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Making Transportation Systems in U.S. Cities Smarter and More Inclusive: A Synthesis of Challenges and Evaluation of Strategies

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Abstract: Smart City (SC) strategies developed by local governments reflect how governments and planners envision SC and apply smart technologies, and what challenges they face and try to address. Little attention, however, has been given to investigating SC strategies or applications, especially in the U.S. context. Moreover, there is insufficient attention paid to whether SC strategies address social issues such as equity and public participatory opportunities. Based on the documentation from the U.S. Department of Transportation 2015 Smart City Challenge, we developed a framework to evaluate SC strategies on urban transportation systems using six standards: *Safety*, *Mobility*, *Sustainability*, *Opportunity*, *Efficiency*, and *Equity*. In addition, we synthesized the challenges U.S. smart cities encounter, and SC strategies proposed by local municipal governments to tackle them. Our findings show that most SC strategies aimed to improve *Efficiency* (78%) and *Mobility* (57%), while less attention has been given to providing *Equity* (8%) or *Opportunity* (7%). The most well-acknowledged challenge that the local governments face is the limited data and tools for decision-making, with 416 SC strategies (27%) proposed to address related issues. Our framework and results contribute to the future SC strategy evaluation and inclusive smart city development. Our study also identified a broad spectrum of available SC strategies planners and policymakers can refer to when designing an SC or overcoming SC challenges.

Keywords: smart city strategy; intelligent transportation system; inclusive smart city; smart city evaluation

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1. Introduction

Governments and policymakers have been actively advocating the Smart City (SC) as a means to establish efficient transportation systems, build up high-quality urban services, minimize environmental impacts [1], and improve citizens' quality of life [2]. The growing significance of SC is demonstrated by an increase in both scholarly publications and reports from private sectors, commonly with a focus on the technological edge, such as technology innovation [3–7]. Nevertheless, SC remains malleable as an abstract idea [8,9], a simple slogan [10], or a panacea for all urban problems [11]. While most attention has been given to exploring SC's definitions, dimensions, and characteristics, rarely have studies investigated the SC strategies or applications in practice.

SC strategies proposed by local governments intuitively reflect how SC is envisioned and how innovative smart technologies are applied to address challenges governments face. Meeting citizens' needs and improving their quality of life [12] should be the main purpose of developing SC strategies [2,13–15]. Masik, et al. [6] warned that "actual development of SC strategies or applications could strengthen a one-sided focus on technological and technical aspects of smartness." Current SC development, however, centers on innovative technologies [3,4,16] with insufficient consideration of services for the citizens towards a more sustainable way of living.

It would be helpful to review the SC challenges and strategies comprehensively and quickly in order to provide practical insights for future SC development. Additionally, evaluating SC strategies can help to involve all citizens in SC development, especially underrepresented populations who are at risk of poor physical, psychological, and/or social health. The understanding of SC is morphing toward city planning and development with the inclusion of social and environmental concerns [17]. Social equity should be given more consideration for planning and decision-making related to SC development [18] to design and build inclusive smart cities [2,19,20]. Unfortunately, there has been little attention paid to evaluating SC strategies' inclusion of underrepresented populations [2,21] and their engagement with local communities.

Several papers made the first efforts to assess SC strategies through case studies [3,22–24]. The limitations of these studies can be attributed either to the limited number of SC plans or initiatives available, or to the insufficient consideration given to underrepresented groups. There is also a lack of a comprehensive investigation and evaluation of SC strategies in the U.S. context. To fill these gaps, this study aims to synthesize both the challenges U.S. mid-size cities are facing and SC strategies proposed by local municipal governments to tackle the challenges, using documentation from the U.S. Department of Transportation (DOT) 2015 Smart City Challenge (SCC). We proposed a framework to evaluate SC strategies to determine whether governments have developed balanced and inclusive proposals with SC strategies that address citizens' needs.

The SCC was originally designed to build a smart transportation system in mid-size U.S. cities, so this study only focuses on transportation-related SC strategies. Nevertheless, this study contributes threefold to the literature. First, this study is among the first attempts to synthesize both SC strategies and the corresponding challenges in the U.S. context based on a large number of SC proposals. The results can guide the private sectors, planners, and policymakers on future SC development in U.S. mid-size cities. Second, this study takes advantage of the documentation from the SCC, which provides an unprecedented opportunity to comprehensively investigate SC strategies across the country to gain a more in-depth understanding of SC development. We synthesized and evaluated SC strategies proposed by 78 mid-sized U.S. cities from comparable applications that were uniformly required. This fills the gap where existing literature suffers from the lack of extensive and adequate documentation about SC initiatives or applications [3]. Third, we added *Equity* and *Opportunity* as critical standards to the proposed SC strategy evaluation framework, which is rare in the existing literature but important. Rather than solely from the perspective of technology innovation, SC strategies are thus evaluated from a citizen-centric standpoint.

2. Background

2.1. SC Development: Technological-Focused to Human-Oriented

The SC has attracted much attention from businesses, governments, media, and academia over the past two decades [17,25,26], with emphasis on the definitions, characteristics, or dimensions of SC [4,8,12,22,27–30]. For example, an SC can be simply defined as an application of information technology to improve traditional infrastructure [31] or the wholesale rethinking of urban life from the perspective of using advanced ICT [32]. Harrison, et al. [33] de-fined the SC as urban areas connecting physical, social, business, and ICT infrastructure to uplift the intelligence of the city.

Existing SC research and discussion are dominated by technical innovations [26]. Some stakeholders, such as local governments or private sectors (e.g., technology vendors, property developers, etc.), sometimes simply believe that a city can be potentially and automatically transformed into a "smart" city by implementing innovative technologies [10]. Shelton, et al. [34] pointed out that technology-oriented SC development is one reason that SC initiatives result in more technocratic and top-down governance. Smart cities often picture themselves as a creation and combination of scientifically grounded technologies, techniques, and visions [35]. This technology-based approach to SC development also causes related social and environmental issues that are often ignored [12], especially for underrepresented populations. The SC research and practice should move beyond technological perspectives to be more participatory and human-centered [36].

We echo other studies in arguing that the utmost goal of SC development should be to improve both the operational efficacy of urban services and the quality of citizens' life [37–39], because an SC must be "human"-oriented, as stated by Blasi, et al. [26]. Albino, et al. [22] specifically pointed out that smart living and smart people, both critical components of smart cities, are associated with security and quality of life. According to Nam and Pardo [27], technology, people (creativity, diversity, and education), and institutions (governance and policy) are the three essential components of smart cities. An SC must strengthen the links between investments in human, social capital, and ICT infrastructures, hence enhancing the quality of life.

2.2. U.S.DOT 2015 Smart City Challenge

In 2015, U.S. DOT launched the SCC among mid-size cities with a population between 200,000 and 850,000. It was the first national SC competition initiated by a U.S. federal agency, explicitly focusing on developing intelligent and technology-aided transportation systems that can apply to U.S. cities. This unprecedented competition aimed to encourage applicant cities to submit creative strategies to address the challenges they are facing [40]. The first round of the SCC received about 78 proposals from 85 cities. In accordance with the Notice of Funding Opportunities (NOFO), which was published in December 2015, each first-round proposal was limited to no more than 30 pages. In March 2016, only seven finalists were selected to be eligible to submit second-round technical applications, with a limit of 75 pages. Columbus (OH) was ultimately awarded the funding of USD 50 million as the winner.

