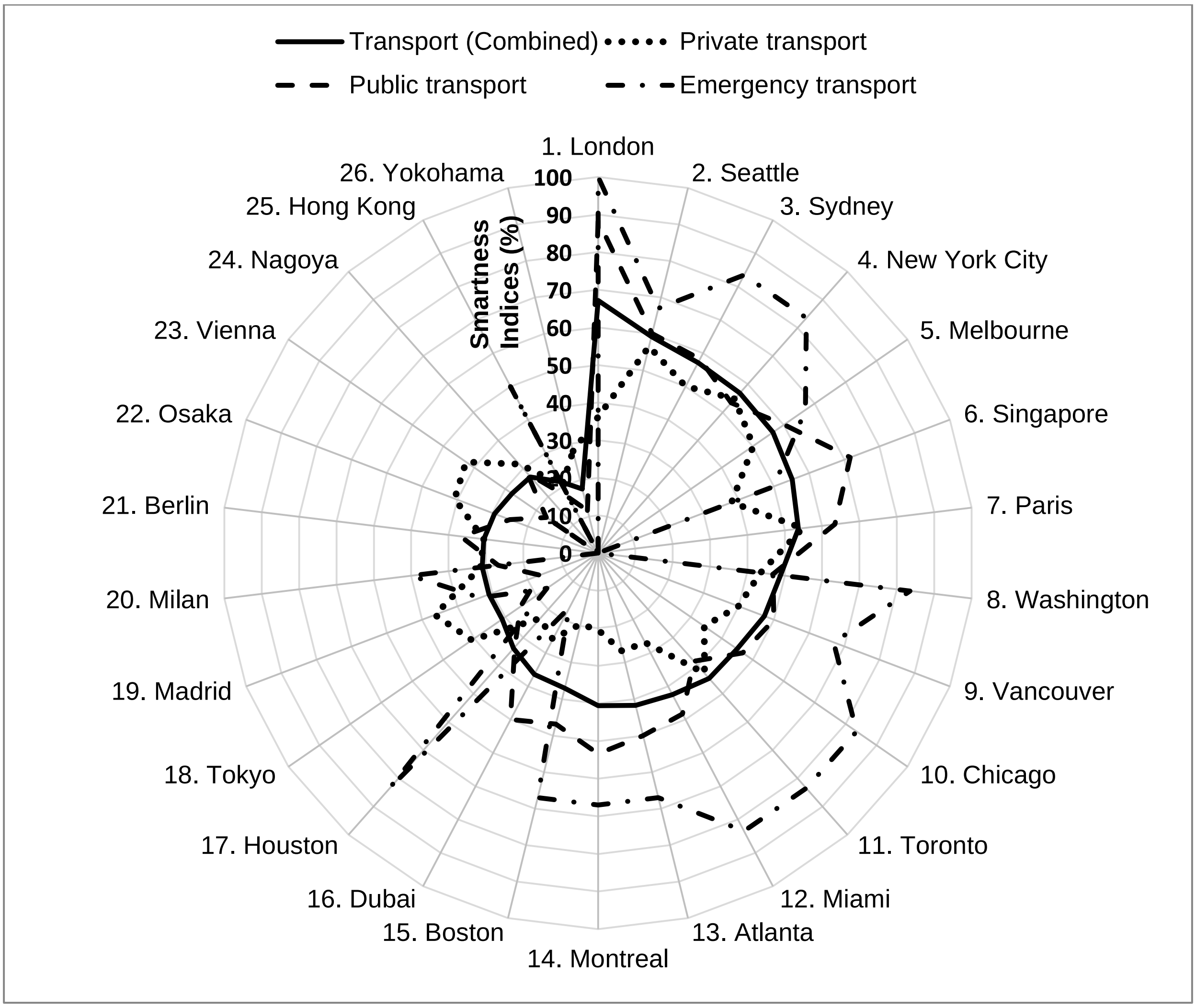

Figure 2 Benchmarking Results

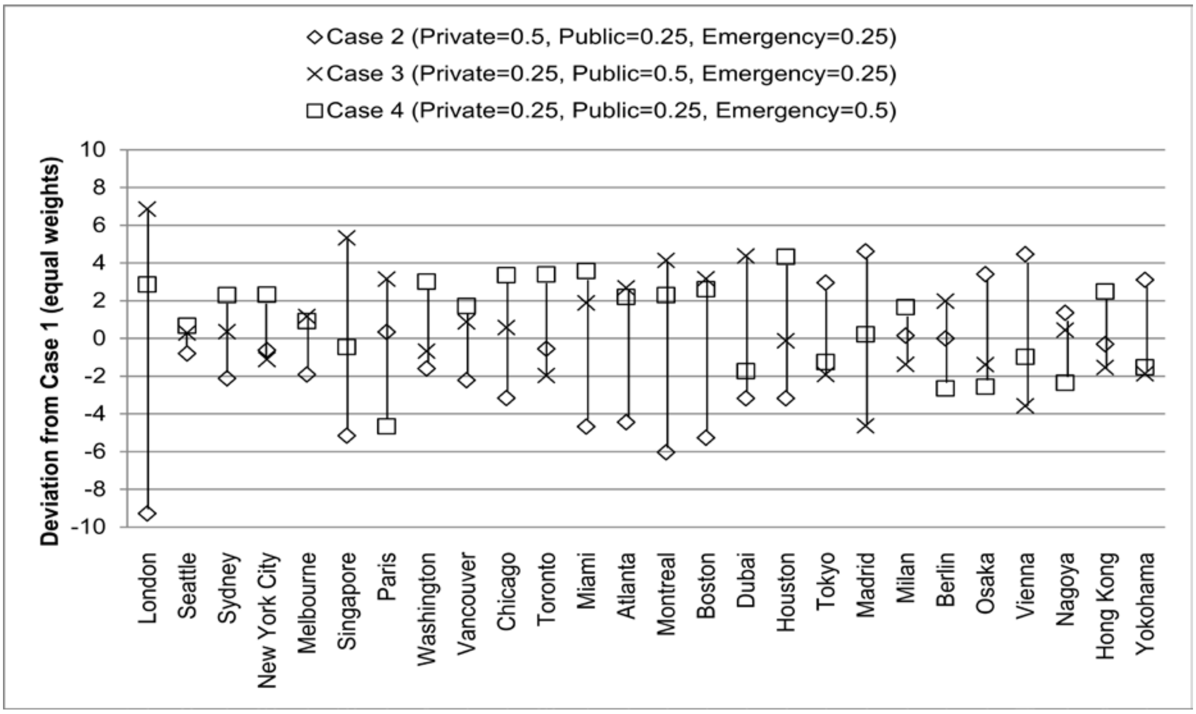

Figure 3 Sensitivities of Smartness Indices Weighted by Sub-systems

Table 1 Generic Matrix of Smartness Indicators

	Private	Public	Commercial and Emergency
Sense	C: En-route detection E: % vehicles equipped with GPS	C: En-route detection E: % vehicles equipped with AVL	C: En-route detection E: % vehicles equipped with AVL
	C: Detect at parking facilities E: % vehicles have smart tags	C: Detect at terminal/depot E: % vehicles equipped with AVL	C: Detect at terminal/depot E: % vehicles equipped with AVL
	C: Detect at intersections E: % intersections have detectors	C: Detect at stations/stops E: % vehicles equipped with AVL	C: Detect at check points E: % check points have detectors
	C: Passenger detection E: Uses occupancy detectors?	C: Passenger detection E: % smart card usage	C: Container/cargo detection E: Uses container tags?
	C: Detect for enforcement E: ANPR usage/smart tags	C: Detect for enforcement E: Enforce bus lanes?	C: Detect for enforcement E: Enforce check points?
Process and Control	C: Control signal; speed limit; expressway entry ramps E: % junctions under adaptive control; % roads with variable speed limit; % metered ramps	C: Signal priority; driverless transit vehicle E: % signals with transit priority; % transit vehicles with driverless control	C: Signal priority E: % junctions have emergency vehicle signal priority
	C: Automated parking systems E: Available?	C: Personalized rapid transit E: Available?	C: Dynamic route guidance E: % emergency vehicles have
	C: In-vehicle safety management E: % vehicles have e-call	C: In-vehicle safety management E: % vehicles have CCTV	C: In-vehicle safety management E: % vehicles have safety systems
	C: Infrastructure safety & security E: % roads/tunnels monitored	C: Infrastructure safety & security E: % stations/terminals monitored	C: Infrastructure safety & security E: Has electronic screening system
