A NOVEL MATURITY-BASED ASSESSMENT MODEL FOR SMART CITIES

by

Alaeldin Suliman

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Supervisors:        Jeff Rankin, PhD, PEng, Department of Civil Engineering
                   Anna Robak, PhD, PEng, WSP Canada

Examining Board:    Eric Hildebrand, PhD, PEng, Department of Civil Engineering, Chair
                   Lloyd Waugh, PhD, PEng, Department of Civil Engineering
                   Trevor Hanson, PhD, PEng, Department of Civil Engineering
                   Yuri Yevdokimov, PhD, Department of Economics

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Dean of Graduate Studies

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ABSTRACT

As a response to the challenges of population and urban growth, the concept of smart city/community (SC) is introduced as a strategic solution to the traditional city-related problems to achieve better services/life quality. However, the SC as an ecosystem is an evolving concept; hence, there is no universally-shared definition or assessment tool. SC assessment models broadly fall into two categories: performance-based and maturity-based models. Most of the available assessment models are based on performance indicators. However, unlike maturity-based models, performance indicators face challenges due to the complexity and evolving nature of SCs. Therefore, this research addresses the problems of a universally-accepted definition of SCs and assessment framework by (1) identifying the key smartness dimensions of a city, (2) building a corresponding novel smartness concept, and (3) developing a full maturity-based assessment model that overcomes the limitations of the performance-based models. The research contribution includes the identification of three key dimensions for SCs, which are Connectivity (C), Sustainability (S), and Resiliency (R); and a corresponding maturity-based assessment model (MM) for SCs referred to as CSR-MM. The applicability of CSR-MM was demonstrated through (1) examining its conformance to the MM design principles, and (2) demonstrating its practically via (a) a sub-domain case study (Fredericton Public Transit, NB) and (b) an outcome comparison against an international assessment tool (ISO37120:2018). The outcome of this study is an SC assessment model that is intended to help municipalities to identify maturity gaps, set prioritized goals, and focus on continuously improving citizens’ well-being.
DEDICATION

IN MEMORY OF MY MOTHER AND FATHER

TO MY WIFE

WITH LOVE AND ETERNAL APPRECIATION
ACKNOWLEDGEMENTS

I would like to take this opportunity to extend sincere thanks to the examining committee and those people who made this work achievable.

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Other thanks are given to thank the manager of the Transits and Parking at the City of Fredericton, Mrs. Meredith Gilbert, for her valuable participation in this research. I also thank fellow graduate students at the Department of Civil Engineering. I am truly grateful to my family members back home for their support and encouragement from thousands of miles away.

Finally, I would like to thank my lovely wife, H. Elammari, for her unconditional love, support, patience, understanding, and taking care of our children. Your spiritual support is the source of my energy ever!
Table of Contents

ABSTRACT ....................................................................................................................... ii
DEDICATION .................................................................................................................. iii
ACKNOWLEDGEMENTS ............................................................................................... iv
Table of Contents .......................................................................................................... v
List of Tables .................................................................................................................. vii
List of Figures ................................................................................................................ ix
List of Symbols, Nomenclature or Abbreviations ........................................................... x

1. Introduction .............................................................................................................. 1

2. Research Mission .................................................................................................... 5
   2.1 Research Goal ...................................................................................................... 5
   2.2 Research Questions ............................................................................................. 5
   2.3 Research Objectives ............................................................................................ 6
   2.4 Research Scope and Limitations ......................................................................... 7
   2.5 Research Methodology ........................................................................................ 8

3. Literature Review ................................................................................................... 9
   3.1 Smart City Definitions and Key Dimensions ....................................................... 9
   3.2 Smart City Models and Key Domains .................................................................. 14
   3.3 Smart City Assessment Frameworks .................................................................... 16
      3.3.1 Performance-based SC Assessment Models ................................................. 16
      3.3.2 Maturity-based SC Assessment Models ....................................................... 21
   3.4 Review Conclusions and Identified Gaps ........................................................... 23

4. The SC Model and Assessment Framework Development ....................................... 26
4.1 The SC Key Dimensions and Smartness Concept .................................................. 26
4.2 The CSR Maturity-based Assessment Framework for SCs .................................... 30
  4.2.1 SC domains ........................................................................................................ 30
  4.2.2 CSR maturity-based scale system for SC .......................................................... 32
  4.2.3 SC maturity-based assessment framework .......................................................... 33
4.3 CSR-MM City Level Calculation: A Hypothetical Example .................................. 38
5. CSR Maturity Model Applicability Demonstration ................................................. 41
  5.1 CSR-MM Conformance with the MM Design Principles ....................................... 42
  5.2 CSR-MM Practical Demonstration ........................................................................ 44
    5.2.1 CSR-MM case study .......................................................................................... 47
    5.2.2 CSR-MM comparison ....................................................................................... 49
  5.3 CSR-MM Applicability Demonstration: Summary and Discussion ...................... 53
6. Summary, Conclusions, Contributions, and Recommendations .......................... 59
  6.1 Work Summary ....................................................................................................... 59
  6.2 Study Conclusions ................................................................................................. 61
  6.3 Research Contributions ......................................................................................... 63
  6.4 Recommendations and Future Work ..................................................................... 64
References ..................................................................................................................... 67
Appendix A: Applying Assessment Models on a Mobility Sub-domain ...................... 71
Appendix B: 90 minute/Interview with the Manager of Transits and Parking at the City of
  Fredericton .................................................................................................................. 79
Curriculum Vitae
### List of Tables

Table 1: Different terms and definitions of smart city concept ................................................. 10

Table 2: The ISO definition and the identified key SC dimensions ........................................... 13

Table 3: The key domains of the SC as proposed by different researchers ......................... 14

Table 4: An aggregation of the proposed SC domains reviewed in the literature .............. 15

Table 5: Comparison of the reviewed SC maturity models ................................................... 22

Table 6: The literature conclusion and identified gaps ............................................................. 25

Table 7: The identified SC domains for the proposed assessment model and their ISO37120:2018 corresponding themes ................................................................. 31

Table 8: The waterfall model for the components of the identified SC dimensions .......... 34

Table 9: The levels of the developed maturity model (CSR-MM) for SC ......................... 35

Table 10: The questions corresponding to the CSR-MM maturity levels for SC .......... 36

Table 11: A hypothetical example for an SC maturity-based assessment ......................... 39

Table 12: CSR-MM conformance to the MM basic design principles ............................. 43

Table 13: The eight domains programs identified by Fredericton municipality .......... 45

Table 14: The case study (Fredericton public transit) assessment result breakdown ...... 49

Table 15: Examining the City of Fredericton mobility indicators against the ISO standards. ................................................................. 50

Table 16: The assessment paragraphs resulted from CSR-MM and ISO37120:2018 ...... 51

Table 17: Application of CSR-MM guiding questions on the Mobility sub-domain (public transportation) of the City of Fredericton ......................................................... 71
Table 18: Application of ISO37120:2018 Mobility indicators on the public transportation of the City of Fredericton

.......................................................... 75
List of Figures

Figure 1: The research methodology proposed for this study ........................................... 8

Figure 2: The key dimensions of city smartness (CSR) ......................................................... 27

Figure 3: The proposed three-dimensional city smartness concept and its components .. 29

Figure 4: The proposed matrix form to re-arrange the smartness indicator and identify the
gaps based on the selected definition. “D” stands for dimension, “Dmn” stands
for Domain, and “I” for indicator. .................................................................................... 30

Figure 5: The proposed scale to the city smartness CSR maturity model (CSR-MM)..... 32

Figure 6: The proposed maturity model of smart cities/communities. ......................... 37

Figure 7: The SC broad domains and the sub-domains of the selected mobility domain as
defined by the pilot city municipality............................................................................ 48
List of Symbols, Nomenclature or Abbreviations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC</td>
<td>Smart City/Community</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>C</td>
<td>Connectivity</td>
</tr>
<tr>
<td>S</td>
<td>Sustainability</td>
</tr>
<tr>
<td>R</td>
<td>Resiliency</td>
</tr>
<tr>
<td>MM</td>
<td>Maturity Model</td>
</tr>
<tr>
<td>CSR-MM</td>
<td>Connectivity, Sustainability, and Resiliency Maturity Model</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardisation.</td>
</tr>
<tr>
<td>CI</td>
<td>Coverage Index</td>
</tr>
</tbody>
</table>
1. Introduction

The world’s population is expected to reach nearly 10 billion people by 2050 (United Nations, 2017). At that time, urban areas will be home to 66% of the world’s population (United Nations, 2014). As a result, urbanization and population growth rates will increase dramatically leading to expanding existing cities, as well as creating new ones. However, cities as urban centers will face challenges including, but not limited to, growth, resources, performance, competitiveness, and residents' livelihoods (Ben Letaifa, 2015).

Population and urbanization growth open significant opportunities in economic growth and human resources. However, many challenges will be created in the physical, technological, and social domains. Physical challenges will include, difficulty of waste management, scarcity of resources, degradation of the natural environment, pollution, health concerns, traffic congestion, and massive investment in infrastructure requirements. Most of the predicted physical problems could be mitigated by technological advancements such as the new wave of computing (Bibri & Krogstie, 2017). However, the population and urbanization increase create technological challenges such as the size explosion of the citizen and infrastructure data. An associated challenge to this size explosion is determining how these data should be used and navigated through the concerns and restrictions of sharing, privacy, and security (Lea, 2015). In addition to the physical and technological challenges, social and organizational challenges will be created by the increase in population. These challenges may include multiple and diverse stakeholders, competing objectives and values, high levels of interdependence, increased crime rates, potential cultural clashes, and social and political complexity (Chourabi et al., 2012).
Within the last two decades, the concept of the “smart city/community” (SC) has been introduced as a response to the current and upcoming urbanization and population growth challenges. It represents a strategic solution that promises to provide more modern cities and societies with better services and improved well-being for their inhabitants. This is an essential goal for any municipality around the globe. Hence, most municipalities will have high interest in pursuing initiatives that improve the well-being of their cities’ residents. The Canadian government, as a relevant example to this research, has recognized the importance of building smart communities. For evidence, the Canadian Federal Budget included $300 million to support the Smart Cities Challenge – 2018, to come up with creative ideas to improve the lives of cities’ residents through innovation and connected technology, as well as to overcome the city-related problems that the traditional approaches have failed to solve (Canada, 2017).

The target of being "smart" in the context of cities/municipalities encompasses a broad set of resources, including information and communication technological (ICT) infrastructure and beyond, to the built and natural infrastructure. A critical component of this target is an assessment framework that identifies the municipality's strategic and technological roadmap towards improved city smartness and, consequently, quality of life.

Although there is a growing consensus worldwide around the need for SCs, there is no universally-accepted SC definition despite many attempts by various research communities to develop a clear understanding of SCs (Bibri & Krogstie, 2017; Neirotti, Marco, Cagliano, Mangano, & Scorrano, 2014). This is because the SC concept as an ecosystem is an evolving concept. Additionally, each municipality worldwide has its own unique
characteristics, goals, problems, challenges, and opportunities. Therefore, to accommodate this complexity, identifying the broad trends or key dimensions of the SC concept is more important than the wording of a specific definition.

Assessing the smartness of cities is an essential component of any municipal transformation project or initiative. This is because regular assessments help city leaders identify gaps and set goals towards improving inhabitants’ quality of life. However, all of the SC assessment models available up to date were developed based on unique/specific SC definitions that control the design of the models and their areas of assessment. Thus, an SC definition and its corresponding assessment model should be adopted or developed specifically –based on broad dimensions– for each city in a way that accommodates the city’s vision. The adopted definition and its corresponding assessment framework should reflect the key broad areas/dimensions of smartness.

Therefore, this research attempts to address the lack of an adaptable universally-accepted assessment approach to smart cities by identifying the key broad smartness dimensions and developing a corresponding assessment framework that accommodates the SCs’ complexity. The assessment model will enable the achieving of enhanced inhabitant well-being by efficiently identifying key areas for improvement, effectively addressing challenges, easily constructing internal benchmarks and making comparisons to others, and consistently monitoring and controlling progress towards the goal of creating sustainable, intelligently connected, and resilient communities. Thus, the majority of the research effort is directed towards the model development since it is the main deliverable of this study.
The research is important to the municipality leaders, management engineers, and policy-makers who are involved in the management and development of the municipal public systems and civil infrastructures of smart cities. By complementing an engineering technical perspective, an engineering management perspective allows better investment decisions about the civilian service/life quality through periodical assessment/evaluation of public municipal infrastructure to identify maturity gaps, set prioritized goals, and focus on continuously improving citizens’ well-being.
2. Research Mission

2.1 Research Goal

As a response to the traditional population/urbanization growth challenges of cities and their negative effects on the quality of life and sustainability, this research is initiated to develop an assessment framework for smart cities, considering existing design principles, to help municipality leaders, policy makers, and management engineers to identify gaps in smartness maturity and monitor transformation progress towards smarter cities. By identifying gaps, better investment decisions are allowed.

2.2 Research Questions

As indicated in the previous section, the identified problems, due to the complexity and evolving nature of SCs, are the lack of a universally-accepted SC definition and the lack of a universally-shared SC assessment framework. Hence, in this regard, four research questions have been developed to guide the research process for this study towards the defined goal. These questions are as follows:

1. What are the key broad dimensions of smart cities that are covered in the SC definitions and terms available in the literature and what is the corresponding smartness concept?

2. What are the key broad SC domains that are proposed to be tested in the available literature?

3. What is the most suitable assessment scaling type, performance-based or maturity-based, to be adopted for SCs?
4. What is the corresponding smart city assessment framework/model (SC dimensions, SC domains, SC scaling system, and assessment measures/questions) that needs to be developed to cover the identified key smartness dimensions?

2.3 Research Objectives

This research comprised seven objectives. These objectives are as follows:

1. To identify the key dimensions for smart cities by reviewing representative previous examples in the literature and identifying their critical definition components (or dimensions).

2. To develop a smartness concept in accordance with the identified key smartness dimensions of cities.

3. To develop a smart city model by reviewing representative previous attempts in the literature and identifying their domains and components that are relevant to the adopted SC key dimensions or definition.

4. To develop an assessment scaling system for SC relevant to the identified SC dimensions.

5. To develop SC assessment measures or guiding questions for the identified SC dimensions and domains.

6. To select a pilot municipality sub-domain, as a case study, based on the availability and accessibility of the information resources and the defined research scope of work, to demonstrate the applicability of the developed assessment model.

7. To demonstrate the applicability of the developed assessment model by ensuring its design soundness and demonstrating its practicality through the case study.
The pilot municipality selected is a medium-sized Canadian city since most of the Canadian population lives in this type of city. Additionally, the city information required for assessment and model applicability demonstration is accessible to the researchers.

2.4 Research Scope and Limitations

The scope of this research study includes identifying the key smartness dimensions and city domains, selecting the most suitable type of SC assessment approaches, and developing accordingly an SC assessment model. The scope of work also includes a demonstration of applicability by comparing the model with the relevant model design principles and demonstrating its practicality by applying it to a sub-domain case study (the mobility of the City of Fredericton). The demonstration also includes a comparison of the assessment result against an international SC assessment tool.

The main limitation in this study is the validation of the assessment model. A robust validation of the developed model should include its application to multiple case studies where each represents a full city. In each case study, the evaluation of all the city domains and sub-domains in at least two different periods, at least one year apart, would be included. However, this study does not include such a rigorous validation as it is beyond the research scope and the limitation in the timeframe and funding. Additionally, such full validation includes the challenges associated with finding the required information and the engagement of a very broad range of personnel within a variety of management domains for a given municipality.
2.5 Research Methodology

After identifying the research questions and objectives, the research methodology to be followed in this research is presented graphically in Figure 1.
3. Literature Review

The literature about smart cities/communities (SC) was examined from several different perspectives. These perspectives include research conducted on (1) SC definitions and key dimensions, (2) SC models and key domains, and (3) SC assessment frameworks including the research projects aiming at developing both performance-based and maturity-based assessment frameworks.