The documentation of SCC provides an unprecedented and holistic dataset for scholars to evaluate SC strategies/applications. The competition itself calls for holistic and detailed proposals with SC strategies to develop smart cities with sustainable and intelligent city-wide transportation systems. In addition, all applicant cities submitted proposals following uniform formats, as required in the Notice of Funding Opportunities (NOFO), allowing us to compare and evaluate them [40]. Although NOFO specifies some visions to follow, their proposals can still fully envision their perceptions and efforts made toward building an SC, as well as the challenges they are facing.

Although SCC is still under-examined, several studies have realized its value for use in evaluating SC strategies [41,42]. Its global influence, for instance, is also remarkable. In 2019, the South Korean central government, for instance, used the SCC as a model to call for its own nationwide smart city project [43]. The SCC documentation fits our study needs and provides an appropriate data source, because it allows us to summarize both SC strategies and challenges that can be targeted for intelligent transportation system development.

2.3. Evaluating SC Strategies and Applications

Scholars have built frameworks to assess SC strategies, applications, or initiatives through case studies from around the world, even if there is as yet no recognized framework for SC strategy evaluation [44]. For example, based on a review of the measures of SC performance, Albino, et al. [22] summarized that the indicators used for SC assessment in current rating systems could be categorized into six components: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. Lee and Hancock [45] proposed a conceptual framework to examine 143 smart green city projects in six dimensions: urban openness, service innovation, partnerships formation, urban proactiveness, smart city infrastructure integration, and smart city governance. Their later work also offered useful insights to improve the delivery of SC projects and called for public and private sector actors' coordination [14]. Alawadhi, et al. [46] developed a preliminary framework to deepen the understanding of SC initiatives through interviews with governmental officials or planners from four North American cities. Their framework emphasized eight aspects including technology, management and organization, policy context, governance, people and communities, economy, built infrastructure, and natural environment. Zubizarreta, et al. [3] conducted a review of 61 applications from 33 smart cities worldwide using the European smart cities classification standards, which focused on the level of integration between economy, people, living, governance, environment, and mobility. They found it difficult to obtain holistic applications to evaluate SC strategies. More recently, Golubchikov and Thornbush [47] recognized the importance of artificial intelligence (AI) in SC development, and used AI to assess 51 SC projects from 12 cities across the world in terms of their operation with AI. They concluded that the presence of discourses around AI in these strategies was very uneven.

These studies assessed SC applications or initiatives from a general perspective of SC development, rather than focusing on building an intelligent urban transportation system. In addition, these studies typically compared or evaluated SC strategies from different countries or continents, without a focus on the U.S. context, where SC development has recently been booming [5].

According to SCC's NOFO, the U.S. DOT particularly requested applicant cities to propose SC strategies that focus on improving safety, enhancing mobility, promoting efficiency, protecting the environment, responding to climate change, and connecting underserved communities [48]. These expectations were developed to build Intelligent Transportation Systems (ITS) in mid-size U.S. smart cities. After the second round of SCC, the U.S. DOT also released its report assessing SC strategies proposed by seven finalists from five aspects: safety, mobility, opportunity, environment, or cross-section. These standards align with another study by Angelidou [24]. They identified ten fundamental characteristics of smart cities, including ICT, human and social capital development, etc., and used these characteristics to examine whether they were adequately presented in the SC plans from 15 global cities. This study mainly contributes in providing a clearer view of defining characteristics of SC strategies, which have rarely been investigated previously. Additionally, within the domain of sustainable urban development, Angelidou, et al. [23] pursued an in-depth examination of 32 SC applications in Europe, aiming to address the specific sustainability challenges related to waste management, air pollution, and energy consumption.

However, it is rare to find inclusiveness used as a standard to evaluate SC strategies, which emphasizes the fulfillment of the needs of underrepresented populations in developing an SC. For example, Wang, et al. [2] evaluated the extent of awareness of inclusiveness demonstrated in the SC strategies, and classified smart cities into three levels ("no-awareness", "awareness-yet-no-action", and "awareness-and-action"). Smart cities with intelligent transportation systems cannot be designed only to fit the needs of active and fully abled people [15,49], as equity issues may arise. Evaluating the SC proposals to ensure that they adequately address public interests thus becomes critical [44], particularly regarding the needs of underrepresented populations (e.g., people with disabilities, seniors, wheelchair users, and visual or hearing-impaired populations) [2,18–20]. Additionally, for smart cities to become innovative and learnable, it is imperative to take into account participatory opportunities when designing smart cities' strategies or applications [36].

In sum, limited research has been conducted to evaluate SC strategies in the U.S. context. Inclusiveness, equity, and participatory opportunities are not commonly considered when evaluating SC strategies, but they are important. A comprehensive framework is needed to investigate and evaluate SC strategies.

3. Data and Methodology

3.1. Data Collection

Similar to the previous studies examining SCC proposals [2,41], we thoroughly reviewed all 78 first-round proposals (applications) from the SCC. We defined an SC strategy as a project, plan, physical or visual product, or a new innovative service specifically proposed to address a challenge or problem. Through open coding and focused coding, we collected and synthesized the SC strategies developed in the proposals, as well as their corresponding challenges and strategy descriptions. Table 1 illustrates the format of the SC strategies collected by showing three of the strategies proposed by Columbus (OH). The challenge identified by the applicant city in the proposal could intuitively reflect why a certain strategy was proposed. Since one applicant city could present multiple SC strategies and the same strategy could also be proposed by more than one applicant city, examples of detailed strategy descriptions were provided to help better illustrate how an SC strategy might be proposed or described differently.

Table 1. Three examples of the SC strategies from Columbus (OH).

Major Challenge	Understanding citizen needs/issues	Aged and insufficient infrastructure	Poor air quality and unbalanced energy use
Challenge	Digital barriers	Education and adoption of CV/AV/EVs	Decarbonization of the grid
Strategy	City services (from kiosks)	Converting public fleets to EVs	Solar panels for EV charging stations
Description	Kiosks would be installed in key transfer locations among travel hubs.	Converting portion of city fleet to EVs and share EV fleet (during off hours) to citizens.	Install solar panels in large arrays adjacent to recharging stations.
Safety			
Mobility	Y	Y	
Sustainability		Y	Y
Opportunity			
Efficiency	Y		
Equity	Y		

3.2. Methodology

After compiling the SC strategies proposed by applicant cities in the SCC, we developed a framework to evaluate SC strategies. Figure 1 illustrates the methodological flow chart, including the proposed evaluation framework and analyses conducted.

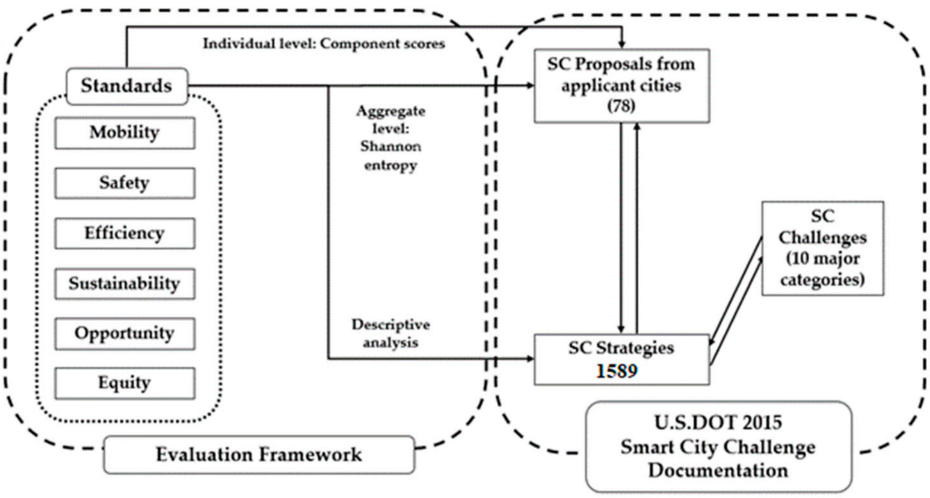

Figure 1. Methodological flow chart.

