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# THE ROLE OF OPEN DATA IN DRIVING SUSTAINABLE MOBILITY IN NINE SMART CITIES

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# THE ROLE OF OPEN DATA IN DRIVING SUSTAINABLE MOBILITY IN NINE SMART CITIES

*Research paper*

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## Abstract

*In today's era of globalization, sustainable mobility is considered as a key factor in the economic growth of any country. With the emergence of open data initiatives, there is tremendous potential to improve mobility. This paper presents findings of a detailed analysis of mobility open data initiatives in nine smart cities – Amsterdam, Barcelona, Chicago, Dublin, Helsinki, London, Manchester, New York and San Francisco. The paper discusses the study of various sustainable indicators in the mobility domain and its convergence with present open datasets. Specifically, it throws light on open data ecosystems in terms of their production and consumption. It gives a comprehensive view of the nature of mobility open data with respect to their formats, interactivity, and availability. The paper details the open datasets in terms of their alignment with different mobility indicators, publishing platforms, applications and APIs available. The paper discusses how these open datasets have shown signs of fostering organic innovation and sustainable growth in smart cities with impact on mobility trends. The results of the work can be used to inform the design of data driven sustainable mobility in smart cities to maximize the utilization of available open data resources.*

*Keywords: Sustainable Mobility, Smart Cities, Data Ecosystem, Open Data.*

## 1 Introduction

With growing world population and urban centers as the foci of economic activities, the rate of urban growth is expected to increase rapidly. Urban conglomerates have become the major sink for socio-economic activities. Complex interactions between the urban growth phenomena, environment, economic development, and human society at large result in many negative effects such as environmental degradation, traffic congestion, etc. In a report on world urbanization, the United Nations (UN, 2014) predicted that 66 percent of the world's population will live in urban areas in 2050. In 1987, the Brundtland commission coined the term *Sustainable Development* (Brundtland et al., 1987) to describe development which meets the present need without compromising future generation needs. Thus in the longer term, its vision is to create a highly self-sufficient, cohesive, inclusive and just society by harmonizing various social, economic, environmental, and cultural aspects.

There are multiple challenges ahead to manage such complexities in an efficient way, thus improving better quality of life for our future generations. Mobility is one of the segments which has been tremendously affected by this change. As per the Oxford dictionary, mobility is defined as the “*ability to move freely and easily*”. However considering mobility only as an agent of movement is a very narrow perspective. It has far reaching effects in the social, economic and environment domains. Consider transportation systems, which can be seen as the lifeline of any city. The rapid increase in population has developed various operational problems especially during peak ‘rush’ hours which has put immense pressure on the carrying capacity of these systems. Problems related to congestion, delays, accidents, carbon emission, public space usage, etc. have impacted the quality of life for citizens and city services. These urban mobility problems are gradually transforming to an urban mobility crisis (Jayes Kim, 2008) .

A smart city is a concept to tackle challenging city issues by integrating sophisticated information and communication technologies (ICT) with traditional urban infrastructure together with the participation of various stakeholders like citizens, and city managers to create a more equitable and sustainable system. Kitchin (Kitchin, 2014) emphasizes that the concept of realizing ICT in urban infrastructures is not new and is labeled with different names like ‘wired cities’, ‘cyber cities’, ‘digital cities’, ‘intelligent cities’, and ‘smart cities’. If we dive into the literature we can find detailed studies regarding frameworks (Ojo, Curry, & Janowski, 2014), characteristics (Giffinger & Pichler-Milanović, 2007), technical aspects (Hernández-Muñoz et al., 2011), critical factors (Chourabi et al., 2012), etc. Curry et al. (Curry, Dustdar, Sheng, & Sheth, 2016) have defined smart city as a “Complex Socio-technical System of Systems”. Several governments and organizations have initiated or are in the process of conceptualizing smart city as a reality depending on the local needs of the city. Cities like Rio de Janeiro, Barcelona, Chicago, Boston (Skills, 2013), and Masdar (Reiche, 2010) already have mature smart city programs while developing countries like India, China, and Nigeria etc. are in the key race to evolve their cities in this direction.

An intriguing phenomenon which has recently attracted the attention is the potential capabilities of massive data generation in Smart Cities. The data gathered using deployed sensors in these cities’ physical infrastructures has opened new paradigms in its development. Big data technologies have rendered us to analyze a plethora of diverse data which, along with usage of developed multivariate analysis approaches, have helped in obtaining insights, which were unknown (Cavanillas et al., 2016). Combining these approaches with trends in Internet of Things and deep learning can be useful in providing solutions to many socio-economic and environmental issues. Smart city datasets are now being published in the public domain by different data stakeholders like governments to enhance transparency and equip their people with the abilities to predict and provide useful insights which can further aid in improving the standard of living.

Open data, specifically open government data, encourages transparency, participation, improved efficiencies and effectiveness of services and foster innovation and self-empowerment. For example, the National Health Services in the UK brought down infection rates from 5000 patients to less than 1200 by publishing the infection rate of all hospitals and encouraging best practices on its open data portal, leading to an economic cost saving of 34 million pounds (Granickas, 2013). Various startups like Yelp (food inspection) and Zillow (real estate property valuation) have been founded using open government data (Schrier, 2014). Baltimore launched CitiStat to collect datasets to monitor the performance of city departments (Schrier, 2014).

