A Review of Measures to Evaluate Smart Sustainable Cities

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Abstract. This paper presents preliminary results of a review of tools that claim to measure aspects of the state of a city, related to the smart, sustainable city concept. Using academic literature as well as online searches, over 50 tools were identified, including standards, indices and models, that each measure a range of city attributes. So far, detailed information about 18 of these tools has been collected from articles, web sites and correspondence. This paper analyses data from this subset, looking at the intended purpose of the tools, what they measure, the nature and transparency of the tools, who is able to use them and for what purposes. The ultimate aim is to be able to advise cities on how to choose measures that are appropriate for their circumstances.

Keywords: Smart city · Intelligent city · Digital city · Resilient city · Sustainable city · Standard · Index · Indices · Measure · Indicator

1 Introduction

Various measures have been proposed to evaluate smart, sustainable cities [1–4]. They include international standards for indicators, models of smart city performance, and composite measures that summarize city performance on a number of indicators. Such measures are of interest to city stakeholders, including city managers, businesses, non-profit organisations and city residents seeking to understand, manage, monitor and improve city performance [5].

Such measures can be used to set targets, measure performance and make management decisions. They can also be used to identify opportunities for business or social enterprise and to hold local governments accountable. Measures which define indicators for specific city dimensions can be useful for cities to identify what can be measured and how. Measures which summarize information help cities to navigate the complexity of evaluating something as multi-faceted as a city [5]. Such tools can also help cities to build capacity in monitoring over time. Well-defined city measures and the regular collection of credible data in standard formats are particularly useful for organisations at national, regional or international levels to be able to compare cities, observe their progress and better understand the relationships between inputs, outcomes and impacts.

Measures of cities have, however, proliferated. This study has to date identified over fifty multi-dimensional measures of city performance. These include international

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standards [6–9], academic research [1–4], and measures administered by private or public organisations [10], [11]. While many of these could be helpful to cities, it is difficult for cities to navigate this wealth of choices, to know which measures are most appropriate, which will best serve their goals, how to find good data and whether to pay the consultancy fees associated with participating in regional or international indexing and ranking.

Huovila et al. [12] compared recently published indicator standards for smart sustainable cities and argue that indicators for a city should be selected depending on (1) at what phase in city development (planning or operation) the measures will be made; (2) the spatial scale (district, city, region or country); (3) the time scale of the evaluation (from real-time to annual) and (4) the purpose of the assessment (target setting, monitoring, reporting, benchmarking or marketing). They argue that, while standardized indices have benefits, they "are always a compromise for a large group of different cities with different agendas, contexts and needs" [12, p150] and that cities should select what they measure based on their needs. These compromises have been recognised by researchers who have developed indices for specific contexts in terms of city size and location [13, 14].

In trying to assist cities to navigate these choices, this research examines the purposes for which the various measures were developed, their transparency and rigour, the ease of using them, and the benefits of using them. This paper is part of an ongoing study and reports on preliminary results in answering the following research questions:

Why? What are the stated and unstated purposes of the smart city measures that have been proposed?

How? What data collection and consolidation methods are proposed and are these processes transparent and rigourous?

2 Background

The idea of a smart city or community has been around since the start of the new millennium [15], and has been variously interpreted as using networked infrastructure to make cities more competitive, urban development led by high-tech and creative businesses, using technology to improve the governance of cities and communities, and the growth of connected and inclusive communities [15–17].

A working group of the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T) analysed definitions and conceptions of smart and sustainable cities to construct a composite definition that would encompass the key elements. They define a smart, sustainable city as "an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects" [18, p. 13]. While this type of consensus definition may not be the most nuanced approach to understanding the construct, it incorporates the key ideas of innovation, the use of information and communication technologies (ICTs), improved quality of life, urban management and competitiveness, while introducing the need for sustainability, and so provides a useful working definition in an otherwise shifting landscape.

As cities grow, and are expected to continue to grow, increased urbanisation magnifies the challenges of managing them in a manner that ensures a good quality of life, while also being sustainable. ICTs and ongoing innovation are seen as key tools for addressing these challenges by improving efficiencies and communication as well as by continually finding new ways to tackle problems [19, 20]. A city is complex, with many interacting systems and the task of keeping a city functioning is shared between city managers, businesses, non-profit organisations and, increasingly, the residents of the city, all of whom have a role to play.