3.1 Smart City Definitions and Key Dimensions

Cities are complex systems that are considered as systems of systems (Arroub, Zahi, Sabir, & Sadik, 2016). The rapid urban growth that brings traffic congestion, pollution, and increasing social inequality risks degrading economic, demographic, social, and environmental dimensions. These changes could surpass municipalities’ abilities to provide adequate services for their citizens (Ramaprasad, Sánchez-Ortiz, & Syn, 2017). The concept of Smart City (SC) as a means to enhance the quality of citizens’ life emerged in the early 1990s and has been gaining increasing importance globally (Neirotti et al., 2014). However, according to Gabrys (2014), the roots of the concept dated back to the 1960s under what is called the “Cyber-netically Planned Cities,” and in urban development plans, it has figured in proposals for networked cities since the 1980s (Bibri & Krogstie, 2017).

Despite many attempts by various research communities to develop a clear understanding of smart cities, a universally-shared definition has not arrived yet (Bibri & Krogstie, 2017; Neirotti et al., 2014). As a result, many terms have emerged to describe the same concept from different perspectives. Table 1 provides many representative examples
of terms and their corresponding definitions of the perceived concept of the future city as modified from the comprehensive reviews of Cocchia (2014), Chourabi et al. (2012), and others including the definitions reviewed by the ISO preliminary report on SC (ISO/IEC, 2015). The definitions are arranged in this table chronologically based on the year of the primary documentation (publication) as well as categorized based on the definition’s key aspects.

Table 1: Different terms and definitions of smart city concept

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Source</th>
<th>Definition’s Key Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(a) TECHNOLOGY-CENTERED DEFINITIONS:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual City</td>
<td>Virtual City concentrates on digital representations and manifestations of cities.</td>
<td>Schuler, D.</td>
<td>City digital representation (ICT/C)</td>
</tr>
<tr>
<td>Digital City</td>
<td>The digital city is a comprehensive, web-based representation, or reproduction, of several aspects or functions of a specific real city, open to non-experts. The digital city has several dimensions: social, cultural, political, ideological, and also theoretical.</td>
<td>Couclelis, H.</td>
<td>City digital representation (ICT/C)</td>
</tr>
<tr>
<td>Smart City</td>
<td>The use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient.</td>
<td>Washburn et al.</td>
<td>(ICT/C)</td>
</tr>
<tr>
<td>Ubiquitous City</td>
<td>Ubiquitous city (U-City) is a further extension of digital city concept. This definition evolved to the ubiquitous city: a city or region with ubiquitous information technology.</td>
<td>Anthopoulos and Fitsilis (2010)</td>
<td>(ICT/C)</td>
</tr>
<tr>
<td>Information City</td>
<td>Digital environments collecting official and unofficial information from local communities and delivering it to the public via web portals are called information cities.</td>
<td>Anthopoulos and Fitsilis (2010)</td>
<td>(ICT/C)</td>
</tr>
<tr>
<td>Smart City</td>
<td>A city combining ICT and Web 2.0 technology with other organizational, design and planning efforts to de-materialize and speed up bureaucratic processes and help to identify, innovative solutions to city management complexity, in order to improve sustainability and livability.</td>
<td>Toppeta (2010)</td>
<td>(ICT/C)</td>
</tr>
<tr>
<td><strong>(b) CITIZEN-CENTERED DEFINITIONS:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge City</td>
<td>A Knowledge City is a city that aims at a knowledge-based development, by encouraging the continuous creation, sharing, evaluation, renewal, and update of knowledge. This can be achieved through the continuous interaction between</td>
<td>Ergazakis et al. (2004)</td>
<td>Citizen knowledge via interaction</td>
</tr>
<tr>
<td><strong>Intelligent City</strong></td>
<td>Intelligently cities are territories with high capability for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management</td>
<td>Komninos, N. (2006)</td>
<td>Citizens and institutions creativity and learning (ICT/C+S)</td>
</tr>
</tbody>
</table>

### (e) SUSTAINABILITY AND FUTURE RELATED DEFINITIONS:

| **Smart City** | A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens | Giffinger et al., (2007) | Forward looking (ICT/C+R.) |
| **Sustainable City** | Sustainable city uses technology to reduce CO2 emissions, to produce efficient energy, to improve the buildings’ efficiency. Its main aim is to become a green city | Batagan (2011) | (S) |
| **Smart Sustainable City** | A smart sustainable city is 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. | Kondepudi et al. (2014) | (ICT/C+S) |
| **Smart City (updated)** | A ‘Smart City’ is one that...... dramatically increases the pace at which it improves its social economic and environmental (sustainability) outcomes, responding to challenges such as climate change, rapid population growth, and political and economic instability ...... by fundamentally improving how it engages society, how it applies collaborative leadership methods, how it works across disciplines and city systems, and how it uses data, information, and modern technologies......in order to provide better services and quality of life to those in and involved with the city (residents, businesses, visitors), now and for the foreseeable future, without unfair disadvantage of others or degradation of the natural environment | ISO/IEC (2015) | (ICT/C + S + R) |
| **Resilient City** | A Resilient City is one that has developed capacities to help absorb future shocks (e.g., earthquakes, floods, disease outbreaks, and terrorist attacks) and stresses to its social, economic, and technical systems and infrastructures so as to still be able to maintain essentially the same functions, structures, systems, and identity. | 100 Resilient City, n.d. | (R) |

* **ICT:** Information and Communication Technologies, **C:** Connectivity, **S:** Sustainability, & **R:** Resiliency
As indicated by several sources, including the Department for Business Innovation and Skills in United Kingdom (2013), there is no absolute definition of a smart city, no end point, but rather a process, or series of steps, by which cities become more “liveable” and resilient and, hence, able to respond quicker to new challenges. This fact is exhibited through the diversity of the SC definitions presented in Table 1. The table shows that ICT plays a central role in most SC definitions. The term ICT implies also the meaning of Intelligent Connectivity Technologies. Hence, it is simply referred to as Connectivity (C) in this research. The definitions provided in Table 1 were analysed by the author to identify the key dimensions/components in each definition. These identified dimensions (i.e., ICT/C, S, and R) are provided explicitly in the last column of Table 1.

Chronologically, as shown in Table 1, the smart city definitions and concepts focused – even until 2010 – on the use of information and communication technologies (ICT/C) to improve the life quality of the city inhabitants. Then, in 2006, the concept was expanded to include some aspects of sustainability (S) in the soft systems (i.e., population creativity) in addition to the ICT dimension. In 2007, the table shows the city dimensions of readiness and adaptation to the future changes by forward-looking (Resiliency; R) are included in the SC concept. Recently in 2015, all of these three dimensions (ICT/C, S, and R) were included in the SC definition adopted by the International Organization for Standardization (ISO). Therefore, it can be concluded that the concept of smart city is not static (i.e., evolving concept).
Therefore, it can be realized that the concept of quality of life through city smartness lies in the overlapping area among the use of information and communication technologies (ICT/C), the need of satisfying sustainability considerations (S), and the required resiliency (R)—flexibility and adaptability to accommodate and adapt to future changes and shocks including proactively securing certain future behaviours and developments. Hence, any definition of smartness to be adapted should include all of these three overlapping areas. The identification of these dimensions is one of the research contributions of this study that are defined to control the scope of the SC concept.

In conclusion, based on the SC definition review conducted, as presented in Table 1, the most recent comprehensive definition is the ISO37120 definition reported in ISO/IEC (2015). This definition touches all of the three identified SC concept dimensions. Hence, it is adopted for this research study. As presented in the last column of Table 1, Table 2 provides a detailed breakdown of this definition in relation to the identified key SC dimensions. This breakdown example explains the extraction process applied to all SC definitions of Table 1 (presented in the last column).

Table 2: The ISO definition and the identified key SC dimensions

<table>
<thead>
<tr>
<th>ISO definition ISO37120 (2014)</th>
<th>Identified dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ‘Smart City’ is one that dramatically increases the pace at which it improves its social, economic, and environmental (sustainability) outcomes, responding to challenges such as climate change, rapid population growth, and political and economic instability</td>
<td>Sustainability pillars</td>
</tr>
<tr>
<td>by fundamentally improving how it engages society, how it applies collaborative leadership methods, how it works across disciplines and city systems, and how it uses data, information, and modern technologies</td>
<td>Resiliency</td>
</tr>
<tr>
<td>in order to provide better services and quality of life to those in and involved with the city (residents, businesses, visitors), now and for the foreseeable future, without unfair disadvantage of others or degradation of the natural environment</td>
<td>Sustainability (Soft domains)</td>
</tr>
<tr>
<td></td>
<td>ICT</td>
</tr>
<tr>
<td></td>
<td>Sustainability (Hard domains)</td>
</tr>
</tbody>
</table>
3.2 Smart City Models and Key Domains

Many attempts at developing SC frameworks and models were reviewed in terms of the identified SC domains. Table 3 lists the key domains of the SC frameworks as proposed by 10 different research articles selected as representative models by Albino et al. (2015) and ISO standards (ISO37120 2014). This table provides an overview of the SC domains suggested explicitly by the authors of the articles reviewed in the literature.

Table 3: The key domains of the SC as proposed by different researchers

<table>
<thead>
<tr>
<th>Source</th>
<th>Key dimensions of a smart city</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mahizhnan (1999)</td>
<td>IT* education, IT* infrastructure, IT* economy, quality of life</td>
</tr>
<tr>
<td>Giffinger (2007)</td>
<td>Economy, mobility, environment, living, people, governance</td>
</tr>
<tr>
<td>Eger (2009)</td>
<td>Technology, economic, development job growth, increased quality of life, sustainable economic development</td>
</tr>
<tr>
<td>Thuzar (2011)</td>
<td>management of natural resources through participatory policies, convergence of economic, social, and environmental goals</td>
</tr>
<tr>
<td>Nam and Pardo (2011)</td>
<td>economic socio-political issues of the city</td>
</tr>
<tr>
<td></td>
<td>economic-technical-social issues of the environment</td>
</tr>
<tr>
<td></td>
<td>interconnection, instrumentation, integration, applications, innovations</td>
</tr>
<tr>
<td></td>
<td>economic, human (talent, innovation, creativity, education)</td>
</tr>
<tr>
<td>Barrionuevo et al. (2012)</td>
<td>Social (traditions, habits, religions, families)</td>
</tr>
<tr>
<td></td>
<td>environmental (energy policies, waste and water management, landscape)</td>
</tr>
<tr>
<td></td>
<td>institutional (civic engagement, administrative authority, elections)</td>
</tr>
<tr>
<td></td>
<td>human capital (e.g. skilled labor force)</td>
</tr>
<tr>
<td></td>
<td>infrastructural capital (e.g. high-tech communication facilities)</td>
</tr>
<tr>
<td></td>
<td>social capital (e.g. intense and open network linkages)</td>
</tr>
<tr>
<td></td>
<td>entrepreneurial capital (e.g. creative and risk-taking business activities)</td>
</tr>
<tr>
<td></td>
<td>management and organizations</td>
</tr>
<tr>
<td></td>
<td>technology, governance, policy context, people and communities</td>
</tr>
<tr>
<td></td>
<td>economy, built infrastructure, natural environment</td>
</tr>
<tr>
<td>ISO37120 (2014)</td>
<td>economy, education, energy, environment, recreation, safety shelter, solid waste, telecommunications and innovation, finance, fire and emergency response, governance, health, transportation, urban planning, wastewater, water, and sanitation.</td>
</tr>
<tr>
<td>ISO37120, (2018)</td>
<td>environment and climate change, energy, solid waste, telecommunication, urban planning, wastewater, water, education, health, housing, transportation, economy, finance, governance, population and social conditions, recreation, safety, sport and culture, urban/local agriculture and food security</td>
</tr>
</tbody>
</table>

* IT stands for Information Technology
In conclusion, Table 3 can be summarized as in Table 4 in order to identify the total number of domains proposed by different research attempts. As shown in Table 4, all the SC domains can be aggregated in 20 domains judgementally based on the domains’ names used and their inferred meanings. By further refinement, these domains can be aggregated further to come up with a broader and more generic SC model (SC domains).

Table 4: An aggregation of the proposed SC domains reviewed in the literature

<table>
<thead>
<tr>
<th>Domain</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT economy +economy + economic + economy + economy + economy + economy</td>
<td>11</td>
</tr>
<tr>
<td>development job growth +sustainable economic development</td>
<td></td>
</tr>
<tr>
<td>economic socio-political issues of the city</td>
<td></td>
</tr>
<tr>
<td>economic-technical-social issues of the environment + finance</td>
<td></td>
</tr>
<tr>
<td>entrepreneurial capital (e.g. creative and risk-taking business activities)</td>
<td></td>
</tr>
<tr>
<td>environment + management of natural resources through participatory policies</td>
<td>8</td>
</tr>
<tr>
<td>environmental (energy policies, waste and water management, landscape)</td>
<td></td>
</tr>
<tr>
<td>natural environment + energy + Environment + water and sanitation + environment and climate change</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Smart City Assessment Frameworks

As found in the literature, SC assessment frameworks can be classified broadly as performance-based and maturity-based assessment models/frameworks. Both of these assessment model types were reviewed separately as in the following subsections.

3.3.1 Performance-based SC Assessment Models

The vast majority of the SC assessment models were found to be based on performance. The literature review conducted included the models proposed by Giffinger (2007), Chourabi et al. (2012), Neirotti et al. (2014), and ISO37120 (2014). These assessment models are selected, among many others, to be reviewed here because they represent the most cited models.

Based on Giffinger et al. (2007), the study of the European Smart Cities Ranking introduced by Vienna University is the most widely quoted, used, and applied SC model in the literature. This model, which can be considered the first comprehensive attempt to develop an SC assessment framework, is based on six distinct dimensions, namely mobility, environment, living, people, economy, and governance. Each dimension comprises a set of factors that is decomposed into indicators that evaluate success under that dimension. The model has in total 74 indicators that have been developed to enable comparison of cities and to assess their development towards the needed direction. The model is limited in assessing the connectivity technologies that contribute towards the city smartness. For instance, it represents the connectivity dimension concisely in just the access to internet broadband. Furthermore, the method presents a number of limitations related to, for example, not being able to properly measure all the indicators in addition to
the fact that most of the indicators are correlated. Moreover, a significant number of
indicators (35%) were available only at the national level (De Santis, Fasano, Mignolli, &
Villa, 2014). Finally, the model lacks the ability to assess the smart city systems in terms
of resiliency and flexibility which represent the protection of the achieved well-being
levels.

Chourabi et al. (2012) introduced a study to develop the clusters (i.e., groups of factors
used in assessing city domains) of smart cities in order to envision SC initiatives. They
identified eight clusters of factors which include (1) management and organization, (2)
technology, (3) governance, (4) policy, (5) people and communities, (6) the economy, (7)
built infrastructure, and (8) the natural environment. The SC model introduced in this
attempt is conceptual. For instance, it does not go to the level of proposing metrics of each
cluster, as well as a referencing and scoring system. The framework created was just to
characterize how to envision a smart city and design initiatives, but not to assess progress
towards them. Additionally, the framework does not assess the resiliency dimension or the
protection of the achieved well-being levels of the smart city systems.

Neirotti et al. (2014) reviewed the current trends in SC initiatives. They introduced
an SC model that includes 22 sub-domains aggregated in hard and soft domains. The hard
domains refer to office and residential buildings, energy grids, natural resources, energy
and water management, waste management, environment, transport, mobility and logistics.
In these settings, an improvement in sustainability relies on the deployment of ICT systems,
along with the introduction of appropriate policy interventions and urban planning. By
contrast, soft domains include areas such as education, culture, policies that foster
entrepreneurship, innovation and social inclusion, as well as communication between local public administrations and the citizens (e-government). In these areas, ICT has a more limited role and is not necessarily aimed at processing and integrating real-time information.