There are abundant open datasets available in the mobility domain. However, the full potential of these datasets remains largely untapped. Little work has been conducted to investigate the potential for open

data in the mobility sector in the context of smart cities. This paper investigates the convergence of open data initiatives across nine smart cities in the mobility domain. It establishes a conceptual taxonomy of common mobility indicators and analyses how these have been nurtured using open data. The paper is organized as follows: Section 2 provides the theoretical background for the study. Section 3 focuses on the methodology, with findings in Section 4. Discussion of findings is presented in Section 5, with a conclusion in Section 6.

## 2 Theoretical Background

This section conceptualizes a theoretical framework for open data and its usage in the context of smart cities. Section 2.1 explains the importance of open data and how it shapes various initiatives in smart cities with discussion on barriers in its adoption; Sec 2.2 focuses on mobility with discussion on sustainable mobility indicators and critically examines the potential of open data in this frame of reference.

### 2.1 Open Data in Smart Cities

The evolution of open data is based on the notion of citizen right to access public information, a basic fundamental principle of democracy. The European Commission and its member states drafted an EU eGovernment action plan 2011-2015 by publishing public information on its portal to harness its capabilities through its reuse (Europeia, 2010). Infusion of open data leads to a wide range of benefits from innovation, collaboration, decision making, and service delivery and gives new insights to policy makers about critical questions. UNE 178301 (PARTNERSHIP, 2015) is one of the standards that set specific guidelines in terms of requirements, indicators, and policies to make open data more mature so that it can be used in the smart city perspective. Various theories postulates the benefits of open data systems: Information Theory (Kraemer & King, 2006; West, 2004) emphasizes that opening data reinforces existing structures instead of changing them, while System Theory (Janssen, Charalabidis, & Zuiderwijk, 2012) points out that a constant feedback loop makes the system better. There can always be questions on the nature of the openness of data in terms of technical, legal and commercial perspectives, but overall the bigger aim is to reap societal benefits from it. Figure 1 illustrates how open data can be aligned to a smart city context and concretized both the System Theory feedback loop concept and the Information Theory reinforcing structure model.

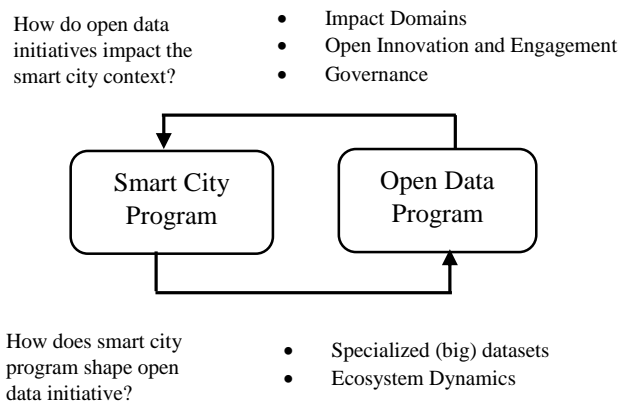


Figure 1. Aligning open data to smart city context (Ojo, Curry, & Zeleti, 2015)

## 2.2 Sustainable Mobility

Sustainable mobility is one of the paradigms to examine the complexities of cities in terms of its spatial, social, and technical dimensions. The foundation for sustainable mobility theory (Wulfhorst & Klug, 2016) includes the roles of technology, public transport, green attitude, and land use planning. The World Business Council for Sustainable Development (WBCSD) defines sustainable mobility as “the ability to meet society’s need to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future” (Stigson, 2004). WBCSD in its report (WBCSD, 2011) classified four target dimensions to cover various mobility aspects including policies, practices, and implementation etc. These dimensions are:

- *Global Environment (G)* - mobility impacts on the global environment
- *Quality of Life (Q)* – social aspects of urban life at local level
- *Economic Success (E)* - economic aspects at local level
- *Mobility System (M)* – performance of mobility.

As shown in Table 1, each dimension has its own cluster of indicators for better defining its purpose. These indicators have been marshaled from various reports and have been assigned to the appropriate dimensions.

Target Dimensions	Indicators	Supporting References
<b>Global Environment (G)</b>	<ul style="list-style-type: none"> <li>• Energy Efficiency</li> <li>• Mitigation and Adaptation</li> <li>• Livability Condition</li> </ul>	(WBCSD, 2011) (Dobranskyte-Niskota, Perujo, & Pregl, 2007)
<b>Quality of Life (Q)</b>	<ul style="list-style-type: none"> <li>• Access</li> <li>• Affordability</li> <li>• Travel time</li> <li>• Risk and Safety</li> <li>• Public Area and Space Usage</li> <li>• Governance</li> <li>• Functional Diversity</li> </ul>	(WBCSD, 2011) (Litman, 2011) (Bongardt, Schmid, & Huizenga, 2011)
<b>Economic Success (E)</b>	<ul style="list-style-type: none"> <li>• Pricing Reforms</li> <li>• Taxes and Subsidies</li> <li>• Facility Costs</li> <li>• Public Finance</li> <li>• R&amp;D</li> </ul>	(OECD, 1999) (WBCSD, 2011) (Litman, 2011)
<b>Mobility System Performance (M)</b>	<ul style="list-style-type: none"> <li>• Security</li> <li>• Congestion and Delays</li> <li>• Intermodal Connectivity</li> <li>• Resilience</li> <li>• Active Mobility</li> <li>• Intelligent System management</li> </ul>	(WBCSD, 2011) (Gillis, Semanjski, & Lauwers, 2015) (Goldman & Gorham, 2006)

