Using Fuzzy AHP for Investigating Barriers to the Development of Smart Mobility in Montrèal

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Abstract

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Mobility is a vital issue for residents and local governments, and it has an impact on sustainability, economy, and lifestyle [1]. Smart mobility focuses on real-time data accessibility [1]. Public Accessibility of real-time data helps smart mobility players to provide efficient, safe, sustainable, and high-quality transportation services [1]. This research aims to investigate and prioritize smart mobility barriers in the city of Montrèal to help decision-makers, policy planners, and smart mobility players to establish effective approaches for safer, smarter, and modern transportation systems in Montrèal [2]. In this research, firstly, 39 smart mobility barriers are identified using an integrative literature review. Secondly, the list of barriers modified by experts from the public, private, and multinational sectors to be compatible with mobility system and infrastructure in Montrèal. Lastly, the Fuzzy Analytical Hierarchy Process (AHP) method is used to prioritize identified barriers. Results show that financial barriers have a major impact on smart mobility development in Montrèal followed by "legal & regulatory", "technical & technological", "administrative", "information & awareness", "others", "social", "policy", "environmental".

Keywords: Smart Mobility, Fuzzy AHP, Smart Mobility Barriers, Prioritization, Montrèal.

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CHAPTER 1: INTRODUCTION

In this chapter, the concept of smart mobility and smart mobility barriers are discussed. Then the reason behind selecting the research topic as well as the goal and methodology steps of the research are provided, and in the end, the thesis outline is provided.

1.1 Smart Mobility

Smart mobility focuses on modern, sustainable, safer, and more efficient transport systems [3]. Information and Communications Technology (ICT), Intelligent Transportation Systems, and vehicle Technology are important pillars of smart mobility systems. Data in smart mobility systems are collected via different resources such as traffic management systems, citizens, vehicles, roads, etc. [3].

Smart mobility aims to improve transportation services, reduce environmental impacts, and optimize the time, money, and energy of the citizens [1].

Based on Freitas et al. (2017), the main areas of smart mobility are shown in Figure 1.

Figure 1 Smart Mobility Key Pillars [3]

- **Driving Safety and Intelligent Transport:** It is about technology for safe and secure interaction of cars with infrastructure around them and other vehicles [3].
- **Smart Lighting Systems:** Focus on technology provided for better lighting and energy-efficient systems that reduce traffic congestion [3].
- **Sharing and Urban Mobility:** Focuses on sustainability in urban transport and includes shared and multimodal transport systems [3].
- **Electric Mobility:** Focuses on climate, environment-friendly, and efficient modes of transport [3].
- **Green Mobility:** without impacting the growth momentum, decrease the environmental impact of the transportation sector [3].
- **Smart Payment Systems:** Focuses on the technologies overcome the limitations of the traditional pavement systems [3].
- **Smart Parking:** Detecting occupancy of the parking bays by using new technologies [3].

1.2 Smart Mobility Barriers

In the transition from traditional mobility systems to smart ones, some challenges and barriers need to be taken into account [2]. Investigating these challenges and barriers help city planners and researchers to come up with plans and solutions for more sustainable, smarter, connected, and efficient transportation systems [2].

1.3 Challenges and Motivation

The literature review showed:

- A limited number of studies investigated barriers in each smart city pillar.
- Just a few studies used specific tools and technics to prioritize and classify the barriers and
- A limited number of studies discuss smart city and mobility barriers in Canada and no study discusses smart mobility barriers in Montrèal.
- No study used both Integrative literature review and experts' opinion to investigate the barriers

Smart mobility was selected as a research topic because of the following reasons.

- most cities around the world face the problem of traffic congestion which impacts all the other smart city pillars. Besides, traffic congestion has a huge negative impact on the economy. Therefore, not only smart mobility reduces traffic congestion and improves traffic safety, but it also reaps economic benefits.
- according to Montréal's Finalist Application for the Smart Cities Challenge, the priority issue in Montrèal is a lack of inclusive and dynamic neighborhood life, therefore, smart mobility development can play a significant part and be a game-changer in this regard and increase the quality of life of Montrèalers.

1.4 Contribution

This research goal is to Investigate, categorize, and prioritize smart mobility barriers in the city of Montrèal.

In this study, at first, smart mobility barriers identified using an integrative literature review and then the list of barriers is modified for the city of Montrèal by mobility experts. After that barriers have been categorized under nine categories including policy, administrative, environmental, social, financial, technical & technological, information & awareness, legal & regulatory, and others. Lastly, Fuzzy Analytic Hierarchy Process (AHP) model is used to prioritize the barriers.

1.5 Outline of the thesis

In the next chapter, researches about smart city, smart city barriers, smart mobility, smart mobility barriers, and Fuzzy AHP/AHP method reviewed. In Chapter 3 smart mobility barriers investigated using literature review and experts' opinion. Then smart mobility barriers prioritized using Fuzzy AHP method. the results are shown, in Chapter 4, and. Chapter 5 presents the summary and conclusion of the thesis.

CHAPTER 2: LITERATURE REVIEW

The research studies with the subjects of smart city, smart city pillars, and smart city barriers as well as smart mobility, smart mobility barriers, and prioritization are reviewed in this section. Scopus, Science Direct, Google Scholar were used to find literature study papers by using the following keywords: ‘smart city development’, ‘barriers in smart city development’, ‘smart city pillars’, ‘smart mobility’, ‘smart mobility barriers’, etc.

2.1 Smart city introduction

Smart city notion is ambiguous, and its definition changes based on the need of each city [1]. Table 1 indicates different definitions of the smart city.

Table 1 Smart City Definitions

Author(s)	Year	Definition
Hall et al [2]	2000	A smart city is an efficient, environmentally friendly, secure, and safe city and it is about advanced and connected technologies.
Balaouras et al [3]	2010	A smart city delivers services to citizens efficiently and it helps citizens to make intelligent decisions about alternatives and actions.
Su et al [4]	2011	A smart city is about Information and communication technologies (ICT).
Lombardi et al [5]	2012	A smart city leads to urban growth and it is not just focused on ICT but it also focuses on social and relational capital, education, and environmental issues.
Söderström et al [6]	2014	Smart cities focus on technologies that optimize urban infrastructure and improve citizen’s quality of life.
Chandrasekar and Kumaran [7]	2019	A smart city is concentrated on technology and it links people, society, and information of the city by using recent technologies for developing a sustainable and greener city which includes competitive, innovative, and a better quality of life.
Mahesa et al [8]	2019	A smart city strategy is expected to solve urbanization problems.
Leon and Romanelli [9]	2019	Smart city projects lead to economic growth, high quality of life, and sustainability.
Suchita and Sujata [10]	2019	A smart city elevates Citizens' standard of living by improving governance, water, power, infrastructure, health, education, safety, and security.
Ahmed and Awasthi [1]	2018	In smart city data from roads, statistics, events collected to provide better city services to citizens.

2.2 Smart City Pillars

The six pillars of a smart city include smart mobility, smart people, smart economy, smart environment, smart living, and smart governance [1].

1. **Smart Mobility** optimizes traffic fluxes and improves the quality of public transport services. Pollution, traffic, and street congestion hurt citizen's quality of life therefore the role of smart mobility is crucial for the citizens' quality of life [11]. Smart mobility supports modern transportation systems. The modern transportation system is a sustainable, safe, and smart transportation system [1].
2. **Smart People** including citizen's data sharing to the government and government commitment to secure and protect data and it also includes integrating people into all other smart city pillars [1].
3. **Smart Economy** helps cooperation improvement among all sectors including public and private ones. Besides, it leads to equal wealth distribution among all citizens and economic growth by creating new innovative ideas [1].
4. **Smart Environment** focuses on approaches for monitoring, measuring, and controlling the use of natural conditions, fossil fuels, and renewable energy resources [12].
5. **Smart Living** aims to build better social infrastructure and it helps citizen's to be more connected to the city and its advancements. It also leads to better public health and safety [1].
6. **Smart Governance** focuses on ICT (Information and Communication Technologies) to improve customer involvement in all areas of public relevance and public security by protecting data and enhancing governance systems [1].

2.3 Smart City Barriers

Table 2 presents the key barriers of smart city projects in various countries including Canada, Malaysia, Egypt, Sweden, India, Spain, Greece, China, Japan, USA, and Ghana.

Table 2 Smart City Barriers

Author(s)	Year	Tools and Techniques	Region	Key Barriers
Ma and Lam [13]	2019	Social Network Analysis (SNA)	Hong Kong (China)	1- Lack of an open data policy 2- Lack of appropriate mechanism to encourage citizen involvement 3- Lack of appropriate infrastructure and legacy and regulatory systems
Mosannenzadeh et al [14]	2017	Empirical Approach and Novel Multi-Dimensional Methodology	Europe	1- Lacking or fragmented political support in the long term at the policy level 2- Lack of good cooperation and acceptance among project partners 3- Insufficient financial investments 4- The trained and experienced personnel shortage
Addae et al [15]	2019	Two-Step Fuzzy DEMATEL	Accra- Ghana	1- High-interest rate and unstable currency

				2- Inadequate infra-structure requiring huge investments 3- Insufficient financial investments in new technologies 4- Low awareness about renewable energy technologies
Lu et al [16]	2018	The Policy Network Theory	China	1- Overly ambitious visions 2- Unrealistic Goals 3- Ineffective policy instruments 4- Lack of tendency of local government.
Zhao and Shen [17]	2018	Literature Review	China	1- Fund problem 2- Policy barrier 3- Technical obstacle and service consciousness.
Jabber and Aluvalu [18]	2017	Literature Review	India	1- Security Challenges 2- Energy Management Challenges 3- Urbanization Challenges
Kaur et al [19]	2017	DEMATEL	Canada	1- Lack of environmental awareness 2- Lack of appropriate training systems 3- Lack of technical expertise 4- Lack of social cohesion or equity for reusable/recyclable product designs

Alexopoulos [20]	2018	Analysis Framework	Greece	1- Lack of experienced Personnel 2- financial reasons 3- Lack of acknowledgment from the side of citizens 4- Immature object
Veselitskaya et al [21]	2019	Descriptive Analysis	Barcelona (Spain)- Charlotte (USA), Shanghai (China), and Tokyo (Japan)	1- The conflict of interests between municipal authorities, citizens, and business 2- Land lease 3- Intellectual property protection 4- Confidentiality of personal information 5- Security of automated systems 6- Lack of opportunities for citizens to participate in city management 7- Lack of resources
Rana et al [22]	2018	Fuzzy Analytic Hierarchy Process (AHP) technique and Sensitivity Analysis	(India)	1- Political instability 2- Lack of cooperation and coordination between service providers 3- Poor private-public participation 4- Lack of an integrated information system model
Shahrokni et al [23]	2015	Smart Urban Metabolism	Stockholm (Sweden)	Accessing

		(SUM) Methodology		and integrating siloed data from the different data owners (utilities, building owners, and so forth).
Hamza [24]	2016	Multidiscipline Literature Review	Egypt	1- Weak integration of social, economic, and political needs 2- lack of appropriate approaches to the development of sustainable cities 3- lack of proper infrastructure, stable politics, and enough funding 4- Economic issues
Brohi et al [25]	2018	Literature Review	Malaysia	The barriers of environmentally friendly alternatives are as follow 1- Weather 2- Safety 3- Security 4- Inappropriate infrastructure
Biresselioglu et al [26]	2018	Literature Review	Europe	1- Lack of a clear definition 2- Embedded institutions and Inadequate regulations and policies 3- Too broad regulations

				4- Technical and market restrictions 5- Perceptions of risks and uncertainty 6- Operational/technical restrictions 7- Lack of information and awareness 8- risks and uncertainty 9- Lack of awareness about sustainability and environmental issues
Balta-Ozkan et al [27]	2013	Conducting Interviews and Workshops	UK	1- Reliability concerns 2- Security concerns

Table 3 indicates research studies about smart mobility development.