The study assessed all 22 domains for 70 cities worldwide and determined a Coverage Index (CI) for each city. CI is defined as the ratio of domains covered by a city’s best practices to the total of the potential domains or sub-domains. A value of either 1 or 0 was assigned to each specific sub-domain depending on whether a city reports best practices in that specific context, or not. Then, CI value was computed by dividing the sum of the indices calculated at the level of an individual domain by the total number of sub-domains. This CI value represents an expression of the number of domains covered by the best practices of an SC. Although the study was comprehensive, the assigned CI values were not based on purely objective measures. For example, when there is no evidence that a city uses a best practice in a specific domain, the authors assign (with an attempt to avoid subjectivity) a score based on their judgement. The major finding of this study is the conclusion that there is no unique global definition and assessment methodology of SC and it is difficult to develop.

The most applied and used smart city model and assessment tool which is developed after Giffinger et al. (2007) is the ISO indicators for city services and quality of life city (ISO37120, 2014). This standard introduces a model consisting of 17 themes. These themes comprise in total almost 100 indicators classified into two classes: core and supporting indicators. The themes are economy, education, energy, environment,
recreation, safety shelter, solid waste, telecommunications and innovation, finance, fire and emergency response, governance, health, transportation, urban planning, wastewater, water, and sanitation. Although the collection of indicators of this well-known standard is comprehensive, they ignore several aspects including city systems’ resiliency against future shocks and changes, and only partially assess the ICT role in the city services. As an example, no indicators assess the role of smart healthcare services. These services may include providing all citizens with remote assistance to prevent and diagnose diseases and deliver the healthcare service. In addition to that, the standard recommends periodical implementation of the introduced core indicators to create a point of reference and assess the progress relative to that starting point. Hence, the framework does not have a scaling (benchmark-target) system for each schematic theme that helps in setting and identifying targets for the city managers. To overcome this limitation, the World Council on City Data (WCCD) developed five certification levels based on ISO 37120 (see www.dataforcities.org/) to provide incentive targets for the cities worldwide based on achieving certification levels. However, the standard used needs to be expanded around the role of ICT in most of the proposed themes as well as the domains’ forward-looking aspects.

In conclusion, all of the reviewed performance-based SC assessment models include scaling systems for ranking based on domains’ performance. Despite the benefits for city ranking, there are disadvantages, as outlined by Giffinger et al., (2007), including that (1) discussion focuses on final ranks and complex interrelations and causalities are unattended or neglected; (2) public attention is mainly focused on the final ranking without considering the methodological aspects behind the ratings; (3) the selective public
perception of results enforces a confirmation of existing stereotypes and clichés; (4) rankings strengthen competition between cities, which may have negative consequences like deregulation, structural and spatial problems, risk for socially acceptable city development, etc.; (5) rankings are excessively acclaimed by the “winners” and ignored by the “losers”; and (6) cities (primarily poor performing ones) oppose comparisons with others (“benchmarking”) in general. In addition to that, (7) rankings tend to follow a “generalistic” approach, as many financiers ask for clear results which can easily be communicated to the public and so most rankings aim at finding the “best” or “most attractive” city in general terms totally ignoring the fact that different activities need different conditions.

It is worth mentioning that, as indicated by Albano (2018), scale systems are categorized in four classes that range, in terms of the conveyed information, from very general to specific scale values. These classes are (1) nominal (descriptive names), (2) ordinal (ranking without meaningful intervals), (3) interval (meaningful intervals with relative benchmark), and (4) ratio (meaningful intervals with absolute benchmark) scaling systems. Due to the difficulty in identifying definitive SC’s maturity stages and performance benchmarks, the vast majority of the scaling systems proposed for assessing SCs in the literature are performance-based city ranking systems (ordinal class). However, these systems face many challenges and limitations related to coping with the complexity and evolving nature of the SCs when considered. On the other hand, maturity-based scaling systems (nominal class) are more adaptive/general to accommodate change and also more useful in identifying maturity gaps and setting goals.
3.3.2 Maturity-based SC Assessment Models

Unlike performance-based models, very few attempts were found in the literature regarding the maturity-based SC assessment models. The earliest maturity model introduced in the literature is the Capability and Maturity Model (CMM) released by the Software Engineering Industry (CMU/SEI, 2010). The CMM was developed as a framework, based on a collection of best practices from the concerned domain, to support the process of improvement of an organization from the standpoint of their quality and effectiveness. The driver for such development is the premise that “the quality of a system or product is highly influenced by the quality of the process used to develop and maintain it” (CMU/SEI, 2010). From then onwards, numerous maturity models have been developed in different areas including smart cities and communities.

In the reviewed literature, very few maturity models were found for SCs. Identified models include (a) IDC Smart City Maturity Model (IDC SCMM; Clarke, 2013), (b) Sustainability Outlook Smart City Maturity Model (SO SCMM; Sustainable Business Leadership Forum, 2014), and (c) Brazilian Smart City Maturity Model (Br-SCMM; Afonso, dos Santos Brito, do Nascimento, Garcia, & Álvaro, 2015). These models were analyzed and assessed by Torrinha and Machado (2017). In comparison to our attempt (1) none of them covers all of the three identified smartness dimensions, (2) there is no shared SC-domain model amongst them because each of them assesses city domains differently than the others, (3) they are not applicable for high maturity levels, (4) they are developed for certain regions (e.g., Brazil or India) and based on certain SC models, and (5) they are designed for assessing specifically the current status (as-is situation). Table 5 presents a
few differences among the reviewed SC maturity models, as modified from Torrinha and Machado (2017), as well as the weaknesses for each model as identified by the author. Hence, due to this heterogeneity in assessing SCs, a maturity model that is compatible with our SC concept perception, and the identified SC dimensions and domains needs to be proposed.

Table 5: Comparison of the reviewed SC maturity models

<table>
<thead>
<tr>
<th>Item</th>
<th>IDC SCMM 2013</th>
<th>SO SCMM 2014</th>
<th>Br-SCMM 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Corporation</td>
<td>India</td>
<td>Brazil</td>
</tr>
<tr>
<td>Purpose</td>
<td>Assessing the As-Is situation of the city.</td>
<td>Gauging preparedness of a city against a set of measures.</td>
<td>Measuring how smart a city can be. Measure and compare different levels a city can reach.</td>
</tr>
<tr>
<td>Scope</td>
<td>A framework defined for cities, for local governments.</td>
<td>Application of the model to key resource areas proposed by the Indian Government.</td>
<td>A model defined for the reality of Brazilian cities</td>
</tr>
<tr>
<td>Focus</td>
<td>Concerned with the governance process of the city and its improvement</td>
<td>Cities’ basic infrastructure and urban resilience</td>
<td>The city basic infrastructure and social conditions</td>
</tr>
<tr>
<td># Domains</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Maturity levels</td>
<td>Ad-Hoc; Opportunistic; Repeatable; Managed; Optimized</td>
<td>Access; Efficiency; Behavior; Systems; Focus</td>
<td>Simplified; Managed; Applied; Measured; Turned</td>
</tr>
<tr>
<td>Weakness</td>
<td>Limited number and coverage of domains. The identified three key SC dimensions were not covered. Concerned with the government process of SCs.</td>
<td>Focuses on cities’ basic infrastructure and social conditions. Hence, the identified three key SC dimensions are not covered. Designed for specific region and not applicable for the high maturity levels.</td>
<td>Focuses on cities’ basic infrastructure and urban resilience. Hence, the identified three key SC dimensions are not covered. Designed for specific region and not applicable for the high maturity levels.</td>
</tr>
</tbody>
</table>
In conclusion, considering the drawbacks of ranking systems, as well as the multidisciplinary, changing, and evolving natures of cities and societies, the nominal scaling systems are identified in this research study as the most suitable scaling system. When nominal scaling systems are based on levels of maturity, the assessment model has several advantages over the other scaling systems including, but not limited to (1) descriptive scaling levels, which are valid despite the future changes and evolutions of the city domains; (2) general measures which are valid despite advancement of the technologies in future times—hence, the indicators will not be considered as outdated; (3) benchmark-target systems—while an initial level of maturity sets a benchmark for the scaling system, the upper limit of maturity identifies a target for the city managers and policy-makers; (4) assessment result to direct the public discussions towards achieving maturity targets and filling maturity gaps rather than focusing on rank levels; (5) simplification of the identification of maturity gaps, which helps in quick prioritization by city managers; and (6) provision of clearer assessment results, which are preferred by financers.

3.4 Review Conclusions and Identified Gaps

As it was presented above, due to the complexity and the evolving nature of SC, a universally-accepted SC definition does not exist. Accordingly, a universally-shared SC assessment framework does not exist. This is because the assessment models are simply the reflection of the adopted SC definition. As a result, it was concluded in this study that SC definition should include the key smartness dimensions identified in this study regardless of the wording of the SC definition. In addition to that, the ISO smart city
definition was found the most recent comprehensive definition that touches all the identified key dimensions in this research.

An assessment framework is a critical part of any smart city transformation. An SC assessment framework encompasses SC domains, an SC scale, and smartness indicators or measures. A wide variety of names were found for SC domains. However, these names are more or less correlated and/or overlapped. Hence, these domains were aggregated into 20 domains that by closer look can be distilled into fewer broad key domains.

SC scale systems, including smartness indicators/measures, were found of two classes: performance-based and maturity-based SC assessment systems. Performance-based systems will face challenges and limitations when the complexity and the evolving nature of the SCs are considered. On the other hand, maturity-based scaling systems (nominal class) are more adaptive/general to accommodate change and also more useful in identifying maturity gaps and setting goals. However, all the reviewed maturity-based systems were found to have some limitations in addition to not covering the key smartness dimensions identified in this research.

To help the reader understand what was concluded from the reviewed literature and to highlight the identified gaps, Table 6 lists the smart city items essential in this research for developing the assessment framework for smart cities.
Table 6: The literature conclusion and identified gaps

<table>
<thead>
<tr>
<th>Smart city framework item</th>
<th>Concluded from the reviewed literature</th>
<th>Gap identified/Work required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>The smart city concept is evolving. Hence, no shared definition exists.</td>
<td>The key smartness dimensions should be identified from reviewing the existing definitions. These dimensions must be considered in any definition regardless its specific wordings.</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Most of the reviewed definitions emphasize the ICT role and ignore other dimensions. However, recent definitions have started to include the sustainability, future looking, and resiliency dimensions.</td>
<td>Only one definition was found to include the identified key smartness dimensions: ICT, sustainability, and resiliency. However, the corresponding assessment model was found to be based on performance measures. Hence, a maturity-based system needs to be developed since it was concluded to be more suitable for SCs.</td>
</tr>
<tr>
<td><strong>Domains/sub-domains</strong></td>
<td>Within the SC models reviewed, there were around 20 domains that are overlapping and partially correlated. Each model has its own SC domains that fit the selected SC definition.</td>
<td>The domains need to be aggregated in super domains and/or re-arranged in domains and sub-domains to fit and cover the three identified SC dimensions.</td>
</tr>
<tr>
<td><strong>Indicators</strong></td>
<td>Each model has its own set of indicators arranged based on the identified domains and sub-domains. Maturity-based indicators were found most of the time hard to implement.</td>
<td>Maturity-based measures need to be developed in a way that reflects the three identified key smartness dimensions. Additionally, these measures should be easy to implement.</td>
</tr>
<tr>
<td><strong>Measuring System</strong></td>
<td>Not enough details about the measured indicators were found explicitly in the literature. Most of the assessment frameworks are performance-based systems. Existing maturity-based systems either have limitations, are hard to implement, or do not cover the key smartness dimensions.</td>
<td>A nominal scaling (benchmark-target) system for SCs based on the maturity model needs to be developed to be easy to implement and cover all the identified key SC dimensions.</td>
</tr>
</tbody>
</table>
4. The SC Model and Assessment Framework Development

4.1 The SC Key Dimensions and Smartness Concept

This research study identifies three SC key dimensions. These dimensions are Connectivity (C), Sustainability (S), and Resiliency (R). These dimensions will be abbreviated in this study as “CSR”. As illustrated in Figure 2, the full smartness of a city/community lies on the overlapping area of these three dimensions. This figure presents a novel way of conceptualizing the smartness concept in the context of modern cities. One of the contributions of this research is to relate the three identified smart city dimensions (CSR) to the concept of smartness.

It is acknowledged that there are definitions that are accepted widely for each of the connectivity, sustainability, and resiliency terms. However, these definitions vary based on the discipline and the field of study. Hence, rather than adopting the perspective of one single discipline, in this research the smartness concept was developed starting from the basic linguistic definitions/meanings of these three terms with minimal adaption for the smart city context. For instance, “connectivity” implies the ability to connect and communicate, and represents the intelligence and digital connectivity technologies (a.k.a. ICT) that include data collection, processing, and information communication; “sustainability” implies the ability to maintain a certain status while growing, and represents the performance viability of the city systems under the restriction of minimized/zero negative impact on the environmental, social, and economical (i.e., the sustainability triple-bottom line) aspects. In contrast, “resiliency” implies the ability to withstand or recover from difficult conditions and represents for urban areas the capacity
of protecting the city systems in order to be functional properly in situations of future
difficulties, changes, shocks, and stresses. In other words, the well-being (quality of life)
of the inhabitants of smart cities is (1) enabled by the extensive use of modern ICT, (2)
sustained/maintained through viable (effective, efficient, and improving) performance of
all city systems, and (3) protected through preventive, adaptive, and proactive plans,
designs, or actions.

![Diagram of city smartness dimensions]

Figure 2: The key dimensions of city smartness (CSR)

It has been recognized that through planning for resiliency and sustainable development
it is necessary and possible to reduce existing current risks and prevent new ones. Hence,
the city smartness concept should include this aspect. In a recent initiative, there are seven
dimensions of urban resiliency (100 Resilient City, n.d.). These dimensions are as follows:

- **Reflective** – which means using past experience to inform future decisions;
- **Resourceful** – which means recognizing alternative ways to use resources;
- **Robust** – which means well-conceived, constructed, and managed systems;
- **Redundant** – which means spare capacity purposively created to accommodate
disruption;
- **Flexible** – which means willingness and ability to adopt alternative strategies in response to changing circumstances;
- **Inclusive** – which means prioritizing broad consultation to create a sense of
shared ownership in decision making;
- **Integrated** – which means bringing together a range of distinct systems and
institutions.
All of these seven resiliency dimensions identified in the 100 Resilient City initiative can be aggregated judgementally in three broad classes as follows:

1. **Preventive**: including Robust, Inclusive
2. **Adaptable**: including Flexible, Redundant, and Integrated
3. **Proactive**: including Reflective, Resourceful

In relation to the SC concept and the three identified key SC dimension mentioned above, **Figure 3** visualizes these dimensions as overlaid areas. The city full smartness concept resides on the overlapping area of these three dimensions. The description of each smartness dimension is as follows:

- **Intelligent Connectivity (C)**–The driver part of the smartness is the intensive use of the modern ICTs that enable modern and intelligent data collection, processing, and high connection and communication functionality among and within city systems.

- **Sustainability (S)**–The viability/progress part of the smartness is to maintain (effective and efficient, zero negative effects) performance and continuous improvement (evolution, positive effects) without compromising the needs of future generations. This should be with respect to triple bottom line considerations (i.e., environment, economy, and society).