Table 1. Sustainable mobility indicators identified from various international organizations

There are various policy measures to define and classify sustainable mobility but on the implementation side, they are still lacking efficacy. There is a lack of a holistic vision and integrated approach in present decision making, leading to large amounts of untapped open mobility data that is seldom reused. ICT provides a lot of potential to use these data to create cost effective mobility solutions (Rusitschka, S., & Curry, E. (2016)). With the advance in time, it has been seen that there is a generational shift from a

traditional transport culture to a more flexible multi-modal transit system. This has happened due to the increase in the number of new innovative technologies that engage more citizen participation. If this can be accelerated then it will open significant opportunities that will enhance the efficiency of transportation systems leading to better societal development and innovation.

### 3 Method

Section 3.1 describes the method used to select the nine smart cities and their various mobility initiatives. Section 3.2 focuses how data has been acquired from these cities while Section 3.3 gives details of the analysis performed on the collected datasets.

#### 3.1 Case Selection

There are certain set of principles and guidelines in order to validate the smartness of a city. Here the cities are selected on three benchmarks: 1) *mission statement*, 2) *open data advocacy* and 3) *open data production* which are explained below:

- *Mission statement*: A smart city should have a well-established mission and plan. There should be a well-crafted strategy to realize the plan and this can be recognized by looking into the pilot projects, trials etc. There would be a number of documents, research proposals, and development plans which describe various smart city initiatives, either implemented or are under process.
- *Open data advocacy*: A smart city should have a strong open data initiative and policies. It should promote harmonization and standardization of best open data practices. There should be a strong focus in the area of open data interfaces, participation, and innovation platforms.
- *Open data production*: Significant amounts of data should be available in public domain for use. (Infoshare, 2016b) derives some important open data characteristics like it should be technically accessible, freely accessible, findable and understandable. This benchmark is crucial as the whole study depends on the availability of this information.

Thus, on the basis of the above criteria, we have selected nine smart cities for this study of open mobility datasets. These cities are: Amsterdam, Barcelona, Chicago, Dublin, Helsinki, London, Manchester, New York and San Francisco (SFO).

#### 3.2 Data Collection

We have conducted an extensive data collection from all the nine smart cities. The data statistics shown in this paper focus on the open data portals of the cities. The data is published under a wide variety of licenses, formats, with a clearly stated purpose (personal or commercial). The authors conducted the study on the data published in these portals in the period from October to March (2016-17). Thus all the information ranging datasets, applications, and application program interfaces (API's) was consolidated under 17 mobility initiatives including transportation, infrastructure, environment, and tourism.

Table 2. shows a comprehensive view of the mobility data initiatives in the nine smart cities. Overall there were 711 different mobility datasets on these portals of which Chicago (170), New York (148), San Francisco (81), London (77) were among the highest. Out of these, 148 datasets were thoroughly reviewed for study. A total of 105 mobility applications and 39 API's were analyzed on the basis of their technological platforms, functionality etc. The Helsinki Region Infoshare (22), Dublin Dashboard (16), and Apps4BCN (16) were initiatives that have diverse applications operating on open data. Transport for London (TFL) (18) has a rich API's repository and provides different capabilities to developers including list (e.g. [http://data.london.gov.uk/api/3/action/package\\_list](http://data.london.gov.uk/api/3/action/package_list)), view and search for a dataset.