	C: Toll/parking charge payment E: Smart card payment?	C: Intermodal and e-fare payment E: Smart card use for all services?	C: Payments at port interface E: Has e-payment system?
Communicate	C: Infrastructure – Vehicle E: Automated highway systems	C: Authority – Vehicle E: % transit vehicles with AVL	C: Authority – Operator E: % emergency vehicle with AVL
	C: Vehicle – Driver E: In-vehicle safety systems	C: Operator – User E: Realtime arrival info on mobile; paratransit booking	C: Operator – Driver E: Tracking commercial drivers; dynamic route guidance
	C: Driver – Infrastructure E: Realtime parking info sharing	C: User – Authority E: Advance intermodal booking	C: Driver – Authority E: In-vehicle communication
	C: Vehicle – Vehicle E: Communication available?	C: Operator – Operator E: Manage services together?	C: Vehicle – Vehicle E: Communication available?
Predict	C: Traffic flow prediction E: Has prediction system?	C: Demand prediction E: % coverage (services)	C: Demand prediction E: % coverage (city area)
	C: Responsive supply E: HOV/HOT lanes managed?	C: Responsive supply E: % services managed	C: Responsive supply E: Available?
	C: Early disaster warning E: Available?	C: Early service failure warning E: Available?	C: Early disaster warning E: Available?
Heal	C: Tunnel recovery E: % tunnels monitored	C: Track/service recovery E: % routes covered	C: Asset recovery E: % vehicle have recovery system
	C: Incident recovery E: Surveillance & response system	C: Incident recovery E: Surveillance & response system	C: Incident recovery E: Surveillance & response system
Prevent	C: Special event planning E: Responsive systems available?	C: Special event planning E: Responsive systems available?	C: Special event planning E: Responsive systems available?
	C: Integrated land use planning E: Has integrated plans?	C: Public transport planning E: Has long term plans?	C: Commercial transport planning E: Has long term plans?