- **Resiliency (R)**– The protection part of the smartness is to sustain/retain the achieved improvement and advancement levels of the quality of life against future shocks and changes. This requires systems with preventive, adaptive, and proactive functionalities.
The developed city’s smartness concept is presented in Figure 3. The figure illustrates each dimension of the three identified key dimensions as a triangle to represent its identified three pillars. While the ICT (or Connectivity) represents the intelligence and digital connectivity technologies that include digital data collection, data processing, and information communication; Sustainability represents the performance viability of the city systems under the restriction of minimized/zero negative impact on the environmental, social, and economic (the triple-bottom line) aspects. The viable performance is simply the effective, efficient, and improving performance. In contrast, urban resiliency represents the capacity to protect the city systems in order to function properly in situations of future difficulties, changes, shocks, and stresses. The protection of city systems includes preventing, adapting, and proacting plans or actions. Additionally, the figure shows that the expansion of the ICT technologies is restricted by the sustainability triangle and by the resiliency triangle. This means that the use of ICT should be, enabling technologies, to reach the objectives of sustainability and resiliency while not disrupting their achievement. In the same illustration, the outer border resiliency represents the fence of protection to the whole system, as indicated above.

Figure 3: The proposed three-dimensional city smartness concept and its components
4.2 The CSR Maturity-based Assessment Framework for SCs

The proposed assessment framework for evaluating smart communities comprises three components arranged in a matrix form. These components, as indicated in Figure 4, are (1) the SC maturity-based scaling model, (2) the SC domains model, and (3) the assessment indicators and measures. Figure 4 illustrates the proposed matrix assessment framework.

![Table 4: Smart Community (SC) domains](image)

Figure 4: The proposed matrix form to re-arrange the smartness indicator and identify the gaps based on the selected definition. “D” stands for dimension, “Dmn” stands for Domain, and “I” for indicator.

4.2.1 SC domains

As noted above, all the proposed SC domains to be assessed against a scaling system are found to be 20 domains as in Table 4. These domains are economy, mobility, environment, social (Equity and Social Inclusion), people, governance, quality of life, IT and built infrastructure, technology, interconnection, instrumentation, integration, applications, innovations, education, institutional, management and organizations, health, fire and emergency response, and urban planning.

By further aggregation, all of these proposed 20 domains can be refined, by a closer look as shown in Table 7, in eight broad domains that cover almost all of the SC domains in the literature. These SC broad domains are (1) Natural environment; (2) Built
infrastructure and ICT; (3) Services; (4) Mobility; (5) Economy and finance; (6) Governance, policy, and management; (7) People, living, and society; and (8) Quality of life. These domains are identified, as a component of an SC model, in order to be assessed against an SC maturity-based scaling system.

In order to provide further details to the eight identified SC domains and also to build consistency with other city domains around the globe, the 19 city themes proposed for SCs in the latest ISO standards (ISO37120, 2018) are mapped in Table 7 as well. This standard is selected because it represents a world-class and the most internationally accepted standard that is designed to be consistent across different cities worldwide.

Table 7: The identified SC domains for the proposed assessment model and their ISO37120:2018 corresponding themes

<table>
<thead>
<tr>
<th>Aggregated Domain</th>
<th>Names of SC domains proposed in various research studies</th>
<th>Corresponding ISO37120:2018 Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural environment</td>
<td>Environment</td>
<td>Environment and Climate Change, Energy, Water</td>
</tr>
<tr>
<td>Built infrastructure and ICT</td>
<td>IT and built infrastructure, technology, urban planning, interconnection, instrumentation, integration, applications</td>
<td>Solid waste, Telecommunication, urban planning, wastewater,</td>
</tr>
<tr>
<td>Services</td>
<td>Education, health, fire and emergency response</td>
<td>Education, Health, Housing</td>
</tr>
<tr>
<td>Mobility</td>
<td>Mobility, transportation</td>
<td>Transportation</td>
</tr>
<tr>
<td>Economy &amp; finance</td>
<td>Economy, finance</td>
<td>Economy, Finance</td>
</tr>
<tr>
<td>Governance, policy, &amp; management</td>
<td>Governance, institutional, administration management and organizations</td>
<td>Governance</td>
</tr>
<tr>
<td>People, living, and society</td>
<td>Social, people, Equity and Social Inclusion</td>
<td>Population and Social conditions, Recreation, Sport and Culture</td>
</tr>
<tr>
<td>Quality of life</td>
<td>Quality of life</td>
<td>Safety, Urban/local agriculture and food security</td>
</tr>
</tbody>
</table>
4.2.2 CSR maturity-based scale system for SC

The city smartness model, which includes a smartness scale based on the concept of maturity, is visualized in Figure 5. The figure conceptualizes that the well-being/quality of life of the inhabitants of SCs, as indicated by Smartness Maturity, is first enabled by the extensive use of modern ICT. That is why the ICT is located at the start of the scale. Then, the achieved well-being is sustainable through viable (effective, efficient, and improving) performance of all city systems based on the ICT enabling technologies. Finally, the resiliency considerations come at the end of the scale representing the protection of the viable city systems’ performance through preventive, adaptive, and proactive plans, designs, or actions. The measuring scale system, for scoring purposes, will be in the sequence of ICT (C), Sustainability (S), and then Resiliency (R) to represent progress in the maturity levels/stages.

![Figure 5: The proposed scale to the city smartness CSR maturity model (CSR-MM).](image)

Since ICTs are enabling technologies controlled by sustainability and resiliency aspects, one may argue that ICTs should be considered after identifying the controlling
aspects. Hence, ICT should not be at the start of the scale. The answer is sustainability and resiliency are assumed by the author as targets that are expected, in mature SCs, to be achieved through the use of ICTs. Therefore, for assessing maturity, as realized by the author, the process starts from the enabling tools represented by ICTs (low maturity levels) to the targets/goals that represent sustainability and/or resiliency (higher maturity levels). However, in the case of developing an ICT-based solution for a sustainability or resiliency issue/problem, the approach follows the opposite of the assessment processes. The issue is first defined to identify the right intelligent technology to be used and the needed data to be processed. Then, the ICT is applied to build solutions or find decisions that align with resiliency/sustainability considerations.

### 4.2.3 SC maturity-based assessment framework

An SC assessment framework encompasses an SC scale, SC domains, and smartness indicators or measures. Scale systems represent the measuring scale for assessing SCs. They are critical components of any assessment framework because they reflect the selected SC concept and definition. Due to the difficulty in identifying definitive SC’s maturity stages and performance benchmarks, the vast majority of the scaling systems proposed for assessing SCs in the literature are performance-based city ranking systems (ordinal class). However, these systems face many challenges related to coping with the complexity and evolving nature of the SCs. On the other hand, maturity-based scaling systems (nominal class) are more adaptive/general to accommodate change and also more useful in identifying maturity gaps and setting goals.
The maturity-based scale implies that each level should include the characteristics of the previous levels or utilize the outcome from the previous steps. Hence, in this study, after an initial component (Component zero), three components are proposed for each of the three SC dimensions. The resulting 10 components, as defined in Table 8, follow a waterfall sequence and at the same time represent stages of the maturity-based assessment model.

Table 8: The waterfall model for the components of the identified SC dimensions

<table>
<thead>
<tr>
<th>SC Dimension</th>
<th>#</th>
<th>Dimension Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Existence</td>
<td>The SC starts with the existence of a unique organizational unit that represents a specific city or society domain or sub-domain.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Data Collection</td>
<td>Then, this organization should collect data intelligently by means of the modern ICT technologies.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Data Processing</td>
<td>Then, these data should be intelligently processed and analyzed in order to obtain useful information and help in taking informed decisions.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Results Communication</td>
<td>Then, the obtained information, results, or decisions are communicated with either other systems or the relevant stakeholders and policy-makers. This step is essential for a successful and viable domain performance (efficient, effective, and improving).</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Effectiveness</td>
<td>Then, the communicated information should help in identifying the right factors that lead to successful performance and improvements in that specific SC domain.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Efficiency</td>
<td>In addition to that, the obtained information should help in doing things right. The word &quot;right&quot; means that the process of doing things in a city domain should have minimized or no negative effects on the triple bottom line considerations (environmental, economic, and social). Furthermore, the process of doing things should consider the continuous improvement and advancement in light of the results obtained and information. Improvements in a domain may be in terms of performance, quality of life, further minimizing the negative effects (or maximizing the positive effects) of the domain activities on the triple bottom line areas. This may require initiatives looking for opportunities for improvements at the current time.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Evolution / improvement</td>
<td>At any stage, part of the improvements should consider protecting the achieved level of life quality, successful performance, or minimized negative effects. The preventability is against losing that level of achievement. This means that the organization has developed and/or is developing backup plans.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Preventability</td>
<td>The second way of protection is by accommodating changes. Hence, the adaptability is the capacity of accommodating changes and risks. The required capacity amount is continuously monitored and controlled based on forward-looking initiatives within the city domains.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Adaptability</td>
<td>At this stage, all the city domains should have forward-looking initiatives that are looking for identifying opportunities (trends) and risks (future shocks and severe changes). Based on these forward-looking studies, the city takes actions proactively rather than reactively.</td>
<td></td>
</tr>
</tbody>
</table>
Based on these 10 components, a 5-level maturity scale is developed since the components represent a waterfall model. This maturity model for each domain of SC is described in Table 9 with further elaborations.

Table 9: The levels of the developed maturity model (CSR-MM) for SC

<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>Dimension Component</th>
<th>Maturity Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial</td>
<td>0: Existence</td>
<td>The city covers the availability of the unique organizational unit for each city sub-domain.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1: Data Collector</td>
<td>The city incorporates intelligent collection of the data regarding its domains.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2: Data Processor</td>
<td>The city analyzes collected data intelligently by means of modern ICT technologies.</td>
</tr>
<tr>
<td>2</td>
<td>Improved</td>
<td>3: Results</td>
<td>The city has intelligent communication of analysis outcomes among the city systems. The communication improves the quality of life.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communicator</td>
<td>The city incorporates the communicated information obtained from the intelligent analysis to perform processes successfully. The performance should improve the quality of life in terms of the triple bottom line considerations.</td>
</tr>
<tr>
<td>3</td>
<td>Sustainable</td>
<td>5: Efficient/</td>
<td>The city uses the communicated information to do the processes and domain activities right. This means that the processes and performance consider minimizing or eliminating the negative effects of the environment, society, and economy. The city considers the use of the communicated information towards continuous improvements. The city domain has initiatives that look continuously for opportunities for further improvements. The opportunities are at the current time not in the future.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>management</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6: Evolving /</td>
<td>The city considers the use of the communicated information towards continuous improvements. The city domain has initiatives that look continuously for opportunities for further improvements. The opportunities are at the current time not in the future.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>improving</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Preventive</td>
<td>7: Preventive</td>
<td>The city has backup plans in all of its domains to protect the domains against reducing/losing the achieved level of performance or prevent the citizens from losing the achieved quality of life.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>The city domains have additional capacity to accommodate changes such as sudden population increase in the city.</td>
</tr>
<tr>
<td>5</td>
<td>Proactive</td>
<td>9: Proactive</td>
<td>The city has initiatives in all domains that look to the future towards opportunities to improve the current quality of life or identify risks in order to mitigate their effects and protect the achieved levels of performance and quality of life.</td>
</tr>
</tbody>
</table>
As can be seen from the descriptions of the model levels, this maturity assessment model is descriptive (describing what should be available at each maturity level) not prescriptive (describing how to achieve each maturity level). Accordingly, the measures are in the form of questions that require objective answers from the managers of the SC domains. Table 10 provides guides to these questions that should be, unlike traditional performance-based indicators, applicable despite any future evolutions and advancements.

Table 10: The questions corresponding to the CSR-MM maturity levels for SC

<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>Dimension</th>
<th>Component</th>
<th>Corresponding Level Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial</td>
<td>0</td>
<td>Existence</td>
<td>Does the city have a unique organizational unit for this (Sub-) domain?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Data Collector</td>
<td>Does the domain collect automatically and store/archive frequently data relevant to improving the performance and life quality?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Data Processor</td>
<td>Does the domain process and analyze frequently and automatically data relevant to improving the performance and life quality?</td>
</tr>
<tr>
<td>2</td>
<td>Improved</td>
<td>3</td>
<td>Results Communicator</td>
<td>Does the domain communicate the obtained automatically results or decisions-to the relevant stockholders- regularly relevant to enhance the life quality?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Effective</td>
<td>Effective = doing the right thing Does this domain, based on the resulted information, identify and address the right factors to improve the life quality under the sustainability triple bottom line considerations?</td>
</tr>
<tr>
<td>3</td>
<td>Sustainable</td>
<td>5</td>
<td>Efficient</td>
<td>Efficient = doing the thing in the right way (no negative effects) Does this domain address the right factors based on following the best practices that have no negative effects with respect to the sustainability triple bottom line considerations?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Evolving / improving</td>
<td>Evolving = continuous improvement and forward-looking for opportunities Does this domain follow practices or have initiatives that are looking for opportunities (in the present time) for improvements that serve the citizens’ quality of life or positively affect the sustainability triple bottom line?</td>
</tr>
<tr>
<td>4</td>
<td>Preventive</td>
<td>7</td>
<td>Preventive</td>
<td>Prevention/protection = availability of backup plans Does this domain have backups to protect the city from losing the achieved level of quality of life?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Adaptable</td>
<td>Adaptability = the capacity to accommodate changes (based on the forward-looking initiative) Does this domain have the capacity to overcome and accommodate future shocks and changes?</td>
</tr>
<tr>
<td>5</td>
<td>Proactive</td>
<td>9</td>
<td>Proactive</td>
<td>Proactive = forward-looking towards identifying Risks /Opportunities Does this domain have forward-looking initiatives to anticipate the future opportunities and risks (shocks/changes) and proactively design acts to improve quality of life and protect the city from losing the achieved level of quality of life?</td>
</tr>
</tbody>
</table>
Since the developed scale represents a maturity level, this scale should be continuing in each city domain without gaps (this will be explained by a hypothetical example later). At this point of model development, it is worth mentioning that the SC domains are treated in the assessment process equally without associating any weights. **Figure 6** illustrates a graphical representation of this five-level maturity model. The figure shows that each higher maturity level encloses (includes) all its lower maturity ones. The lowest maturity level in all SC domains represents the overall SC maturity. In order to determine the overall SC maturity level, the lowest maturity level in all SC domains is then used to represent the overall maturity level of the whole city. This overall maturity indicator is selected to encourage the city leaders and decision-makers towards filling the maturity gaps.

![Figure 6: The proposed maturity model of smart cities/communities.](image)

To give the reader a better understanding to the developed model, the next section describes a hypothetical example to show the calculations involved in determining the SC overall maturity level in the developed CSR maturity model (CSR-MM).
4.3 CSR-MM City Level Calculation: A Hypothetical Example

Once the guiding questions are answered for each city domain, binary responses are obtained. The questions need to be answered objectively based on close investigation and/or interviews with all relevant institutions and city leaders. While any obtained positive answer is represented by “1”, the obtained negative answer is indicated by “0”. By this means, the overall city smartness maturity level, in the CSR-MM, can be calculated.

Table 11 shows a hypothetical example of a city assumed with 3 domains out of 4 domains identified in the complete proposed SC domains model. In this table, it is assumed that all SC domains are treated equally (without weight incorporation). Additionally, all the 10 guiding questions in Table 10 are answered objectively/accurately and these answers are turned to binary digits of “0” and “1” to represent the positive and negative outcomes respectively. The minimum value is then used to come up with the overall maturity level of the city under consideration using the CSR-MM. For the city leaders and decision-makers, this calculation style has several advantages including identifying the maturity gaps, emphasising the importance of the lower levels, and setting targets to fulfil the current maturity level to proceed to the next one.

Based on the assessment calculation in the example of Table 11, the maturity level of the SC domains is level-1 (initial). However, this maturity level fulfils \textbf{66.7\%} of the assessment criteria at that maturity level. These overall results were found through calculations in both vertical and horizontal directions. While the vertical calculation determines the SC maturity level, the horizontal calculation finds the degree of fulfilling that maturity level across the selected city domains that are under assessment.
The SC maturity level is determined by the vertical direction calculations. The calculation starts by determining each domain’s maturity by finding the last positive answers (i.e., 1) from the beginning of the scale before encountering any negative answers (i.e., 0). Then, the maturity level is the corresponding level to those last positive answers (i.e., 1). The overall SC maturity level is then found as the corresponding lowest level of all levels of the SC domains.