City	Amsterdam	Barcelona	Chicago	Dublin	Helsinki	London	Manchester	New York	San Francisco																																																		
<b>Open Data Initiatives</b>	<ul style="list-style-type: none"> <li>Municipality of Amsterdam</li> </ul>	<ul style="list-style-type: none"> <li>OpenDataBCN</li> <li>Apps4BCN</li> </ul>	<ul style="list-style-type: none"> <li>City of Chicago Data Portal</li> <li>Chicago Digital</li> </ul>	<ul style="list-style-type: none"> <li>Dubl:nked</li> <li>Dublin Dashboard</li> </ul>	<ul style="list-style-type: none"> <li>Helsinki Region Infoshare</li> </ul>	<ul style="list-style-type: none"> <li>London Datastore</li> <li>Transport For London</li> </ul>	<ul style="list-style-type: none"> <li>DataGM</li> <li>Manchester City Council</li> </ul>	<ul style="list-style-type: none"> <li>NYC OpenData</li> <li>NYC Developer Portal</li> </ul>	<ul style="list-style-type: none"> <li>SF OpenData</li> <li>SAN FRANCISCO DATA</li> <li>FLYSFO</li> </ul>																																																		
<b>Ref</b>	(Municipality of Amsterdam, 2016)	(OpenDataBCN, 2016), (Apps4BCN, 2016)	(DataPortal, 2016), (Digital, 2016)	(Dublinked, 2016), (Dashboard, 2016)	(Infoshare, 2016a)	(Datastore, 2016), (London, 2016)	(DataGM, 2016), (Council, 2016)	(N. Opendata, 2016), (N. D. Portal, 2016a)	(S. OpenData, 2016), (S. F. Data, 2016)																																																		
<b>Dataset in Glance</b>	<table border="1"> <caption>Data for Dataset in Glance Chart</caption> <thead> <tr> <th>City</th> <th>Open Dataset in Mobility Domain</th> <th>Reviewed Dataset</th> <th>Applications</th> <th>API</th> </tr> </thead> <tbody> <tr> <td>Amsterdam</td> <td>4</td> <td>11</td> <td>11</td> <td>4</td> </tr> <tr> <td>Barcelona</td> <td>0</td> <td>16</td> <td>16</td> <td>0</td> </tr> <tr> <td>Chicago</td> <td>17</td> <td>16</td> <td>16</td> <td>5</td> </tr> <tr> <td>Dublin</td> <td>4</td> <td>16</td> <td>16</td> <td>4</td> </tr> <tr> <td>Helsinki</td> <td>2</td> <td>22</td> <td>22</td> <td>2</td> </tr> <tr> <td>London</td> <td>18</td> <td>4</td> <td>4</td> <td>18</td> </tr> <tr> <td>Manchester</td> <td>1</td> <td>3</td> <td>3</td> <td>1</td> </tr> <tr> <td>New York</td> <td>4</td> <td>7</td> <td>7</td> <td>4</td> </tr> <tr> <td>San Francisco</td> <td>3</td> <td>10</td> <td>10</td> <td>3</td> </tr> </tbody> </table>									City	Open Dataset in Mobility Domain	Reviewed Dataset	Applications	API	Amsterdam	4	11	11	4	Barcelona	0	16	16	0	Chicago	17	16	16	5	Dublin	4	16	16	4	Helsinki	2	22	22	2	London	18	4	4	18	Manchester	1	3	3	1	New York	4	7	7	4	San Francisco	3	10	10	3
City	Open Dataset in Mobility Domain	Reviewed Dataset	Applications	API																																																							
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San Francisco	3	10	10	3																																																							

Table 2. Mobility open data initiatives in nine smart cities with datasets statistics

### 3.3 Analysis

The study followed the mixed strategy of a content analysis approach (Hsieh & Shannon, 2005; White & Marsh, 2006) as described in (Ojo et al., 2015). It followed a conventional and direct approach of content analysis to analyze the web pages, documents, datasets etc. In the conventional content analysis, all the coding categories which look relevant are derived directly from the source, while in the directed approach we need to find out the codes which are already present and well established in the theory and literature. We tried to align the coding categories as per the Smart City Initiative Design (SCID) framework (Ojo et al., 2014) which focuses on various core questions like: aim, potential impact, key enablers, stakeholders, and domains affected by the initiatives.

Using the directed approach, we classified the mobility data under four mobility target dimensions i.e. Global Environment(G), Quality of Life(Q), Economic Success(E), and Mobility System(M) as discussed in Section 2.2. The conventional content analysis approach was used to discover the various keywords and codes from the data. These codes were later consolidated as categories and indicators (sub codes) under the target dimensions. Similarly, various sets of technical questions on the nature of mobility data were evaluated which is shown in Table 3.

## 4 Findings: Open Mobility Data

In this section, the results of the study are presented. Section 4.1 focuses on the nature of mobility datasets produced by the different cities, Section 4.2 focuses on how these datasets are consumed by different stakeholders inside the city. Section 4.3 discusses the expected impacts on the mobility domain.

Critical Set of Questions to Evaluate Mobility Open Datasets	Approach	Nature
Q.1 What are the types of open mobility data that are available?	Create Taxonomy for Mobility Domain as per datasets released as open data.	Production
Q.2 What are the characteristics of the data (format, batch, real-time, license, etc.)?	Classifying dataset as per their format	
Q.3 What end-user applications have been developing using the data?	Classify applications developed using the data for end-users	Consumption
Q.4 What API's are available to support app developers?	Classify API support	
Q.5 What Open Data Portal technology was used?	Identify portal platform.	

Table 3. Approach to evaluate mobility open datasets

#### 4.1 Availability

Most of the mobility data was present under the transportation section of portals but other sections like environment, health, and tourism were also taken into account. As shown in Table 4, we have classified data into 7 major dataset categories with specific indicators related to them. We also map each dataset categories to the defined 4 target dimensions: Global Environment(G), Quality of Life(Q), Economic Success(E), and Mobility System(M). Since the dimensions are parent categories, it is possible that one or more dimension represent the same category. The mobility taxonomy was created by combining open datasets tags with well-established mobility keywords already present in the literature. The categories are as follows:

- *Modes of Transport*: There were nearly 448 datasets covering the major transport modes like bus, railways, ferries, flights, cycles, etc., and associated aspects like schedules, arrival, departures, delays, timetables, stations, and stop points. All the cities have significant datasets in bus, car, rail and cycles with New York (38) leading in bus datasets, Helsinki (29) and London (25) leading in rail datasets.
- *Accidents*: This category focuses on major quality of life (Q) aspects including deaths, injuries, crashes, safety, penalties, offenses, etc. Overall nearly 68 datasets belong to this category in which London (21) was on top.
- *Traffic*: It consists of all the information related to traffic (M, Q) including signals, congestion, cameras, counts, rising volumes, jams etc. There were a total of 131 datasets with Dublin (24) and San Francisco (22) ranking among the top.
- *Services*: This category covers all the 4 mobility dimensions with services including sharing, pooling, maintenance, notices, and requests offered to the citizens. There were nearly 326 datasets in which Chicago (110) and New York (103) were on top.
- *Sustainability*: Nearly 140 datasets covering all the environmental dimensions (G) like carbon emission, noise hindrance, greenhouse gasses, impact on health, energy, and alternative fuels. Chicago (51), London (27) and Helsinki (25) have significant datasets.
- *Tourism*: 185 datasets cover aspects like events, culture, heritage, travel, wayfinding, and leisure.



Dataset Categories	Indicators	Target Dimensions	Number of Dataset Available in each Smart City						
			Barcelona	Amsterdam	Chicago	Helsinki	Dublin	London	New York
Mode of Transport	Bus/Trucks	M							
	Car/Taxi	M							
	Cycles/Bikes	M							
	Metro/Rail/Tubes/Trams	M							
	Boat/Ships/Ferry/ Fleets	M							
	Flights	M							
Accident	Casualties/Injuries	Q							
	Safety	Q							
	Penalties/Offenses	M,Q							
Traffic	Count /Volumes	M,Q							
	Signals/Speed Bumps	M							
	Traffic Information: Schedule/Current Situation/Warning/Camera	Q,M							
Services	Road Work/Maintenance	E,Q							
	Requests	Q							
	Signs	M							
	Timetables	M							
	Permits/Licenses	E							
	Meter/Freight	E							
	Bike/Car Sharing	E,M,G							
Sustainability	Environment	G							
	Health	G							
	Energy Consumption	G							
Tourism	Events	M							
	Culture/Heritage/ Leisure	M							
	Visitors	M							
	Travel/ Wayfinding	Q,M							
Infrastructure	Parking/ Garages/ Loading/Unloading	M,Q							
	Fuel Stations/Charging Points/ Bike Shops	E,M,Q,G							
	Entry/Exits/Stops	M							
	Routes/Bridges/Pavements /Lanes/Subways	E,M							

Table 4. Comprehensive view of available open mobility datasets in nine smart cities

Nearly all the cities have abundant datasets as shown in the graph.

- *Infrastructure*: Dealing with all spatial characterization like public space usage, roads, stops, stations, charging points, bridges, lanes, etc. This category has nearly 429 datasets present with Chicago and New York having about 100 datasets each.

From a data quality perspective, it is difficult to determine the completeness of datasets within each category or indicator. Typically there are multiple datasets which cater to various applications. There is no metric that quantifies completeness of these data in terms of their coverage, but this is an important future work direction to follow.

### 4.2 Characteristics

On the basis of the nature of ‘How data changes’, we have classified the datasets into two categories: static and dynamic. As shown in Table 5, the dynamic data is further classified into realtime, daily, weekly, monthly and quarterly.

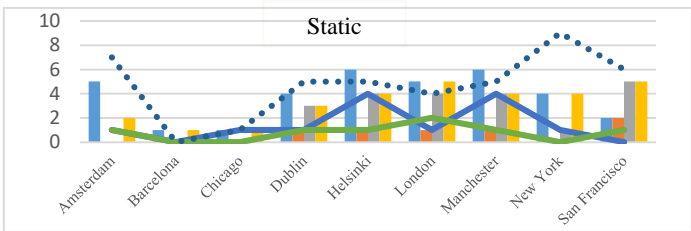
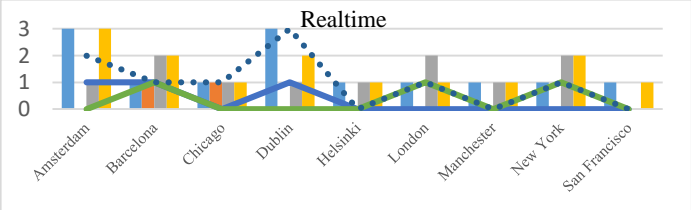
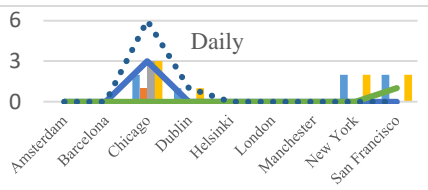
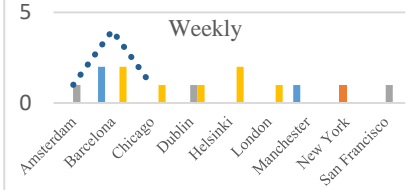
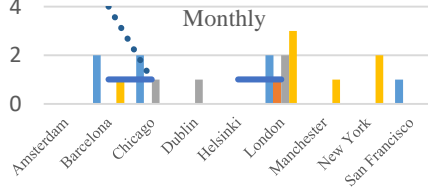
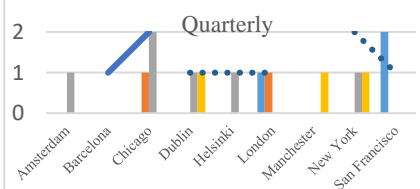
Nature and characteristics of dataset	Dataset Categories	
	Mode of Transport	Accident
	Services	Sustainability
	Infrastructure	Traffic
		Tourism
<p><b>Static</b></p> <p>Static data refers to data which changes very rarely like bus/tram stop locations, gas stations, routes information, parking facilities, environmental regulation etc. The update frequency of these datasets is half yearly, yearly or more.</p>		
<p><b>Dynamic</b></p> <p>Updated frequently like monthly or daily traffic volumes, carbon emissions, traffic incident notices etc. The update frequency of these data ranges from realtime, daily, weekly, monthly to quarterly.</p>		
<p>Realtime data is updated constantly at an update frequency from minutes to seconds like the locations of buses or trains, and their arrivals. These datasets were available in fewer numbers, as they require significant effort to establish robust technical platforms to stream real-time data</p>		
		