C: Capability; E: Extent

Table 2 Cities Selected for Benchmarking

City	Country	Infrastructure Rank (MERCER, 2009)	Population (Millions)
Singapore	Singapore	1	4.44
Yokohama	Japan	5	3.65
Vancouver	Canada	6	2.15
London	United Kingdom	8	8.57
Hong Kong	Hong Kong	8	7.21
Sydney	Australia	11	4.33
Tokyo	Japan	12	35.68
Paris	France	13	9.90
Montreal	Canada	15	3.68
Atlanta	United States	15	4.51
Vienna	Austria	18	2.32
Toronto	Canada	18	5.21
Washington DC	United States	24	4.34
Chicago	United States	28	8.99
Berlin	Germany	29	3.41
Osaka	Japan	29	11.29
Nagoya	Japan	29	2.26
New York City	United States	32	19.04
Boston	United States	33	4.47
Melbourne	Australia	35	3.73
Dubai	United Arab Emirates	35	2.26
Madrid	Spain	43	5.57
Miami	United States	47	5.59
Milan	Italy	49	2.95
Seattle	United States	49	3.07
Houston	United States	49	4.46

Table 3 Selected Indicators of Smart Transportation

	Capability	Extent
Private Transport	Detection for enforcement (Toll collection, speed, red-light, occupancy) - able to detect individual vehicle?	No use of Automatic number plate recognition (ANPR) system, Uses ANPR system, Able to detect individual vehicles with ID
	Operation – Automated and coordinated Traffic signal control	% intersections covered under Network-coordinated signal system. – NA, TP, PC, FC.
	Operation – Automated Speed limit control	% roads have Variable speed limit displays – NA, TP, PC, FC.
	Operation – Automated Expressway entry control	% expressway entry points equipped with ramp metering – NA, TP, PC, FC.
	Express operation - automated parking	Automated parking system (human less) available - Not Available or Available
	Transaction - paying tolls/parking charges/enforcement fines	Electronic (instant) transaction system available? - Mixed (both paper-based and e-transaction), Toll/parking charge payment by e-transaction only, Enforcement fines payment by e-transaction only.
	User - Infrastructure communication - Parking information sharing	Real-time parking lot availability info sharing on web/mobile platform - a. NA, b. Info found on web/Roadside displays, c. Info found on mobile (PC), d. Info found on mobile (FC)
	Traffic flow prediction - able to predict traffic flow and speed?	Have a prediction system - NA, Study phase, Trial phase, PC, FC
	Responsive supply - able to predict demand & adjust supply?	HOV/HOT lanes available - NA, Fixed time operation, Responsive operation (timing decided based on predicted demand)?
Public Transport	Detection en-route - able to detect individual transit vehicle?	% public buses and taxis equipped with Automatic Vehicle Location System (GPS). Similar for trains (continuous tracking/point tracking). – NA, TP, PC, FC.
	Detection of passengers - able to detect individual passenger?	Use of smart cards - have a centralized system that track passenger's movements through their smart cards - a. NA, b. Trial phase, c. PC (Cash and card mixed), d. FC (Smart card only).
	Detection for enforcement - able to detect unauthorized vehicles automatically?	Have a bus lane enforcement system? - No automatic enforcement system, Need human to interpret violations, Able to detect violations automatically
	Operation - Transit signal priority - able to provide priority signal?	% intersections have automated transit signal priority system – NA, TP, PC, FC.
	Operation – Human-less transit operation	% public transit vehicles have driverless control system. - Not Available or Available
	Express operation - faster transit service	Extent: Have express transit services for both bus and train (fast, non-stop etc.)? - Not Available or Available
	Express operation - faster transit service	Have Personalized Rapid Transit system? – NA, Study and design stage, Trial stage, In service.
	Transaction - Intermodal and electronic fare collection	Integrated system for all modes and services? - No intermodal fare collection, Different cards for a group of modes and services, Single smart card accepted by all modes and services.
	Vehicle - User communication - Passenger information management	Real-time transit arrival information is available on mobile platform (% bus stops/train stations/transit services covered under this service) – NA, TP, PC, FC.
	Vehicle - User communication - Para transit management	% taxis/taxi service providers provide real-time and SMS-based taxi booking service – NA, TP, PC, FC.
Emergency Transport	Operation - Emergency vehicle priority signal - able to provide priority signal?	% intersections have automated emergency vehicle signal priority system – NA, TP, PC, FC.
	Emergency Vehicle (operator) - User (driver) communication	Providing real-time guidance to drivers (dynamic route guidance) – NA, TP, PC, FC.

(NA – Not available, TP – Trail phase, PC – Partial coverage, FC – Full coverage)