Table 11: A hypothetical example for an SC maturity-based assessment

<table>
<thead>
<tr>
<th>Maturity Scale</th>
<th>Smartness Dimension</th>
<th>Component</th>
<th>SC Domains</th>
<th>City Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dmn1</td>
<td>Dmn2</td>
</tr>
<tr>
<td>1 Initial SC</td>
<td>Intelligent Connectivity</td>
<td>0-Existance</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-Data Collection</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-Data Processing</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2 Improved SC</td>
<td>Sustainability</td>
<td>3-Results Communication</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-Effectiveness</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3 Sustainable SC</td>
<td>Resiliency</td>
<td>5-Efficiency</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-Evolution</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4 Protected SC</td>
<td></td>
<td>7-Preventability</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-Adaptability</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5 Proactive SC</td>
<td></td>
<td>9-Proactivity</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corresponding Maturity level</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (66.7%)</td>
<td>66.7%†</td>
</tr>
</tbody>
</table>

City Smartness level (Lowest/Minimum level) = Initial SC

† The percentages used in finding the degrees of fulfilling the identified maturity level.

The degree of the fulfilment of that maturity level is determined by the horizontal calculations. These calculations start by taking the horizontal summation of the values corresponding to each SC maturity component. This sum is then divided by the total
number of domains and multiplied by 100. The resulting percentages represent the degree of satisfying each of the 10 SC components separately. The total average of all of these percentages within the identified maturity level, via the vertical calculations, indicates the degree of fulfilling the calculated overall SC maturity level. In our hypothetical example, the degree is found to be 66.7% (\([75+50+75]/3\)). This means that 33.3% are still needed to be satisfied before the SC can be considered at level II (2) of maturity.

The vertical calculation provides the maturity level of the assessed domain or sub-domain. Hence, results are applicable regardless the number of the assessed sub-domains. In contrast, the horizontal calculation cannot be calculated if only one sub-domain is chosen to be assessed. This demonstrates the scalability of the developed model. In other words, the model can be applied for any number of sub-domains and the assessment results can be easily aggregated, at any scale level (i.e., sub-domain scale, domain scale, and municipality scale level), both vertically and horizontally.

To explain the aggregation algorithm, consider a case of assessing one domain that has a set of sub-domains. For the overall domain assessment, the aggregation of the result from the sub-domains (lower levels) to the domains (higher levels) is determined based on the vertical calculation. The overall aggregated maturity level is simply identified by the minimum achieved level in the lower levels. If the degree of fulfilling each maturity level is required within the assessed domain, the horizontal calculation provides an aggregation for the achieved scores of each sub-domain. This horizontal aggregation can be considered as an overall assessment of the domain at each maturity level.
5. CSR Maturity Model Applicability Demonstration

The validation of maturity models (MMs) is usually challenging since there are no reference data or results in most cases. As reviewed in the literature, assessment frameworks’ validation is usually done through model applications to multiple case studies and/or intensive experts’ interviews/reviews. In this research, the validation of the model is narrowed, as a comprehensive validation is beyond the research scope. The CSR-MM conformance with the basic MM design principals is inspected and the model practicality is demonstrated through a case study and a comparison.

The pilot city for this research is a medium-sized Canadian municipality as this study is conducted in Canada. Statistics Canada (StatCan) classifies urban population center (POPCTR) sizes as small, medium, and large. The medium-sized class is defined as having a population of 30,000 to 99,999, with a density of 400 or more people per square kilometer (Statistics Canada, 2015). More than 40% of the Canadian population live in medium-sized (54 municipalities) and small-sized municipalities (857 municipalities) which together represent over 96% of the Canadian municipalities. Accordingly, looking forward in population growth, a significant percentage of small municipalities will reach the medium scale in either the short or long term (Vaillancourt, 2015). Thus, it is a wise decision to apply the developed assessment model onto a medium-sized Canadian city. Based on this condition, the pilot municipality selected for this research study is the City of Fredericton in New Brunswick. This is because this city has several advantages including the following:

1. It is a medium-sized Canadian Municipality with population of almost 60 thousand residents and a density of 427 people per square kilometer, as per Statistics Canada.
2. Data and information resources are accessible for research initiatives aimed at assessing the performance towards the pre-identified municipality goals.

3. Municipality leaders are actively working towards city smartness and sustainability.

4. Interviewing municipality leaders and domains’ managers is possible.

5. The municipality participated in Infrastructure Canada’s Smart Cities Challenge and was one of 20 finalists.

The applicability demonstration of the developed CSR-MM is presented through (1) CSR-MM conformance with the MM design principles, and (2) CSR-MM practical demonstration based on: (a) a case study; and (b) a comparison against a world-class assessment model (i.e., ISO37120).

5.1 CSR-MM Conformance with the MM Design Principles

This section evaluates the conformance of the developed CRS-MM to the MM design principles of developing maturity models. This because developing maturity models based on standard design principles can maximize its usage purpose. The design principles for MMs were introduced by Röglinger & Pöppelbuß (2011) and applied on SCs maturity models by Torrinha and Machado (2017). Table 2 presents 10 design principles along with their descriptions and the corresponding evaluation on CSR-MM developed in this research study. Based on these 10 design principles of MMs (see Table 12), the developed CSR-MM is found to be a unique descriptive model in terms of identifying gaps, for city leaders, in SC maturity levels that cover the three key SCs dimensions. Also, the developed model concept has been shared with the Canadian construction research community (annual meeting of the Canadian Society for Civil Engineering, 2019). Additionally, the full model description is being documented in a refereed journal. The CSR-MM is also applied on a pilot sub-domain for assessment. The assessment outcome is reviewed and
approved by the sub-domain leader/expert. Additional details about the practical demonstration of the CSR-MM are provided in the following sub-section.

Table 12: CSR-MM conformance to the MM basic design principles

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>The Proposed Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application Domain</strong></td>
<td>Defines the specificity of the model and distinguishes it from other models</td>
<td>The model is unique because it assesses the city maturity in terms of the three key smart city dimensions (ICT, Sus, and Res.).</td>
</tr>
<tr>
<td><strong>Pre-requisites of Applicability</strong></td>
<td>Conditions for applicability and the intended benefits from using it</td>
<td>The model is useful in identifying gaps. Identifying gaps in the city and acting upon them will allow better investment decisions towards the achievement of long-term urban sustainability and resiliency.</td>
</tr>
<tr>
<td><strong>Purpose of use</strong></td>
<td>The outcome of the maturity assessment, whether is comparison, description, or prescription</td>
<td>The CSR-MM addresses the “what” should be done to improve. Hence, it is a descriptive not prescriptive. Descriptive models set a guidance towards SC instead of detailed instructions. Hence, they are more powerful in accommodating the complexity and long-term evolution of SCs.</td>
</tr>
<tr>
<td><strong>Target Groups</strong></td>
<td>The requirements of the intended audience, who needs the model, why its application, how to be applied</td>
<td>The model is designed for city leaders and policymakers to help them in leading and guiding the SC transformation initiatives.</td>
</tr>
<tr>
<td><strong>Differentiation Factors from Similar MM</strong></td>
<td>Understand the need for a new model; support the development of a new model or improving an existing one.</td>
<td>None of the available MMs covers all the key dimensions of SC. Hence, as a new contribution, this model is developed.</td>
</tr>
<tr>
<td><strong>Validation of the Model</strong></td>
<td>Support appropriate model development by understanding domain through literature review and validation through experts’ interviews or case studies.</td>
<td>The model is implemented on a mobility sub-domain (public Transit) as an example and the results were confirmed by the domain manager. Additionally, the Model concept was reviewed and accepted by two subject experts at an international conference. Moreover, the full model currently will be documented in a refereed journal.</td>
</tr>
<tr>
<td><strong>Descriptor of the Maturity and its Dimensions</strong></td>
<td>Clear and concise identification of the levels and the model dimensions.</td>
<td>Clear descriptions of the model levels where provided in Tables 8, 9 &amp; 10 in addition to a hypothetical example in Table 12.</td>
</tr>
<tr>
<td><strong>Definition of Maturity Levels</strong></td>
<td>Descriptions of the characteristics of each level.</td>
<td>Full high-level description was provided in Table 9</td>
</tr>
<tr>
<td><strong>Definition of Maturity Paths</strong></td>
<td>Define the paths between the stages and the description activities to be performed at each level.</td>
<td>Full high-level description was provided in Tables 9 and 10.</td>
</tr>
<tr>
<td><strong>Model Documentation</strong></td>
<td>The design process should be documented, which methods were applied.</td>
<td>The developed model concept was documented in an annual meeting of the Canadian Society for Civil Engineering (CSCE 2019). Additionally, the full-length model description and application will be documented in a refereed journal.</td>
</tr>
</tbody>
</table>
5.2 CSR-MM Practical Demonstration

By exploring the pilot city, it was found that its municipality (City of Fredericton) initiated eight city domain programs to improve the inhabitant quality of life and consequently the city’s smartness. As it is published publicly, at the official city website, each domain is based on a controlling statement that reflects the surveyed vision of the city residents. In addition to that, a set of key measuring indicators (dashboard) to monitor the performance of each domain against the defined resident vision is identified.

The eight domain programs, their vision statements, and their corresponding performance indicators are provided in Table 13. The table also shows the corresponding SC domains identified in Section 4.2.1. From this table, it can be seen that the environment, economy, and mobility domains have the best match in terms of domain name and definition (content) between the eight domains defined by the City of Fredericton and those identified in this study (i.e., the last columns of Table 13).

For demonstration purposes, applying the CSR-MM to a case study could be made on any of the eight domains defined by the City of Fredericton. Among the natural environment, economy, and mobility domains, the mobility domain has been selected as a pilot domain in this study, to demonstrate the practicality of the CSR-MM for several reasons including the following:

1. The domain has a unique organizational unit within the municipality.
2. The domain manager was available for interview.
3. The domain information is accessible and available on-line.
4. The domain conducts regularly strategic plans and studies and shares them publicly.
Table 13: The eight domains programs identified by Fredericton municipality.

<table>
<thead>
<tr>
<th>City Domain Program</th>
<th>Corresponding SC domain (CSR-MM)</th>
<th>Vision Statement</th>
<th>Key Performance indicators</th>
<th>Notes</th>
</tr>
</thead>
</table>
| Corporate           | Governance, policy, & management and Services | I want municipal internal services that operate efficiently to provide effective and responsive services; that partner with external direct service providers to share responsibility for achieving priority results and meeting community needs. | 1. Shared Responsibility Score  
2. Benchmark Cost of Internal Services  
3. Development of integrated 3-5 year operating plans  
4. Effectiveness of Lean 6 Sigma  
5. Sustainability Ratio | The domain seems to expand across multiple domains and does not have a unique organizational unit |
| Economic Vitality   | Economy and Finance               | I want a strong, resilient and growing economy | 1. Room nights  
2. Start-ups & commercialization success  
3. Employment | There is a good fit in the domain content |
| Environmental Stewardship | Natural environment            | I want a clean, green community: water, land and air. | 1. Greenhouse Gas emissions  
2. potable water protection  
3. Maintenance of green space and forest canopy  
4. Solid waste reduction and diversion. | There is a good fit in the domain content |
| Governance & Civic Engagement | Governance, policy, and management | I want a city government that is responsible and responsive to its Residents and businesses; that provides vision, leadership and decision-making for the common good; and that makes me feel informed, engaged, and consulted | 1. Collaboration & Consultation  
2. Opportunities  
3. Council Satisfaction | The domain seems to expand across multiple domains and does not have a unique organizational unit |
| Domain                  | People, living, and society | A vibrant, inclusive, well-planned, connected and active community | 1. A Connected and Engaged Community  
2. An Affordable, well Planned and Designed Community  
3. Active and Culturally Rich Lifestyle | The domain seems to expand across multiple domains and does not have a unique organizational unit |
|-------------------------|-----------------------------|-------------------------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------|
| Public Safety           | People, living, & society and Quality of life | A safe and secure community | 1. Crime severity index  
2. Fire loss  
3. Percentage of Citizens that feel Safe and Secure | The domain seems to expand across multiple domains and does not have a unique organizational unit |
| Mobility                | Mobility | I want my city to have safe, accessible options for movement of people and goods in and around my community. | 1. Number of traffic, pedestrian and cycling collisions  
2. Percentage of residents who use alternate modes of transportation  
3. Condition of our roads  
4. Progress on Reducing Active Transportation Network Gaps. | There is a good fit in the domains’ content since it focuses on transportation |
| Sustainable Infrastructure | Built infrastructure and ICT | I want a municipal infrastructure that is always available for its intended service and purpose at a cost that both current and future generations can afford. | 1. Debt Servicing Cost  
2. Ratio of Property Tax to Income  
3. Reduction of Infrastructure Deficit  
4. Sustainability Ratio | The domain does not include ICT and hence does not fit the CSR-MM domain |
The mobility domain is divided broadly by programs leaders of the City of Fredericton into sub-domains: (1) active transportation network (sidewalks, bike lanes, trails, and paths), (2) vehicular transportation network, and (3) public transit. Among all of the mobility sub-domains, Fredericton public bus systems is the most mature system since it is operated by a unique organizational unit within the municipality and has a future vision that has been developed recently based on a comprehensive strategic study and planning.

Therefore, for this research study, Fredericton Transit (the Fredericton bus system) is the sub-domain selected to be assessed in accordance with the developed CSR-MM. This particular sub-domain has been selected for our research due to (1) the accessibility of the required information resources, (2) the availability of a very recent strategic study, as well as (3) the possibility of interviewing the sub-domain manager for the model outcome confirmation since this manager formally accepted to participate in this research study.

### 5.2.1 CSR-MM case study

In consideration of the scope and time limitations of this research study, the CSR-MM has been applied on a pilot sub-domain as a case study for practical demonstration purposes. This sub-domain is Mobility/Public Transit of the City of Fredericton, Canada. In order to provide the reader with better understanding of the identified SC domains and the location of the sub-domain selected as a case study for practicality demonstration purposes, **Figure 7** illustrates the SC domains structure. The sub-domains shown are as defined by the pilot city municipality.
Figure 7: The SC broad domains and the sub-domains of the selected mobility domain as defined by the pilot city municipality.

To validate the CSR-MM assessment outcome, all the model guiding questions, provided in Table 10, were applied on the Mobility/Public Transit sub-domain of the City of Fredericton. The answers were determined initially from the most recent strategic plan of the transit institution (Fredericton Transit, 2019). The detailed assessment outcomes were provided in Appendix A (Table 17). These outcomes were presented, reviewed, and approved by the Manager of the Transits and Parking, City of Fredericton in a structured interview. A copy of the meeting agenda and minutes are attached in Appendix B and a brief version of Fredericton public transit assessment outcome is presented below in Table 14.
Table 14: The case study (Fredericton public transit) assessment result breakdown.