3.2.1. Evaluation Framework

The framework consists of six standards: *Safety*, *Mobility*, *Sustainability*, *Opportunity*, *Efficiency*, and *Equity*. The standards included in the framework are derived from an exploration of the existing literature or reports, such as [2,40,50]. We also believe that these six standards are particularly suitable for evaluating SC strategies that are focused on solving SC challenges related to building urban transportation systems.

The first standard is *Safety*. The U.S. DOT also explicitly required in the NOFO that urban transportation systems need to improve the safety of travelers, goods, and system operations [48]. Therefore, the integration of urban safety into SC development or SC strategies is doubtlessly essential, especially for pedestrians, bicyclists, or transit passengers [51,52]. It is also one of the standards the U.S. DOT summarized for evaluating SC strategies proposed by the seven finalists.

The second standard is *Mobility*, which is one of the essential topics faced by smart cities to improve urban traffic, ensure faster travel with more options, reduce transfer costs, alleviate mobility issues, and ultimately improve the quality of life [53–57] by implementing ICT in modern transport technologies [22,51,53,54,58,59]. As a critical component of smart cities, it has been commonly used by previous studies [22,53] and required in the NOFO [48] to assess SC performance, thus enhancing mobility.

The third standard is *Sustainability*. The framework defines Sustainability from a perspective that emphasizes environmental concerns instead of economic or social concerns [60]. Similar to the previous studies [23,56,61–64], it is imperative to consider the environmental impact of urbanization or population growth and the derived pressure on energy and other natural resources under the SC context. An SC needs to be built in a more sustainable, equitable, inclusive, and livable way, and these conditions are considered necessary for a sustainable future [36,63,65], which also aligns with the requirement of NOFO to make the smart transportation system more environmentally sustainable [48].

The fourth standard is *Opportunity*, which refers to the participatory opportunities provided to citizens, such as public engagement, involvement in decision-making processes, and outreach or education due to inaccessible innovative technologies. This standard is considered from an individual or micro-perspective. It has been previously used by [46,66–69] to emphasize the importance of the participation of society members. A citizen-centric approach to smart cities is also in alignment with this standard.

The fifth standard is *Efficiency*. From a government or macro-perspective, smart cities strive for systematic efficiency in their operations to reduce cost, reallocate resources appropriately, and provide more societal services [70]. The NOFO from the U.S. DOT specified that our future transportation systems need to be more accessible and efficient [48].

The last, but not the least important, standard is *Equity*. Although equity was not often given sufficient attention in evaluating SC strategies, it is fundamentally required to fulfill the needs of underrepresented residents [2,15,18–20,49]. Similar to the study by Wang, et al. [2], we are adding *Equity* to the framework to fulfill the need to build inclusive smart cities.

Each SC strategy may fulfill one or more standards in the framework, indicating whether the SC strategy is mentioned in the proposal with an explicit intention or consideration to fulfill the standard(s). For example, the SC strategy "Wireless Inductive Charging" fulfills both *Sustainability* and *Efficiency* standards because it could promote the use of EVs to optimize energy consumption and improve charging efficiency. Similarly, each applicant city may also propose multiple SC strategies in the proposal. However, the proposals, consisting of SC strategies, should not focus on just one aspect of the framework. Instead, a balanced proposal is expected to include both a considerable amount of SC strategies and fulfil every standard in the framework. In this study, the framework is used as the criteria to evaluate both SC strategies and applicant smart cities.

3.2.2. Analyses

To analyze SC strategies, we first analyzed the compiled SC strategies by investigating their emphasis based on the six standards of the framework. This allowed us to identify the standards that receive the most or least attention. Then, we used the six standards described in Section 3.2.1 (i.e., *Safety*, *Mobility*, *Sustainability*, *Opportunity*, *Efficiency*, and *Equity*) to evaluate SC proposals at both individual and aggregate levels.

At the aggregate level, the Shannon entropy was calculated for each SC proposal (or applicant SC) to measure whether the SC strategies were proposed in a balanced way. Originating from information theory, Shannon entropy was initially used to measure information uncertainty [71]. Later, this measure was adapted to a variety of fields to measure the evenness and balance across different standards [72], such as the level of a mix of land-use types (e.g., Song, et al. [73]) and the multiple dimensions of sustainability (e.g., Ding, et al. [74]). Our study used Shannon entropy to measure the level of balance of SC strategies developed in a proposal, with particular attention to the six standards in the framework. Adapted from the study of Shannon [71], our study used Equation (1) to calculate the entropy of all 78 SC proposals.

$$e_j = -k\sum_{i=1}^{n}\left(\frac{x_{ij}}{s_j}\right)\ln\left(\frac{x_{ij}}{s_j}\right),\ \text{with } s_j = \sum_{i=1}^{n} x_{ij} \tag{1}$$

and $k = 1/\ln(n)$. Here, x_{ij} denotes the number of strategies proposed by an SC proposal j that can fulfill the particular standard i, and $n = 6$. Based on the Shannon entropy value, we ranked all 78 SC proposals from the most balanced to the least, and visualized the top five and the bottom five SC proposals.

At the disaggregate level, we used the metric of individual component score to quantify the efforts that an SC proposal exerted to improve one of six essential components of an SC, namely, the six standards described in the framework. The component score for a standard i and a proposal j is calculated in Equation (2):

$$r_{ij} = \frac{x_{ij}}{t_j} \tag{2}$$

where t_j indicates the total number of strategies proposed by SC j. Each SC proposal will receive six component metric scores to represent its performance under each standard. The component score indicates the proportion of SC strategies in one proposal that satisfies a particular standard. For example, if one city has a component score of 0.41 under the *Equity* standard, this means 41% of SC strategies in its proposal aim at improving the equity aspect of the transportation system.

After calculating the component scores, we first identified the top ten SC proposals that have paid the most attention to a particular standard. Next, we used radar charts to visualize the component scores of SC proposals and compared the most balanced (i.e., with high Shannon entropy) with the least balanced SC proposals (i.e., with low Shannon entropy). Since a radar chart is suitable for visualizing multi-dimensional data [75], it can intuitively show whether SC proposals are balanced or not (i.e., paying equal attention to the six standards) [76]. We did not consider proposals with fewer than ten SC strategies in order to ensure that component scores would not be biased under particular standards. For example, Columbus (GA) proposed two strategies, and one of them focuses on solving safety issues. It therefore has a 0.5 component score under the "*Safety*" standard, which is higher than all the other SC proposals.

Lastly, as each SC strategy has its corresponding challenge, we synthesized SC strategies and classified challenges into nine major categories, using open and focused coding approaches. Table 2 shows the nine major categories of challenges with explicit descriptions. For example, EV adaptive charging stations and inductive EV charging were both seen as part of the "EV charging" strategy to deal with the challenge of aged and insufficient infrastructures. By synthesizing both strategies and challenges, the frequency of strategies under each challenge was computed and visualized.