Table 3 Smart Mobility

Author(s)	**Year**	**Objectives**
Brohi et al [25]	2018	Analyzing air pollutants, public transport and smart city initiatives
Awasthi and Chauhan [29]	2011	Evaluating the impact of environment-friendly transport measures on city sustainability
Biresselioglu et al [30]	2018	Barriers and motivators analysis for electric mobility diffusion

Faria et al [31]	2013	Reviewing the current IoT technologies to the development of the smart city and smart mobility
Alonso et al [11]	2016	Developing an evaluation model about the mobility concept in smart cities
Bamwesigy and Hlavackova [32]	2019	Discussing sustainable and smart transport definitions for modern cities.
Aleta et al [33]	2017	Investigating Spanish smart city development initiatives regarding environmental and mobility issues.
Papa and Lauwers [34]	2015	Criticize current smart city approaches and discussed the main risks behind these approaches.
Haydar [35]	2020	Investigating Beirut's parking problems and potential impacts of shareable mobility, municipality policies, and smart public transportation system on reducing parking demands.
Tiwari [34]	2012	Discussing smart mobility barriers and suggest viable solutions.
Ollier [35]	2018	Discussing social justice, social development and transportation systems in the city of Montreal.
Porru et al [36]	2019	Comparing smart mobility solutions and challenges in an urban area and rural area.
Docherty et al [37]	2018	Discusses modes and methods of governance that could contribute to the smart mobility transition.
Miralles-Guasch and Domene [38]	2010	Discusses motivations, barriers, and user preferences of transportation systems at the University of Barcelona

Table 4 shows research studies using fuzzy AHP/AHP/hybrid methods to select, classify, and prioritize alternatives.

Table 4 Application of AHP Method for Prioritization

Author(s)	Year	Objectives
Calabrese et al [36]	2019	Using Fuzzy AHP method for analyzing sustainability issues
Ikram et al [37]	2020	Using AHP and G-TOPSIS approach for Prioritizing barriers of integrated management system (IMS) implementation
Singh and Sarkar [38]	2018	Prioritizing eco-design solutions Using Fuzzy AHP-TOPSIS method
Al Garni and Awasthi [39]	2017	Using Fuzzy AHP and GIS-based Approach for prioritizing the sites of solar PV
Zhou et al [40]	2019	Using Fuzzy AHP method to investigate and prioritize green supply chain management barriers
Hosseinzadeh et al [41]	2019	Investigating and prioritizing key success factors of knowledge-based organizations Using AHP approach
Boonkanit and Kantharos [42]	2016	Using AHP methodology for finding and prioritizing methods of industrial waste management
Chiouy et al [43]	2011	Identifying and prioritizing sustainable suppliers using Fuzzy AHP method
Kurniawan et al [44]	2017	Using AHP approach for smart operation room prioritization

2.4 Research gaps

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CHAPTER 3: RESEARCH METHODOLOGY

In this chapter, an appropriate Multiple-criteria decision-making (MCDM) methodology was selected for prioritizing smart mobility barriers using literature reviews and an interactive/automatic tool. Then methodology steps are provided.

3.1 Multiple-criteria decision-making (MCDM)

MCDM methodologies help users to select suitable plans/options/choices/categories, etc. between different alternatives based on various quantitative/qualitative criteria in certain/uncertain/risky environment [48].

MCDM is a reliable decision-making theory and that includes various methods and techniques [49]. These methods and techniques are widely used for comparative analysis and alternative evaluation [50].

Finding the most appropriate MCDM methodology is the first step for decision-makers.

3.2 Appropriate MCDM Approach

There are many factors to consider for choosing the most appropriate MCDM methodology [49]. Problem characteristics and the MCDM method's characteristics need to be considered [49].

For more certainty, four different sources are used to find a proper method.

Firstly, An Interactive /Automatic Tool for Selecting the MCDM Method created by Munier (2019) was used to find the most appropriate approach. A screenshot of the Interactive /Automatic Tool's result is shown in Figure 2.

In Figure 2 the different MCDM methods are in columns. They are listed in increasing capacity from left to right for scenarios modeling, and thus, Simple Additive Weighting (SAW) is the first with low capacity and SIMUS the last with the largest capacity. There are three areas:

The first area, 'Scenario characteristics' details the different criteria, or conditions that can exist in a scenario. The second area is the 'Membership matrix' that matches the different MCDM methods with every criterion. The third area is the right column that informs the total number of methods that can handle or match each characteristic.

The first row below the matrix indicates the total number of criteria chosen by the decision maker which is 7 in this case including Single scenario, Large projects involving people consultation, Quantitative criteria, Relationship between alternatives, Dependency between alternatives, Clustering, Necessity to evaluate criteria relative importance. The second row below the matrix shows the results or the total number of requirements that can handle each method. As can be seen, the highest score corresponds to the AHP method. The third row below the matrix shows the scores for each method. The lowest is considered the most appropriate for a determined scenario. The result of this tool reveals AHP technique is the best choice for this study.

	Scenario characteristics	Your problem and needs	SAW	AHP	TOPSIS	VIKOR	PROMETHEE	MOORA	ELECTRE	ANP	LP	SIMUS	Methods matching each scenario characteristics
			Working matrix										
1	Single scenario	1	1	1	1	1	1	1	1	1	1	1	10
2	Several scenarios												
3	An alternative may be in different scenarios												
4	Single objective												
5	Many objectives												
6	No rank reversal												
7	Necessity to have an optimal solution												
8	Several DMs (Group decision-making)												
9	Easiness to change the initial matrix												
10	Large projects involving people consultation	1											
11	Linguistic initial matrix												
12	Qualitative criteria												
13	Quantitative criteria	1											
14	Using a particular normalization procedure												
15	Using any normalization procedure												
16	Independent alternatives	1											
17	Relationship between alternatives												
18	Dependency between alternatives												
19	Large number of criteria												
20	Independent criteria (Compensatory methods)	1	1	1	1								3
21	Relationship between criteria												
22	Necessity of knowing criteria validity range												
23	Correlation between criteria												
24	Necessity to express criteria pos. actions (benefits)												
25	Necessity to express criteria neg. actions (costs)												
26	Criteria duality												
27	Low modeling & computing time(large projects)												
28	Clustering	1		1						1	1	1	4
29	Necessity to consider externalities												
30	Necessity to consider joint ventures												
31	Necessity to use resources												
32	Necessity to use thresholds in resources												
33	Necessity to link resources												
34	Performance values as linear functions												
35	Performance values as non-lineal functions												
36	Integer performance values												
37	Decimal performance values												
38	Objective performance values												
39	Subjective performance values												
40	Performance values expressed as math. formulas												
41	Performance values in binary format												
42	Negative performance values												
43	Result needed in integers												
44	Results needed in decimals												
45	Results needed in binary format												
46	Necessity to evaluate criteria relative importance	1	1	1	1	1	1	1	1	1			8
47	Want to use subjective weights												
48	Want to use objective weights												
49	All criteria with the same weight												
50	Sensitivity analysis (SA) with weights												
51	SAs with criteria marginal values												
52	A considering simultaneously all pertaining criteria												
53	Necessity to have graphics in SA												
54	No theoretical complexity												
	Total requirements for your problem	7											
	Total per method matching your requirements		3	4	3	2	2	2	2	3	2	2	
	Most appropriate method, the lower the better		4	3	4	5	5	5	5	4	5	5	

Figure 2 Interactive/Automatic Tool for Selecting the MCDM Method (Munier, 2019)

Secondly, based Haddad and Sanders (2018) [49], six scenarios considered for MCDM problems and this research study is under scenario one (Scenario one: criteria weights and risk factors that could affect criteria weights are unknown to the decision-makers) in this case AHP is recommended most.

Thirdly, In Velasquez and Hester (2013) [51] research study, different MCDM methods are reviewed and analyzed precisely, and based on this research, AHP is an advantageous method because it is scalable, easy to use, fits many sized problems and it is not data intensive.

Lastly, according to Mardani and et al (2015) [50], from 393 studies and their different application areas, the AHP technique has been used more than other MCDM techniques (32.57%).

Therefore, there is enough evidence that AHP is a great choice for this research study.

3.3 Analytic Hierarchy Process (AHP) Method

Analytic Hierarchy Process (AHP) is one of the popular methods of MCDM techniques for assessing and prioritizing alternatives under multiple criteria. AHP is a multicriteria tool for decision-making and it is used for prioritizing multiple-choice criteria into a hierarchy based on their importance and generating an overall rank of alternative [35].

Using pair-wise comparisons is the major characteristics of the AHP technique. pair-wise comparisons are used to compare alternative considering criteria and their weights [51].

3.4 Fuzzy AHP

Fuzzy logic deal with insufficient, uncertain, and imprecise data and the evolution of available knowledge [51].

Fuzzy AHP used as a methodology for this research because Fuzzy AHP is an extended version of AHP for dealing with the following problems:

1- Any changes in factors or alternatives lead to rank reversal problem or priority changes
2- The hypothesis of factors independence
3- Respondents bias and subjectivity for completing pair-wise comparisons
4- If respondents have divergent priorities and context is the same, consensus measure [22].

Fuzzy AHP analyzes complex system behavior and determines system variables relative importance for the evaluation of the responses [23]. Therefore, as human judgments are the important factors to prioritize smart mobility barriers, Fuzzy AHP technique is the most appropriate technique for this research study.

3.5 Implementation

This study aims to investigate, classify, and prioritize smart mobility barriers. Research methodology including four steps. First, smart mobility barriers list is prepared by performing an integrative literature review, then a list of barriers modified by experts to be compatible with Montréal mobility system. Second, identified barriers are classified into nine categories based on experts' suggestions: policy, administrative, environmental, social, financial, technical and technological, information and awareness, legal and regulatory, and others. The last step is to use Fuzzy AHP to prioritize the barriers to help smart mobility players and policymakers to focus on key barriers and develop efficient approaches. Figure 3 indicates the methodology steps of this research study.

1-Barrier Investigation	Montrèal smart mobility barriers identified using literature review and experts' consultation.
2-Barrier Classification	Finalized Barriers classified into nine different categories based on experts' opinion.
3- Barrier Prioritization	Fuzzy-AHP method used to prioritize barriers

Figure 3 Research Methodology

3.5.1 Step1: Barrier Investigation

Following 39 worldwide smart mobility barriers were found through an integrative literature review.

1- High IT infrastructure and intelligence deficit (N. P. Rana et al, 2018)

2- Lack of standard metrics for finding optimal routes (S. Porru, 2019)

3- Need for the employment of a dynamic definition of the optimal route (S. Porru, 2019)

4- Lack of policies and standards to promote adherence to air quality standards (J.Glasco, 2019)

5- Poor private-public partnership (PPPs) (N. P. Rana et al, 2018)

6- Lack of coordination between public authorities (S. Porru, 2019)

7- Lack of coordination between transport providers, urban planners, and social and environmental organizers (M. Ollier, 2018)

8- Lack of public participation

9- Complex and time-consuming authorization procedures for project activities (Mosannenzadeh et al., 2017)

10- Lack of sustainability considerations (N. P. Rana et al, 2018)

11- Lack of sustainable business models (S. Porru, 2019)

12- Lack of involvement of citizens (N. P. Rana et al, 2018)

13- Low acceptance of new projects and technologies (Mosannenzadeh et al., 2017)

14- Cost of training and skills development (N. P. Rana et al, 2018)

15- Global economy volatility (N. P. Rana et al, 2018)

16- Higher operational and maintenance cost (N. P. Rana et al, 2018)

17- Risk and uncertainty (Mosannenzadeh et al., 2017)

18- Privacy and security issues (N. P. Rana et al, 2018)

19- System failures issues (N. P. Rana et al, 2018)

20- Issues of integration and convergence for IT network (N. P. Rana et al, 2018)

21- Lack of scalable and available data (N. P. Rana et al, 2018)

22- Lack of integration of Transport Systems (S. Porru, 2019)

23- Lack of skilled and trained personnel (Mosannenzadeh et al., 2017)

24- Low awareness level of the community regarding the impact of smart mobility on their lives (My idea)

25- Lack of technological knowledge among the planners (N. P. Rana et al, 2018)

26- Lack of awareness among expert's regarding transport-related social cohesion or equity (M. Ollier, 2018)

27- Limited information about local needs (M. Ollier, 2018)

28- Lack of understanding of mobility challenges (M. Ollier, 2018)

29- Data openness issues (N. P. Rana et al, 2018)

30- Lack of policies, regulations, and directions (N. P. Rana et al, 2018)

31- Inadequate regulations for new technologies (Mosannenzadeh et al., 2017)

32- Regulatory instability (Mosannenzadeh et al., 2017)

33- Non-effective regulations (Mosannenzadeh et al., 2017)

34- Unfavorable local regulations for innovative technologies (Mosannenzadeh et al., 2017)

35- Insufficient or insecure financial incentives (Mosannenzadeh et al., 2017)

36- Inappropriate weather conditions (My idea)

37- Lack of cycling infrastructure (A. A. de Sousa et al, 2014)

38- Inappropriate road conditions (A. A. de Sousa et al, 2014)

39- Lack of physical and digital sustainable infrastructure to support innovative mobility solutions (J.Glasco, 2019)

This list of barriers modified by smart mobility experts to be compatible with mobility systems and current transportation infrastructure in Montrèal. The finalized list of barriers can be found as follow.

1- Sub-optimal use of IT infrastructure and intelligence (Paul Cote,2020)

2- Standardized metrics for finding optimal routes are not defined and/ or shared (Paul Cote,2020)

3- Lack of effective Private-Public Partnership (PPPs) (Paul Cote,2020)

4- Lack of effective coordination between public authorities (Paul Cote,2020)

5- Lack of coordination between transport providers, urban planners, and social and environmental organizers (M. Ollier, 2018)

6- Lack of public participation

7- Complex and time-consuming authorization procedures for project activities (Mosannenzadeh et al., 2017)

8- Lack of sustainability considerations (N. P. Rana et al, 2018)

9- Lack of sustainable local business models (Paul Cote,2020)

10- Lack of involvement of citizens (N. P. Rana et al, 2018)

11- Higher operational and maintenance cost (N. P. Rana et al, 2018)

12- Risk and uncertainty (Mosannenzadeh et al., 2017)

13- Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions (Paul Cote,2020)

14- Privacy and security issues (N. P. Rana et al, 2018)

15- Integration and convergence issues across IT networks (N. P. Rana et al, 2018)

16- Lack of integration of Transport Systems (S. Porru, 2019)

17- Lack of skilled and trained IT resources (Paul Cote,2020)

18- Lack of physical and digital sustainable infrastructure to support innovative mobility solutions (J.Glasco, 2019)

19- Low awareness level of the community regarding the impact of smart mobility on their lives (My idea)

20- Lack of awareness among expert's regarding transport-related social cohesion or equity (M. Ollier, 2018)

21- Data openness issues (N. P. Rana et al, 2018)

22- Regulations for new technologies are not accessible and they are not shared effectively (Paul Cote,2020)

23- Lack of updated regulations to reflect current and future industry environment (Paul Cote,2020

24- Insufficient financial investments (Paul Cote, 2020)

25- Inappropriate weather conditions (My idea)

26- Lack of cycling infrastructure (A. A. de Sousa et al, 2014)

27- Inappropriate road conditions (A. A. de Sousa et al, 2014)

28- Lack of appropriate pedestrian mobility infrastructure (Expert Opinion - Benoit Balmana, 2020)

29- A lot of organizations/players involved in mobility and this makes it complex to control and coordinate (Expert Opinion - Benoit Balmana, 2020)

30- Issues of retrofitting established transportation infrastructure (Expert Opinion- David Herz, 2020)

Experts were contacted via LinkedIn and ResearchGate. Totally 15 experts were selected to contact with but just six experts were interested in providing feedback on the list of worldwide smart mobility barriers. Table 5 Shows more detailed information of experts who accepted to respond to the survey in Appendix i.

Table 5 Experts' Demographic Information

Name	Position	Education	Work Experience
Hamed Esmaeeli	Senior Transport Planner & University Instructor	PhD, transportation/mobility management	12 years
Benoit Balmana	CEO (Experimenting smart and sustainable transport)	Master, Project Management	23 years

Jean-Francois Cantin	Advisor (Expert in urban mobility)	Industrial Engineer	19 years
Paul Côté	Strategic advisor	Bachelor- Social Science	24 years
Chunyan Lai	Assistant Professor (developing method to support new transport systems)	Ph.D., Electrical and Electronic Engineering	4 years
David Herz	Senior engineer (urban planning & transportation)	Master of Economics and Bachelor of Civil Engineer	12 years

3.5.2 Step2: Barrier Classification

Smart mobility barriers based on expert's opinions categorized into nine categories including policy, administrative, environmental, social, financial, technical & technological, information & awareness, legal & regulatory, and others. Table 6 Shows smart mobility barriers under each category.

Table 6 Smart Mobility Barrier Classification

Barrier Category	Barriers
Policy	**POL1-** Sub-optimal use of IT infrastructure and intelligence (Paul Cote,2020)
	POL2- Standardized metrics for finding optimal routes are not defined and/ or shared (Paul Cote,2020)
Administrative	**ADM1**- Lack of effective Private-Public Partnership (PPPs) (Paul Cote,2020)
	M2- Lack of effective coordination between public authorities (Paul Cote,2020)

	ADM3- Lack of coordination between transport providers, urban planners, and social and environmental organizers (M. Ollier, 2018)
	ADM4- Lack of public participation (N. P. Rana et al, 2018)
	ADM5- Complex and time-consuming authorization procedures for project activities [16]
Environmental	**ENV1**- Lack of sustainability considerations (N. P. Rana et al, 2018)
	ENV2- Lack of sustainable local business models (Paul Cote,2020)
Social	**SOC1**- Lack of involvement of citizens (N. P. Rana et al, 2018)
Financial	**FIN1**- Higher operational and maintenance cost (N. P. Rana et al, 2018)
	FIN2- Risk and uncertainty (Mosannenzadeh et al., 2017)
	FIN3- Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions (Paul Cote, 2020)
	FIN4- Insufficient financial investments (Paul Cote, 2020)
Technical & Technological	**T&T1**- Privacy and security issues (N. P. Rana et al, 2018)
	T&T2- Integration and convergence issues across IT networks (N. P. Rana et al, 2018)
	T&T3- Lack of integration of Transport Systems (S. Porru, 2019)
	T&T4- Lack of skilled and trained IT resources aul Cote,2020)
	T&T5- Lack of physical and digital sustainable infrastructure to support innovative mobility solutions (J.Glasco, 2019)
Information & Awareness	**I&A1**- Low awareness level of the community regarding the impact of smart mobility on their lives (My idea)

	I&A2- Lack of awareness among expert's regarding transport-related social cohesion or equity (M. Ollier, 2018)
Legal & Regulatory	**L&R1**- Data openness issues (N. P. Rana et al, 2018)
	L&R2- Regulations for new technologies are not accessible and they are not shared effectively (Paul Cote,2020)
	L&R3- Lack of updated regulations to reflect current and future industry environment (Paul Cote,2020)
Others	**OTH1**- Inappropriate weather conditions (My idea)
	OTH2- Lack of cycling infrastructure (A. A. de Sousa et al, 2014)
	OTH3- Inappropriate road conditions (A. A. de Sousa et al, 2014)
	OTH4- Lack of appropriate pedestrian mobility infrastructure (Balmana, 2020)
	OTH5- A lot of organizations/players involved in mobility and this makes it complex to control and coordinate (Expert Opinion - Benoit Balmana, 2020)
	OTH6- Issues of retrofitting established transportation infrastructure (Expert Opinion- David Herz, 2020)

3.5.3 Step3: Barrier Prioritization

Fuzzy AHP method is used for prioritizing Smart Mobility Barriers. Figure 4 shows Fuzzy AHP flowchart and it is presented by Al Garni et al (2016). This flowchart reveals the goal of using Fuzzy AHP method, planning, and Fuzzy AHP steps including fuzzification, fuzzy operations, defuzzification, and consistency checking of this research study.

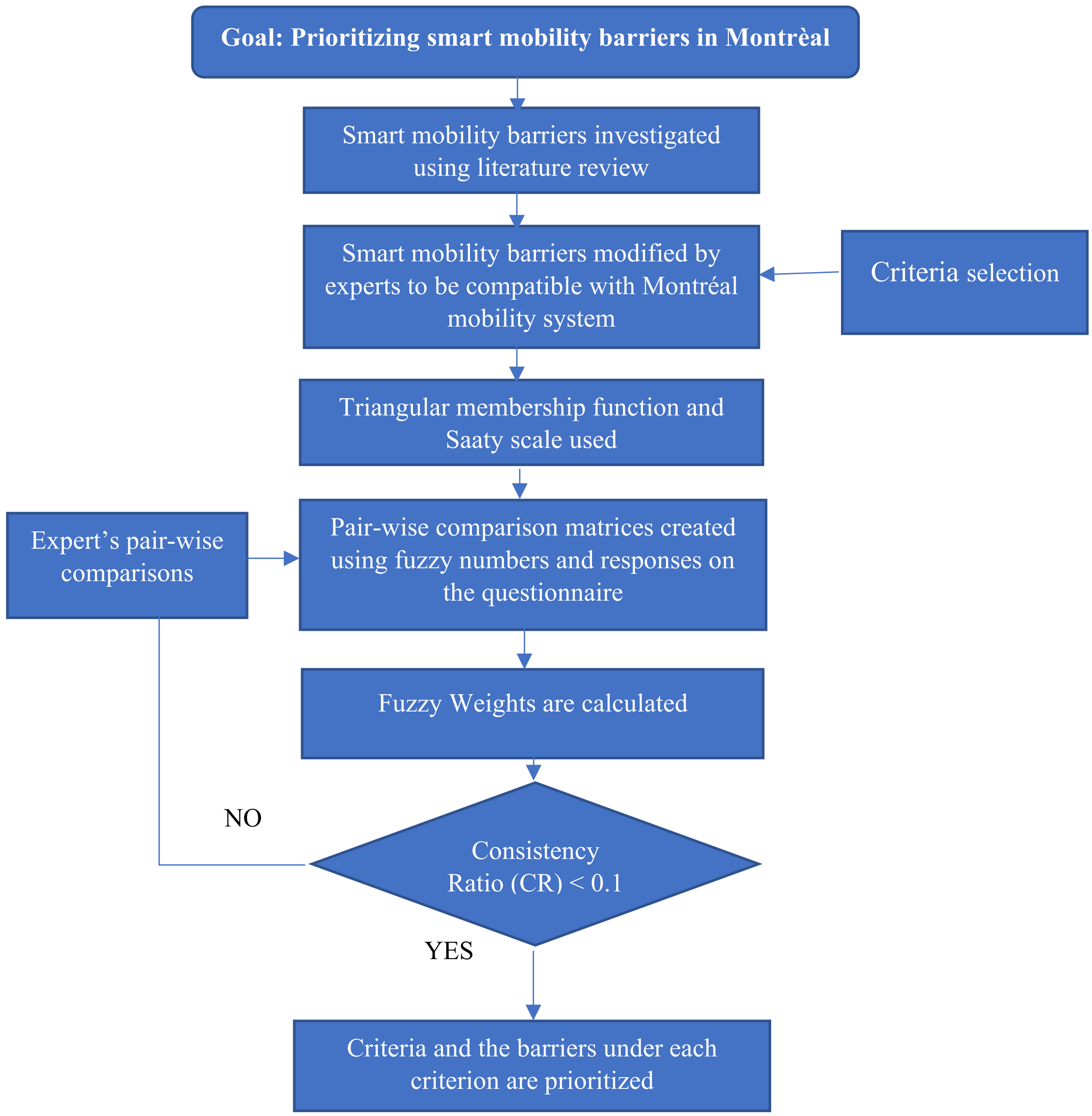

Figure 4 Fuzzy AHP Flowchart [52]

Nine criteria and 30 alternatives are defined by experts. Figure 5 indicates the Analytical Hierarchy Process Diagram including research goal, criteria, and alternatives of the study. This diagram is used by Sael et al (2019).

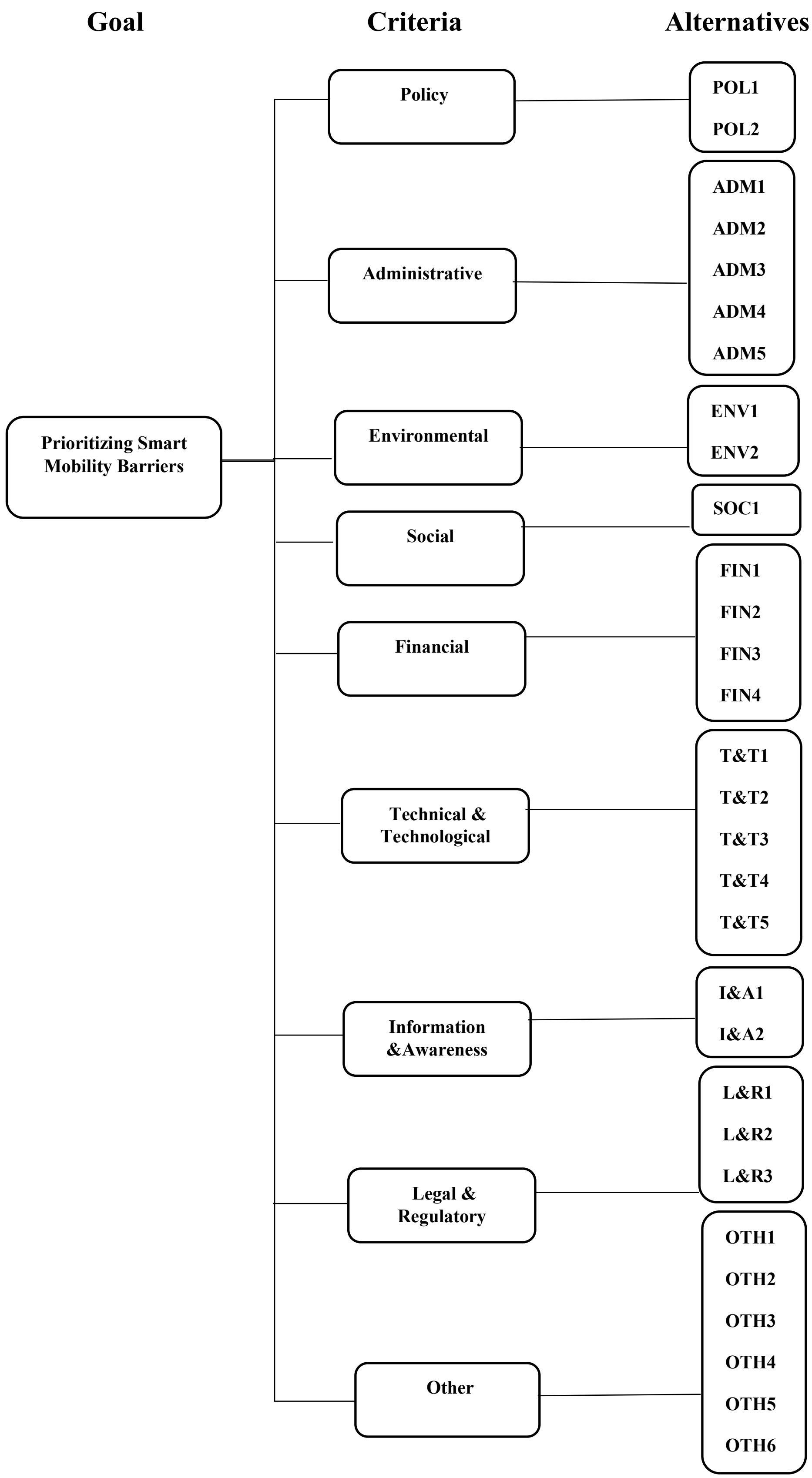

Figure 5 Analytical Hierarchy Process Diagram [53]

3.5.3.1 Questionnaire Development and Data Collection

A total of 15 experts who work in Montrèal as an urban transportation planner, transportation engineer, smart and sustainable transportation designer/planner, and urban mobility analyst/researcher, were contacted using LinkedIn and email. Four out of 15 experts provided their responses to the Fuzzy-AHP survey in Appendix ii. The detailed experts' background is provided in Table 7.

Table 7 Experts' Demographic Information

Name	Position	Education	Work Experience
Hamed Esmaeeli	Senior Transport Planner & University Instructor	PhD, transportation/mobility management	12 years
Assumpta Cerda	Project coordinator	Master of urban planning	12 years
Paul Côté	Strategic advisor	Bachelor- Social Science	24 years
David Herz	Senior engineer (urban planning & transportation)	Master of Economics and Bachelor of Civil Engineer	12 years

The questionnaire has three sections, section 1 is for personal information and the finalized list of smart mobility barriers can be found in section 2 as a reference for experts and section 3 has pairwise comparison tables. In section 3, the experts were asked to first compare nine smart mobility criteria with each other and then compare barriers under each criterion with each other using Saaty's scale as shown in table 8. Table 8 is presented by Harker (1987).

Table 8 Saaty's Scale of Importance Intensities [54]

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments

3.5.3.2 Fuzzy Pairwise Assessment Matrix

When the experts performed pairwise comparisons using the Saaty scale shown in table 8. The scale of relative importance converted to fuzzy numbers using a triangular membership function.

$\tilde{A}$ includes the fuzzification of judgments of all pairwise comparisons.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1,1,1) \end{bmatrix}$$

(1)[55]

$\tilde{a}_{ij}$ = they are triangular fuzzy numbers and they represent the comparison between i and j

$i,j \in \{1,2, \ldots,n\}$[55].

$\tilde{a}_{ij}$ represented by $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. l_{ij} is the lower bound, u_{ij} is the upper bound and m_{ij} is between l_{ij} and u_{ij} ($l_{ij} \leq m_{ij} \leq u_{ij}$) [55].

Triangular membership function defined in equation 2.

$$\mu(x) = \begin{cases} \frac{x-l}{m-l}, & x \in [l,m], \\ \frac{u-x}{u-m}, & x \in [m,u], \\ 0, & otherwise \end{cases}$$ (2) [55]

And reciprocal values represented by $\tilde{a}_{ji} = (\frac{1}{uij}, \frac{1}{mij}, \frac{1}{lij})$

Table 9. shows fuzzy numbers concerning the scale of relative importance and it is presented by Pamucar (2016).

Table 9 Fuzzification of the Saaty's Scale [56]

Definition	Standard Value	Fuzzy Numbers	Reciprocal Fuzzy Numbers
The same importance	1	(1,1,1)	(1,1,1)
Weak dominance	3	(2,3,4)	$(\frac{1}{4}, \frac{1}{3}, \frac{1}{2})$
Strong dominance	5	(4,5,6)	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{4})$
Very strong dominance	7	(6,7,8)	$(\frac{1}{8}, \frac{1}{7}, \frac{1}{6})$
Absolute dominance	9	(9,9,9)	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{9})$

3.5.3.2.1 Fuzzy Weights

After creating fuzzified pairwise comparison matrices using fuzzy numbers, the geometric mean values are calculated.

Fuzzy geometric mean values calculated by the following formula:

$$\tilde{r}_i = [\tilde{a}_{i1} \otimes \ldots \otimes \tilde{a}_{in}]^{1/n}$$ (3) [55]

$\tilde{a}_{in}$ = Pairwise comparison between i and n

n= Totall number of criteria

After that the Eq. 4 is used to calculate fuzzy weights:

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\sum_{i=1}^{n} \tilde{r}_i \right)^{-1}, i = 1, 2, \ldots, n$$

(4) [55]

i= row number in each comparison table

n= number of criteria/ alternatives in each comparison table

3.5.3.2.2 De-Fuzzification

Fuzzy wights are de-fuzzified by using the Center of Area (COA) formula and normalized.

Center of Area (COA) equation defined as follows:

$$w_i = \frac{l_i + m_i + u_i}{3}, i = 1, 2, \ldots, n$$

(5) [57]

3.5.3.2.2 Calculating the consistency

Consistency ratio measures the judgments' consistency [58]. If CR is not less than 0.1, responses are not acceptable and they are considered to be purely random judgments and it is recommended to review the judgments or ask respondents to provide their answers again [58].

CR is obtained through Eq. 6

$$C.R. = \frac{C.I.}{R.I.}$$

(6)[59]

R.I. is a random consistency index and it depends on the size of the pairwise comparison matrix. [46].

C.I. is consistency index and it is obtained through Eq. 7

$$C.I. = \frac{\lambda_{\max} - n}{n - 1}$$

(7) [59]

where λ_{max} is the largest eigenvalue of the comparison matrix; and n is the size of the matrix [59].

CHAPTER 4: RESULT AND DISCUSSION

Totally seven experts participated in the study who are from academia and the transportation/urban mobility/urban planning industry. As shown in Figure 6 most of them have more than 11 years of professional experience.

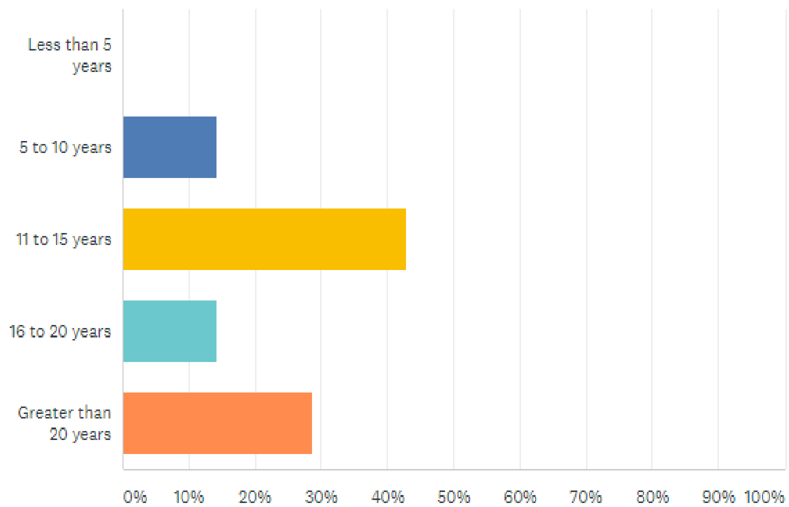

Figure 6 Expert's Professional Work Experience

Figure 7 reveals most of the experts are working in the public sectors.

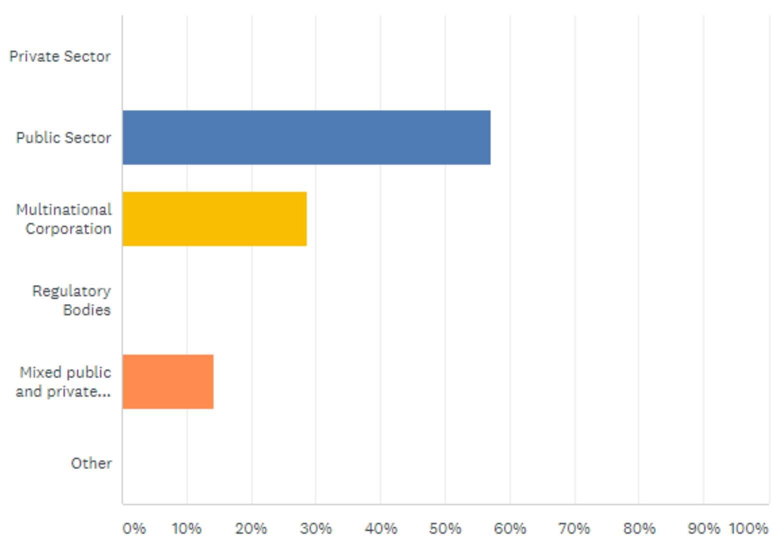

Figure 7 Expert's Work Profile Classification

Four experts have completed comparison tables in the Fuzzy AHP survey in Appendix ii.

First, smart mobility experts were asked to complete a comparison table for nine smart mobility criteria and their responses are incorporated by geometric mean. Figure 8 shows a pairwise comparison matrix of nine smart mobility criteria after incorporating experts' responses.

	POL			ADM			ENV			SOC			FIN			T& T			I & A			L & R			OTH		
Policy	1	1	1	0.904	1	1.107	1	1.14	1.32	0.71	0.76	0.84	0.33	0.33	0.33	0.64	0.76	0.93	0.59	0.61	0.64	0.58	0.58	0.58	0.78	0.88	1.03
Administrative	0.9036	1	1.107	1	1	1	1.414	1.7	2.06	2.21	2.43	2.63	0.52	0.58	0.64	0.71	0.76	0.84	0.64	0.45	0.5	0.45	0.51	0.59	1.52	1.97	2.45
Environmental	0.7598	0.88	1	0.408	0.447	0.5	1	1	1	1.68	1.97	2.21	0.4	0.44	0.47	0.76	0.88	1	0.41	0.45	0.5	0.49	0.58	0.69	0.45	0.51	0.59
Social	1	1	1	0.38	0.411	0.452	0.452	0.51	0.59	1	1	1	0.74	0.81	0.88	0.76	0.88	1	1.19	1.32	1.41	0.97	1.14	1.28	1.11	1.16	1.22
Financial	3	3	3	1.565	1.732	1.917	3	3	3	1.14	1.23	1.36	1	1	1	1.41	1.5	1.57	1.92	2.01	2.12	1.11	1.16	1.22	1.92	2.01	2.12
Technical & Technological	1.0746	1.316	1.565	1.189	1.316	1.414	1	1	1	1	1	1	1	1	1	1	1	1	0.9	1	1.11	1	1	1	0.82	1	1.22
Information & Awareness	1.5651	1.627	1.682	1.565	2	2.236	2	2.24	2.45	1	1	1	0.47	0.5	0.52	0.9	1	1.11	1	1	1	0.24	0.27	0.31	0.49	0.59	0.71
Legal & Regulatory	1	1	1	1	1	1	1.456	1.73	2.06	0.78	0.88	1.03	0.82	0.86	0.9	1	1	1	3.22	3.71	4.12	1	1	1	1.11	1.26	1.46
Others	0.971	1.136	1.278	0.408	0.508	0.658	1.682	1.97	2.21	0.82	0.86	0.9	0.33	0.33	0.33	0.82	1	1.22	1.41	1.7	2.06	0.69	0.79	0.9	1	1	1

Figure 8 Pairwise Comparison Matrix of Smart Mobility Criteria

Then, fuzzy geometric mean values calculated using Eq. 3. For example, fuzzy geometric mean value of policy criterion can be found as follow:

$\tilde{r}_{policy} = ((1\times 0.9036\times 1\times 0.7071\times 0.333 \times 0.6389 \times 0.5946 \times 0.5773 \times 0.7825)^{1/9}$

$,(1\times 1 \times 1.1362 \times 0.7598 \times 0.3333 \times 0.7598 \times 0.6147 \times 0.5773 \times 0.8801)^{1/9},$

$(1\times 1.1066 \times 1.3160 \times 0.8409 \times 0.3333 \times 0.9306 \times 0.6389 \times 05773 \times 1.029)^{1/9} = (0.6923,$

$0.7421, 0.8064)$

$\tilde{r}_i$ for the other eight criteria are calculated and table 10 shows the results.

Table 10 Fuzzy Geometric Mean Values

Smart Mobility Category	**Fuzzy Geometric Mean**		
Policy	0.692358245	0.742160966	0.806487627
Administrative	0.916831471	0.976961178	1.099463985

Environmental	0.622670709	0.697822382	0.779692645
Social	0.792254069	0.860323125	0.930254629
Financial	1.6533554	1.72329009	1.803336221
Technical & Technological	0.99347786	1.06293507	1.129830964
Information & Awareness	0.855681723	0.940466654	1.017263605
Legal & Regulatory	1.142628091	1.223597084	1.311775183
Others	0.806184108	0.913032787	1.027619803

After that fuzzy weights are calculated using Eq. 4. For example, policy fuzzy weight can be obtained as follow:

$\tilde{w}_{Policy}$= (0.6923, 0.7421, 0.8064) × ((1/9.905), (1/9.140), (1/8.475)) = (0.069, 0.081, 0.095)

Fuzzy weights are calculated for the other eight criteria and they are de-fuzzified using Eq. 5. Results in table 10 and figure 8 reveal that financial barriers are the most important barriers to smart mobility development in Montrèal.

Table 11 Fuzzy Weights of the Criteria

Smart Mobility Category	**Fuzzy Weights**			**Defuzzification**	**Normalization**
Policy	0.06989476	0.081193995	0.095155823	0.082081526	0.081420214
Administrative	0.092555719	0.10688164	0.129723503	0.109720287	0.108836296
Environmental	0.062859683	0.076343259	0.091994338	0.07706576	0.076444859
Social	0.079979416	0.094121188	0.109758838	0.094619814	0.093857484
Financial	0.166909081	0.188531617	0.212771946	0.189404215	0.187878229

Technical & Technological	0.100293305	0.116287367	0.133306441	0.116629038	0.115689384
Information & Awareness	0.086382547	0.102889061	0.120024849	0.103098819	0.102268175
Legal & Regulatory	0.115350278	0.133864135	0.154773666	0.134662693	0.133577747
Others	0.081385677	0.099887737	0.121246755	0.100840057	0.100027612

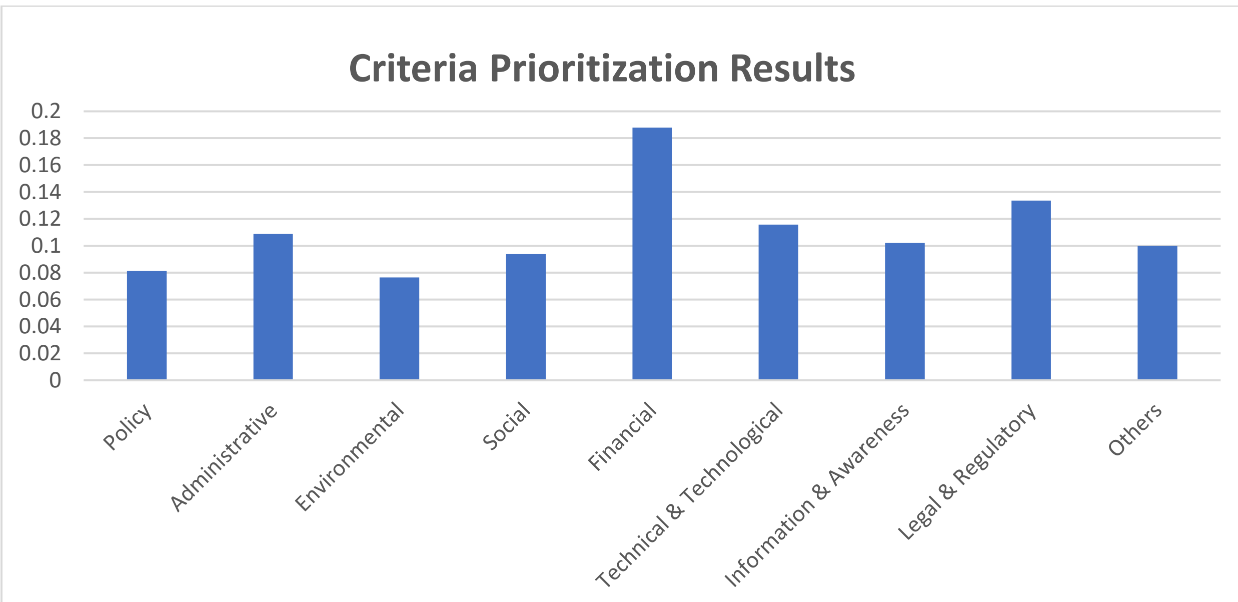

Figure 9 Criteria Prioritization Results

Fuzzy weights of barriers under each of the nine categories are in Appendix iii.

The ranking of smart mobility barriers under nine categories can be found in the following tables.

Table 12 "Financial" Barriers Ranking

1. Financial
1. Insufficient financial investments (FIN4)
2. Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions (FIN3)
3. Risk and uncertainty (FIN2)
4. Higher operational and maintenance cost (FIN1)

Table 13 "Legal & Regulatory" Barriers Ranking

2. Legal & Regulatory
1. Lack of updated regulations to reflect current and future industry environment (L&R3)
2. Regulations for new technologies are not accessible and they are not shared effectively (L&R2)
3. Data openness issues (L&R1)

Table 14 "Technical & Technological" Barriers Ranking

3. Technical & Technological
1. Privacy and security issues (TECH1)
2. Lack of integration of Transport Systems (TECH3)
3. Lack of physical and digital sustainable infrastructure to support innovative mobility solutions (TECH5)
4. Integration and convergence issues across IT networks (TECH2)
5. Lack of skilled and trained IT resources (TECH4)

Table 15 "Administrative" Barriers Ranking

4. Administrative
1. Lack of coordination between transport providers, urban planners, and social and environmental organizers (ADM3)
2. Lack of effective coordination between public authorities (ADM2)
3. Lack of public participation (ADM4)
4. Long and complex procedures for the authorization of project activities (ADM5)
5. Lack of effective Private-Public partnership (PPPs) (ADM1)

Table 16 "Information & Awareness" Barriers Ranking

5. Information & Awareness
1. Lack of awareness among expert's regarding transport-related social cohesion or equity (I&A2)
2. Low awareness level of the community regarding the impact of smart mobility on their lives (I &A1)

Table 17 "Other" Barriers Ranking

6. Other
1. Issues of retrofitting established transportation infrastructure (OTHER6)
2. A lot of organizations/players involved in mobility and this makes it complex to control and coordinate (OTHER5)
3. Inappropriate weather conditions (OTHER1)
4. Lack of cycling infrastructure (OTHER2)
5. Lack of appropriate pedestrian mobility infrastructure (OTHER4)
6. Inappropriate road conditions (OTHER3)

Table 18 "Social" Barriers Ranking

7. Social
1. Lack of involvement of citizens (SOC1)

Table 19 "Policy" Barriers Ranking

8. Policy
1. IT infrastructure and intelligence not optimized (POL1)
2. Standardized metrics for finding optimal routes are not consolidate and/ or shared (POL2)

Table 20 "Environmental" Barriers Ranking

9. Environmental
1. Lack of sustainability considerations (ENV1)
2. Lack of sustainable local business models (ENV2)

In this research consistency ratio (CR) is checked for each comparison table using Eq. 6. CR for all matrices is less than 0.1. Therefore, all the judgments are consistent for prioritizing smart mobility barriers.

CHAPTER 5: CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

Smart mobility improves citizens quality of life by reducing traffic congestion and improving traffic safety and investigating barriers to the development of smart mobility help city planners and service provider in the transition from the current transportation system to the smart one. This research aims to investigate and prioritize barriers to help decision-makers to find effective approaches for modern, safe, and sustainable mobility systems in Montrèal. Initially, 39 smart mobility barriers have been defined using an integrative literature review. Then, the list of barriers modified by experts to be compatible with Montréal mobility system.

Results show that 30 smart mobility barriers have been defined for the city of the Montrèal and they have been categorized under nine different categories (policy, administrative, environmental, social, financial, technical & technological, information & awareness, legal & regulatory, and other).

These barriers are prioritized using Fuzzy AHP method and findings show that, among nine smart mobility categories, the financial category has the highest priority followed by "legal and regulatory", "technical & technological", "administrative", "information & awareness", "other", "social", "policy" and "environmental. Finally, the global preference weights of barriers under each category are determined.

5.2 SWOT Analysis

Strengths, weaknesses, opportunities and threats of this research study are analyzed as follow.

- **Strength:**

1- Research Topic: The literature review shows A limited number of studies investigated smart mobility barriers and it also shows investigating and prioritizing smart mobility barriers in Montrèal is a unique research topic.

2- Experts' background: Very knowledgeable and highly experienced experts accepted to participate in this research.

3- Prioritization technique: Detailed analysis was implemented to find the most appropriate MCDM method to prioritize the barriers.

- **Weakness:**

1- Number of Respondents: The number of respondents is very important in the questionnaire-based research studied. In this study, seven experts shared their knowledge. It is recommended to have more respondents to have more valid and comprehensive results.

- **Opportunity:**

This research aims to help decision-makers, policy planners, and smart mobility players to establish effective approaches for safer, smarter, and modern transportation systems in Montrèal.

- **Threat:**

1- Biased responses: Biased responses lead to unreliable results.

5.3 Future Works

Due to the COVID-19 situation, face-to-face interviews with smart mobility experts and participating in workshops and conferences to contact with smart mobility experts is impossible.

Thus, experts were contacted via LinkedIn and seven of them accepted to participate in this research. For future work, it is recommended to have more respondents to come up with better results.

For future work, barriers can be evaluated further using DEMATEL techniques to find the barriers to casual relations [23]. Future research could suggest solutions for defined barriers and explore drivers of smart mobility development. It is also recommended to perform Sensitivity Analysis to verify the findings. Moreover, the researchers could investigate the other five smart city pillars' (smart people, smart economy, smart environment, smart living, smart governance) barriers for the city of Montrèal.

Appendix i

Questionnaire

Section 1: Personnel Information

1. Your professional qualification:
   ☐Bachelor
   ☐Master
   ☐Ph.D
   ☐Other

2. Your Occupation category:
   ☐Academic
   ☐Professional
   ☐Technical Expert
   ☐Designer
   ☐Administrator/Manager
   ☐If any other, please specify_________________

3. Your related work experience:
   ☐Less than 5 years
   ☐5 to 10 years
   ☐11 to 15 years
   ☐16 to 20 years
   ☐Greater than 20 years

4. Your work profile classification:
   ☐Private Sector
   ☐Public Sector
   ☐Multinational Corporation
   ☐Regulatory Bodies
   ☐Mixed public and private ownership
   ☐If any other, please specify_________________

Section 2: Barrier verification for the city of Montreal

5. The following table shows the list of worldwide smart mobility barriers. Please verify each barrier for the city of Montreal.

Barrier Category	Barriers	YES/NO	Comment
Policy	High IT infrastructure and intelligence deficit		
	Lack of standard metrics for finding optimal routes		
	Need for the employment of a dynamic definition of the optimal route		
	Lack of policies and standards to promote adherence to air quality standards		
Administrative	Poor private-public partnership (PPPs)		
	Lack of coordination between public authorities		
	Lack of coordination between transport providers, urban planners, and social and environmental organizers		
	Lack of public participation		
	Complex and time-consuming authorization procedures for project activities		
Environmental	Lack of sustainability considerations		
	Lack of sustainable business models		
Social	Lack of social involvement		
	Low acceptance of new projects and technologies		
Financial	High cost of training		
	Economical instability		
	High cost of maintenance and operation		
	Risk and uncertainty		
Technical & Technological	Issues of Privacy and security		
	Systematic failures		
	Issues of integration and convergence for IT network		
	Lack of scalable and available data		
	Lack of integration of Transport Systems		
	Shortage of trained and experienced personnel		
Information & Awareness	Low awareness level of the community regarding the impact of smart mobility on their lives		
	Lacking technological knowledge among the planners		
	Lack of awareness among expert's regarding transport-related social cohesion or equity		
	Limited information about local needs		
	Lack of understanding of mobility challenges		
	Data openness issues		

Legal & Regulatory	Lack of policies and regulations		
	Lack of directions/rules for new technologies		
	Instable regulations		
	Non-effective regulations		
	Unfavorable local regulations for innovative technologies		
	Inadequate financial investments		
Others	Inappropriate weather conditions		
	Lack of cycling infrastructure		
	Inappropriate road conditions		
	Lack of physical and digital sustainable infrastructure to support innovative mobility solutions		

If any other smart mobility barriers applicable for the city of Montreal, please specify: ____

____

____

____

Appendix ii

Fuzzy AHP Questionnaire

Section 1: Personnel Information

1. Your professional qualification:

   ☐Bachelor
   ☐Master
   ☐Ph.D
   ☐Other

2. Your Occupation category:

   ☐Academic
   ☐Professional
   ☐Technical Expert
   ☐Designer
   ☐Administrator/Manager
   ☐If any other, please specify_________________

3. Your related work experience:
   ☐Less than 5 years
   ☐5 to 10 years
   ☐11 to 15 years
   ☐16 to 20 years
   ☐Greater than 20 years

4. Your work profile classification:
   ☐Private Sector
   ☐Public Sector
   ☐Multinational Corporation
   ☐Regulatory Bodies
   ☐Mixed public and private ownership
   ☐If any other, please specify_________________

Section 2: Barrier prioritization

Please kindly find the following table containing smart mobility barriers using extensive literature review and experts' opinions under nine categories including policy, administrative, environmental, social, financial, technical and technological, information and awareness, legal and regulatory, and others.

Barrier Category	Barriers
Policy	**POL1-** Sub-optimal use of IT infrastructure and intelligence
	POL2- Standardized metrics for finding optimal routes are not defined and/ or shared
Administrative	**ADM1**- Lack of effective Private-Public Partnership (PPPs)
	ADM2- Lack of effective coordination between public authorities
	ADM3- Lack of coordination between transport providers, urban planners, and social and environmental organizers
	ADM4- Lack of public participation
	ADM5- Complex and time-consuming authorization procedures for project activities
Environmental	**ENV1**- Lack of sustainability considerations
	ENV2- Lack of sustainable local business models
Social	**SOC1**- Lack of involvement of citizens
Financial	**FIN1**- Higher operational and maintenance cost
	FIN2- Risk and uncertainty
	FIN3- Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions
	FIN4- Insufficient financial investments
Technical & Technological	**T&T1**- Privacy and security issues
	T&T2- Integration and convergence issues across IT networks
	T&T3- Lack of integration of Transport Systems
	T&T4- Lack of skilled and trained IT resources

	T&T5- Lack of physical and digital sustainable infrastructure to support innovative mobility solutions
Information & Awareness	**I&A1**- Low awareness level of the community regarding the impact of smart mobility on their lives
	I&A2- Lack of awareness among expert's regarding transport-related social cohesion or equity
Legal & Regulatory	**L&R1**- Data openness issues
	L&R2- Regulations for new technologies are not accessible and they are not shared effectively
	L&R3- Lack of updated regulations to reflect current and future industry environment
Others	**OTH1**- Inappropriate weather conditions
	OTH2- Lack of cycling infrastructure
	OTH3- Inappropriate road conditions
	OTH4- Lack of appropriate pedestrian mobility infrastructure
	OTH5- A lot of organizations/players involved in mobility and this makes it complex to control and coordinate
	OTH6- Issues of retrofitting established transportation infrastructure

5. Please compare each Smart mobility category with each other.

Please select one number per row below using the scale:

1=Equal 3=Moderate 5= Strong 7=Very strong 9=Extreme

Policy	9	7	5	3	1	3	5	7	9	Administrative
Administrative	9	7	5	3	1	3	5	7	9	Environmental
Environmental	9	7	5	3	1	3	5	7	9	Social
Social	9	7	5	3	1	3	5	7	9	Financial
Financial	9	7	5	3	1	3	5	7	9	Technical & Technological
Technical & Technological	9	7	5	3	1	3	5	7	9	Information & Awareness
Information & Awareness	9	7	5	3	1	3	5	7	9	Legal & Regulatory
Legal & Regulatory	9	7	5	3	1	3	5	7	9	Others
Others	9	7	5	3	1	3	5	7	9	Policy
Policy	9	7	5	3	1	3	5	7	9	Environmental
Administrative	9	7	5	3	1	3	5	7	9	Social
Environmental	9	7	5	3	1	3	5	7	9	Financial
Social	9	7	5	3	1	3	5	7	9	Technical & Technological
Financial	9	7	5	3	1	3	5	7	9	Information & Awareness
Technical & Technological	9	7	5	3	1	3	5	7	9	Legal & Regulatory
Information & Awareness	9	7	5	3	1	3	5	7	9	Others
Legal & Regulatory	9	7	5	3	1	3	5	7	9	Policy
Others	9	7	5	3	1	3	5	7	9	Administrative
Policy	9	7	5	3	1	3	5	7	9	Social
Administrative	9	7	5	3	1	3	5	7	9	Financial
Environmental	9	7	5	3	1	3	5	7	9	Technical & Technological
Social	9	7	5	3	1	3	5	7	9	Information & Awareness
Financial	9	7	5	3	1	3	5	7	9	Legal & Regulatory
Technical & Technological	9	7	5	3	1	3	5	7	9	Others
Information & Awareness	9	7	5	3	1	3	5	7	9	Policy
Legal & Regulatory	9	7	5	3	1	3	5	7	9	Administrative

Others	9	7	5	3	1	3	5	7	9	Environmental
Policy	9	7	5	3	1	3	5	7	9	Financial
Administrative	9	7	5	3	1	3	5	7	9	Technical & Technological
Environmental	9	7	5	3	1	3	5	7	9	Information & Awareness
Social	9	7	5	3	1	3	5	7	9	Legal & Regulatory
Financial	9	7	5	3	1	3	5	7	9	Others
Technical & Technological	9	7	5	3	1	3	5	7	9	Policy
Information & Awareness	9	7	5	3	1	3	5	7	9	Administrative
Legal & Regulatory	9	7	5	3	1	3	5	7	9	Environmental
Others	9	7	5	3	1	3	5	7	9	Social

6. Please compare each Smart mobility barriers with each other.

Please select one number per row below using the scale:

1=Equal 3=Moderate 5= Strong 7=Very strong 9=Extreme

Sub-optimal use of IT infrastructure and intelligence **(POL1)**	9	7	5	3	1	3	5	7	9	Standardized metrics for finding optimal routes are not defined and/ or shared **(POL2)**

Lack of effective Private-Public Partnership (PPPs) **(ADM1)**	9	7	5	3	1	3	5	7	9	Lack of effective coordination between public authorities **(ADM2)**
Lack of effective coordination between public authorities **(ADM2)**	9	7	5	3	1	3	5	7	9	Lack of coordination between transport providers, urban planners, and social and environmental organizers **(ADM3)**
Lack of coordination between transport providers, urban planners, and social and environmental organizers **(ADM3)**	9	7	5	3	1	3	5	7	9	Lack of public participation **(ADM4)**

Lack of public participation **(ADM4)**	9	7	5	3	1	3	5	7	9	Complex and time-consuming authorisation procedures for project activities **(ADM5)**
Complex and time-consuming authorisation procedures for project activities **(ADM5)**	9	7	5	3	1	3	5	7	9	Lack of effective Private-Public Partnership (PPPs) **(ADM1)**
Lack of effective Private-Public Partnership (PPPs) **(ADM1)**	9	7	5	3	1	3	5	7	9	Lack of coordination between transport providers, urban planners, and social and environmental organizers **(ADM3)**
Lack of effective coordination between public authorities **(ADM2)**	9	7	5	3	1	3	5	7	9	Lack of public participation **(ADM4)**
Lack of coordination between transport providers, urban planners, and social and environmental organizers **(ADM3)**	9	7	5	3	1	3	5	7	9	Complex and time-consuming authorization procedures for project activities **(ADM5)**
Lack of public participation **(ADM4)**	9	7	5	3	1	3	5	7	9	Lack of effective Private-Public Partnership (PPPs) **(ADM1)**
Complex and time-consuming authorization procedures for project activities **(ADM5)**	9	7	5	3	1	3	5	7	9	Lack of effective coordination between public authorities **(ADM2)**

Lack of sustainability considerations **(ENV1)**	9	7	5	3	1	3	5	7	9	Lack of sustainable local business models **(ENV2)**

Higher operational and maintenance cost **(FIN1)**	9	7	5	3	1	3	5	7	9	Risk and uncertainty **(FIN2)**
Risk and uncertainty **(FIN2)**	9	7	5	3	1	3	5	7	9	Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions **(FIN3)**
Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions **(FIN3)**	9	7	5	3	1	3	5	7	9	Insufficient financial investments **(FIN4)**

Higher operational and maintenance cost **(FIN1)**	9	7	5	3	1	3	5	7	9	Lack of financing physical and digital sustainable infrastructure to support innovative mobility solutions **(FIN3)**
Risk and uncertainty **(FIN2)**	9	7	5	3	1	3	5	7	9	Insufficient financial investments **(FIN4)**
Insufficient financial investments **(FIN4)**	9	7	5	3	1	3	5	7	9	Higher operational and maintenance cost **(FIN1)**

Privacy and security issues **(TECH1)**	9	7	5	3	1	3	5	7	9	Integration and convergence issues across IT networks **(TECH2)**
Integration and convergence issues across IT networks **(TECH2)**	9	7	5	3	1	3	5	7	9	Lack of integrated transport systems **(TECH3)**
Lack of integrated transport systems **(TECH3)**	9	7	5	3	1	3	5	7	9	Lack of skilled and trained IT resources **(TECH4)**
Lack of skilled and trained IT resources **(TECH4)**	9	7	5	3	1	3	5	7	9	Lack of physical and digital sustainable infrastructure to support innovative mobility solutions **(TECH5)**
Lack of physical and digital sustainable infrastructure to support innovative mobility solutions **(TECH5)**	9	7	5	3	1	3	5	7	9	Privacy and security issues **(TECH1)**
Privacy and security issues **(TECH1)**	9	7	5	3	1	3	5	7	9	Lack of integrated transport systems **(TECH3)**
Integration and convergence issues across IT networks **(TECH2)**	9	7	5	3	1	3	5	7	9	Lack of skilled and trained IT resources **(TECH4)**
Lack of integrated transport systems **(TECH3)**	9	7	5	3	1	3	5	7	9	Lack of physical and digital sustainable infrastructure to support innovative mobility solutions **(TECH5)**
Lack of skilled and trained IT resources **(TECH4)**	9	7	5	3	1	3	5	7	9	Privacy and security issues **(TECH1)**
Lack of physical and digital sustainable infrastructure to support innovative mobility solutions **(TECH5)**	9	7	5	3	1	3	5	7	9	Integration and convergence issues across IT networks **(TECH2)**

Low awareness level of the community regarding the impact of smart mobility on their lives **(I &A1)**	9	7	5	3	1	3	5	7	9	Lack of awareness among expert's regarding transport-related social cohesion or equity **(I&A2)**

Data openness issues **(L&R1)**	9	7	5	3	1	3	5	7	9	Regulations for new technologies are not accessible and they are not shared effectively **(L&R2)**
Regulations for new technologies are not accessible and they are not shared effectively **(L&R2)**	9	7	5	3	1	3	5	7	9	Regulations need to be updated to reflect current and future industry environment **(L&R3)**
Regulations need to be updated to reflect current and future industry environment **(L&R3)**	9	7	5	3	1	3	5	7	9	Data openness issues **(L&R1)**

Inappropriate weather conditions **(OTHER1)**	9	7	5	3	1	3	5	7	9	Lack of cycling infrastructure **(OTHER2)**
Lack of cycling infrastructure **(OTHER2)**	9	7	5	3	1	3	5	7	9	Inappropriate road conditions **(OTHER3)**
Inappropriate road conditions **(OTHER3)**	9	7	5	3	1	3	5	7	9	Lack of appropriate pedestrian mobility infrastructure **(OTHER4)**
Lack of appropriate pedestrian mobility infrastructure **(OTHER4)**	9	7	5	3	1	3	5	7	9	A lot of organizations/players involved in mobility and this makes it complex to control and coordinate **(OTHER5)**
A lot of organizations/players involved in mobility and this makes it complex to control and coordinate **(OTHER5)**	9	7	5	3	1	3	5	7	9	Inappropriate weather conditions **(OTHER1)**
Inappropriate weather conditions **(OTHER1)**	9	7	5	3	1	3	5	7	9	Inappropriate road conditions **(OTHER3)**
Lack of cycling infrastructure **(OTHER2)**	9	7	5	3	1	3	5	7	9	Lack of appropriate pedestrian mobility infrastructure **(OTHER4)**
Inappropriate road conditions **(OTHER3)**	9	7	5	3	1	3	5	7	9	A lot of organizations/players involved in mobility and this makes it complex to control and coordinate **(OTHER5)**
Lack of appropriate pedestrian mobility infrastructure **(OTHER4)**	9	7	5	3	1	3	5	7	9	Inappropriate weather conditions **(OTHER1)**

A lot of organizations/players involved in mobility and this makes it complex to control and coordinate **(OTHER5)**	9	7	5	3	1	3	5	7	9	Lack of cycling infrastructure **(OTHER2)**
Issues of retrofitting established transportation infrastructure **(OTHER6)**	9	7	5	3	1	3	5	7	9	Inappropriate weather conditions **(OTHER1)**
Issues of retrofitting established transportation infrastructure **(OTHER6)**	9	7	5	3	1	3	5	7	9	Lack of cycling infrastructure **(OTHER2)**
Issues of retrofitting established transportation infrastructure **(OTHER6)**	9	7	5	3	1	3	5	7	9	Inappropriate road conditions **(OTHER3)**
Issues of retrofitting established transportation infrastructure **(OTHER6)**	9	7	5	3	1	3	5	7	9	Lack of appropriate pedestrian mobility infrastructure **(OTHER4)**
Issues of retrofitting established transportation infrastructure **(OTHER6)**	9	7	5	3	1	3	5	7	9	A lot of organizations/players involved in mobility and this makes it complex to control and coordinate **(OTHER5)**

Appendix iii

Pairwise comparison matrices and fuzzy wights for barriers under each smart mobility category can be found as follow.

Policy Barriers Prioritization:

	Pol1			Pol2		
Pol1	1	1	1	1.7321	1.7321	1.7321
Pol2	0.5774	0.5774	0.5774	1	1	1

Policy Barriers	Geometric Mean			Fuzzy Weights			Defuzzification
Pol1	1.316074	1.316074	1.316074	0.633975	0.633975	0.633975	0.633974596
Pol2	0.759836	0.759836	0.759836	0.366025	0.366025	0.366025	0.366025404

Administrative Barriers Prioritization

	ADM1			ADM2			ADM3			ADM4			ADM5		
ADM1	1	1	1	0.4082	0.5081	0.658	0.184	0.227	0.297	0.639	0.669	0.707	0.537	0.669	0.841
ADM2	1.5197	1.968	2.4495	1	1	1	0.841	1	1.189	1.682	2.236	2.913	1.682	2.28	2.828
ADM3	3.3636	4.4006	5.4216	0.8409	1	1.1892	1	1	1	1.278	1.732	2.213	2	2.59	3.13
ADM4	1.4142	1	1	0.3433	0.4472	0.5946	0.452	0.577	0.783	1	1	1	1.107	1.236	1.414
ADM5	1.1892	1.4953	1.8612	0.3536	0.4387	0.5946	0.319	0.386	0.5	1	1	1	1	1	1

Administrative Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
ADM1	0.481385	0.552837	0.650332	0.074236	0.100331	0.138888	0.104484612	0.100887627
ADM2	1.293027	1.585878	1.888175	0.199401	0.28781	0.403247	0.296819275	0.286600982
ADM3	1.485297	1.815826	2.137969	0.229051	0.329542	0.456594	0.338395719	0.326746116
ADM4	0.753408	0.795774	0.919708	0.116185	0.14442	0.196417	0.152340466	0.147095997
ADM5	0.669313	0.759836	0.88838	0.103216	0.137897	0.189726	0.143613306	0.138669278

Environmental Barriers Prioritization:

	ENV1			ENV2		
ENV1	1	1	1	1.1892	1.3161	1.4142
ENV2	0.7071	0.7598	0.8409	1	1	1

Environmental Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
ENV1	1.090508	1.147203	1.189207	0.517758	0.568235	0.615722	0.567238141	0.565821367
ENV2	0.840896	0.871686	0.917004	0.399246	0.431765	0.474786	0.435265784	0.434178633

Financial Barriers Prioritization:

	FIN1			FIN2			FIN3			FIN4		
FIN1	1	1	1	0.7825	0.9391	1.1892	1	1.088	1.189	0.639	0.669	0.707
FIN2	0.8409	1.0648	1.2779	1	1	1	0.76	0.88	1	0.76	0.88	1
FIN3	0.8409	0.9193	1	1	1	1	1	1	1	1	1	1
FIN4	1	1	1	1	1	1	1	1	1	1	1	1

Financial Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
FIN1	0.840896	0.90913	1	0.206953	0.236672	0.275237	0.239620676	0.238624469
FIN2	0.834729	0.952995	1.06322	0.205435	0.248091	0.292638	0.248721276	0.247687233
FIN3	0.957603	0.97919	1	0.235676	0.25491	0.275237	0.255274475	0.254213188
FIN4	1	1	1	0.24611	0.260328	0.275237	0.260558364	0.25947511

Technical & Technological Barriers Prioritization:

	TECH1			TECH2			TECH3			TECH4			TECH5		
TECH1	1	1	1	3.4641	3.873	4.2426	3.464	3.956	4.427	3.834	4.213	4.559	3.834	4.213	4.559
TECH2	0.3333	0.3333	0.3333	1	1	1	0.38	0.411	0.452	1	1	1	1	1	1
TECH3	0.2259	0.2528	0.2887	2.2134	2.4323	2.6321	1	1	1	2.06	2.28	2.449	1.414	1.495	1.565
TECH4	0.3333	0.3333	0.3333	1	1	1	0.485	0.439	0.408	1	1	1	0.595	0.615	0.639
TECH5	0.2608	0.2374	0.2193	1	1	1	0.639	0.669	0.707	1.565	1.627	1.682	1	1	1

Technical &Technological Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
TECH1	2.813725	3.068305	3.298315	0.42636	0.488567	0.554922	0.489949521	0.488166143
TECH2	0.661475	0.672005	0.684802	0.100232	0.107003	0.115214	0.107483271	0.107092041
TECH3	1.078104	1.159476	1.238416	0.163364	0.184624	0.208356	0.185447788	0.184772772
TECH4	0.62612	0.617665	0.613554	0.094875	0.098351	0.103227	0.098817612	0.098457923
TECH5	0.764324	0.762765	0.764324	0.115817	0.121455	0.128593	0.121955028	0.121511121

Information & Awareness Barriers Prioritization

	I&A1			I&A2		
I&A1	1	1	1	0.4082	0.4472	0.5
I&A2	2	2.2361	2.4495	1	1	1

Information & Awareness Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
I&A1	0.638943	0.66874	0.707107	0.281201	0.309017	0.3444	0.311539362	0.310475061
I&A2	1.414214	1.495349	1.565085	0.622401	0.690983	0.762282	0.691888613	0.689524939

Legal & Regulatory Barriers Prioritization:

	L&R1			L&R2			L&R3		
L&R1	1	1	1	1.1067	1.3161	1.5197	1.107	1.236	1.414
L&R2	0.658	0.7598	0.9036	1	1	1	0.452	0.508	0.595
L&R3	0.7071	0.8091	0.9036	1.6818	1.968	2.2134	1	1	1

Legal & Regulatory Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
L&R1	1.069913	1.176047	1.290491	0.318107	0.382834	0.461418	0.387453149	0.38309539
L&R2	0.66742	0.728169	0.812958	0.198438	0.237038	0.290675	0.242050312	0.239327927
L&R3	1.059463	1.167731	1.259921	0.315	0.380127	0.450487	0.381871666	0.377576683

Other Barriers Prioritization:

	OTH1			OTH2			OTH3			OTH4			OTH5			OTH6		
OTH1	1	1	1	1.6119	1.7321	1.8612	0.866	1.065	1.316	2.28	2.59	2.913	0.537	0.669	0.841	0.25	0.333	0.5
OTH2	0.3333	0.3333	0.3333	1	1	1	0.904	1	1.107	0.841	0.919	1	0.931	1.136	1.414	0.931	1.136	1.414
OTH3	0.7598	0.9391	1.1547	1	1	1	1	1	1	0.841	0.919	1	0.226	0.293	0.42	0.226	0.293	0.42
OTH4	0.3433	0.3861	0.4387	1	1.0878	1.1892	1	1	1	1	1	1	0.42	0.531	0.707	0.42	0.531	0.707
OTH5	1.1892	1.4953	1.8612	0.7071	0.8801	1.0746	2.378	3.409	4.427	1.414	1.884	2.378	1	1	1	1	1	1
OTH6	2	3	4	0.7071	0.8801	1.0746	2.378	3.409	4.427	1.414	1.884	2.378	1	1	1	1	1	1

Other Barriers	Geometric Mean			Fuzzy Weights			Defuzzification	Normalization
OTH1	0.867908	1.010526	1.200937	0.119420084	0.161776481	0.225628	0.168941644	0.163607992
OTH2	0.776584	0.856798	0.95058	0.106854262	0.137165918	0.178592	0.140870738	0.136423312
OTH3	0.565218	0.648389	0.76733	0.077771373	0.103801476	0.144164	0.108578846	0.105150906
OTH4	0.626876	0.70066	0.799339	0.086255273	0.112169547	0.150177	0.11620074	0.11253217
OTH5	1.189207	1.427226	1.661754	0.163629337	0.228486439	0.312205	0.234773676	0.227361643
OTH6	1.29684	1.602836	1.887749	0.178439057	0.256600139	0.354664	0.263234547	0.254923977

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