Table 5. Classification of mobility datasets as per their nature of change in nine smart cities

It is of quite importance to understand the nature of datasets i.e. in what formats are they available and how easy it is for different stakeholders like developers and citizens to interact with them. Table 6 shows that the data formats have been classified under three categories: 1) Documents, 2) Machine Readable Data, and 3) Developer Friendly Format. When these formats (Figure 2(a)) are consolidated under the three categories, it was quite interesting to see that all the cities have developer-friendly data formats (Figure 2(b)). It's a positive sign that a sufficient effort has been made to make the data developer friendly so that different users can use it more. This can facilitate application development as well as automatic data search, query, and enrichment (Hasan et.al 2013).

Dataset Interactivity	Description	Dataset Formats
<b>Documents</b>	The specific aim of these datasets is to provide general information and are thus the least developer friendly. The cost of effort to visualize and use them is significant.	Zip/Tar,Pdf/Txt/Doc/pt, Image, Bin
<b>Machine Readable Data</b>	These datasets are somewhat developer friendly. Some effort is required to deploy and visualize them in applications.	Tabular(xlsx),Csv/Tsv, Json, Html,Xml
<b>Developer Friendly Format</b>	Highly developer friendly data in which a minimum or no effort is required to use them.	Geojson, Api's/Odata, Wms/Wfs,Kml/Kmz, Rdf,Shape/Sbn/Sbx

Table 6. Categorization of various open mobility datasets as per developer interactivity

A key question arises on the usage policies and licenses under which these data were made public. The license category of all nine smart cities are as follows 1) Helsinki: Creative Common Attribute (CCA) 4.0, 2) Manchester: Open Government License (OGL), 3) New York: Public, 4) Barcelona: CCA 3.0, 5) Amsterdam: CCA, 6) Chicago: NA, 7) London: UK OGL v2, 8) San Francisco: CCA 3.0, 9) Dublin: CCA 4.0. One of the main aims of open data is enhanced access. Releasing open data may lead to security and privacy breaches leaking various personal and other identifiable information. There are various mobility datasets ((HRI, 2017), (OpenData, 2017)) which have sensitive information, where user profiling can be done by combining it with other social media data for instance. There is no description whether Privacy Impact Assessment (ICO., 2014) and Anonymisation Code of Practises (ICO.) have been performed on these datasets or not, before releasing them.

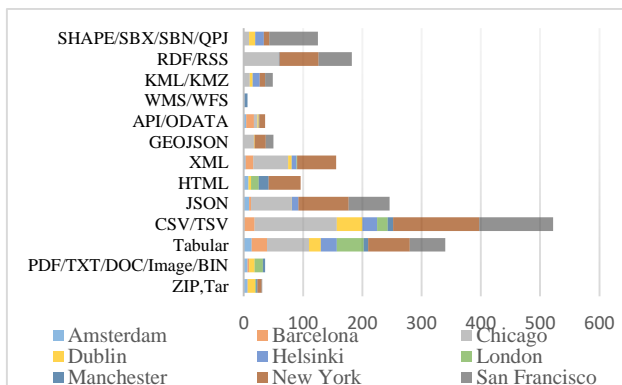


Figure 2(a). No. of dataset formats in nine smart cities

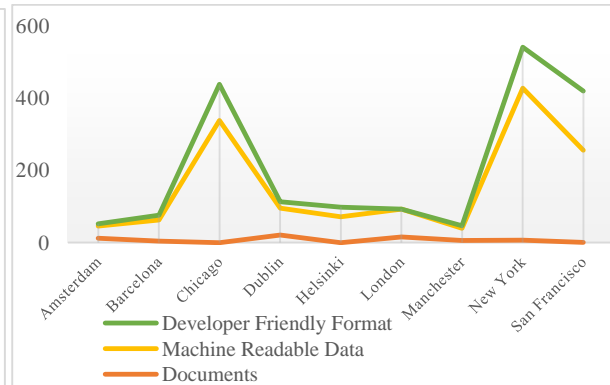


Figure 2(b). Comparison of dataset formats in terms of developer interactivity


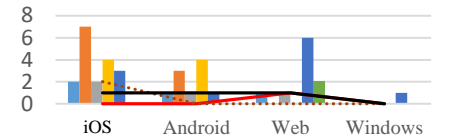
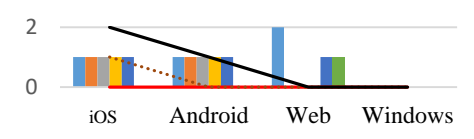
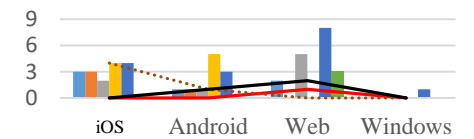
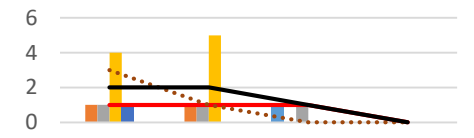
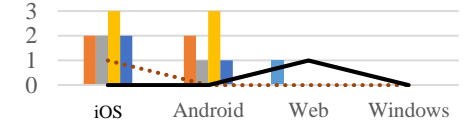
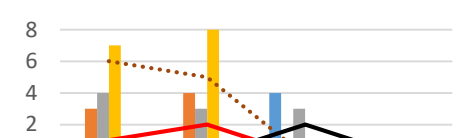
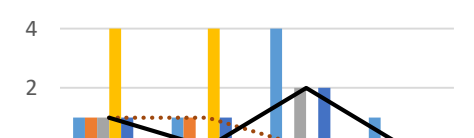
Application Categories	Indicators	Famous Applications	No. of Applications in different technical platforms 
<b>Timetable /Schedule</b>	Status updates like arrival and departure of bus, train, metro etc.	URBANSTEPBARCELONA, Transporter, Bussinavi, Mcr Metro, Dösa Tracker, Nyssa, NextStop NYC, Roadify.	
<b>Traffic</b>	Conditions/Situations, Congestion, Traffic and Live Cameras, Real Time Traffic Visualization	TRÀNSIT, NYC Way, DOT Data Feeds, Park Shark, Chicago Traffic Tracker	
<b>Routes</b>	Route Search, Convenient Ways, Multimodal route combination, Fastest and Cheapest Mode, Route Suggestions, Fares, Proximity route suggestion	CITYMAPPER, Transporter, Spot in Helsinki, CTA apps TransitChatter, Offline Bike Maps, Hit the Road	
<b>Parking</b>	Prices and Free Parking, Availability and Occupancy, Advance Booking, Book using credit and Debit card, Winter Parking Places	WAZYPARK , AreaDUM, Best Parking, NYC Way, Park Shark, SpotHero, Chicago Winter Parking, FasPark Chicago, Park.it Lite, Parkola,SFpark Parking App, Dublin Parking, Park Ya	
<b>Tourism</b>	Trip/Journey Planner, Events, Locate Places, Places of Attraction, Visualization by mixing various layers of data	Spot in Helsinki, TripGo, OpenTravelTime, NYC Way, Events Calendar, Setting Alert, Dublin Bus	
<b>Infrastructure /Services</b>	Sidewalks, Bus/Bike Stations, Fuel Locations, Tow away zones, Streetlight Repairs, Street Signs, Stop points, Sharing/Pooling, Requests, Alerts, Advisories, Social Media feeds	URBANSTEPBARCELONA, Alternative Fuel Locations API, Roadify, Setting Alert, Sweep Around, Map Alerter, Helsinki Bikes, Tube map, Transit-BayiBartNow	
<b>Sustainability</b>	Energy Consumption, Road Noise Levels, Air Quality, Cycling Routes, Electric Charging Points, Walkability, Environmental Permits, Opportunities of Solar and Wind Energy map, Health	Energy Atlas, Adopt A Sidewalk, Walkonomics, Walk Dublin, Setting Alert, Road noise levels in Helsinki	

Table 7. Classification of applications available in selected smart cities as mobility indicators and platforms

### 4.3 Applications

There is a diverse range of mobility applications which confirms the notion of connected urban mobility. Overall 105 mobility related application were analyzed. Based on end usage, Table 7 shows 7 applications categories: 1) Timetable, 2) Traffic, 3) Routes, 4) Parking, 5) Tourism, 6) Infrastructure and services, and 7) Sustainability explaining their purpose. Similarly, the distribution of these applications is depicted across different platforms i.e. mobile (iOS, Android, Windows) and web applications.

### 4.4 Application Programming Interfaces (API) and Open Data Portal Platforms

Some of the API's reviewed from the open data portals are: HSL Journey Planner (Helsinki) (API, 2016), Open 311 enquiry (N. D. Portal, 2016b) , DoT data feeds (Portal) (New York), TFL Unified API (London, 2016) (London), Park Shark (Municipality of Amsterdam, 2016b) and charging points for electric transport (Municipality of Amsterdam, 2016a) (Amsterdam), Chicago Traffic Tracker (C. o. C. D. Portal, 2016) and Alternative Fuel Locations (Chicago), SFO things to do (S. O. Data, 2016)(San Francisco), Dublin Bikes and Noise Monitor (Dubl:nked, 2016) (Dublin), Metro shuttle bus (GM, 2016) (Manchester). These API's were published on various open data publishing platforms like CKAN, Socrata, DKAN, Junar, and OpenDataSoft, which publish data of national and regional governments, organizations and companies. The selected smart cities data portals were hosted on CKAN (CKAN, 2016) and Socrata's SODA (Socrata, 2016) platforms. Table 8 shows the number of open transport sector API's available specifically for these cities. Here the number of API's are more, as query collected all API's related to different datasets hosted by different entities like government, private organizations, NGO's etc.

Open Data Platforms	Amsterdam	Barcelona	Chicago	Dublin	Helsinki	London	Manchester	New York	San Francisco
CKAN	3	10	0	2	1	10	1	0	0
Socrata	0	0	151	0	0	0	0	744	133
CKAN Query	Barcelona	<a href="http://ckan.opendata.nets.upf.edu/dataset?q=barcelona">http://ckan.opendata.nets.upf.edu/dataset?q=barcelona</a>							
	London	<a href="https://datahub.io/api/3/action/package_search?q=london%20transport%20isopen:true">https://datahub.io/api/3/action/package_search?q=london%20transport%20isopen:true</a>							
Socrata Query	New York	<a href="https://www.opendatanetwork.com/search?q=new%20york&amp;categories=transportation">https://www.opendatanetwork.com/search?q=new%20york&amp;categories=transportation</a>							

Table 8. No. of Mobility API's present on various open data platforms in selected Smart Cities

## 5 Discussion: Impact of Open Data on Mobility

Mobility is not only a matter of developing transport infrastructure and services but also of overcoming the social, economic, political and physical constraints to movement (Un-Habitat, 2013). Thus, the objective of the study was to understand the convergence of open mobility data and its effect in the context of smart cities. This section analyses the change in mobility trends and its impact with respect to open data in different domains. Some of the impacts are discussed below:

- *Better Parking Management:* Open data applications like Sfparkingapp, Dublin Parking, Wazypark, Nycway, Parkola and Park.It Lite have revolutionized the parking domain. Some of their impacts are: 1) real-time information on the availability of current parking spaces, 2) current pricing and tariffs, 3) information regarding disabled friendly parkings, 4) better management of space usage, 5) peak management, and 6) facility cost savings for government.
- *Intelligent Traffic Management:* Real-time API's like HSL, Park Shark, Chicago Traffic Tracker, and TRANSIT have boosted traffic efficacy. The impacts associated with them are 1) improved safety- by providing advisories, warnings, and potential collision areas, 2) improved productivity- reducing

congestion by providing real-time updates of traffic situation and suggesting alternative routes, 3) better planning through interactive visualizations showing live camera pictures, schedules, etc.

- *Improved Travel Planning*: Apps like CityMapper, Transporter, TransitChatter, Travel Time Map, and TFL API have made transit easier and faster. People now can choose options with the most effective, fastest or cheapest route combined with public transport (bus, train etc.) making the travel more accessible and convenient.
- *Active Mobility*: Improving people's awareness of 'Active' options like walking and cycling. Apps such as Helsinki Bikes, BikePoint, Adopt a Sidewalk, and Walkonomics have inspired them to choose these options by providing the information like pedestrian-friendliness of streets, bike trails, etc.
- *Increased Trend in Ride-Sharing*: Open data and ride-sharing applications have defined a new paradigm in public transport. Apps like TaxiShareChicago, Urbanstepbarcelona, TripGo, and Carpoolworld API have made the travel convenient, economical, and accessible to a larger mass by bring potential travelers together.
- *Increased Environmental Awareness*: Various open data applications (Energy Atlas) regarding Air polluting emissions, Noise Hindrance, Water effluents like oil spills, GHG and Ozone emissions have made people aware of their surroundings and thus inspired them to work collaboratively to increase energy efficiency by choosing cleaner fuels, electric vehicles and avoiding habitat destruction. Resilient mobility has become one of the motto of today's smart cities.
- *Fostering Innovation and R&D*: The resulting data from smart infrastructure, traffic, land use planning has opened immense opportunities for government and entrepreneurs to develop new innovative solutions and services to resolve mobility challenges.
- *Mobility as a Service (MaaS)*: MaaS is a mobility distribution model where the transportation needs of individuals are satisfied by a service provider over a single interface (Hietanen, 2014). This is one of the biggest fundamental changes in mindset which has given rise to mobility service providers like ride-sharing, trip planning, digital payments, on-demand services etc.

## 6 Conclusions

This study helps us to better understand open mobility data in the context of smart cities and understand its impact in nine smart cities. Our findings show that diverse mobility datasets are available which can be aligned with the present literature to get new critical insights. Presently, various open data publishing platforms and mobile stores have made the availability of these API's and applications easily accessible to end-users and developers. With the increase in number of new initiatives like hackathons and competitions have fostered plausible innovation and collaboration. These initiatives are already making positive impacts on our society. The findings indicate that small steps have already been taken by the governments and citizens to make mobility more sustainable, affordable and accessible. Sustainable mobility is changing from traditional transport infrastructure and it is moving towards services including demand-oriented measures. Arguably, we are moving towards more citizen-centric and participatory mobility model leveraging ICT and open data as its backbone.

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