<table>
<thead>
<tr>
<th>Maturity Scale</th>
<th>Smartness Dimension</th>
<th>Mobility Domain</th>
<th>Mobility Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Active Tans. Systems</td>
<td>Fredericton Public Transit</td>
</tr>
<tr>
<td>1 Initial SC</td>
<td>Intelligent Connectivity</td>
<td>0-Existance</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-Data Collection</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-Data Processing</td>
<td>-</td>
</tr>
<tr>
<td>2 Improved SC</td>
<td>Sustainability</td>
<td>3-Results Communication</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-Effectiveness</td>
<td>-</td>
</tr>
<tr>
<td>3 Sustainable SC</td>
<td></td>
<td>5-Efficiency</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-Evolution</td>
<td>-</td>
</tr>
<tr>
<td>4 Protected SC</td>
<td>Resiliency</td>
<td>7-Preventability</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-Adaptability</td>
<td>-</td>
</tr>
<tr>
<td>5 Proactive SC</td>
<td></td>
<td>9-Proactivity</td>
<td>-</td>
</tr>
</tbody>
</table>

Corresponding Maturity level: (1)

City Smartness level (Lowest/Minimum level) = Initial SC

5.2.2 CSR-MM comparison

Comparing the developed CSR-MM against a relevant assessment model is valuable for highlighting the advantages and limitations of both models. Regarding the mobility domain, two sets of assessment indicators were found relevant to this study. On the one hand, since the selected case study is the mobility domain of the City of Fredericton, the set of indicators developed by the Fredericton municipality for monitoring the mobility domain performance, as provided in Table 13, should be compared against CSR-MM because they are very relevant. On the other hand, since CSR-MM was developed in light
of the SC definition adopted by ISO standards, the set of ISO indicators of the mobility theme should be relevant to CSR-MM comparison.

However, by a closer look at the two sets of mobility assessment indicators and examining the Fredericton municipality (four) indicators against the ISO transportation (nine) indicators (ISO37120, 2018), it was found that the ISO indicators are more comprehensive. Thus, it is wise to choose the ISO transportation indicators for the comparison, since almost all of the Fredericton municipality indicators are already included. Table 15 presents the investigation results.

Table 15: Examining the City of Fredericton mobility indicators against the ISO standards.

<table>
<thead>
<tr>
<th>City of Fredericton mobility indicators</th>
<th>Comments and Relation to ISO37120:2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of traffic, pedestrian and cycling collisions</td>
<td>This indicator is <strong>similar and correlated</strong> to the ISO transportation indicator number 19.5. This indicator measures the transportation deaths per 100,000 population.</td>
</tr>
<tr>
<td>Percentage of residents who use alternate modes of transportation</td>
<td>This measure is <strong>included indirectly</strong> in the ISO transportation indicators as Percentage of commuters using a travel mode to work other than a personal vehicle (ISO indicator number 19.3).</td>
</tr>
<tr>
<td>Condition of the roads</td>
<td>This indicator requires a Pavement Management System that measures and tracks the Pavement Condition Index (PCI). However, the CSR-MM model suggests assessing the roads condition and the maturity of its tracking process under the <strong>Built infrastructure and ICT</strong> domain of SCs.</td>
</tr>
<tr>
<td>Progress on Reducing Active Transportation Network Gaps.</td>
<td>This indicator requires identifying the city gaps in the active transportation networks then measuring the gap reduction. Since a gap database is not available yet, this indicator cannot be computed. However, this indicator related to active transportation is included indirectly in the ISO measures as Kilometres of bicycle paths and lanes per 100 000 population (ISO indicator number 19.4)</td>
</tr>
</tbody>
</table>

Therefore, in reference to the Table 15, the ISO standards (ISO37120, 2018) has been selected to be compared against the CSR-MM. This is for several reasons: (1) this ISO model is considered the world-leading framework for SC assessment; (2) this ISO model is the most recent assessment framework available to date; (3) the ISO model is developed
based on a definition, presented in Table 2, that is adopted for developing CSR-MM; (4) unlike other assessment models described in the literature, the indicators of this ISO model are available with clear description to be implemented; and (5) ISO is a standard which provides opportunities for comparing different cities against each other or comparing the same city at different times. Furthermore, due to the unavailability of application details of other SC maturity models, although the ISO model is a performance-based assessment framework, comparing it to CSR-MM will highlight the crucial advantages of maturity-based models over the performance-based ones.

Therefore, this section presents the assessment of the selected pilot sub-domain (i.e., Fredericton Public Transit) as an outcome of applying both CSR-MM and ISO37120:2018 assessment frameworks in a paragraph form that includes the key ideas identified. While the two concluding assessment paragraphs are presented in Table 16, the details of applying both assessment frameworks are provided in Appendix A (Table 17 and Table 18).

Table 16: The assessment paragraphs resulted from CSR-MM and ISO37120:2018

<table>
<thead>
<tr>
<th>Assessment Model Outcome: Mobility - Fredericton Public Transit system</th>
<th>CSR-MM — Summary of Table 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Does the city have an independent institution for this (Sub-) domain?</td>
<td>Unique organizational unit is available for Fredericton Transit that looks after the Public Transit. Its name is Fredericton Public Transit located at 470 St. Mary’s street. Fredericton, NB.</td>
</tr>
<tr>
<td>- Does the domain collect and store/archive regularly (frequently) and automatically data relevant to improving the performance and life quality?</td>
<td>Data collection related to the service operation is being conducted but not automatically. For instance, no real-time customer feedback collector, no passenger counting system, and no internal/external camera systems are currently installed to count passengers, improve safety, and attract ridership by increasing the perception that safety is monitored and taken seriously. However, the system does have operator behaviors monitoring.</td>
</tr>
<tr>
<td>- Does the domain process and analyze regularly (frequently) and automatically data relevant to improving the performance and life quality?</td>
<td>Data processing is not fully automatic. For instance, no automatic route planning functionality is available (limited), no alert functionality is available, and no on-demand/dynamic scheduling is available in any route. Additionally, the schedules are still based on paper maps. Currently, Fredericton Transit makes limited use of its somewhat outdated technology. Technology like automatic vehicle location (AVL) and automatic passenger counters (APC) can enable evidence-based decisions, such as route and service planning.</td>
</tr>
</tbody>
</table>
- **Does the domain communicate the results obtained or decisions-to the relevant stockholders**- regularly (frequently) and automatically for the purpose of enhancing life quality?

**Results/Information communication** is very possible through the ReadyPass App. However, the technology does not support bi-directional communication to collect requests and feedback or even answer questions to the riders.

- **Does this domain, identify and address the right factors to improve the life quality under the sustainability triple bottom line considerations?**

**Effectiveness** is improving service/life quality based on automatically identifying the right factors or responses by exploiting the outcome of data processing. However, it does not appear to be an intelligent connection between the system and the riders to identify the right factors for life quality based on technology in terms of data collection, processing and communication. For example, there is no dynamic schedule update based on processing the collected feedback from the riders. In addition to that, there is no rider’s usage tracing functionality.

- **Does this domain address the correct factors based on following best practices that have no negative effects with respect to the sustainability triple bottom line considerations?**

**Efficiency** is performing operations with minimum negative effects on the sustainability pillars (environment, society, economy) by taking advantages of the technology or following best practices. However, concerning the environmental aspect, the transit system still relies on diesel as its primary propulsion source for conventional buses.

- **Does this domain follow practices or have initiatives that are looking for opportunities (in the present time) for improvements that serve the citizens’ quality of life or positively affect the sustainability triple bottom line?**

**Evolution** is the improvement in the service/life quality or the positive effect on the sustainability pillars. Fredericton Transit is on the move toward vibrant and quality transit system. However, objective indicators to support that have not been developed or measured yet.

- **Does this domain have backups to protect the city from losing the achieved level of quality of life?**

**Prevention** against losing the achieved service/life quality levels seems to exist. For instance, the organization has a bus maintenance plan to prevent sudden breakdown of buses, as well as has a number of seven spare buses which is higher than the peers’ average and industry standards.

- **Does this domain have the capacity to overcome and accommodate future shocks and changes?**

**Adaptability** is the capacity of the transit system to accommodate sudden increase of the population. The system has 21 buses on the roads in the peak hours. So, theoretically, the system has 33% of extra capacity (7 buses) which is higher than its peers.

- **Does this domain have forward-looking initiatives to anticipate the future opportunities and risks (shocks/changes) and proactively design acts to improve quality of life and protect the city from losing the achieved level of quality of life?**

**Proactivity** is the initiative to look in the future for continuous system improvement. Fredericton Transit Strategic Plan is a good periodical initiative for this. The management has assigned employees to monitor and control the progress towards the identified goals.

**Core indicators:**

The Fredericton Transit system has 254.2 Km public transport system per 100 000 population. Annual number of public transport trips is 23.62 Trip per capita.

**Supporting indicators:**

There are 16.3% of commuters using a travel mode to work other than a personal vehicle. There are 1,202.3 Km of paths /lanes per 100 000 population. There were 10.3 transportation deaths per 100000 population. There is 0% of population living within 0.5 km of public transit running at least every 20 min during peak periods. Average commute time (ACT) is 15.4 minutes.

**Profile indicators:**

There are 0.348 personal automobiles per capita.
By examining Table 16, the richness of the information content is highlighted in the CSR-MM assessment outcome. The information highlights maturity gaps. In addition, some suggestions are given in the outcome as part of the assessment. This should make it easy for the city leaders to set action plans. On the other hand, the ISO assessment outcome does not provide gaps. Although the outcome may enable ranking and comparisons with other cities, the outcome requires a benchmark or standard to be compared against in order to set clear goals and/or design action plans. It is very important to indicate that the CSR-MM outcome is for only a sub-domain (Public Transit) of the mobility domain, while the ISO standard indicators outcome represents the full assessment for the city mobility domain. This should demonstrate the outcome information richness and usefulness of the CSR-MM in contrast to the ISO standard indicators outcome in particular, as well as all the performance assessment models in general.

5.3 CSR-MM Applicability Demonstration: Summary and Discussion

The design soundness of CSR-MM has been inspected and its practically has been demonstrated. The model soundness inspection revealed that the developed model satisfies the 10 basic design principles of developing maturity models as introduced by Torrinha and Machado (2017). This conformance to the basic design principles should assure the usefulness and practicality of using the CSR-MM.

The practicality of CSR-MM was also demonstrated. The practicality demonstration was designed to include (1) applying the CSR-MM to the Fredericton Public Transit system, (2) interviewing the transit system manager, and (3) comparing the model outcome
to the obtained result from the ISO37120:2018 standard since it represents the up to date world-class SC assessment model.

When the model was applied to the Fredericton Public Transit system, the assessment result revealed many maturity gaps in the system. The gaps are identified in all of the three key smartness dimensions as in the following:

a) *The Connectivity SC dimension* emphasizes the use of the modern connectivity technologies for automation. The assessment shows that the transit system lacks both the automatic passengers’ counter and real-time customer feedback collector. Additionally, the system does not fully process the available data automatically to provide, for instance, an automatic route planning functionality. Furthermore, the great communication initiative though a phone App *(ReadyPass)* does not support bi-directional communication to collect riders’ requests and feedback. Thus, a score of “0” was given to each of the three connectivity components.

b) *The Sustainability SC dimension* represents the viability of the system performance. Regarding the effectiveness components of the performance, it is based on improving service/life quality based on automatically identifying the right factor or responses by exploiting the outcome of data processing. However, still there is no intelligent connection seeming to exist between the system and the riders to identify the right factors for life quality based on technology in terms of data collection, data processing and communication. For example, there is no dynamic schedule update based on processing the collected feedback from the riders. In contrast, the performance efficiency is performing operations with minimum negative effects on the sustainability triple-bottom-line by taking advantages of the technology or following
best practices. However, concerning the environmental aspect, the transit system still relies on diesel as its primary propulsion source for conventional buses. The improvement in the service/life quality or positively affect the sustainability components is referred to the performance evolution. The transit system is moving toward transformation into improved service quality. However, objective indicators to support that transformation have not been developed or measured yet. As a result of this assessment, a score of “0” was given to each of the three sustainability components.

c) The Resiliency SC dimension represents the protection of the achieved levels of services and performances. Unlike previous SC dimensions, the transit system performs well in the resiliency dimension. For instance, prevention against losing or reducing the achieved service/life quality levels seems to exist. For instant, the institute has a bus maintenance plan to prevent sudden breakdown of buses as well as seven spare buses which is higher than peers’ average and industry standards. The system adaptability pillar is the capacity of the transit system to accommodate sudden increase of the population. The system seems to have 33% of additional capacity which is higher than peers’ and industry standards. The proactivity pillar of this dimension is about looking to the future for continues system improvement. Fredericton Transit Strategic Plan is a great initiative for that. It is consistently periodical and has an executive and monitoring committee for monitoring and control. Therefore, it is expected that the Fredericton transit system will improve drastically in the coming years in all SC dimensions. The score given to each of the three resiliency components is “1”.

55
As a result of applying the CSR-MM assessment tool, the overall maturity level of the transit domain is found to be initial (level I). This is because the overall level depends critically on the lowest identified gap (minimum level) as indicated in the development section of the CSR maturity model in this study. When the manager of the Fredericton public Transit was interviewed, she agreed to all the model outcomes and confirmed the identified gaps. In this regard, it is worth at this point to indicate that she highlighted strongly the following properties:

1. CSR-MM is more informative and effective in assessing the domains smartness than the city of Fredericton indicators being used.

2. Although the ISO standards indicators are standardized and more comprehensive than the city of Fredericton indicators, the CSR-MM is more comprehensive and informative than the ISO indicators.

3. CSR-MM helped her to identify gaps and goals to be achieved. It has many advantages over the performance indicators of the City of Fredericton and/or the ISO indicators.

4. CSR-MM looks robust, attractive and promising. She could not identify disadvantages or limitations during the process of applying the model to the Fredericton public transit system

In comparison to the outcomes of the CSR-MM, ISO standard assessment model does not help in identifying gaps when it was applied to the transit system. It requires city leaders to identify gaps and set goals based on investigating the city’s needs and wants. After that, a study needs to be conducted to identify the indicators and measures relevant to the
identified targets that need to be monitored. For example, knowing that the annual number of public transport trips is 23.6 trip per capita will not be useful unless a study has been conducted to determine the required target number. Otherwise, the city leaders will need to compare the ISO assessment results to similar cities to set goals and benchmarks. However, this may distract from efforts to focus on the city gaps versus how the city ranks among others.

Furthermore, it was noted that some of the ISO indicators were note applicable to the selected case study. For example, while one of the supporting indicators requires the population living close to public transit running at least every 20 minutes (3 times/hour), the highest frequency available in the public transit routes was found to be every 30 minutes (2 times/hour) during peak periods. The inapplicability of some indicators can limit the assessment tool as a whole and impacts the benefits to most medium-sized and small-sized Canadian cities which together represent over 96% of the Canadian municipalities. More importantly, while the ISO standard indicators outcome represents the full assessment of the city mobility domain, the CSR-MM outcome is for only a sub-domain of the mobility domain. This should further confirm the outcome information richness, usefulness, and the practicality of the CSR-MM in contrast to ISO standard indicators.

It is concluded that the CSR-MM presents a real research contribution by providing improvements over the currently SC assessment tools available in the literature. One of these improvements is the scalability of the model. It can be at the sub-domain level (for a single sub-domain), domain level with a set of sub-domains, municipality level with a set
of domains, and even higher scale levels. In each of these scale levels, the CSR-MM is applicable and its outcome is still useful and valid.
6. Summary, Conclusions, Contributions, and Recommendations

6.1 Work Summary

In this study, the key dimensions of the SC concept have been identified based on reviewing and analyzing the relevant literature. These dimensions are intelligent Connectivity (C), Sustainability (S), and Resiliency (R). While connectivity (C) represents the intelligence and digital connectivity technologies that include data collection, processing, and information communication, sustainability (S) represents the performance viability of the city systems under the restriction of minimized/zero negative impact on the environmental, social, and economic aspects (the sustainability triple-bottom line). In contrast, urban resiliency (R) represents the capacity of protecting the city systems in order to function properly in situations of future changes, shocks, and stresses. Accordingly, it was recommended that any SC definition should include these key dimensions.

Many SC domains have been examined in the SC relevant literature. First, these SC domains were distilled to 20 domains after removing the repeating ones. Then, the SC domains were aggregated in eight broad SC domains including (1) Natural environment; (2) Built infrastructure and ICT; (3) Services; (4) Mobility including transportation; (5) Economy and finance; (6) Governance, policy, and management; (7) People, living, and society; and (8) Quality of life. These domains are identified as a component of an SC model, in order to be assessed against an SC maturity-based scaling system.