Table 2. Nine major categories of challenges identified by the SCC applicants.

Category Codes	Major Categories of Challenges	Description
A	Limited data and tools for decision-making	Insufficient data to monitor transportation system, or understand transportation challenges due to adverse weather (hurricanes or flooding)
B	Lack of travel options	Lack of unreliable transit service; FMLM issues; car-dependency due to urban growth; lack of accessibility and limited mobility
C	Delays and congestion	Delays at intersections; freight delays and congestion
D	Aged and insufficient infrastructure	Insufficient EV infrastructure; aged infrastructure due to high maintenance and operational cost
E	Understanding citizen needs/issues	Digital barriers; needs and issues of particular population groups (e.g., people with disability, seniors, or wheelchair users)
F	Interoperability, privacy, and data security	Data Storage and Management; Cooperation between different agencies
G	Pedestrian/bicyclist safety	Collisions with pedestrians or bicyclists
H	Lack of parking space and information	Lack of available parking; need for productive use of parking spaces
I	Poor air quality and unbalanced energy use	Vehicle emissions; decarbonization of the grid

4. Results

4.1. SC Strategies Evaluation

We synthesized 1589 SC strategies, with about 21 strategies on average and 38 at most proposed per applicant city. Figure 2 shows the percentage of SC strategies satisfying each standard. Among 1589 SC strategies, *Efficiency* and *Mobility* received the most attention, with about 78% of the strategies proposed to improve the city-wide operational efficiency, and 57% focused on improving individual transport mobility. About one-fifth of all SC strategies were proposed to emphasize *Sustainability* (21%) and *Safety* (18%), while *Equity* (9%) and *Opportunity* (7%) received much less attention, with the lowest number of strategies.

Figure 3 shows to what extent a proposal pays balanced attention to all six standards using Shannon entropy. All 78 applicant cities have been ranked from high to low based on their Shannon entropy value, ranging between 0 and 1. A value approaching 1 indicates that an SC proposal offers a similar number of strategies in each standard, and a value near 0 suggests that a proposal only focuses on strategies related to a particular standard. A higher Shannon entropy value indicates a more balanced proposal.

Figure 3 also shows that the entropy values of all 78 applicant cities are between 0.5 and 1. Among these cities, Baltimore (MD), Austin (TX), Tampa (FL), San Francisco (CA), and Rochester (NY) achieved the highest entropy values, suggesting that their SC proposals are quite balanced, with a similar number of SC strategies satisfying six standards. In contrast, the proposals from Newport News (VA), Spokane (WA), Columbus (GA), Toledo (OH), and Sacramento (CA) reached the lowest entropy values, indicating that their SC proposals are less balanced, focusing only on a few standards. Most of the finalists, as indicated by the black triangles in Figure 3, except Columbus (OH), rank within the first quantile based on the entropy values, indicating that their proposals are balanced with diverse SC strategies across multiple standards. As the final winner of SCC, Columbus (OH) has an entropy value of 0.75, which is slightly lower than the average (0.76).

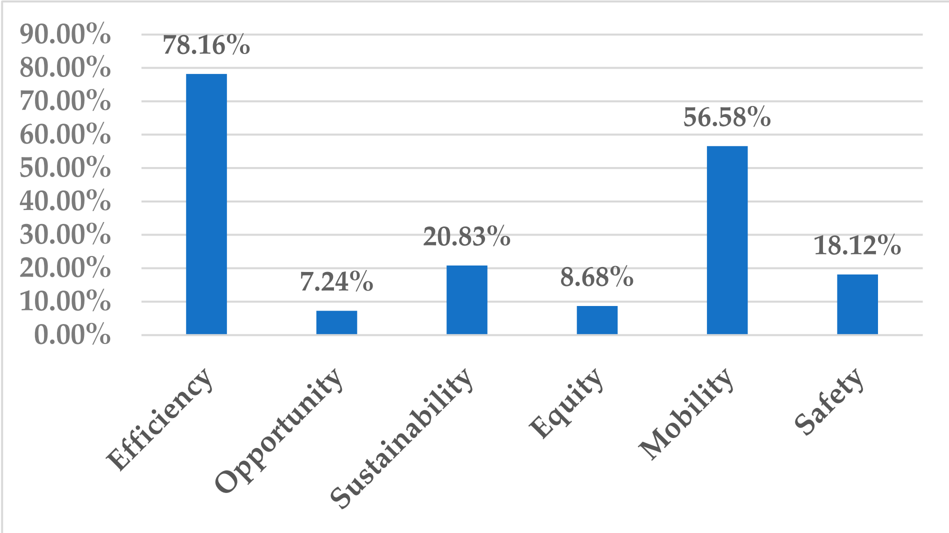

Figure 2. Percentage of SC strategies under six standards.

In Figure 4a, b, radar charts are used to visualize the top and bottom five applicant cities based on their entropy values. This shows that the top five applicant cities pay relatively equal attention to all six standards, compared with the bottom five. The top five applicant cities at least developed some SC strategies to tackle the *Safety*, *Equity*, and *Opportunity* issues in their proposals, as shown in Figure 4a, while the bottom five cities only devoted their efforts to improving *Efficiency* and *Mobility*, as shown in Figure 4b.

Figure 4c shows the top ten applicants concerning each of the six standards. Corresponding to the patterns shown in Figure 2, the scores of *Efficiency* and *Mobility* standards in Figure 4c are also much higher (between 0.75 and 1.0) than those for the other four standards (between 0.1 and 0.5). The majority of the SC strategies aim at improving the *Efficiency* and *Mobility* aspects of smart cities, while only a small proportion of SC strategies are concerned with *Equity*, *Opportunity*, *Safety*, and *Sustainability* issues. This is indicated by the ordered average scores of the six standards. Moreover, the *Opportunity* standard received the least attention. The black triangles denote the SC challenge finalists in Figure 4c. Finalists tend to emphasize the *Equity* aspect in the proposed SC strategies, compared with other standards. It should be noted that four applicant cities (i.e., Columbus (GA), Lubbock (TX), Newport News (VA), and Spokane (WA)) who proposed fewer than ten strategies were not considered in Figure 4c, because they might generate a biased component score. All other analyses and figures include all 78 of the proposals.

4.2. Synthesis of Smart City Strategies and Challenges

In total, 294 SC strategies out of the 1589 proposed strategies remain after removing the duplication. We then combined the similar ones based on the descriptions and ended up with 139 unique strategies. For example, "traveler information website", "traveler information kiosks", and "transit information" were updated to "transit/traveler information" as a new strategy.

We linked the SC strategies and their corresponding challenges. Figure 5a shows the proportions of 139 unique strategies that are devoted to resolving nine categories of challenges. An uneven pattern can be found among the efforts devoted to resolving different challenges. For example, nearly half of the strategies (48%) are proposed to tackle the challenge (A) *limited data and tools for decision-making*, and the challenge (B) *lack of travel options*. However, the last four challenge categories—(F) *interoperability, privacy, and data security*, (G) *pedestrian/bicyclist safety*, (H) *lack of parking space and information*, and (I) *poor air quality and unbalanced energy use*—comprise less than 6% of SC strategies, respectively. The challenge (I) *poor air quality and unbalanced energy use* received the least attention from SC applicants, as only 3.77% of strategies were proposed to resolve this issue. These challenges with a limited number of solutions require more attention.

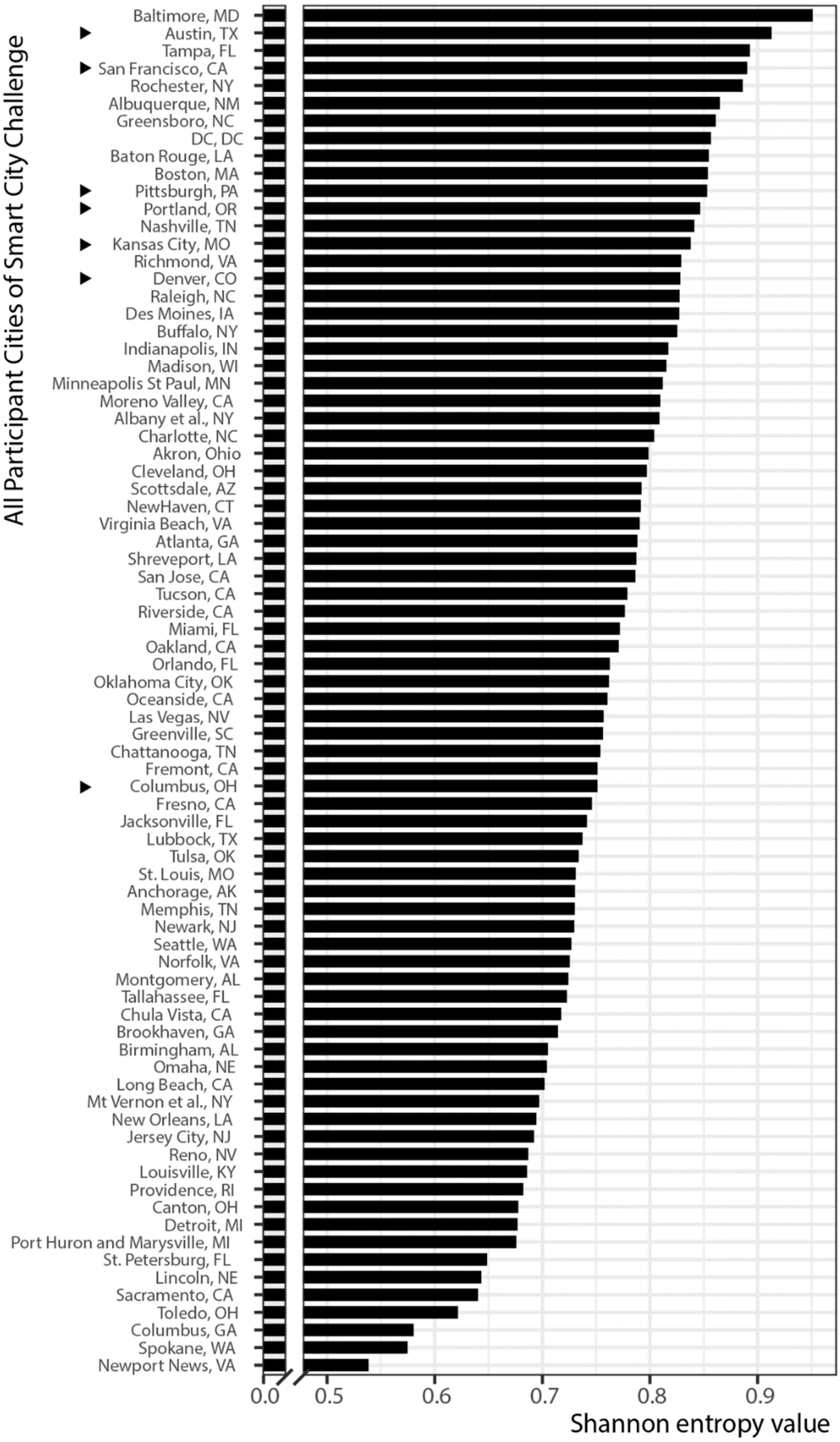

Figure 3. Rank of SC proposals based on their level of balance on the six standards using Shannon entropy (seven finalist cities in the second round of SCC are marked with a black triangle).

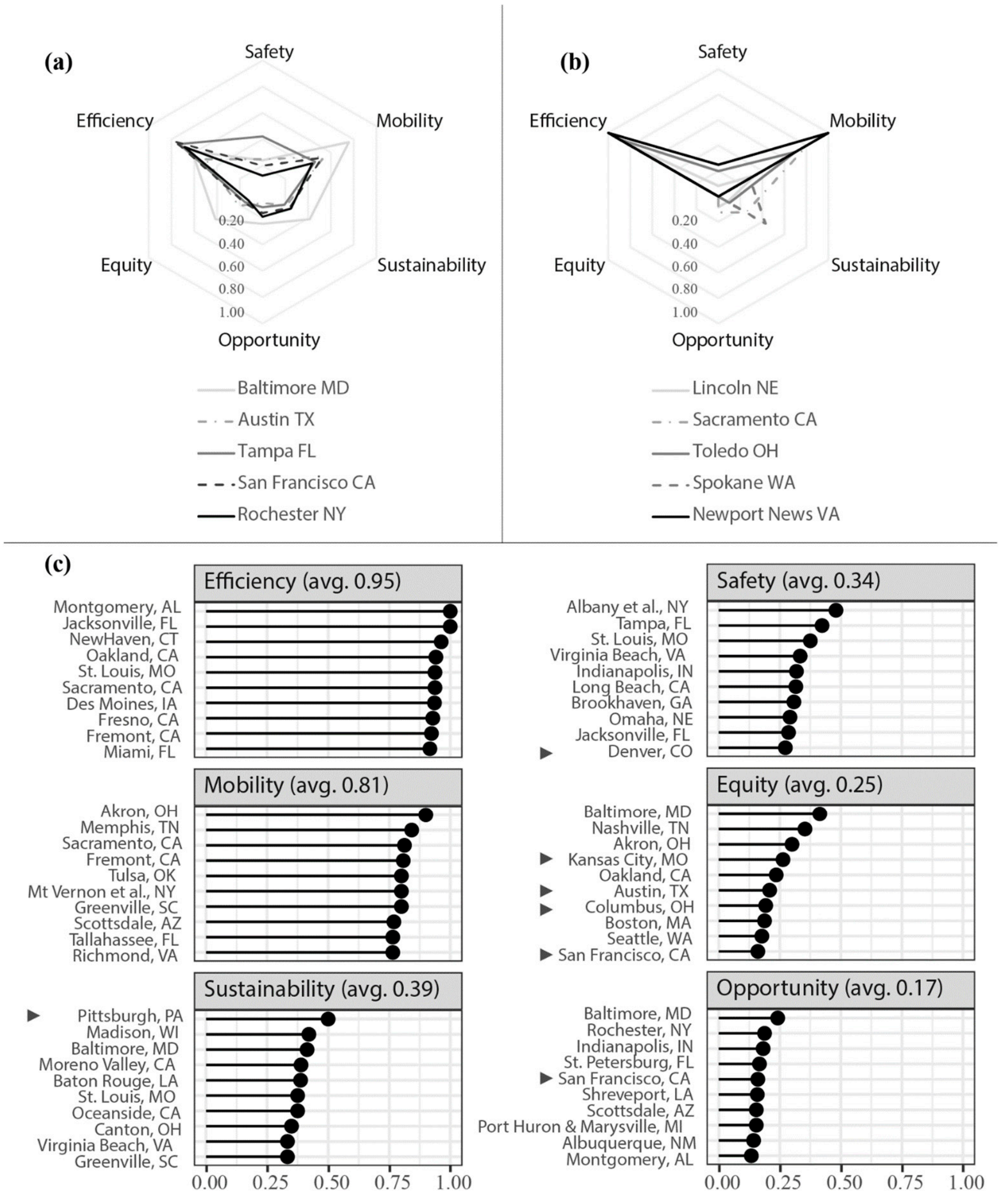

Figure 4. (**a**) Top five applicant cities with the highest entropy values using radar chart; (**b**) Bottom five applicant cities with the lowest entropy values using the radar chart; (**c**) Top ten SC proposals with the highest component score under the six standards (the black triangles denote the SC challenge finalists).

We then further investigated and visualized SC strategies proposed over three times under at least one major challenge category, because strategies with a frequency under three are not representative and are not solid solutions to the corresponding challenges. Additionally, for the sake of visualization, a total of 56 strategies were finally visualized and analyzed, as shown in Table 3. An explicit description has been provided for every SC strategy. Some strategies were proposed multiple times to solve various challenges.

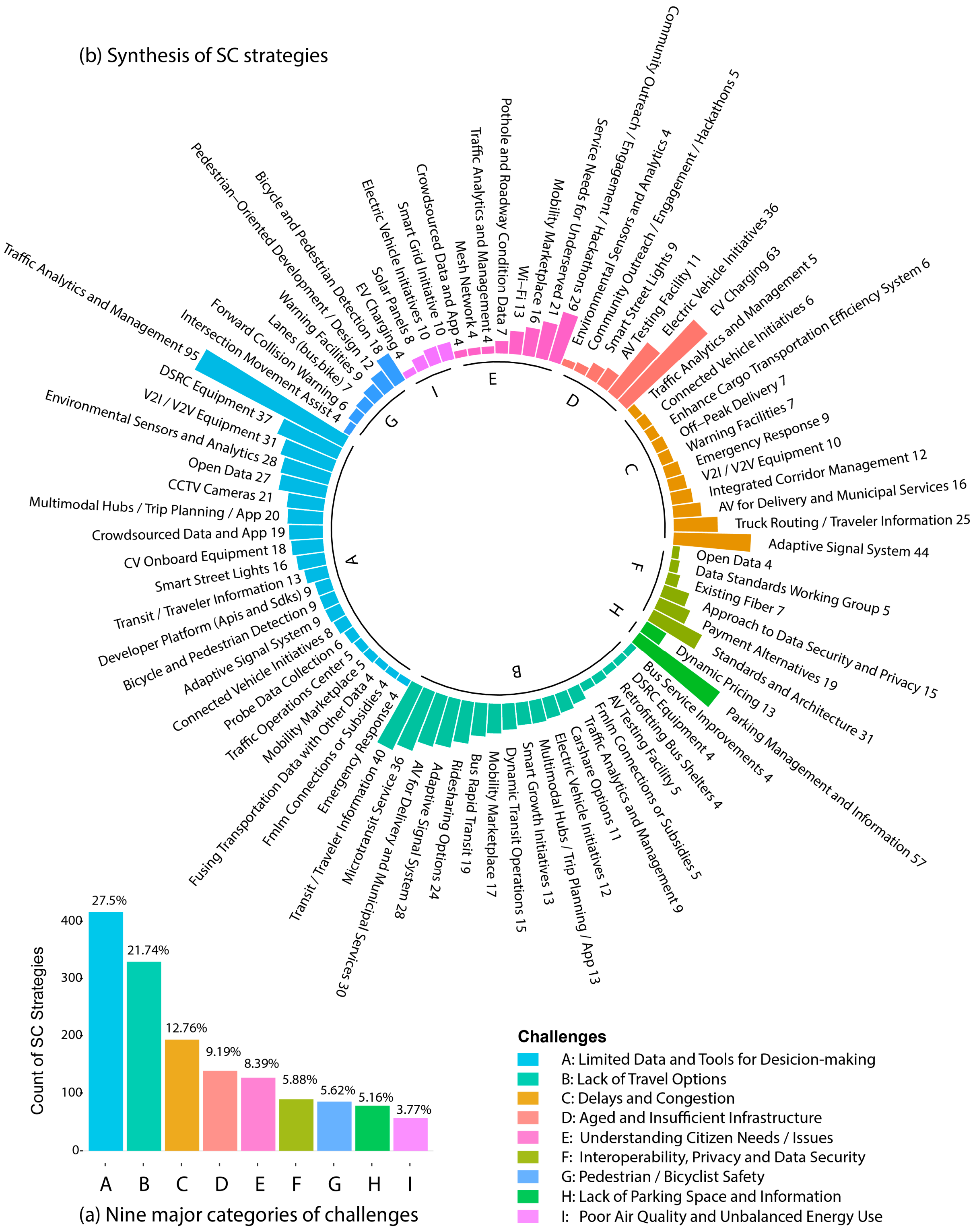

Figure 5. (**a**) Distribution of 139 unique SC strategies under nine major challenge categories; (**b**) synthesis of 56 SC strategies under the corresponding challenges.

Table 3. Description of 56 representative SC strategies.

Code	Corresponding SC Strategies	Description
A, B, C	Adaptive Signal System	Smart traffic sensors to enable traffic light signals to work efficiently.
F	Approach to Data Security and Privacy	To ensure the privacy protection of personal identifiable information.
B	AV for Delivery and Municipal Services	AV facilities for different services such as driver-assist technologies for snowplows, self-driving streetcars, and autonomous drones to perform last-mile delivery.
B, D	AV Testing Facility	Pilot AV transit projects in demonstration zones and show the public an accessible instrumented environment to learn about and experience CV/AV technologies.
A, G	Bicycle and Pedestrian Detection	Bicycle and pedestrian sensors and count stations as input for real-time and long-term monitoring for maintenance and improved operations.
B	Bus Rapid Transit	(Electric) Bus Rapid Transit serves mobility hubs and runs more frequently.
B	Bus Service Improvements	Install driver-assisted automation, GPS, automated vehicle location, or automated passenger counters to improve collision avoidance and efficiency.
B	Carshare Options	Urban and suburban automated car share vehicles, electric car sharing plans, or car sharing options in currently underserved areas.
A	CCTV Cameras	Surveillance technology to monitor and analyze traffic, pedestrian activities, and street furniture operations and to provide real-time images of traffic system.
E	Community Outreach/Engagement/Hackathons	Citizen engagement initiatives such as creating website or organizing hackathons, to carry out active media campaign for awareness raising or education purposes; connection with special needs groups—low-income, seniors, blind, deaf, mentally disabled, English as a second language—to ensure connection during the planning stages.
A	CV Onboard Equipment	Examples include in-vehicle networking equipment, car-to-car communication system, green driving aids, turn-by-turn navigation system, mobile eye sensors.
A, C	Connected Vehicle Initiatives	Connected buses or vehicle-to-vehicle bus rapid transit.
A, E	Crowdsourced Data and Apps	Collection of crowdsourced information generated by smartphone apps, sensors, open data platform, and news media or social media network.
F	Data Standards Working Group	Standardization of ITS, GIS maps, incident reporting systems, and center-to-center communication.
A	Developer Platform (APIs and SDKs)	Prioritize the provision of data to public and private sector clients, and promote the provision of data to private technology developers.
A, B	DSRC Equipment	Use DSRC to facilitate V2V or V2I communication.
H	Dynamic Pricing	Smart metering technology allows for the variable pricing of space-based overall parking demand, real-time information of parking supply, and market price.
B	Dynamic Transit Operations	Adapt to pre-defined route deviations based on passenger needs and travel patterns; promote alternate modes of transportation to avoid congestion.
D, I	EV Charging	EV charging stations in public and private space; develop apps to check status and easily locate available charging stations.

Table 3. *Cont.*

Code	Corresponding SC Strategies	Description
B, D, I	EV Initiatives	Cultivate an electric vehicle community and encourage the adoption of electric and hybrid vehicles; partnership with car manufacturers to promote shared electric fleet.
A, C	Emergency Response	Emergency preemption systems will override traffic signals in emergency situations; Emergency Communications and Evacuation can provide travelers/evacuees with passable routes and current traffic and road conditions during emergent situations.
C	Enhance Cargo Transportation Efficiency System	Expedited clearance programs and systems for freight; routing and scheduling algorithm based on real-time data.
A, D	Environmental Sensors and Analytics	Install sensors to collect environmental data such as air quality and wastewater, detect the chemical composition of the contaminants; integrate environmental data with traffic data.
F	Existing Fiber	Enhanced fiber optic networks to provide advanced network services.
A, B	FMLM Connections or Subsidies	Lyft/Uber subsidies for the FMLM connections in areas where bus lines do not have enough ridership.
G	Forward Collision Warning	Forward collision warning to drivers and pedestrians.
A	Fusing Transportation Data with Non-Transportation Data	Fusion of multiple data streams for compilation and analysis.
C	Integrated Corridor Management	Develop an ITS to accommodate different smart technologies such as EV, semi-autonomous auto, AV, transit, bike, pedestrian dynamics.
G	Intersection Movement Assist	Warn the driver when it is not safe to enter an intersection due to high collision probability.
G	Lanes (Bus, bike)	Exclusive bus/bike lanes
E	Mesh Network	Employ a mesh network for easier and faster public access to internet.
B	Micro-transit Service	Sharing mobility of conventional bikes, E-bikes and scooters, mobility-on-demand services for the first/last mile transit.
A, B, E	Mobility Marketplace	A digital platform integrates multimodal mobility services and allows users to access the platform of mobility services customized in real time to the traveler's needs and characteristics.
A, B	Multimodal Hubs/Trip Planning/App	Provide real-time traffic information and route analysis of seamless transfer between modes, including public transit, bike share, and e-scooters.
C	Off-Peak Delivery	Off-peak delivery
A, F	Open Data	Easily-accessible, open-source data operating and visualization platforms to citizens, businesses, and developers of applications.
H	Parking Management and Information	Parking sensors to generate data parking infrastructure usage and identify available parking spots to reducing time spent looking for parking in congested areas.
F	Payment Alternatives	Payment methods for unbanked.
G	Pedestrian-Oriented Development/Design	Pedestrian-oriented development/design.
E	Pothole and Roadway Condition Data	Road sensors to alert when roads are damaged and in need of repair.
A	Probe Data Collection	Acquire private sector data for operations (e.g., real-time alerts, performance monitoring, etc.).

Table 3. *Cont.*

Code	Corresponding SC Strategies	Description
B	Retrofitting Bus Shelters	Retrofitting bus shelters with rider-friendly interface that interconnects user data with safety, transit, energy, and environment.
B	Ridesharing Options	Ridesharing options.
E	Transit Service Needs for Underserved Populations	Smartphone apps for people with disabilities, paratransit services to elderly, disabled and low-income citizens to meet their medical, educational, employment and life sustaining need, etc.
I	Smart Grid Initiative	Smart Grid platform to optimize energy flexibility and efficiency.
B	Smart Growth Initiatives	Smart growth initiatives.
A, D	Smart Street Lights	Smart street lights.
I	Solar Panels	Installation of solar panels.
F	Standards and Architecture	Standards and architecture for data structure and network protocols.
A, B, C, E	Traffic Analytics and Management	Collect real-time data to provide information on the performance of the transportation system.
A	Traffic Operations Center	Traffic control center can receive, analyze, and transmit information from multiple platforms on traffic congestion and allow for optimization and redirection of traffic flow.
A, B	Transit/Traveler Information	Provide real-time transit schedules and locations of transit vehicles, and alternative routes and modes.
C	Truck Routing/Traveler Information	Dynamic freight trip planning service/dynamic truck restrictions.
A, C	V2I/V2V Equipment	Use equipment for a wireless exchange of data between vehicles and/or roadway infrastructure.
C, G	Warning Facilities	Curve speed warning, highway–rail intersection warning, work zone alerts, etc.
E	Wi-Fi	Wi-Fi installation.

Note: code refers to the Category Code in Table 2; explanations of acronyms and abbreviations can be found in Abbreviations.

Figure 5b is used to highlight the frequencies of the different SC strategies for the nine major challenges. For example, the strategy "EV charging (n = 63)" for the challenge category (D), as shown in Figure 5a, has been proposed 63 times among all proposals to overcome the challenge (D) *aged and insufficient infrastructure*. It can also be found that some challenges could be coped with via a wide range of strategies, such as the challenge (A) *limited data and tools for decision-making* and the challenge (B) *lack of travel options*, while other challenges have limited options for solutions, such as (I) *poor air quality and unbalanced energy use* and (H) *lack of parking space and information*.

Furthermore, Figure 5b shows the most mentioned SC strategies under each challenge category. For example, the strategy "Traffic analytics and management (n = 95)" is the most mentioned strategy to cope with (A) *limited data and tools for decision-making*. The strategies "Transit/Traveler Information (n = 40)", "Adaptive signal system (n = 44)", and "EV charging (n = 63)" are frequently mentioned to tackle the challenges of (B) *lack of travel options*, (C) *delays and congestion*, and (D) *aged insufficient infrastructure,* respectively. The top five most mentioned SC strategies are "Traffic analytics and management (n = 95)", "EV charging (n = 63)", "Parking management and information (n = 57)", "Adaptive signal system (n = 44)" and "Transit/Traveler Information (n = 40)".

5. Discussion

The framework we developed allowed us to evaluate SC strategies proposed by U.S. mid-size cities. Not surprisingly, the majority of SC strategies focused on enhancing *Efficiency* and *Mobility* among all the standards in the framework, because NOFO specifically requires applicant cities to consider approaches to allow people to move faster with more travel options. In addition, these two aspects are also relatively easier to achieve than others (i.e., *Opportunity*, *Safety*, and *Equity*). Improving *Mobility* and *Efficiency* could be fulfilled as a short-term interest through technological innovations, such as the deployment of autonomous and connected vehicles. The achievement of *Equity* and the provision of participatory opportunities often require more long-term social and economic investments, such as citizen involvement through negotiation and active partnerships with private sectors. It further emphasizes the interdisciplinarity of SC development, which entails collaborative efforts and integrated approaches [36] across specialists from diverse disciplines [24,77] in SC planning.

Our analysis identified a broad spectrum of available SC strategies that future planners can refer to when designing an SC. These SC strategies could be sector-based (e.g., partnerships with academic, or commercial sectors), technology area-based (e.g., shared electric connected automated shuttles), and priority-based (e.g., smart freight signal priority system). Although they were proposed in 2015, these SC strategies continue to be valuable in directing the development of current SC plans, given that the SCC is the most recent large-scale SC competition in the U.S. and no additional or comparable competitions have been launched since then. The SCC, including the proposed SC strategies, remains the most recent, reliable and accessible data source of information with the greatest academic potential for examining SC development.

In synthesizing both SC strategies and challenges, it is evident that some SC strategies are capable of addressing multiple issues simultaneously. As an example, EVs have been extensively recommended as an option for improving air quality and uneven energy consumption, perhaps minimizing congestion or delays, and providing another environmentally friendly mode of transportation. The implementation of EVs, however, necessitates the installation of charging stations, the modification of existing road conditions, and private sector assistance, all of which provide an opportunity to upgrade aging and inadequate infrastructure. In the meantime, planners must ensure that various SC strategies can be executed in a balanced, synergistic, and effective manner [15]. This, from another perspective, reflects that this synthesis is just the first step toward a comprehensive understanding of SC strategy and SC development.

We also discovered that an increasing number of applicant cities are focusing more on the utilization of data in cities. The importance of data, particularly real-time and big data, in urban transportation systems, municipal administration, and surveillance is becoming more prominent in the majority of applicant smart cities. This is further supported by the fact that over 26.2% of SC strategies were presented to address the requirement for greater data to enhance decision-making processes (Figure 5a). Unsurprisingly, this is consistent with the results of prior research [77,78]. Urban analytics and urban big data [79] can be viewed as the core of the “datafication” and “dataveillance” concepts that are central to such SC initiatives [80]. This also raises challenges of data access, ownership, and privacy. Since individuals are generating tremendous volumes of data in diverse formats proactively or passively every day, it is critical to think about how to establish public trust between data providers and owners. Which governmental agencies, or public sectors, should own or access citizen-generated data? What policies should be implemented to protect privacy and prevent data misuse or illegal use?

Our analysis suggests that *Equity*, as one critical and novel standard in the proposed framework, needs more attention from practitioners and planners. It is encouraging to find that seven finalists devote significantly more attention to increasing inclusiveness among their proposals than the other applicant cities. Compared with other standards (e.g., *Mobility* and *Efficiency*), the amount of SC strategies concerning *Equity* is falling behind. This indicates that local authorities did not consider inclusion as the highest priority throughout the SC development. This is consistent with the finding from Wang, et al. [2] that insufficient attention has been given to underrepresented populations when developing SC initiatives. Ultimately, smart cities must meet the demands of both active, fully abled individuals and marginalized populations [15]. We therefore expect that future urban planners and scholars will prioritize the needs of disadvantaged populations, and use inclusiveness as a fundamental criterion in evaluating SC proposals and creating inclusive smart cities.

It is also interesting to note that Columbus (OH), as the final winner, submitted an unbalanced proposal compared with other applicant cities, because it has a low Shannon entropy index. Nonetheless, more attention was given to addressing inclusiveness in Columbus's SC proposal, with a 0.19 component score for the *Equity* standard (ranked as 7th out of 78 applicant cities). Since the selection criteria are not public, it remains unclear whether addressing equity in the proposed SC strategies played a significant role in SCC's selection, which is similar to the findings of Ref. [2].

We suggest future research take a deeper look into whether and to what extent SC strategies have been implemented when such data are available, since examining the implementation of strategies is out of the scope of this study. The final winner, Columbus (OH), created a website (https://smart.columbus.gov/projects#projects-title (accessed on 9 January 2023)) providing information on the progress of 18 follow-up projects. A few projects are either fully executed or currently under construction, for instance, electric vehicle charging infrastructure, multimodal trip planning applications, and self-driving shuttles. It is, however, not easy to track the status of all proposed projects or strategies from Columbus and other applicant cities. In addition, the execution of certain strategies involves long-term investments and it may be years before data are available.

6. Conclusions

This paper proposed a framework to evaluate 1589 SC strategies developed by 78 applicant cities using the first-round documentation from the U.S. DOT 2015 Smart City Challenge. We synthesized SC strategies and linked them to related SC challenges, aiming to develop a protocol for evaluating and understanding SC strategies from a practical perspective. By summing up an SC strategy table, our work can directly assist planners and governments in the U.S. to deal with further research and development regarding smart cities.

Our findings are beneficial for policymakers and planners to formulate balanced and inclusive SC development plans with diverse SC strategies. First, the framework can be utilized in future research to evaluate SC strategies, plans, or overall development. Our framework indeed emphasizes *Equity* and *Opportunity*, which have been rarely considered by previous studies. This study also found that insufficient attention has been paid to addressing *Equity*. Therefore, adding *Equity* into the framework lends support to the call for recognizing inclusiveness raised in earlier research [2,44].

Second, the collaboration between the public and private sectors, as well as between government and commercial models, must be leveraged in the development of smart cities in order to increase public participation opportunities between residents and the government [24]. Most applicant cities give insufficient attention to providing public participatory opportunities when developing SC strategies, while the private sector has a substantial role in contributing high-level expertise and extensive financial resources. Innovative schemes of collaboration and funding with the participation of the public and private sectors should be rethought and cultivated.

Third, it is easy to see a growing awareness of the collection of urban big data (e.g., traffic data, transit data, or probe data) [79] and the applying of urban analytics during smart cities development in the U.S. Almost all SC proposals mentioned data infrastructure and analytic platforms as the basis of their smart transportation system. As concluded by Kandt and Batty [77], integrating various forms of urban data and analyses will be an essential step in promising SC initiatives in urban policy and planning. More importantly, planners should make adequate considerations regarding what data to collect and how to make good use of these data to address citizens' needs via analyses.

Last, this study built a many-to-many relationship between challenges and strategies. While there may be many SC strategies responding to an SC challenge, planners should ensure a proper selection of SC strategies to efficiently solve challenges through a thorough examination of the on-the-ground situation.

This study has some limitations. First, due to the SCC requirements, the applicant cities only focused on developing an intelligent and smart transportation system, thus making our synthesis and evaluations limited to the transportation aspects. We expect future studies to show a comprehensive understanding of SC development by examining other components, such as governance, smart health, and smart agriculture/farming. Second, it is possible that certain SC strategies were not sufficiently described to tackle a particular challenge, or that city planners were aware of some challenges but not fully prepared to propose any solutions in the documentation yet. Third, the 30-page proposal limit in the first round may also lead to insufficient space to explain applicant cities' plans for building smart cities. Future research is encouraged to collect SC proposals and plans, as comprehensively as possible, from a broader spectrum of U.S. cities. Last, it remains unclear how many SC strategies have been implemented. Since the SCC was announced seven years ago and new technologies and challenges have emerged, it is important to perform follow-up studies to assess how far those strategies or initiatives have progressed, and whether any new SC strategies have become available.

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Abbreviations

A list of acronyms and abbreviations:

AV	Autonomous Vehicle
API	Application Programming Interface
CCTV	Closed-Circuit Television
CV	Connected Vehicle
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
EV	Electric Vehicle
FMLM	First Mile Last Mile
GPS	Global Positioning System
ICT	Information and Communications Technology
ITS	Intelligent Transportation System
NOFO	Notice of Funding Opportunities
SC	Smart City
SCC	Smart City Challenge
SDK	Software Development Kit
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

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