All of these role-players would benefit by having information about the current state of the city and how it changes over time. Such information can inform planning, help in identifying appropriate interventions, and be used to monitor the state of the city, manage the city and to establish a common language between role-players [12]. In addition, national, regional and international bodies are interested in information that is comparable across cities so that they can understand how cities are faring and to inform policy interventions at these levels.

Measures of the state of a city, and how well it is performing, are complex because cities are multi-dimensional [21]. Cities need to function well in providing facilities, a safe environment, and services, like power, water and waste removal. They need to cater for residents with transportation, healthcare, education and leisure facilities. Cities also need to facilitate business activities and trade while preserving the environment and anticipating future change. Any attempt to understand how a city is performing, needs to examine a wide range of city dimensions and collect information about each.

Indicators are measures of specific aspects of city performance and form the basis of higher-level composite measures. Six international sets of indicators have been identified for measuring aspects of city functioning, including smartness and sustainability [12]. While indicators form the basis of measuring cities, there have been many attempts to combine sets of indicators into composite measures that summarize the performance of a city [1–4]. One way of creating consolidated measures is through the creation of city indices. Indices are commonly used to create single measures of multi-faceted constructs. Such measures simplify a lot of information and they facilitate comparisons, in the form of city rankings [5].

There has been a proliferation of studies that construct indices for smart and sustainable cities, as well as indices implemented by private companies and national, regional or international organisations. This study reports preliminary results of a review that seeks to understand this proliferation of measures, what they are being created for, their quality and uses.

3 Methods

This study began with an investigation into smart city indices, in order to understand how many there were in existence and what they were used for. Searches were made of web sites and academic literature, initially to establish what smart city measures had been proposed, by whom and for what purposes.

The initial search in the Web of Science was for journal or conference papers that included the terms “smart city” and the term “index”, carried out in May 2019. This

returned 100 papers. An initial search through the titles of these papers identified 41 papers that appeared to be about the construction of or evaluation of a smart city index. Reading the abstracts of these papers eliminated a further twenty-eight papers that either duplicated work reported in another paper (1 paper), or constructed indices for only one aspect of a city, such as transport, happiness or construction efficiency (14 papers). Of the remaining 26 papers, full text access was not available for ten and the authors of these papers were e-mailed to request copies.

The remaining 16 papers were downloaded and read, capturing information about the index constructed, the purpose, the geographical focus, the target cities, how many cities had been evaluated, the dimensions, indicators and data sources, as well as the methods of construction. Also noted were any references in these papers to other existing indices and these were used to expand the list. For these indices I looked for details either through any reference given or by searching online for further information.

A review done by the United Nations University [22] identified fifteen smart city measures and those were included in the list. This work made it clear that it might be necessary to look beyond indices to other measures of smart cities as that review had included standards and maturity models, so the list was expanded to include those as well. Searches were carried out using Google and Duck Duck Go, for "smart city index" and "smart city maturity model", and the first two pages of results were examined for likely web sites that provided measures for smart cities. Similar information was captured for these measures, when it was available.

The current list includes references to 57 smart city measures. Work is still ongoing to collect details about each of these and to eliminate duplicates. Not all measures identified were clearly named and some sources referred to the same measure by different names, so duplicates are still coming to light as the data collection and analysis continues. New measures also come to light as the work proceeds, so this number is expected to change over time. This preliminary paper reports on the 18 measures for which there is currently comprehensive data.

Not all of the measures analysed were, strictly speaking, measures. For example, the standard ISO37101 is a standard for city or community management systems, although it includes how to monitor these systems. The two models are frameworks that describe the characteristics of smart cities. One of them is used to evaluate city smartness, but there are no details as to how this is done. The other invites cities to apply for smart city status and access to government funding for smart initiatives, giving information about how the application will be scored. The two sets of indicators give details of indicators that can be used to measure aspects of city performance and how to calculate them. The remainder of the measures examined are consolidated indices, based on a set of city dimensions (and sometimes sub-dimensions), with each dimension being measured by one or more indicators.

The analysis of the data is informed by the research questions. To establish the intended purposes of the measures I examined stated purposes, and then looked for commonality and differences between them using thematic analysis. I also looked for unstated purposes where these could be deduced from the originator of the measure, the intended users, and the kind of relationship between the two.

The measures were evaluated for transparency based on how public the information is. Intended or reported sources of data were examined and compared. While it is not possible to evaluate the accuracy of data sources used, I did look for efforts to ensure data quality. Finally, if there was a consolidation process (as in constructing an index), descriptions of this process, the rationale for the process and indications of rigour, in the form of statistical analyses, were examined and compared.

4 Why? Purposes of City Measures

Measures of city performance are created with different purposes in mind, some more clearly expressed than others. To understand what the intended purposes of the selected measures were, this section starts by analysing the nature of the measures and where they originated. The 18 measures that were examined for this paper included two standards, one set of indicators, two smart city "models" and thirteen indices. One of the standards is for a set of indicators, so there are effectively two sets of indicators.

The measures originate from academic sources, from governments, from international bodies and from private companies and individual consultants. Eight of the measures have academic roots; five of them from groups of researchers, two from a consortium of universities and one from a research institute which is university-based, but includes local government and business partners. Five of the measures originated from international organisations, three from private companies or individuals and two from national governments. The predominance of academic measures may reflect the approach taken to sourcing the data and the full set of measures, which is still to be analysed, may reveal different proportions between these sources.

The purposes that are ascribed to the measures show some interesting themes. The predominant theme (in nine cases) is about measurement and some do not expand in any way on the purpose of this measurement. For example, one private company's index is intended to provide "balanced benchmarking" and an "objective perspective" on where cities work and where they don't. One academic index is intended to "simplify and summarize a complex concept" and another aims to "measure the intellectual capital of cities". One international organization's index is intended for "comparative ranking of cities" and another aims to "to measure prosperity and sustainability of cities".

Others are explicit about the reasons for measuring and the most common ones are to aid decision-making (four measures) and to improve conditions in cities (four measures). Purposes such as "to steer the performance of city services", to "prioritize investments" and to "manage city sustainability" suggest that the measures are useful to city authorities in making decisions. Other measures aim at "helping cities, communities and companies become smart", or to "foster smartness and resilience" and improve quality of life.

Four of the measures aim at "urban innovation" or to "develop valuable ideas and innovative tools", while another three are positioned as tools themselves, to aid learning. One index, with academic origins, is trying to "find relationships" between city characteristics and innovation and another to "assess and analyse development patterns" in cities. Other goals are competitive. One index, constructed by a private company, is "for cities to compete for companies, tourists and talent" while another government measure was designed for cities to compete for funding. Finally, two of the measures developed

by international organisations are tools for achieving the sustainable development goals (SDGs) or to meet other compliance requirements.

There is a clear relationship between the origins of the measures and the cities or communities to which they are intended to be applied. Those measures with academic and government origins were looking at cities in specific geographic areas. This is unsurprising for governments which were creating measures for their own countries (India and Brazil). For academics, the choice of cities was influenced by where they were based, usually researching cities in their country, but also by the availability of data. Six of the studies were based in Europe and two in China. There appears to be good data available, at least for larger cities, in both Europe and China.

International organisations, not surprisingly, create measures that can be applied globally (all five cases), and the two standards can be applied at different scales, including "communities of all sizes, structures and types, in developed or developing countries, at local, regional or national levels, and in defined urban or rural areas". Private companies and consultants focus on their target markets with one only measuring "global or regional capitals of business and finance" and another aiming to measure smartness in "cities, communities and companies".

Observing the targets of these different measures allows some speculation about the less explicit purposes of the measures. While the explicit purposes are to measure with an eye to improving conditions in cities, academic researchers are pursuing knowledge and national governments are creating tools to measure outcomes or progress on initiatives they are implementing. International organisations are interested in creating measures that facilitate global monitoring and analysis, in pursuit of their goals for global development, while private companies are seeking to collect information that supports their business goals through its usefulness to their clients.

5 How? Data Collection and Consolidation

5.1 Indicators

The indices that were examined were based on between five and ten different city dimensions. These dimensions were then associated with between 18 and 96 indicators. The academic papers that were not from research groups tended to consider fewer indicators (between 18 and 32), but those produced by research groups considered between 81 and 96 indicators. Private companies and consultants used between 39 and 67 indicators, the one government index used 81 indicators and the one index produced by an international organisation used 72 indicators with the option to extend that, depending on budget. (The other index proposed by an international organisation was still under development, so the number of indicators was not yet fixed.)

Indicators need to be consistent across cities and across time, in order to allow meaningful comparisons. For example, city data can be affected by the selection of city boundaries [12, 23] and so need to be interpreted in their contexts. Consistency depends on having detailed definitions of each indicators, so as to avoid multiple interpretations, as well as guidance on how the data might be sourced. The two indicator sets examined for this study, ISO37120 and the ITU-T Key Performance Indicators for Smart, Sustainable Cities [9], both provide such definitions and guidance on data sources. As such they

are valuable resources. Indeed, two other measures that were examined made use of the ITU-T indicators as the basis of their measures. The ISO37120 standard proposes 111 indicators and the ITU-T Key Performance Indicators for Smart, Sustainable Cities uses 55 core and 36 advanced indicators.

Most measures proposed a mandatory, common set of indicators, while two that try to be more flexible or developmental, suggest that the set could be negotiated with the cities. Clearly flexibility limits comparability, but this provision allows the wider application of the index to cities where data might not yet be available or feasible.

5.2 Data

All measures depend on some kind of data or information about the city or community being evaluated. Two of the measures did not say what the source of data was. Those that did, gave three sources of data. Either data is collected by the city itself or data is collected from the cities through an externally administered survey. In these cases, there was sometimes an external verification process. The third source of data was trusted third parties that aggregate and verify data.

Indicators depend on reliable and comprehensive data and trusted third parties seem to be the most reliable source. Some world regions are well supplied with data. For example, Eurostat is used by researchers as a reliable source of data about cities in Europe. Some countries have good national data collection points, but many parts of the world have limited data sources. This limits the number of cities that can make effective use of indicators, although, where data is not available for a particular indicator, various techniques can be used to compensate. For example, national data can be used to substitute for city data [1].

Where cities collect data themselves there is always a risk that they omit data that might show the city in a bad light or skew the data collection towards data that is easier to collect or appears more favourable. Despite this, an important discourse, present in the measures proposed by international organisations, is that of developing the capacity of cities to collect accurate data. These bodies are concerned to strengthen data collection practices at local and national levels in order to fill gaps in our knowledge of the global state of affairs and to facilitate the kind of monitoring and policy work that they undertake. Skills in data collection within cities will also strengthen the ability of national and regional bodies to provide good data.

Surprisingly, given that smart cities are strongly associated with real-time data, only one index suggested the use of real-time data “if available”. Real-time data collected from city residents or sensors in the city would give accurate and timeous information that might be less open to manipulation. Researchers have argued that “smart cities need smart indicators” as people, companies and governments “generate digital data on almost all the urban activities they perform, but it is estimated that only 5% of the available digital information is currently being used” [5, p618].

5.3 Consolidation and Validation

The level of detail provided on how the measures were to be applied differed widely. In the case of the two models one provided no information and the other provided guidelines

as to how the scoring of applications to be considered smart would be applied. The indicator sets and standards, however, gave detailed information about how they were to be used.

Indices are constructed from the indicators through various consolidation techniques, some more complex and rigorous than others. Again, differing levels of detail were provided on how that consolidation takes place and the rationale for using a particular method. The one government index gave no information about how the index was calculated. Of the indices developed by private companies, one gave no information about the construction, a second gave some information about a board of experts who agreed on the method and the third explained that the evaluated cities would be ranked on each sub-index and these scores totaled for the final index. Of the two indices proposed by international organisations one was similarly short on detail, explaining only that the final measure is a "weighted mean of standardized indices from each of six dimensions" and that it would be "adjusted to the priorities of the country and the availability of information". The other was still under development.

For many of the academic indices, researchers were trying to arrive at a minimal or representative set of indicators, that provide an accurate measure of city smartness or resilience. These papers focused on validating the index as an accurate measure and explained in detail the techniques used to do this. Academics explain the statistical techniques they use, the reliability of their results and they give their rationale for decisions made about the consolidation with comments like: "This approach ensures that the cities being compared have a useful amount of homogeneity and uses the underlying structure of the dataset to weight and aggregate our data while guaranteeing the consistence, coherence and reproducibility of our results." [1, p484]. They are also careful to specify where indices are constructed for specific regions, and are not applicable more broadly [24, 25].

This means that the indices produced by academic sources are the most rigourous and also the most transparent. Those produced by governments, international organisations, and private companies and consultants appear less transparent. Without transparency it is not possible to comment on their rigour.

Given the promise of new data analytical techniques one might expect to see some of these being used in the evaluation of smart cities, but that was not the case in this set of data. Chinese researchers are beginning to use such techniques. For example, Liu et al. [26] made use of an "influential network relation map (INRM)" to analyse the relationships between indicators and compare the performance of two cities.

6 Conclusion and Next Steps

This paper identified measures of city performance, including indicator sets, models and indices.

Two sets of city indicators were examined, both of which provide details of what can be measured and how. Such indicator sets are useful base measures for cities and can save cities the work of agreeing and defining indicators. Indicator sets are transparent, although not always easy to implement due to the difficulty of sourcing data, but they do serve as a development tool for cities and communities who want to improve their

data collection and measurement. Some standards have to be purchased, so there may be a cost in accessing them. Standard indicators also facilitate comparisons across cities. Standards for city indicators do not necessarily improve management of cities or quality of life, but establishing good measures is a step towards those bigger goals.

This paper has not examined models in any depth. The sub-set of data examined did not give much information about how models might be used for measuring cites, although many of the indices are underpinned by models of city performance which inform the dimensions and sub-dimensions to be investigated.

Composite indices that measure city performance originate from three types of sources and these origins appear to influence the uses and usefulness of the indices.

The first source are academic researchers who construct indices either to test or illustrate technical aspects of index construction, or to support conceptual understandings of smart cities. These indices tend to be rigourous in their construction and the norms of academic publishing ensure that they are transparent. The indices are clearly associated with specific objectives and types of cities. However, except for cities that fit their criteria, they are unlikely to be useful. The academic presentation of the techniques also means that the information is not in an accessible format for cities and communities.

The second source of composite indices is private companies or consultants who use them to support customers with information about cities. Of the three examined in this paper, two were using this data to inform clients about the benefits of investing in or locating in leading cities. A different two were looking to assist cities to improve their performance. The transparency of these indices varied. They all described the dimensions they used, two listed some information about the indicators used and one described the consolidation process. Those that are only measuring leading cities are of little use to other cities and communities. The third, which purports to help cities, communities and companies, gives the least information and so would not assist a city in measuring itself.

The third source of composite indices is national or international bodies. This group were interested in national or international monitoring, comparisons and, in one case, the allocation of resources to cities. These indices were similarly mixed in terms of transparency. They all listed dimensions and indicators, but only one gave details of how all the indicators were measured. All were designed to be applied to cities with the originating body playing a consulting role. There was not enough information provided for a city to apply the process entirely independently. This configuration may relate to a desire to ensure the quality of data collected since these bodies, while supporting a capacity development discourse, seem to be motivated primarily from a desire to collect comparable data across cities. There was little information about the process adopted for consolidation or justification of the choice, missing the opportunity to raise awareness of the technical considerations in such a process. Marsal-Llacuna et al. advise that "official normalizing bodies have to take the lead in the elaboration of summarizing indices" [5, p621], and this seems to be something not yet effectively addressed.

This paper reports on preliminary results of a survey of measures of the performance of cities. Detailed information about the remaining measures is still being collected and will be reported in due course. However, patterns are already starting to emerge in the purposes, construction, transparency and potential uses of the indices. Going forward,

the patterns need to be confirmed using more data. From this work, recommendations are expected for practitioners as to which measures to use and how to use them effectively.

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