It was concluded in this research that the maturity-based scaling systems (nominal class) are more adaptive/general to accommodate change, and also more useful in identifying maturity gaps and setting goals, than the performance-based systems. Hence, it
was concluded that nominal descriptive maturity models are more relevant to the SC concept due to their complexity and evolving nature. Thus, a maturity-based assessment model system was developed in this research. This system is called the CSR maturity model (CSR-MM) for Smart city’s assessment.

The developed CSR-MM includes five levels of maturity as follows: initial, improved, sustainable, preventive, and proactive. These levels, as cumulative staged levels, are based on nine items that cover all the three identified key dimensions of an SC (ICT, sustainability, and resiliency). In more detail, the enabling SC dimension is ICT which includes stages of intelligent data collection, processing, and result communication. The sustainability dimension reflects the viable performance of city systems. This performance is defined as effective, efficient, and improving performance to maintain sustainability. Finally, the resiliency dimension represents the capacity of the systems to be functional in the cases of future shocks, stresses, and changes. It also represents the protection against losing the achieved levels of the life quality and sustainable performances. The stages of this dimension include preventive, adaptive, and proactive planes, designs, and actions for protecting the achieved service/life quality levels. In this research, questions were developed to identify the existence of each of the nine components. This existence is represented as binary digits. While 1 represents the existence of the component of the SC domain under consideration, 0 indicates no existence. These binary values are then aggregated to calculate the overall SC maturity level which is the lowest maturity level among all SC domains. This is to simplify the setting of goals for city leaders and to help them focus on filling the smartness maturity gaps identified.
The applicability of CSR-MM was demonstrated. First, the design soundness of the developed model was ensured by examining the model components against the basic design principles of maturity models. Second, the practicality of the developed model was demonstrated in two ways: (1) applying it to a case study (the transit sub-domain of the mobility domain for the City of Fredericton) and also confirming the assessment outcome by the sub-domain manager in a structured interview, and (2) comparing the assessment outcome to ISO37120:2018 mobility indicators, as it represents the leading international SC assessment tool. The results of the applicability demonstration highlight the advantages of the developed CSR-MM over current approaches (municipality or ISO). It was concluded that the CSR-MM presents a real research contribution by providing scalability and improvements over the SC assessment tools currently available in the literature.

6.2 Study Conclusions

All the answers for the identified research questions were determined as presented in the previous subsection. Additionally, many conclusions were drawn in this research study including the following:

1. SC is an evolving concept. Hence, a universally-shared definition does not exist.
2. All the reviewed SC assessment frameworks were designed based on unique SC definitions. Accordingly, there is no universally-accepted assessment methodology.
3. All of the SC definitions reviewed in the relevant research literature cover one or more of three key broad dimensions. These dimensions are connectivity (ICT/C), sustainability (S), resiliency (R).
4. Many SC domains were introduced in the SC models to be assessed against specific measures. These domains overlap each other and hence they were aggregated into eight key broad SC domains.

5. Most of the assessment frameworks introduced in the literature are performance-based models. However, due to the complexity and evolving nature of SC concepts, these types of models will possess limitations and face challenges due to their inflexibility.

6. Maturity-based assessment models are more adaptive/general to accommodate changes and also more useful in identifying maturity gaps and setting goals than the performance-based systems. Hence, it was concluded that nominal descriptive maturity models are more suitable to the evolving SC concept.

7. The CSR maturity model (CSR-MM) developed in this research for smart city’s assessment is the only maturity model that covers the three key SC dimensions.

8. The developed CSR maturity model (CSR-MM) satisfies the basic design principles of maturity models, as recommended in the relevant literature, for smart cities’ assessment.

9. The developed CSR maturity model (CSR-MM) is easy to implement and successful in identifying maturity gaps. Additionally, it is general and customizable, in terms of the maturity measurers, by municipality leaders in order to accommodate complexity, future changes, and the evolving nature of SCs.

10. The developed CSR maturity model (CSR-MM) is scalable which means it can be applied at the sub-domain levels (even for a single sub-domain), domain levels
with sets of sub-domains, municipality level with a set of domains, and even higher levels.

11. The CSR-MM is developed in this study to addresses the “what” should be done to improve. Hence, it is descriptive not prescriptive. This means it intended to help in identifying gaps and provides high level guidance.

12. The developed CSR maturity model (CSR-MM) presents a real research contribution by providing scalability and improvements over the SC assessment tools currently available in the literature.

6.3 Research Contributions

The research contribution of this study has been presented in this section from two perspectives: the researchers’ perspective and the practitioners’ perspective. From the researchers’ perspective, the main contributions of this study are as follows:

1. The identification of connectivity, sustainability, and resiliency as the three key dimensions that control the concept and definitions of SC.
2. The interpretation of the overlapping area of the connectivity, sustainability, and resiliency dimensions as the core of the city’s smartness.
3. The development of the city’s smartness concept, based on the identified three key dimensions, as three integrated triangles where each triangle side represents an SC dimension pillar (nine pillars in total).
4. The development of the maturity-based smartness scale for SCs based on the city smartness concept (i.e., the water fall model of the nine smartness pillars).
5. The development, based on the literature review, of the eight broad SC domains that need to be tested against the SC smartness scale.

From the practitioners’ perspective, the contribution of this study is the development of the CSR-MM as a practical assessment tool for SCs. The tool provides scalability and improvements/advantages over the SC assessment tools currently available in the literature including the following capabilities: to cope with the evolving nature of SCs, to help in evaluating the current maturity status, to identify maturity gaps, and to define smart goals in each city domain. In addition, based on the assessment output, the developed tool can be used to set a benchmark for an SC to monitor maturity advancements and/or make comparisons to other cities; if the same CSR model was used.

6.4 Recommendations and Future Work

In this research, it is identified that there is still a room for model improvement and developing more detailed and robust maturity measures/indicators that are easy to apply. Hence, it is recommended in this study to:

1. Further improve the CSR-MM to satisfy the design principles of the descriptive maturity models as outlined by Röglinger & Pöppelbuß (2011) and applied by Torrinha and Machado (2017). The model improvement includes (1) increasing the verifiability of the assessment criteria so the maturity assessment can be compared and replicated, (2) providing clear guidance (manual) to the user on how to conduct the assessment in light of understanding of what needs to be measured, and (3) developing clear recommendations to the user on ensuring the assessment results are valid and accurate.
2. Further expand the breakdown of the SC domains and provide more structure with accurate details. The eight domains identified in this research represent broad categories of SC domains. Hence, for further domain details, the scope of each domain needs to be defined clearly. This scope will help in identifying the sub-domains and in the same manner the sub-subdomains if needed. The adopted themes by the ISO37120:2018 standard are recommended as a starting example of the sub-domains.

3. Further improve the CSR-MM by including the feedback from additional expert interviews and rigorous reviews. Each domain/sub-domain in a city has its own manager who is very familiar with it. This manager is considered the domain/sub-domain expert. Hence, the feedback and insights gathered from such an expert either through interviews or reviews are essential for both the model validation and improvement. This recommendation of model validation should be conducted based on (i.e., after) the SC domain breakdown.

4. Further apply the CSR-MM to multiple case studies, where each case represents a full city with its domains/sub-domains in at least two different points in time, at least one year apart. The intent is to achieve a rigorous validation that will help in more accurate identification of the model’s capabilities and limitations.

5. Full documentation of the improved CSR-MM in a specialized peer-reviewed society or high impact journal of high reputation. This recommendation further satisfies two items of the model conformance to the MM design principles which are: model review; and model documentation.
6. Despite the limitations identified for the performance indicators, it is acknowledged that performance-based models have several advantages that should not be overlooked. Hence, this suggests an opportunity to integrate performance-based models with the CSR-MM. This integration can enhance the monitoring and controlling targets of achieving viable (effectiveness, efficient, and improving) performance at the sub-domain level. It is further suggested that the management leadership of the unique organizational unit that looks after the sub-domain would decide the relevant set of performance indicators to be integrated.

The future work should address the six recommendations and perform them in their sequence to maximize improvements in the developed CSR-MM for both research and practice.
References

100 Resilient City. (n.d.). 100 Resilient Cities – Helping cities around the world become more resilient to the physical, social and economic challenges that are a growing part of the 21st century. Retrieved from https://www.100resilientcities.org/


68


Appendix A: Applying Assessment Models on a Mobility Sub-domain

Table 17: Application of CSR-MM guiding questions on the Mobility sub-domain (public transportation) of the City of Fredericton.\(^n\)

<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>#</th>
<th>Dimension Component</th>
<th>Corresponding Level Question</th>
<th>Mobility / Fredericton Public Transit Evaluation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Existence</td>
<td></td>
<td></td>
<td>Does the city have a unique organizational unit for this (Sub) domain?</td>
<td>Yes, it is called “Fredericton Transit” and it is led by the Manager of Transit and Parking at City of Fredericton.</td>
<td>1</td>
</tr>
</tbody>
</table>
| 1 | Data Collector |   |                     | Does the domain collect and store/archive regularly (frequently) data relevant to improving the performance and life quality? | limited  
Integrating the ReadyPass App is great technology that aims to help in improving the city public transit performance and experience to the city passengers, transit agency, and bus drivers, as it is reported in the website (http://www.readypass.ca/). However, no real-time customer feedback collector, no passenger counting system, and no internal/external camera systems are currently installed to count passengers, improve safety, and attract ridership by increasing the perception that safety is monitored and taken seriously. The needed data should be identified after developing performance criteria, objectives data collection methods, and tracking tools. The collected data should help in Real-time performance and monitoring public feedback. | 0     |
| 1 | Initial        |   |                     |                                |                                |       |
| 2 | Data Processor |   |                     | Does the domain process and analyze regularly (frequently) data relevant to improving the performance and life quality? | limited  
No complete automatic data processing system is currently available. For example, no automatic route planning functionality is available in ReadyPass App and no on-demand/dynamic scheduling is available in any route. On-demand solutions such as the one envisioned for Fredericton allow agencies to create “pop-up” routes in real-time based on demand for service. Many of these newer software packages require only a tablet onboard the vehicle and a cellular connection which Fredericton Transit already has. Currently, Fredericton Transit makes limited use of its somewhat outdated technology. Technology like automatic vehicle location (AVL) and automatic passenger counters (APC) can enable evidence-based decisions, such as route and service planning. | 0     |

\(^n\)Note: this table does not include explicitly the key smartness dimensions.
Table 17: Continued.

<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>#</th>
<th>Dimension Component</th>
<th>Corresponding Level Question</th>
<th>Mobility / Fredericton Public Transit Evaluation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Improved</td>
<td></td>
<td>Results Communicator</td>
<td>Does the domain communicate the results obtained or decisions to the relevant stakeholders regularly (frequently) relevant to enhance the life quality?</td>
<td>limited Integrating the ReadyPass App is great technology that communicate to the riders in real-time the actual buses’ arrival time which definitely improves the life quality. However, other than that, comprehensive bi-directional communication between the system and riders does not seems to exist. For example, this kind of communication eliminates “running-blind” in the sense that it allows operations to get real-time feedback and information on how service is operating to adjust on-the-fly and provide a more proactive service as opposed to a reactive one. Furthermore, the App has limited route planning, and does not have alert or notification functionalities.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Improved</td>
<td></td>
<td>Effective</td>
<td>Effective = doing the right thing. Does this domain, based on the resulted information, identify the right factors to improve the life quality under the sustainability triple bottom line considerations?</td>
<td>No  The goal of the Strategic Plan is to increase Fredericton Transit ridership and improve operational efficiency. This includes operations, safety (driver &amp; passenger), and rider satisfaction. A key focus of Fredericton’s public transit system is to increase ridership by improving core area frequency of service. However, still there is no intelligent connection seeming to exist between the system and the riders to identify the right factors for life quality based on technology in terms of data collection, processing and communication. For example, the system has no customer usage tracking, and hence no dynamic schedule update based on processing the collected feedback from the riders.</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note: this table does not include explicitly the key smartness dimensions.*
Table 17: Continued.

<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>Dimension Component</th>
<th>Corresponding Level Question</th>
<th>Mobility / Fredericton Public Transit Evaluation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Sustainable</td>
<td>Efficient</td>
<td>Efficient = doing things in the right way (no negative effects). Does this domain address the identified right factors based on following the best practices that have no negative effects with respect to the sustainability triple bottom line considerations?</td>
<td>Limited</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The system seems to be on the right track. However, still there is limited connection between the system operation efficiency and the use of technology.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>In addition to that, with respect to the environmental consideration, the system still relies on diesel as its primary propulsion source for conventional buses.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Therefore, lower-emission propulsion source, such as diesel-electric hybrid buses or battery electric buses (BEBs) should be considered to satisfy the sustainability requirements.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Evolving / improving</td>
<td>Evolving = continuous improvement and forward-looking for opportunities. Does this domain follow practices or have initiatives that are looking for opportunities (in the present time) for improvements that serve the citizens' quality of life or positively affect the sustainability triple bottom line?</td>
<td>Partially, Fredericton Transit Strategic Plan is a good initiative for quality system improvement. However, it should be developed periodically (every five years) Investigation revealed that Fredericton Transit is on the move toward vibrant and quality transit system. However, objective indicators to support that have not been developed or measured yet. The KPI is to increase the ridership. However, evolution is the improvement in the service/life quality or the positive effect on the sustainability pillars.</td>
<td>0</td>
</tr>
</tbody>
</table>

* Note: this table does not include explicitly the key smartness dimensions.
<table>
<thead>
<tr>
<th>#</th>
<th>Maturity level</th>
<th>#</th>
<th>Dimension Component</th>
<th>Corresponding Level Question</th>
<th>Mobility / Fredericton Public Transit Evaluation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Preventive</td>
<td>7</td>
<td>Preventive</td>
<td>Prevention/protect ion = availability of backup plans or alternatives. Does this domain have backups to protect the city from losing the achieved level of quality of life?</td>
<td>The domain has an asset management plan (maintenance) to prevent sudden breakdown of buses. Also, it has 7 spare buses which is higher than peers’ average and industry standards.</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Preventive</td>
<td>8</td>
<td>Adaptable</td>
<td>Adaptable = the capacity to accommodate changes (based on the forward-looking initiative). Does this domain have the capacity to overcome and accommodate future shocks and changes?</td>
<td>In case of an event that makes a lot of people come to the city suddenly, up to what percentage increase % (Capacity) in riders can the transit system serve? The transit system has 21 buses on road in peak hours and 7 extra buses. This means that the system has a capacity of 33% to accommodate sudden changes. This capacity is higher than the industry standards.</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Proactive</td>
<td>9</td>
<td>Proactive</td>
<td>Proactive = forward-looking towards identifying Risks/Opportunities. Does this domain have forward-looking initiatives to anticipate the future opportunities and risks (shocks/changes) and proactively design acts to improve quality of life and protect the city from losing the achieved level of quality of life?</td>
<td>Is there an initiative for supporting the concept of continues improvement? Yes, Fredericton Transit Strategic Plan is a good initiative for proactive quality system improvement. However, is it periodical and does it have an executive committee? Yes</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: this table does not include explicitly the key smartness dimensions.
<table>
<thead>
<tr>
<th>ISO Mobility Indicators</th>
<th>Description</th>
<th>Calculation</th>
<th>Calulated Value</th>
<th>Info. Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilometres of public transport system per 100 000 population (core indicator)</td>
<td>The extent of a city’s transportation network can provide insight into traffic congestion, transportation system flexibility and urban form. This indicator reflects the &quot;Community infrastructures&quot; and &quot;Mobility&quot; issues. It can allow an evaluation of the contribution to the &quot;Attractiveness&quot;, &quot;Preservation and improvement of environment&quot;, &quot;Well-being&quot; and &quot;Social Cohesion&quot; purposes of the city.</td>
<td>Shall be calculated as the total length (in km) of the public transport systems operating within the city (numerator) divided by one 100 000th of the city’s total population (denominator)</td>
<td>148.009km / 0.58220 = 254.22 Km/100k</td>
<td>Transit Strategic Plan 2019, Table 3-PP.90</td>
</tr>
</tbody>
</table>

| Annual number of public transport trips per capita (core indicator) | Transport usage is a key indicator of how easy it is to travel in the city by modes other than single occupancy vehicles. The indicator might also provide insight into transportation policy, traffic congestion, accessibility and urban form. This indicator reflects the "Mobility" issue. It can allow an evaluation of the contribution to the "Preservation and improvement of environment", "Responsible resource use" and "Well-being" purposes of the city. | Shall be calculated as the total annual number of public transport trips originating in the city - "ridership of public transport" - (numerator) divided by the total city population (denominator). | 1375140 / 58220 = 23.6 Trip/capita | Transit Strategic Plan 2019, Table 3-PP.90, the annual ridership in 2016 is 1375140. | 

The city population in 2016 is 58220 ([Transit Strategic Plan 2019](#)).
From the **Transit Strategic Plan 2019, Table 3-PP.90**, the annual ridership in 2016 is 1375140.

The city population in 2016 is 58220.
The total length of the public transport system (12 city routes) was measured with a scale from the transit PDF map. It was found to be 148.009km.
<table>
<thead>
<tr>
<th>Kilometres of bicycle paths and lanes per 100 000 population (supporting indicator)</th>
<th>Percentage of commuters using a travel mode to work other than a personal vehicle (supporting indicator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle lanes also require smaller infrastructure investments than other types of transportation infrastructure. Cycling has less of an environmental impact. This indicator provides cities with a useful measure of a diversified transportation system. This indicator reflects the &quot;Mobility&quot; and &quot;Community infrastructures&quot; issues. It can allow an evaluation of the contribution to the &quot;Preservation and improvement of environment&quot;, &quot;Responsible resource use&quot; and &quot;Well-being&quot; purposes of the city.</td>
<td>The mode of transportation used to commute to work is a key indicator of transportation policy, traffic congestion, urban form and energy use. This indicator reflects the &quot;Mobility&quot; issue. It can allow an evaluation of the contribution to the &quot;Preservation and improvement of environment&quot;, &quot;Responsible resource use&quot; and &quot;Well-being&quot; purposes of the city.</td>
</tr>
<tr>
<td>Shall be calculated as the total length (in km) of bicycle paths and lanes (numerator) divided by one 100 000th of the city’s total population (denominator).</td>
<td>Shall be calculated as the number of commuters working in the city who use a mode of transportation other than a private Single Occupancy Vehicle (SOV) as their primary way to travel to work (numerator) divided by all trips to work, regardless of mode (denominator).</td>
</tr>
<tr>
<td>700 km / 0.58220 = 1,202.3 Km/100k</td>
<td>9.4%+1.5%+ 1.0%+4.4% = 16.3%</td>
</tr>
</tbody>
</table>

The city population in 2016 is 58220 (*Transit Strategic Plan 2019*).

From [http://www.fredericton.ca/en/roads-parking](http://www.fredericton.ca/en/roads-parking), the length of the lane roads is 700 km

From the *Strategic Plan 2019, Table 1-PP.4* in 2016, the
Walked mode share = 9.4%  Bicycle mode share = 1.5%
Other mode shares = 1.0%  Transit mode share = 4.4%
... SOV:
Car mode share = 75.4%  Car (passenger) share = 8.3%
### Transportation deaths per 100000 population (supporting indicator)

Traffic accident rates and, specifically, fatality rates, can serve as indicators for the overall safety of the transportation system, the complexity and congestion of the roadway and transport network, the amount and effectiveness of traffic law enforcement, the quality of the transportation fleet (public and private), and the condition of the roads themselves. Traffic deaths represent the most severe type of traffic safety failure, allowing cities to focus on their most urgent traffic safety needs.

- **Proximity to reliable and connected public transit provides the foundation for greater mode share, thus reducing congestion and other externalities, Greater transportation options also improve the livability of cities.**
  - This indicator reflects the “Mobility”, “Living and working environment” and “Community infrastructures” issues. It can allow an evaluation of the contribution to the “Attractiveness”, “Social cohesion” and “Well-being” purpose of the city.

- **Shall be calculated as the total number of deaths related to transportation of any kind within the city’s administrative boundary (numerator), divided by one 100 000th of the city’s total population (denominator).**

  - The city population in 2016 is 58220 (Transit Strategic Plan 2019).
  - From Fredericton Open Data, the total number of deaths related to transportation of any kind within Fredericton city is = 6
  - Ref: https://bit.ly/2Hf34Wq

<table>
<thead>
<tr>
<th>Percentage of population living within 0.5 km of public transit running at least every 20 min during peak periods (supporting indicator)</th>
<th>Transportation deaths per 100000 population (supporting indicator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity to reliable and connected public transit provides the foundation for greater mode share, thus reducing congestion and other externalities, Greater transportation options also improve the livability of cities. This indicator reflects the “Mobility”, “Living and working environment” and “Community infrastructures” issues. It can allow an evaluation of the contribution to the “Attractiveness”, “Social cohesion” and “Well-being” purpose of the city.</td>
<td>Traffic accident rates and, specifically, fatality rates, can serve as indicators for the overall safety of the transportation system, the complexity and congestion of the roadway and transport network, the amount and effectiveness of traffic law enforcement, the quality of the transportation fleet (public and private), and the condition of the roads themselves. Traffic deaths represent the most severe type of traffic safety failure, allowing cities to focus on their most urgent traffic safety needs.</td>
</tr>
<tr>
<td>Shall be calculated as the total number of inhabitants living within 0.5 km of public transit running at least every 20 min during peak periods (numerator) divided by the total city population (denominator)</td>
<td>Shall be calculated as the number of deaths related to transportation of any kind within the city’s administrative boundary (numerator), divided by one 100 000th of the city’s total population (denominator).</td>
</tr>
</tbody>
</table>
| Fredericton area = 132.6km²  
The route of highest frequency is 10N-11S  
Area around route 10N-11S = 21.49km X 1 km  
However, the frequency of this route is 30 min which is less than the minimum frequency required by this indicator (20 min)  
This indicator is not applicable (N/A) | 6 / 0.58220 = 10.3 Deaths/capita |

The city population in 2016 is 58220 (Transit Strategic Plan 2019). From Fredericton Open Data, the total number of deaths related to transportation of any kind within Fredericton city is = 6
Ref: https://bit.ly/2Hf34Wq
### Average Commute Time (Supporting Indicator)

Commute times play an important role in the quality of life of working people, due to the negative effects of commuting on productivity and health (mental and physical). This indicator reflects the "Mobility" and "Community Infrastructures" issues.

### Number of Personal Automobiles Per Capita (Profile Indicator)

Measuring each type of transportation infrastructure sheds light on travel behaviour. The use of automobiles as a travel mode provides access to work, shopping, school and other community services. This measure can also inform the need for further transport facilities.

### Number of Two-Wheeled Motorized Vehicles Per Capita (Profile Indicator)

This indicator is important to cities that use two-wheeled motorized vehicles such as motorcycles and scooters as a major mode of transport.

Shall be calculated as the total number of two-wheeled motorized vehicles (TWMV) in the city (numerator) divided by the total city population (denominator).

The city population in 2016 is 58220 (Transit Strategic Plan 2019).

The number could not be found.

<table>
<thead>
<tr>
<th>Number of two-wheeled motorized vehicles per capita (profile indicator)</th>
<th>Number of personal automobiles per capita (profile indicator)</th>
<th>Average commute time (supporting indicator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This indicator is important to cities that use two-wheeled motorized vehicles such as motorcycles and scooters as a major mode of transport.</td>
<td>Measuring each type of transportation infrastructure sheds light on travel behaviour. The use of automobiles as a travel mode provides access to work, shopping, school and other community services. This measure can also inform the need for further transport facilities.</td>
<td>Commute times play an important role in the quality of life of working people, due to the negative effects of commuting on productivity and health (mental and physical). This indicator reflects the &quot;Mobility&quot; and &quot;Community Infrastructures&quot; issues.</td>
</tr>
<tr>
<td>Shall be calculated as the total number of two-wheeled motorized vehicles (TWMV) in the city (numerator) divided by the total city population (denominator).</td>
<td>shall be calculated as the total number of registered personal automobiles in a city (numerator) divided by the total city population (denominator)</td>
<td>shall be defined as a one-way commute (not round trip) and include only travel from home to place of employment</td>
</tr>
<tr>
<td>( = \frac{\text{N/A TWV/capita}}{} )</td>
<td>( = \frac{\text{Approximated number of registered personal cars in 2016}}{} )</td>
<td>ACT = 15.4 min.</td>
</tr>
<tr>
<td>( = \frac{\text{Population}}{} )</td>
<td>( = \frac{20,275}{58,220} = \text{0.348 car/capita} )</td>
<td></td>
</tr>
<tr>
<td>The city population in 2016 is 58220 (Transit Strategic Plan 2019). The actual number of registered personal cars could not be found. However, from Statistics Canada (StatCan) the number of people who commute by cars in 2016 is used instead. This is = 17965+2310=20,275. Ref: StatCan <a href="https://bit.ly/2F2if2y">https://bit.ly/2F2if2y</a></td>
<td>From the Strategic Plan 2019, Table 1-PP.4, the annual commute time is 15.4min for the city of Fredericton.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: 90 minute/Interview with the Manager of Transits and Parking at the City of Fredericton

**Expert Interview**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Maturity assessment of Fredericton Public Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>With</td>
<td>Manager of Transits and Parking at the City of Fredericton</td>
</tr>
<tr>
<td>By</td>
<td>A.S Graduate Researcher at the Civil Engineering Dept., UNB</td>
</tr>
<tr>
<td>Date</td>
<td>June 06, 2019 @ 1:30pm</td>
</tr>
</tbody>
</table>

**Topic engagement:**

I am developing an assessment model to assess the smartness of cities. This model provides a path for identify gaps and guide improvement of city domains. The model covers three aspects:

- **Intelligent connectivity** represents the use of modern technologies for better services/life quality.
- **Sustainability** represents the domain viable performance (effective, efficient, improving) that should have minimum/zero negative effects on the sustainability pillars (environment, economy, society).
- **Resiliency** represents the protection form losing or reducing the achieved levels of services and life quality.

**Fredericton public transit** has been chosen as a pilot sub-domain to be assessed by this model. The model has ten questions. I have developed preliminary answers to initiate the discussion. All of your comments will be incorporated in this interview minutes.

**The objectives of this interview** are to validate the determined answerers to the guiding questions of the developed assessment maturity model and to get your insights with respect to the differences between the performance-based assessment models and the maturity-based ones.

---

1. Does the city have an independent institution for this (Sub-) domain?

**Unique organizational unit** is available for Fredericton Transit that looks after the Public Transit. Its name is Fredericton Public Transit located at 470 May’s street. Fredericton, NB.

2. Does the domain collect and store/archive regularly (frequently) and automatically data relevant to improving the performance and life quality?

**Data collection** related to the service operation is being conducted but not automatically. For instance, no real-time customer feedback collector, no passenger counting system, and no internal/external camera systems are currently installed to count passengers, improve safety, and attract ridership by increasing the perception that safety is monitored and taken seriously. However, the system does have operator behaviors monitoring.

3. Does the domain process and analyze regularly (frequently) data relevant to improving the performance and life quality?

**Data processing** is not fully automatic. For instance, no automatic route planning functionality is available (limited), no alert functionality is available, and no on-demand/dynamic scheduling is available in any route. Additionally, the schedules are still based on paper maps. Currently, Fredericton Transit makes limited use of its somewhat outdated technology. Technology like automatic vehicle location (AVL) and automatic passenger counters (APC) can enable evidence-based decisions, such as route and service planning.
4. Does the domain communicate the results obtained or decisions to the relevant stockholders regularly (frequently) for the purpose of enhancing life quality?

**Results/Information communication** is very possible through the ReadyPass App. However, the technology does not support bi-directional communication to collect requests and feedback or even answer questions to the riders.

**Effective** = doing the right thing

5. Does this domain, identify and address the right factors to improve the life quality under the sustainability triple bottom line considerations?

**Effectiveness** is improving service/life quality based on automatically identifying the right factors or responses by exploiting the outcome of data processing. However, it does not appear to be an intelligent connection between the system and the riders to identify the right factors for life quality based on technology in terms of data collection, processing and communication. For example, there is no dynamic schedule update based on processing the collected feedback from the riders. In addition to that, there is no rider’s usage tracing functionality.

6. Does this domain address the correct factors based on following best practices that have no negative effects with respect to the sustainability triple bottom line considerations?

**Efficiency** is performing operations with minimum negative effects on the sustainability pillars (environment, society, economy) by taking advantages of the technology or following best practices. However, concerning the environmental aspect, the transit system still relies on diesel as its primary propulsion source for conventional buses.

7. Does this domain follow practices or have initiatives that are looking for opportunities (in the present time) for improvements that serve the citizens’ quality of life or positively affect the sustainability triple bottom line?

**Evolving** = continuous improvement and forward-looking for opportunities

**Evolution** is the improvement in the service/life quality or the positive effect on the sustainability pillars. Fredericton Transit is on the move toward vibrant and quality transit system. However, objective indicators to support that have not been developed or measured yet.

8. Does this domain have backups to protect the city from losing the achieved level of quality of life?

**Prevention** against losing the achieved service/life quality levels seems to exist. For instance, the institute has a buses’ maintenance plan to prevent sudden breakdown of buses, as well as has a number of seven spare buses which is higher than the peers’ average and industry standards.

9. Does this domain have the capacity to overcome and accommodate future shocks and changes?

**Adaptability** is the capacity of the transit system to accommodate sudden increase of the population. The system has 21 buses on the roads in the peak hours. So, theoretically, the system has 33% of extra capacity (7 buses) which is higher than the other peers.

10. Does this domain have forward-looking initiatives to anticipate the future opportunities and risks (shocks/changes) and proactively design acts to improve quality of life and protect the city from losing the achieved level of quality of life?

**Proactiveness** is the initiative to look in the future for continuous system improvement. *Fredericton Transit Strategic Plan* is a good periodical initiative for this. The management has assigned employees to monitor and control the progress towards the identified goals.

11. In comparison to the city of Fredericton indicators, which is the more informative model for you, CSR-MM or the city indicators?

It is clear to me that CSR-MM is more informative and effective in assessing the domains smartness.
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Do you agree that the ISO standards indicators are standardized and more comprehensive than the city of Fredericton indicators?</td>
<td>Yes, I agree.</td>
</tr>
<tr>
<td>13. In comparison to the ISO standards indicators, which is the more informative model for you, CSR-MM or the ISO indicators?</td>
<td>Yes, it is clear to me that the CSR-MM is more comprehensive and informative than the ISO indicators.</td>
</tr>
<tr>
<td>14. Do you agree on the advantages of the developed CSR-MM over the performance indicators of the City of Fredericton and/or the ISO indicators?</td>
<td>Yes, this clear. CSR-MM helped me to identify gaps and goals to be achieved.</td>
</tr>
<tr>
<td>15. Do you see any disadvantages or limitations in the developed CSR-MM model?</td>
<td>I have no comments.</td>
</tr>
<tr>
<td>16. Any other comments, suggestions, or recommendations?</td>
<td>No, it looks robust, attractive, and promising.</td>
</tr>
</tbody>
</table>
Curriculum Vitae

Candidate’s full name: Alaeldin Suliman

Universities attended (with dates and degrees obtained):

2017: Ph.D., Geomatics Engineering, University of New Brunswick, Canada
2014: Diploma in University Teaching, University of New Brunswick, Canada
2007: M.Sc., Civil-Surveying Engineering, University of Benghazi, Libya
2002: B.Sc., Civil Engineering, University of Benghazi, Libya

Publications:
