Intégrer le transport durable dans les processus décisionnels pour le réaménagement de rues: Application de l'aide multicritère à la décision

Thèse

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Résumé

Les nombreux impacts négatifs liés à la démocratisation de l'automobile dans le dernier siècle ont mené à repenser les systèmes de transport et les pratiques de planification des transports. Les systèmes de transport devraient être planifiés pour protéger la viabilité écologique à long terme, pour fournir une accessibilité de base et pour assurer un accès équitable intergénérationnel et intragénérationnel au transport : c'est le transport durable. Plusieurs actions et stratégies ont été proposées dans les dernières décennies pour mettre en œuvre le transport durable. Le réaménagement des rues en faveur du transport actif et en commun est une de ces stratégies. Toutefois, il existe actuellement un décalage entre les plans, qui adoptent une vision de transport durable, et la pratique, qui réalise encore des projets de transport non-durables. Les différentes échelles de gouvernements requièrent de nouveaux outils d'aide à la décision pour changer les processus décisionnels. L'aide multicritère à la décision (AMCD) est une approche de mise en œuvre par divers processus possibles et proposant diverses méthodes d'analyse qui est de plus en plus discutée dans la littérature en transport afin d'intégrer une perspective holistique dans les processus décisionnels et l'évaluation de projet. Dans cette optique, cette thèse étudie plus particulièrement l'utilisation de l'AMCD pour améliorer les processus décisionnels liés au réaménagement de rues.

Tout d'abord, une revue de littérature a été réalisée afin de mieux comprendre les méthodes d'évaluation actuellement utilisées dans les processus décisionnels en transport. Les deux principales méthodes d'évaluation dans le domaine (analyse coût-bénéfice et AMCD) ont été analysées selon leurs forces et leurs faiblesses perçues, les différentes manières de les combiner et leurs capacités à intégrer les principes de développement durable dans les processus décisionnels. Afin de considérer les différentes conceptualisations de l'aide à la décision, les résultats ont été analysés en considérant quatre approches d'aide à la décision basées sur le concept d'agir communicationnel d'Habermas (objectiviste, conformiste, ajustable et réflexive).

Ensuite, une méthode pour développer un outil cartographique d'AMCD qui priorise le réaménagement de rues en rues conviviales a été proposée et a été appliquée en collaboration avec la Ville de Québec, Canada. Les rues conviviales sont l'objet d'un mouvement populaire en Amérique du Nord pour l'aménagement de « rues pour tous ». L'outil a été développé lors d'ateliers multidisciplinaires (transport, urbanisme, environnement, infrastructure, etc.) réunissant des professionnels de Québec selon la méthode d'AMCD MACBETH. Le développement de l'outil a été réalisé en cinq phases : (1) la structuration du problème, (2) la construction d'échelles d'attractivité, (3) l'élicitation de taux de substitution, (4) la validation du modèle et (5) la production de cartes de priorité. Forte du succès de la démarche, la Ville de Québec intègre cet outil dans sa stratégie de rues conviviales depuis 2017.

Pour faire suite à l'outil développé avec la Ville de Québec, un cadre d'évaluation post-projet dans un contexte d'AMCD a été développé et appliqué à propos du développement et de l'utilisation de l'outil. Le cadre d'évaluation se base sur cinq questions : pourquoi évaluer?, quoi évaluer?, sur quoi est basée l'évaluation?, comment évaluer? et qui est impliqué dans l'évaluation?. L'évaluation a pris la forme d'une série d'entretiens individuels réalisés avec les professionnels impliqués dans le développement et l'utilisation de l'outil cartographique d'AMCD. Les entretiens portaient sur le développement, l'utilisation et la pérennité de l'outil et ont été analysés selon la méthode d'analyse thématique.

Enfin, afin d'évaluer le potentiel d'application de la démarche dans d'autres contextes, les pratiques et les perceptions de professionnels quant à la réfection et au réaménagement de rues provenant de 11 municipalités québécoises ont été documentées lors d'ateliers multidisciplinaires de groupe (infrastructure, transport, urbanisme, environnement et géomatique). Les objectifs de ces ateliers étaient (1) de brosser un portrait des pratiques actuelles et (2) d'identifier les enjeux et les défis à développer un outil cartographique d'AMCD dans des contextes municipaux différents. Les ateliers ont été analysés en schématisant les processus décisionnels actuels et en utilisant la méthode de cartographie causale. Une série de lignes directrices a été proposée pour permettre le développement d'outils cartographiques d'AMCD au sein de municipalités. Ainsi, ces lignes directrices visent à faciliter le développement d'un nouveau type d'outils d'aide à la décision pour les municipalités, mais également à permettre d'améliorer les processus décisionnels actuels des municipalités afin de mieux arrimer les visions et les objectifs adoptés dans les politiques et les plans avec les projets réalisés et les pratiques professionnelles.

Mots-clés : Aide multicritère à la décision, rues conviviales, planification des transports, système d'aide à la décision spatiale, réaménagement et réhabilitation de rues, collaboration intersectorielle.

Abstract

The numerous negative impacts linked to the democratization of cars in the last century led to rethink transportation systems and transportation planning practices. Transportation systems should be planned to safeguard long-term ecological vitality, provide basic accessibility and ensure equal access to transport services. This is sustainable transportation. Many actions and strategies were proposed in the last decades to implement sustainable transportation. Redesigning streets in favor of active and public transportation is one of these strategies. However, there is currently a gap between the plans, that adopt a sustainable transportation vision, and practices, that still realize unsustainable transportation projects. The different government levels require new decision aid tools to change their decision processes. Multicriteria decision aiding (MCDA) is one method that is more and more discussed in the transportation literature to integrate a holistic perspective to decision processes. In this regard, this thesis studies more specifically the use of MCDA to improve decision processes linked to street redesigns.

First of all, a descriptive literature review was conducted to better understand the evaluation methods that are currently used in transportation decision processes. The two main evaluation methods in the field (cost-benefit analysis and MCDA) were examined according to their perceived strengths and weaknesses, to the different ways to combine them and to their abilities to integrate sustainable development principles in the decision processes. To take into account the different conceptualizations of decision-aiding, the results were analyzed according to four decision-aiding approaches based on the concept of communicative action from Habermas (objectivist, conformist, adjustive and reflexive).

Subsequently, a method to develop a multicriteria spatial decision support system (MC-SDSS) to prioritize the streets to redesign as Complete Streets was proposed and applied in collaboration with the City of Quebec in Canada. Complete streets is a popular movement in North America for sustainable transportation to design « streets for everyone ». The MC-SDSS was developed during multidisciplinary group workshops (transportation, urban planning, environment, infrastructure, urban design and public participation) gathering Quebec City professionals using the MCDA method MACBETH. The development of the MC-SDSS was split in five phases: (1) structuring the problem, (2) constructing attractiveness scales, (3) deriving scaling constants, (4) validating the model and (5) producing priority maps. The process has been successful. Indeed, Quebec City has been using this MC-SDSS in the elaboration of its Complete Streets strategy since 2017.

Following the MC-SDSS developed in Quebec City, a post-project evaluation framework, specific to MCDA, was generated and applied to the MC-SDSS. The evaluation framework is based on five questions: why evaluate?, what to evaluate?, on what is the evaluation based?, how to evaluate? and who is involved in the evaluation?. The evaluation was applied under the form of a series of individual interviews carried with the professionals

involved in the development and use of the MC-SDSS. The interviews were about the development, use and future of the MC-SDSS and were analyzed according to the thematic analysis method. Based on the challenges and difficulties identified in the thematic analysis, various recommendations are suggested to improve practices.

Finally, to assess the potential to export the development of MC-SDSS to other contexts, the practices and perceptions of professionals from 11 municipalities in the Province of Quebec were documented during multidisciplinary group workshops (infrastructure, transport, urban planning, environment and geomatics). The objectives of these workshops were (1) to create a portrait of current practices for street rehabilitation and redesign to integrate urban planning, transportation and environment and (2) to identify the issues and challenges of developing MC-SDSS in various municipal contexts. The workshops were analyzed by schematizing the current decision processes and by using the causal mapping method. A series of guidelines is proposed to allow the development of MC-SDSS with the municipalities. Those guidelines aim at easing the development of a new type of decision support system for municipalities, but also at allowing the improvement of current municipal decision processes by better integrating the sustainable vision adopted in the politics and plans and the projects realized by the professionals.

Keywords: Multicriteria decision aid, Complete Streets, transportation planning, spatial decision support system, street redesign and rehabilitation.

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Liste des abréviations, sigles, acronymes

ABC : Activity-based coding

ACB : Analyse coût-bénéfice

AHP : Analytic hierarchy process

AMCD : Aide multicritère à la décision

BCR : Benefit-cost ratio

CBA: Cost-benefit analysis

CEA: Cost-effectiveness analysis

CP: Capital plan

CSP-i: Complete Street Priority index

GDSS: Group decision support system

GIS: Geographic information system

IP: Intervention plan

MACBETH: Measuring attractiveness by a category-based evaluation technique

MAE: Multiple Account Evaluation

MAVT: Multi-attribute value theory

MC-SDSS: Multicriteria spatial decision support system

NACH: Normalized-angular choice

NPV: Net present value

OD: Origin-Destination

OR : Operational research

PPU: Programme particulier d'urbanisme

PPN : Plans, policies and norms

PSM : Problem structuring method

QR : Question de recherche

RO : Recherche opérationnelle

ROC: Recherche opérationnelle comportementale

RQ : Research question

SDSS : Spatial decision support system

SIG : Système d'information géographique

SOA: Strategic option assessment

SUMINI: Sustainable mobility inequity indicator

TEA: Techno-economic analysis

TRID: Transport Research International Documentation

WTA: Willingness to accept

WTP: Willingness to pay

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Avant-propos

Cette thèse prend la forme d'une thèse par articles. En plus des chapitres d'introduction et de conclusion, elle est composée de quatre chapitres issus d'articles publiés ou qui ont été soumis pour publication dans des revues avec comité de lecture. Les chapitres sont présentés en ordre logique de lecture et non par ordre chronologique des travaux. Dans les faits, la plupart des travaux associés au chapitre 2 ont été effectués avant les travaux du chapitre 1 alors que la majorité des travaux associés aux deux derniers chapitres ont été effectués en parallèle. L'introduction et la conclusion ont été écrites rétrospectivement aux quatre chapitres. Les chapitres ont été écrits indépendamment l'un de l'autre. Par conséquent, certains éléments permettant de mettre en contexte les chapitres sont répétés entre eux.

Tous les chapitres ont pour premier auteur l'auteur de cette thèse, Francis Marleau Donais. Celui-ci a effectué le recrutement des participants, la collecte de données, l'analyse des données, la production des tableaux et des figures et la rédaction principale des chapitres. Les co-auteurs sont les mêmes pour chaque article, soit Irène Abi-Zeid et Owen Waygood qui agissaient comme codirecteurs et Roxane Lavoie qui agissait comme directrice de cette thèse. Aucun autre auteur n'a contribué à la rédaction des chapitres.

Le chapitre 1 intitulé « *A review of cost–benefit analysis and multicriteria decision analysis from the perspective of sustainable transport in project evaluation »* a été soumis en mars 2019 au journal « EURO Journal on Decision Process » et a été publié en décembre 2019. Le chapitre 2 intitulé « *Assessing and ranking the potential of a street to be redesigned as a Complete Street: A multi-criteria decision aiding approach* » a été soumis en mai 2018 au journal « Transportation Research Part A: Policy and Practice » et a été publié en juin 2019. Le chapitre 3 intitulé « *A framework for post-project evaluation of facilitated multicriteria decision aiding processes: Development and application from the stakeholders' perspective* » a été soumis au journal « Group Decision and Negotiation » en avril 2020. Le chapitre 4 intitulé « Integrating sustainable transportation in street rehabilitation and redesign decision processes: A portrait of cities from the Province of Quebec, Canada » a été soumis au journal « Transportation Research Part A: Policy and Practice » en juillet 2020.

Le chapitre 1 a été publié dans un journal européen et a été écrit dans un anglais britannique alors que les autres chapitres ont été publiés ou soumis dans des journaux états-uniens et ont été écrits dans un anglais états-unien.

Comparativement aux articles publiés, les numéros des figures, des tableaux et des annexes ont été changés afin de pouvoir suivre l'ordre logique de la thèse. Certaines informations faisant état des différences entre la version en ligne et papier des articles ont été retirées. De plus, le matériel supplémentaire qui est publié en ligne, séparément des articles, a été intégré dans les annexes de cette thèse.

En plus des articles dans des journaux révisés par des pairs qui sont inclus dans cette thèse, des articles de conférences et des rapports ont été écrits et plusieurs communications scientifiques et par affiche ont été réalisées dans le cadre de cette thèse.

Articles scientifiques dans des conférences avec comité de lecture

MARLEAU DONAIS, Francis, ABI-ZEID, Irène, WAYGOOD, Owen et LAVOIE, Roxane (2018). "Integrating sustainable transportation in decision-making processes : A comparison between Cost-Benefit Analysis and Multi-Criteria Decision aiding". Dans *Proceedings of the CTRF 53rd Annual Conference*, pp. 263-271, Gatineau, Canada.

MARLEAU DONAIS, Francis, ABI-ZEID, Irène et LAVOIE, Roxane (2017). "Building a Shared Model for Multi-Criteria Group Decision Making." Dans *Group Decision and Negotiation. A Socio-Technical Perspective*, pp. 175–86. Lecture Notes in Business Information Processing. Springer, Cham.

MARLEAU DONAIS, Francis, ABI-ZEID, Irène et LAVOIE, Roxane (2017). "A Loose-Coupling Integration of the MACBETH approach in ArcGIS". Dans *Proceedings of the 2017 International Conference on Decision Support System Technology*, pp. 125-131. Namur, Belgique.

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MARLEAU DONAIS, Francis, ABI-ZEID, Irène et WAYGOOD, Owen (2017). *Mise à jour et calcul du potentiel de rues conviviales pour l'ensemble du territoire de la ville de Québec*. Rapport de recherche pour la ville de Québec, Université Laval, Québec, Canada. 39 p.

MARLEAU DONAIS, Francis, LAVOIE, Roxane et ABI-ZEID, Irène et DELISLE, Jean-Philippe (2016). *Évaluation du potentiel des rues à être aménagées en rues conviviales – Une approche par analyse multicritère*. Rapport de recherche pour la ville de Québec, Université Laval, Québec, Canada. 58 p.

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MARLEAU DONAIS, Francis, ABI-ZEID, Irène, WAYGOOD, Owen et LAVOIE, Roxane (2019*). Réfection de rues, analyse multicritère et potentiel d'aménagement de rues conviviales : Portrait des enjeux et défis pour les municipalités québécoises.* Congrès INFRA 2019 du Centre d'expertise et de recherche en infrastructure urbaine (CERIU), 2 au 4 décembre 2019, Montréal, Canada.

MARLEAU DONAIS, Francis, ABI-ZEID, Irène, WAYGOOD, Owen et LAVOIE, Roxane (2019*). Decision Analysis Meets Sustainable Planning in Quebec City : The case of Multicriteria Decision Aiding and Complete Streets*. 2019 Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting, 20 au 23 octobre 2019, Seattle, États-Unis.

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Introduction

La démocratisation de l'automobile au 20e siècle a entraîné une grande augmentation de la liberté de mouvement au sein des populations des pays industrialisés. En milieu urbain, l'automobile a d'abord été utilisé à des fins récréatives pour sortir de la ville puis pour résider à l'extérieur de la ville. Les populations urbaines n'étaient plus contraintes à résider en ville à proximité de leur lieu de travail. À l'inverse, en milieu rural, l'automobile a permis à la population d'avoir plus facilement accès aux différents services situés en ville. Afin de faciliter cette liberté et cette rapidité de mouvement, des réseaux de routes et d'autoroutes reliant les villes et permettant d'accéder directement aux centres-villes ont été planifiés et construits dans la seconde moitié du 20e siècle (Muller 2017; Beaudet et Wolff 2012; Poitras 2014). Plusieurs pays ont mis en œuvre différents programmes et lois pour accélérer la construction de ces réseaux.

Aux États-Unis, le Federal Aid Highway act de 1956 a donné l'impulsion au développement d'un réseau autoroutier traversant le pays. Au Canada, l'adoption de la Loi de la route transcanadienne en 1949 a donné naissance à une route nationale, comprenant plusieurs segments d'autoroute, traversant le pays et faisant près de 8 000 km (Noxon et al. 2013). Dans la région de Québec, le plan de circulation et de transport de 1968, communément appelé plan Vandry-Jobin, est à l'origine de plusieurs projets autoroutiers existant aujourd'hui (p. ex., l'autoroute Félix-Leclerc, l'autoroute Henri IV et le pont Pierre-Laporte), mais également de projets annulés ou encore d'actualité, comme un troisième lien reliant les villes de Québec et de Lévis (Commission d'aménagement de Québec et al. 1968).

L'attrait de l'automobile et les investissements massifs dans les infrastructures la favorisant ont eu pour conséquence de redéfinir la façon de se déplacer. L'automobile fait aujourd'hui partie intégrante du mode de vie de la majorité des sociétés occidentales. Que ce soit au Canada, aux États-Unis, en Grande-Bretagne ou en France, le nombre de ménages avec plus d'un véhicule, le nombre de véhicules par ménage et le nombre de kilomètres parcourus par véhicule ont tous augmenté depuis les années 70 (Andre et al. 2019, Hanson 2017; Hutton 2013). Toutefois, cette planification des transports axée sur la voiture et sa liberté de mouvement entraîne des conséquences néfastes sur la société et sur les générations futures : pollution, bruit, accidents, congestion et étalement urbain (Gärling et Steg 2007; Tumlin 2012; Graham et Marvin 2001).

Ces conséquences se manifestent également au Québec que ce soit sous la forme de pollution, d'accident de la route ou d'étalement urbain. En effet, le secteur du transport routier (transport des personnes et de marchandises) est le plus important secteur émetteur de gaz à effet de serre (GES) au Québec. En 2016, 34,4 % des GES provenaient du secteur du transport routier. Alors que plusieurs secteurs ont connu une diminution de leurs émissions de CO_2 équivalent depuis 1990 (p. ex., les transports maritime et aérien, l'enfouissement des

déchets ou la combustion industrielle), le transport routier est le secteur ayant connu la plus forte croissance des émissions (une hausse relative de 52,3 % et absolu de 9,28 Mt de CO_2 équivalents) (Delisle et al. 2018). De plus, malgré un bilan de sécurité routière qui s'est amélioré au fil des années, 35 070 accidents, dont 333 décès et 1 334 blessés graves, ont été recensés par la Société d'assurance automobile du Québec en 2019 (Société de l'assurance automobile du Québec 2020). Par ailleurs, l'étalement urbain n'a pas cessé d'augmenter au Québec. Plus particulièrement, entre 2006 et 2016, 83% de la croissance démographique de la région métropolitaine de recensement de Montréal et 97% de celle de Québec ont eu lieu en banlieue dépendante à l'automobile et en milieu rural. La situation est pire dans les plus petites régions métropolitaines de recensement telles que Trois-Rivières, Saguenay et Sherbrooke, où c'est une décroissance démographique qui est constatée dans les centres urbains (Gordon, Hindrichs, et Willms 2018).

En réaction à ces nombreux problèmes également présents dans les autres pays industrialisés, une réflexion internationale pour changer les pratiques de planification des transports a été initiée dans les années 90. Cette réflexion vise à définir de nouvelles pratiques qui diminueraient les conséquences négatives décrites précédemment à propos du déploiement du réseau routier (Gudmundsson et Höjer 1996; Gudmundsson et al. 2016b).

Planification des transports

La planification des transports est un processus décisionnel qui analyse les habitudes de déplacement des personnes et des biens, et les caractéristiques démographiques à travers le temps sur un territoire (planification locale, régionale, provinciale ou fédérale) pour comprendre les problèmes et circonstances favorables d'un système de transport et évaluer les solutions possibles pour répondre aux besoins du territoire. Ainsi, la planification des transports vise à produire l'information nécessaire aux décideurs et à leur communiquer afin qu'ils puissent prioriser les infrastructures, les politiques et les législations à propos d'un système de transport en toute connaissance de cause (Institute of Transportation Engineers 2010; Meyer et Miller 2001). En complément, c'est un processus qui vise à élaborer, à construire et à gérer un système de transport pour en maximiser les impacts positifs et en minimiser les impacts négatifs (Miller 2017). Dans une perspective plus large, la planification des transports peut se faire selon différents systèmes qui dépendent du mouvement étudié : (1) le mouvement des personnes et des marchandises, (2) le mouvement d'énergie et de matière et (3) le mouvement de l'information (Gudmundsson et al. 2016a). Ce mouvement des personnes et des biens peut se faire par route (transport routier), par chemin de fer (transport ferroviaire), par voie fluviale (transport fluvial) ou par les airs (transport aérien). Dans le cadre de cette thèse, c'est la planification des transports terrestres par route pour le mouvement des personnes qui est étudiée.

La planification des transports terrestres considère les problèmes et les enjeux de transport dans une dynamique d'abord métropolitaine, puis sur un territoire de plus en plus petit (municipale, arrondissement, quartier) selon des enjeux de plus en plus spécifiques. Le processus de planification implique plusieurs étapes et cycles itératifs qui peuvent varier d'un auteur à l'autre (Hutton 2013; Meyer et Institute of Transportation Engineers 2016; Meyer et Miller 2001; Priemus 2008; Sciara et Handy 2017). Les principales étapes dans la littérature sont :

1. Identification et formulation du problème;
2. Définition de la vision et des objectifs;
3. Collecte de données et analyse de la performance du réseau;
4. Développement de différentes stratégies et actions;
5. Priorisation et évaluation des stratégies et actions;
6. Réalisation des stratégies et actions;
7. Opération du système de transport;
8. Implantation et suivi des stratégies et actions.

Traditionnellement, la planification des transports a principalement traité du mouvement des véhicules plutôt que de traiter du mouvement des biens et des personnes qui étaient à l'intérieur de ces véhicules.

Vers une planification du transport durable

En réaction aux problèmes d'une planification des transports axée sur la voiture, le concept de transport durable s'est concrétisé au courant des années 90 en parallèle au concept de développement durable. Le système de transport ne doit plus être considéré comme un système isolé, monosectoriel, lequel n'est pas influencé par d'autres facteurs extérieurs. Dans les faits, le système de transport interagit avec de nombreux systèmes (écosystème, utilisation du sol, développement économique, santé de la population) afin d'être partie intégrante de la ville. De plus, le transport s'inscrit dans un système social qui est influencé par les politiques publiques et par les forces du marché.

Bien que plusieurs définitions à propos du transport durable aient été proposées au fil des ans, aucune définition commune n'a encore émergé (Holden, Gilpin, et Banister 2019; Holden et al. 2020; Gudmundsson et al. 2016b). Certaines définitions du transport durable sont plus proches de la définition donnée par le rapport *Our Common Future* (World Commission on Environment and Development 1987), mieux connu sous le nom de rapport Brundtland, alors que d'autres sont plus spécifiques à certains enjeux du domaine des transports. Black (1996) définit le transport durable comme « un système de transport qui satisfait les besoins actuels de transport et de mobilité sans compromettre la capacité des générations futures à répondre aux leurs »[1]. Banister (2008) décrit

[1] Pour les sections écrites en français dans cette thèse, toutes les citations en anglais sont traduites en français par l'auteur de la thèse

le transport durable comme « une approche qui nécessite des actions pour diminuer le besoin de se déplacer, pour encourager le transfert modal, pour réduire la longueur des trajets et pour encourager une plus grande efficience du système de transport ». Les cinq principes du transport durable issus de la conférence de l'OCDE *Toward Sustainable Transportation* sont également intéressants puisqu'en plus de la protection de l'environnement et de la viabilité économique, ils incluent les notions d'accès, de prise de décision et d'urbanisme.

Afin de synthétiser les nombreuses définitions, Gudmundsson et al. (2016b) proposent une liste des éléments présents dans plusieurs définitions et classifiés selon les trois dimensions du développement durable: environnement, société et économie (tableau I.1).

Tableau I.1 Caractéristiques d'une définition générale du transport durable (traduit de Gudmundsson et al. 2016b)

Dimension	**Sujet**	**Un système de transport durable…**
Environnement	Dommages environnementaux et sur la santé	Minimise les activités qui causent des dommages sérieux à l'environnement et à la santé publique
	Bruit	Minimise le bruit
	Utilisation du sol	Minimise l'utilisation du sol
	Émissions et déchets	Limite la production d'émissions et de déchets à l'intérieur d'un niveau que la planète est capable d'absorber
	Ressources renouvelables	Assure que les ressources renouvelables sont gérées et utilisées afin de ne pas réduire la capacité écologique du système à produire les ressources
	Ressources non-renouvelables	Assure que les ressources non-renouvelables sont utilisées au taux ou sous le taux de développement des ressources substituts
	Énergie	Fonctionne avec des sources d'énergie renouvelables
	Recyclage	Réutilise et recycle ses composantes
Société	Accès	Offre un accès aux biens, aux ressources et aux services tout en réduisant le besoin de se déplacer
	Sécurité	Opère de façon sécuritaire et assure un mouvement sécuritaire des biens et des personnes
	Équité intragénérationnelle	Promeut l'équité entre les sociétés et groupes au sein de la même génération, particulièrement en relation aux préoccupations de justice environnementale
	Équité intergénérationnelle	Promeut l'équité entre les générations
	Abordabilité	Est abordable
Économie	Efficient	Opère de façon efficiente pour supporter une économie compétitive
	Coût social	Assure que les utilisateurs selon leur moyen paient le plein coût social et environnemental des décisions en transport
	Emploi	Offre des opportunités d'emploi pertinentes et bien payées

La définition adoptée dans les chapitres suivants de cette thèse est celle de Holden et al. (2013; 2020) basée sur les trois impératifs du développement durable : satisfaire les besoins humains, assurer une justice sociale et respecter les limites environnementales. Le transport durable est alors défini comme un système de transport qui assure que les activités de transport ne menacent pas à long terme la viabilité écologique (limites environnementales), fournit une accessibilité de base en transport (besoins humains) et assure un accès équitable inter et intragénérationnel au transport (justice sociale).

Mobilité et accessibilité

Deux autres concepts importants à définir pour comprendre la planification des transports sont ceux de mobilité et d'accessibilité. Dans la pratique, la distinction entre les deux n'est pas toujours claire et les termes sont parfois confondus (Handy 2002; 2020). L'accessibilité fait référence à la capacité d'accéder à différentes destinations potentielles (p. ex. le nombre d'activités à l'intérieur d'un rayon d'une certaine distance ou d'un certain temps de déplacement) alors que la mobilité fait référence à la capacité potentielle à se déplacer entre différents lieux d'activité, en référence au mouvement des personnes et des objets (p. ex. les niveaux de services utilisés traditionnellement en planification des transports : la vitesse ou la densité moyenne de circulation) (Hanson 2017).

Les deux concepts sont souvent opposés l'un à l'autre. Par exemple, l'étalement des activités sur le territoire lié à une planification axée sur l'automobile au courant du 20e siècle a amené à compenser une perte d'accessibilité piétonne par un gain de mobilité automobile (Hanson 2017). À l'inverse, un territoire dense avec de nombreuses activités à proximité crée une forte accessibilité, mais rend les déplacements rapides plus difficiles (Tumlin 2012). Toutefois, ceux-ci ne sont pas toujours en opposition. Il est possible d'avoir un système de transport qui permet à la fois de bonnes mobilité et accessibilité ou, à l'inverse, de mauvaises mobilité et accessibilité.

Plusieurs auteurs contrastent l'approche traditionnelle de planification des transports axée sur l'efficacité des déplacements, soit la mobilité, à une approche de planification des transports durables axée sur l'amélioration de la qualité de l'accès aux activités, autrement dit, l'accessibilité (Litman 1999; Banister 2008; Handy 2020). Toutefois, il ne semble pas y avoir de consensus sur le terme pour qualifier ce nouveau paradigme de planification des transports. Certains le nomment mobilité durable (Holden, Gilpin, et Banister 2019; Banister 2008; Berger et al. 2014), d'autres le qualifient plutôt d'accessibilité durable (Curtis 2008; Gil Solá, Vilhelmson, et Larsson 2018; Curtis et Scheurer 2010) ou encore l'appellent tout simplement transport durable (Holden, Linnerud, et Banister 2013; Gudmundsson et al. 2016b; Tumlin 2012). Au Québec, le terme mobilité durable est très répandu dans la littérature grise. Toutefois, la définition de mobilité durable fournie dans la Politique de mobilité durable du gouvernement québécois se définit en partie par le concept d'accessibilité.

> Pour être durable, la mobilité doit être efficace, sécuritaire, pérenne, équitable, intégrée au milieu et compatible avec la santé humaine et les écosystèmes. **La mobilité durable limite la consommation d'espace et de ressources, donne et facilite l'accès**. Elle favorise le dynamisme économique, elle est socialement responsable et respecte l'intégrité de l'environnement. (Ministère des Transports, de la Mobilité durable et de l'Électrification des transports 2018b)

Par conséquent, pour éviter toute confusion, le terme transport durable sera utilisé dans cette thèse comme un terme englobant à la fois les aspects de la mobilité et de l'accessibilité.

Opérationnaliser le transport durable

Afin d'opérationnaliser un système de transport durable, les différents niveaux de gouvernement (national, provincial, régional et municipal) peuvent adopter des politiques et des plans pour mettre en œuvre des stratégies et des actions. Comparativement à l'approche traditionnelle de planification des transports, qui se concentrait principalement sur les interventions physiques en augmentant la capacité du réseau (nouvelles infrastructures ou agrandissement de celles-ci), la planification durable exige également d'intervenir sur les dimensions sociale et comportementale grâce à des politiques. La planification durable ne devrait plus se concentrer uniquement sur le transport automobile, mais plutôt sur tous les modes de transport (marche, vélo, transport en commun et automobile) (Banister 2008). En Europe, la Commission Européenne (2014) recommande aux municipalités d'adopter un *Sustainable urban mobility plan*. Au Québec, le Ministère des Transports, de la Mobilité durable et l'Électrification des transports (2018a) prévoit, dans son plan d'action 2018-2023 issu de la politique de mobilité durable, de créer un programme pour que les municipalités développent des plans de mobilité durable intégrés.

Les politiques et les plans de transport durable ont en général pour objectifs : (1) d'augmenter l'accessibilité, (2) de réduire l'utilisation de l'automobile, (3) d'augmenter l'utilisation du transport en commun, (4) d'augmenter les déplacements actifs (vélo et marche), (5) de substituer électroniquement des déplacements, ou encore (6) de réduire les GES. Ces objectifs se traduisent en général en des actions qui (a) intègrent la planification des transports à la planification du territoire ; (b) mettent en place des mesures fiscales et réglementaires ; (c) améliorent les technologies du transport ; (d) construisent ou améliorent les infrastructures de transports ou (e) sensibilisent et éduquent la population aux enjeux de transport durable. Le tableau I.2 présente une liste non exhaustive de différentes mesures pouvant être mises en place selon le champ d'action et l'objectif (Buehler, Pucher, et Altshuler 2017; Buehler et al. 2017; Tremblay-Racicot 2019; Banister 2005b).

Au Québec, les trois objectifs du plan d'action de mobilité durable du Ministère des Transports du Québec (2018a) sont de réduire, transférer et améliorer. Plus précisément, ces objectifs visent à réduire les déplacements motorisés et les distances à parcourir, à transférer vers les modes de transports moins

énergivores et produisant moins de GES comme les modes actifs ou de transport en commun, et à améliorer l'efficacité des technologies pour réduire l'empreinte carbone.

Tableau I.2 Liste non-exhaustive de mesures pouvant être mises en place dans une perspective de transport durable (Buehler, Pucher, et Altshuler 2017; Buehler et al. 2017; Tremblay-Racicot 2019; Banister 2005b)

Objectifs	Champs d'action	Mesures
Augmenter l'accessibilité	Intégrer transport et urbanisme	Créer des développements axés sur le transport collectif (transit-oriented development) Développer des zones sans-auto Mixité des utilisations du sol
Augmenter l'utilisation du transport en commun	Développement technologique	Information en temps réel
	Infrastructure de transport	Améliorer l'offre de service Aménager des voies réservées Moderniser les véhicules et les stations
	Mesures fiscales et règlementations	Intégration tarifaire Rabais sur les titres de transport en commun
Augmenter l'utilisation du vélo	Infrastructure de transport	Aménager et améliorer les infrastructures cyclables
Augmenter le transport actif	Infrastructure de transport	Aménager des rues conviviales
Augmenter les déplacements à pied	Infrastructure de transport	Aménager et améliorer les infrastructures piétonnes
Réduire l'utilisation de l'automobile	Infrastructure de transport	Aménager des mesures de mitigation de la vitesse Réduire l'offre de stationnement Réduire la capacité routière (retirer des voies)
	Mesures fiscales et règlementations	Augmenter le prix du permis de conduire Augmenter le prix du stationnement Compliquer l'acquisition du permis de conduire Instaurer un péage dans des zones de congestion Instaurer un péage routier Taxer l'essence
	Autres champs d'action	Covoiturage Auto en libre-service
Réduire les GES	Développement technologique	Voiture à hydrogène Voiture électrique
Substituer électroniquement	Développement technologique	Activités à distance Télétravail

Aménager des rues plus durables

Dans le cadre de cette thèse, nous nous intéressons plus particulièrement aux stratégies que les municipalités peuvent adopter pour aménager les rues afin d'augmenter l'utilisation des transports actifs et de diminuer l'utilisation de l'automobile. Il a été décidé d'étudier ces stratégies puisque, comme il sera décrit au cours de la présente sous-section, l'intégration des principes de transport durable et de développement durable dans les processus de réfection et de réaménagements des rues est encore rare en Amérique du Nord.

À travers les dernières décennies, différents concepts d'aménagement ont été proposés pour permettre un meilleur partage de l'espace entre l'automobile et les autres modes. Dans le rapport « Traffic in Towns », sous la supervision de Colin Buchanan au Royaume-Uni, le concept d'espace partagé entre les modes est introduit (Ministry of Transport 1963). Ces espaces devaient être aménagés à l'intérieur de zones « environnementales », c'est-à-dire des milieux de vie de quartier. Toutefois, le rapport conceptualise cette idée sans proposer de façon concrète d'aménager ces espaces partagés. Ce n'est que quelques années plus tard, aux Pays-Bas, puis dans les pays avoisinants, que ce concept se matérialisera sous la forme de « woonerfs », terme qui peut se traduire par îlot ou zone résidentielle (Karndacharuk, Wilson, et Dunn 2014).

Il en ressort deux types d'aménagement de rues pour partager l'espace entre les modes de transport : les rues partagées et les rues apaisées. Les rues partagées ont pour particularité de n'avoir aucune ségrégation entre les modes de transports, les piétons ont la priorité sur les rues et peuvent ainsi circuler ou s'arrêter librement. Pour leur part, les rues apaisées visent à diminuer la vitesse des automobiles en changeant l'aménagement physique des rues, mais les modes de transports continuent à être ségrégués (Karndacharuk, Wilson, et Dunn 2014). En Amérique du Nord, les rues apaisées se sont manifestées sous différents concepts d'aménagement : les rues vivantes (Appleyard 1980), l'apaisement de la circulation (Ewing et Brown 2009; Transportation Association of Canada et Canadian Institute of Transportation Engineers 1998), les diètes de rues (Knapp et al. 2014; Thomas 2013) et le design sensible au contexte urbain (Institute of Transportation Engineers 2010).

Plus récemment, dans une optique de transport durable, un concept populaire d'aménagement de rues apaisées au sein des municipalités nord-américaines est apparu. Il s'agit de celui des rues conviviales, appelées « Complete Streets » en anglais. Depuis la création du concept en 2004 par la National Complete Street Coalition, plus de 1600 municipalités états-uniennes et plus de 100 municipalités canadiennes ont adopté une résolution, un décret, une politique, un plan ou un guide de design de rues conviviales (Complete Streets for Canada 2019; Smart Growth America 2020). Les rues conviviales se définissent comme étant des rues aménagées pour être accessibles, sécuritaires et confortables pour tous, peu importe le mode de transport (marche, vélo, transport en commun, automobile) et le type d'usager (enfant, adulte en santé, personne à mobilité réduite, personne âgée). L'approche se veut également sensible au contexte urbain, au caractère, à

l'échelle et aux besoins du quartier (McCann 2013). Par conséquent, une rue ne sera pas conçue et aménagée de la même façon selon sa localisation (centre-ville, périphérie, milieu rural), sa fonction (rue locale, collectrice, artère mineure, artère majeure) ou sa signification auprès de la communauté (utilisation du sol et utilisation qui en est faite par les citoyens) (Kingsbury, Lowry, et Dixon 2011). Telle que conceptualisée par la National Complete Street Coalition, l'approche des rues conviviales incite également à changer les processus décisionnels en place via l'adoption de politiques et de résolutions afin d'encourager les changements vers des pratiques d'aménagement de rues conviviales (McCann 2013; 2011).

Cependant, malgré une forte mobilisation à travers l'Amérique du Nord au niveau municipal, il y a encore peu de littérature scientifique sur les rues conviviales. Une revue partielle des politiques adoptées par les municipalités (n=113) montrait que la plupart de ces politiques proposaient de changer le design actuel des rues sans pour autant adopter les outils législatifs nécessaires et proposer un nouveau processus décisionnel permettant d'implanter ces changements (Gregg et Hess 2019). De plus, dans un contexte où les municipalités ont un budget et des ressources humaines restreints, celles-ci peuvent difficilement aménager toutes les rues en rues conviviales et requièrent de prioriser les projets de rues conviviales. De plus, Hui et al. (2018) ont montré qu'aucune méthodologie quantitative n'avait été proposée pour mesurer la performance de « convivialité » des rues en matière de déplacement, d'environnement et d'urbanisme. Cette situation amène à se questionner sur la façon de développer une méthode quantitative qui considérerait également les aspects sociotechniques en matière de transport, d'environnement et d'urbanisme afin de prioriser les projets de réaménagement de rues en rues conviviales (**enjeu de recherche**).

Barrières à une planification des transports durables

Ce constat à l'égard des rues conviviales est également vrai pour les politiques et plans de transport durable adoptés à différentes échelles gouvernementales. Il existe en pratique un décalage entre ces plans, qui adoptent une vision durable, et leur mise en œuvre, qui permet encore des projets non-durables (Berger et al. 2014; Banister 2008; Hull 2008). Pour expliquer cette difficulté à changer les pratiques en planification des transports, les auteurs utilisent différents termes : barrières, dépendance au sentier ou phénomène de verrouillage (Geels et al. 2012; Cantarelli et al. 2010; Curtis et Low 2012; Driscoll 2014; Banister 2005a; 2005b). La dépendance au sentier se décrit comme une tendance spécifique lors d'un processus décisionnel à aller constamment vers les mêmes décisions malgré la diversité de résultats possibles. Plus cette dépendance est forte, plus il devient difficile de renverser une dépendance au sentier (Hämäläinen et Lahtinen 2016; Webster 2008). Plusieurs études ont analysé comment ces phénomènes pouvaient affecter de diverses façons les prises de décision en transport, que ce soit par une dépendance au sentier qui soit économique ou environnementale (Cantarelli et al. 2010; Driscoll 2014; Zhan, de Jong, et de Bruijn 2017; Finnveden et Åkerman 2014).

Plus précisément, la littérature sur la transition des régimes sociotechniques (Geels et Schot 2007) identifie le système de transport actuel, appelé automobilité, comme un régime sociotechnique stable et verrouillé, c'est-à-dire que plusieurs mécanismes contribuent à maintenir et à renforcer le régime en place, ce qui a pour conséquence de créer une inertie décisionnelle (Geels et al. 2012). Plusieurs facteurs contribuent au maintien de l'automobilité et restreignent la transition vers un système de transport durable : (a) les faibles coûts de la technologie automobile associés aux économies d'échelle; (b) les investissements non-récupérables dans les infrastructures et les machines; (c) le style de vie des gens et leurs comportements; (d) les institutions, les législations et les systèmes de subventions actuelles favorisent le système en place et empêchent la mise en œuvre d'un autre système; (e) les schémas cognitifs et mentaux des décideurs en poste limitent leur attention à certains types d'alternatives; et (f) la résistance d'acteurs puissants qui veulent protéger leurs investissements passés (Geels et al. 2012).

La littérature en transport identifie quant à elle des barrières de ressources, des barrières institutionnelles et politiques, des barrières sociales et culturelles, des barrières légales, des barrières liées à des effets secondaires et des barrières physiques (Banister, 2005a; Curtis et Low, 2012; Hebbert, 2005; Hess et Lea, 2014; Nieuwenhuijsen et al., 2019; Rietveld et Stough, 2005). Premièrement, les barrières de ressources sont liées au manque de ressources financières et physiques au moment opportun pour pouvoir mettre en œuvre des politiques ou des infrastructures. Deuxièmement, les barrières institutionnelles et politiques sont associées aux problèmes et conflits intraorganisationnels (p. ex. entre les départements d'ingénierie, d'urbanisme et d'environnement dans une municipalité) et interorganisationnelles entre les différentes échelles gouvernementales (p. ex. municipale, régionale, provinciale et fédérale) et les différents secteurs (public et privé). Troisièmement, les barrières sociales et culturelles sont liées à l'acceptabilité sociale de la mise en œuvre de mesures, une acceptabilité qui dépend du type de mesure, certaines mesures encouragent un mode (p. ex. les mesures ayant pour objectif d'augmenter le transport actif) et risquent d'être plus acceptables alors que d'autres découragent l'utilisation d'un mode (p. ex. les mesures visant la réduction de l'utilisation de l'automobile) et risquent d'être plus difficilement acceptables. Quatrièmement, les barrières légales sont liées à des lois et à des normes issues ou non du domaine des transports. Cinquièmement, les barrières liées à des effets secondaires sont quant à elle parfois difficiles à anticiper, elles peuvent se manifester lorsqu'une nouvelle politique est adoptée ou qu'une infrastructure est construite (p. ex., la création d'une nouvelle ligne de tramway peut avoir pour effet d'embourgeoiser les quartiers longeant la ligne et de déplacer des populations plus vulnérables). Dernièrement, les barrières physiques réfèrent à des barrières rendant plus difficile la mise en œuvre d'une action (p. ex., la présence d'une forte pente ou d'une rivière peut restreindre la mise en œuvre de certaines actions).

Planification des transports et science de la décision

Afin de surmonter les barrières à une planification des transports durables, il ne faut pas seulement changer les actions à mettre en œuvre, mais il faut également changer les processus décisionnels en place. Plusieurs auteurs critiquent les processus décisionnels sous-jacents à la planification des transports qu'ils considèrent inadéquats pour intégrer le transport durable pour les raisons suivantes :

- les stratégies et les plans identifient des buts et des objectifs, mais les mesures de performances et les moyens de les mesurer sont mal définis et incohérents (Meyer et Miller 2001; Tumlin 2012);
- les indicateurs et mesures de performances reflètent encore une vision de l'ancien paradigme de planification des transports axé sur l'automobilité et ne sont pas adaptés au nouveau paradigme de transport durable (Marsden et al., 2010);
- les processus décisionnels nécessitent une meilleure intégration des différents points de vue et arguments des diverses parties prenantes (Macharis, Turcksin, et Lebeau 2012);
- le manque de vision holistique des projets fait échouer la vision initiale, cohérente avec les principes de durabilité (Pryn, Cornet, et Salling 2015).

Considérant les nombreuses barrières à la mise en place d'actions visant le transport durable, il apparaît nécessaire d'aider les gouvernements et les organismes publics à définir de nouveaux processus décisionnels et à créer de nouveaux outils d'aide à la décision afin de mieux intégrer les notions de transport durable dans les processus décisionnels. Ces outils devront assurer une meilleure communication et favoriser une collaboration accrue entre les différentes parties prenantes pour mieux tenir compte de l'ensemble des considérations et des besoins de la société dans une perspective de transport durable.

Avant de développer ces nouveaux processus décisionnels et outils, il est d'abord nécessaire de se questionner sur les processus décisionnels actuels dans les municipalités pour aménager des rues dans une perspective de transport durable. Par ailleurs, afin d'assurer la mise en œuvre de ces processus et outils, il convient également d'identifier les avantages et les barrières pour les municipalités à développer de nouveaux outils d'aide à la décision pour prioriser l'aménagement de rues dans une perspective de transport durable (**enjeu de recherche**).

Science de l'aide la décision

L'aide à la décision se définit comme « l'activité de celui qui, prenant appui sur des modèles clairement explicités mais non nécessairement complètement formalisés, aide à obtenir des éléments de réponse aux questions que se pose un ou des intervenants dans un processus de décision » (Roy et Bouyssou 1993, 21). Dans cette définition de Roy, les intervenants correspondent aux divers acteurs qui conditionnent directement la décision en fonction du système de valeurs dont ils sont porteurs.

Bien que le lien entre la littérature en science de la décision et le transport ne soit pas toujours bien établi, la planification des transports constitue un processus d'aide à la décision (Cascetta et al. 2015). Dans l'approche traditionnelle de planification des transports, l'aide à la décision est monocritère. Par exemple, l'approche « predict and provide » se base habituellement sur le niveau de service d'une infrastructure. La demande automobile est prédite à partir de projections démographiques et la majorité des décisions sont prises en fournissant les infrastructures qui permettent le maintien ou l'amélioration du niveau de service dans le futur (Bertolini, Clercq, et Straatemeier 2008; Owens 1995). Par exemple, le Highway Capacity Manual (National Research Council et Transportation Research Board 2016), qui est utilisé mondialement par plusieurs ingénieurs en transport pour faire la conception d'infrastructures, est basé sur le concept de niveau de service (Roess et Prassas 2014). Cette approche monocritère est également utilisée pour prioriser les projets d'infrastructures de transport. La majorité des pays occidentaux basent leurs décisions pour réaliser des infrastructures de transport sur des analyses coût-bénéfice (Odgaard, Kelly, et Laird 2006; Hayashi et Morisugi 2000; Mackie, Worsley, et Eliasson 2014; Bristow et Nellthorp 2000). Celles-ci visent à monétiser et à comparer les bénéfices (aspects positifs) et les coûts (aspects négatifs) socio-économiques de différentes options sur la durée de vie d'un projet. Habituellement, l'option avec le meilleur ratio bénéfice-coût ou avec la plus grande valeur nette actuelle sera retenue (Mackie et Nellthorp 2001).

Bien que les approches monocritères puissent permettre de trouver la solution maximisant l'unique critère considéré, celles-ci représentent une simplification de la réalité selon des hypothèses précises (Roy 2016). La prise en compte des nombreux enjeux liés au transport durable amène à considérer l'aide à la décision dans un contexte multicritère plutôt que monocritère. Dans les faits, l'aide multicritère à la décision ne vise pas à trouver « la bonne réponse », mais plutôt à considérer une diversité de points de vue, à gérer et à rendre explicites les éléments subjectifs d'une décision et à faciliter l'apprentissage et la compréhension d'un problème auquel des décideurs font face en structurant leurs priorités, valeurs et objectifs (Belton et Stewart 2002; Roy 2016; Belton et Pictet 2002). Les termes analyse multicritère (*multicriteria analysis*), analyse multicritère de la décision (*multicriteria decision analysis)* et prise de décision multicritère (*multicriteria decision making*) se retrouvent également dans la littérature. À moins d'indication contraire, c'est le terme aide multicritère à la décision qui sera utilisé dans cette thèse.

Les spécificités entre les approches monocritères et multicritères amènent à se questionner sur les différences entre l'aide multicritère à la décision et l'analyse coût-bénéfice dans un contexte de transport durable (**enjeu de recherche**).

Conceptualiser l'aide à la décision

Avant de décrire plus en détail l'aide multicritère à la décision, il convient de mieux comprendre ce qui est entendu par une décision « rationnelle ». Dans les faits, il existe plusieurs types de rationalité et cela a un impact sur ce qui sera considéré comme une décision « rationnelle ». Par exemple, Simon (1976) a introduit les concepts de rationalité substantive, de rationalité procédurale et de rationalité frontière. La rationalité substantive vise à atteindre un objectif spécifique et est basée sur l'hypothèse que les acteurs ont des objectifs préétablis clairement définis et qu'ils agiront toujours pour maximiser leur utilité ou leur profit. La rationalité procédurale, quant à elle, provient des champs de la psychologie et du comportement, et relève plutôt du processus et du raisonnement qui mènent à la prise de décision. L'échange d'information et la construction d'une nouvelle réalité à travers le processus décisionnel rendent celle-ci rationnelle (Simon 1986). Enfin, la rationalité frontière suggère que la capacité des acteurs à comprendre la complexité des enjeux et des problèmes est restreinte par le temps ou les ressources nécessaires pour avoir toutes les informations pour trouver la solution optimale, mais qu'il est tout de même nécessaire de trouver une bonne solution (Pomerol 2006; Katsikopoulos 2016).

Ces rationalités se traduisent de différentes façons dans les sciences de l'aide à la décision. Roy (1992) identifie trois voies pour produire des connaissances en aide à la décision : la voie du réalisme, la voie axiomatique et la voie constructiviste. Landry (1995) propose quant à lui trois manières de conceptualiser les problèmes et les connaissances : une vision objective, une vision subjective et une vision constructive. Tsoukiàs (2007) propose plutôt quatre approches d'aide à la décision selon des modèles de rationalités différentes : une approche normative, une approche descriptive, une approche prescriptive et une approche constructive. Enfin, Meinard et Tsoukiàs (2018) suggèrent quatre approches d'aide à la décision basées selon le concept d'agir communicationnel d'Habermas : une approche objectiviste, une approche conformiste, une approche ajustable et une approche réflexive. En se basant sur ces différentes conceptualisations, quatre approches d'aide à la décision ressortent de la littérature: (1) une aide à la décision basée sur la recherche de la vérité, (2) une aide à la décision basée sur la recherche d'un comportement à suivre, (3) une aide à la décision basée sur la recherche d'une compréhension intrinsèque de l'individu, et (4) une aide à la décision basée sur la construction d'une réalité propre au problème étudié (Tableau I.3). Les deux premières approches peuvent être associées à une rationalité substantive alors que les deux dernières approches peuvent être associées à une rationalité procédurale.

Ces différentes conceptualisations de l'aide à la décision amènent à s'interroger sur les diverses perceptions à l'égard de l'aide multicritère à la décision et de l'analyse coût-bénéfice et sur le rôle que ces conceptualisations peuvent avoir sur ces perceptions (**enjeu de recherche)**.

Tableau I.3 Résumé des quatre conceptualisations de l'aide à la décision selon différents auteurs

	Roy (1992)	Landry (1995)	Tsoukiàs (2008)	Meinard et Tsoukiàs (2018)
Recherche d'une vérité absolue	**Voie du réalisme et la quête d'une description pour découvrir :** Il préexiste un certain nombre d'objets sur lesquels il est possible de raisonner objectivement.	**Vision objective :** Les connaissances reflètent une réalité objective. La structuration d'un problème vise à révéler la structure de la réalité.	**Approche normative :** La rationalité est établie en fonction de normes et de comportements économiques idéaux.	**Approche objectiviste :** C'est une quête objective de la vérité. Il existe une formulation non questionnable du problème et de la solution qui est indépendante du contexte décisionnel.
Recherche d'un comportement à suivre	**Voie axiomatique et la quête de normes pour prescrire :** Il existe des cadres de références (normatifs) à suivre. Leur poursuite, sans nécessairement les atteindre, rend la décision acceptable.	N/A	**Approche descriptive :** La rationalité est connue en observant comment les décideurs prennent des décisions pour construire un modèle de comportements empirique.	**Approche conformiste :** Les décisions sont régulées par des normes, celles-ci seront jugées acceptables si elles sont prises selon les attentes comportementales des autres.
Recherche d'une compréhension intrinsèque de l'individu	N/A	**Vision subjective :** Les connaissances reflètent les représentations mentales d'un individu. La structuration d'un problème vise à structurer les pensées d'une personne.	**Approche prescriptive :** La rationalité est découverte à travers la modélisation des préférences et l'aide à la décision.	**Approche ajustable :** Chaque décision prise est unique à un certain contexte selon les besoins, préférences et valeurs des parties prenantes.
Construction d'une nouvelle réalité propre au problème	**Voie constructiviste et la quête d'hypothèses de travail pour recommander :** Il n'existe pas de vérité extérieure, elle doit être construite progressivement selon les objectifs et les systèmes de valeurs des acteurs impliqués.	**Vision constructive :** La modélisation est un processus pour aider quelqu'un à créer un sens à une situation. La structuration d'un problème vise à construire une représentation d'un objet pour planifier une intervention.	**Approche constructive :** La rationalité est un processus d'apprentissage qui aide à construire une rationalité nouvelle et commune entre les parties prenantes.	**Approche réflexive :** Il n'y a aucun a priori quant à une vérité objective, attentes comportementales, préférences des parties prenantes. C'est un processus d'apprentissage pour construire une nouvelle rationalité.

Aide multicritère à la décision

Plus précisément, l'aide multicritère à la décision (AMCD) est un champ de recherche, issu de la recherche opérationnelle, qui a émergé dans les années 60 et 70. L'AMCD consiste en une famille de méthodes qui vise à expliciter la prise en compte de plusieurs critères (Belton et Stewart 2002). Au début, les chercheurs en AMCD s'intéressaient principalement aux développements mathématiques des méthodes et se souciaient peu du processus pour appliquer les méthodes dans la pratique. L'accent était mis sur l'évaluation des alternatives, aussi appelées options ou actions, et l'exploration des solutions possibles selon un problème prédéterminé. Ce n'est que dans les années 80 qu'un intérêt croissant envers le processus décisionnel entourant la construction d'un modèle d'AMCD s'est développé (Belton et Stewart 2002; 2010).

Le développement d'un modèle d'AMCD implique au minimum deux acteurs : l'analyste et le client. Le client est un individu ou un groupe d'individus qui requiert l'aide d'un analyste pour étudier une situation décisionnelle. L'analyste, quant à lui, peut prendre deux rôles auprès du client, celui d'expert ou de facilitateur. À titre d'expert, l'analyste adopte une rationalité substantive pour trouver une solution optimale à un problème, alors qu'en tant que facilitateur, l'analyste adopte une rationalité procédurale pour développer le modèle de façon interactive avec le client afin de trouver une solution satisfaisante (Franco et Montibeller 2010).

Décision de groupe en aide multicritère à la décision

La prise en compte de différents points de vue en AMCD suppose, la majorité du temps, l'implication de plusieurs parties prenantes au sein du processus. En AMCD, trois procédures sont généralement définies pour effectuer des décisions de groupe : (1) le partage des préférences du groupe à travers des discussions et des négociations lors de rencontres entre les participants pour arriver à un consensus; (2) l'agrégation des préférences individuelles des participants à l'aide d'un vote ou de calculs mathématiques, sans discuter des causes créant des divergences d'opinions et (3) la comparaison des préférences individuelles comme base de discussion entre les participants (Belton et Pictet 1997). Une autre dynamique de groupe, explorée notamment dans les conférences de décision et dans les méthodes de structuration de problème, est de partager les préférences en rencontres de groupe, pour ensuite subdiviser le groupe lorsqu'il s'agit d'obtenir des informations plus précises (Damart 2010; Phillips 2007). Cette dynamique pourrait être associée à un mélange des approches (1) et (3) où il y a un partage des préférences à travers des discussions, mais également la création de préférences « individuelles » en sous-groupe pour ensuite servir de base de discussion pour l'ensemble des participants.

Suivi des processus d'aide multicritère à la décision

Dans un contexte de transport durable, la procédure de partage des préférences lors d'ateliers de groupe semble pertinente afin de considérer les différents points de vue (ingénierie, urbanisme, environnement, santé publique, design urbain, etc.). Par contre, malgré les nombreux cas d'étude qui utilisent cette démarche, peu de recherches rapportent les détails à propos du déroulement de ces ateliers de groupe et de l'utilisation des modèles développés au sein des organisations clientes (Braune, Pinkwart, et Reeg 2009; Marttunen, Lienert, et Belton 2017). Par conséquent, il est difficile de connaître véritablement les bonnes pratiques et les différents défis pouvant être reliés au développement en groupe de modèles d'AMCD et à l'utilisation d'outils basés sur ces méthodes. Il y a déjà plus de 25 ans, un manifeste pour une nouvelle ère d'AMCD appelait à mieux rapporter les cas d'étude d'AMCD en explorant, entre autres, l'évaluation post-projet (également appelée dans la littérature : évaluation a posteriori, analyse ex post ou évaluation) des interventions d'AMCD (Bouyssou et al. 1993). Une dizaine d'années plus tard, Montibeller (2005) entrevoyait également des opportunités de recherche dans l'évaluation des résultats des interventions d'AMCD, la validation des modèles d'AMCD et la

documentation des interactions entre facilitateurs et clients. Toutefois, malgré ces deux appels provenant de la communauté d'AMCD, il ne semble pas y avoir actuellement de cadre d'évaluation post-projet consacré pour évaluer a posteriori une démarche d'AMCD.

Il apparaît donc nécessaire de développer un tel cadre afin d'améliorer la qualité de l'information rapportée dans les interventions d'AMCD et ainsi de faire évoluer les pratiques en AMCD (**enjeu de recherche**).

Objectifs de la thèse

Cette thèse vise à répondre aux quatre enjeux de recherche soulevés dans les pages précédentes afin d'explorer comment l'AMCD peut être utilisée dans un contexte de transport durable. Plus particulièrement, elle s'intéresse à comment l'AMCD peut permettre de mieux intégrer et de surmonter les barrières liées au transport durable dans les processus décisionnels associés à la réfection et au réaménagement des rues. À partir des enjeux identifiés, quatre questions de recherche (QR) et des sous-questions de recherche (SQR) ont été formulées :

QR 1. Quelles sont les similarités et les différences entre l'aide multicritère à la décision et l'analyse coût-bénéfice dans un contexte de transport durable ? (**Chapitre 1**)

SQR 1.1. Est-ce que les différentes conceptualisations de l'aide à la décision influencent les perceptions à l'égard de l'aide multicritère à la décision et de l'analyse coût-bénéfice ?

QR 2. Comment développer une méthode quantitative qui prend en compte des éléments sociotechniques en se basant sur l'AMCD pour prioriser les projets de rues conviviales en termes de transport, d'environnement et d'urbanisme ? (**Chapitre 2**)

QR 3. Comment évaluer a posteriori un projet d'aide multicritère à la décision ? (**Chapitre 3**)

QR 4. Quelles sont les pratiques actuelles dans les municipalités pour aménager des rues dans une perspective de transport durable ? (**Chapitre 4**)

SQR 4.1. Quels sont les avantages et les barrières à développer des outils d'aide à la décision basés sur l'approche multicritère?

Par conséquent, les quatre chapitres de cette thèse ont respectivement pour objectifs et sous-objectifs de :

1. Comprendre les processus décisionnels actuels pour évaluer les projets de transport dans une perspective de transport durable.
   - 1.1. Identifier les avantages, les désavantages et les raisons qui amènent certains auteurs à préférer l'utilisation de l'AMCD ou de l'ACB ;
   - 1.2. Identifier les liens qui peuvent exister entre les préférences pour une méthode et les différents modèles de rationalités et conceptualisations de l'aide à la décision ;

1.3. Identifier les raisons qui incitent certains auteurs à combiner AMCD et ACB ;

1.4. Créer une typologie des différentes manières de combiner les AMCD et ACB dans l'évaluation de projet et identifier les raisons pour lesquelles les auteurs décident de choisir un type de combinaison en particulier.

2. Développer un cadre pour créer un outil cartographique d'aide multicritère à la décision pour prioriser l'aménagement de rues conviviales et l'appliquer.

2.1. Structurer un problème décisionnel dans un contexte multidisciplinaire selon l'approche de Value-Focus Thinking (Keeney 2007) ;

2.2. Construire un modèle d'AMCD selon la méthode MACBETH (Bana e Costa, De Corte, et Vansnick 2012) pour prioriser le réaménagement de rues en rues conviviales ;

2.3. Intégrer le modèle d'AMCD à l'intérieur d'un système d'information géographique afin de produire un outil cartographique d'AMCD.

3. Développer un cadre pour concevoir une évaluation post-projet pour évaluer les retombées d'une démarche et d'un outil d'AMCD et l'appliquer.

3.1. Proposer une méthode pour évaluer le processus d'AMCD réalisé à l'objectif 2 ;

3.2. Comprendre le processus de modélisation et, plus spécifiquement, les forces et les faiblesses perçues par les participants aux ateliers multidisciplinaires ;

3.3. Documenter le processus d'adoption et d'appropriation de l'outil cartographique d'AMCD, l'utilisation de l'outil et les améliorations possibles de l'outil dans le futur par les utilisateurs de l'outil ;

4. Générer un portrait des pratiques actuelles de municipalités pour intégrer le transport durable dans la réfection et le réaménagement de rue et explorer les avantages et les défis à développer des outils cartographiques d'AMCD.

4.1. Documenter les processus décisionnels actuels pour la réfection et le réaménagement de rues, et comment les professionnels municipaux incluent le transport durable dans ces processus ;

4.2. Identifier les avantages, les enjeux et les défis reliés au développement d'un outil cartographique d'AMCD ;

4.3. Proposer des recommandations pour améliorer les processus décisionnels de réfection et de réaménagement de rues ;

4.4. Proposer une série de lignes directrices flexibles pour permettre de développer des outils cartographiques multicritères pour prioriser la réfection et le réaménagement de rues.

Structure de la thèse

Le premier chapitre de cette thèse effectue une revue de littérature sur deux des principales méthodes d'évaluation en transport (l'analyse coût-bénéfice et l'aide multicritère à la décision). Cette revue présente

comment ces méthodes intègrent les principes de développement durable et les différentes parties prenantes dans les processus décisionnels en transport. De plus, afin de mieux comprendre pourquoi certains auteurs dans la littérature préfèrent une méthode plutôt qu'une autre, la revue de littérature analyse les deux méthodes selon différentes approches d'aide à la décision basées sur le concept d'agir communicationnel d'Habermas (objectiviste, conformiste, ajustable et réflexive). Les résultats montrent que les deux méthodes ont leurs forces et leurs faiblesses et que celles-ci varient selon l'approche d'aide à la décision. Toutefois, dans un contexte de transport durable, l'AMCD ou une combinaison des deux méthodes semblent être des approches plus prometteuses.

Le deuxième chapitre développe un cadre pour créer un outil cartographique d'AMCD afin d'identifier les rues à réaménager en priorité selon des principes de rues conviviales. Le cadre est appliqué au cas de la Ville de Québec. Le développement de l'outil a impliqué l'organisation d'ateliers multidisciplinaires (transport, urbanisme, environnement, ingénierie…) réunissant des professionnels de la Ville de Québec. Le développement de l'outil consiste en cinq grandes phases : (1) la structuration du projet, (2) la construction d'échelles d'attractivité, (3) l'élicitation des taux de substitution, (4) la validation du modèle et (5) la production de cartes de priorité. Malgré certaines difficultés rencontrées lors du développement de l'outil, celui-ci s'avère un succès et a entraîné un changement du processus décisionnel pour prioriser la réfection et le réaménagement des rues à la Ville de Québec.

Le troisième chapitre fait suite à la mise en œuvre de l'outil cartographique d'AMCD développé avec la Ville de Québec. Entre la réalisation de modèles et d'outils d'AMCD techniquement valides et fiables et leur utilisation, peu de suivis sont habituellement effectués dans la littérature en AMCD. À partir de la littérature pour évaluer les exercices de participation citoyenne, un cadre d'évaluation post-projet spécifique au domaine de l'AMCD est proposé et appliqué au cas de la Ville de Québec. À cette fin, une série d'entretiens individuels a été réalisée avec les participants des ateliers multidisciplinaires, avec les responsables de la stratégie de rues conviviales et avec les utilisateurs de l'outil. Les résultats montrent que l'AMCD a permis d'établir une discussion multidisciplinaire, de structurer la décision et d'améliorer le processus décisionnel, alors que les difficultés rencontrées sont liées au changement de pratiques professionnelles, aux problèmes de communication, au travail multidisciplinaire, à la compréhension des résultats et aux données utilisées dans l'outil. Les participants ont également apprécié l'exercice d'effectuer un suivi post-projet. De plus, différentes pistes de solution aux problèmes rencontrés sont proposées afin d'améliorer les pratiques.

Enfin, le quatrième et dernier chapitre élabore un diagnostic des pratiques actuelles et explore les avantages et les défis à développer des outils cartographiques d'AMCD dans des villes de tailles différentes. Pour y arriver, 88 professionnels impliqués dans la réfection et le réaménagement de rues (infrastructure, transport, urbanisme,

environnement et géomatique) provenant de 11 villes québécoises ayant entre 40 000 et 500 000 habitants ont été rencontrés dans des ateliers de groupe. Les rencontres ont été analysées en schématisant les processus décisionnels et en cartographiant les relations de cause à effet à l'aide de cartes causales. Il en ressort que le développement d'un outil cartographique multicritère partage plusieurs des caractéristiques identifiées par les participants à propos de leur processus décisionnel idéal pour la réfection et le réaménagement de rues. Des lignes directrices sont suggérées pour développer des outils cartographiques multicritères au sein des municipalités et d'autres recommandations sont faites pour améliorer les pratiques. Le principal défi ne consiste pas à développer un nouvel outil, mais plutôt à changer les comportements et les processus décisionnels au sein des organisations municipales.

Le tableau I.4 résume les quatre chapitres en faisant un parallèle entre les questions de recherche, les objectifs, les méthodes de collecte de données, les méthodes d'analyse, les étapes de la méthode, les participants et la littérature mobilisée dans chaque chapitre.

Tableau I.4 Résumé des quatre chapitres selon les questions de recherche auxquels l'article répond, la méthode, le cadre de recherche proposé, les participants et le cadre d'analyse.

	1er chapitre	2ième chapitre	3ième chapitre	4ième chapitre
Titre du chapitre	A review of cost–benefit analysis and multicriteria decision analysis from the perspective of sustainable transport in project evaluation	Assessing and ranking the potential of a street to be redesigned as a Complete Street: A multi-criteria decision aiding approach	A framework for post-project evaluation of facilitated multicriteria decision aiding processes: Development and application from the stakeholders' perspective	Sustainable transportation in municipal decision processes: Findings on policy and current practices
Objectif	Comprendre les processus décisionnels actuels pour évaluer les projets de transport dans une perspective de transport durable.	Développer un cadre pour créer un outil cartographique d'aide multicritère à la décision pour prioriser l'aménagement de rues conviviales et l'appliquer.	Développer un cadre pour concevoir une évaluation post-projet pour évaluer les retombées d'une démarche et d'un outil d'AMCD et l'appliquer.	Générer un portrait des pratiques actuelles de municipalités pour intégrer le transport durable dans la réfection et le réaménagement de rue et explorer les avantages et les défis à développer des outils cartographiques d'AMCD.
Collecte de données	Revue de littérature descriptive sur l'AMCD et les ACB dans le domaine du transport.	Séances de travail de groupe et de sous-groupe avec des professionnels de la Ville de Québec.	Série d'entretiens individuels avec des professionnels de la Ville de Québec.	Série d'entretiens de groupe avec les professionnels de différentes municipalités.
Méthode d'analyse	Analyse des résultats dans une perspective de transport durable et selon quatre approches d'aide à la décision.	Utilisation de la méthode MACBETH (Bana e Costa, De Corte, et Vansnick 2012) et intégration du modèle dans un système d'information géographique.	Analyse thématique des entretiens selon une démarche descriptive et continue.	Analyse des entretiens selon une schématisation des processus décisionnels et technique de cartographie causale.

Étapes de la méthode	1. Formulation du problème de recherche 2. Recherche de la littérature 3. Sélection des articles à inclure 4. Extraction des données 5. Analyse et synthèse des données	1. Structuration du problème 2. Construction des échelles d'attractivité 3. Élicitation des taux de substitution 4. Validation des résultats 5. Production de cartes de priorisation	Questions pour développer une évaluation : • Pourquoi évaluer ? • Quoi évaluer ? • Sur quoi est basée l'évaluation ? • Comment évaluer ? • Qui est impliqué dans l'évaluation?	1. Recrutement des villes participantes au projet 2. Développement du questionnaire 3. Organisation de rencontres de groupe 4. Analyse qualitative des données basées sur les processus décisionnels et les cartes causales 5. Validation des résultats auprès des professionnels
Participants	Non-applicable	Professionnels de la Ville de Québec en infrastructure, en transport, en urbanisme, en design urbain, en environnement, en architecture du paysage et en participation citoyenne.	Professionnels de la Ville de Québec ayant agi comme participants aux rencontres multicritères, étant responsable de la stratégie de rues conviviales ou étant des utilisateurs de l'outil cartographique multicritère.	Professionnels en infrastructure, en transport, en urbanisme, en environnement et en géomatique de 11 villes québécoises ayant entre 40 000 et 500 000 habitants.
Cadre théorique	Planification des transports et science de la décision, conceptualiser l'aide à la décision et opérationnaliser le transport durable	Aide multicritère à la décision, aménagement des rues plus durables, opérationnaliser le transport durable et décision de groupe en aide multicritère à la décision	Aide multicritère à la décision, décision de groupe en aide multicritère à la décision et suivi des processus d'aide multicritère à la décision	Barrière à une planification des transports durables, aménager des rues plus durables, planification des transports et science de la décision et aide multicritère à la décision

1 Chapitre 1: A review of cost-benefit analysis and multicriteria decision analysis from the perspective of sustainable transport in project evaluation

1.1 Résumé

Les processus décisionnels en transport ont traditionnellement appliqué les analyses coût-bénéfices (ACB) afin d'évaluer des bénéfices principalement liés aux gains de temps et des coûts associés aux infrastructures et à leur maintien. Toutefois, un changement vers des pratiques plus durables a commencé à s'opérer au cours des dernières décennies pour pallier les impacts négatifs de l'automobilité. Par conséquent, les processus décisionnels reliés aux projets de transport deviennent de plus en plus complexes à cause de la prise en compte d'aspects multidimensionnels et de la variété des parties prenantes impliquées, lesquels ont souvent des points de vue conflictuels. Afin de supporter une prise de décision rigoureuse, l'analyse multicritère est, en plus des ACB, souvent utilisée par les gouvernements et les villes. Cependant, il n'y a toujours pas de consensus dans le domaine du transport quant à la méthode qui est la plus appropriée pour intégrer les principes de durabilité. Cet article présente une revue de littérature descriptive liée aux AMC et aux ACB dans le domaine du transport. Parmi les 66 articles retenus, nous avons identifié les forces et les faiblesses perçues des deux méthodes, les différentes manières de les combiner et la capacité de chacune des méthodes à supporter un processus décisionnel en transport durable. Les résultats ont été analysés plus en détail selon quatre types de rationalité (objectiviste, conformiste, ajustable et réflexive). Nos résultats montrent que les deux méthodes peuvent aider à améliorer les processus décisionnels. Toutefois, nous observons qu'en adoptant une perspective plus holistique et globale et en facilitant une approche participative, l'AMC ou une combinaison des deux méthodes apparaissent comme les méthodes d'évaluation les plus prometteuses pour intégrer le transport durable.

Mots-clés : transport durable, analyse multicritère, analyse coût-bénéfice, rationalité, aide à la décision

1.2 Abstract

Transport decision processes have traditionally applied cost-benefit analysis (CBA) with benefits mainly relating to time savings, and costs relating to infrastructure and maintenance costs. However, a shift toward more sustainable practices was initiated over the last decades to remedy the many negative impacts of automobility. As a result, decision processes related to transport projects have become more complex due to the multidimensional aspects and to the variety of stakeholders involved, often with conflicting points of view. To support rigorous decision making, multicriteria decision analysis (MCDA) is, in addition to CBA, often used by governments and cities. However, there is still no consensus in the transport field regarding a preferred method that can integrate sustainability principles. This paper presents a descriptive literature review related to MCDA and CBA in the field of transport. Among the 66 considered papers, we identified the perceived strengths and weaknesses of CBA and MCDA, the different ways to combine them and the ability of each method to support sustainable transport decision processes. We further analysed the results based on four types of rationality (objectivist, conformist, adjustive and reflexive). Our results show that both methods can help improve the decision processes and that, depending on the rationality adopted, the perceived strengths and weaknesses of MCDA and CBA can vary. Nonetheless, we observe that by adopting a more global and holistic perspective and by facilitating the inclusion of a participative process, MCDA, or a combination of both methods, emerge as the more promising appraisal methods for sustainable transport.

Keywords: Sustainable transport, multicriteria decision analysis, cost-benefit analysis, rationality, decision aiding

1.3 Introduction

The increasing awareness of social inequities and environmental degradation related to anthropogenic activities has led researchers and practitioners since the end of the 20th century to define the concept of sustainable development and to explore new solutions. As a result, many related environmental sectors such as energy or agriculture production have adjusted their practices in order to integrate sustainability (Elzen, Geels, et Green 2004). Transport is no exception; in response to the numerous documented negative impacts of the transport networks specifically designed for automobility (noise, air pollution, public health degradation, urban sprawl, traffic, social inequity, etc; (Nieuwenhuijsen et al. 2019), the concept of sustainable transport[2] has emerged and several definitions were proposed (Gudmundsson et al. 2016). The definition adopted in this paper is that of Holden et al. (2013) where sustainable transport is defined as a system of transport that safeguards long-term ecological sustainability, satisfies basic human needs and promotes intragenerational and intergenerational equity.

Nevertheless, a path dependency toward unsustainable behaviours and practices is still found in transport (Curtis et Low 2012; Driscoll 2014), a situation also encountered in other fields such as agricultural technology (Vanloqueren et Baret 2009), energy production (Lafferty et Ruud 2008) or urban water management (R. Brown et Farrelly 2007). A path dependency is defined as a sequence of steps during a problem solving or modelling process that will lead inevitably to similar outcomes or solutions (Geels et al. 2012). Despite the inclusion of sustainability objectives in project assessments, there is often a gap between potential decision processes, meant to be coherent with sustainable transport objectives, and the existing decision processes, that still allow for unsustainable transport infrastructures and policies (Marsden et al. 2010). This is illustrated by Finnveden and Åkerman (2014) using two case studies in Sweden where, by not including long-term climate goals and project impacts on future transport systems such as the generation of new traffic, infrastructure assessment practices have led to unsustainable solutions. This was also observed by Banister (2008) who coined the term *schizophrenic path* to describe this situation: "when it is clear that action is needed, but no effective action is taken to remedy the situation". Therefore, a better understanding of current project assessment methods and their associated weaknesses and strengths is needed to help improve the integration of sustainability principles into current transport project assessment practices.

To support rigorous strategic decision-making, several methods may be used for the assessment of transport projects. Two such methods are generally used by governments and cities: cost-benefit analysis (CBA)[3], the

[2] The term sustainable mobility is also used by some authors. The difference between the two is that mobility refers to the potential of a person to move from an origin to a destination whereas transport refers to the travel of a person from an origin to a destination. In this paper, the term sustainable transport will be used.

[3] CBA is also known as Benefit-Cost Analysis (BCA), which may be a better term as the name is more coherent with the method. However, the term CBA will be used in this paper since the majority of the literature uses this term.

most widespread and frequently applied project evaluation method in transport, and multicriteria decision analysis (MCDA). Other methods that quantify economic impacts, such as techno-economic analysis (TEA), cost-effectiveness analysis (CEA) or activity-based costing (ABC), are sometimes used; but they are not as widespread as CBA and are therefore outside the scope of this paper. CBA may be more commonly used; however, MCDA is quite often used in countries such as Austria, Belgium and Germany (Hayashi et Morisugi 2000; Bristow et Nellthorp 2000; Odgaard, Kelly, et Laird 2006; Mackie, Worsley, et Eliasson 2014). To this day, no consensus has yet emerged in the transport field regarding the preferred method for integrating sustainability principles.

Since the application of CBA in transport was not initially developed to take into account sustainability objectives, some authors have suggested that MCDA may better integrate sustainability principles (Banister 2008; Gudmundsson et al. 2016). In parallel, other authors have advocated combining both methods to address different aspects of the same project (Haezendonck 2007; Beria, Maltese, et Mariotti 2012; Mouter, Annema, et Wee 2013). This has led to a flourishing development of appraisal frameworks in transport, albeit with no agreement on whether and how CBA and MCDA should be combined, or if one method is better than the other in terms of taking into account sustainability objectives.

A few papers, comparing CBA and MCDA from the perspective of their respective fields, can be found in the literature on the environment (Joubert et al. 1997; Saarikoski et al. 2016), on environmental risk management (Brouwer et van Ek 2004; Gamper, Thoeni, et Weck-Hannemann 2006), on energy (Medjoudj, Aissani, et Haim 2013), on sustainable development (Klaas De Brucker, Macharis, et Verbeke 2013) and on water management (Lai, Lundie, et Ashbolt 2008). However, such literature reviews in the field of transport are rare and are narrative reviews (Browne et Ryan 2011; Beria, Maltese, et Mariotti 2012; Bueno, Vassallo, et Cheung 2015). Furthermore, they do not involve a systematic or a comprehensive search of all the literature and therefore, lack methodological information and cannot be replicated. In addition, none of the published papers in the transport field addressing CBA and MCDA describe or analyse the different philosophical backgrounds, or rationalities, underlying the two, a necessary step to understand why some individuals choose CBA while others prefer MCDA.

The aim of this review paper is to present a descriptive literature review related to MCDA and CBA based on a structured coverage and an explicit selection strategy of journal and proceeding papers. Our main goal is to compare the use of the two methods, in the context of sustainable transport, from the perspective of the different rationality conceptualisations defined by Meinard and Tsoukiàs (2018): objectivist, conformist, adjustive and reflexive (discussed in further details in section 1.4). A descriptive review (Paré et al. 2015) was therefore deemed relevant since our goal is not limited to identifying what is written on the different methods, but rather to

apply a search strategy that cover a representative sample of the literature and to perform a content analysis. Moreover, to enhance the quality of this literature review, we followed the relevant guidelines given by Templier and Paré's (2018) for systematicity and transparency of literature review evaluations.

More specifically, this paper aims to answer the following research questions:

- What are the perceived strengths and weaknesses of CBA and MCDA, and how are these perceptions related to different rationalities underlying decision-aiding processes?
- What are the different ways of combining CBA and MCDA and what motivates their combination in those differing ways?
- Do either (or both) CBA and MCDA have the capability to include sustainability in transport in project assessments?

This paper is structured as follows: Section 1.4 describes the four decision-aiding approaches and contains an overview of CBA, MCDA and project assessment frameworks used in transport. Section 1.5 presents our literature review methodology. Section 1.6.1 presents a general analysis of the reviewed papers. Section 1.6.2 summarises the perceived strengths and weaknesses of CBA and MCDA with an emphasis on sustainable transport. Section 1.6.3 describes how CBA and MCDA are combined in the literature, the rationale behind the various combination frameworks and the reasons for preferring one framework over another. Section 1.7 discusses the comparison results from the perspective of different decision-aiding approaches and analyses CBA's and MCDA's capability to better integrate sustainability in project assessments. Finally, Section 1.8 summarises the paper and explores future avenues for research related to project assessment in transport.

1.4 Project assessment in transport

Addressing transport problems implies dealing with complex situations and unexpected consequences. Solutions come in many forms, including policies (carbon taxation, land-use policies, technological regulation) or infrastructure development (highways, highspeed trains, tramway lines); also referred to as soft and hard interventions respectively. Decision-makers need to appreciate the compromises between the investments required, the potential to achieve the desired outcomes, and the different impacts on society. Therefore, the main aim of transport project assessment is to produce and communicate relevant information to enable the decision-makers to acquire full knowledge of transport problems and issues (Meyer et Miller 2001; Haezendonck 2007; Notteboom et Winkelmans 2007).

Nonetheless, what is considered a "good" decision may vary depending on the type of rationality pursued. Putting the question of sustainability aside for the moment, a better understanding of what is a "good" decision can be discussed from a rationality perspective. Genard and Pirlot (2002) explored the concept of decision-aid model

validity from a philosophical perspective according to the four pretensions to validity that form a whole called rationality by Habermas: truth, normative justness, sincerity and intelligibility. Then, following the work of Simon (1976), Tsoukiàs (2008) expanded on the four approaches to decision-aiding (normative, descriptive, prescriptive and constructive). However, in order to take into account the social dimension of rationality in decision processes, Meinard and Tsoukiàs (2018) defined four new decision-aiding approaches based on the concept of communication action from Habermas. In this literature review, we adopt their definitions as follows:

a) an objectivist approach where rationality is strategically shaped and accepts that there are unquestionable formulations of problems and solutions (strategic conception of rationality and similar to a normative approach);
b) a conformist approach where rationality is derived from observing stakeholders in order to build an empirical behaviour model (norm-regulated conception of rationality and similar to a descriptive approach);
c) an adjustive approach where rationality is unique to a particular context according to stakeholders' needs, preferences and values (dramaturgic conception of rationality and similar to a prescriptive approach);
d) a reflexive approach where rationality is a learning process to build a new rationality with no authoritative conception, no behavioural expectations and no inner preferences (communicative conception of rationality and similar to a constructive approach).

The above decision-aiding approaches structured the theoretical framework that was used to analyse the papers in this review. The following sub-sections describe CBA (section 1.4.1) and MCDA (section 1.4.2), two project assessment methods commonly used to aid decision-makers and how they are included in assessment frameworks (i.e. how a method or several methods are used in practice to assess projects) depending on the country (section 1.4.4).

1.4.1 Cost-benefit analysis

Cost-benefit analysis (CBA) is a method rooted in the field of economics. CBA aims at finding, for a given problem, the solution that will achieve the greatest overall societal welfare. It involves monetising the socio-economic costs (negative impacts) and benefits (positive impacts) of each alternative over the life of a project. The range of impacts (be they positive or negative) are typically limited due to technical constraints. For example in situations where it is not possible to assign a market value to a given impact, the valuation is estimated directly using stated preference methods such as willingness-to-pay (WTP) and willingness to accept (WTA) or indirectly using revealed preference methods like hedonic pricing (Nash 1997). WTP represents the monetary amount that an individual would pay to obtain a good (e.g. a person could be asked in a stated preference survey: *how much would they pay per month to reduce crowding in metro during peak hours?*). WTA represents the minimum

monetary amount required to compensate the loss of a good (Brown and Gregory 1999). For example, a person may be asked *how much is required to compensate for the increase in noise caused by a new motorway near their residence?* As for hedonic pricing, it examines the relationship between the sale price of a good, its physical and environmental characteristics in order to quantify the value of a specific characteristic. For example, to measure the price of accessibility, the increase in price, over a given time period, of houses near a new train station compared to the increase in price, over the same time period, of similar houses that are not close to a train station, can be examined to determine the hedonic price effect (Dubé, Thériault, et Des Rosiers 2013). A CBA that includes these non-market values is sometimes called social cost-benefit analysis as opposed to a traditional CBA (Haezendonck 2007).

Furthermore, considering that costs and benefits may arise at different points over the lifetime of a project, CBA requires the conversion of future monetary values to net present values through discounting, based on a reference period and a discounting rate. These parameters vary depending on the country's appraisal guidelines. For example, in the field of transport planning, in the United States, the discount rate is 7% and the evaluation period depends on the project's lifetime (25-30 years), whereas, in the United Kingdom, the discount rate is between 2.5% and 3.5 % and the evaluation period is by default 60 years (Gwee, Currie, et Stanley 2011; Mackie, Worsley, et Eliasson 2014). The reference period aims at determining the period over which the impacts will be considered. A longer reference period will include more long-term effects in the evaluation. As for the discounting, it is based on the assumption that benefits or costs that occur in the short term are more relevant than the ones occurring in the long term. The higher the discount rates, the lower the value of future costs and benefits in a CBA. Thus, future impacts such as climate change would be more heavily discounted (given lower consideration) in the American system as compared to the British one.

A project that achieves only gains/benefits without any losses/costs should, of course, be implemented. However, situations with only benefits and no downside effects rarely exist in real life. To resolve this conundrum, CBA was established on utilitarian principles and according to the Hicks-Kaldor compensation test (van Wee, 2011): an act is considered right only if the societal welfare improvement is "higher" for those who gain than the negative impacts on those who lose (Klaas De Brucker, Macharis, et Verbeke 2013; Saarikoski et al. 2016). Consequently, alternatives are compared according to the benefit-to-cost ratio (BCR) or the net present value (NPV) difference in order to determine the alternative with the highest societal welfare (Mackie et Nellthorp 2001). A BCR value that is larger than 1 or a positive NPV are signs that the project is economically efficient. Transforming effects into monetary values and aggregating them through a BCR or NPV allows for a complete compensation between the different considered effects (Ackerman et Heinzerling 2004).

1.4.2 Multicriteria decision analysis

Multicriteria decision analysis (MCDA) was developed in the field of operational research. It consists of a family of methods that aim at explicitly taking into account multiple criteria (Belton et Stewart 2002). MCDA is also called multi-criteria decision-making or multi-criteria decision aiding. Following discussions and debates with the stakeholders, a MCDA process can help create a consensus around a common value structure that involves multidimensional aspects and takes into account criteria from different fields (Munda 2005; Roy 2016). MCDA can help solve three types of problems: choice problematic (selection of one or of a small set of alternatives among several), sorting problematic (classification of alternatives according to predefined categories) and ranking problematic (partial or complete ordering of alternatives). A MCDA process consists usually of two main phases: (1) a problem structuring phase and (2) a model building and alternatives assessment phase. Problem structuring aims at identifying the values, the concerns and the issues of stakeholders and constructing a set of criteria and alternatives. Model building seeks to define the parameters that will serve to assess the alternatives. Since it is rooted in stakeholders' preferences and objectives, MCDA is often referred to as objective-driven as opposed to market-driven or efficiency-driven for CBA. Two of three main schools of thought in MCDA have been used in transport assessment projects: single-synthesising criterion methods that build utility or value functions (cardinal data) and outranking-based methods that build binary preference relations (ordinal data; Greco et al. 2016a).

1.4.2.1 Single-synthesising criterion methods

Single-synthesising criterion methods are compensatory methods and yield total pre-orders where all the alternatives are ranked with a score from best to worst with a possibility of *ex-aequo* (alternatives with equal scores). They are based on two basic preference relations (strict preference and indifference). They involve building partial value functions for every criterion and aggregating them through different forms of weighting to build a global value function. The weighting in single-synthesising criterion methods does not represent the importance of criteria, but rather the relative importance of criteria as a function of the constructed local value functions, with AHP (Analytic Hierarchy Process) being an exception (Belton et Stewart 2002). Throughout the years, various methods have been developed including MAVT (Multi-Attribute-Value-Theory; Dyer 2016), MACBETH (Measuring Attractiveness by a Category-Based Evaluation Technique; Bana e Costa et al. 2016) and AHP (Saaty 1977; 2016).

1.4.2.2 Outranking methods

Outranking methods are partial compensatory ordinal methods where the alternatives are ranked from best to worst (in a ranking problematic) with a possibility of *ex-aequo* and of incomparability (partial pre-orders). They are based on four basic preference relations (indifference, strict preference, weak preference and incomparability) used to define an outranking relation (an alternative A is at least as good as an alternative B).

These methods involve determining outranking relations between the alternatives based on pairwise comparisons and on credibility indices of the assertion *A is at least as good as B*. Some methods use weights that represent the voting power of criteria. Various outranking methods have been developed throughout the years including the ELECTRE family and some versions of PROMETHEE (José Rui Figueira, Mousseau, & Roy, 2016; Brans & Smet, 2016).

1.4.3 Similarities between the methods

Despite being developed in two different fields, CBA and MCDA single-synthesising criterion methods share several similarities (Marshall, McNeill, et Reeve 2011). They both aim at improving the decision process by rigorously comparing the advantages (benefits) and the disadvantages (costs) of each alternative. To compare the alternatives, they both involve a form of weighting and transform original units into uniform units for comparison. However, the underlying preference types are different: CBA use the sum of individual consumer preferences (i.e. monetary values and shadow prices) whereas MCDA use the involved stakeholders' preferences (i.e. utility functions, swing weights…). In fact, the results of a CBA and an MCDA will be the same in the very specific and limited conditions where: the criteria scores are the same, the shadow prices are equal to the MCDA weights, the weight on cost is unity and the MCDA aggregation method used is a weighted sum (Atkinson et al. 2018). Moreover, CBA and single-synthesising criterion methods both allow a complete compensation between the criteria (Browne et Ryan 2011). The possible undesirability of a total compensation effect is one of the factors that led to the development of MCDA outranking methods that are partial compensatory methods (Roy 1985).

1.4.4 An overview of some assessment frameworks in transport

Various transport project assessment frameworks have been designed, in different countries, based on CBA and MCDA. These frameworks involve mainly CBA with BCR and NPV, although some frameworks also include non-monetised and qualitative impacts. The way these non-monetised impacts are included in the analysis varies: some frameworks evaluate environmental impacts or conduct life-cycle analysis (also known as life-cycle assessment) separately, while others integrate CBA explicitly into a MCDA or a summary table (i.e. a table that presents the alternative's impacts according to several dimensions, unaggregated). Moreover, it is not typically the choice of an individual or a group to decide whether a CBA or a MCDA should be used, rather, it is a requirement from governmental administration such as a Department of Transport. In the majority of western countries, conducting a CBA or an economic assessment according to specific guidelines is a prerequisite to any transport project development (Odgaard et al. 2006; Hayashi and Morisugi 2000; Bristow and Nellthorp 2000; Mackie et al. 2014). The next paragraphs present some of these frameworks.

In Denmark, the *Overview of the Effects of Infrastructure* (OEI manual, previously known as OEEI) recommends monetising effects as much as possible. Subsequently, the non-monetised effects are presented in parallel with a qualitative description (Jong et Geerlings 2003; Mouter, Annema, et van Wee 2015). In Germany, the *Federal Transport Infrastructure Plan* assesses projects according to four different modules: cost-benefit analysis, environmental and nature conservation, spatial planning, and urban development. However, it is not clear how these different modules interact (Federal Ministry of Transport and Digital Infrastructure 2016).

In the United States, projects that are funded by the federal government require a CBA. However, regional level projects that are planned by Metropolitan Planning Organizations often use a variant of MCDA (Hayashi et Morisugi 2000; Mackie, Worsley, et Eliasson 2014). In Canada, the assessment frameworks differ depending on the province, but are usually based on a CBA or a MCDA. One framework used in the provinces of Alberta and British Columbia is *Multiple Account Evaluation* (MAE). The MAE's particularity is to consider the different interests and objectives of stakeholders by introducing the concept of an account. Each account represents a different point of view (financial performance, customer service, environment, economic development and social). The performances of alternatives within an account can be aggregated, but individual accounts' performances are presented in a disaggregated form to decision-makers (Crown Corporations Secretariat 1993; Shaffer 2010).

In Australia, the CBA Guidelines introduced the concept of *Adjusted CBA* as an optional appraisal technique, presented as a hybrid of CBA and MCDA. The guidelines suggest weighing the costs and benefits in order to better represent the government's objectives and are therefore more policy-driven (Australian Transport Assessment and Planning 2018). In Japan, a CBA is used as a filter to screen the projects and retain only those deemed worthy of further investigation. The remaining projects are then ranked using a *Benefit Incidence Table* acknowledging, for each stakeholder, whether the effects are positive or negative and whether it is possible to measure these effects (measurable in monetary terms, roughly measurable and difficult to measure). However, it is not clear how the tables are interpreted.

1.5 Methodology

The procedure used to review the literature consists of five steps: (1) formulating the problem, (2) searching the literature, (3) screening for inclusion, (4) extracting data and (5) analysing and synthesising data (Templier et Paré 2015). In order to identify the papers related to CBA and MCDA in the transport field, two multidisciplinary databases (Web of Science and ABI-INFORMS) and two transport-related databases (Transport research international documentation (TRID) and OVID-transport) were searched. The keywords used were variants of *multicriteria decision analysis* AND *cost-benefit analysis* AND *transport* (Fig. 1.1). The search was limited to papers published in peer-reviewed journals and conference proceedings. The covered language was English.

The keyword *transport* or one of its variants were not used in the TRID and OVID-transport databases since they are transport-specific databases. Fig. 1.1 summarises the literature screening process in a flow diagram.

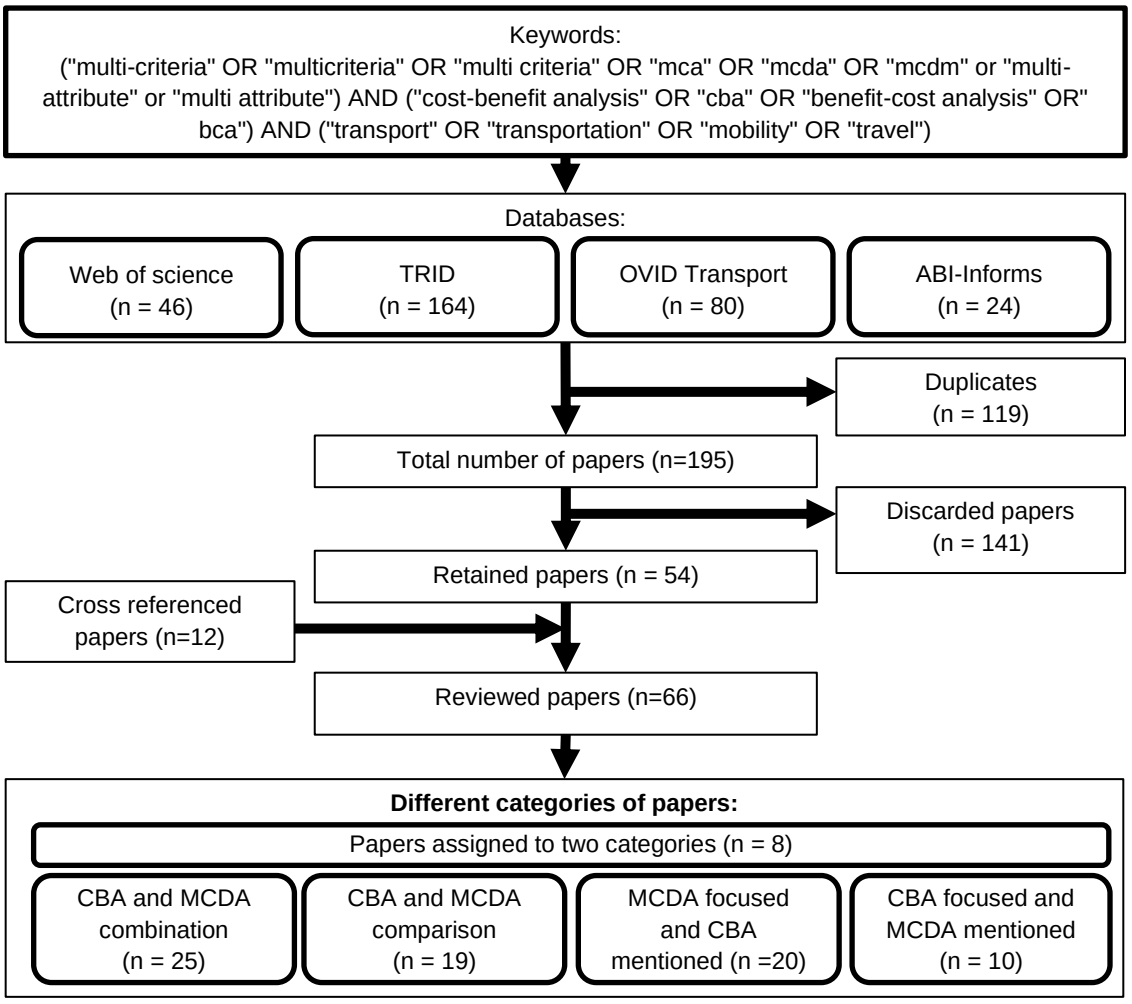

Figure 1.1 Flow diagram of literature screening process

The period of the literature search was limited to publications from 2000 to 2018. This choice was made in order to reflect the current state of CBA and MCDA; the two methods and their practices have evolved significantly over the last two decades. The papers were filtered based on the title and the abstract, and only those relevant to the research questions were retained. Furthermore, only papers about ground-based transport for people or land freight transport were kept; papers about sea and air transport were discarded. This choice was made because they represent a different type of transport problem and usually involve different decision processes. Furthermore, a conference paper from the same authors and on the same subject later published in a journal was considered a duplicate; in these cases, only the journal papers were included in the review. To minimise publication bias and mitigate the search tools limitations, cross-referenced papers were also included in our

literature review (n=12). They were either backward references or forward references, always within the 2000-2018 timeframe. A total of 66 papers were reviewed.

The papers were analysed and synthesised using text-coding and a thematic analysis based on the research questions (Paillé et Mucchielli 2016). Each text sample linked to a theme was coded and served as a basis for the results' presentation.

Furthermore, in a general analysis, the publication year, title, authors, journal, country of origin of the first author (university of origin), field of transport (freight, road infrastructure, train infrastructure, general policy) and the inclusion of a case study were noted for each paper. For case studies, the type of decision (operational, tactic or strategic), which MCDA method was used and whether the CBA monetised environmental or social aspects were recorded. The papers were then sorted into four categories (Fig. 1.1). A small number of papers were assigned to two categories (n=8).

Moreover, papers considering explicitly or implicitly sustainable transport were identified among the selected papers. The papers were analysed according two themes: involving stakeholders in the decision process and having a holistic vision, which was further split into three sub-themes following Holden et al.'s (2013) definition: long-term ecological sustainability, satisfying basic human needs and intra and inter-generational equity.

Comparison papers were further sub-classified into two categories: (1) papers highlighting the differences in the results obtained when both methods were applied to the same project and (2) papers that present the strengths and the weaknesses according to different points of view (infrastructure, equity, policy, etc.). For the first category, the differences in the results were identified and the reasons explaining these differences were analysed. As for the second category, the strengths and the weaknesses as perceived by the authors were recorded and grouped according to different themes (e.g. transparency, simple to understand and ethical consideration).

Combination papers refer to papers that propose to combine CBA and MCDA in a new assessment framework. Four types of combination frameworks were identified in the literature (Fig. 1.2). Two papers were classified into two categories, and two papers mentioning methods combination were not explicit enough to allow for the identification of one of the four frameworks. For each combination paper, the reasons behind adopting a combination framework rather than a CBA or MCDA method, as well as the justification for using one of the four combination frameworks were recorded. Papers that did not include or were not explicit enough about these two elements were excluded.

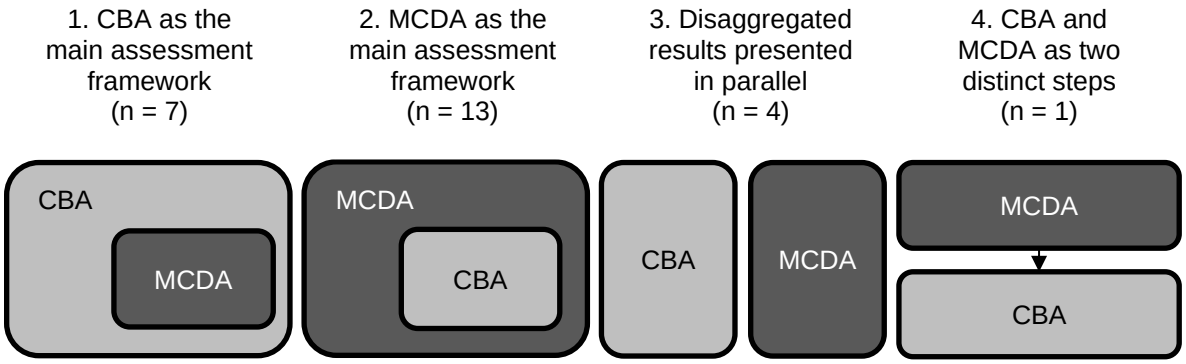

Figure 1.2 Conceptualisation of the different frameworks to combine CBA and MCDA

As for the papers that focus on MCDA and mention CBA, and papers that focus on CBA and mention MCDA, they were either case studies or in-depth reflection about practices, processes or theoretical problems of a method. For case studies, the reasons why one method was preferred over another were noted. As for reflection papers, the strengths and weaknesses cited were added to the ones identified in the comparison papers according to the same themes used for comparison papers.

1.6 Results

Section 1.6.1 presents the results of the general analysis of papers on MCDA and CBA. Section 1.6.2 presents the strengths and weaknesses of CBA and MCDA as identified in the literature. Section 1.6.3 presents how CBA and MCDA are combined in the literature.

1.6.1 General analysis

Out of the 195 papers identified, 66 were reviewed. At least one paper on the subject was published per year and a slight increase of the number of published papers can be seen in the last five years (2014-2018 (n=26)) compared to the two previous five-year periods (2003-2007 (n=15) and 2008-2013 (n=18); Fig. 1.3).

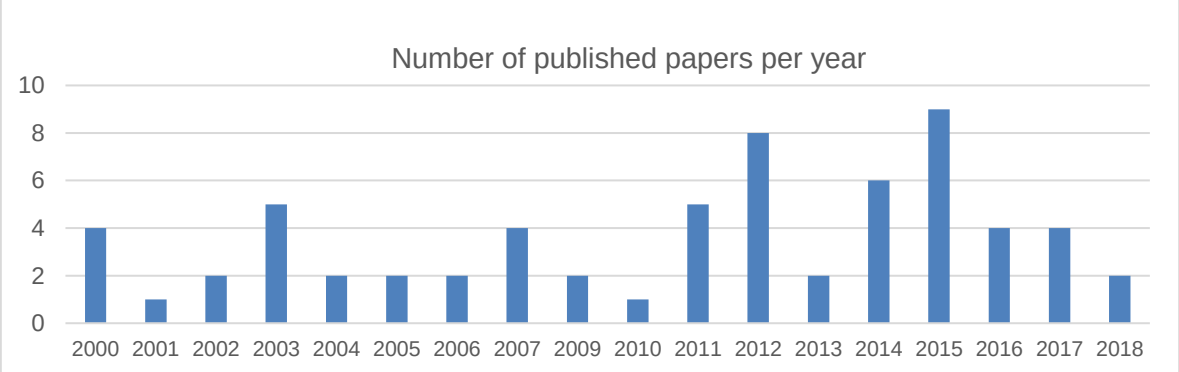

Figure 1.3 Number of published papers according to the year of publication

42 papers included case studies. The majority of papers that developed a combination framework (23/25) or were centered on MCDA (16/20) were case studies; whereas the majority of comparison papers (11/15) and papers focusing on CBA (8/10) did not include a case study. Most of the case studies were applied for strategic decisions (38 out of 42) and no case studies involved operational decisions. AHP was the most frequently used method (n=15) and was often combined with other methods (n=12). Case studies that used a form of multi-attribute utility/value theory were also frequent (n=12). However, few case studies used outranking methods (n=3). As for case studies that included a CBA, 16 out of 25 monetised environmental or social aspects.

Moreover, 23 papers explicitly included sustainability considerations (either sustainable transport or sustainable development applied to transport) and 10 included these considerations implicitly. The majority of paper focusing on CBA did not include sustainability (8/10) and no trend for the other category of papers were identified (comparison papers, combination papers and MCDA focussed papers). Appendices A to C present the full results of this general analysis.

1.6.2 Comparison between the methods

Based on the papers that compared both methods, sections 1.6.2.1 to 1.6.2.4 present the strengths and weaknesses of CBA and MCDA as identified in the literature. Table 1.1 summarises the perceived strengths and weaknesses of CBA and MCDA.

Tableau 1.1 Summary of the perceived strengths and weaknesses of CBA and MCDA

	CBA	**MCDA**
Strengths	• Rigorous process • Achieves different roles • Common language • Economic efficiency driven • Transparent • Reflects the values of “all” people	• Inclusion of stakeholders • Integrates qualitative and subjective aspects • Importance of process over results • Objectives driven • Variety of methods • Transparency of the process
Weaknesses	• Ethically dubious • Lack of transparency • Incorporating impacts that are not, or are difficult to monetise • Difficulty to deal with equity • Inclusion of stakeholders • Individual values versus collective values • Strategic behaviours	• Qualitative and subjective assessment • Issues about weighting • Subject to creating a “black box” effect • Double counting • Time and resources consuming • Forces the consensus

As for the papers that compare the differences in results when CBA and MCDA were applied to the same project, two papers were identified in the literature: the resulting preferred projects following a CBA were not the same as those following a MCDA. Tudela et al. (2006) explained these differences by the lack of consideration for non-economic aspects in CBA. The case study showed that the provision of information through a MCDA process allowed people to be more aware of factors such as noise and visual impacts, which translated into a weight shift from the CBA parameters to the MCDA parameters for the noise and visual impacts. As for Leviakangas et al. (2002), they explained the differences by observing that CBA was not flexible enough to assess new kinds of transport such as intelligent transport systems, a limitation that was not observed through their application of MCDA.

1.6.2.1 CBA perceived strengths

As the most used assessment method in practice, CBA has evolved and has been adapted to new considerations over the years. The assumptions and theory underlying CBA (social welfare theory, WTP, hedonic prices, etc.) are well-known, have been analysed and debated through the years and are now formalised under various norms, guidelines and structured frameworks (Damart and Roy 2009; Beria et al. 2012; Dimitriou et al. 2016). This formalisation has led many to perceive CBA as a "neutral", rigorous, transparent and formal method since it allows its users to compare clearly and precisely the costs and the benefits translated into monetary terms (Browne et Ryan 2011; Beria, Maltese, et Mariotti 2012; Babashamsi et al. 2016; Hickman et Dean 2017). This is particularly the case for "hard" effects that are quantifiable and measurable in monetary terms (e.g. construction and maintenance costs) or where assumptions are made that make it possible to measure impacts in monetary terms (e.g. benefits to freight transport, travel time savings). According to Nadafianshahamabadi et al. (2017), the use of CBA can help prevent the implementation of transport projects that may have negative impacts on the social welfare. It can also increase the legitimacy of a process that is highly political by making an objective quantification of economic impacts.

Despite the perception of neutrality and objectivity, the role of CBA in the transport decision process may vary. Sometimes, CBA is a decision-making method with a prescriptive role: a project should only be done if the NPV is positive or if the BCR is higher than 1 (Beria, Maltese, et Mariotti 2012). Other times, CBA acts as a decision aiding method with an informative role similar to a survey of wider societal impacts, in which case the NPV or BCR play a less significant role in the decision process. As a consequence, CBA provides a global picture of a situation and in an iterative process, can help to generate improved alternatives by identifying the pros and cons of existing alternatives (Jong et Geerlings 2003; Rudolph et al. 2015).

It is generally accepted that the common language used in CBA, i.e. monetary terms to express the various impacts across time and space, facilitates communications to decision-makers and public authorities. Moreover, the use of a normalised approach to monetise impacts allows for comparability between projects. According to

some authors, notwithstanding the transport modes (bus, rail, car, bicycle) or the regional contexts (urban, suburban, rural), the projects can always be compared (Hickman et Dean 2017; Cornet et al. 2018).

One of the most frequently cited strengths of CBA (12 out of 19 comparison papers) is that it highlights economic efficiency and welfare impacts. Governments have restricted budgets and therefore must choose the alternative that will create the most advantages and cost the least. It must be evident that the efforts are worth it (Hüging, Glensor, et Lah 2014).

Since CBA is market-driven, its results reflect the values of "all people" as the monetary values are defined according to the individuals' preferences through willingness to pay or observed behaviour (Weisbrod et Street 2011; Bristow et Nellthorp 2000; Dimitriou, Ward, et Dean 2016). It can even be considered an "economic democracy" where individuals express their preferences with their money ("vote") and, if they lose, the monetary gain compensates for the loss. This is different from a political democracy where individual that "lost their election" have to accept the vote of the majority without compensation (Munda 2017).

1.6.2.2 CBA perceived weaknesses

The costs and benefits that are traditionally included in a CBA aim at estimating the efficiency of a transport project. CBA is excellent for incorporating economic factors. However, despite the development of different techniques to monetise non-monetary and qualitative aspects, the emphasis of CBA on monetary aspects tends to ignore or underestimate environmental, social and strategic impacts that are relevant to sustainable transport (Salling, Leleur, et Jensen 2007; Salling et Pryn 2015; Cornet et al. 2018). This restricts CBA to a narrower vision of project impacts and may create bias toward specific transport projects. This concern was identified in a survey addressed to Dutch politicians by Annema et al. (2015) where politicians acknowledged that CBA results are incomplete and expressed interest in a more global project vision.

Generally, there is a consensus among economists about the direct economic impacts that should be included in transport project assessment, but which intangible and non-direct economic aspects should be included and how they can be monetised is still highly debatable (Beria, Maltese, et Mariotti 2012; Annema, Mouter, et Razaei 2015; Babashamsi et al. 2016). The development of social CBA was aimed at addressing this issue. However, according to some authors, determining the monetary value through WTP is hard, subjective and may vary in different social contexts (K De Brucker, Verbeke, et Macharis 2004; Damart et Roy 2009; Thomopoulos et Grant-Muller 2013). For example, it has been shown, through revealed preference studies, that a WTP linked to CO2 emissions can vary significantly depending on how the information is framed (e.g. from $0/tonne to nearly $400/tonne of CO2 emissions; Daziano et al. 2017). In addition, the monetisation of every impact (quantitative non-monetary and qualitative) raises several ethical considerations. It must be assumed that everything can be valued with money, including environmental, security and health aspects, which may be perceived as an immoral

practice by some (Browne et Ryan 2011; van Wee 2012; Hüging, Glensor, et Lah 2014; Dimitriou, Ward, et Dean 2016; Hickman et Dean 2017). For example, in a survey addressed to different Dutch professionals involved in the transport field, Mouter et al. (2013) showed that some aspects like travel time saving and biodiversity were deemed incomparable by urban planners, but totally comparable by economists.

Moreover, in a CBA, despite a population's sensitivity to environmental issues, travel time-saving benefits often highly compensate the negative environmental consequences (Kelly et al. 2015; Hickman et Dean 2017). In fact, since travel time gains represent the majority of benefits (between 50 % to 90%) according to Mackie and Nellthorp (2001), Gwee et al. (2011), and Browne and Ryan (2011), this may lead to discarding transport projects such as public transit or cycling infrastructure that have only small gains or losses in time gains, but that have other benefits, harder to measure. Consequently, this favours projects that encourage longer travel distances (e.g. expanding or building new highways) which is in clear contradiction with the sustainable transport objective of reducing travel distance and reducing land consumption (Hickman et Dean 2017). All these aspects make the CBA results potentially subject to interpretation and prevent decision-makers from fully understanding the different impacts and the trade-offs between impacts. As pointed out by Mouter et al. (2013), the counter effect of this situation on decision-makers is to assign either too much or too little value to CBA results.

Although the translation process of impacts in monetary terms may be clear for experts and some decision-makers, the complex calculations and the underlying hypotheses can render the outcome non-transparent and difficult to understand for other stakeholders. This process can reduce political issues to a technical debate that only transport experts can fully comprehend (Damart et Roy 2009; Hickman et Dean 2017). In fact, Beukers et al. (2012) showed that stakeholders using CBA, but not directly involved in the CBA process (planners, advisors, lobbyists), perceived CBA as a black box. In fact, the NPV and BCR summarise the information in one number, and CBA reports are not explicit enough about the compensation that occurs between impacts (e.g., natural capital being completely replaceable by human capital). For example, some economists have concluded that mobile phones should not be banned while driving because the cost of compensating all drivers using their mobile phone (consumer surplus) would be higher than the monetary gain linked to the decreased risk of (the relatively infrequent) accidents and fatalities (Hahn et Tetlock 1999; Redelmeier et Weinstein 1999).

As mentioned, a clear CBA limit identified in the literature is the problem of including equity principles. Traditionally, CBA does not consider the distribution of the increase in welfare among various socio-economic groups and different regions. The aggregation of gains and losses in one value undermines the capacity to clearly identify the winners and the losers in the process; a transport project could easily favour wealthier groups (or regions) at the expense of lower income groups (or regions) and reinforce inequities (van Wee 2012; Martens 2016; Hickman et Dean 2017). An equal value for travel time gain is often assumed to counter this effect (e.g.

the average monetary value of travel time of commuters in the United States is of 12 $/h, irrespectively of an individual's hourly income; Mackie et al. 2014). This is viewed as a partial solution by Nahmias-Biran and Shiftan (2016). A possible improvement is to use a distribution matrix that informs decision-makers of the consequences of each alternative on each stakeholder or to allocate different weights to different socio-economic groups (Beria, Maltese, et Mariotti 2012; Munda 2017). Nonetheless, few CBA guidelines include equity distribution in practice, with Germany being one of the exceptions (Bristow et Nellthorp 2000).

Equity over time is another concern. The use of discount rates reduces long term impacts to a value of almost zero which results in disadvantages for future generations and a disequilibrium between short and long-term social and environmental impacts (Dimitriou, Ward, et Dean 2016; Hickman et Dean 2017; Cornet et al. 2018). An environmental impact could take several decades before it manifests (loss of biodiversity, water quality degradation, climate change) and go way beyond the usual reference period considered in CBA (i.e. between 20 and 60 years), which makes future generations voiceless (Nadafianshahamabadi, Tayarani, et Rowangould 2017; Hickman et Dean 2017). Furthermore, the range of discount rates used for transport projects in different countries is a sign that there still is no consensus on how to deal with long-term impacts in CBA (Gwee, Currie, et Stanley 2011). Therefore, some authors argue that the choice of a discount rate and a reference period are value judgements making it difficult to claim that CBA is objective from a positivist point of view (Nadafianshahamabadi, Tayarani, et Rowangould 2017).

The inclusion of stakeholders and of collective values in the decision process is also difficult in a CBA (Damart et Roy 2009) since it cannot consider public debates surrounding a transport project and may thereby increase controversies at later stages of the project (Dimitriou, Ward, et Dean 2016; Hickman et Dean 2017). For example, Beukers et al. (2012) showed that the lack of discussion between stakeholders regarding the assumptions used in the CBA creates a gap and a communication deficit between planners and economists.

The Hicks-Kaldor principles, on which CBA is based, assume that people act as individual consumers who behave rationally (by maximising their welfare) with no regards to collective issues. Sustainable transport requires the consideration of issues that are larger than individuals and that affect society as a whole and is often considered a tragedy of the commons' problem (K. Brown, Adger, et Cinner 2019). Basing monetary values on individual preferences may go against societal interest in the long term (Damart et Roy 2009). For example, it is not because someone does not use a service that the person does not value this service (e.g. someone might still value having bus service in a city, without necessarily being a bus user; van Wee 2012). Therefore, public policy cannot rely only on the aggregation of individual preferences or willingness to pay in order to make a decision (Munda 2017).

The obligation to apply CBA to some projects and its use as a decision-making method rather than as a decision-aiding method creates strategic behaviours. For example, it was reported in the transport infrastructure literature that some decision-makers and practitioners deliberately underestimate costs and overestimate benefits to facilitate projects implementation (e.g. strategically selecting favourable unit values or scenario assumptions; Flyvbjerg et al. 2002; van Wee 2012; Kelly et al. 2015). This might happen when CBA is introduced at a too advanced stage of the planning process to act as a decision aiding method, because the decision has already been made. Consequently, the obligation to conduct a CBA is sometimes perceived as a hurdle that must be overcome in order to get funding for a project, rather than a method to improve the project and the decision process (Beukers, Bertolini, et Te Brömmelstroet 2012; Kelly et al. 2015). For example, if CBA outcomes align with the political interests, the method's limitations will be ignored, whereas when CBA results do not support the political interests, the limitations will be highlighted (Mouter, Annema, et Wee 2013).

1.6.2.3 MCDA perceived strengths

Since MCDA is objectives driven, all aspects that matter can possibly be assessed, including those that are intangible, qualitative and non-monetary quantitative (Griskeviciute-Geciene 2010; Hüging, Glensor, et Lah 2014; Annema, Mouter, et Razaei 2015; Nadafianshahamabadi, Tayarani, et Rowangould 2017). MCDA goes beyond economic efficiency; it does not require assigning monetary values to positive or negative impacts in order to properly assess projects (Thomopoulos et Grant-Muller 2013; Cornet et al. 2018). It can inform decision-makers of the degree to which an alternative achieves policy objectives, such as the ones defined in a sustainable mobility plan, and show the trade-offs between the different objectives (Weisbrod et Street 2011; Tudela, Akiki, et Cisternas 2006). From a sustainability perspective, showing the achievement of policy objectives is insightful since it gives a more holistic and multidisciplinary perspective on projects (Browne et Ryan 2011; Hüging, Glensor, et Lah 2014; Dimitriou, Ward, et Dean 2016). One such objective is equity. The Sustainable Mobility Inequity Indicator (SUMINI) is a MCDA appraisal method that was specifically designed by Thomopoulos and Grant-Muller (2013) to complement current project assessment methods. It considers five types of equity (i.e. horizontal equity, vertical equity, environmental equity, regional/spatial equity and accessibility). It is an informative method since it highlights which types of equity are enhanced or deteriorated by a given project.

Among its other identified strengths, MCDA is perceived to facilitate the inclusion of stakeholders (e.g. decision-makers, experts, citizens, etc.) in the decision process (Annema, Mouter, et Razaei 2015). The stakeholders' participation may take different forms: individual interviews (Scannella et Beuthe 2003), online surveys (Spiekermann et Wegener 2004; Thomopoulos et Grant-Muller 2013; Nadafianshahamabadi, Tayarani, et Rowangould 2017), the Delphi method (Kang et Lee 2007), group workshops (Marleau Donais et al. 2019), decision conferencing (Barfod, Salling, et Leleur 2011; Barfod et Salling 2015) renamed planning workshop

when it only includes experts and no decision-maker (Barfod 2018), or a mix of interviews and surveys (D'Este 2009; Cornet et al. 2018). This can be a factor of success as it articulates the issues and objectives of the stakeholders who, otherwise, would not have been considered (e.g. landscape, noise impacts; Tudela et al. 2006). Using a deliberative process among stakeholders, MCDA can develop a consensus to resolve conflicts and to propose a solution that reflects the preferences of the involved individuals and groups (K De Brucker, Verbeke, et Macharis 2004; Browne et Ryan 2011; Hüging, Glensor, et Lah 2014). Moreover, the expression of these preferences according to transport policy objectives adds transparency and can contribute to explaining the rationale behind the choices made (Thomopoulos et Grant-Muller 2013; Munda 2017).

As a way to include stakeholders with divergent values and preferences, multi-actor multi-criteria analysis (MAMCA) is a method developed specifically in the transport field that was used in three different reviewed papers (Macharis, Milan, et Verlinde 2014; Balm et al. 2016; Cornet et al. 2018). This method builds a MCDA model according to the values and preferences of each stakeholder group (e.g. users, public transit operators, local governments and federal government) to show the trade-offs and conflicts that may occur between the various groups. Cornet et al. (2018) proposed to penalise alternatives that have diverging viewpoints within groups compared to alternatives that are more consensual. Bana e Costa (2001) developed such a method for investment policy in new intermunicipal road links by analysing conflicts between stakeholders regarding the alternatives and, in an iterative process, developed new alternatives that were collectively more attractive.

Several of the papers recognise that MCDA is not a decision-making method, but a decision process that aids to structure the decision. It is not the result that matters, but the process leading to the decision that makes a project successful (Spetzler 2007; Browne et Ryan 2011). From a MCDA perspective, it is difficult to qualify a decision as good or bad only on the basis that a mathematical model is valid and accurate (Munda 2017). As a matter of fact, the problem structuring nature of MCDA often allows the transformation of an ill-defined problem (which is usually the case for sustainable transport) into a set of structured relations and criteria. At the early stages of projects, it helps the involved stakeholders to learn about other stakeholders' objectives, to give a wider perspective on the problem, to develop alternatives that may better achieve their objectives and to identify the uncertainties surrounding the decision process (Bristow et Nellthorp 2000; Galves 2005; Gamper et Turcanu 2007). Thus, it makes complex situations more transparent and facilitates the choice of an alternative that strikes the right balance between the various and often conflictual objectives (Dimitriou, Ward, et Dean 2016).

1.6.2.4 MCDA perceived weaknesses

MCDA has been subject to several criticisms namely that of being arbitrary, subjective and having a black box effect (D'Este 2009; Quinet et Meunier 2012). The involvement of stakeholders in the construction, with a facilitator, of the MCDA model parameters (e.g. criteria, weights, value function, threshold) is perceived as a subjective process (in a positivist paradigm) which in itself, is both a strength and a weakness (Hüging, Glensor,

et Lah 2014; Bueno, Vassallo, et Cheung 2015; Nahmias-Biran et Shiftan 2016; Hickman et Dean 2017). Subjectivity is negatively perceived in decision processes because of the lack of procedures and norms to obtain parameters (Sayers, Jessop, et Hills 2003), of the lack of transparency regarding how parameters are elicited (Browne et Ryan 2011) and because it is susceptible to biases since parameters are based on the preferences of the involved stakeholders (often decision-makers or experts). Therefore, the selection of the stakeholders involved in the process may have a great influence on the results since stakeholders have different expertises and values. It could lead to different rankings depending on the group's composition (Gamper et Turcanu 2007; Annema, Mouter, et Razaei 2015; Babashamsi et al. 2016; Nahmias-Biran et Shiftan 2016; Nadafianshahamabadi, Tayarani, et Rowangould 2017).

Moreover, certain stakeholders may dominate during group workshops and the presence or absence of stakeholders at workshops can have an impact on the final outcomes (Rudolph et al. 2015; Marleau Donais, Abi-Zeid, et Lavoie 2017). Some stakeholders could also have a hidden agenda and provide biased information or may be reluctant to share knowledge or power with other stakeholders during group workshops (Gamper et Turcanu 2007). The MCDA process works well when stakeholders have similar sets of objectives, but it can pose quite a challenge when the objectives are different or even conflictual. Therefore, aiming for a consensus could force a result on the stakeholders and lead to a loss of richness and viewpoints (Hüging, Glensor, et Lah 2014). Also, forcing the consensus through weighting or aggregation could dissatisfy some stakeholders and raise suspicion toward the process (D'Este 2009). A study about a highway project in Tehran, Iran (Nadafianshahamabadi, Tayarani, et Rowangould 2017) and a study about freight distribution in Thessaloniki, Greece (Macharis, Milan, et Verlinde 2014) have shown how stakeholders with different technical knowledge and values ultimately led to favour distinct projects. The question of how to best handle different values is still unclear; a debate between the various stakeholders perspectives must take place and the use of, an often meaningless, mathematical average is perceived as problematic (Hickman et Dean 2017). Consequently, stakeholder interactions, discussions and debates can render the decision process more time and resources consuming. Furthermore, it requires that all key stakeholders be gathered, which can be difficult and costly to achieve (Gamper et Turcanu 2007; D'Este 2009).

On a different note, the complexity of mathematical procedures that are sometimes required, in order to aggregate the alternatives' performances over many criteria, was identified as another weakness. This perceived black box effect can make it difficult for non-technical decision-makers and stakeholders to understand how MCDA arrives at the results (Griskeviciute-Geciene 2010; Browne et Ryan 2011). In addition, according to Browne and Ryan (2011), the use of single-synthesising criterion methods allows, as with CBA, to aggregate aspects that might be incomparable. This creates a loss of information and hides the trade-offs that might occur

between criteria performances. A black box effect can also be created when the MCDA results are locked within software to which stakeholders have no access or that is not user-friendly (D'Este 2009).

Furthermore, the possibilities of double-counting impacts when criteria are loosely defined within a MCDA are perceived as undesirable since the effects considered in the set of criteria can be unclear and inconsistent. A special care is needed to avoid such situations that create bias in assessment (Scannella et Beuthe 2003; Beria, Maltese, et Mariotti 2012; Annema, Mouter, et Razaei 2015; Nahmias-Biran et Shiftan 2016).

1.6.3 Combination of Methods

In order to resolve some of the issues with CBA or MCDA, some authors have suggested combining both methods into a new framework; the term hybrid model is also found in the literature. The combination of MCDA and CBA usually refers to three different steps : (1) using CBA to measure monetary impacts (e.g. infrastructure cost, operating cost, travel time), (2) using MCDA to measure quantitative non-monetary and qualitative impacts (e.g. land-use planning, accessibility, equity distribution) and (3) combining the results of the CBA part and MCDA part according to different frameworks. However, what is considered as a monetary impact varies depending on the author. For example, some authors monetised air pollution and noise and included the impacts within the CBA part (Bekefi, Kiss, et Tanczos 2003; Leleur, Petersen, et Barfod 2007; Chen, Wang, et Dougherty 2008; Gühnemann, Laird, et Pearman 2012; Shiau 2014), whereas other authors kept these impacts in their original units and included them in the MCDA part (Panou et Sofianos 2002; Hüging, Glensor, et Lah 2014; Macharis, Milan, et Verlinde 2014; Salling et Pryn 2015).

1.6.3.1 Reasons to Combine CBA and MCDA

Authors suggesting a combination of the two methods find that traditional economic analyses, such as CBA, are too narrow, provide limited information to the decision-makers and do not capture all decision criteria (Leleur, Petersen, et Barfod 2007). The best CBA solution may be the most efficient economic solution, but it may be in conflict with sustainable transport objectives and lead to a project that is not the most advantageous from this new perspective (Prokopowicz et Dabrowska 2016). Hence, for these authors, the combination of CBA with a MCDA can overcome such CBA limitations by including all of the essential aspects and the various stakeholders' perspectives in the decision process. Moreover, the combination of both methods allows to handle sustainability in several ways: it eliminates the hurdles related to the integration of non-monetisable, non-quantitative or intangible aspects (Ambrasaite, Barfod, et Salling 2011; Gühnemann, Laird, et Pearman 2012); it better copes with complex problems linked to sustainable transport by giving a more holistic and multidisciplinary perspective (Salling et Pryn 2015); it takes into account equity concerns and a better distribution of impacts (Thomopoulos et Grant-Muller 2013); it includes governmental objectives of sustainability and sustainable transport and it aids with choosing projects aligned with these governmental objectives (Salling et Landex 2006; Gühnemann, Laird,

et Pearman 2012). Consequently, CBA and MCDA are not seen as competitors, but as complementary since, together, they provide the global picture and therefore potentially improve decisions.

Few criticisms have arisen of the combination of CBA and MCDA, though this may be due to it being too recent. The only identified criticism is that the combination of two complex methods may further complicate project appraisal and create a bigger black box effect for decision-makers (Annema, Mouter, et Razaei 2015). As pointed out by Mouter et al. (2013), further research is required regarding the perception of the advantages and disadvantages of combining CBA and MCDA.

The following sections (1.6.3.2 to 1.6.3.5) present in further detail the different combination frameworks and the rationale behind choosing a specific framework. Although the reasons were often numerous, the authors were not always explicit in their justification and did not state their reasons for choosing a framework.

1.6.3.2 Framework with CBA as the main method and MCDA as a component

In the few combined frameworks proposed where CBA is the main method, the aim was always to add the MCDA-criteria to the CBA-impacts. The most frequent framework in the literature is COSIMA (5 papers out of 7) which converts the MCDA results with a calibration factor to express the trade-off between the CBA part and the MCDA part, and then calculates a total return rate. The calibration factor is determined by using shadow pricing methods such as WTP for the MCDA-criteria (Salling et Landex 2006; Leleur, Petersen, et Barfod 2007; Salling, Leleur, et Jensen 2007; Ambrasaite, Barfod, et Salling 2011; Barfod, Salling, et Leleur 2011). COSIMA's authors preferred this type of combination because it can include wider impacts and present the results to the decision-makers in a total return rate similar to CBA, a language with which, according to the authors, decision-makers are familiar. One of the other frameworks with CBA as the main method is Strategic Options Assessment (SOA) that uses an extension of the Australian adjusted CBA and weighs spatially or temporally the monetary values according to policy objectives. For example, if the objective is to support urban renewal, a higher score will be given to the future benefits that have implications in the identified renewal area (Prosser, Fensham, et Schmahmann 2015). This framework is perceived as safeguarding the rigour of CBA while retaining the flexibility of MCDA.

1.6.3.3 Framework with MCDA as the main method and CBA as a component

Other authors have suggested frameworks where MCDA is the main method. 13 such papers were identified in the literature. They rely principally on the idea that CBA results should be considered as a single criterion (cost or economic efficiency) to be included in a MCDA (Tsamboulas et Mikroudis 2000; Barfod et Salling 2015). Some authors also perceived that MCDA is easier, more practical and better takes into account local issues by measuring the objectives' degree of achievement. Interestingly enough, the COSIMA method was recently disavowed by some of its creators because they judged it too difficult to apply in practice. They suggested that

including CBA results within a MCDA was more appropriate because it was difficult to elicit the shadow prices and the economical trade-offs of MCDA components in a CBA overarching framework (Barfod et Salling 2015; Salling et Pryn 2015)

1.6.3.4 Framework with disaggregated results in parallel

As another alternative, some authors prefer to present, side by side, disaggregated results of CBA and MCDA (4 papers). The perceived complementary nature of CBA and MCDA implies that they should not be aggregated and that their results represent two distinct sets of values (i.e. CBA represents consumer values whereas MCDA represents decision-maker values; Macharis et al. 2014; Balm et al. 2016). Furthermore, the presentation of results in parallel allows decision-makers to understand how the impacts are distributed, what are the trade-offs and who are the losers and the winners. It also avoids double-counting effects that could occur when combining the two methods (Spiekermann et Wegener 2004).

1.6.3.5 Framework with MCDA and CBA as two steps

Finally, the methods can be combined as two different steps in the assessment process. Only one such paper was identified in the literature. This type of combination was chosen because CBA is perceived as mathematically more rigorous, but with a narrower vision than MCDA. In a first step, MCDA allowed for a larger set of alternatives to be screened according to a holistic vision and to choose 2 or 3 alternatives that would be examined in further detail in a second step with CBA (Rogers 2000). In other words, MCDA allows the alternatives to be assessed at a strategic level (how it relates to policy objectives) whereas CBA assesses the alternatives at the project level (the financial costs and benefits of implementing the projects).

1.7 Discussion

1.7.1 Comparing CBA and MCDA from a rationality perspective

The comparison of CBA and MCDA in the field of transport has shown that both methods have perceived strengths and weaknesses, and that what is viewed as a strength by one author could, at the same time, be considered a weakness by another. The rigour of CBA to assess projects in terms of economic efficiency is praised whereas the flexibility of MCDA to take into account a wide array of qualitative and quantitative criteria is recognized. However, CBA is considered as both transparent and non-transparent and MCDA's inclusion of subjective and qualitative aspects is deemed both a strength and a weakness.

The contradictions identified above may be explained by the different ways of conceptualising rationality and the decision aiding approaches of Meinard and Tsoukias (2018). In the reviewed papers, most of the arguments in favour of CBA are linked to an objectivist approach. CBA is usually conducted according to predefined norms or guidelines with an aim of economic efficiency (i.e., an unquestionable formulation of the problem that is

independent from the context). Since CBA is based on the Hick-Kaldor principle, a "good" solution will be the one with the most favourable benefit-cost ratio (BCR). However, a CBA that will deviate from the guidelines in calculating the BCR or a decision that will not choose the solution with the best BCR will be considered as illegitimate (i.e., non-acceptable in a particular organisational context; Landry et al. 1996). In an objectivist approach, integrating subjective aspects should be avoided and is considered a weakness. This may explain some of the strategic behaviours adopted by certain stakeholders who alter results in order to implement transport projects that would be, without alteration, illegitimate from an objectivist approach (Flyvbjerg, Holm, et Buhl 2002). In addition, several of the arguments against MCDA are justified in an objectivist approach. The ill-defined nature of multicriteria problems (i.e., problems must be structured according to the context) with only satisficing solutions and no optimal solution is in contradiction with an objectivist stance. In MCDA, norms and guidelines hardly exist since the different parameters used usually reflect stakeholders' values.

Conversely, several of the arguments identified in the transport literature in favour of MCDA are related to an adjustive approach or a reflexive approach. For example, the inclusion of stakeholders in the process and the elicitation of their preferences, values and needs according to the specificity of each problem is in line with an adjustive approach where the inclusion of subjectivity is viewed as a strength. The tendency in MCDA to grant more importance to the process than to the results is in line with a reflexive approach. In fact, some MCDA processes will structure an ill-defined problem according to objectives, behaviours and inner preferences that are constructed through the process. In addition, several criticisms addressed to CBA are linked to an adjustive approach (e.g. non-transparency, trying to monetise every impact and concerns about collective values). From an adjustive perspective, if the elicited preferences contradict the norms, it is because the norms are ill-conceived. Consequently, if economic efficiency does not reflect the stakeholders' preferences in a specific context (e.g. equity, environmental protection, accessibility), then CBA is not suitable for the project.

However, as pointed out by Tsoukiàs (2008), it is not the method that defines the decision approach, but rather how rationality is conceived of and how the decision process is conducted. For example, in reaction to criticism of MCDA's subjectivity, Salling and Pryn (2015) adopted an objectivist approach to MCDA where the weights between the sustainability dimensions are predefined according to the nested model for sustainability (i.e., environment is more important than social, which is more important than economic) and the weights between criteria within a dimension are all the same. Nonetheless, the use of such an objectivist approach disregards some of MCDA's advantages such as problem structuring and stakeholders' involvement.

1.7.2 On the combination of CBA and MCDA in transport

The study of the various combination frameworks in transport shows that there is still no consensus on how MCDA and CBA should properly interact. Despite the common goal to include a larger set of impacts in project

assessment, different authors had different justifications for choosing a given framework over another. Nonetheless, the recent shift by some authors (Barfod et Salling 2015; Salling et Pryn 2015) from CBA toward MCDA as the main method in transport, illustrates that CBA may be difficult to apply in practice. Still, the combination of both methods does not exactly fit one of the four decision-aiding approaches proposed by Meinard and Tsoukiàs (2018) and, depending on the context and the stakeholders, the combination could be applied according to different approaches.

1.7.3 Integrating sustainable transport in project assessment

The inclusion of sustainable transport in project assessment raises the question of whether current evaluation methods allow these new principles to be integrated. As is recommended by Gudmundsson et al. (2016) project assessments geared toward sustainability should have a holistic vision and include stakeholders in the decision process. No matter the method, sustainable transport can be considered within different decision-aiding approaches. For example, sustainable transport could be considered in project assessment as the only objective truth to follow (objectivist approach), as norms and behaviours expected to apply in practice (conformist approach) or as the inner stakeholders' preferences and values (adjustive approach). CBA is an appropriate method when the aim is to choose a project with the objective of economic efficiency. However, in light of the weaknesses highlighted in the previous sections, CBA poorly takes into account several aspects inherent to sustainable transport. Despite the recent developments to include non-monetised impacts, the assumptions on which CBA is based are in conflict with the objectives of sustainability. Sustainable transport requires projects to be assessed from a collective perspective rather than from an aggregated individual perspective as suggested by social welfare theory. It also needs to consider long-term impacts on the society and the environment; two aspects that usually have a weak voice in CBA (due to future discounting), when they are not totally ignored.

MCDA, given its more flexible nature, can more easily include various aspects to form a holistic vision and to integrate stakeholders in the decision process. Depending on the project, it can inform stakeholders of the degree of fulfilment of the different objectives toward sustainable transport and identify the alternative that best suits a problem. However, as pointed out by Bueno et al. (2015), despite MCDA's potential to take into account sustainability, it is not necessarily the case in practice. For example, MCDA does not always consider a life-cycle approach of impacts (i.e., considering impacts over the whole life-cycle from the conception to the end of life processing; Bueno et al. 2015) or can sometimes include experts or decision-makers in the decision process and exclude other stakeholders (Tsamboulas et Kopsacheili 2003; Spiekermann et Wegener 2004; Barfod et Salling 2015; Cornet et al. 2018). Moreover, despite the claim of several papers that stakeholders were included, there were case studies that did not explicitly report how or which stakeholders participated in the decision process (Anagnostopoulos et al. 2001; Panou et Sofianos 2002; Salling, Leleur, et Jensen 2007; Tischler 2017). This raises a concern since developing models that are theoretically valid, but that are only tested in fictive case

studies is only a first step in the right direction. These models must ultimately be applied in practice with real stakeholders to assess how they perform in the real world, if they are to have any valuable contribution.

1.7.4 Limits of this Study

To ensure the quality of this literature review, Templier and Paré's (2018) guidelines were followed: the research questions and key concepts were clearly stated; the literature search and screening process were defined; the data extraction methods according to the different categories of papers were described and the results were analysed. However, this literature review is not without limits. The inclusion of both CBA and MCDA as keywords in the databases seems to have created a positive bias toward papers related to MCDA. More papers focussing on MCDA were identified in the review than papers centred on CBA. More specifically, the abstracts of papers that focus on MCDA were usually positioned in opposition or as a complement to CBA. This situation seemed less common in papers that emphasize CBA (as it is often the standard or norm). To counterbalance this effect, cross-referenced papers about CBA were thoroughly searched.

Furthermore, the search was limited to English databases, indexing journal and conference papers and excluded reports, books and grey literature. Also, data extraction was based on text coding of the papers according to various analysis themes as described in the methodology, which is a subjective process. Despite these search limitations, a redundancy in the arguments and the points of view were observed in the results and the analyses of the retained papers. This leads us to believe that the full spectrum of reported weaknesses and strengths of both methods in the field of sustainable transport were covered. The inclusion of other documentation in the literature review would not necessarily have contributed new answers to our research questions.

1.8 Conclusion

The aim of this paper was to better understand the perceived strengths and weaknesses of CBA and MCDA methods in the field of transport, to analyse the different ways to combine them and to further analyse if and how they have the capability to better include sustainability in transport. To answer our research questions, a systematic review of papers in four distinct databases was achieved, the papers were text coded according to various themes and the results for each theme were analysed. In addition, the two methods were analysed with respect to four different decision-aiding approaches (objectivist, conformist, adjustive and reflexive) to further comprehend the distinct conceptualisations of rationality of what make a "good" decision.

The results showed that both methods have strengths and neither are exempt from weaknesses; different decision-aiding approaches influence the positive or negative perceptions of how methods are applied. In any case, the use of one method or the other will always improve decision-making relative to unaided decision-making (Hajkowicz 2007). The combination of both methods is a possible avenue to improve existing decision

processes, but, in a context of sustainable transport, this combination has mostly served to solve problems inherent to CBA. Further research on this topic is required to analyse the pros and cons of combining both methods.

A strong focus during the comparison was set on how the methods included the principles of sustainable transport. The results showed that CBA is excellent for measuring economic efficiency, but lacks flexibility to appropriately consider aspects inherent to sustainable transport such as equity between social groups and over time, environmental impacts, or stakeholders' inclusion. As for MCDA, despite its weaknesses, our results have shown that it has the capability to consider quantitative and qualitative information and to include stakeholders from many different horizons. Therefore, in complex and uncertain environments such as sustainable transport, the use of MCDA or the combination of CBA and MCDA may be more suitable to decision-making processes than CBA alone.

In further research, it would be interesting to compare the different perceptions of MCDA and CBA and the various ways to combine them across various fields. This comparison could highlight similarities and/or divergences across fields. Moreover, the identification of practices developed in other fields where methods are combined could improve the general practices of CBA and MCDA in transport. For example, planning for resiliency allows transport networks and infrastructures to better recover following disasters and disruptions (Ganin et al. 2019). However, transport networks that are the most efficient and that minimize the travel time (which is usually the principal benefits considered in CBA) are not necessarily the ones that are the most resilient (Ganin et al. 2017). This raises several questions on how to consider resilience in project assessment in a context of climate change.

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2 Chapitre 2: Assessing and ranking the potential of a street to be redesigned as a Complete Street: A multi-criteria decision aiding approach

2.1 Résumé

Afin d'améliorer la mise en œuvre des transports durables dans les villes, l'aménagement des rues doit favoriser les modes de transports actifs et en commun. Toutefois, les processus décisionnels actuels pour l'élaboration de projets de transports ne tiennent pas toujours compte des exigences du transport durable et ignorent souvent les enjeux qui peuvent provenir d'autres domaines comme la protection de l'environnement, la santé ou le design urbain. Le cadre méthodologique proposé dans cet article vise à intégrer les principes de durabilité dans un processus décisionnel en créant de meilleures collaboration et communication entre des professionnels de domaines différents. Le cadre est basé sur des rencontres de groupe, sur la structuration de problème, sur l'aide multicritère à la décision et sur les systèmes d'information géographique. Il a été appliqué à la Ville de Québec, Canada. L'objectif des rencontres de groupe était d'identifier les rues qui devraient être réaménagées en priorité comme des rues conviviales, un mouvement populaire en Amérique du Nord qui promeut l'aménagement de « rues pour tous ». Pour aider la communication des résultats et leur utilisation pour des décisions futures, ceux-ci ont été intégrés et présentés dans un système d'information géographique. Conséquemment, cet outil convivial est présentement utilisé pour supporter la prise de décisions des élus de la ville de Québec afin de choisir les rues à réaménager comme des rues conviviales tout en assurant la transparence et la traçabilité des décisions. Une telle approche pourrait mieux soutenir les politiques ayant pour objectif de rendre les systèmes de transport plus durables en permettant l'intégration de différentes considérations, en favorisant la transparence et en améliorant la communication des résultats.

Mots-clés : transport durable; rues complètes; aide multicritère à la décision; décision de groupe; cas d'étude; MACBETH.

2.2 Abstract

In order to increase the sustainability of transportation in cities, streets must provide infrastructures that favor active and public transportation modes. However, the current decision-making processes in transportation projects do not always explicitly take into account sustainable transportation requirements and often ignore concerns that may arise in other fields such as environmental protection, health, or urban design. The proposed framework in this paper aims at integrating sustainability in a decision-making process by creating better collaboration and communication between professionals of such disparate fields. The framework is based on group workshops, problem structuring, multi-criteria decision aiding and geographic information systems. It was applied in Quebec City, Canada. The objective of the workshops was to identify higher priority streets that should be redesigned as Complete Streets, a popular movement that advocates “streets for everyone” in North America. To facilitate communication and use for future decisions, the results of the analysis were integrated and presented in a geographic information system. As a result, this user-friendly tool is currently used to support decision-making by Quebec City officials who must choose the streets to be redesigned as Complete streets while ensuring transparency and traceability. Such an approach may better support policies to make the transport system more sustainable by integrating various considerations, being transparent and improving communication of the outcome.

Keywords: sustainable transportation; Complete Street; multicriteria decision aid; group decision; case study; MACBETH.

2.3 Introduction

To facilitate the new technology of cars, North American cities began to develop in the early 20th century networks of streets and highways that mainly favor car-based mobility and accessibility (Fogelson 2003; Newman et Kenworthy 1999). This has resulted in many negative impacts such as pollution, safety issues, urban sprawl, public health degradation, traffic, and social inequities (Gärling et Steg 2007; Tumlin 2012). To counter these effects, a shift in transportation planning practices from a mainly engineering-based approach towards a sustainable approach is needed and new practices are being put in place to support this shift (Banister 2008; Geels et al. 2012). One of the most popular practices today towards sustainable transportation in North American cities is the Complete Streets approach. This policy and design approach aims to create streets that are safe, accessible and comfortable for all users, no matter their capacities or mode of travel (McCann 2013). Moreover, being a context-sensitive approach, every street has the potential to become a Complete Street regardless of the street type (be it local, arterial, or urban boulevard) or the context (be it central, pre-World War II development, or new suburbs). The design will be adapted according to the character, the scale and the needs of the surrounding area (Kingsbury, Lowry, et Dixon 2011). However, it is physically and financially impossible to redesign them all at once. Furthermore, to enact a change to streets that have been developed following a similar design approach for more than a few generations will require a clear and transparent approach. A street prioritization process that can take into account the various conflicting objectives involved in a transparent way and do this over a large number of streets without significant human resources is therefore required.

The ideas behind the Complete Streets movement are not new. However, what makes the Complete Streets approach different from similar earlier approaches like Woonerfs, Traffic calming or Livable streets is the emphasis placed on the adoption of policies that encourage planners and engineers to change their current design practices and that incite them to change their decision-making processes (McCann 2013). At the current time, most of the Complete Streets policies and design guidelines pertain to the "how" of street design rather than to the "*where*" streets should be redesigned by priority (Hui et al. 2018). Most often, it is the engineering service that chooses the "where" with no particular consideration of other dimensions such as urban planning, environment or public health (McCann 2013). However, better collaboration and communication between the different municipal services would favor the redesign of streets that have a greater need and an overall higher potential to become Complete Streets.

Traditional assessment methods in transportation such as cost-benefit analysis do not properly integrate social and environmental aspects; they are often based on biased assumptions that may neglect or ignore some dimensions such as social equity (Damart et Roy 2009; Gudmundsson et al. 2016; Hickman et Dean 2017; Mackie et Nellthorp 2001). The development of a framework that considers Complete Streets principles requires more holistic and multidisciplinary approaches that go beyond traditional emphasis on vehicular traffic flow.

Multicriteria decision aiding (MCDA) is one such approach. It consists of a family of methods that seek to explicitly take into account multiple criteria by helping individuals or groups to explore decisions that matter (Belton et Stewart 2002). MCDA is also known as multicriteria decision analysis or multicriteria decision-making. In this article, the term "aiding" is used because we see MCDA as a process that can help to create a consensus around a common framework of values and objectives for the involved stakeholders through facilitator supported discussions and debates (Munda 2005; Roy 2016). As with other decision aiding approaches, the MCDA process is there to support the decision makers, and not to replace them.

The adoption of a Sustainable Mobility Plan ("*Plan de mobilité durable"*) by Quebec City, Canada in 2011 led their urban and transportation planners to initiate projects to modify their current practices and to rethink street design within a more sustainable framework (Ville de Québec, 2011). As a consequence, their practices are increasingly geared towards the principles of Complete Streets (known locally as "*rues conviviales*") and their street selection process has started to evolve. Prior to this project, planning services could choose a few street segments[4] among those previously identified by the engineering service for infrastructure work, and develop special design projects. Although a step in the right direction, this could be considered a reactive approach. This process was still not totally satisfactory from the perspective of proactively implementing changes towards the Sustainable Mobility Plan objectives in the most appropriate locations. This need led to the development of our research project in collaboration with Quebec City professionals.

The aim of this paper is to present the spatial multi-criteria decision aiding model developed to assess and rank Quebec City's street segments as a function of their potential to become Complete Streets. This model, based on the MCDA approach MACBETH (Carlos A. Bana e Costa, De Corte, et Vansnick 2012), was constructed, over numerous workshops, on a consensual basis among the different city professionals who participated in the project. The model is now included as a decision-aid tool in the Complete Streets strategy of Quebec City for street selection and is actively applied since 2017. It acts as a first guide to identify street segments as potential candidates for redesign as a Complete Street. It does not address any street design issues.

This paper is structured as follows: Section 2.4 contains an overview of project assessment methods in the transportation field. Section 2.5 describes our methodology. Section 2.6 presents its application in Quebec City and explains the different constructed criteria. Section 2.7 presents the model results. Section 2.8 provides a description of some of the encountered challenges and limitations. Finally, Section 2.9 summarizes the paper and explores future MCDA applications for sustainable transportation.

[4] A street segment represents a portion of a street between two adjacent intersections and can range from an alley to a highway, excluding freeways.

2.4 Transportation Projects Assessment Methods – Background

Many methods can be found in the literature for prioritizing and selecting an alternative from a given set of alternatives. The most often used method in the transportation field is cost-benefit analysis (CBA) considered by some decision makers as neutral and impartial (Lee Jr. 2000; Bickel et al. 2005; Damart et Roy 2009). The aim of CBA is to find a solution to a given problem that will provide the most improvement in societal welfare. It is based on the Hicks-Kaldor compensation test: if the increase in societal welfare is higher for those who gain (benefits) than the decrease for those who lose (costs), the project should be implemented. To achieve this, costs and benefits on various dimensions are typically monetized to allow for their direct inclusion. Subsequently, alternatives are compared according to the benefit-to-cost ratio or the actual net value difference in order to determine the alternative with the highest societal welfare (De Brucker, Macharis, et Verbeke 2013; Saarikoski et al. 2016).

From a sustainability perspective, this method and other monetary-based techniques are ill-suited for measuring social and environmental impacts (Gudmundsson et al. 2016). Over the years, several criticisms of monetary-based techniques have been raised including: being a pseudo-objective approach, suffering from ethical and equity problems, underestimating or ignoring qualitative aspects, and lacking adequate procedures for stakeholder inclusion and discussions (Ackerman et Heinzerling 2004; Beria, Maltese, et Mariotti 2012; Browne et Ryan 2011; Bueno, Vassallo, et Cheung 2015; Hickman et Dean 2017). The perceptions of neutrality and impartiality in CBA are mainly based on the mathematical calculation stage and ignore all of the omissions and subjective decisions made prior to this stage.

Multi-criteria decision aiding (MCDA) offers an alternative that may better suit the complexity of integrating sustainability principles. Rather than being based on market preferences as in CBA, MCDA models are jointly constructed according to stakeholders' preferences and priorities (Munda 2005; Roy 2016), thus they may be more closely linked to policy objectives (Bristow et Nellthorp 2000). Other MCDA advantages are that it structures an ill-defined and complex problem to give a broader picture of the situation, it considers tangible and intangible aspects and it is composed of various methods that are adapted to different decision contexts (Dimitriou, Ward, et Dean 2016; Hüging, Glensor, et Lah 2014; Tudela, Akiki, et Cisternas 2006). As a result of MCDA advantages, they are increasingly used in the transportation field when it comes to project assessment in areas such as infrastructure, logistics, mobility management, and public transportation (Camargo Pérez, Carrillo, et Montoya-Torres 2015; Macharis et Bernardini 2015; Mardani et al. 2015). Some MCDA methods have been criticized on the basis that the mathematical complexity of some methods creates black box effects, that the participatory processes with many stakeholders are resource and time consuming, and that some methods force the aggregation of incomparable aspects through weighting (Beria, Maltese, et

Mariotti 2012; Browne et Ryan 2011). It is worth noting that this last point is not true of ordinal MCDA methods that were precisely developed to shed light and identify incomparabilities in decision processes (Roy 2016).

In term of prioritizing interventions, some studies have used MCDA to assess: the potential of walking environments (Lee et al. 2013), the potential of cycling infrastructures (Barfod 2012), transportation sustainability (Olofsson, Hiselius, et Várhelyi 2016) or sustainable transport scenarios (Hickman et al. 2012). Other studies have categorized or prioritized interventions with multiple criteria without using an MCDA approach: Jones et al. (2008) proposed a set of performance indicators based on the degree of problem given Link and Place functions of street segments; and Transport for London (2013) developed a framework to categorize streets according to their building and network context. As for prioritizing Complete Streets interventions, Hui et al. (2018) reviewed different classification frameworks to measure the "completeness" of streets. They emphasized the lack of quantitative frameworks and noted that most frameworks deal only with street designs and geometries. Furthermore, they suggested that a framework that could consider all the streets in a network and prioritize interventions would be of a great aid to develop better policies for cities. The proposed model in this paper aims to response this problem. To our knowledge, our project is the first application of MCDA to evaluate the potential in order to prioritize street segments to become Complete Streets (Complete Streets for Canada 2018).

2.5 Methodology

2.5.1 Case study

Quebec City is the capital of the province of Quebec in Canada. It is located in the south east of Canada, has approximately 531 000 inhabitants, an area of 453 km^2 and a population density of 1 173.2 hab/km^2 (Statistique Canada 2017). Founded in 1608, the City is one of the oldest in North America. It is composed of historical and central neighborhoods with higher population densities, of older suburban neighborhoods with medium densities that were developed along streetcar lines in the first half of the 20^{th} century and of younger suburban neighborhoods with low densities that sprawled following the construction of freeways from the 60s to the 80s (Dufaux, Labarthe, et Laliberté 2013). Quebec City is often mentioned as the Canadian metropolitan area with the highest number of freeway kilometers per inhabitants (Communauté métropolitaine de Québec 2013). The motorization rate is of 1.25 vehicles per household. The modal shares for a complete day are of 74.7% for the car (including carpooling), 9.9 % for public transit and 11.2 % for non-motorized transportation (walking and cycling). These statistics are, however, different in the central neighborhoods where the modal shares are of 58.4% for the car, 17.1% for public transit, 20.1% for walking, and 2.0% for cycling (MTQ 2015).

To slow down and hopefully reverse the trend toward urban sprawling and a car-centric transportation, Quebec City adopted a Sustainable Mobility Plan in 2011 and a Metropolitan land-use and development plan in 2012. In

addition, the City adopted several other plans: a bicycle plan, a street tree plan and many neighborhood plans, including what is locally named *Programmes particulier d'urbanisme* (PPUs). PPUs are lower level plans that are developed through a participative process with citizens and that focus on a few streets or a neighborhood to specify, frame and harmonize the development of a sector. Despite these numerous plans, the previous decision process did not properly involve the various municipal departments and has often led to rebuilding streets in the same way as they were before the intervention. As a consequence, the elaboration of a Complete Streets strategy by Quebec City required, in addition to a new street segment design process, the development of a new street selection process based on a collective vision among the different departments. As a result, our project was defined to develop a spatial MCDA-based decision model, in collaboration with Quebec City professionals, to assess and rank street segments based on their potential to be redesigned as Complete Streets.

2.5.2 Framework

In order to build this model, we developed a framework based on the multicriteria method MACBETH for ranking alternatives (Carlos A. Bana e Costa et Vansnick 1994) and on the GIS software ArcMAP 10.2 (ESRI 2014) for the visual representation of the resulting ranking. Using the preferences of the involved participants, MACBETH allows one to build interval-level scales for the criteria, whether originally qualitative or quantitative; to derive the criteria weights or scaling constants; and to obtain an aggregated score for each alternative. The MACBETH method is an established method in the MCDA field. MACBETH is an integrated planning process with a constructivist approach that puts forward questions to stakeholders in a way that helps them to reach a consensus by minimizing conflicts during workshops. Finally, MACBETH can rank a large set of alternatives and is supported by a user-friendly software, M-MACBETH (Carlos A. Bana e Costa, De Corte, et Vansnick 2005). MACBETH was recently used in various applications to assess project sustainability (C. A. Bana e Costa, da Silva, et Correia 2004; Lavoie et al. 2015; Lavoie, Deslandes, et Proulx 2016; Mateus, Bana e Costa, et Matos 2017). However, it is a less common approach in transportation planning; its application to the prioritization of street segments to restructure as Complete Streets is novel. We chose to use MACBETH because our objective was to obtain, for each street segment, an aggregated score based on a weighted mean. Based on this index, the street segments are then ranked from highest priority to lowest priority with possibilities of ex aequo (i.e. two or more street segments could have the same priority). However, being based on a weighted mean, some concerns may arise about the compensation that could occur between criteria; a good performance on a criterion X could be compensated by a bad performance on a criteria Y (Ackerman et Heinzerling 2004). Compensation between criteria may allow a weak sustainability paradigm, where a gain in human capital could compensate a loss in environmental capital, rather than a strong sustainability paradigm, where an environmental loss could not be compensated in any way (Cinelli, Coles, et Kirwan 2014). As such, the process of aggregating and then discussing the results through validation with the stakeholders is critical.

The proposed framework for this project was an iterative process and it was organized into five phases: (1) structuring the problem, (2) constructing attractiveness scales, (3) deriving scaling constants, (4) validation, and (5) producing geographical priority maps. Many steps were involved in each phase and are further described in the section 2.6 Application (Fig. 2.1).

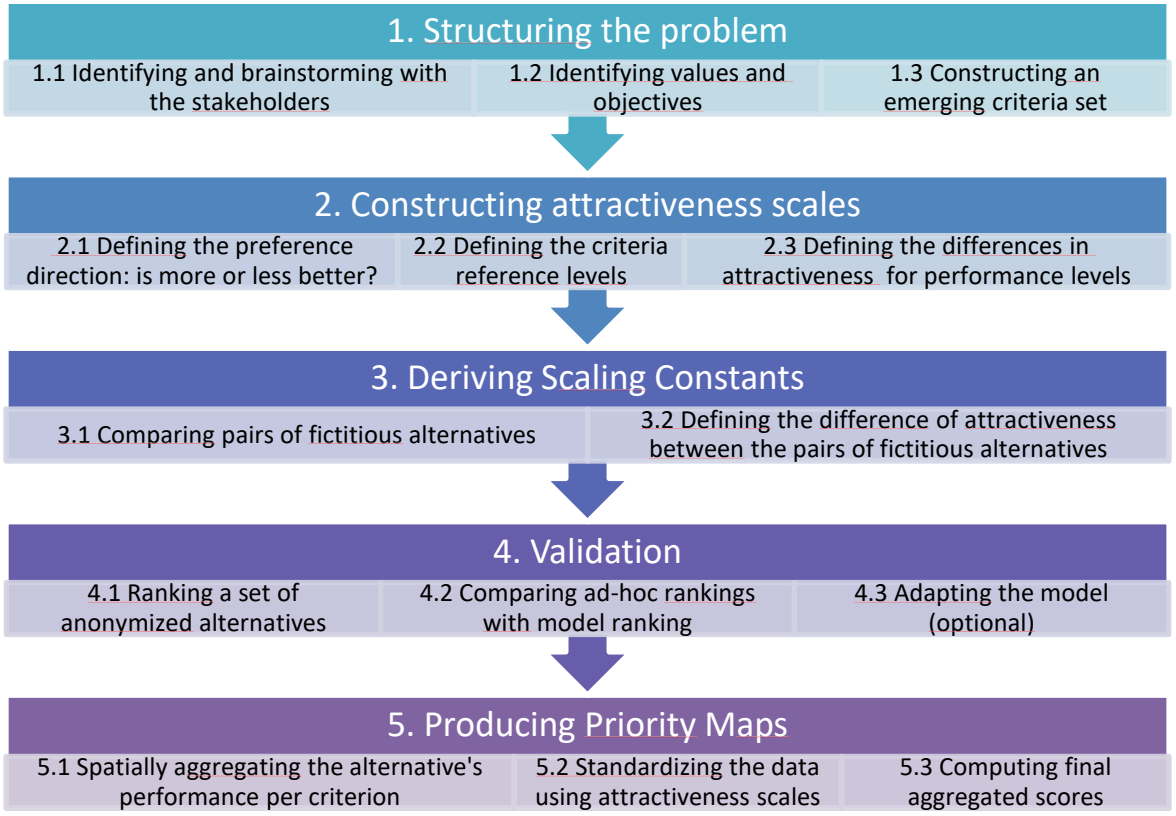

Figure 2.1 Developed framework

2.6 Application

The framework was applied during group workshops and subgroup workshops with 11 Quebec City professionals including: a transportation engineer, an infrastructure engineer, three urban planners from different departments, a project manager, an urban designer, an environmental planner, a landscape architect, an advisor in public participation and the sustainable development project director. Group workshops involved all the professionals, whereas subgroup workshops were smaller meetings held with one to four professionals to define parameters linked to their respective domains and specific expertise. The authors acted as facilitators during the workshops and did not aim to influence the decisions one way or another. The participants were selected to represent the different professionals and departments involved in street selection and design process; they were chosen during a preparatory meeting with the project manager, the urban designer responsible for the application of Complete Streets in Quebec City and the project director. The involvement of citizens in the project

was also a concern. However, as a first step towards a Complete Streets strategy, the concept of Complete Streets was still ill-defined. The City wanted to limit the group size and to first define a common vision between the professionals for street selection and at a later stage, to involve the citizens in the street design process. The authors do not claim that this is best practice, but simply that it was how the City wished to proceed. Nonetheless, one of the criteria constructed, *citizen dimension*, was meant to echo documented citizens' concerns. The set of alternatives that was assessed by the model was naturally defined by the data availability for the 20 000+ street segments in Quebec City. The street segments were chosen as the unit of analysis because the context around a street segment could easily change along a street and may change from one segment to another.

2.6.1 Structuring the Problem

The first phase in a MCDA approach is the problem structuring phase (see Fig. 2.1). It consisted of defining with the participants (i.e., persons involved in the group workshops) the problem that is to be solved and constructing a complete, yet concise, set of objectives to be translated into criteria and associated scales. The steps followed in this first phase are similar to the ones suggested by Belton and Stewart (2010).

During brainstorming sessions, the participants' concerns about the decision problem were identified using a series of questions inspired by Keeney's Value Focused Thinking approach (2007) in order to articulate the participants' values: *What makes a street more attractive to redesign it as a Complete Street?*; *What are the constraints or threats to redesigning a street?*; *If there were only one street to redesign, which one would it be? And why? Which consequences are desirable? Undesirable?* etc. This led to the definition of more than thirty dimensions (i.e., observable attributes that could describe street segments) that were later grouped into six categories: geometry design problems, current urban context, social context, urban planning, site potential, and infrastructure.

Subsequently, the obtained concerns and values were organized and displayed, using Cmap-Tools, as a conceptual map that summarizes the issues at hand (Cmap 2017). The conceptual map allowed us to pinpoint and emphasize the various project objectives and sub-objectives.

Finally, a critical evaluation of the conceptual map was conducted with the participants to define a set of common objectives which led us to retain eleven criteria on which to assess the potential of a street segment to be redesigned as a Complete Street. The resulting criteria, the reference levels needed to construct interval-type scales, and their corresponding measurement units are presented in Table 2.1 and are further detailed in the following sections. Universal accessibility and street hierarchy were not retained in this case because these criteria have an influence on the street design and not on the street selection. The professionals also discussed

the potential increase in active transportation modal share as a possible criterion, but finally rejected it due to the difficulty and uncertainty in assessing a segment on such a criterion.

Tableau 2.1 The selected criteria, their measurement scales, and their reference levels ("good" and "neutral").

Criterion	Measurement scale	"Good" reference	"Neutral" reference
Bicycle network	Bicycle path planning priority (mixed ordinal and cardinal scale, 5 steps)	Prioritized bicycle path	Planned bicycle path
Bus network	Bus network priority scale (ordinal scale, 10 steps)	High service bus route ("Metrobus")	Neighborhood bus route
Connectivity	Space syntax normalized angular choice (cardinal scale)	1.15	0.95
Citizen dimension	Citizen dimension scale (ordinal scale, 4 steps)	Petition	Neighborhood council resolution
Human activity density	Human activity/ ha (cardinal scale)	200	100
Pedestrian flow	Pedestrian estimated average annual daily traffic (cardinal scale)	1 000	500
Safety	Collisions & pedestrian flow (ordinal scale, 8 steps)	1-2 collisions & 0-1 000 or 3-4 collisions & 2 000+	1-2 collisions & 2 000+
Street width	Meter (cardinal scale)	15	10
Social and material deprivation	Social and material deprivation index (ordinal scale, 8 steps)	Unfavorable for material and moderately unfavorable for social deprivation	Moderately unfavorable for both material and social deprivation
Urban planning	Number of plans (ordinal scale, 15 steps)	1 priority-level-1 plan or 2 priority-level-2 plans	1 priority-level-3 plan
Urban tree canopy index	% of urban tree canopy (cardinal scale)	16	40

2.6.2 Constructing Attractiveness Scales

Following the structuring phase, the next step is to model the problem according to a chosen multi-criteria aggregation method, such as MACBETH, for example. MACBETH computes interval-level scales that translate a performance value on a given criterion into an attractiveness value, reflecting the participants' preferences. The attractiveness scales were built for each criterion by asking the participants: (1) to first specify the preference direction (i.e. are criteria values to be minimized or maximized for a higher redesign priority), (2) to define "good" and "neutral" reference levels, (3) to identify criteria steps for ordinal scale criteria, and (4) to express the perceived difference of attractiveness between pairs of performances.

For example, Fig. 2.2 present the attractiveness scale that was built with the participants for the street width criterion to standardize the scale. The x-axis represents the street width in meters and the y-axis the MACBETH attractiveness values (the attractiveness of a street segment's evaluation on a given criterion as perceived by the professionals). The higher the attractiveness of a street segment's evaluation on a criterion, the more inclined are the professionals to redesign the segment as a Complete Street, based on this criterion. Thus, the "good" reference level, indicated by a green dot (usually assigned an attractiveness value of 100, although attractiveness values can exceed 100), represents a desirable level. As such, a score of "good" (100) would be a street segment that professionals would identify as being a good candidate for redesign as a Complete Street because of its potential from the perspective of a specific criterion (e.g. for the street width criterion, the participants were asked: *what street width is satisfying to design a Complete Street?* They answered that streets with a width of 15m are considered good candidates to design a Complete Street). As for the "neutral" reference level, indicated by a blue dot (usually assigned an attractiveness value of 0, although attractiveness values can be lower than 0), it refers to a level that is at the lower limit of attractiveness. In this case, it would be a street segment that professionals are neither in favor of nor against redesigning as a Complete Streets from the perspective of a specific criterion (e.g. for the street width criterion, the participants were asked: *what is the lowest acceptable street width required to design a Complete Street?* They responded that the lowest acceptable street width is of 10 m).

Then, the criteria steps (identified by yellow dots) were defined by the participants. Afterward, the perceived differences in attractiveness between the various steps were expressed by the participants based on a 7-point semantic scale: *null, very weak, weak, moderate, strong, very strong or extreme*. The orange brackets on Fig. 2.2 show the differences of attractiveness between the different steps for the street width criterion. For each criterion, all this information was elicited and entered in the M-MACBETH software (Carlos A. Bana e Costa, De Corte, et Vansnick 2005) to generate the attractiveness scales. The attractiveness scales are not necessarily linear scales as certain thresholds and plateaus likely exist (e.g. the attractiveness scale for the street width criterion on Fig. 2.2 has an S-shape). Readers interested in learning how the scales were built in more detailed explanation can refer to Appendix D. Moreover, the attractiveness scales for the other criteria are available at Appendix E.

The criteria, the rationale that led to their choice and the thoughts by the professionals as well as the manner in which the respective attractiveness scales were built (steps and preference direction) are further discussed in the sections below. Recall that the aim of the model and its criteria was not to rank segments in terms of design, but to rank the segments so that the city can identify which one to prioritize to become Complete Streets.

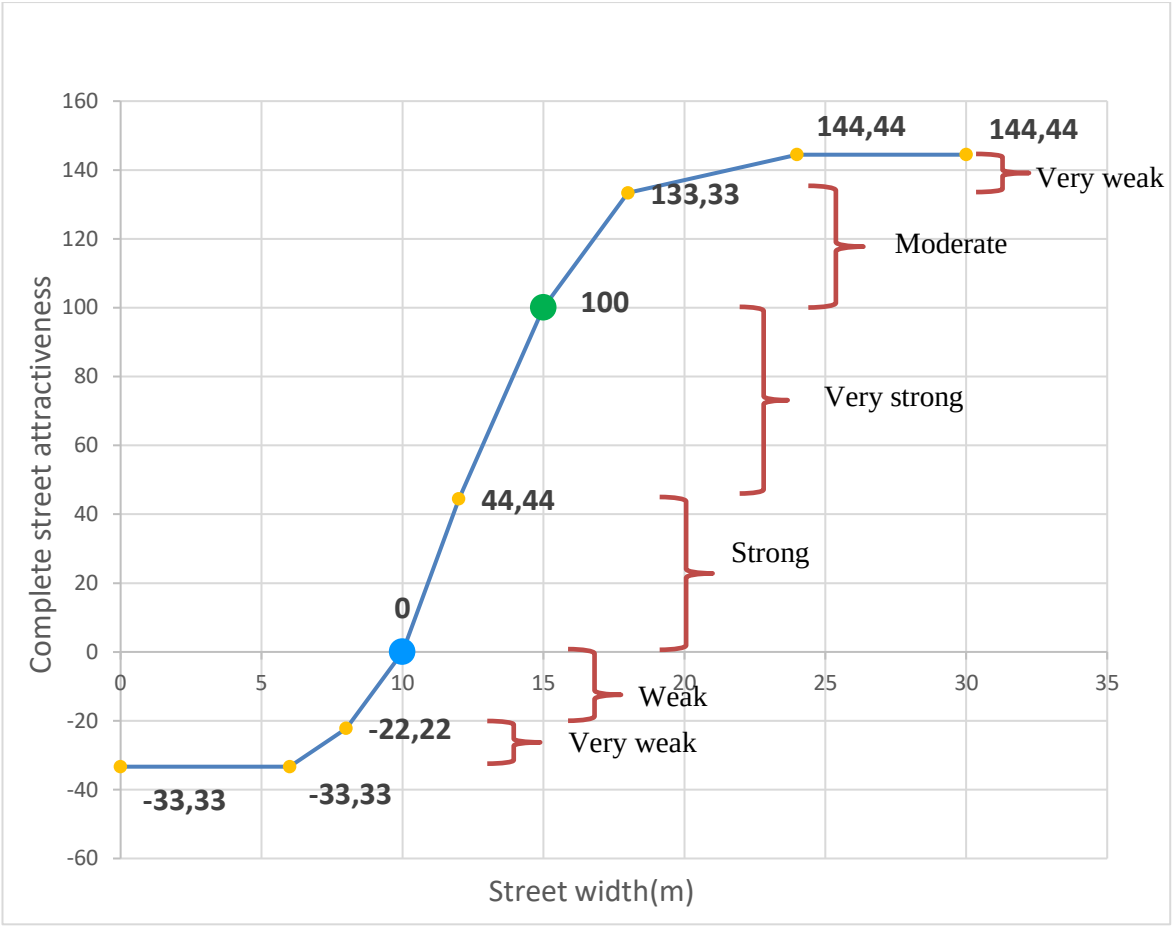

Figure 2.2. Constructed attractiveness scales for the street width criterion and the difference of attractiveness between the steps. The "good" and "neutral" references are respectively indicated by a green dot and a blue dot.

2.6.2.1 Bicycle Network

The segments' preference order on this criterion is defined according to the following planning categories of bicycle paths found on the segment: existing, planned, and prioritized bicycle paths (Vélo Québec 2015; Ville de Québec 2008). The resulting constructed scale for evaluating a segment on this criterion contains five steps: (1) segments where no bicycle path were identified in the different plans; (2) segments that already have one existing bicycle path and that is in a good state, (3) segments with a planned bicycle path, but not prioritized; (4) segments with an existing bicycle path that need to be rebuilt to maintain the cycling network's quality and (5) segments with a prioritized bicycle path that does not exist yet, but that were identified as priorities to complete the existing cycling network. The bicycle network criterion was built during a subgroup workshop with a cycling transportation planner and a project manager. All other things being equal, the higher the bicycle path value on the scale, the more inclined were the professionals to design a street segment as a Complete Street.

2.6.2.2 Bus Network

The segments' preference order on this criterion is based on whether the segment is on existing or planned bus routes. Using the six bus network categories found in the Sustainable Mobility Plan of Quebec City and adding planned bus routes, the following echelons were defined: (1) segments without a bus network, (2) neighborhood network (low frequency (>30 minutes) buses), (3) planned neighborhood network, (4) regular bus (15-30 minute interval buses), (5) planned regular bus, (6) eXpress (commuter buses from suburban regions to poles of employment), (7) planned eXpress, (8) Metrobus (high frequency (<10 minutes during rush hour, 15 minutes off-peak) "bendy" buses typically with designated lanes at rush hour), (9) planned Metrobus and (10) bus rapid transit (Ville de Québec 2011). This classification is used as a proxy for the commercial speed, the frequency, and the ridership. Furthermore, planned bus routes were judged more interesting than existing bus routes, but were never preferred to a bus route from a higher-ranked network. The bus network criterion was built during a group workshop with all the professionals. All other things being equal, the higher the bus network value on the scale, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.3 Citizen Dimension

Taking into account the citizens' positions and opinions is not an easy criterion to construct in the absence of an active participative process in parallel to the workshops. In Quebec City, there are three channels for citizens who wish to make requests or proposals regarding streets to City officials: citizen complaints, citizen petitions, and neighborhood council resolutions. Neighborhood councils are legal structures that allow citizens from a neighborhood to express their opinions concerning their neighborhood and City projects. These councils are led by citizens where the neighborhood elected official acts as a mere observer. The neighborhood council resolutions are recommendations made to the City administration.

Based on these three channels, a smaller group of three public participation professionals was formed to define the citizen dimension criterion in a subgroup workshop. The group chose to use citizen petitions and neighborhood council resolutions that targeted segments as indicators for this criterion. The complaints were rejected as an indicator because of their low reliability. The explanation given by the professionals was that complaints are not always justified and the number of complaints on the same segments is not always a sign of greater citizen concern. For example, a citizen could make many unjustified complaints on the same street segment where a citizen from another segment would make only one justified complaint. The authors do not argue that this is appropriate, but simply that this was the argument made by the participants. Next, petitions were preferred to resolutions since they refer to a strong local mobilization related to a segment. The constructed ordinal scale for this criterion consists of four echelons, depending on whether the segment had been subject to: (1) no mobilization, (2) a neighborhood council resolution, (3) a petition, or (4) a petition and a resolution. All

other things being equal, the higher the citizen mobilization value on the scale, the more inclined were the professionals to design a segment as a Complete Street.

To create the database for this criterion, the neighborhood council reports and borough council reports between 2006 and 2016 were all analyzed. Neighborhood council reports contain all the adopted resolutions and borough reports contain all the filed petitions. To deal with the large number of documents at hand (5 587 documents), a Python language script was written to identify every resolution and petition dealing with street design and transportation. A manual sorting procedure was further applied to confirm the results of the automatic identification of pertinent resolutions.

2.6.2.4 Connectivity

Many methods exist to measure the connectivity of a city's street network. The Quebec City urban design team decided to use Space Syntax as it allows one to analyze spatial forms and their influence on human activity (Hillier 2007). Among the different Space Syntax measures, the two urban designers that participated in the subgroup workshop chose the *Normalized angular choice* (NACH), which measures the potential of a segment to be used as the shortest path from every segment to every other segment within a given radius (Hillier, Yang, et Turner 2012). In other words, a segment with a high connectivity is a segment that is more likely to be used by pedestrians (e.g. grid networks usually have a high NACH, tree-like networks have a low NACH and dead end have a NACH of 0). Using Quebec City's street network in an axial map format, the NACH was calculated with the DepthmapX software for every street segment (Varoudis 2015). All other things being equal, the higher its connectivity, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.5 Human Activity Density

To represent the proximity of a segment to local and major trip attractors, the group decided to use the human activity density. This density is calculated by summing up the numbers of residents, students and workers in a dissemination area, the smallest geostatic unit from the Canadian Census data, and dividing this sum by the dissemination surface in hectares. A dissemination area consists of one or more neighbouring blocks of houses, and a population of 400 to 700 persons. The segments within the same dissemination area have the same value. The data to evaluate this criterion was extracted from the Canadian census and from database of the colleges, universities and Quebec City school boards. The human activity density criterion was built during a subgroup workshop with two urban planners and a project manager. All other things being equal, the higher the density, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.6 Pedestrian Flow

Pedestrian flow can also influence the choice of the segment to be redesigned as a Complete Street. The pedestrian flow for an average day was estimated from the 2011 Quebec City origin-destination (OD) survey.

Quebec City OD surveys are studies conducted every five years with approximately 5% of households in the metropolitan area to gather information about the population's travel habits. City transportation planners preferred OD survey to pedestrian flow counts because the count methods may vary from one count to another and, depending on the season, the results can be very different. Moreover, OD surveys provide data for all segments, and not only for the intersections and segments where pedestrian counts were conducted.

For each pedestrian OD trip, we started by calculating the route (itinerary between the origin and destination) with the ArcGIS Network Analyst tool (ESRI 2014). We then computed a weighted pedestrian flow for every route, where the weights reflect the geographical and sociodemographic stratification of the OD survey respondents. Then, the weighted routes' flows were summed for each street segment. The pedestrian flow criterion was built during a subgroup workshop with a transportation engineer. All other things being equal, the higher the pedestrian flow, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.7 Safety

Safety was obviously another concern for the professionals. This criterion was defined by the number of collisions involving pedestrians over a period of two years as a function of pedestrian flows. The city professionals chose to jointly use these measures to construct the scale because they felt that accident rates (a relative rate) dilute the number of collisions and do not take into account the human factor linked to injuries and collisions (an absolute rate). They therefore defined seven echelons for collisions per pedestrian flow and ordered them during a group workshop (Table 2.2). The steps range from A, reflecting the lowest Complete Street potential, to G, the highest Complete Street potential. For the same number of accidents, the professionals prefer to act on the segments with a lower pedestrian volume because it was more dangerous for each pedestrian. The safety criterion was built during a group workshop with all professionals. All other things being equal, the higher the number of pedestrian collisions with a lower pedestrian volume, the more inclined were the professionals to design a segment as a Complete Street.

Tableau 2.2 Classification according to the number of collisions and the pedestrian flow

	0 – 999 pedestrians	1 000 – 1 999 pedestrians	2 000 pedestrians and more
1 or 2 collisions	C	B	A
3 or 4 collisions	E	D	C
5 coll. or more	G	F	E

2.6.2.8 Social and Material Deprivation

To improve public health and promote healthy habits, the professionals decided to use a social and material deprivation index to identify areas that can benefit the most from a Complete Street. The index was developed by Pampalon et al. (2011) for Québec's Ministry of Health and Social Services and calculated at the dissemination area scale. The street segments within the same dissemination area have the same index value.

The index is based on six socio-economic indicators and expresses deprivation along two dimensions: the material deprivation (the proportion of people with no high school diploma, the population/employment ratio, and the average income) and the social deprivation (the proportion of people living alone, the proportion of individuals either separated, divorced or widowed, and the proportion of single-parent families). The six indicators defining the deprivation index were retained following a principal component analysis of over one hundred variables (Pampalon et al., 2011). For each of the two components (material and social), the distribution is divided into quintiles ranging from the least deprived group (Quintile 1) to the most deprived group (Quintile 5). For our decision group, the professionals decided that social deprivation has a bigger impact on the quality of life than material deprivation. They therefore built an ordinal scale with eight steps: (1) favorable both materially and socially , (2) favorable materially and moderately unfavorable socially or moderately unfavorable materially and favorable socially, (3) moderately unfavorable both materially and socially, (4) unfavorable materially and favorable socially, (5) unfavorable materially and moderately unfavorable socially, (6) favorable materially and unfavorable socially, (7) moderately unfavorable materially and unfavorable socially, and (8) unfavorable both materially and socially. The social and material deprivation criterion was built during a subgroup workshop with an environmental planner with knowledge in health geography and a project manager. All other things being equal, the higher the value on this criterion, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.9 Street Width

Narrow streets can be an obstacle to the design of a Complete Street as the intention is to provide the right balance of space for all modes according to the urban context (walking, cycling, public transport, and private motor vehicles). Therefore, the professionals favored wider streets as it would be easier to implement many transportation modes, as well as planting new trees. The street width criterion is the distance in metres between the lot lines on each side of the street, the space within which the city can legally work. The data were calculated using street centre lines and lot lines shape files in ArcMap. The criterion was built during a group workshop with all the professionals. All other things being equal, the higher its width, the more inclined were the professionals to design a segment as a Complete Street (see Fig. 2.2 in section 2.6.2).

2.6.2.10 Urban Planning

As one of the main tools for urban planning and transportation professionals, plans play an essential role. In a Complete Street context, professionals are interested in plans that act at the street level and that identify specific segments, streets or areas. In order to take them into account, the different types of existing plans pertaining to streets or segments were identified, including neighborhood plans and master plans. The professionals subsequently ranked the plans according to a priority level ranging from 1, the highest priority, to 3, the lowest priority. They then ranked all the possible combinations according to the number and the priority level of plans

(e.g. 2 plans of priority-level-1 and 1 plan of priority-level-2). The 15-step urban planning criterion was defined during a group workshop with all the professionals. All other things being equal, the greater the number of higher priority plans, the more inclined were the professionals to design a segment as a Complete Street.

2.6.2.11 Urban Tree Canopy Index

As one of the measures geared towards improving public health, Quebec City professionals wished to increase the tree canopy index. The urban tree canopy index is defined as the percentage of the ground area covered by leaves, branches and stems of trees view from above relative to the total studied area (e.g., city blocks, neighborhoods, cities; Varin and Boulfroy, 2015). The data was produced, for each segment, by Quebec City geomatic specialists using multispectral band aerial photos. The criterion was defined during a subgroup workshop with an environmental planner and a project manager. All other things being equal, the lower its urban tree canopy index, the more inclined were the professionals to design a segment as a Complete Street.

2.6.3 Deriving Scaling Constants

Since MACBETH computes an aggregated weighted average for each alternative (street segment), the weights or scaling constants, must be defined with the participants. These are elicited by comparing pairs of fictitious alternatives built in such a way that all the criteria have “neutral” scores except one criterion with the corresponding “good” score. There are as many fictitious alternatives as there are criteria. Additionally, an alternative where the value for all criteria is the “neutral” score is also used. Thus, the total number of fictitious alternatives is the total number of criteria plus one (12 fictitious alternatives in this case study).

These alternatives are used to determine preferences, which is a means for scaling of the criteria. To accomplish this, the group analyzed pairs of street segments (i.e., alternatives). For each pair, they chose the street segment they preferred to design as a Complete Street and qualified the difference in attractiveness using the previously defined MACBETH semantic scale (see Table 2.3). In the example presented in Table 2.3, the group of professionals strongly preferred segment B (they chose their preference level from the list to the right), with a human activity of 200 activities/ha and a street width of 10 m, to the segment A, with a human activity density of 100 activities/ha and a street width of 15 m, with equal values on the remaining criteria. The comparison results were entered in M-MACBETH to obtain the scaling constants. Moreover, it was not necessary to compare every pair of fictitious alternatives to build the model since M-MACBETH can infer part of the comparisons from partial judgments using a linear mathematical program.

Tableau 2.3 Example of a pairwise comparison of two fictitious segments (the original of this table was in French on a white board for discussion among the participants).

Criteria	Street A	**Street B**	Preference
Bicycle network	Planned bicycle path	Planned bicycle path	Extreme
Bus network	Neighborhood bus route	Neighborhood bus route	Very strong
Connectivity	0.95	0.95	**Strong**
Citizen dimension	Neighborhood council resolution	Neighborhood council resolution	Moderate
Human activity density	100	**200**	Weak
Pedestrian flow	500	500	Very weak
Safety	1-2 coll., & 2 000+	1-2 coll., & 2 000+	Non-existent
Street width	**15**	10	
Social and material deprivation	Moderately unfavorable for both material and social deprivation	Moderately unfavorable for both material and social deprivation	
Urban planning	1 priority-level-3 plan	1 priority-level-3 plan	
Urban tree canopy index	40	40	

2.6.4 Validation

Validation is essential in order to ensure that the constructed models are consistent with the preferences expressed by the participants. This was achieved by comparing the ranking of a set of 20 anonymized street segments obtained by our model with the ranking provided by the participants in a final group workshop. The set of anonymous alternatives was chosen to be representative of a wide variety of contexts and included two fictitious alternatives namely, an all “neutral” alternative and an all “good” alternative. Based on the authors’ experience, a set of 20 well-chosen alternatives is sufficient to capture the diversity in a set of alternatives (i.e. alternatives with values that range from a very low priority to a very high priority and that score high or low on different criteria). To facilitate the ranking process, the professionals started by grouping the street segments into different categories ranging from a very low priority to a very high priority, without explicitly giving a name to categories. Following this, the professionals then conducted a within-category ranking. All of the alternatives were also ranked by M-MACBETH using the previous information (attractiveness, scaling). When the ranking obtained by M-MACBETH differed from the ad hoc ranking, the participants were asked to discuss and explain their choices. At the end of this process, 80% of segments (16 segments) were ranked in the same order as that obtained by the MCDA model. As for the four segments that had a different ranking from the one obtained by the model, we tried to adjust slightly the attractiveness scales while remaining coherent with the information elicited through the validation, but the changes in the model were worsening the ranking.

2.6.5 Producing Priority Maps

The final phase in spatial MCDA is to combine a GIS with the MCDA model to process data, incorporate spatial information, assess the alternatives and obtain the final scores or rankings. This series of steps produces maps

to better visualize the participants' preferences and end results. It helps decision makers to easily analyze a large amount of data and to achieve a broader view of the situation. The procedure for spatial multicriteria problems usually implies two main functions: the spatial aggregation and the multicriteria aggregation (Malczewski et Rinner 2015). We added a third function, standardization, conducted between the spatial aggregation and the multicriteria aggregation.

First, the different sets of data for each criterion were spatially aggregated to obtain a map presenting the segments' original values on each criterion. Then using the results of M-MACBETH, the segments' original values on each criterion were standardized according to the attractiveness scales in order to convert the original criteria values into attractiveness maps. Finally, these attractiveness values were multiplied by their respective scaling constants and summed to calculate, for each street segment, a final score, the Complete Street Priority index (Marleau Donais et al., 2016). In order to support this technical process, we developed a set of tools in the Python language to help integrate the M-MACBETH results in ESRI ArcMap 10.2.2 (Marleau Donais, Abi-Zeid, et Lavoie 2017).

2.7 Results

The Quebec City network is composed of nearly 22 000 street segments. The analysis was limited to the segments inside the urban perimeter, for a total of nearly 20 500 street segments. The segments outside the perimeter were excluded because data was missing for many criteria. Furthermore, data for the security criterion was not available for 4 of the 6 boroughs (*arrondissements*). It was therefore agreed with the professionals, to attribute a value of 0 on the security criterion, the "neutral" reference level to the segments in the boroughs without data.

The results are presented as street network maps for each of the eleven criteria (Fig. 2.3 and Fig. 2.4). The color scale used to represent the criteria attractiveness values varies from a very low priority index in pink to a very high in red. Between the two extremes, street segments near the neutral reference level take on a blue shade and street segments near the good reference level take on a green shade. Moreover, white segments are segments that were not under study. The criteria maps show that for the same segment, its performance values may vary considerably from one criterion to another. Some criteria maps have measurements at the specific street or segment levels (e.g. 3.3a Bicycle network, 3.3b Bus network or 3.4g Safety), while others are measured on a larger scale namely areas that include several streets or segments (e.g. 3.4h Social and material deprivation or 3.4j Urban planning).

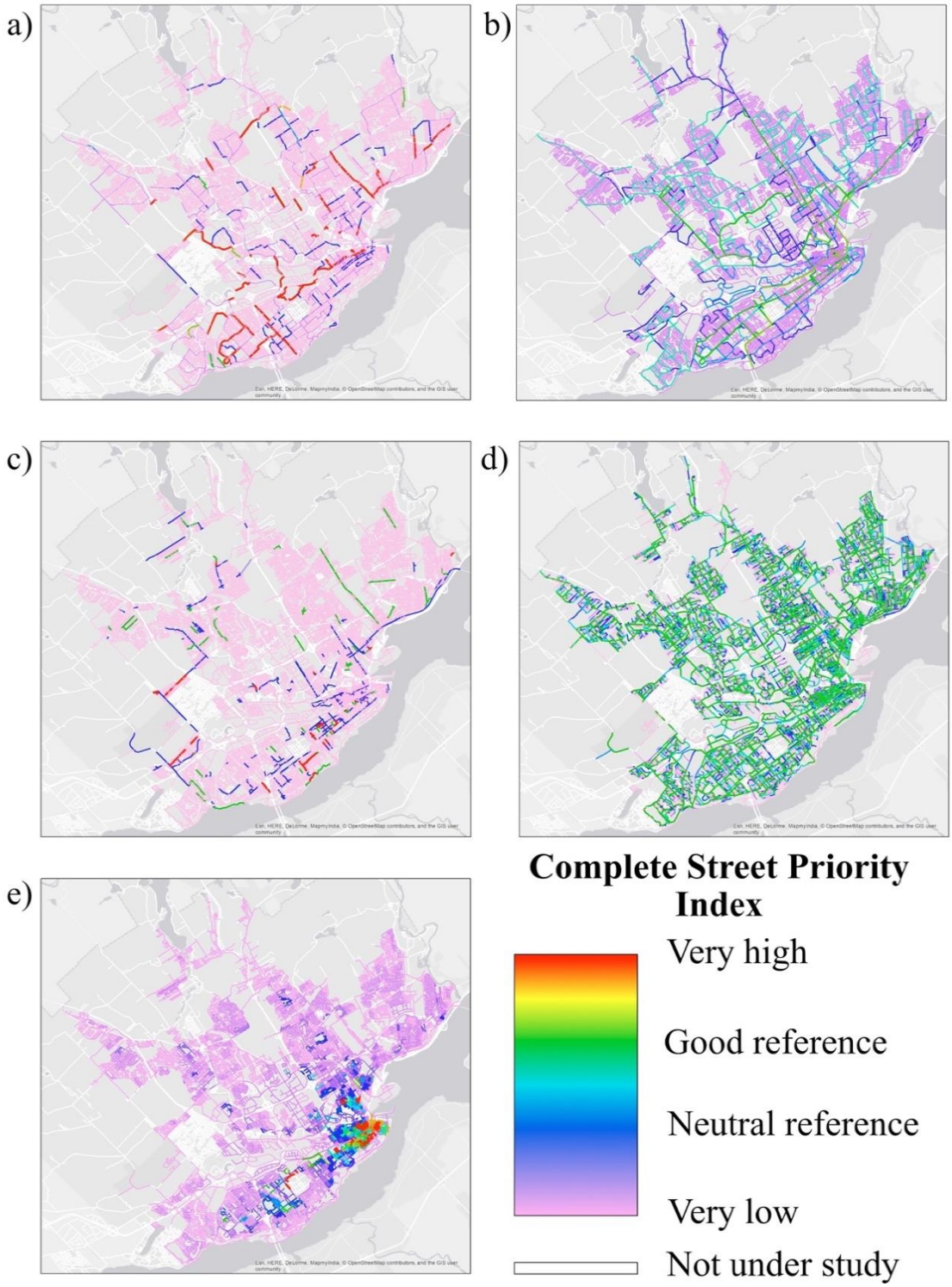

Figure 2.3 Standardized maps for the evaluation of CSP-i. a) Bicycle network, b) Bus network, c) Citizen dimensions, d) Connectivity, e) Human activity density.

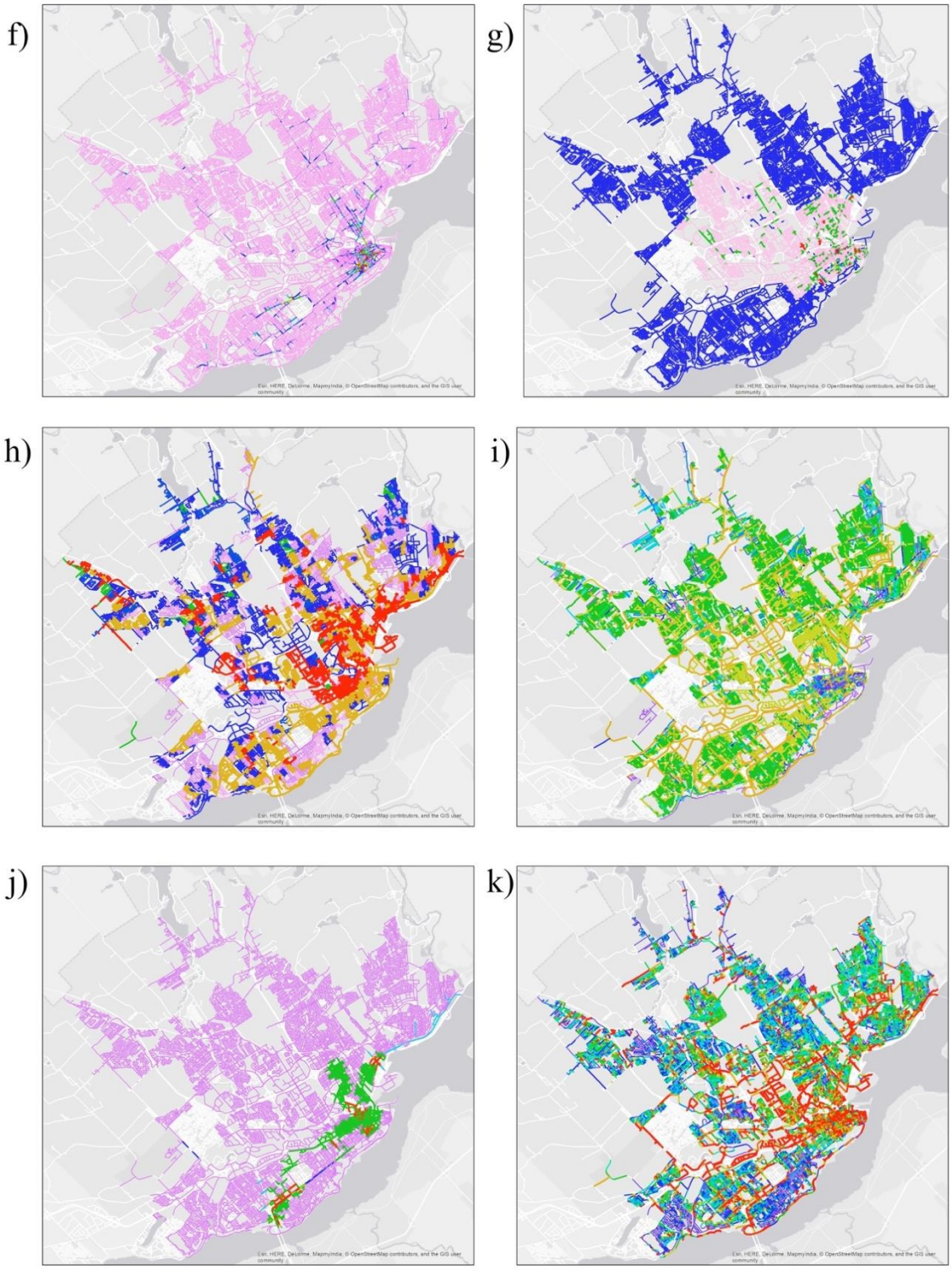

Figure 2.4 Standardized maps for the evaluation of CSP-i. f) Pedestrian flow, g) Safety, h) Social and material deprivation, i) Street width, j) Urban planning, k) Urban tree canopy index.

As for the aggregated results, they are presented at the neighborhood (*quartier*) scale. The neighborhoods are a smaller administrative separation of the boroughs that better represent the urban structure of Québec City; there are a total of 35 neighborhoods in Quebec City. Very often, one of the main issues with the spatial MCDA is the spatial variability of the participants' preferences and values. It was therefore decided not to compare segments with different urban contexts, but rather to analyze a segment relative to the other segments in the same neighborhood. This approach is in agreement with the Complete Street concept of context sensitivity and allows a better understanding of the internal neighborhood structure. Fig. 2.5 shows the Complete Street Priority index (CSP-i), ranked from 1 to 10, for all the neighborhoods, where the neighborhoods are delimited by black lines. The segments in the first rank have the highest priority and the segments ranked in the tenth rank have the lowest priority. The ten rank levels were defined by computing the CSP-i decile for each neighborhood.

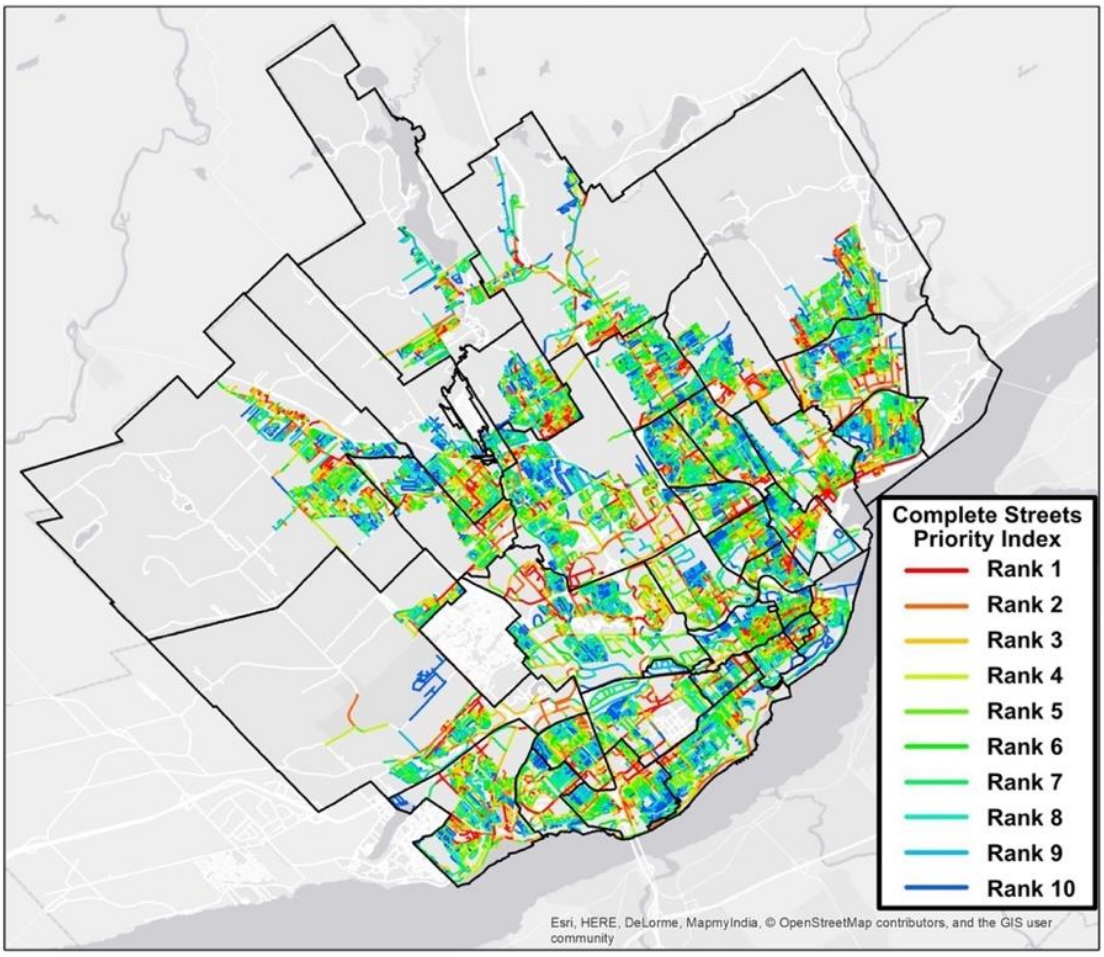

Figure 2.5 CSP-i for the aggregate criteria according to each neighborhood

An example is now given of two street segments in the same neighborhood. In Table 2.4, two segments are compared from the neighborhood of Sillery, one of the oldest suburbs in Quebec City. Chanoine-Morel Avenue

is a street segment with a high potential (rank 1), while Godefroy Avenue is a street segment with a low potential (rank 10). Street views of both streets are shown in Fig. 2.6. Chanoine-Morel Avenue is a local commercial street that is near a primary school, while Godefroy Avenue is a typical suburban residential street for Quebec City. Chanoine-Morel Avenue will be redesigned in 2019 to improve cyclist and pedestrian safety and to increase the greenery by reducing the carriage way width, increasing sidewalk width and planting around 40 trees.

Tableau 2.4 Comparison of values for two street segments in the Sillery neighborhood: Chanoine-Morel Avenue with a high potential and Godefroy Avenue with a low potential.

	Chanoine-Morel Avenue		**Godefroy Avenue**	
	Original value	Standardized value	Original value	Standardized value
Bicycle network	Existing bicycle path	0	No bicycle path	-100
Bus network	No bus	-41,67	No bus	-41,67
Connectivity	1,16	100	0,15	-166,67
Citizen dimension	No mobilization	-100	No mobilization	-100
Human activity density	118,13	18,125	24,52	-62,73
Pedestrian flow	575	14,67	0	-75
Safety	Data not available	-	Data not available	-
Street width	19,8	138,51	15,2	102,22
Social and material deprivation	Unfavor. mat. and moderately favor. soc.	142,86	Favorable both mat. and soc.	-71,43
Urban planning	No plan	-47,06	No plan	-47,06
Urban tree canopy index	0	185,71	36	14,29
Complete streets priority index	**Rank 1**		**Rank 10**	

Figure 2.6 Street views of two street segments in the Sillery neighborhood: Chanoine-Morel Avenue with a high potential (left) and Godefroy Avenue with a low potential (right).

2.8 Discussion

This case study was a first experience for Quebec City and their professionals in applying MCDA to support more sustainable transportation through the policy and street design concept of Complete Streets. The MACBETH approach allowed for the inclusion of quantitative and qualitative criteria that were often excluded

from the decision process surrounding street segment selection. The purpose was not to design complete streets, but to prioritize the street segments for redesign. The approach allowed the city to transparently construct attractiveness scales representing the "preference value" of a segment's performances on the numerous criteria. These scales were positively perceived by the professionals because they are the result of several discussions and reflect their combined interpretations of a segment's performance. For many concepts related to sustainable transportation or to Complete Streets, this was the first time that the professionals had thought about how to measure and interpret the developed criteria. For example, the urban planning criterion led to the classification of urban plans and to their prioritization. The safety criterion changed the usual collision rate interpretation to include a more human-centered approach by informing the decision makers of the number of people injured and contextualizing this information within the pedestrian flow. The citizen dimension criterion has given meaning to different citizen requests by directly incorporating them in the tool.

The results of this study were included in the newly devised Complete Streets strategy of Quebec City. As the process is well documented and transparent, it will be easier to explain to elected officials and citizens the rationale behind the choice of a street to be designed as a Complete Street. Furthermore, as some Quebec City professionals stated, without a standardized process that included all the segments, some segments would never be redesigned and would continually be delayed despite their high potential.

As can be expected, the project had its limitations. For all the city professionals involved, this was a first experience with multi-criteria workshops. They were not used to the approach and did not expect to have to answer so many questions. The most challenging step in the process was to define the measurements units and the attractiveness scales. The development of attractiveness scales was highly time consuming in a group workshop setting, sometimes tiring for the professionals and particularly long for some qualitative scales that needed to be built from scratch. To overcome this hurdle, we decided to hold subgroup workshops for criteria that needed a specific expertise in a field. The subgroup workshops pertained to one or two criteria from a specific field and gathered only the relevant professionals. Thus, the workshops were shorter, between 30 and 60 minutes, and had simpler objectives which helped to keep the focus and led the professionals to gain confidence in the process. In the case where attractiveness scales were built during subgroup workshops, the results were presented at the next group workshop to validate the scales and ensure the consensus with the rest of the group. The attractiveness scales of connectivity, human activity density, deprivation, urban tree canopy index, cycling network, pedestrian flow and citizens dimension were constructed in subgroup workshops. A group workshop setting meant that the group as a whole expressed and debated their opinions and preferences. As such, it was a much more holistic and inclusive decision process than would normally have occurred. In further research, stakeholders that are not associated with the city administration (e.g. non-

governmental organization, public health actors, citizen experts…) could be included in the process to have an external point of view and create an even more holistic perspective.

The five months project duration was another challenge. This fairly long duration is explained by the difficulty in gathering all the professionals at the same time and by the fact that three criteria required extensive data treatment and computer programming. Next, the fact that not all professionals attended all the workshops may have influenced the final results. Despite scheduling workshops two to four weeks in advance, it was difficult to mobilize everyone at every group workshop. It was therefore decided, jointly with the professionals present at the meetings, to always provide the information to the best of their knowledge and to respect the decisions made by the group during the previous workshops.

The proposed model was specifically developed for Quebec City. However, it could be exported to another city with the proper adjustments. The criteria selected here related to priorities for Quebec City, which may not be same as other cities. As such, MACBETH group workshops would be required to set up the criteria, the scales and the scaling constants in order to establish a consensus between the professionals and obtain parameters that would represent the priorities of the planners from the different cities. Also, to ensure the model adaptability, the availability of the data to assess the criteria is crucial. In this case study, all the criteria are based on existing city data. Even if some needed extensive data processing, the process did not require us to gather field data. In a less affluent data context, a collaborative MCDA approach using group workshops and the proposed framework could still be used. However, rather than using an approach based on a synthesizing criterion like MACBETH, an outranking approach (Belton et Stewart 2002) such as ELECTRE-Tri C (Almeida-Dias, Figueira, et Roy 2010) could be utilized to sort street segments according to defined classes. Outranking methods require less information and allow for more qualitative information.

Following this research, the professionals from the Complete Streets team of Quebec City have tested the model in their day-to-day practices and compared the results to street projects that were already planned for 2017. The model was tested on a sample of streets in and around the Cité-Limoilou Borough (a central borough). In that sample, 100% of the projects planned in 2017 which had already been identified as having a strong potential as Complete Streets were identified as high potential street segments by the model. The test thus validated the model accuracy and convinced city professionals of its value in allowing them to rapidly assess a segment's potential. A subsequent analysis of the data for all city boroughs led the professionals to estimate that the model is accurate in approximately 95% of all cases.

In a series of mapping overlays, the Complete Streets team then compared the model with a sample of 310 street projects planned by the engineering department for 2018-2019. Among these projects, approximately 25%

of them presented characteristics with a high potential to be redesigned as Complete Streets.[5] What would have taken several days (or possibly several weeks) of analysis using the city's previous methods to identify streets to redesign was completed in a half-day meeting using the new model. Furthermore, this new method allowed them to take Complete Street principles into account since the inception of a project, which was not the case before.

2.9 Conclusion

The multi-criteria model developed in this study is a decision aid tool that allows for the integration of sustainable development dimensions in the decision-making process. The aim was to assess the 20 000+ Quebec City street segments on the basis of their potential to be designed as Complete Streets following a consensus among professionals from different fields. Prior to this study, there was no standardized method in Quebec City to assess a street according to Complete Streets principles. The existing process was the engineering infrastructure management process that only took into account the infrastructure obsolescence. The use of MCDA allowed the City to incorporate multidisciplinary aspects to the project by including environmental, public health, socioeconomic and transportation aspects. Using the MACBETH approach, a constructivist MCDA method, the model was built and set according to the preferences, the values and the concerns of a Quebec City multidisciplinary professional group. The criteria and parameters were established according to the group's expertise, knowledge and common objectives. The several scales and scaling constants elicited with the professionals revealed how they interpreted the criteria in their practice and what their priorities are. This new tool is not a meant as a substitute to the decision makers; it is a decision aiding tool to support them and ensure the transparency of the decision-making process.

In March 2017, the Quebec City mayor revealed the city's Complete Streets strategy to the population and the media. The multi-criteria model and the cartographic tools were integrated as one of the key elements of their strategy. The strategy received good local media coverage (newspaper and television). The mayor qualified the project as the "quintessence of transdisciplinary" work. During the summer of 2017 and 2018, several segments that were identified with a high potential by the model, were redesigned as Complete Streets. Furthermore, the developed tool was highlighted as one of the 12 best Complete Streets initiatives in 2017 in North America (Smart Growth America et National Complete Street Coalition 2018).

[5] Examples of streets that were identified and redesigned by the City are consultable at the following links:
https://www.ville.quebec.qc.ca/apropos/planification-orientations/amenagement_urbain/rues-conviviales/salaberry-st-jean/index.aspx
https://www.ville.quebec.qc.ca/apropos/planification-orientations/amenagement_urbain/rues-conviviales/canardiere/

As for future research, the next step could be to define, using MCDA, the criteria that influence the street design. A lot of existing Complete Streets design guidelines use classifications or decision-making trees, but, to our knowledge, none of them use a MCDA approach. A new model is needed to identify typologies that will associate segments to typologies, and for each typology, propose different compatible street designs. The use of MCDA would be a good avenue to integrate sustainability concerns in the design process and in Complete Street design guidelines.

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3 Chapitre 3: A framework for post-project evaluation of facilitated multicriteria decision aiding processes: Development and application from the stakeholders' perspective

3.1 Résumé

Plusieurs modèles d'aide multicritère à la décision (AMCD) basés sur la facilitation d'ateliers de groupes ont été développés au cours des dernières décennies et ont été appliqués dans différents domaines. Ces modèles sont conçus pour améliorer les processus décisionnels. Toutefois, le manque de suivi et d'évaluation post-projet limite la compréhension à propos de la façon dont les ateliers de groupe sont perçus et de la manière dont les résultats sont utilisés par la suite au sein d'une organisation. Cette situation contraste avec la recherche en participation citoyenne, où une riche littérature a été développée pour évaluer les projets a posteriori. En se basant sur cette littérature, cette étude vise à développer un cadre qualitatif pour évaluer un processus décisionnel d'AMCD. Pour illustrer l'applicabilité du cadre, nous avons mis en œuvre celui-ci pour évaluer notre un processus d'AMCD à Québec où un système spatial d'aide à la décision a été développé pour prioriser le réaménagement de rues en rues conviviales. La principale motivation à la conduite d'une évaluation post-projet était d'apprendre à propos des perspectives des professionnels impliqués dans le projet. Par conséquent, des entrevues individuelles ont été réalisées avec les professionnels de la Ville de Québec qui utilisent actuellement le système d'aide à la décision, sont responsables du projet ou ont participé au développement du système. Cette recherche a identifié que le changement de pratiques dans le milieu de travail, les problèmes de communication et la nécessité d'un travail multidisciplinaire étaient à la base des différents défis auxquels ont fait face les facilitateurs. À partir de cette expérience, des leçons apprises et des solutions possibles pour améliorer les pratiques actuelles de facilitation en AMCD sont proposées.

3.2 Abstract

Numerous multicriteria decision aiding (MCDA) models based on facilitated group workshops have been developed over the last decades and are now applied in various domains. These models are designed to improve decision processes. However, the lack of follow-up and post-project evaluations limit the understanding of how the facilitated group workshops were perceived and how the results were subsequently used within the organization. This is in contrast with the public participation field of research, where a rich literature was developed for a posteriori evaluation of projects. Based on this literature, our research aims at developing a qualitative framework to evaluate an MCDA decision process. In order to illustrate its applicability, we apply our strategy to an MCDA process in Quebec City where a spatial decision support system to prioritize the redesign of streets into Complete Streets was developed. The main motivation for conducting a post-project evaluation was to learn about the perspectives of the professionals involved in the project. Therefore, individual interviews were conducted with the Quebec City professionals that currently use, were leaders of the project, or have participated in the development of the decision support system. This research has identified that the change of practices within the workplace, communication problems, and the requirement of multidisciplinary work were at the root of the various challenges that were faced by the facilitators. Based on this experience, lessons learned and potential solutions to enhance current facilitated MCDA practices are proposed.

3.3 Introduction

The emergence of multicriteria decision aiding (MCDA) in the last decades has led to the development of several methods and numerous applications in various fields (Malczewski 2006; Behzadian et al. 2010; Govindan et Jepsen 2016). These applications often involve stakeholders through facilitated modeling based on different approaches such as decision conferencing (Phillips 2007), social multi-criteria evaluation (Munda 2008), decision analysis interviews (Marttunen, Lienert, et Belton 2017) or group workshops (Salo et Hämäläinen 2010). Despite the large number of MCDA case studies in the literature, few actually evaluate, a posteriori, the facilitated process by reporting on what happened during the group workshops or on how the resulting artifacts[6] (Simon 1996) were subsequently used and perceived within the aided organization. Nonetheless, post-project evaluations can be of interest to several stakeholders: *Facilitators* and *MCDA analysts* are interested in learning about best practices in order to improve their own practice. *Participants* wish to express their views of the process and share their experiences. *People impacted by the decisions* need to understand how a decision was made in order to ensure legitimacy, transparency and accountability. *Model and tool (artifact) users* need to continuously improve their artifacts and therefore to identify the strengths and weaknesses of these artifacts. *Academics* are interested in better understanding how people behave during MCDA group workshops and how they interact with the artifacts.

Post-project evaluations (also called ex-post analysis, a posteriori evaluation or evaluation) may be defined as the rigorous process of carefully analyzing the development and application of an MCDA or operational research (OR) method, as a function of what is meant by a "successful" project (theoretically or empirically). Various key characteristics can be examined in such an evaluation: the process (in reference to the *how of the artifact development*), its outcome (in reference to the *what of the artifact*) or its adoption and use by professionals (in reference to the *how of the artifact adoption and use*) (Rowe et Frewer 2000; 2004; Keren et de Bruin 2005; White 2006). Although many authors agree on the importance of conducting such post-project evaluations (Rouwette, Vennix, et Mullekom 2002; Midgley et al. 2013), MCDA papers containing these evaluations are scarce, as was highlighted in reviews on the joint use of problem structuring methods (PSM) and MCDA (Marttunen, Lienert, et Belton 2017) and on the application of MCDA in sustainable energy systems (Braune, Pinkwart, et Reeg 2009). This is a disappointing situation considering the calls in manifestos, more than 25 years ago, to improve the quality of reporting and to evaluate MCDA interventions and their outcomes (Bouyssou et al. 1993; Montibeller 2005).

[6] The term artifacts will be used in this paper as a global term that refers to the set of new objects (models, tools, or decision support systems) that are created and designed in an MCDA or OR project (Dresch, Lacerda, et Antunes Jr. 2014). In more particular cases, the specific term such as "the model" or "the tool" will be used.

The scarcity of post-project evaluations is also true from a broader OR perspective, where few research studies have investigated the applications of OR methods in practice and the uses of OR artifacts in organizations (Becker 2016; de Gooyert et al. 2017). Our observation is not new and echoes Ackoff (1962; 1979a; 1979b) and Churchman (1970) who have argued more than 50 years ago that OR needs to observe and analyze its own practices to better understand the artifacts' building processes and implementation and, therefore, to enhance future OR practice. The same observations have sparked, in recent years, the revival of interest in behavioral operational research (BOR), (Kunc, Malpass, et White 2016; Franco et Hämäläinen 2016). Nonetheless, some frameworks to design post-project evaluations had been developed in OR, namely to evaluate group decision support systems (Eden 1995; McCartt et Rohrbaugh 1995; Eden et Ackermann 1996), to measure the value and effectiveness of PSMs (White 2006; Rouwette, Vennix, et Felling 2009; Midgley et al. 2013), to evaluate the effectiveness of group model building (Rouwette, Vennix, et Mullekom 2002) or to assess decision quality (Yates, Veinott, et Patalano 2003; Keren et de Bruin 2005).

When it comes to MCDA, there are, to our knowledge, no proper frameworks in the literature to design a post-project evaluation study. When such an evaluation is conducted in an MCDA case study, it is often condensed into one or two paragraphs in the results or the discussion section, with a few exceptions (Paschetta et Tsoukiàs 2000; Mustajoki, Hämäläinen, et Marttunen 2004; Barcus et Montibeller 2008; Greene et al. 2010; Lienert et al. 2011; Ferreira, Santos, et Rodrigues 2011). Furthermore, due to the lack of post-project reporting and analysis, the literature on how to develop expertise as a facilitator or how to overcome the difficulties encountered is scarce. The possible solutions are not well documented and often require the borrowing of concepts from the literature on facilitation and meeting animation techniques (Phillips et Phillips 1993; French et al. 1998; Proctor 2004; Phillips 2007; 2017; Franco et Montibeller 2010). This is also a challenge for those who teach MCDA and whose task it is to train the next generation of facilitators. As a result, one of the main motivations behind this descriptive research project was to document a facilitated MCDA group decision process, its outcome, and the adoption and use in practice of the resulting artifacts in order to identify good practices, challenges and make recommendations.

The situation is quite different for public participation processes in urban planning and environmental planning. As a matter of fact, a rich literature was developed to ex-post analyze these processes and outcomes; several authors have proposed evaluation frameworks for public participation exercises (Rowe et Frewer 2000; 2004; Chess 2000; Fung 2006) or participative modeling projects (Jones et al. 2009; Voinov et Bousquet 2010; Basco-Carrera et al. 2017). This literature is relevant to our work since it shares many characteristics with facilitated MCDA as a group decision process. Both research streams aspire to improve traditional decision-making by including diverse stakeholders in order to reduce conflicts and enhance stakeholders' shared knowledge. Also, both can take on many forms; from a small group of stakeholders during facilitated workshops to a large number

of stakeholders surveyed through questionnaires. For example, Rowe and Frewer (2004) developed an agenda to conduct evaluation research by reviewing past published post-project evaluations. Fung (2006) developed a three-dimensional framework to study mechanisms of participation based on who participates, how participants communicate with each other, and what types of links exist between discussions and policy actions. Jones et al. (2009) proposed an evaluation framework for cross-case analysis based on two components: the facilitator's questionnaire[7] and the participants' evaluation guide. Within this literature, one framework is of particular interest to this research, namely the one proposed by Chess (2000), because of its simplicity and flexibility. It revolves around various key questions for designing a public participation evaluation.

The aim of this paper is to adapt Chess's post-project evaluation framework for MCDA projects and to apply it to the evaluation of a case study in transportation planning in Quebec City, Canada, to better understand the project's benefits and challenges. The case study involved MCDA facilitated group workshops with 11 Quebec City professionals. The goal was to identify, in the Quebec urban area, the streets with the highest potential to become Complete Streets, a popular movement advocating "streets for everyone" in North America (Smart Growth America et National Complete Street Coalition 2018). The project led to the creation of two artifacts, an MCDA model and a spatial decision support system (SDSS) based on the model. The SDSS is used by the city's planning professionals since 2018. We chose this particular case study since, despite the fact that the SDSS is today fully operational and accepted, considerable challenges and issues were encountered during the decision modeling process (Marleau Donais, Abi-Zeid, et Lavoie 2017b). The lessons learned in this research allow us not only to formulate several suggestions that may improve MCDA facilitated modeling practices, but also to aid students and MCDA facilitators who wish to learn about other real-life experiences. More specifically, the objectives in this paper are to answer the following research questions:

- How can a post-project evaluation framework be adapted and applied for an MCDA project?
- What are the perceptions of the different stakeholders (group workshop participants, artifact users and project leaders) of the process, of the resulting artifacts (model and SDSS), and of the artifacts' adoption and operational use in an MCDA project?

This paper is organized as follows: Section 3.4 presents the adapted evaluation framework of MCDA facilitated group workshops. Section 3.5 introduces the case study in Quebec City. Section 3.6 explains how the framework was applied to our case study through the development of an interview guide and a series of individual interviews. Section 3.7 summarizes the results of the individual interviews such as the perceived benefits, difficulties and challenges related to the MCDA model development, the SDSS adoption and use, as well as the anticipated future of the SDSS. Section 3.8 proposes some recommendations to improve practices based on

[7] Jones et al. (2009) refer to facilitator as designer in their paper

the feedback provided by the interviewees and on our experience. It also discusses the limits of our post-project evaluation and explores future avenues for research. Section 3.9 concludes the paper.

3.4 A post-project evaluation framework for MCDA projects

Chess (2000) proposed a framework for designing an evaluation method of public participation in an environmental planning setting, based on five key questions: (1) *why evaluate?* (2) *what to evaluate?* (3) *on what is the evaluation based?* (4) *how to evaluate?* and (5) *who is involved in the evaluation?* (Tableau 3.1). In this section, we present our adapted framework to design the evaluation of facilitated MCDA projects. For each key question, we define and present examples, from the MCDA literature, of different possible post-project evaluation designs.

Tableau 3.1 Key questions to design evaluation for facilitated MCDA project (adapted from Chess (2000))

Why evaluate?	Summative evaluation, formative evaluation or impact evaluation
What to evaluate?	Process, outcomes, artifact's adoption or uses
On what is evaluation based?	Theory, participants, past experiences or goal-free analysis
How to evaluate?	Quantitative method, qualitative method or mixed method approach
Who is involved in the evaluation?	External actors (external evaluation) or internal actors (participatory evaluation)

3.4.1 Why evaluate?

There are different reasons for evaluating a project. One such reason is to learn about good practices and to validate the artifacts (*Summative evaluation*). This is usually done in a closing session, at the end of the last workshop or through a follow-up questionnaire. Some authors in MCDA have used this approach for different purposes: to see whether the stakeholders agree with the MCDA results (Schuwirth, Reichert, et Lienert 2012), to understand the usefulness of MCDA to support decision-making (Lienert et al. 2011) or to identify the strengths and weaknesses of the process (Ferreira, Santos, et Rodrigues 2011). One could also evaluate an ongoing project to correct and improve practices and make them more effective in the subsequent workshops (*Formative evaluation*). For example, participants could be asked to complete a survey at the end of each workshop, or an open discussion between the participants and the facilitators could close each workshop. Furthermore, an evaluation could take place a few years after the project's completion and focus on the project's impacts in the long-term (*Impact evaluation*). This type of evaluation is more complex to implement and requires a commitment from the evaluators over an extended period of time (Brown et Chin 2013).

3.4.2 What to evaluate?

Three aspects of MCDA projects may be analyzed: the modeling process (artifacts development), the outcome (produced artifacts) and the adoption and uses of the resulting artifacts. More specifically, process evaluations aim at analyzing the construction phase of the artifacts to understand the unfolding of the facilitated modeling process, as well as the context in which the process is inserted (e.g., attitude of the stakeholders toward the process, organizational culture). Outcome evaluations serve to determine not only the artifacts' validity (for example, a mathematically sound artifact applied according to OR best practices), but also whether the participants and the strategic stakeholders consensually agree with the results, which makes them organizationally acceptable and ensures the artifact's legitimacy (Landry, Banville, et Oral 1996). Finally, evaluating the artifacts' adoption and uses seeks to understand how the artifacts are used and what could be improved to better support the users in practice. Moreover, analyses may be conducted at three different levels: the individual level (e.g. developing new knowledge, documenting how professionals use the artifacts); the group level (e.g. creating a shared language, developing a common vision); or at the organizational level (e.g. analyzing the commitment to the process and the outcomes).

3.4.3 On what is the evaluation based?

The set of criteria used for evaluating a project varies according to what constitutes a "successful" process, outcome, or artifact adoption and use. The different perspectives of how a "success" is defined reflect three of the four pretensions to validity initially identified by Habermas and cited and applied by Genard and Pirlot (2002) to decision-aiding. These pretensions to validity are (1) the truth, characterized by a descriptive or observational statement (e.g., are things like you say they are?, why it is like this?); (2) the justness, characterized by a regulatory or prescriptive statement (why are you doing this?, why did you not act differently?); and (3) sincerity, characterized by an expressive statement (why are you feeling like this?). The different pretensions to validity imply that different sets of evaluation criteria may be used depending on whether they are based on theory, on past experiences, on the users, or if they are goal-free, as explained below.

Evaluations based on theory use normative criteria that may be applied universally across studies and that reflect a specific theory such as the competing values approach for group decision processes (McCartt et Rohrbaugh 1995) or the elements of decision quality (Matheson 2013); this is an objective representation of the world with claims to uncover the truth. This approach facilitates the replicability of the evaluation method and consequently the comparison between studies when the same evaluation criteria are used in different studies. However, it may create leading question biases in the evaluation (e.g. if respondents are directly asked if they developed a common language during the project, it will more likely lead the respondents to answer positively) (Choi et Pak 2005).

In evaluations based on experience, criteria are defined by reviewing past evaluation experiences in the literature or by asking a group of experts or MCDA practitioners to define the criteria according to their experiences; this is a social representation of the world with claims to justness.

Evaluations based on the users require that they define the criteria of evaluation at the beginning of the project according to their own goals. In this context, users can be either the facilitators (criteria defined based on the facilitator's own experiences), the participants (personal objectives or organizational objectives) or the artifacts users. The evaluation thus reflects the various goals of the users (facilitators, participants or artifacts users); this is a subjective representation of the world with claims to sincerity.

Finally, goal-free evaluations aim at gaining information (e.g., increasing understanding of artifact development to identify strengths and weaknesses) without constraining the evaluations by framing and focusing the evaluation on specific goals or theories.

3.4.4 How to evaluate?

An evaluation method can follow a qualitative design, a quantitative design, or a mixed method approach. Online surveys (Mustajoki, Hämäläinen, et Marttunen 2004) or questionnaires during a workshop (Marttunen et Hämäläinen 2008; Geldermann et al. 2009) are quantitative methods that can provide, for example, the percentage of stakeholders that agree or disagree with a statement. However, such surveys are not well suited to achieve an in-depth understanding of the respondents' positions since they consist of questions that are often closed, limiting further investigation. As an alternative, group discussions with workshop participants (Schuwirth, Reichert, et Lienert 2012) or a series of individual interviews (Barcus et Montibeller 2008) are frequently used in qualitative approaches. Once interviews are conducted, different qualitative methods (e.g. thematic analysis or phenomenology analysis; Paillé and Mucchielli 2016a) can be used to analyze the results. However, the external validity of the research is lower since the results are less generalizable. A mixed method that uses data triangulation (i.e. collecting data using different means on the same topic, e.g. interviews, questionnaires, etc.) is another possible approach (Midgley et al. 2013). For example, a mixed method could be a facilitated plenary discussion with the participants followed by a questionnaire to be completed later (Greene et al. 2010). Nonetheless, the choice of one approach over another is often guided by different epistemological choices such as, for example, a positivist, an interpretive or a critical paradigm (Mingers et Brocklesby 1997).

3.4.5 Who is involved in the evaluation?

Since there are different perspectives in an MCDA project, various actors can participate in an evaluation. These actors can take on various non-exclusive roles such as designing the evaluation, evaluating the project, or analyzing the results. If external actors (i.e., actors not involved with the artifact: external researchers, evaluation

consultants) design and evaluate the project or the artifact, the evaluation is referred to as an *external evaluation*; whereas if some internal actors (i.e., actors involved with the artifact: participants, artifact users, facilitators) design and evaluate the project or the artifact, it is referred to as a *participatory evaluation*. Other actors such as decision-makers or people impacted by the decision linked to the artifact could also be involved in a participatory evaluation. External evaluations aim at minimizing the interactions between the evaluator and the internal actors to maintain objectivity, while participatory evaluations aim at empowering the internal actors by encouraging them to think about their own practices rather than judging what is right or wrong (Chess 2000).

3.5 Case Study

In 2015, our research team at Laval University received a request from the City of Quebec, Canada, to help with the prioritization process for the rehabilitation and redesign of streets as Complete Streets. With approximately 531,000 inhabitants, Quebec City is the capital of the province of Quebec, is located in the south east of Canada, and is one of the oldest cities founded by the French in North America, in 1608 A.C. (Communauté métropolitaine de Québec 2013; Statistique Canada 2017). As in many other North American cities, the engineering department in Quebec City had been single-handedly choosing the streets to be rehabilitated on the basis of an infrastructure obsolescence criterion (Hess 2009; McCann 2013). This often led to rebuilding streets similar to the way they were before the intervention and overlooking new street design approaches such as Complete Streets. Nonetheless, professional practices in Quebec City had been increasingly geared toward the principles of Complete Streets and a few streets had already received a special design treatment. However, the selection process of these few streets was still subordinated to the engineering department and represented a high cognitive burden for Quebec City professionals. Consequently, mistakes were made, some projects were overlooked, and professionals were frustrated and disappointed by the results. Aware of these limitations, Quebec City professionals aimed for a more structured, rigorous and transparent decision process, conducted in collaboration with professionals from different fields (i.e., transportation, infrastructure, urban planning, etc.), that takes into account the various viewpoints, preferences and objectives.

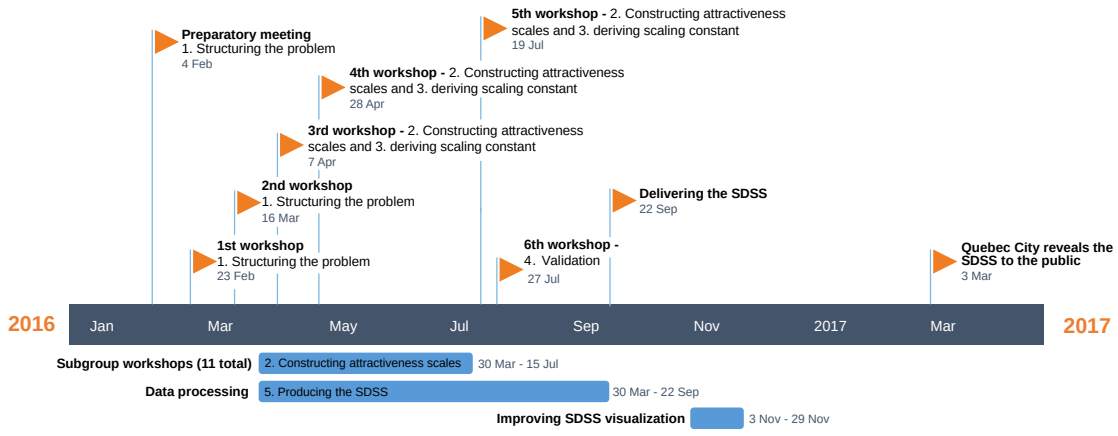
3.5.1 Project Description

Quebec City's identified need for an improved decision-making process led to a collaboration between our research team and a Quebec City team in 2016. 11 Quebec City professionals from different backgrounds were gathered in group workshops to develop a new multicriteria based decision process. The professionals consisted of a transportation engineer, an infrastructure engineer, three urban planners from different departments, a project manager, an urban designer, an environmental planner, a landscape architect, an advisor in public participation and the sustainable development project director. In total, six group workshops and 11 subgroup workshops (smaller workshops that gathered between two and four professionals with a specific expertise) were

held over a period of six months. The workshops allowed us to develop an MCDA model, implemented in a geographic information system (GIS), to assess the 20,000+ street segments in Quebec City. This spatial decision support system (SDSS) is referred to as a "cartographic tool" by the professionals. The development process involved five iterative steps: (1) structuring the problem following the Value Focus Thinking approach (Keeney 1996) to develop a set of objectives and criteria; (2) constructing interval level attractiveness scales and (3) deriving scaling constants for the calculation of a weighted average based priority index, using the MCDA method MACBETH (Bana e Costa, De Corte, et Vansnick 2016); (4) validating the model with the professionals using a subset of the alternatives; and (5) producing the SDSS as a set of street priority maps in a GIS (Marleau Donais et al. 2019). The workshops were facilitated according to decision conferencing principles (Phillips 2007). The attractiveness scales and the scaling constants were revisited several times during the project. In addition, the data processing leading to the development of the SDSS was conducted in parallel to the various workshops.

During the group workshops, two to three MCDA analysts acted as facilitators. The first facilitator (a master's student at the time and the first author here) led the discussions, the second facilitator captured the information using the M-MACBETH software (Bana e Costa, De Corte, et Vansnick 2005), and the second and the third facilitators (professors) advised the first facilitator and analyzed the workshop discussions. The objectives of the group workshops varied from one workshop to another. As for the subgroup workshops, they were aimed at constructing, with smaller groups of professionals, interval level attractiveness scales for one or two specific criteria. Only professionals with an expertise linked to the criterion being constructed (e.g., urban planning, environment, urban design, cycling transportation, etc.) were gathered. Figure 3.1 presents the timeline of the project and the objectives of each (sub)workshop. Since data processing was required to develop the attractiveness scale for some criteria, a gap of two months between the fourth and the fifth workshop was required. Marleau Donais et al. (2017, 2019) describe in more detail the process leading to the development of the SDSS.

Figure 3.1 Timeline of the project



3.5.2 Implementation of the SDSS in Quebec City

In March 2017, the mayor of Quebec City revealed the city's Complete Streets strategy to the population and the media. Subsequently, the SDSS was integrated as one of their strategy's key elements (Ville de Québec 2017). The SDSS is, since then, used operationally and several streets have been rehabilitated and redesigned. In order to ensure the transition from an academic project to an operational SDSS, our research team expanded the model to the whole city in 2017. A follow-up collaboration was conducted in 2018 to enhance the Quebec City's team's understanding of the SDSS and to resolve some technical issues. As a result, the SDSS was recognized as one of the 12 best initiatives toward Complete Streets in 2017 (Smart Growth America and National Complete Street Coalition 2018). The project was awarded the OR Practice Price in 2019 by the Canadian Operational Research Society (CORS 2019), a first for Laval University since the creation of the prize 37 years ago, and was a finalist for the Practice Award in 2019 by the Decision Analysis Society section of INFORMS (Decision Analysis Society 2020).

Despite the acclaims received after the project's completion, the road to success was not a smooth one. In fact, we faced many challenges during the group workshops (Marleau Donais et al. 2017a). This led us to conduct a post-project evaluation to learn about and compare the challenges from the participants and the SDSS users' perspectives. Furthermore, we were interested in their suggestions on how to improve our facilitation of MCDA group decision processes and the resulting artifacts.

3.6 Method

Based on the framework's key questions introduced in the section 3.4, we developed the present method to conduct a *summative evaluation* (**why evaluate?**) of the Quebec City project to prioritize streets to be rehabilitated and redesigned as Complete Streets. The evaluation took place two years after the delivery of the first version of the developed artifacts (the SDSS) to Quebec City. The objectives of the evaluation were twofold (**what to evaluate?**):

1. to better understand the modeling process, and more specifically, the perceived strengths and the weaknesses from the workshops' participants perspectives (*process evaluation*);
2. to document the appropriation and adoption process of the SDSS by the professionals, how it is used and how it could be improved in the future (*artifact adoption and use evaluation*).

Prior to our post-project evaluation, an *outcome evaluation* had already been conducted to validate the model with the participants by ranking anonymized alternatives and comparing the model's ranking with the participants' best estimated ranking (Marleau Donais et al. 2019).

The evaluation was *participatory*, based on a series of individual interviews with the professionals involved at different steps of the project (**who is involved in the evaluation?**): the workshop participants, the Complete Streets project leaders, and the SDSS users. The evaluation was conducted by the main facilitator since the aim of this evaluation was not to establish the quality of the SDSS, but rather to be a learning process for the facilitators to better understand Quebec City professionals' perspective about the project and improve future practices in MCDA. In addition, Chess (2000) points out that involving internal actors (here, the participants and the SDSS users) renders the evaluation more useful and credible by better answering the needs.

We adopted a qualitative research approach (**how to evaluate?**) rather than a quantitative one to unravel and articulate the reasons behind the challenges encountered by the facilitators. This is in line with Becker (2016), who suggests that, in order to develop a better understanding of OR interventions, OR analysts should study the application of OR techniques based on the concepts and methods of social sciences. Furthermore, it echoes the GDSS literature suggesting that open-ended methods, such as in-depth interviews and qualitative analyses, may produce richer and more relevant data than questionnaire research (Eden 1995; Eden et Ackermann 1996). The interview guide was designed as a goal-free evaluation (**On what is the evaluation based?**). Considering the few MCDA post-project evaluations in the literature, we did not want to limit our evaluation and questionnaire to theory or to past experiences, rather, we wished to gather as much information as possible regarding the various impacts of the project. We wished for the professionals to share their experience about the process and the SDSS with their own words, thereby minimizing leading question biases.

Once the different key questions were answered, a method in three steps was followed during the post-project evaluation: developing an interview guide (section 3.6.1), conducting semi-directed interviews (section 3.6.2) and analyzing the interviews using thematic analysis (section 3.6.3).

3.6.1 Developing an Interview Guide

Prior to conducting the interviews, we developed an interview guide to reflect our two evaluation objectives. The guide consisted of some common questions to all professionals along with some specific questions for each professional category. It consisted of five sections: (1) previous experiences with MCDA; (2) process to develop the artifacts (model and the SDSS); (3) use of the SDSS; (4) future of the SDSS; and (5) open questions about MCDA. To avoid leading question biases, no question was directly asked about the advantages usually linked with MCDA (e.g., structuring a problem, developing a common language, learning, etc.). The questions were open-ended (e.g.*, can you share with me your experience with the MCDA project and the different workshops?; what do you like about the SDSS? dislike?*). The interviewer prodded for more details when the interviewees were not explicit enough (e.g., *can you tell me more about this specific aspect? what do you mean?*). Nonetheless, some questions about the OR intervention approach, i.e. expert mode versus facilitation mode

(Franco et Montibeller 2010) were asked more directly. The full translated interview guide is available in Appendix F.

3.6.2 Semi Directed Interviews

The stakeholders were interviewed in January and February, 2019. The main facilitator from the group workshops acted as the interviewer and followed a semi-directed interview structure. All of the interviews were recorded, were in French (the language of use in Quebec City) and lasted approximately one hour. Of the 11 group workshop participants contacted, seven accepted to be interviewed. The four others declined since they felt that they had not been involved enough in the process or were now working in another department and did not have the time. Two of the interviewed participants are now project leaders for the implementation of the Complete Streets strategy in Quebec City. Following the participants' interviews, snowball sampling was used to recruit eight SDSS users. Five accepted to be interviewed and three declined the interview since they felt that they had not yet used the SDSS extensively enough to form an opinion.

3.6.3 Analysis Process

All the interviews were transcribed and analyzed according to a thematic analysis approach that consisted of coding text samples using N-Vivo 12 software (QSR International 2019). A thematic analysis is a systematic process to pinpoint, regroup and analyze themes from a corpus (e.g., transcribed interviews, organizational documents and notes from observations; Paillé and Mucchielli 2016b). In practice, it consists of: (1) becoming familiar with the raw data by listening to the audio records and reading the transcriptions and personal notes about the interviews; (2) generating initial themes (common aspects relevant to the research objectives covered in the different interviews) by coding text samples (associating a theme to a text sample) from the transcriptions and notes; (3) documenting the connections, convergences or divergences between the themes, and progressively grouping the themes into a hierarchy starting from the specific to the more general and abstract; and (4) organizing and structuring the various themes and categories under the form of a tree (i.e., similar themes are gathered in the same tree branch). In an iterative analysis, the codes, the text samples, the themes and the hierarchy are revisited several times, as it was the case in this study. For the post-project evaluation, the corpus consisted mainly of the transcribed interviews. Nonetheless, the notes that were taken during the workshops over the duration of the project were also analyzed to corroborate the results of the interviews with the professionals.

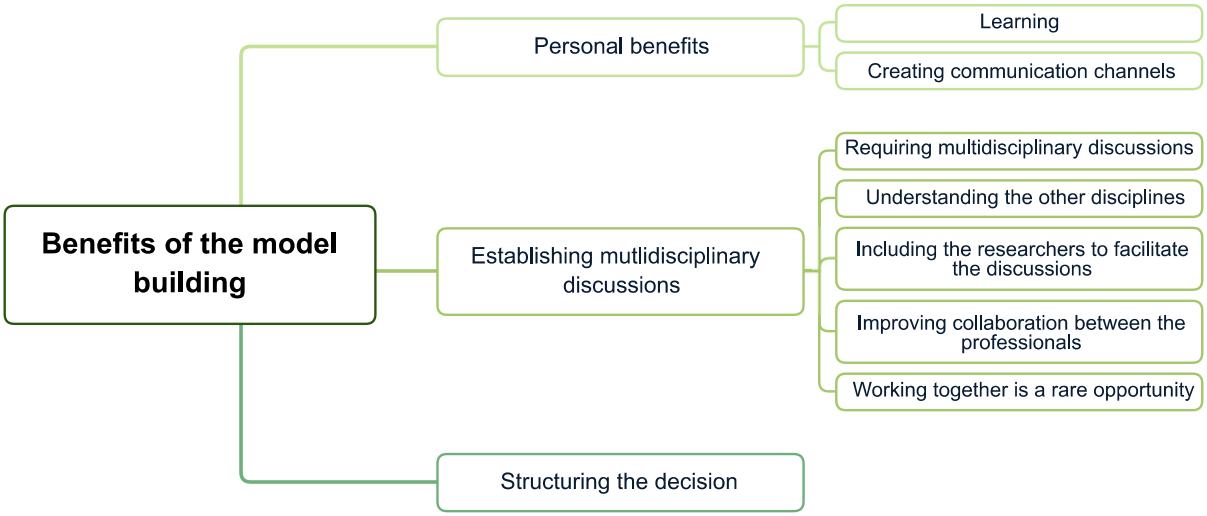
3.7 Results

In order to make the results more legible, the tree summarizing the results of the thematic analysis was split into several trees (Figures 3.2 to 3.6). The analysis was further grouped into five categories: benefits of the model building (section 3.7.1), difficulties and challenges of the model building (section 3.7.2), benefits of the SDSS's adoption and uses (section 3.7.3), difficulties and challenges of the SDSS's adoption and uses (section 3.7.4), and future of the SDSS (section 3.7.5). All the quotations reported in this section were translated from French into English. The names given to the quotes are there to aid the reader and were anonymized using the most common names in the province of Quebec.

3.7.1 Benefits of the model Building

The professionals involved in the workshops identified several benefits to the model building process (Fig. 3.2).

Figure 3.2 Benefits of the model building as reported by the interviewed professionals



3.7.1.1 Personal benefits

On a personal level, the participants expressed that the project enabled them not only to learn about the domains, the language, the backgrounds, the needs and the technical issues of the other participants, but also about MCDA and how they can use it in their practice.

> "I think that it is a learning experience about the other disciplines because often, we do not know what they do. We do not know the impact of an action we might take on the other [colleagues]" (M. Tremblay)

Moreover, some professionals mentioned that it created or strengthened communication channels among them, and subsequently led them to collaborate more often on projects.

3.7.1.2 Establishing multidisciplinary discussions

The participants perceived positively the multidisciplinarity of the workshops. They stated that multidisciplinary discussions were a requirement in order for the project outcomes to be adopted by the professionals in their practices. It enabled them to understand the impacts of their own practices on others and to break professional silos. In fact, the project was the first experience where they were able to meet at several occasions over a long period of time, to develop a new decision process in a multidisciplinary setting. They were used to only occasional collaborations with other departments on specific projects (e.g., the redesign of a given street). Furthermore, according to the participants, the inclusion of facilitators, external to the organization, in this case university researchers, had motivated them to collaborate and improved the project's credibility and their trust in the resulting artifacts. After being asked to summarize one good move of the project, one of the professionals answered:

> "A good move, it is the innovation, the trans-disciplinarity, the working together. It is about changing cultures, it is major! And this, it allows us to gather around a tool. It is everyone's tool." (Ms. Gagnon)

3.7.1.3 Structuring the decision

The participants reported that the modeling phase helped them to construct a holistic view, to find compromises between their professional visions, and to structure the decision by interconnecting the different ideas.

3.7.2 Difficulties and challenges of the model building

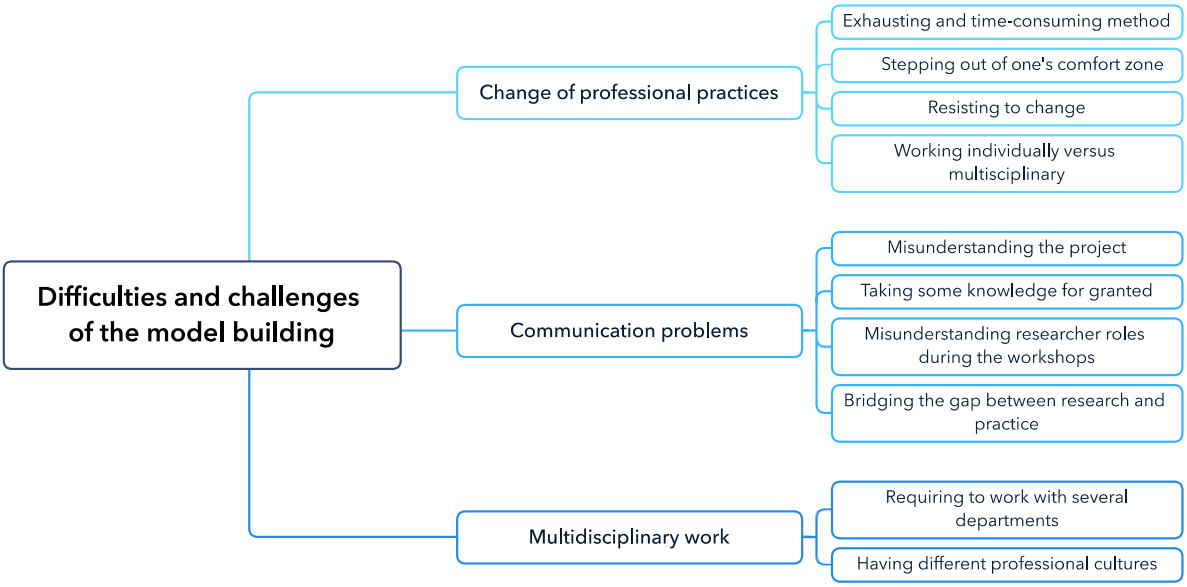
The participants also reported difficulties and challenges encountered during the model building process (Fig. 3.3).

3.7.2.1 Change of professional practices

The process was perceived as long and intellectually exhausting. Each workshop lasted between two and three hours; the participants felt they had to answer a large number of questions. It was particularly demanding since they had to explain, discuss and justify their points of view to other professionals with different discipline backgrounds and objectives. In fact, some professionals stated that they did not wish to confront their ideas, felt that working in a group was ineffective, and expressed that it was easier for them to work individually. Professionals invoked that a better management of change within the organization for the whole process could have eased the modeling phase; the project changed the working methods that Quebec City professionals were used to for several years. When asked to name one bad move associated with the project, one participant answered the following, referring to their own internal organizational process:

"A bad move, we have discussed it, it is in managing the process, not only the tool and the method, but from A to Z. To manage it in terms of change, to be a little bit more visionary, but that is basically all of us who should have been a little bit more...but we learn." (Ms. Roy)

Figure 3.3 Difficulties and challenges of the model building as reported by the interviewed professionals



Furthermore, several participants felt outside of their comfort zone. They were not enthusiastic about having to change their practices. Interestingly, for some, the project was more "rational" than usual since it removed some professional freedoms, while for others it was too "subjective" since there were no true or objective answers during the model development.

"Honestly, we had doubts, was this really going to work? [...] we thought: « It is a more rational approach». It could be seen as a way of taking away…how to say that … the creative side ... and maybe some of the personal or professional judgments»" (M. Côté)

"At first people were like, «Ahhh … this is a soft process. Does it have any real value? We could have changed the people around the table, and we would have had ten other [street evaluation] criteria», that is the kind of statement that came out." (M. Bouchard)

3.7.2.2 Communication problems

The participants also identified communication issues as a challenge. The Complete Streets strategy was in its infancy at the time and the Quebec City's strategic objectives were still fuzzy. The participants had difficulties understanding the project at the beginning; some wondered why they were invited to the workshops and were doubtful about the potential results of the project. A lot of background work was required to structure their knowledge. One participant even stated feeling like a "*tourist"* at the first workshop. In parallel to our MCDA

project to identify *where* to design Complete Streets, some professionals had already been working on a project pertaining to *how* to design Complete Streets. It resulted in a confusion between the goal of prioritizing streets to become Complete Streets and the goal of designing Complete Streets. However, this is not an issue of MCDA, but simply an issue of coinciding projects. Furthermore, due to the project's nature as a partnership between Quebec City and Academia, some participants were doubtful and feared that the project would be too theoretical and not represent reality. Despite our conscious efforts to act in a facilitator mode, some participants still felt that we sometimes acted more as domain experts than as facilitators. They believed there was a gap between our academic perspective, working on a research project, and their organizational perspective, working on an operational project, which took several workshops to fill by creating a common language.

> "I'm going back to the original goal, bridging science and operations for [Quebec] City. At first, I think that it seemed more like the experts will explain how it works, and we are almost lab rats for a university project. And that upset some people at first. Afterwards, it really fell into place, but I think that this aspect may have upset a few people." (M. Bouchard)

Furthermore, the participants indicated that the facilitators might have overestimated the participants' knowledge relevant to the project and the knowledge about the technical domains of their colleagues. As a consequence, some participants restricted their interventions in the group discussion. One participant stated: "I had difficulties giving an opinion since I had the feeling that I was not competent enough compared to the others."

Finally, since the main facilitator was a student, some participants reported that the roles of the facilitators were not always clear; it should have been stated at each workshop that this was also a learning process for the student-facilitator who might sometimes hesitate or make some mistakes, and that the professors-facilitators would help and correct the student-facilitator during the workshops, when deemed necessary.

As a solution to minimize future communication problems, some of the interviewed participants suggested that examples be presented from other similar MCDA projects to explain what the final results could look like in order to reassure them and increase their confidence with respect to their own project. They also suggested that, as facilitators, we should spend more time explaining the project, the method that would be used, and the SDSS's potential impacts on professional activities. Further to that, they suggested that each participant should better define his/her expectations, objectives, and background at the first workshop. In addition to the summary that we presented at the beginning of each workshop, one participant expressed the wish to have, before the workshop, a meeting account of the previous workshop in order to refresh their memory.

3.7.2.3 Multidisciplinary work

Not surprisingly, since the project involved participants from different professional and departmental cultures (engineering, environment, transport, urban planning, public participation, etc.), their objectives and concerns were different and sometimes contradictory. To reach a consensus or a compromise, the professionals reported that they had to defend their positions and actively listen to others to understand their perspectives, which resulted in longer deliberations and negotiations. They confirmed our previous observations that the project's duration was long, and that the group workshops were lengthy and laborious. Nonetheless, the participants still thought that facilitated group workshops were required to get to a consensus. As one of the participants declared: "*just having so many departments sit at the same table and forcing them to make a decision is in itself a success*." The participants, as we had also noted, confirmed schedule and attendance problems were mainly due to the numerous departments involved. Furthermore, not all participants had enjoyed the full support of their respective department heads to take time to attend the workshops, a direct consequence of some department heads not fully understanding the project. As expressed by some participants, a stronger support from the different heads and a clearer explanation of the project to the department heads could have helped. As well, being fully transparent with the participants (e.g., managing expectations) that deliberation could at times be lengthy, but such discussions would lead to better outcomes in terms of trust in the process.

3.7.2.4 Repeated absences

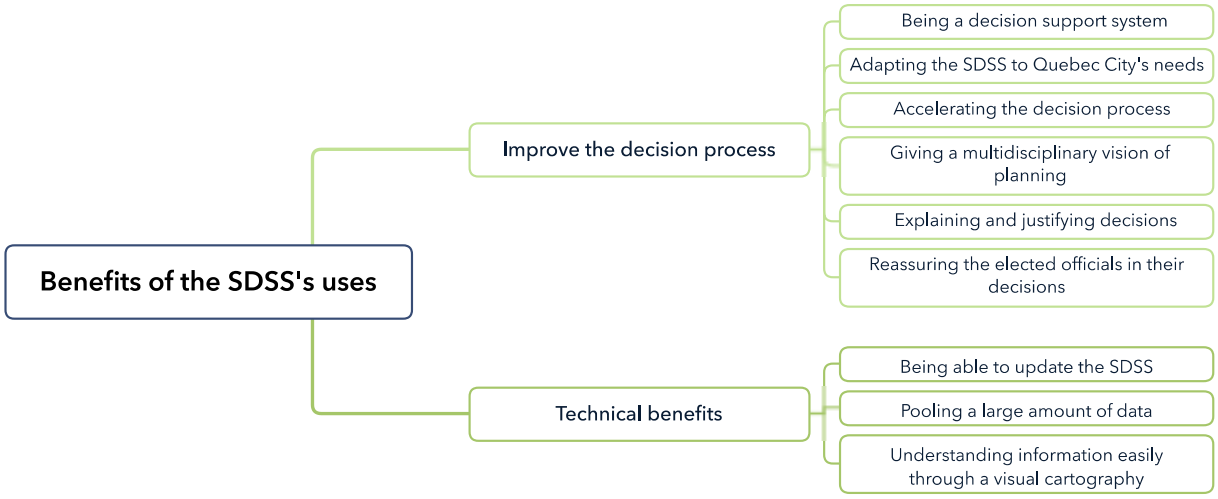
All the interviewed participants reported that they disliked the absences of various professionals from a group workshops to another, and that it affected negatively the project and the group life. They explained these absences by the cumulated effects of the difficulties reported above. Furthermore, five of the seven interviewed participants had noted that one professional completely dropped out of the group workshops but were unable to clearly provide reasons that could explain the dropping out.

Nonetheless, the introduction of subgroup workshops after the first two workshops was qualified as "an *essential step in the project"* by some of the participants. The subgroup workshops aided the participants to untangle and understand the different aspects considered in the project, allowed them to work more efficiently on specific aspects of the model and improved their confidence in the process.

3.7.3 Benefits of the SDSS's adoption and uses

Since the SDSS's implementation in 2018, the professionals have been using it in their day-to-day operations and have identified several benefits linked to its use (Fig. 3.4).

Figure 3.4 Benefits of the SDSS's adoption and uses as reported by the interviewed professionals



3.7.3.1 Improve the decision process

Quebec City professionals appreciated that the SDSS was presented as a decision support system rather than as a decision-making system whereby it suggests different streets with a high potential to become Complete Streets without imposing a decision. They also liked the fact that the SDSS was designed based on their preferences, objectives and needs, and not on the ones found in the literature or in another city. They added that its operational use has accelerated their decision process and the analysis of the different alternatives. One of the Complete Streets project leaders estimated that using this SDSS has resulted in an approximate time saving of six to nine months for each street rehabilitation project. The professionals also indicated that the SDSS created a common vision of planning that took into account the numerous plans developed by the different departments throughout the years. Consequently, the SDSS aided the users in the decision process by creating a coherent, well thought-out and structured discourse to explain and justify why a street has higher priority than another street.

The SDSS users reported this as being valuable not only internally, in discussions among the professionals, but also externally, in public consultations with citizens. For example, following a public consultation where analyses based on the SDSS were presented by Quebec City professionals, city residents expressed a high level of satisfaction since they were able to better understand the decisions made by the city. They felt that the city's process had increased in transparency and legitimacy as a consequence of using the SDSS. The professionals also stated that the use of the SDSS reassured the elected officials since it allowed them to have a holistic vision and to take decisions based on structured process. Such feedback is likely important to relay to individuals new to MCDA (see 5.2.3), as it will reassure them that the outcome of the deliberations will lead to tools appreciated by both decision makers and those who would be impacted by the decision.

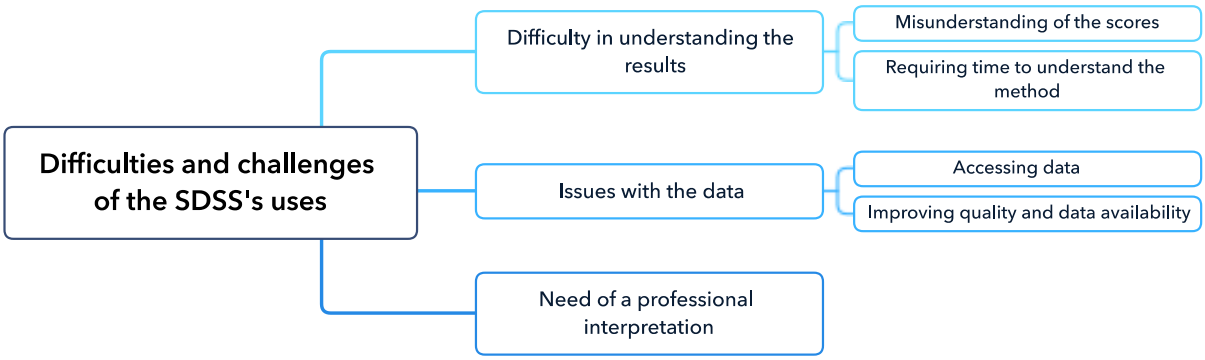
3.7.3.2 Technical benefits

From a technical perspective, the SDSS users reported that, for the first time, they were able to gather a large amount of data from various fields into one database. They were surprised by the amount of information available for each street segment in the SDSS. They indicated that the intuitive visual cartography in the SDSS ranging from cold colors to warmer ones helped to quantify and frame professionals' preferences in a way that is easily understood by citizens and elected officials. They also praised the ability of the SDSS to be updated with new data.

3.7.4 Difficulties and challenges of the SDSS's adoption and uses

On the downside, the professionals reported difficulties and challenges in the adoption and use of the SDSS (Fig. 3.5).

Figure 3.5 Difficulties and challenges of the SDSS's adoption and uses as reported by the interviewed professionals



3.7.4.1 Difficulties in understanding the results

The SDSS users had sometimes difficulties in understanding the meaning of the MACBETH attractiveness scores and how they were obtained. The professionals had the impression that they did not fully comprehend the MCDA theory behind the SDSS. This was initially a barrier to the proper adoption and use of the SDSS. Fortunately, they were able to solve this challenge with our support in 2018. Still, one of the professionals, although from an engineering background, mentioned that the MACBETH method seemed too complex for him to take the time to understand how the model developed work and the limits of its.

3.7.4.2 Issues with the data

Some issues with the data were also brought forward. Some professionals found that the access to some of the original data was difficult since it was distributed across different departments. Other users disliked the use of proxies in the model. These were used when Quebec City lacked data for some criteria (e.g. citizen petitions

and resolutions were used as a proxy for citizens' concerns). Some participants would have liked that the SDSS use objectively measured data that better reflect reality, which was impossible due to data unavailability.

> "Sometimes, we had good ideas, but we had no data. Other times, we had one type of data and we had no choice, but to work with it, even if we knew that it was not ideal." (M. Gauthier)

3.7.4.3 Need for professional interpretation

Finally, the users and Complete Streets strategy's leaders observed that the SDSS needed some form of professional interpretation and that some caution should be taken in its use. For example, a rehabilitation project usually affects several street segments, but the SDSS scores each street segment (i.e., the portion of a street between two adjacent intersections) individually. Therefore, the professionals still need to examine and interpret the SDSS results according to their professional judgment when comparing various possible rehabilitation projects. One of the strategy's leaders mentioned that in one specific case, the interpretative nature of the map was exploited by a professional, external to the project, to deliberately misinterpret the map and push a non-priority project. To avoid such situations in the future, the SDSS could include an improved visualization interface that allows one to compare alternatives based on their performances on all criteria simultaneously (performance profiles), in their original units as well as in the MACBETH attractiveness units. At the current time, performances can be visualized one criterion at a time as a layer in the GIS.

3.7.5 Future of the SDSS

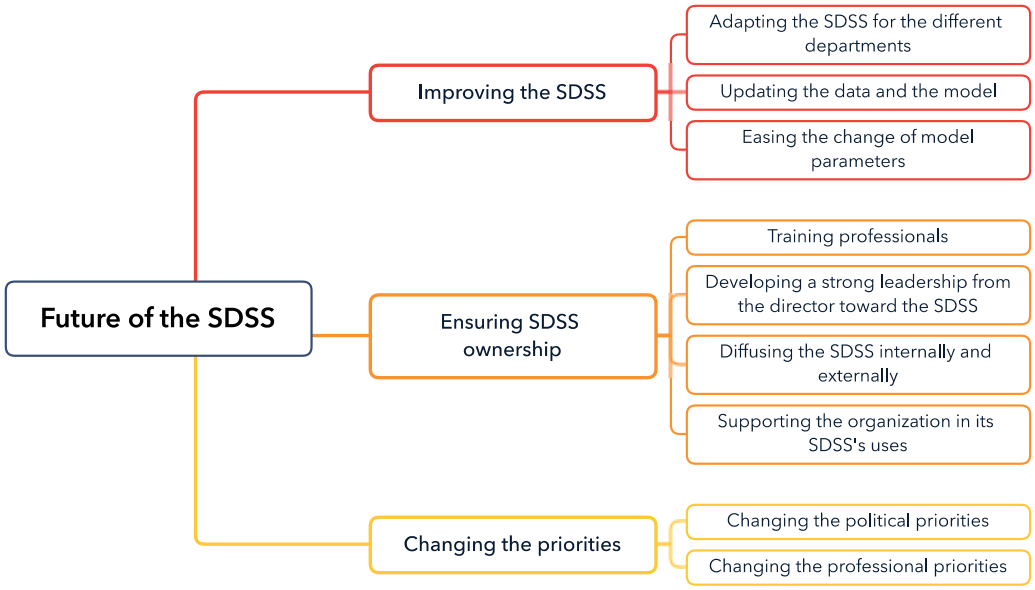
During the interviews, the professionals also invoked different ways to ensure the continued use of the SDSS in the future (Fig. 3.6).

3.7.5.1 Improving the SDSS

The SDSS users reported that the MACBETH attractivity scores on the various criteria within the database were difficult to express in lay language and should be made more explicit. It was also expressed that, to keep the SDSS relevant, the model and the data should be updated regularly. Several professionals mentioned the projected future tramway to illustrate why the SDSS should be updated regularly and why it should be easier to update. In fact, Quebec City is currently developing plans for a structuring public transit network that includes a new tramway which has major impacts on Complete Streets prioritization. The structuring public transit network was first planned as a tramway in 2011, was changed to a bus rapid transit in 2015, was outright canceled in 2017, and was then resurrected as a tramway in 2018 with major changes to the initial route. In 2020, the project is still subject to heated debates and its projected route has recently been slightly altered again. To ease data update, the MACBETH method could be integrated as a plugin in a GIS software. A first set of tools to help the computation of MACBETH score in ArcMAP (ESRI 2014) was developed for the project (Marleau Donais, Abi-Zeid, et Lavoie 2017a). However, the professionals wished for a full and dynamic integration where information

can move seamlessly between the GIS and the MCDA modules in one interface according to the user's needs (Chakhar et Mousseau 2017).

Figure 3.6 Aspects to ensure the future of the SDSS as reported by the interviewed professionals



Furthermore, some users expressed concerns that to change the model parameters (adding criteria, changing planning objectives), new group workshops would be required. This situation is problematic since Quebec City does not have the expertise to facilitate MCDA workshops which makes them dependent on qualified facilitators external to the city's employees.

3.7.5.2 Ensuring SDSS ownership

Ensuring the ownership of the SDSS can help its long-term viability. Since it is a multicriteria SDSS, the professionals expressed that they will require training in geomatics and potentially in MCDA to improve their understanding. The professionals also suggested that a strong leadership from the higher management was required to ensure that the proper resources are allocated to maintain the SDSS up to date.

> "The fact that people take ownership of it, the fact that at a higher level, I would say, the directors believe in it, that they assign the human resources, that they assign the right people to be able to feed it. That for sure will create a winning situation […] where people really take ownership of it." (Ms. Gagnon)

The ownership of the SDSS also requires better information dissemination among the professionals (e.g., workshops to present the SDSS's benefits), but also to the elected officials and citizens (e.g. public participation events). One professional suggested that the internal Complete Streets team should periodically present the SDSS to refresh the other professionals' memory of how it works. Moreover, they expressed a wish that our

research team remain available to support the employees of Quebec City sporadically as needed. The SDSS users also suggested customizing the SDSS for the various departments to ease its integration within the different professional practices.

3.7.5.3 Changing the priorities

Finally, the professionals indicated that the change of priorities in the organization could in the future impact the SDSS's sustainability. The election of new officials, the change of political priorities or the rise of a new planning approach could lead to a shift in priorities and to shelving the SDSS.

3.8 Discussion

As previously indicated, few papers mention an a posteriori evaluation of their MCDA project. This post-project evaluation, as a formal follow up to an MCDA project, has been an enriching experience for our research team to better understand the perspective of participants and users in an MCDA project. Based on the results above, we offer in section 3.8.1 some recommendations and tips for improving practices for other MCDA projects. In section 3.8.2, we explore the limits of this evaluation and propose future research avenues.

3.8.1 Implication of our results for other MCDA projects

Our results indicate that several of the benefits and positive aspects formulated by the professionals regarding the development process, the artifacts' adoption and its use confirm conclusions from other studies on MCDA and group facilitation. Indeed, the use of facilitated MCDA group workshops helped participants to create a feeling of ownership, to learn about other participants' perspectives and to build a shared understanding of the problem (Phillips et Phillips 1993; Banville et al. 1998; Salo et Hämäläinen 2010; Phillips 2011). In addition, the perspectives provided by the interviewees helped us better understanding the reasons behind the challenges encountered as facilitators during the process (e.g., attendance problem, participants' difficulties to express preferences, etc.) (Marleau Donais, Abi-Zeid, et Lavoie 2017b).

Considering the challenges and recommendations expressed by the professionals and our own experience with the project, we identified various good practices (section 3.8.1.1 to 3.8.1.5) that are relevant to other MCDA projects in contexts similar to ours, namely within a western culture and where participants and users are from the same organization but have different backgrounds (e.g., engineering, transportation, environment, urban planning). However, decision situations involving actors from different organizations (e.g., municipalities, provincial governments and the federal government) or involving public-private relationship add political and governance issues that were not present in this case study and that might impact our recommendations.

3.8.1.1 Setting the table for the project at the first workshop

Considering the comments expressed by the professionals during the post-project evaluation, it would be beneficial at the first workshop to ask the participants some specific questions during the introduction. These questions should allow each participant to express his/her expectations and objectives about the project and tell about his/her professional background and experience with MCDA. This suggestion is consistent with the "hopes and fears" script in group model building where participants express their greatest hopes and fears for the project (Andersen et Richardson 1997; Hovmand et al. 2012). As a consequence, this could help the facilitating team to better manage expectations and possible challenges.

Another common practice in group facilitation is to explain the project, the method, and the potential results during the first workshop. Considering the participants' comments, we suggest that it could be useful to also present some similar case studies. this would help the participants understand what they can expect from an MCDA project and inform them of the challenges that the group may face during the project. Once the participants have introduced themselves and the project has been presented, participants should understand why they are involved in the project, what their role will be and what they can expect from the project. These recommendations to set the table might lengthen the start of the project, but will allow to accelerate the process by already answering questions that usually emerge at a later stage.

3.8.1.2 Recalling the project's status and activities

To help the participants recall the project's status and activities, especially when some time passes between workshops, a summary of the project's status at the beginning of each workshop should be presented. It should include the objectives, the global method, the achievements accomplished since the beginning of the project, the tasks to complete during the workshop and the roles of the different facilitators during the workshop. This is in line with Andersen and Richardson (1997) who suggested clarifying the purpose and the group products (i.e., what has been produced during the group workshops) in group model building.

The development of a workshop logbook to continuously share the project's progress between the facilitators and the participants, during the process, is another possible solution (Leleur 2017). This logbook should include a summary of the project and of each meeting, a glossary of the shared language developed and the definition of each criterion. However, our experience in different projects has shown that few participants read the documentation that we send before the workshops.

3.8.1.3 Subgroup workshops

The addition of subgroup workshops midway into the process helped the participants to better understand and improve their confidence in the project and was identified as a successful approach by the professionals. The shorter workshops (30 to 60 minutes) allowed us to move forward quickly for particular subparts of the model,

such as defining the scales for a specific “criterion”, that involved smaller groups with a specific expertise. They allowed the participants to have more time, in a less formal setting, and to think more freely about their preferences, as compared to group workshops. This use of subgroup workshops, also identified as thematic workshops in the literature, is an approach that has been highlighted in group facilitation literature such as decision conferencing (Phillips 2007) and cognitive mapping (Damart 2010). However, from our perspective as facilitators, their use raises questions about the lack of discussion within the group as a whole.

3.8.1.4 Attendance problems

Attendance problems were the only negative aspect consistently mentioned by all the interviewed participants. The interviews revealed that this was a consequence of the cumulated challenges that occurred during the project. Facilitators facing this situation should discuss this issue openly during a workshop to enable the participants to express their frustrations and identify possible solutions to reduce and, if possible, to eliminate the various causes of these absences in future workshops. In our case, a stronger leadership from the different department directors could have helped convince the professionals, who were less open to changing their practices, to stay in the workshops.

3.8.1.5 Difficulties in understanding the results and the MCDA method

The difficulties expressed by the SDSS users, in understanding the final scores computed by the model and the mathematics behind the MCDA method, are a reflection of criticism found in the literature sometimes portraying MCDA methods as black boxes (D’Este 2009; Browne et Ryan 2011; Quinet et Meunier 2012). This issue highlights the difficulties in communicating MCDA methods in a lay language to audiences who are not familiar to MCDA. The solution we adopted in our subsequent projects is to create a standalone presentation that explains in more detail the principles and logic behind the MCDA method without going into the mathematical details. This presentation is shared to the participants who express a will to learn more about the method.

All of the above tips and solutions were implemented by our team in one form or another in subsequent projects (mostly with the public sector, but in different fields such as water management, architecture, impact assessment, asset management and public health).

3.8.2 Limits of the adapted framework for MCDA post-project evaluation and lessons learned

Our adapted MCDA post-project evaluation framework is simple and easy to understand, which we hope will encourage practitioners and academics to adopt it in their future practice. Nonetheless, our research method (section 3.6) has its limits, and it could be interesting to design post-project evaluations differently by allowing a different set of answers to the key questions (see Table 1).

Although we adapted a framework from the public participation literature, it was not within the scope of our project to organize public consultations. Nonetheless, a possible extension of this study would be to include city residents in the evaluation. Their involvement could help assess the perceived legitimacy of the artifact outside of the organization. Nonetheless, it is worth mentioning that Quebec City did organize public consultations where the results of the artifact were presented to residents. In those consultations, residents gave very positive feedback regarding the SDSS and the transparency of the decisions (see 3.7.3.1).

As for the interviews, future studies could have an interviewer who is external to the project rather than one of the project's facilitators, in order to avoid or minimize socially desirable answer biases (e.g., not wanting to hurt/offend the person who conducted the original work). This type of bias might have influenced our results and it would be difficult to evaluate precisely its impact. Still, both positive and negative aspects were easily and freely expressed by the interviewees as it was clearly communicated to them that the objective was to evaluate and improve the process and resulting artifact. The involvement of the professionals who declined our invitation to participate in the evaluation process may have allowed us to document additional benefits or challenges about the model building. However, we believe that they would not have significantly contributed new information to the evaluation since we had reached a saturation point in the last interviews, where no new aspects or issues were added by the professionals.

Furthermore, interview results could also be analyzed using other methods such as causal mapping to clearly identify the causes-consequences relationships and therefore better highlight the elements that caused positive and negative outcomes and perceptions, and consequently identify the good practices.

Otherwise, by conducting post-project evaluations for other MCDA projects, it would be possible to investigate the different ways to design a post-project evaluation by answering differently to the key questions and observe whether the results converge or diverge. For example, a post-project evaluation could be designed using a mixed research approach (in reference *to how to evaluate?*) and based on theory and participants goals (in reference to *on what is based the evaluation?*). Frameworks developed in the OR literature such as the one proposed by Midgley et al. (2013) or Rouwette et al. (2002) could also be adapted to evaluate a posteriori MCDA group facilitated processes.

Finally, future studies could explore how to realize a post-project evaluation that is less time-consuming and that does not require organizing several individual interviews. In our most recent projects, we included formative evaluations at the end of our workshop by asking the participants to answer in writing four open-ended questions. Other possibilities could be a group interview or a survey once the project report has been delivered to the client organization.

3.9 Conclusion

The design of an MCDA post-project evaluation framework and its application to a case study has enabled us to learn about the participants and the users' perceptions during and after the facilitated process, regarding the process itself, and the produced artifacts (MCDA model and SDSS). From our perspective as facilitators, this qualitative evaluation allowed us to acquire a broader picture of the project and to document the advantages, disadvantages and challenges perceived by the participants as well as their suggestions for possible improvements. The interviewees appreciated this follow-up activity because it enabled them to reflect on the project in retrospect, a too often neglected phase, particularly in MCDA projects. They identified issues and proposed several solutions worthy of further exploration. On the basis of these results, we have thought about our practices to highlight some behaviors that could minimize the different issues we encountered during this project.

Following this research, several questions for future research projects can be raised with regards to post project evaluations. An interesting avenue is to explore the links and applicability of Design science research evaluation frameworks to MCDA (Venable, Pries-Heje, et Baskerville 2016). A better understanding of the behaviors of the individuals involved in the modeling process, the outcomes, the artifacts' adoption and their use, as pursued by behavioral operational research, would also shed light on what makes MCDA artifacts successful, or where it fails to flourish, in an organization. The analysis of the micro-process of the group facilitated workshops (Ackermann, Yearworth, et White 2018) seems to be a means to understand more specifically the various interactions between the facilitators and the participants.

In essence, to improve practices and develop MCDA artifacts that will meet practical needs, more case studies should focus on the key factors and interactions between actors, processes and models that influence a project development over time and its use in an organization (Ormerod 2014). This paper allowed us to identify some good practices and propose several recommendations to improve practices based on the successes and challenges encountered in a case study. As a consequence, we have since adapted some of our facilitation practices (e.g., subgroup workshops, project reminder) and are further exploring new avenues to overcome these challenges in future research projects. The value of our post-project evaluation can be summarized in the words of one of the Complete Street strategy leaders in Quebec City:

> "I am glad that we are doing this together because it is an aspect with which we felt helpless at first. We felt that it was a great research project, but that once it was done, it was done. "Yeah…, but wait. For us, it was not finished." There is a life after the research project, and this, I think, is an aspect that you were able to catch up in the last year, but it is something that has to be taken into consideration in all [research] projects. If you are supporting other cities or if a new student

takes over the project, this step should not be forgotten. It is not because a project is done that everything is functional and that an organization will necessarily work with it." (M. Bouchard)

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4 Chapitre 4: Sustainable transportation in municipal decision processes: Findings on policy and current practices for street rejuvenation

4.1 Résumé

Plusieurs villes ont adopté des politiques ou des plans avec des objectifs de transport durable, comprenant le réaménagement et la réfection des rues afin de favoriser le transport actif et collectif. Néanmoins, l'implantation d'un plan de transport durable est souvent parsemée de divers obstacles organisationnels et communicationnels. Afin de mieux comprendre les raisons sous-jacentes à ces obstacles, une recherche qualitative a été effectuée auprès de professionnels provenant de 11 municipalités, ayant une population entre 40 000 et 500 000 personnes, dans la province de Québec, Canada. Les objectifs étaient de brosser un portrait des pratiques actuelles, de décrire les caractéristiques du processus décisionnels idéals des professionnels participants et d'explorer la pertinence de développer des outils d'aide multicritère à la décision cartographique dans une perspective de planification des transports durables. En se basant sur ces résultats, une série de lignes directrices pour améliorer l'intégration du transport durable dans les processus décisionnels liés à la revitalisation des rues est proposée.

Mots-clés : transport durable, aide multicritère à la décision, carte causale, réfection et réaménagement de rues, système spatial d'aide à la décision, collaboration intersectorielle.

4.2 Abstract

Many cities have adopted policies or plans to attain sustainable transportation objectives, including the redesign and rehabilitation of streets that favor active and public transportation. However, the implementation of any sustainable transportation plan is often riddled with various organizational and communicational obstacles. In order to understand the reasons behind these obstacles, a qualitative research study was conducted with professionals employed in eleven cities, ranging in size from 40,000 to 500,000 inhabitants, in the province of Quebec, Canada. The objective was to paint a picture of current decision-making practices, to describe the characteristics of the participants' *ideal* decision-making process and to explore the suitability of spatial multicriteria decision support systems within sustainable transportation planning. Based on the findings, a series of guidelines are proposed to improve the integration of sustainable transportation concepts in street rejuvenation decision-making process.

Keywords: Sustainable transportation, multicriteria decision aid, causal map, street rehabilitation and redesign, spatial decision support system, cross-sector collaboration.

4.3 Introduction

An increasing awareness of the various negative impacts due to automobility, such as pollution, safety issues, urban sprawl, public health degradation, traffic and social inequities (Gärling and Steg, 2007; Tumlin, 2012) has led to a global movement aimed at adopting sustainable transportation practices (Gudmundsson et al., 2016a). As a result, a shift in transportation planning, from a mainly engineering-based approach focused on facilitating motor vehicle movement to a more sustainable transportation approach, has been promoted and observed in the last decades (Banister, 2008; Geels et al., 2012). Local authorities and cities are adopting various plans and policies containing strategies and actions to support sustainable transportation (Bezerra et al., 2020; Isaksson et al., 2017; Reigner and Brenac, 2019). These include restricting car use (e.g., by increasing taxes on fuel, reducing parking supply, implementing congestion pricing), promoting public transportation (e.g., by building attractive public transit services, developing fare integration, providing real-time information), integrating land use and transportation planning (e.g., by developing integrated policies, establishing transit-oriented developments, constructing smart growth neighborhoods), or (re)designing streets to foster active transportation (e.g., designing shared streets, car-free zones, multimodal streets) (Banister, 2005a; Buehler et al., 2017a, 2017b; Hull, 2008; Tremblay-Racicot, 2019).

The last strategy, pertaining to revisiting street design, has been widely discussed and promoted. In fact, throughout the years, several concepts have been proposed to better share and reallocate spaces between different users and modes (Karndacharuk et al., 2014). Since rehabilitating existing streets often entails large construction expenses, cities can seize this opportunity to leverage the costs by designing streets that support sustainable transportation modes rather than rebuilding them in the same way (Hess, 2009). However, the integration of sustainable transportation principles in street rehabilitation and redesign decision process, hereafter called street rejuvenation decision process, is still relatively uncommon in North America. Most decision processes are engineering focused and often ignore active transportation, urban planning, public health, or environmental issues (Federation of Canadian Municipalities, 2018; Hebbert, 2005; Hess, 2009; McCann, 2013).

An implementation gap still exists in transportation planning between intended practices, meant to be coherent with sustainable transportation objectives, and actual practices, which often leads to unsustainable transportation infrastructures and policies (Geels et al., 2012; Gudmundsson et al., 2012; Marsden et al., 2010). Current decision processes in transportation planning, in general, lack a holistic perspective, often fail to integrate different stakeholders' points of view, or have not transitioned from an automobility paradigm to a paradigm of sustainable transportation (Bueno et al., 2015; Macharis et al., 2012; Marsden et al., 2010). A possible solution when it comes to street rejuvenation is to shift the emphasis from mainly physically modifying streets to changing practices and behaviors in municipal and governmental organizations (Gudmundsson et al.,

2016a; McCann, 2013). Therefore, learning about institutional environments and current decision processes around street rejuvenation is a prerequisite to enabling and facilitating a full implementation of sustainable transportation, since it can help identify how barriers and mechanisms unfold and create a path dependency.

To our knowledge, few authors have studied how the implementation gap emerges in street rejuvenation decision processes (Hess, 2009; Hess et al., 2014). This prompted us to conduct a research project in the province of Quebec, Canada, where our aim was three-fold. First, we wished to better understand, from the point of view of professionals working in municipalities, current decision processes related to street rejuvenation in cities: Who is doing what and how? Why is it that way? What are the problems, the barriers and the potential opportunities? Second, we sought to explore, with the same professionals, how the process may be improved and what an ideal decision process would look like from their perspective. Third, given that a solution had overcome some of the barriers to integrating sustainable transportation for street rejuvenation in Quebec City (Marleau Donais et al., 2019), namely the development of a multicriteria spatial decision support system, we wanted to examine how such a solution might be applied in smaller municipalities with different resources such as data and professional expertise. This led us to formulating the following research questions (RQs):

- RQ1: What are the current decision processes for street rejuvenation, and how do professionals at the municipal level include sustainable transportation in these processes?
- RQ2: How can street rejuvenation decision processes be improved?

- RQ2: What are the perceived advantages, issues and challenges related to the development of a multicriteria spatial decision support system?

To answer these RQs, our research strategy was inspired by the deliberative practitioner approach of learning from practitioner through participatory processes (Forester, 2012, 1999). More specifically, we designed and applied a qualitative research method in five phases where a series of group workshops were conducted with municipal professionals from various technical backgrounds and cities involved in street rejuvenation in the province of Quebec, Canada. The results reported in this paper are organized as follows: section 4.4 describes the conceptual framework while section 4.5 outlines the research method including the population and sample frames, the recruitment strategy, the questionnaire design, the data collection through group workshops and the data analysis. Section 4.6 provides a picture of the general decision process currently in place in the cities, the characteristics of an ideal decision process, and the advantages and challenges identified by the professionals. Section 4.7 highlights the main findings of this paper, proposes guidelines that cities could follow to improve their decision process, and presents the limits of the study. Finally, Section 4.8 contains a conclusion and future research avenues.

4.4 Conceptual framework

4.4.1 Implementing sustainable transport: a gap between vision and action

Sustainable transportation can be defined in varying degrees of detail (Gudmundsson et al., 2016). One concise definition describes it as designed to safeguard long-term ecological vitality, satisfy basic human needs and promote intragenerational and intergenerational equity (Holden et al., 2013). As more and more cities and governments began to adopt sustainable transportation policies and to implement strategies, a growing literature developed to document an implementation gap between expected and actual outcomes (Banister, 2008; Berger et al., 2014; Hull, 2008, 2005).

To describe the causes of this gap, different terms and concepts were coined in the literature such as path dependency and barriers (Banister, 2005b; Cantarelli et al., 2010; Curtis and Low, 2012; Driscoll, 2014; Geels et al., 2012). Path dependency could be defined as a specific tendency in a decision process to constantly make the same decisions despite the numerous possible alternatives (Hämäläinen and Lahtinen, 2016; Webster, 2008). From this perspective, the current transportation system is a stable socio-technical regime locked in automobility (i.e. a mobility where people are highly dependent on cars) where various mechanisms contribute to maintain and strengthen the current regime and thereby creating a decision inertia (Geels et al., 2012; Geels and Schot, 2007). As for barriers, they could be defined as different forces that could reduce the impact, limit or even make impossible the implementation of sustainable transportation policies or infrastructures. The main barriers identified in the literature are: resource barriers, institutional and policy barriers, social and cultural barriers, legal barriers, physical barriers and knowledge barriers (Banister, 2005a; Curtis and Low, 2012; Hebbert, 2005; Hess and Lea, 2014; Nieuwenhuijsen et al., 2019; Rietveld and Stough, 2005).

To overcome those barriers, different solutions have been proposed. Among them, city professionals must adopt new ways of planning by integrating a range of stakeholders, creating and using new analytical tools and encouraging grass roots change (Curtis and Low, 2012). In fact, following the principles of collaborative and communicative planning (Healey, 1997; Innes, 1998), transportation planning and decision process should be more open, communicative, transparent and transdisciplinary to democratize decision-making and create an ownership of decision (Curtis and Low, 2012; Hrelja et al., 2013; Vigar, 2017). Moreover, several planners still use a predict-and-provide approach and monetary-focused tools such as cost-benefit analysis which, in general, favor automobility solutions (Banister, 2008; Gudmundsson et al., 2016b; Nieuwenhuijsen et al., 2019). The development of new analytical tools, such as planning support system or decision support system, could help decision makers and planners integrate the new paradigm of sustainable transportation in their practices (Curtis and Scheurer, 2010; Gudmundsson et al., 2012; Nijkamp et al., 2007; Salling and Pryn, 2015; te Brömmelstroet and Bertolini, 2008).

4.4.2 The potential of multicriteria spatial decision support system

One successful North American project that overcame barriers to integrating sustainable transportation in planning is the development of a Complete Street strategy in Quebec City, Canada (Ville de Québec, 2017). This strategy was the result of a collaborative socio-technical process which resulted in a multi-criteria spatial decision support system (MC-SDSS) (Marleau Donais et al., 2019). Since its adoption, seven Complete Street projects have been implemented, five are underway and ten pilot projects are in development.

An MC-SDSS, also referred to as Geographic Information System – Multicriteria Decision Aiding (GIS-MCDA), is a computer-based system that allows the combination of geographic data with decision makers' preferences to solve a spatial problem, resulting in an output that can be visualized as a decision map (Chakhar and Mousseau, 2017; Malczewski and Rinner, 2015). In the case of Quebec City, the MC-SDSS was developed collaboratively, during facilitated group workshops, with eleven Quebec City professionals (with backgrounds in infrastructure, transportation, environment, urban planning, and public participation) to create a common planning vision and assess the 20,000+ street segments in Quebec City (Marleau Donais et al., 2019). To give an idea of the MC-SDSS developed in collaboration with Quebec City, Fig. 4.1 provides an example of a map created for a specific neighborhood to help prioritize streets according to their Complete Street potential. The streets are ranked from the highest priority (rank 1) in red to the lowest (rank 10) in blue. Chapter 2 describes in more details the development process and the MC-SDSS.

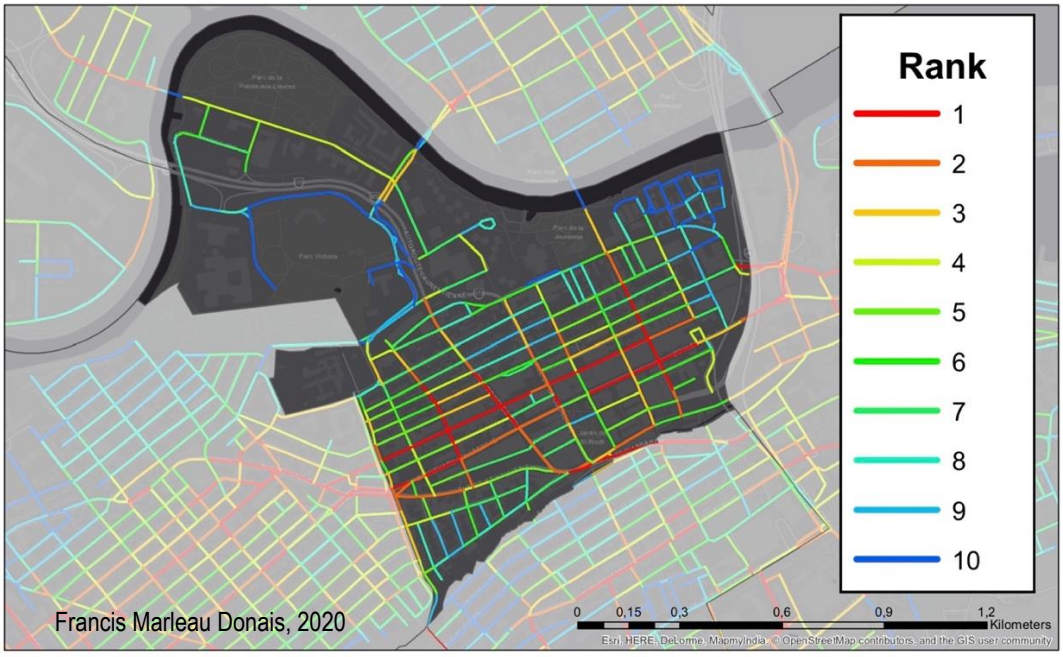

Figure 4.1 Example of a map created by the MC-SDSS developed in Quebec City to prioritize streets according to their Complete Street potential. The streets are ranked from the highest priority (1) to the lowest (10).

By adopting a collaborative approach for developing the MC-SDSS, it was possible to establish a multidisciplinary discussion, to structure a common vision that considered numerous plans (e.g sustainable mobility plan, urban tree plan, and urban planning neighborhood plans), to ease and accelerate the decision process and, in the end, to improve the transparency and legitimacy of decisions (Marleau Donais et al., under review). In fact, the MC-SDSS was a success both from a practitioner's perspective, recognized as one of the 12 best complete streets initiatives in 2017 by the National Complete Street Coalition, and from a research perspective, awarded the practice prize in Operational Research in Canada in 2019 (CORS, 2019) and finalist to the 2019 Decision Analysis Society practice award (Decision Analysis Society, 2020).

4.5 Research Method

Our research paradigm was post-positivist: Our view is that reality exists, but that it can only be approximated; our stance was that of critical realists aiming to capture close approximations of the complex reality. Furthermore, we sought to maintain an objective position in relation to the phenomenon we were studying by ensuring that empirical data, namely participants' responses, and not our impressions, drive our findings (Guba and Lincoln, 1994). We strove to capture participants' perspectives in rigorously disciplined ways by a detailed analytic process of the data acquired and a confirmation of the patterns through validation with the participants. This required immersion and familiarity with the data at the microscopic level. Without pretending to having developed a grounded theory, our results are nonetheless grounded in data and our reasoning is mainly inductive.

Our research method was qualitative and organized in five phases: (1) recruiting cities to participate in the project, (2) designing the questionnaire, (3) collecting data during group workshops, (4) analyzing results using qualitative data analysis techniques, and (5) validating the results with the participants. Each phase involved many steps that are further described below (Fig. 4.2).

4.5.1 Population and sampling frame identification – Recruitment strategy

The population of the province of Quebec consists of over eight million inhabitants. It includes 1476 municipalities and 126 cities (of more than 10,000 inhabitants). Most of its cities are located in the south of the province along the St-Lawrence river, with Montreal and Quebec City being the two most populous. The temperature varies greatly, with seasonal extremes varying from below - 20 ^{o}C during the winter to over 30 ^{o}C during the summer. Therefore, the weather has an important impact on how people travel (Miranda-Moreno and Nosal, 2011), but also on street design due to snow accumulation and plowing considerations.

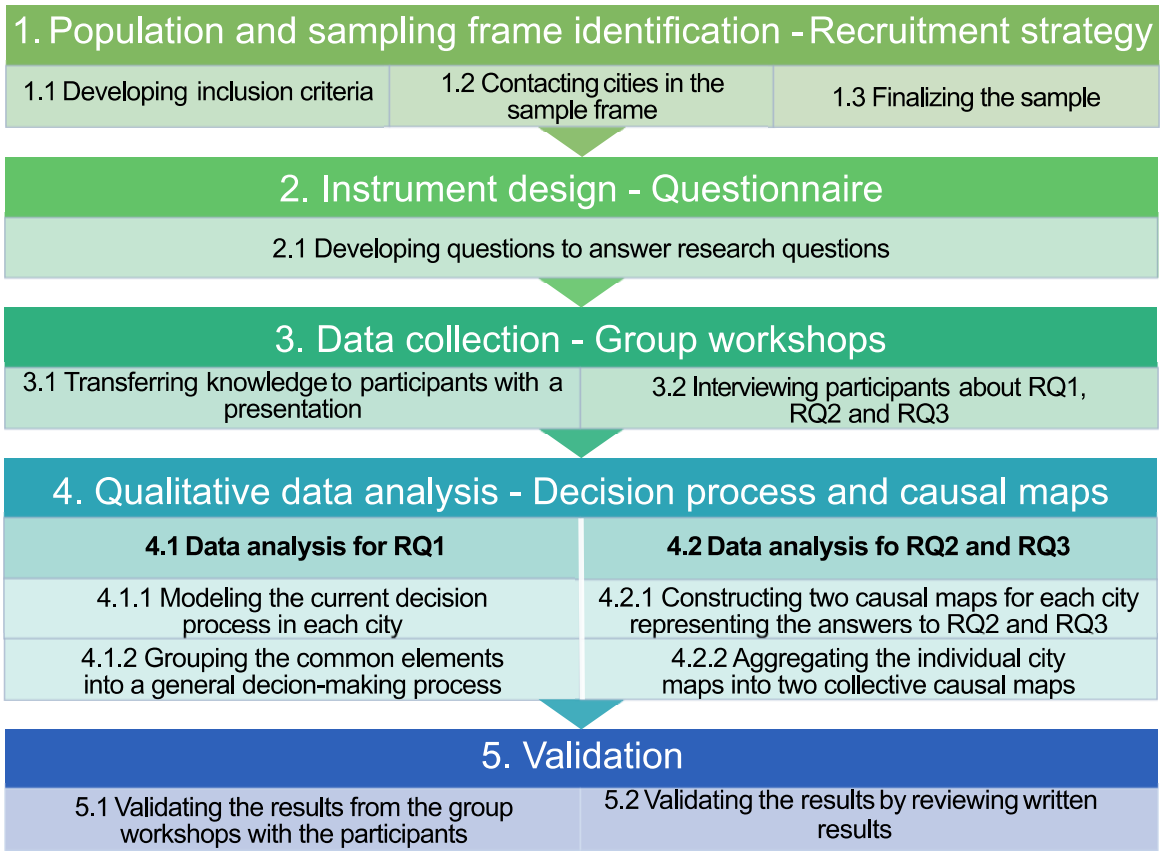

Figure 4.2 Summary of the five phases of the proposed research method.

In order to construct our sample, potential cities were identified using two inclusion criteria: (1) cities with a population of between 40,000 and 500,000 inhabitants (27 cities) and (2) cities that adopted or were working on a sustainable transportation plan or an active transportation plan (10 out of 27 cities). We also contacted cities within the population range where city employees had expressed interest toward the Quebec City MC-SDSS (6 out of 27 cities). A total of 16 cities were contacted (planned sample) and 11 cities accepted to participate in the research project (actual sample). As for the five non-participating cities, they either declined the invitation, did not answer the invitation after two reminders, or we were not able to agree on a suitable date for a meeting.

Tableau 4.1 summarizes the characteristics of the cities included in this study and Fig. 4.3 shows the cities' location in the province of Quebec. Cities in the surrounding areas of metropolitan cities such as Montreal, Quebec City, or Ottawa, are classified as satellite cities in this paper, while others are major regional centers outside the metropolitan areas that developed independently of metropolitan cities.

Tableau 4.1 Characteristics of the cities under study (Statistics Canada, 2017).

City	General characteristics			Main mode of commuting from household to workplace		
	Population	Density (ppl/km^2)	Urban role	Car (drvr. and pass.)	Public transit	Walk
Brossard	85 721	1895.4	Satellite city	67.8%	28.3%	2.4%
Drummondville	75 423	305.2	Regional center	92.6%	1.1%	4.3%
Gatineau	276 245	805.8	Satellite city	76.2%	16.4%	4.3%
Granby	66 222	433.4	Regional center	91.3%	1.0%	5.7%
Laval	422 993	1710.9	Satellite city	78.7%	17.8%	2.3%
Lévis	143 414	319.4	Satellite city	89.0%	5.6%	3.8%
Rimouski	48 664	143.3	Regional center	88.0%	1.0%	8.4%
Saint-Jean-sur-Richelieu	95 114	419.7	Satellite city/ regional center	88.2%	5.7%	4.2%
Sherbrooke	161 323	456.0	Regional center	87.4%	5.4%	5.7%
Trois-Rivières	134 413	464.6	Regional center	91.1%	2.6%	4.6%
Victoriaville	46 130	547.7	Regional center	90.4%	0.4%	6.0%

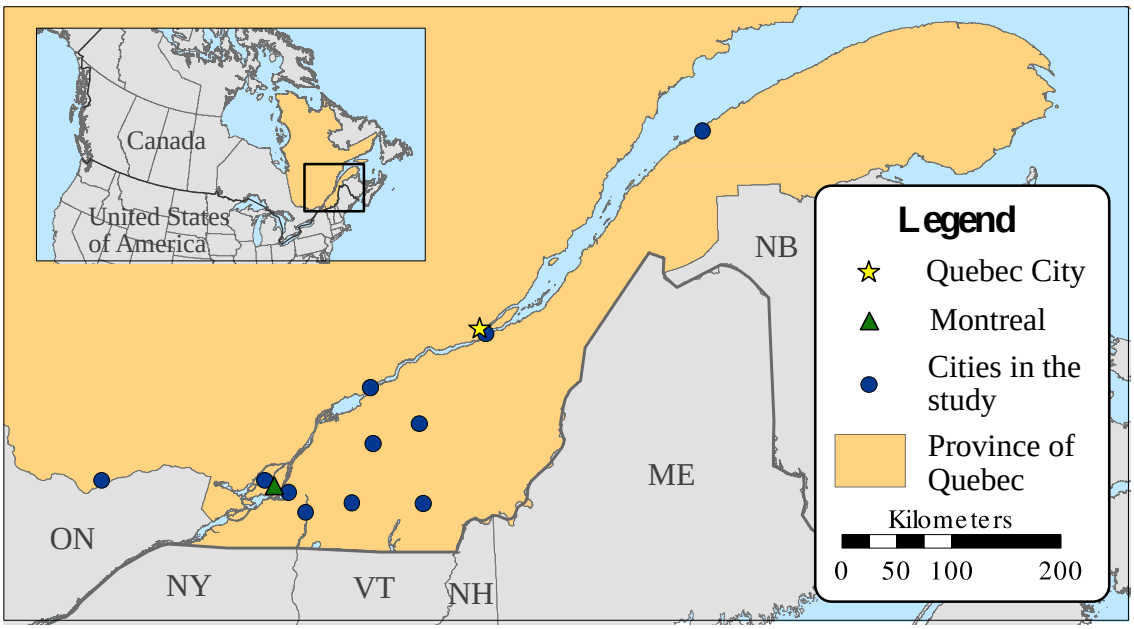

Figure 4.3 Locations of the cities under study in the province of Quebec.

4.5.2 Instrument design - Questionnaire

In order to answer the RQs, a questionnaire was developed consisting of six questions to be used during group workshops in a semi-guided interview format. Questions 1 and 2 are related to RQ1, question 3 pertains to RQ2, while questions 4 to 6 address RQ3.

Q1. Can you, from your personal perspective, explain the current decision process in your city for prioritizing streets to be rehabilitated and redesigned?

Q2. What are the plans that exist in your city in terms of sustainable development and sustainable transportation? How are they integrated in the current rehabilitation and redesign decision process?

Q3. Describe the characteristics of your ideal decision process for planning street rehabilitation and redesign.

Q4. Which aspects of an approach or a tool similar to the MC-SDSS developed in Quebec City do you find interesting? What benefits or advantages do you foresee in adopting such an approach in your city?

Q5. What do you think are the challenges and issues (technical, organizational, external) of developing and implementing a similar approach and tool in your city?

Q6. Which resources are or may be available to implement such an approach in your city?

4.5.3 Data collection - Group workshops

A group workshop was organized in each city. Each workshop lasted between two and three hours and gathered between 4 and 13 professionals (hereafter called participants). All the discussions were audio recorded. The participants had diverse technical backgrounds namely infrastructure, transportation, environment, urban planning, and geomatics. Their distribution per group varied from one city to another (see Tableau 4.2). Participants were classified according to their professional background rather than their department since department structures differ from one city to another (e.g., geomatics professionals can belong to the engineering department, the urban planning department, or the information technology department). To ensure a diversity of points of view and minimize biases (e.g., group thinking, recall bias), we interviewed in every city, with the exception of one, at least one professional from each of the following backgrounds: infrastructure, urban planning, and transportation. In total, we interviewed 88 professionals: 32 from infrastructure (infrastructure engineers or technicians), 19 from urban planning (urban planners, urban designers, architects, or landscape architects), 24 from transportation (transportation engineers, planners, or technicians), 8 from environment (biologists, environmental planners, or landscape architects specialized in environment), and 4 from geomatics. In one city, the elected official responsible for the sustainable transportation plan was present during the workshop. Moreover, the participants had different roles within the city organization (department heads, division chiefs, and professionals).

The workshops were organized in two parts: (1) a knowledge transfer part where we presented the complete street principles, the general principles of MCDA, the project conducted in Quebec City, and the new decision process adopted by Quebec City, lasting approximately one hour; and (2) a discussion part where the participants were asked to provide answers to the six questions defined in the previous sub-section, lasting between one and two hours.

Tableau 4.2 Distribution of the participants according to their field of expertise.

	Infra-structure	Urban planning	Transpor-tation	Environ-ment	Geomatics	Elected official	Total
City 1	4	3	1	1	0	0	9
City 2	2	2	1	1	0	1	7
City 3	8	2	3	0	0	0	13
City 4	2	1	4	0	1	0	8
City 5	5	2	1	0	1	0	9
City 6	1	2	3	0	1	0	7
City 7	2	0	1	1	0	0	4
City 8	2	1	1	1	0	0	5
City 9	3	2	3	1	0	0	9
City 10	1	3	4	1	1	0	10
City 11	2	1	2	2	0	0	7
Total	**32**	**19**	**24**	**8**	**4**	**1**	**88**

To avoid anchoring biases and reduce the influence that department heads and more self-assertive individuals may have on group discussions, the participants were first asked to answer Q1 to Q6 privately on paper (Phillips, 2011; Phillips and Phillips, 1993). They subsequently shared their answers in a group discussion facilitated by the first author. The individual questionnaires were collected at the end of the workshops.

4.5.4 Qualitative data analysis

The questionnaires of the participants and the audio records were all transcribed. We used the N-Vivo 12 software (QSR International, 2019) to manage and analyze the content from the transcribed interviews. The data analysis was conducted in two steps: first, by depicting decision processes and second, by using causal mapping, a method from the field of soft operational research where the aim is to better understand and structure complex situations (Rosenhead and Mingers, 2001).

In order to answer RQ1, we first drew conceptual models, based on empirical data from the participants, to depict the current decision-making process of each city as described by participants in Q1 and Q2. Detailed analysis allowed us to observe a pattern throughout the answers. The elements common to the models were therefore grouped into a single model representing the general decision-making process called the *current street rejuvenation decision process*.

In order to answer RQ2 and RQ3, we analyzed the interviews' transcripts according to the causal mapping technique. Causal mapping (also known as cognitive mapping or oval mapping) is a qualitative analysis method that aims at representing the cause and effect relationships between different concepts to develop planning strategies (Bryson et al., 2004; Eden and Ackerman, 2001). Causal mapping has been used for different

purposes including: to explore risks that European cities may face in the future about critical infrastructure, climate change and social issues (Marana et al., 2019), to document what makes communities of practice specialized in health service work in the United Kingdom (Pyrko et al., 2017), and to identify success factors in construction projects (Williams, 2016).

Causal mapping allows one to articulate different concepts and connect them in order to explore a given strategic issue, such as developing an MC-SDSS or changing a decision process. Each concept is stated in an action-oriented way using a verb and containing around six to eight words. Arrows between concepts represent causal relations and mean "*may lead to*", "*as a result of*", or "*caused by*". The structure underlying a causal map follows the one presented in Fig. 4.4. Concepts at the top of the map refer to goals and missions whereas concepts at the bottom refer to actions that can be implemented to support strategies and achieve goals (Ackermann and Eden, 2001; Bryson et al., 2004; Eden, 1992). Maps can be read either from bottom to top (*why do you want to do this?*) or from top to bottom (*how do you do this?*). A causal map does not necessarily always contain all the five categories of concepts described in Fig. 4.4, as is the case in this paper where maps do not always contain missions or assumptions.

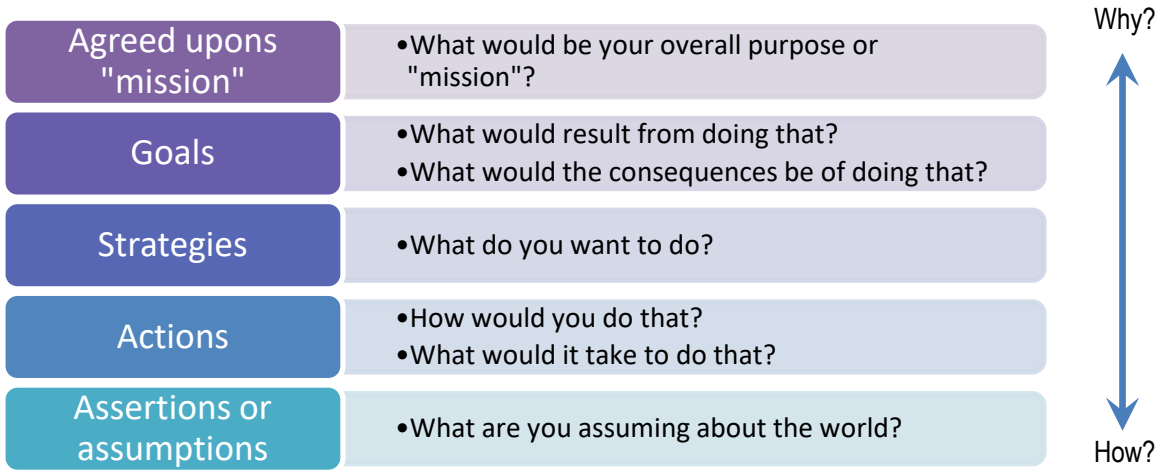

Figure 4.4 The general structure underlying a causal map, adapted from Bryson et al. (2004).

Compared to content analysis or thematic analysis, causal mapping provides the additional capacity of analyzing interdependence between concepts and their causal relations (Pyrko and Dorfler, 2018). Moreover, it is a tool well suited to follow the recommendations of Banister (2005b) who emphasized the need to study the full range of causes and effects that take place during the implementation of sustainable transportation.

As technical support, we used Decision Explorer (Banxia Software, 2019), a software for creating and analyzing causal maps. For each city, two maps were created: one to structure the characteristics of an ideal decision process (Q3); and a second to represent the relations between the advantages, the issues, the challenges, and

the resources available (Q4 to Q6). Subsequently, the individual city maps were aggregated into two collective maps that summarize the main concepts and relations identified by the participants and present common patterns. This was an iterative process: the concepts, the links and the location of the concepts on the maps were revisited several times. Considering the large number of mapped concepts and links, the maps presented in this paper are synthesized to make them legible. The original full maps are available in French in the Appendix G.

4.5.5 Validation

Roughly eight months after the first workshops, we contacted the cities to validate the results and the general conclusions of our analysis, namely the patterns discovered and the causal maps. Out of the 11 cities, four accepted to have a live meeting and four others to review, offline, the written results. Another city accepted to have a live meeting at a later time, but the meeting was canceled due to the COVID-19 outbreak. The validation feedback provided by the participants was used to improve and further nuance our analysis. In addition, this follow-up allowed us, in two cases, to document the strategy that cities had developed for street rejuvenation since our first meeting with them.

4.6 Results

The results of questions 1 and 2 (RQ1) are summarized in section 4.5.1, of the question 3 (RQ3) in section 4.5.2 and of questions 4, 5 and 6 (RQ3) in section 4.5.3.

4.6.1 Current decision-making process (RQ1)

A diagram of the general decision-making process pattern (*current street rejuvenation decision process*) for street rejuvenation as described by the participant (empirical data) is presented in Fig. 4.5. In all of the participating cities, the participants stated that the decision process was mainly driven by the infrastructure engineering department and, consequently, that the engineering planning process (the five steps in the blue rectangles of Fig. 4.5) was at the center of the interactions with the other stakeholder groups. Stakeholders can operate in the technical and professional dimension (professionals in urban planning, environment, transportation, and geomatics), the government dimension (federal and provincial government), and the social and political dimension (e.g., individual citizens, citizen advocacy groups, non-profit and for-profit organizations, and the city elected officials). In Fig. 4.5, blue arrows represent links within a stakeholder group whereas black arrows represent formal links and black dashed arrows represent informal links between stakeholder groups. Since the decision-making process was fundamentally an engineering-centered one, it was observed that some professionals outside the engineering department perceived it as an engineering black box. They were learning about the decision process as the infrastructure professionals were describing it during the workshops.

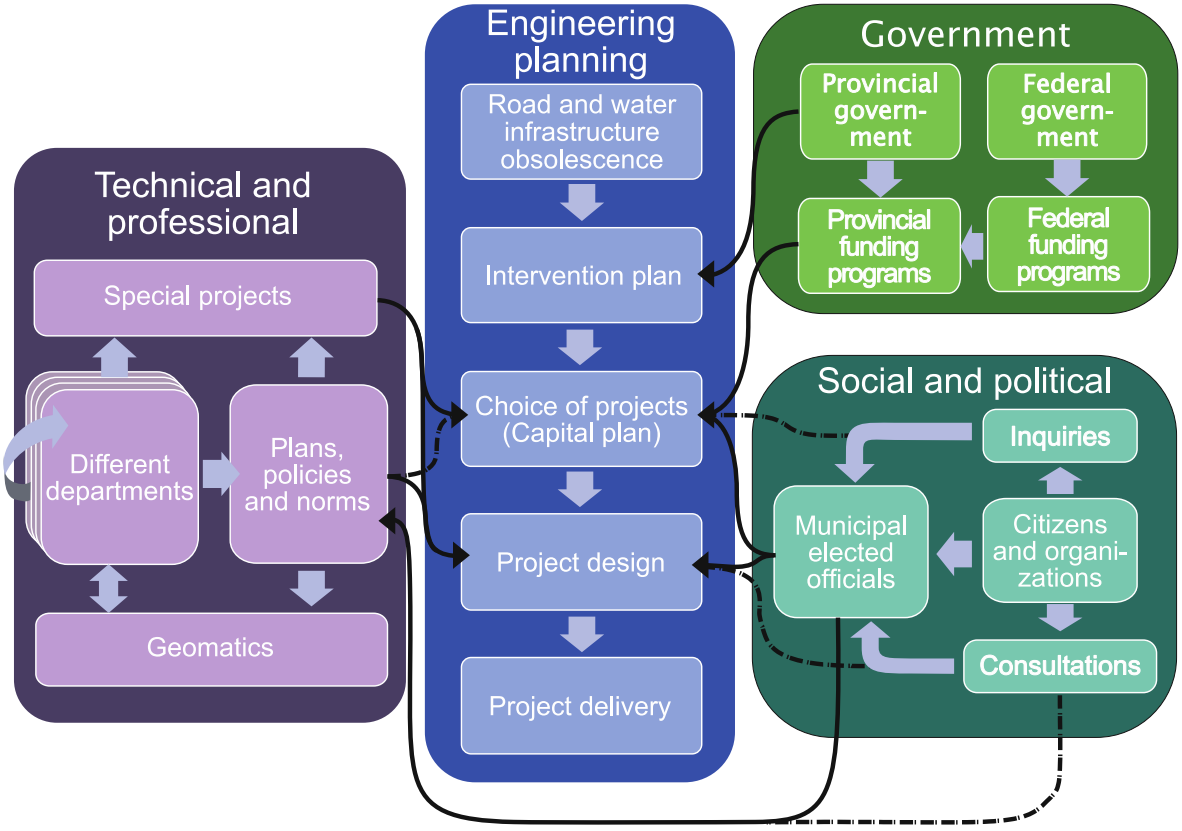

Figure 4.5 Decision-making process – *Current street rejuvenation decision process*

During the validation phase, the participants were mostly in agreement with our proposed *current street rejuvenation decision process* and recommended only minor modifications (adding links, modifying links, and changing labels). They mentioned that more links could be added, but that the most important ones were already present and that adding more links would make the figure unintelligible.

4.6.1.1 Engineering planning dimension

The engineering planning process is at the center of the figure and is structured in five steps. The participants stated that this infrastructure-centered decision structure was set in place following the introduction of the fuel tax program by the provincial government in 2005 and updated in 2014 and in 2019. The provincial government uses this program to provide funding to cities for infrastructure rehabilitation (prioritizing water infrastructure first, and then street pavement). However, to be eligible for this funding, the cities are required to assess the state of their infrastructures and develop an intervention plan that prioritizes the street projects as a function of an obsolescence criterion. Based on the intervention plan, the cities then choose the streets to be rehabilitated by adopting a three-year or five-year capital plan (CP). In some cities, the participants mentioned that despite the fact that it is not best practices, the CPs were highly influenced by social and political pressures and were revised a few times a year; in one city, the CP was even revised every month. Once the street projects are chosen,

engineers, with the aid of professionals from different departments, design the projects according to the different plans, policies, and norms (PPNs). Finally, the street projects are implemented and delivered.

4.6.1.2 Technical and professional dimension

The professionals from the non-engineering departments (urban planning, transportation, environment and geomatics) can influence the current decision-making process in various ways (technical and professional dimension in purple on Fig. 5). The production of plans, policies and norms (PPNs) is one such possibility to exert influence over the street rehabilitation. During the workshops, the participants identified various PPNs linked to sustainable transportation and sustainable development that were or could be integrated in the street rejuvenation decision process. Table 3 lists all the PPNs that were identified by the participants. Initially, we had planned to document which cities had which PPNs and how the PPNs were integrated. However, in several cases, the participants had difficulties in expressing how the PPNs were integrated. In addition, the validation workshops showed that we could not rely on the participants' answers to Q2. In the four live validation meetings, the participants stated, in relation to the global list of Tableau 4.3, that they had forgotten to identify some PPNs. Consequently, we were not able to quantify how many cities have adopted each type of PPNs and to explain the reasons behind the differences between cities.

Tableau 4.3 Global list of plans, policies, and norms (PPNs) identified by the participants that integrate sustainable transportation and sustainable development in their street rejuvenation decision process.

Transportation	**Urban planning and development**	**Environment**
Sustainable transportation plan/policies	Land use and development plan (region level)	Park and green spaces plan/policies
Active transportation plan/policies	Official Community Plan (city level)	Forestry and greening plan/policies
Cycling and/or pedestrian network (often integrated into the active mobility plan)	Programme particulier d'urbanisme ("specific urbanism program", neighborhood level)	Greenhouse gas reduction plan/policies
Universal accessibility plan	Integrated development plan	Heat island mitigation plan
School corridor	Plan for developing or urbanizing sectors	Wetland conservation plan
Public transit plan	Plan or program specific to a city	Ecological corridor plan

In some cases, the activities of the different departments and the adoption of PPNs may lead to special projects such as revitalizing old parts of the city or *Programmes particuliers d'urbanisme* (a specific planning tool in the Province of Quebec that allows cities to develop a neighborhood by creating specific land-use zoning, architectural standards and policies). In these cases, special projects have a direct influence on the choice of

street projects included in the capital plan. In addition, informal discussions between the professionals pertaining to the contents of the PPN, as well as their individual views, can influence this choice. However, the impact of these informal discussions on the decision process is highly dependent on the personal priorities of the professional and his/her network within the city's organization. These informal interventions are therefore infrequent and unconnected since they lack a complete interdepartmental vision of the city.

The participants stated that during the project design step (fourth step in the blue rectangle), they would expect professionals from outside the engineering department to have more weight than in the previous steps. However, in practice, it is usually the infrastructure professionals who first design the street project according to the planned budget. They subsequently consult other professionals, who can only react to the engineering planning process. Consequently, other professionals do not always have the time nor the additional budget to integrate the various PPNs in the street design. During the interviews, participants from every city had at least one example of a street rehabilitation project that generated frustrations or disappointments due to the lack of inclusion of professionals from different backgrounds earlier on in the project.

> "The problem, however, is that yes, we have a budget to analyze the project, but we do not have the budget related to the redesign [of the street], therefore we cannot [implement the redesign once it has been proposed.]"

Moreover, it was mentioned in smaller cities (fewer than 100,000 persons), that they do not always have internal expertise in urban design or landscape architecture, which makes it harder to design streets differently from standard car-focused streets.

The integration of PPNs from the different fields in geomatics databases was identified as a good way to exchange information between departments and professionals. However, at the current time, geomatics data is only partially integrated and shared across departments. The extent of integration varies among cities. Geomatics databases are not always shared between departments and projected plans are often not incorporated in databases (e.g., the existing cycling network is in the database, but not the projected cycling network). In several cases, some participants were surprised to learn, during the workshops, of the existence of a plan or a policy in another department of their own city.

4.6.1.3 Government dimension

As reported previously, the availability of funding programs has a great impact on the choice of the street projects since cities are required to conduct an intervention plan in order to be eligible for provincial funding programs. There are two main sources of public funding. One is the provincial government that directly funds the cities. The other is the federal government that transfers the funds to the provincial government to be managed

according to its own provincial programs. The participants stated that the link between the federal and the provincial subsidies was nebulous. Also, the funding programs do not always cover costs linked to a change in street design. This can create problematic situations such as in one city where a 17 m wide residential street, with a low vehicle volume, a bike lane and near a community center and a park, was in need of repaving and redesign. Since the street was overly wide, all the participants agreed that it should be redesigned differently to improve safety and increase space for active transportation. However, the street was not eligible for any subsidy program and as such, the city did not have the budget to plan and design the street differently despite the identified need for change.

4.6.1.4 Social and political dimension

Citizens, citizen advocacy groups, and organizations can influence the choice and design of streets. They can act in three different ways: (1) by making requests and inquiries regarding a given street, the accumulation of inquiries will usually impact the priority of one street over another; (2) they can speak out during public consultations on a specific street project, usually the design, or a new plan or policy; or (3) they can put pressure directly on elected officials. Regarding the influence of major private actors, one participant specified that: “big corporate citizens can have a lot of influence. In our city, it is [anonymized company]. If [anonymized company] want something, they will get it.”

As for elected officials, their influence on the street rejuvenation decision process greatly varies from one city to another. In some cities, the participants reported that elected officials wish to depoliticize the decision process and make it more transparent by basing it on mostly technical criteria. However, in other cities, the participants reported a strong political interference where it was even difficult to conform to the obsolescence criterion required by the intervention plan. In addition, elected officials influence the contents of PPNs since they are the ones who adopt them. Some officials chair on the committees leading to PPN adoptions developed by the professionals. In our research, the only elected official who participated in the workshops was one chairing on the sustainable mobility plan committee of his/her city.

4.6.2 Characteristics of an ideal decision process (RQ2)

In response to Q3, the participants expressed qualitative features, but also some technical features that would characterize their ideal decision process. The mapping of the ideal decision process resulted in a causal map of 75 concepts with 97 links. Three clusters were identified in the full map and each is centered around a different concept: multidisciplinary integration (section 4.6.2.1), communication (section 4.6.2.2), and planning (section 4.6.2.3). Considering the high number of concepts, the clusters were summarized for legibility reasons in Figs. 4.6-4.8. Some concepts are repeated in Figs. 4.6-4.8 since the clusters within the full map are interconnected.

4.6.2.1 Multidisciplinary integration cluster

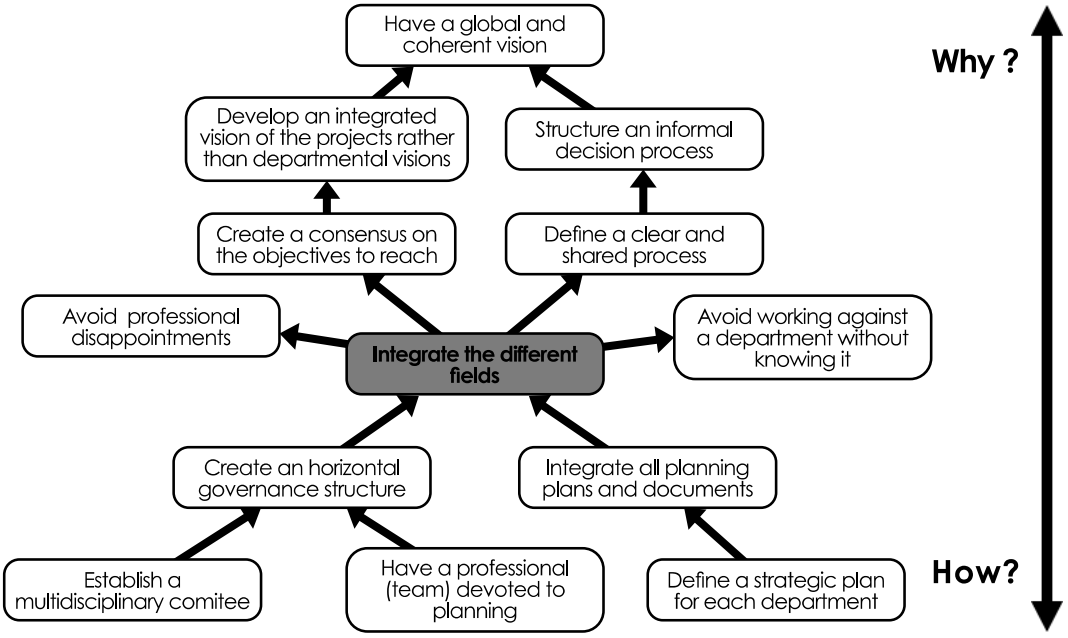

Figure 4.6 The multidisciplinary integration cluster of the causal map of an ideal decision process

The participants expressed the wish to integrate, in their ideal decision process, the different technical fields in order to create a consensus around the objectives and to develop an integrated vision. In parallel, the integration would help define a clear and shared decision process and to structure discussions and practices that are normally informal. Consequently, the participants stated that an integrated vision and a structured decision process would create a global and coherent vision of action plans to implement. Working in an integrated way would also help the professionals avoid situations where departments are working at odds with each other as well as situations where professionals are not able to contribute to street design because they were not informed or were informed too late.

To achieve a multidisciplinary integration, the participants reported two main strategies. First, a horizontal governance structure rather than an engineering-driven structure should be created by establishing a multidisciplinary committee that gathers all the professionals associated with street rejuvenation. This governance structure would be supported by a professional (or a team depending on the size of the city) who would only work on the planning aspects of street rejuvenation and act as a liaison professional between the different fields. Second, all the relevant plans and planning tools that were previously defined by the different departments would be integrated in the decision process.

Interestingly, one participant stated in a validation workshop that the decision process they used to develop their new parking management strategy (a successful project) was similar to Fig. 4.6. Other participants from the same city agreed with the statement, but qualified the process leading to the parking management strategy as

time-consuming and mentioned that measuring the time and monetary gains associated with the project was difficult.

4.6.2.2 Communication cluster

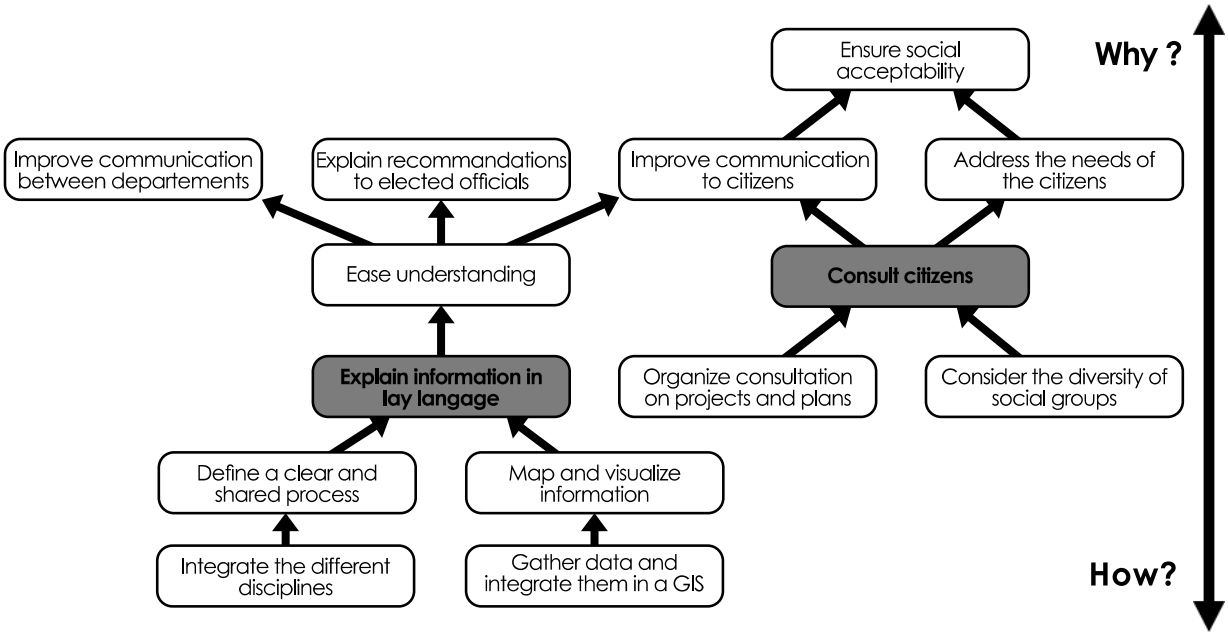

Figure 4.7 The communication cluster of the causal map on the ideal decision process

In their ideal decision process, the participants would improve communication and facilitate understanding by using a simple lay language to explain recommendations and decisions to elected officials, citizens and professionals from different departments. Two courses of action were identified to support explanations in lay language: (1) defining a clear and shared process by integrating the different fields (referring to the integration cluster) and (2) mapping and visualizing information about the streets by gathering data and integrating them in a GIS rather than presenting a large number of information in a database.

In parallel, public consultation would allow for improved communications with citizens whose needs (it was hoped by participants) would be better addressed. As a consequence, citizens could more easily understand the urban changes that would impact their lives, and professionals could propose street designs that are acceptable to a larger number of citizens, thereby ensuring wider social acceptability. Furthermore, consulting citizens requires participation at two levels: at the micro level, for street rejuvenation projects; and at the macro level, for plans and policies linked to street redesign (e.g., sustainable mobility plan or urban forestry). The consultations would also need to consider the diversity of social groups, which requires different forms of consultation (live meetings, online surveys, door-to-door visits).

4.6.2.3 Planning cluster

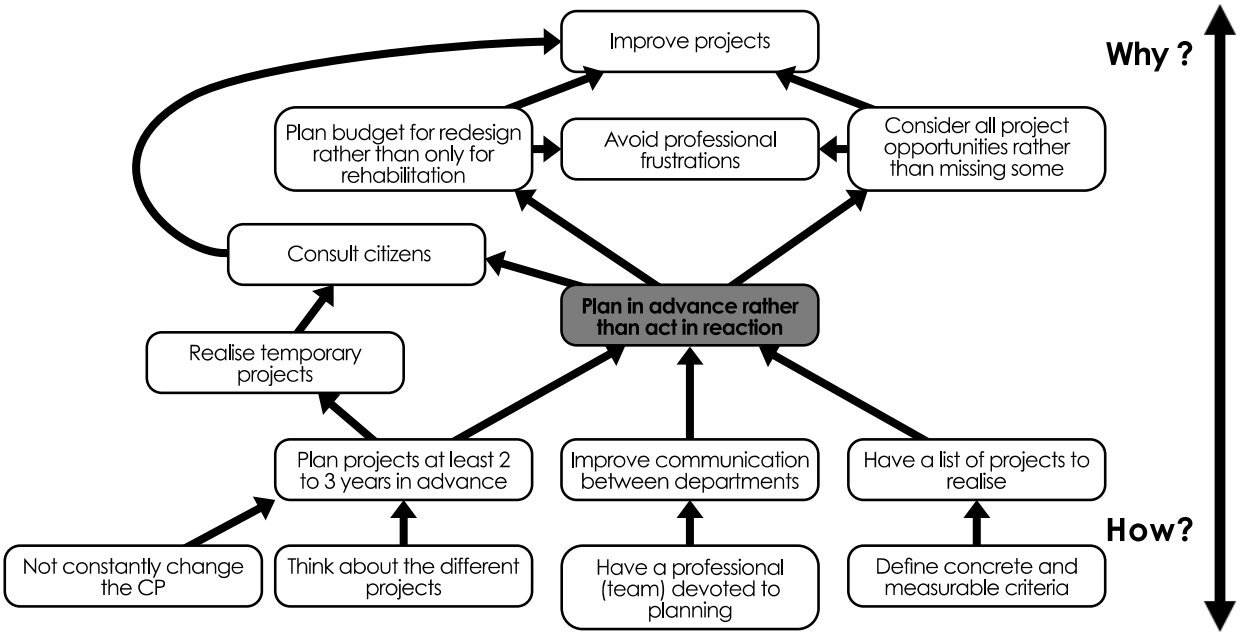

Figure 4.8 The planning cluster of the causal map on the ideal decision process

The participants wished to plan in advance in order to have enough time to consult citizens and to plan a budget for redesigning streets that includes active transportation, environmental and urban planning issues rather than only budgeting the rehabilitation of streets in the same way as before. They also wished to consider all rehabilitation projects as opportunities to design streets differently. In order to plan in advance rather than react, three main strategies were identified by the participants: (1) planning projects at least two to three years in advance (ideally five years) by avoiding constant capital plan revision and better capturing the needs around the different projects; (2) improving communication between departments by having a professional or a team, depending on the size of the city, that is devoted to planning and who could transmit the planning needs between departments; and (3) having a list of projects that considers the needs of all departments, developed based on concrete and measurable criteria that would be used to evaluate all the possible projects. Moreover, planning projects in advance would allow to test and implement temporary street redesign and obtain citizens' feedback.

4.6.3 Advantages, challenges and barriers (RQ3)

Following the discussions regarding their current processes, the participants were asked to reflect on the presentation of the new decision process and MC-SDSS developed in Quebec City. They answered Q4 to Q6 by expressing advantages, challenges, and barriers related to the development of a similar MC-SDSS in their city.

The mapping of the advantages, challenges, and barriers to develop an MC-SDSS for street rejuvenation resulted in a causal map of 87 concepts with 119 links. Four clusters were identified in the full map (resources, data, cartography, and multidisciplinary). A synthesized version of the full map is shown in Fig. 4.9. Most of the challenges and barriers identified by the participants are located at the bottom and the center of the map whereas most of the perceived advantages are located in the higher tier of the map.

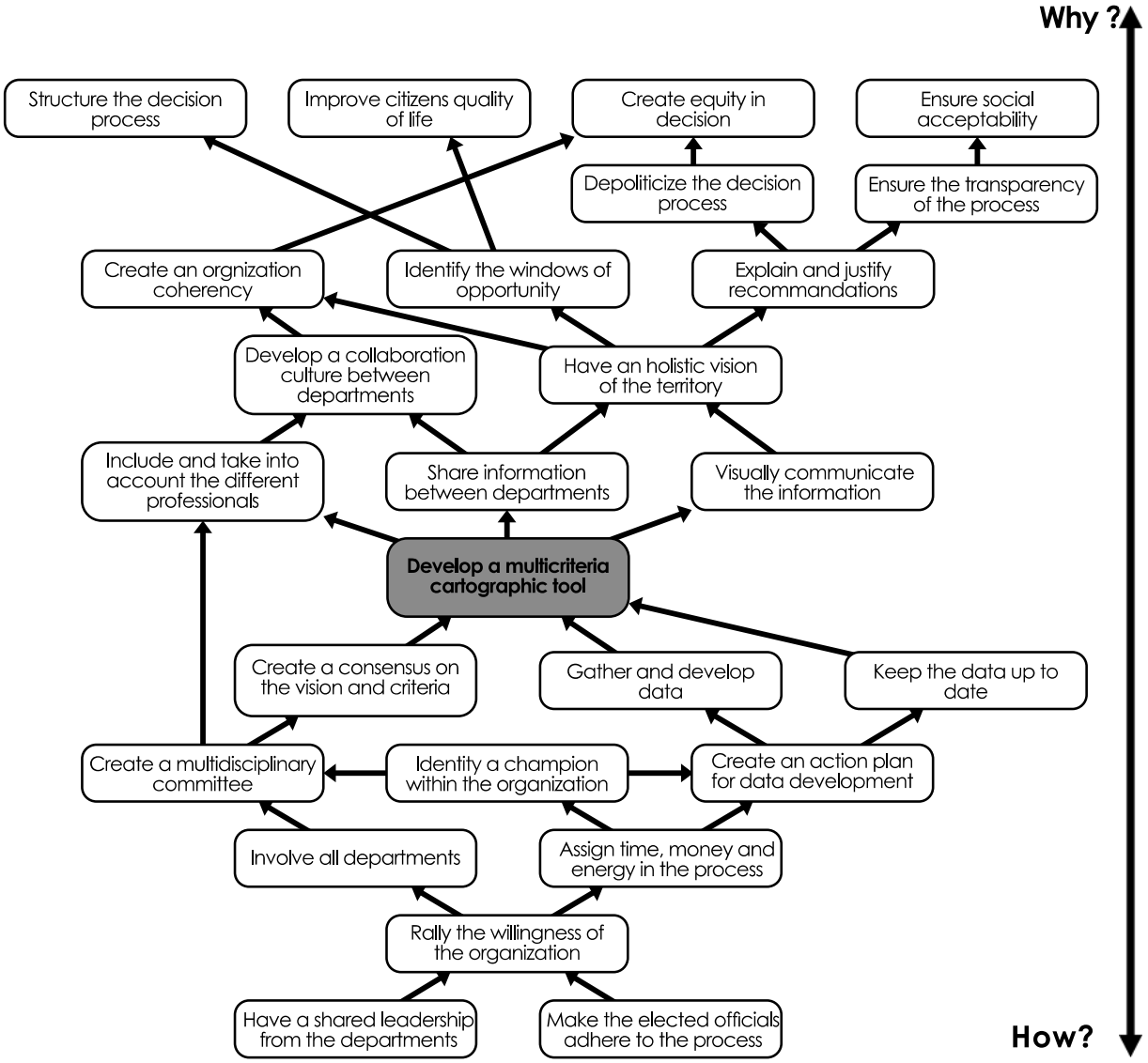

Figure 4.9 Causal map of the advantages, issues, and challenges to develop an MC-SDSS

The most important challenge identified by the participants was that of rallying the support of the elected officials and of the department heads to develop an MC-SDSS. The participants emphasized that both groups must be on board to develop and implement such a tool. The management's support is crucial to ensure that all departments are involved in a multidisciplinary committee, to minimize resistance to change, whereas elected

officials are required to secure the investments in the human and financial resources (hiring or reallocating professionals to work on the project and hiring consultants to help in developing the data). Echoing some answers to Q1, it was mentioned that if the political stakeholders are not interested in higher objectives such as depoliticizing or ensuring the transparency of the decision process, then it would be difficult to develop and implement an MC-SDSS.

To ensure the smooth development of an MC-SDSS, the participants indicated the need for a champion to lead a multidisciplinary committee and to supervise the development of the data in order to ensure coherence. Although gathering all the relevant professionals from different fields and collaboratively building an MC-SDSS was deemed difficult, the participants insisted that creating a multidisciplinary committee was a fundamental requirement.

As seen at the top half of the map, the participants agreed that the development of an MC-SDSS would allow to: take into account the different fields' perspectives rather than only the engineering perspective; improve information sharing by gathering different data in one database; and (considering the spatial and visual nature of the MC-SDSS) ease the communication of information. It would also help to break professional silos and create a collaboration culture within the organization, "an everyday challenge". In addition, the participants perceived that sharing information and communicating information visually would give them a holistic vision of their territory. A holistic vision and a culture of collaboration would further lead to a higher decision coherency between departments in the organization by analyzing various street projects, on an equal footing and, according to the same objectives. The participants expressed that the holistic vision of a territory given by an MC-SDSS would help them identify windows of opportunity for collaboration that otherwise would have been overlooked. It would also contribute to better explaining and justifying recommendations around street prioritization to politicians, citizens and other professionals.

At a higher level, the participants noted that identifying windows of opportunity may help achieve two goals: (1) to better plan street projects and consequently structure a more formal decision process and (2) to improve citizens' quality of life by ensuring that every aspect of sustainable transportation in street projects is taken into account (for example, allowing more space for pedestrians, greening the streetscape or increasing safety). In parallel, the participants added that, by being able to explain and justify recommendations, they may achieve two other goals: (1) to create more equitable decisions by depoliticizing the decision process and acting more coherently with their plans and (2) to ensure social acceptability by being more transparent around the decision process and its results.

4.7 Discussion

4.7.1 Learning from street rejuvenation current decision processes

The representation of the common pattern of the different cities' decision processes in one diagram (Fig. 4.5 – *current street rejuvenation decision process*) allowed us to identify some major issues in the current decision processes of medium to large size cities (40,000 to 500,000 inhabitants) in the province of Quebec. As previously observed in other cities (Flyvbjerg, 1998; Hess, 2009; McCann, 2013), the decision process is infrastructure engineering centered. Furthermore, it is mostly based on an obsolescence criterion, with a few exceptions. Forty years after the Aalborg project in Denmark (Flyvbjerg, 1998), things seem to have changed very little in terms of power relations between different departments in Quebec municipalities. During the interviews, it became clear that it was mostly engineers and department heads who knew the details of the rejuvenation decision process in their cities. Several participants learned about these details during the workshops. In fact, none of the cities had a diagram to visualize their decision process, such as the one proposed in this paper (Fig. 4.5). The processes were tacit knowledge, neither shared nor understood by all. This has resulted in a knowledge barrier that gives more power to the professionals who know about the process, in this case infrastructure professionals, and limits the possibilities for changes in the decision process.

Drawing such a diagram may help a city understand its current decision process by identifying good practices, as well as current issues. This can lead to designing solutions to improve practices that are adapted to their organization. For example, in a recent collaborative project with a city in the province of Quebec, it quickly became clear to us that there was no common vision of the decision process between the stakeholders around the table. We therefore created a diagram to formalize two distinct visions of a decision process and identify the points of disagreement. This enabled the professionals to discuss their divergences and reach a common vision of their decision process, which was a prerequisite in order for us to continue the project.

Furthermore, drawing up a list of the policies, plans, and norms (PPNs) related to the street rejuvenation was a first for the participants. It allowed them to learn about the PPNs of other departments, to document the PPNs that were integrated in the current decision processes and how they were integrated (formally or informally). It also helped them to identify the lack of integration between several PPNs. It confirmed that there is a gap between the sustainable vision expressed in the plans and the actions taken by the professionals. This gap is explained not only by intraorganizational barriers (professional and departmental silos), but also by behaviors where other partners are not brought on board in the project in a timely and formal manner. In one city, the participants suggested organizing a dedicated activity to list and identify how all PPNs related to street rejuvenation should be integrated in the decision process.

Overall, although infrastructure professionals are open to change current practices, different factors, described above, create a power dynamic that strengthens the role of infrastructure professionals to choose and design projects. Consequently, it creates a gap between the sustainable vision expressed by the various departments and how streets are actually rehabilitated, namely the same way as before. The urban planning department head from one city summarized this situation by saying that:

> "For cities in the province of Quebec, the trigger is an [infrastructure] engineering one because it is a call for street rehabilitation and not a call for street transformation."

4.7.2 Assessing the potential to develop MC-SDSS

As for the development and use of MC-SDSSs, participants' perceptions of such an approach were rather positive. Interestingly, the comparison of the concepts at the top of the causal maps (representing goals in this case) for RQ2 and RQ3 reveals several similarities (Figs. 6-9). For example, the development of an MC-SDSS during multidisciplinary facilitated group workshops would help build a consensus around the objectives to reach, create a list of projects to implement and represent information visually by integrating the various PPNs in a map.

On the downside, several challenges to develop MC-SDSSs were identified. These challenges pertain to some of the known barriers to implementing sustainable transportation (Banister, 2005b, 2005a). They include: resource barriers such as assigning funding, time, and energy; institutional and policy barriers at the organization level that create professional silos and a lack of departmental coordination; institutional barriers at the intergovernmental level due to the strong influence of governments on the decision process; and finally, social and cultural barriers due to possible pressure from citizens and elected officials against redesigning streets for sustainable transportation. As highlighted by other studies (Bardal et al., 2020; Hrelja, 2015; Hrelja et al., 2013; Hysing, 2009) and by the participants, political leadership and commitment toward sustainable transportation are key aspects to overcome some of these barriers. Above all, the main challenge expressed by the participants was related to changing behaviors in the organization and resistance to change. As summarized by one of the department head:

> "The true answer is in our behaviors, because if we are already inclusive here, the tool (MC-SDSS) is only an accessory. The first step is to share information, and that is always the challenge."

It is worth nothing that although the main goal of this study was not knowledge transfer, an exchange and education process did take place. In fact, at the end of workshops, several participants reported a higher awareness of issues surrounding street rejuvenation decision processes. They were glad that our research team had contacted them and that the workshops enabled them to discuss the topic. In five of the cities, participants

expressed an interest in developing their own MC-SDSS. In two cases, the group workshops did in fact lead to a follow-up research project with our team: one to identify the streets with the higher potential to be redesigned as shared streets and a second to improve municipal asset management.

4.7.3 Improving decision processes

Our results raise the question of how to develop collaborative behaviors around street rejuvenation between professionals from different departmental cultures. The public management literature on cross-sector collaboration (each field can be seen as a different sector) highlights some solutions that mirror several characteristics of the ideal decision process identified by the participants. More specifically, public management outlines collaboration as something needed in public organizations such as cities, but also as challenging to implement and even more difficult to sustain (Bryson et al., 2015, 2006; Divay et al., 2019). Therefore, based on the empirical data and on the summary frameworks proposed by Bryson et al. (2015) on cross-sector collaboration, we propose flexible guidelines for cities that wish to improve their decision process and develop an MC-SDSS for street rejuvenation, as follows:

1. Identify previous conditions that can prompt changes in the current decision process and the development of an MC-SDSS (e.g., previous street redesign failures or missed windows of opportunity for collaboration).
2. Identify boundary-spanning leaders that can explain the importance and relevance of sustainable transportation and of changing the decision process. For example, department heads could promote the project to their team and elected officials, while other professionals could champion the project to win the support of colleagues.
3. Define a mission statement that offers general directions that professionals could rely on during the development of a new decision process and an MC-SDSS.
4. Create a collaboration structure, such as a horizontal governance structure, which gathers the different professionals concerned by street rejuvenation.
5. Define a common vision of the roles that streets should play in the city (e.g., links and places (Jones, Marshall, et Boujenko 2008), complete streets (McCann 2013)).
6. Review the existing plans, policies and norms and analyze their current level of integration in the decision process and consider how they can be integrated in a new decision process.
7. Develop data into a GIS by integrating information reviewed in PPNs. The creation of an action plan for developing and maintaining data could facilitate this initiative.
8. Develop an MC-SDSS to define criteria, evaluate streets from a multidisciplinary perspective and create a list of streets to prioritize the rejuvenation.

9. Evaluate the decision outcomes of the new decision process and MC-SDSS, and improve the MC-SDSS according to the feedback.

In cities that lack the human or financial resources to develop data and an MC-SDSS, conducting the first six steps is already a move in the right direction, namely that of a better integration of sustainable transportation in street rejuvenation. As put forward by two department heads (urban planning and engineering) in a validation meeting, cities have a lot of power considering the numerous existing laws and planning tools; however, they do not use them to their full potential because they have not developed the habit to do so.

In addition, a change in governmental funding programs is needed to trigger change in municipal decision processes. By only considering street obsolescence as an eligibility criterion, the current funding programs create a path dependence that leads to rehabilitating streets in the same old way, namely as car-centered streets. The provincial government could strongly encourage cities to integrate sustainable transportation by modifying the eligibility requirements to funding programs and consequently breaking path dependence (Bryson et al., 2015). For example, the government could require that cities include other performance measures than infrastructure obsolescence in their intervention plans such as the deficit of walkability, safe cycling infrastructure, or tree canopy. The government could also require multidisciplinary integration in the choice and the design of street projects in order to be eligible for funding. Furthermore, the government could "nudge" cities, strongly emphasizing without imposing, by offering extra funding if sustainable transportation concerns are included in the intervention plans (Thaler and Sunstein, 2008).

4.7.4 Limits

This research is not without limits. For example, more cities in the province of Quebec could have been included in this study. However, since we had reached a saturation point, where no new aspects or issues were brought forward in the last organized workshops, we did not deem it necessary to contact more cities. Although we observed that the participants were open and transparent in sharing information about their good, as well as their not-so-good practices, we were not able to always address all possible biases. For example, some participants talked more than others and may have directed the discussion toward some topics. In some cities, some participants were less comfortable expressing opinions when department heads also participated in the discussions. Some topics identified individually on paper were not or were only briefly discussed with the group. Nonetheless, the use of an individual paper questionnaire still allowed us to include these topics in the analysis. Moreover, in one city, the participants directly discussed the questions without filling out the questionnaire first.

No strong conflict between departments or different professional perspectives were expressed during the workshops. Still, some jokes were made during the workshops about the sometime divergent perspectives. Moreover, after a workshop, one department head mentioned off the record that in practice, some conflicts may

emerge in similar multidisciplinary exercises. This raises the question whether workshops organized by field of expertise could have led us to different results.

As for data analysis, all the causal maps were created after the group workshops using the recorded audio. On a few occasions where the professionals did not provide all the relevant information, individual city maps lacked some concepts or links to fully explain the causal relationships. Therefore, the resulting maps may have been different if the decision processes and the causal maps had been created interactively with the participants. Also, this did not address in depth the power relationship around the implementation of sustainable transportation as other studies have done (Flyvbjerg, 1998; Hrelja et al., 2013; Vigar, 2017).

4.8 Conclusion

The aim of this paper was to present the research results of a qualitative study aimed at better understanding current practices and decision processes around street rejuvenation in a sustainable transportation context. Another aim was to unravel common characteristics of an ideal process for street rejuvenation, followed by an exploration of how a multicriteria spatial decision support system could help integrate sustainable transportation goals in this process. Following Forester (2012, 1999) approach to document current professional practices, group interviews with professionals involved in street rejuvenation from 11 variable sized cities in the province of Quebec, Canada, were organized. Our conclusions are grounded in empirical data and consist of observations and propositions. Based on our findings and on the literature on cross-sector collaboration, we proposed a series of nine guidelines to help overcome some of the identified challenges.

First, we were able to observe a common pattern for the current decision-making processes where a path dependency still exists that results, most of the time, in rehabilitating the streets the same way as they were prior to rehabilitation work. Various mechanisms and barriers contributing to this path dependency were identified such as: governmental funding that only considers street obsolescence, an imbalance of power in favor of the engineering department as well as a lack of communication and knowledge sharing between different departments.

Second, based on the data gathered, we were able to document the characteristics of an ideal decision process, which has many common characteristics with a process previously implemented in Quebec City for complete streets. In addition, by comparing the current processes with the characteristics of an ideal process, we identified the need (1) to involve the different fields at the early stages of the process by creating a horizontal governance structure and by integrating the plans, policies and norms, (2) to enhance communication between departments and better take into account the concerns of citizens and elected officials and (3) to plan project in advance to avoid acting in reaction. We thereby hypothesize that cities can improve their practices aimed at achieving

sustainable transportation by adopting several of the actions and strategies identified in the ideal decision process' causal maps (Figs 4.6-4.8).

Third, we postulate that the development and use of MC-SDSSs can help improve the cities' street rejuvenation decision process by increasing transparency, structuring the decision process, creating an equity in decision and enhancing social acceptability. Our results, in combination with previous work (Marleau Donais et al., 2019), have shown that if favorable initial conditions exist in a city, an MC-SDSS developed through multidisciplinary facilitated group workshops is an effective approach to improve cities' professional practices for sustainable transportation. However, many challenges can arise, some of which are human related, such as securing upper management support or resistance to change, while others are technical and budget related such as the availability and cost of data required for an MC-SDSS. Moreover, according to our experience with other projects, these results are also relevant for other spatial problems that cities may face such as protecting drinking water source or assessing the ecological value of wetlands.

The method and the results of our study are of interest to cities looking at evaluating, understanding and improving their decision processes toward sustainable transportation. The organization of multidisciplinary group workshops was a trigger for city professionals to discuss a specific issue, namely street rejuvenation, and to think about their own practices. The strong interest expressed by the participants in our study highlights that, despite the mobilization in transportation planning around sustainable transportation for over 25 years, cities still require new tools, strategies and decision-making processes to help them break the path dependence toward unsustainable practices and overcome the implementation gap. Our findings can be a starting point to help cities improve their own decision process.

In future research, it would be pertinent to document the points of view of other stakeholders involved in the decision process around street rejuvenation. Those additional stakeholders would include (but are not limited to): elected officials, since they decide which, and how streets will be rehabilitated; citizens, since street redesigns directly impact their living environment; and public servants from the provincial government, since their funding programs strongly influence the shape of a city organization's decision processes. The points of view of professionals from smaller cities (10,000 to 40,000 persons), from Canadian cities in other provinces, or from cities in other countries could also be documented. Other research could explore more specifically the different power dynamics that occur in cities and how they influence the street rejuvenation and the implementation of sustainable transportation. Further, our results could serve as hypotheses to be tested using an hypothetico-deductive approach and quantitative research methods. The results of this paper would be enriched, and their external validity enhanced through a comparison highlighting similarities and differences in

how social, political and governmental environments influence the integration of sustainable transportation in street rejuvenation.

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Conclusion

L'introduction du concept de transport durable dans les années 1990 avait pour objectif de repenser les systèmes de transport et la manière de les planifier afin d'atténuer leurs impacts néfastes sur la société et l'environnement. Les initiatives mises en place visaient à réduire l'utilisation de l'automobile, à augmenter l'utilisation du transport actif et collectif, à améliorer l'accessibilité et à substituer des déplacements par les technologies (p. ex. télétravail, rencontres virtuelles) (Banister 2005b). L'une des initiatives possibles afin d'augmenter l'utilisation du transport actif est de modifier l'aménagement des rues. Dans cet optique, plusieurs municipalités nord-américaines ont adopté une politique ou un guide d'aménagement de rues conviviales, un mouvement pour aménager des « rues pour tous » connu en anglais sous le nom de « complete streets » (McCann 2013; Smart Growth America 2020). Toutefois, près de 25 ans après l'introduction du concept de planification des transports durables, la tendance est que, malgré certains changements, plusieurs barrières limitent toujours la mise en œuvre de ces nouvelles initiatives, y compris l'aménagement de rues conviviales (Hess et al. 2014; Banister 2005a; Curtis et Low 2012). Bien que plusieurs municipalités aient adopté des politiques, un changement des pratiques d'aménagement ne s'est pas nécessairement concrétisé (Gregg et Hess 2019). En parallèle, afin d'inclure les différents points de vue à prendre en compte dans une perspective de transport durable, certains auteurs suggèrent d'utiliser l'aide multicritère à la décision (AMCD) plutôt que les analyses coût-bénéfice (ACB) (Banister 2008; Gudmundsson et al. 2016). L'utilisation de l'AMCD dans une perspective de transport durable est encore récente et, dans les rares cas où elle est réellement appliquée, peu ou aucun suivi n'est fait des cas d'études en AMCD pour connaître les bonnes pratiques et les défis surmontés.

Par conséquent, cette thèse avait pour principal objectif d'explorer comment l'AMCD peut être utilisée dans un contexte réel afin de mieux intégrer les concepts de transport durable dans l'évaluation de projet et de surmonter les barrières liées à leur mise en œuvre. Plus particulièrement, cette thèse a porté sur les processus décisionnels liés à la réfection et au réaménagement de rues au sein des municipalités du Québec. À cette fin, les différentes questions de recherche identifiées sont :

QR 1. Quelles sont les similarités et les différences entre l'aide multicritère à la décision et l'analyse coût-bénéfice dans un contexte de transport durable ? (**Chapitre 1**)

SQR 1.1. Est-ce que les différentes conceptualisations de l'aide à la décision influencent les perceptions à l'égard de l'aide multicritère à la décision et de l'analyse coût-bénéfice ?

QR 2. Comment développer une méthode quantitative qui prend compte des éléments sociotechniques en se basant sur l'AMCD pour prioriser les projets de rues conviviales en termes de transport, d'environnement et d'urbanisme ? (**Chapitre 2**)

QR 3. Comment évaluer a posteriori un projet d'aide multicritère à la décision ? (**Chapitre 3**)

QR 4. Quelles sont les pratiques actuelles dans les municipalités pour aménager des rues dans une perspective de transport durable ? (**Chapitre 4**)

SQR 4.1. Quels sont les avantages et les barrières à développer des outils d'aide à la décision basés sur l'approche multicritère?

Afin de répondre à ces questions, une démarche en quatre étapes a été proposée. Pour chacune de ces étapes, un chapitre de thèse a été écrit.

Résumé de la thèse

Cette section résume la démarche accomplie et les principaux résultats de chacun des chapitres.

Chapitre 1 :

Le premier chapitre étudie l'AMCD et l'ACB dans une perspective de transport durable. À cette fin, une revue de littérature descriptive comparant les forces et les faiblesses de l'AMCD et de l'ACB a été effectuée. Les revues de littérature antérieures comparaient les deux méthodes selon une approche narrative, ce qui limitait la reproduction de la démarche et des résultats. De plus, afin d'expliquer certaines oppositions entre les forces et les faiblesses des deux méthodes, les résultats ont par la suite été analysés selon quatre approches de l'aide à la décision (objectiviste, conformiste, ajustable et réflexive) proposées par Meinard et Tsoukiàs (2018) en se basant sur le concept d'agir communicationnel d'Habermas. De plus, les différentes façons et raisons de combiner les deux méthodes ont été documentées.

Les résultats de la revue de littérature montrent que les deux méthodes permettent d'améliorer un processus décisionnel par rapport à un processus non-aidé, et présentent des avantages et des inconvénients qui diffèrent selon la conception de la rationalité. Plus précisément, plusieurs des avantages de l'ACB et des désavantages de l'AMCD reflètent une approche objectiviste de l'aide à la décision. Par exemple, les ACB sont réalisées en fonction de normes ou de guides qui visent un objectif d'efficience économique. Ainsi, la « meilleure » solution sera celle qui est la plus efficiente économiquement : il s'agit d'une conception objectiviste. En contrepartie, par la nature de l'AMCD, les problèmes ne sont pas clairement définis. Il y a seulement des solutions satisfaisantes et aucune solution optimale, allant ainsi à l'encontre d'une approche monocritère. En fait, plusieurs des avantages de l'AMCD reflètent une approche ajustable ou réflexive de l'aide à la décision. Par exemple, l'inclusion des parties prenantes en AMCD afin de construire un système de valeurs commun et d'éliciter les préférences est un avantage dans une approche ajustable, puisqu'elle permet de considérer les aspects subjectifs, alors que l'ACB se base sur un objectif d'efficience économique qui peut être extérieur aux parties prenantes. Conséquemment, dans une approche ajustable ou réflexive, si les préférences élicitées auprès des parties prenantes contredisent l'objectif d'efficience économique sur lequel se base l'ACB, c'est parce que cet objectif ne reflète pas les valeurs des parties prenantes.

Finalement, dans un contexte de transport durable, l'AMCD ou une combinaison des deux méthodes semblent être des approches plus prometteuses. L'ACB apparaît comme une méthode appropriée lorsque l'objectif est l'efficience économique, mais elle n'a pas la flexibilité pour considérer certains enjeux cruciaux du transport durable tels que l'équité ou l'inclusion de différentes parties prenantes.

Chapitre 2

Le deuxième chapitre relate la construction d'un outil cartographique d'AMCD pour prioriser l'aménagement de rues en rues conviviales à l'intérieur du périmètre urbain de la Ville de Québec. Un modèle multicritère basé sur la méthode MACBETH (Bana e Costa, De Corte, et Vansnick 2012) a été développé en collaboration avec 11 professionnels de la Ville de Québec provenant de différents domaines (transport, infrastructure, urbanisme, design urbain, environnement et participation citoyenne) lors de rencontres et de sous-rencontres de groupe. Ensuite, le modèle a été intégré dans un système d'information géographique (SIG) afin d'évaluer plus de 20 000 segments de rues et de visualiser les résultats. En 2017, une première version de l'outil a été intégrée dans la stratégie de rues conviviales de la Ville de Québec et est aujourd'hui utilisée dans les pratiques professionnelles. Afin de tester l'efficacité de l'outil cartographique, les professionnels ont comparé la liste des projets de rues déjà planifiés pour l'arrondissement La Cité-Limoilou avec les résultats du modèle. 100% des projets planifiés avaient été identifiés par le modèle comme des rues à fort potentiel. Le cas d'étude et l'outil cartographique d'AMCD ont même reçu plusieurs distinctions professionnelles et académiques : une des 12 meilleures initiatives pour des rues conviviales en 2017 par la National Complete Streets Coalition, prix de la pratique en 2019 par la Société Canadienne de Recherche Opérationnelle (SCRO), et finaliste du meilleur cas d'étude en 2019 par la Decision Analysis Society (DAS).

Chapitre 3

Le troisième chapitre propose un cadre pour évaluer a posteriori un projet d'AMCD et l'applique au projet de rues conviviales de Québec. Le cadre proposé adapte l'approche de Chess (2000) et se base sur cinq questions : *pourquoi évaluer ?*, *quoi évaluer ?*, *sur quoi baser l'évaluation ?*, *comment évaluer ?* et *qui est impliqué dans l'évaluation ?*. Pour évaluer le projet réalisé avec la Ville de Québec, une série d'entrevues individuelles avec les professionnels impliqués dans le développement et l'utilisation de l'outil a été réalisée. Les objectifs de l'évaluation étaient (1) de mieux comprendre le processus de modélisation et, plus particulièrement, les forces et les faiblesses perçues des participants aux ateliers de groupe d'AMCD et (2) de documenter le processus d'appropriation et d'adoption de l'outil par les utilisateurs. L'évaluation montre que les professionnels ont apprécié l'instauration de discussions multidisciplinaires, la structuration de la décision, les apprentissages réalisés et l'amélioration du processus décisionnel. Par ailleurs, ils ont exprimé que les principaux défis étaient les problèmes de communication, la nécessité de travailler avec des professionnels de différents domaines et la difficulté à comprendre certains résultats. Finalement, les professionnels de la Ville de Québec ont apprécié

que cette évaluation soit réalisée et ont suggéré que des évaluations post-projet soient également réalisées pour les projets de recherche subséquents. Cette situation montre que l'analyse post-projet est une perspective de recherche pertinente qui mérite d'être utilisée de nouveau dans le futur.

Chapitre 4

Enfin, le quatrième chapitre brosse un portrait des municipalités québécoises quant au processus de réfection et de réaménagement des rues. De plus, il documente la perspective des professionnels (transport, infrastructure, urbanisme, environnement et géomatique) de plusieurs municipalités à l'égard du développement d'un outil cartographique d'AMCD et des caractéristiques du processus décisionnel idéal pour prioriser la réfection et le réaménagement de rues. À cette fin, les professionnels de 11 municipalités ayant entre 40 000 et 500 000 habitants ont été rencontrés lors d'ateliers de groupe. Le processus décisionnel de chacune des municipalités a été schématisé avant d'être mis en commun dans un processus décisionnel général. La méthode de cartographie causale (Bryson et al. 2004) a ensuite été utilisée afin d'illustrer les relations de cause à effet quant aux avantages et aux barrières au développement d'outils cartographiques d'AMCD et aux caractéristiques du processus décisionnel idéal pour la réfection et le réaménagement de rues. Pour valider et bonifier les résultats, les professionnels de quatre municipalités ont été rencontrés une deuxième fois.

L'analyse des résultats montre que plusieurs des avantages mentionnés par les professionnels à propos d'un outil cartographique multicritère sont similaires aux caractéristiques décrites par ceux-ci à propos d'un processus idéal. À l'inverse, plusieurs des défis identifiés sont semblables aux barrières qui avaient été précédemment constatées dans la littérature pour implanter le transport durable (Banister 2005a; 2005b). Parmi ces barrières, le manque de ressources liées au temps et aux ressources humaines disponibles et les barrières institutionnelles à l'échelle de l'organisation, qui créent des silos professionnels, peuvent être nommés. Pour finir, le principal défi exprimé par les professionnels est d'entreprendre le changement des comportements au sein des municipalités.

Contributions à la recherche et retombées pour la société

Les principales contributions de cette thèse sont :

- La réalisation d'une revue de littérature descriptive comparant l'AMCD et l'ACB;
- Le développement et l'application d'une méthode pour construire un outil cartographique d'AMCD pour évaluer le potentiel d'aménagement de rues conviviales;
- Le développement et l'application d'un cadre d'évaluation post-projet pour un projet d'AMCD;

- La réalisation d'un portrait des pratiques des municipalités quant à la planification des travaux de réfection et de réaménagement des rues;
- La proposition de neuf lignes directrices pour les villes afin de développer un outil cartographique d'AMCD pour planifier la réfection et le réaménagement de rues.

Contributions générales

Plus précisément, les résultats de cette thèse illustrent que, dans une perspective de transport durable et même de développement durable, il existe un fort potentiel d'application de l'AMCD combinée aux systèmes d'information géographique (SIG) pour développer des outils pour la gestion municipale afin de mieux arrimer les visions et objectifs des plans avec les projets priorisés. Au fil des années, les villes ont adopté un nombre croissant de politiques et de plans et ont collecté de plus en plus de données pour les aider à prendre de meilleures décisions. Toutefois, ces données ont une valeur seulement si elles sont transformées en informations et en connaissances auprès des professionnels. Les rencontres avec la Ville de Québec ont montré que, malgré l'existence de plusieurs bases de données, celles-ci n'étaient pas toujours exploitées et que les professionnels ne connaissaient pas nécessairement bien les données. Conséquemment, les professionnels avaient besoin d'aide pour structurer leurs préférences à l'égard de celles-ci. Pour plusieurs des critères intégrés dans l'outil d'AMCD de la Ville de Québec, c'était la première fois que les professionnels interprétaient les données. De plus, le projet a permis de mettre en parallèle un grand nombre de données provenant de différents départements. La situation était similaire dans les onze municipalités rencontrées subséquemment. Les professionnels ont mentionné un fort potentiel à utiliser la géomatique, mais les données étaient souvent sous-utilisées ou n'étaient pas nécessairement partagées entre les services. À plusieurs reprises, le directeur de l'urbanisme d'une des municipalités rencontrées a mentionné que la géomatique au sein des municipalités devait prendre un rôle d'aide à la décision qui fait dialoguer les objets entre eux plutôt que d'être une géomatique de représentation des objets. Ainsi, la création d'outils cartographiques d'AMCD vient répondre à ce besoin de mise en valeur des données en mobilisant les connaissances des professionnels pour expliciter l'information pertinente et créer de nouvelles connaissances. De plus, l'AMCD permet de concrétiser les objectifs et les visions exprimés dans les politiques et dans les plans municipaux en une information pouvant être utilisée dans les processus décisionnels. Les projets de recherche qui ont suivi avec la Ville de Québec et avec deux des municipalités rencontrées (Granby et Sherbrooke) illustrent d'autant plus le besoin de mise en valeur des données à l'aide de l'AMCD.

D'autre part, les avantages et les inconvénients de l'AMCD ont été étudiés selon trois perspectives au cours de cette thèse: une perspective basée sur la littérature scientifique (chapitre 1), une perspective basée sur l'expérience des participants au développement d'un outil cartographique d'AMCD et de ses utilisateurs

(chapitre 3) et une perspective basée sur des utilisateurs potentiels d'un outil cartographique d'AMCD (chapitre 4). Le tableau C.1 compare les avantages, les inconvénients et les barrières selon ces trois perspectives.

La comparaison des trois perspectives montre que, dans les trois cas, l'inclusion de différents acteurs et d'enjeux quantitatifs et qualitatifs est perçue comme une force de l'AMCD puisqu'elle permet de tenir compte d'enjeux provenant de plusieurs disciplines, de mieux comprendre le point de vue des autres acteurs participant au développement du modèle d'AMCD et d'exprimer les préférences de façon délibérative et transparente. L'intégration des objectifs adoptés dans les politiques au sein des modèles d'AMCD est aussi une force relevée dans les trois perspectives afin de pouvoir mieux expliquer et justifier les décisions ou les recommandations. La perspective de la littérature scientifique révèle que la variété des méthodes pour tenir compte de différents contextes décisionnels est une force. Toutefois, les participants et les utilisateurs potentiels n'ont pas identifié cette force. Cela peut s'expliquer par le fait que la plupart connaissaient peu les méthodes d'AMCD et par conséquent ignoraient la flexibilité associée à ces méthodes.

En ce qui a trait aux inconvénients et aux barrières, il ressort dans les trois perspectives qu'il est nécessaire d'avoir le temps et les ressources pour développer un modèle d'AMCD, et de travailler avec des professionnels de différentes cultures afin d'établir, ou même parfois de forcer, un consensus. Les aspects plus techniques comme le double comptage et les enjeux liés à la pondération ressortent comme des inconvénients dans la littérature scientifique, alors qu'ils ne semblent pas préoccuper les professionnels des municipalités. À l'inverse, les professionnels ont identifié comme barrières la disponibilité des données et leur mise à jour pour évaluer les options et la gestion du changement liée à de nouvelles méthodes qui sortent de leur zone de confort. Plus précisément, les barrières liées à la disponibilité et à la mise à jour des données peuvent s'expliquer par la grande quantité de données nécessaire pour développer les outils cartographiques basés sur l'AMCD comparativement à d'autres AMCD qui analysent un nombre plus restreint d'options. Ces aspects n'étaient pas ressortis dans la revue de littérature. De plus, l'aspect de boîte noire relevé dans la littérature a aussi été identifié par certains utilisateurs, puisqu'ils trouvaient les résultats difficiles à comprendre, mais cela n'a pas été mentionné par les utilisateurs potentiels.

Tableau C.1 Comparaison des avantages, des inconvénients et des barrières à une démarche d'AMCD selon les différentes perspectives étudiées durant la thèse

Perspective basée sur	Avantages	Inconvénients/barrières
La littérature scientifique	• Inclusion des parties prenantes • Intègre les aspects qualitatifs et subjectifs • Processus avant les résultats • Basée sur les objectifs • Variété de méthodes • Transparence du processus	• Évaluation qualitative et subjective • Enjeux liés à la pondération • Sujet à créer des boîtes noires • Double comptage • Requiert beaucoup de temps et de ressources • Force le consensus
L'expérience de participants et d'utilisateurs	• Établissement d'une discussion multidisciplinaire • Apprentissage et meilleure compréhension des autres disciplines • Améliore la collaboration entre les professionnels • Structure la décision • Permet d'expliquer et de justifier les décisions	• Requiert beaucoup de temps et de ressources • Sort les gens de leur zone de confort • Requiert de travailler avec plusieurs professionnels de différentes cultures • Difficulté à comprendre les résultats
Des utilisateurs potentiels	• Structure le processus décisionnel • Assure la transparence du processus • Développe une culture de collaboration entre départements • Explique et justifie les recommandations • Intègre les objectifs des politiques et plans municipaux • Intègre les différents enjeux professionnels	• Mettre le temps, l'argent et l'énergie • Repose sur la volonté de l'organisation • Gestion du changement • Collecte, développement et mise à jour des données • Trouve un consensus entre les professionnels

La réalisation de cette thèse contribue également à améliorer les pratiques en milieu professionnel. Les nombreuses rencontres avec des professionnels de plusieurs municipalités ont permis de les initier au concept de rues conviviales et à l'analyse multicritère dans un contexte de gestion municipale. De plus, ces rencontres ont permis de créer un forum d'échange entre des professionnels provenant de différents domaines pour parler de la planification des travaux de réfection et de réaménagement des rues, un enjeu dont ils n'auraient autrement pas discuté. Plusieurs professionnels ont grandement apprécié les rencontres et ont mentionné avoir appris durant celles-ci, même si ce n'était pas leur but. De plus, afin d'assurer un transfert des connaissances plus large du milieu académique vers le milieu professionnel, les résultats ont été partagés lors de plusieurs congrès professionnels, soit ceux de l'Association québécoise des Transports (AQTR), du Centre d'expertise et de recherche en infrastructure urbaine (CERIU), de l'Association des ingénieurs municipaux du Québec (AIMQ) et de l'Institute of Transportation Engineering (ITE).

Plus spécifiquement, les différents chapitres de la thèse fournissent chacun des contributions plus particulières.

Contributions du chapitre 1

Par rapport aux précédentes revues de littérature réalisées sur les ACB et AMCD dans le domaine du transport, le chapitre 1 contribue de quatre manières au domaine, soit : (1) la réalisation d'une revue de littérature descriptive plutôt que narrative permettant ainsi d'avoir une méthodologie de recherche reproductible; (2) l'analyse des résultats de la revue de littérature selon quatre conceptions de l'aide à la décision (objectiviste, conformiste, ajustable et réflexive) permettant de mieux expliquer les avantages et les désavantages associés aux deux méthodes; (3) l'identification de différentes manières de combiner les deux méthodes et la documentation des raisons pour lesquelles les auteurs préféraient utiliser un type de combinaison plutôt qu'un autre et (4) l'analyse des deux méthodes dans une perspective de transport durable selon leur capacité à inclure les parties prenantes dans le processus décisionnel et à avoir une vision holistique.

Contributions du chapitre 2

Le chapitre 2 a pour contribution d'avoir appliqué pour la première fois l'AMCD à l'enjeu de rues conviviales, permettant ainsi de considérer à la fois les perspectives environnementales, urbanistiques et de transports dans l'évaluation du potentiel de rues conviviales. Dans les faits, Hui et al. (2018) ont même montré qu'il n'y avait encore aucune méthode quantitative dans la littérature permettant de considérer le potentiel de rues conviviales selon ces trois perspectives. La seule autre approche a été proposée en juillet 2020, soit plus d'un an après la publication du chapitre 2 dans un journal scientifique. Cette approche considère ces trois perspectives à l'aide d'un tableau de bord (Mariano et al. 2020). Le développement de l'outil a également permis de créer une discussion multidisciplinaire entre les professionnels de la Ville de Québec. Pour plusieurs, c'était la première fois qu'ils participaient à une démarche regroupant des professionnels provenant d'autant de disciplines différentes. En ce qui a trait à l'outil, il accélère le processus d'analyse de la Ville de Québec. Les professionnels de la Ville estiment qu'il crée une économie de temps approximative de six à neuf mois entre l'identification des priorités et la réalisation des travaux. D'autre part, afin de faciliter l'intégration du modèle dans un SIG, une série de scripts informatiques permettant d'inclure la méthode MACBETH au logiciel ArcGIS a été développée (Marleau Donais, Abi-Zeid, et Lavoie 2017) et est encore utilisée par l'équipe de recherche à l'Université Laval pour des projets combinant AMCD et SIG. Des traitements de données qui, manuellement, pourraient durer entre une ou deux journées de travail durent maintenant moins d'une heure.

Contributions du chapitre 3

Quant au chapitre 3, il a pour principale contribution d'avoir proposé, à notre connaissance, un des premiers cadres d'évaluation post-projet spécifique aux interventions d'AMCD et de l'avoir ensuite appliqué à un projet concret, soit la priorisation du réaménagement de rues en rues conviviales. Cette contribution est d'autant plus

pertinente puisque deux manifestes avaient été publiés par la communauté de recherche en AMCD appelant à réaliser des évaluations post-projets dans les processus d'AMCD (Bouyssou et al. 1993; Montibeller 2005). Plusieurs des bénéfices et avantages exprimés par les professionnels rencontrés (p. ex., apprentissage, création d'une compréhension commune du problème ou création d'un sentiment d'appartenance envers l'outil) confirment les conclusions d'autres études en aide multicritère à la décision et en facilitation de groupe (Phillips et Phillips 1993; Banville et al. 1998; Salo et Hämäläinen 2010; Phillips 2011). L'analyse a également permis d'identifier les difficultés rencontrées par les utilisateurs de l'outil cartographique d'AMCD et les facteurs qui assureraient la pérennité de l'outil. De plus, ce chapitre aide les facilitateurs et les analystes en AMCD en documentant les bonnes pratiques, les difficultés que pourrait rencontrer un facilitateur dans des rencontres d'AMCD et les solutions possibles pour surmonter ces problèmes. Ces solutions incluent l'utilisation des méthodes de structuration de problème avec les participants (Rosenhead et Mingers 2001), la présentation d'exemples d'autres projets au début du projet, la création d'un journal de bord des rencontres, l'utilisation de rencontres de sous-groupe en parallèle à des rencontres de groupe lorsque possible et l'amélioration de l'intégration de la méthode MACBETH aux logiciels de SIG.

Contributions du chapitre 4

Enfin, le chapitre 4 a pour contribution d'avoir documenté le point de vue de professionnels et de leurs pratiques informelles à propos de la réfection et du réaménagement de rues dans 11 municipalités québécoises, puis de les avoir illustrées sous la forme d'un schéma et de cartes causales. Avant ces ateliers de groupe, aucune des municipalités rencontrées n'avait réalisé d'exercice de schématisation pour comprendre son processus décisionnel et pour pouvoir facilement l'expliquer aux autres professionnels. Cet exercice a permis d'illustrer les différentes relations entre les acteurs impliqués dans le processus, et plus particulièrement de mettre en évidence la forte influence de l'ingénierie des infrastructures et des programmes de financement des gouvernements sur la structure des processus décisionnels actuels des municipalités. À partir des résultats et de la littérature sur la collaboration intersectorielle (Bryson, Crosby, et Stone 2015; 2006), neuf lignes directrices ont été proposées pour permettre le développement d'un outil cartographique multicritère. L'implication de villes extérieures aux régions métropolitaines de Montréal et de Québec est également une contribution d'un point de vue d'urbanisme et d'aménagement du territoire en documentant des réalités moins souvent étudiées. Plusieurs des professionnels rencontrés ont mentionné n'avoir jamais participé à un projet de recherche ou à un projet portant sur les enjeux de gestion municipale auparavant.

Limites et particularités de la méthode proposée

D'autre part, les résultats de cette thèse comportent certaines limites et particularités liées à la méthode de recherche proposée. Tout d'abord, la revue de littérature a utilisé une démarche descriptive afin de composer

un échantillon représentatif de la littérature sur le sujet. De plus, elle s'est limitée aux articles de revues et de conférences recensés dans des bases de données de langue anglaise. Les rapports, les livres et la littérature grise ont été exclus. L'utilisation d'une autre approche de revue de littérature (p.ex., systématique, narrative ou critique) aurait pu donner des résultats différents. De plus, l'utilisation de mots-clés liés à la fois à l'AMCD et à l'ACB a fait ressortir un plus grand nombre d'articles traitant de l'AMCD. Les articles en AMCD se justifient souvent comme une alternative à l'ACB, ce qui est moins fréquent pour les articles en ACB.

Ensuite, l'outil cartographique multicritère développé avec les professionnels de la Ville de Québec a pour particularité de refléter leurs préférences à l'égard de la priorisation d'aménagement de rues conviviales à la suite de plusieurs discussions et débats. L'implication d'autres professionnels de la Ville dans le projet provenant des mêmes domaines ou encore d'autres domaines (p. ex., santé publique) aurait pu mener à un modèle légèrement différent; les critères inclus ou les priorités exprimées auraient été distincts. Par ailleurs, la version finale de l'outil présente une priorisation par quartier, les rues entre différents quartiers ne devraient donc pas être comparées entre elles. Selon les rétroactions obtenues, cette subtilité ne semble pas toujours être comprise par les acteurs externes au projet de rues conviviales. Une meilleure communication des particularités de l'outil à propos des quartiers dans les cartes produites aurait pu limiter ces ambiguïtés auprès de ces acteurs. Une mise en garde aurait également pu accompagner l'utilisation des données.

D'autre part, malgré la mise en œuvre de mesures pour minimiser les biais de groupe lors des rencontres avec les professionnels de la Ville de Québec et des autres municipalités, il n'était pas possible de les éliminer complètement. Dans les faits, certains professionnels ont parlé plus que d'autres, d'autres ne pouvaient pas être présents et la volonté d'arriver à un consensus a pu parfois créer de faux consensus ou une pensée de groupe. Lors de l'analyse post-projet, il aurait pu être intéressant d'analyser les rencontres en détail en fonction des biais possibles en AMCD (p. ex. le faux consensus, la pensée de groupe, la polarisation des idées ou l'excès de confiance) (Montibeller 2018; Montibeller et von Winterfeldt 2018).

L'outil et le modèle ont aussi pour particularité de pouvoir être adaptés au contexte de chaque municipalité selon les priorités respectives des professionnels. Les principes de transport durable ou de rues conviviales donnent une ligne directrice à suivre aux professionnels, mais ne spécifient pas sur la base de quelles caractéristiques une rue ou un aménagement devrait être priorisé plutôt qu'un autre. Par exemple, entre deux rues similaires, faut-il intervenir en priorité sur une rue en milieu défavorisé ou sur une rue ayant un déficit d'accessibilité universelle? C'est aux parties prenantes (élus, professionnels ou citoyens) de chacune des municipalités de définir ces priorités.

Le quatrième chapitre visait à donner une validité externe à l'outil développé avec la Ville de Québec en analysant d'autres contextes de villes québécoises. Néanmoins, les résultats de ce doctorat reflètent la réalité

des municipalités québécoises et il se pourrait que les résultats soient différents dans les autres provinces canadiennes, aux États-Unis ou dans le reste du monde. Les contextes législatifs, les programmes de subvention ou encore les différences culturelles sont tous des facteurs qui pourraient influencer les priorités et les processus décisionnels des municipalités.

Ensuite, les professionnels de quelques municipalités ont exprimé que l'ajout d'un critère lié à un indice de déficit de « convivialité », semblable aux indices de déficit d'état des infrastructures (p.ex., état de la surface, confort au roulement, capacité structurale et susceptibilité au gel pour les chaussées) serait souhaitable dans le futur. Cet indice mesurerait l'écart de convivialité entre la situation actuelle et celle désirée par rapport aux aspects urbanistiques, environnementaux et de transport. L'outil développé dans cette thèse intègre déjà certains critères liés à un déficit comme l'indice canopée ou utilise les réseaux planifiés comme des proxys du déficit, mais il n'intègre pas de critères construits dans une logique d'écart et directement liés aux déficits. De plus, un critère de déficit permettrait de faire un suivi des interventions pour documenter à plus long terme comment une intervention se traduit en des changements physiques et comportementaux. Différentes mesures avant-après sur le terrain, telles que l'augmentation du nombre de piétons et de cyclistes, l'augmentation de la végétation et la diminution du nombre de voitures, pourraient être prises pour savoir si l'intervention réduit le déficit.

D'autre part, cette thèse se concentre sur la priorisation du réaménagement de rues comme action pour mettre en œuvre le transport durable. L'aide à la décision multicritère pourrait aider à concrétiser d'autres types d'actions liées au transport durable telles que l'instauration de péages routiers, la réduction de l'offre de stationnement, la modernisation d'arrêts d'autobus ou la création de « transit-oriented developments ». Plusieurs revues de littérature documentent différentes applications possibles (Macharis et Bernardini 2015; Mardani et al. 2015; Basbas et Makridakis 2007; Camargo Pérez, Carrillo, et Montoya-Torres 2015).

Perspectives de recherche

Le caractère exploratoire de cette thèse a permis d'étudier une diversité de sujets de recherche. Toutefois, certains sujets ou méthodes ont été abordés superficiellement et mériteraient d'être étudiés plus en détail dans le futur.

Combinaison entre l'aide multicritère à la décision et l'analyse coût-bénéfice

La revue de littérature a montré que différentes méthodes pour combiner l'AMCD et l'ACB existaient. Toutefois, ces méthodes étant très récentes, il y a encore peu de littérature sur leurs avantages et inconvénients et sur les bonnes pratiques à adopter pour leur application. Il apparaît nécessaire dans le futur de mieux documenter la mise en œuvre de ces méthodes dans la pratique et l'interprétation que les décideurs font des résultats issus de cette combinaison. De plus, la revue de littérature a uniquement analysé les combinaisons dans le domaine

des transports. Il serait intéressant d'étudier les autres approches de combinaisons existantes dans d'autres domaines d'application tels que l'énergie, la foresterie ou l'agriculture.

Un agenda pour l'évaluation post-projet en AMCD

L'exploration de l'évaluation post-projet lors du 3e chapitre de la thèse montre un potentiel de recherche qui a encore été très peu exploité. Malgré un manifeste et un appel à mieux rapporter les interventions d'AMCD (Bouyssou et al. 1993; Montibeller 2005), les articles se concentrent rarement sur les interactions entre les facilitateurs et les participants, et très peu d'articles font un suivi des processus d'AMCD. Le développement d'un cadre pour développer différentes méthodes d'évaluation post-projet à l'aide de cinq questions est un premier pas. Toutefois, ce cadre a été adapté à partir de la littérature en participation citoyenne. Afin de développer un cadre propre à l'AMCD, il semble nécessaire de mieux documenter les pratiques actuelles d'évaluation post-projet en AMCD. Cette documentation pourrait se faire à l'aide de deux approches : (1) une revue de littérature systématique des cas d'étude effectuant une évaluation post-projet d'AMCD et (2) un sondage et des entrevues auprès de facilitateurs en AMCD issus de la recherche et de la pratique. Dans les faits, le chapitre 3 recense une dizaine d'articles qui effectuent une évaluation post-projet, mais il existe probablement plusieurs autres articles qui n'ont pas été identifiés dans le chapitre. Cette documentation permettrait également de mieux diagnostiquer ce qui fonctionne et ne fonctionne pas dans la facilitation d'ateliers d'AMCD, les bénéfices de la démarche et les barrières et défis qui peuvent être rencontrés par un facilitateur d'AMCD. De plus, l'existence d'un cadre d'évaluation post-projet à suivre en AMCD selon différentes approches possibles inciterait peut-être les auteurs à partager davantage les interactions entre facilitateurs et participants dans les articles plutôt que de seulement présenter les critères et les résultats du modèle d'AMCD.

Exploration de la recherche opérationnelle comportementale

Un autre sujet qui pourrait être développé est la recherche opérationnelle comportementale (ROC). La ROC vise à comprendre les interactions entre les modèles de recherche opérationnelle (RO), les acteurs impliqués dans la RO et la pratique de la RO. Dans un contexte d'AMCD, les aspects de ROC qu'il serait intéressant d'étudier plus en détail sont par exemple les microprocessus décisionnels (c.-à-d., de comprendre les pratiques et les routines des différents acteurs lors des processus de décision en groupe), les biais individuels et de groupes qui peuvent exister dans la structuration de problème et la construction des préférences pour développer un modèle d'AMCD, les solutions pour minimiser ces biais, ou encore l'influence de différentes méthodes ou de différentes façons d'animer des rencontres de groupe sur les résultats. Une évaluation post-projet pourrait également être une méthode pour effectuer de la ROC.

Apprentissage de l'aide multicritère à la décision et de la facilitation de rencontres

Un sujet abordé brièvement en parallèle de cette thèse, mais qui n'a pas été intégré et qui mérite d'être mieux étudié est l'apprentissage de l'AMCD et de la facilitation d'ateliers d'AMCD (Marleau Donais et Abi-Zeid 2018). À notre connaissance, il existe très peu de littérature sur la facilitation et l'enseignement de la facilitation de rencontres de groupe d'AMCD. La facilitation de rencontres d'AMCD est souvent perçue comme un « art » plutôt qu'une « science ». Dans ce contexte, la littérature sur l'enseignement des méthodes de structuration de problème est pertinente puisqu'elle présente certaines similarités (Ackermann 2011; Ackermann et al. 2020; Yearworth et al. 2013). Toutefois, il semble nécessaire d'enrichir la littérature scientifique d'un point de vue d'AMCD. Une première approche serait celle que nous avons adoptée en 2018, soit de documenter la perspective des étudiants par rapport à leur processus d'apprentissage et aux difficultés qu'ils ont rencontrées à animer des ateliers de groupe. Une deuxième approche serait de partager son expérience, en tant que professeur, lors de l'enseignement de l'AMCD et de partager ce qui fonctionne et ne fonctionne pas auprès des étudiants. Une troisième approche serait de comparer différentes manières d'enseigner l'AMCD, que ce soit en effectuant une revue des plans de cours en AMCD ou en sondant des professeurs de différentes universités. La publication d'articles adoptant l'évaluation post-projet ou la recherche opérationnelle comportementale appliquée à l'AMCD pourrait également être une approche intéressante pour permettre aux étudiants de mieux comprendre le déroulement des rencontres de groupe, les biais qui peuvent être présents et les différents comportements que peuvent adopter les participants durant les rencontres.

Guide d'aménagement de rues

Un autre sujet qui n'a pas été abordé dans cette thèse, mais qui a été mentionné à quelques reprises lors des rencontres avec les professionnels des municipalités, est le développement de guides d'aménagement de rues. Similairement aux guides et aux arbres décisionnels utilisés par certaines villes pour aménager des rues conviviales (Gregg et Hess 2019), plusieurs professionnels désiraient avoir un guide d'aménagement de rues. Ce guide devrait permettre de proposer différents types d'aménagement selon différents contextes urbains afin de mieux tenir compte des aspects de transport durable et d'environnement. Certains professionnels allaient même plus loin et auraient aimé avoir des outils permettant de proposer et de visualiser les nouveaux aménagements en trois dimensions afin de pouvoir les présenter aux citoyens et aux élus. Dans cette optique, il serait intéressant de documenter à partir de la littérature scientifique et grise ce que contient et devrait contenir ce type de guide, de collaborer avec une ou plusieurs municipalités pour développer ces guides et par la suite de documenter comment ceux-ci sont utilisés par les professionnels et sont reçus par les élus et les citoyens. D'autre part, certains professionnels ont exprimé le manque de ressources (guides, bonnes pratiques, lignes directrices) pour encadrer les nouveaux développements et l'urbanisation de secteurs plus ruraux. Ils auraient

aimé connaître les pratiques des autres municipalités et avoir un outil qui permettrait de prioriser les nouveaux développements.

Méthodes de structuration de problème

La technique de cartographie causale et la schématisation des processus décisionnels utilisés pour analyser les données dans le chapitre quatre sont toutes deux issues du champ des méthodes de structuration de problème (PSM). Elles proviennent respectivement des méthodes de PSM : Strategic Options Development and Analysis (SODA) et Soft System Methodology (SSM). Il pourrait s'avérer pertinent d'étudier l'utilisation des PSM lors de rencontres de groupe pour aider à analyser différents enjeux liés au transport durable. Dans le cadre de cette thèse, les cartes causales ont été réalisées après les entrevues. Toutefois, celles-ci auraient pu être réalisées lors des ateliers de groupe de façon participative afin de comprendre le processus actuel et d'ensuite construire un nouveau processus décisionnel imaginé par les professionnels.

Aide multicritère à la décision en contexte municipal

Les rencontres avec les professionnels des municipalités ont montré qu'il y a un fort intérêt pour l'AMCD à l'échelle municipale et pas seulement pour la priorisation d'aménagement de rues conviviales. Parmi les idées de projets qui ont été discutées par les professionnels, il y a entre autres la priorisation de l'aménagement d'infrastructures vertes pour effectuer de la biorétention et de la biofiltration dans une perspective d'adaptation aux changements climatiques ou la priorisation de la réfection et du réaménagement des parcs et espaces verts. Dans deux cas, les rencontres avec les municipalités ont mené à la réalisation d'un nouveau projet de recherche. Un premier projet visait à prioriser les rues résidentielles à réaménager selon des principes de rues partagées avec la Ville de Sherbrooke et un deuxième projet avait pour objectif d'effectuer la gestion des actifs de la Ville de Granby selon les différents services rendus (transport, traitement et distribution de l'eau, parcs à vocation récréative, sécurité civile, etc.). L'utilisation de différents cas d'étude au sein de municipalités crée un contexte propice à comparer différentes interventions dans une perspective de ROC et à analyser l'influence de différents types de comportements des facilitateurs et des participants durant les rencontres de groupe.

L'aide multicritère à la décision, quelle place pour une meilleure intégration du transport durable dans la planification?

Cette thèse a mis en lumière plusieurs barrières et difficultés à surmonter pour permettre la mise en œuvre des mesures de transport durable. Les rencontres avec la Ville de Québec et onze autres municipalités ont montré que, malgré une volonté de changer les pratiques vers le transport durable, il existait des barrières organisationnelles principalement liées à la résistance au changement et aux problèmes de communication, mais également à des contraintes monétaires et humaines. Ces barrières et le décalage qu'elles créent entre les plans et leur mise en œuvre dans la pratique produisent une dépendance de sentier qui amène les

organisations municipales à adopter des comportements et des pratiques qui sont contraires aux objectifs adoptés dans leurs politiques et plans de transport durable.

Ainsi, cette thèse a étudié comment améliorer les pratiques des professionnels des municipalités québécoises afin de surmonter ces barrières associées à l'implantation du transport durable. Pour y arriver, un enjeu précis a été étudié, soit la planification des travaux de réaménagement et de réhabilitation des rues, avec une approche spécifique pour y remédier, en l'occurrence le développement d'outil cartographique d'AMCD. Cette thèse a montré que cette solution présente un fort potentiel pour aider à mettre en œuvre le transport durable et qu'elle répond à plusieurs des besoins exprimés par les professionnels des municipalités lorsqu'il est question de la planification de la réfection et du réaménagement des rues. Le développement et l'utilisation de tels outils permettent d'avoir un point de vue holistique sur les projets, d'amorcer une discussion multidisciplinaire entre les parties prenantes et d'améliorer la planification des interventions dans une ville. Par conséquent, ils permettent de mieux intégrer les principes de transport durable dans l'évaluation de projet en arrimant les visions et les objectifs définis dans les politiques et les plans aux pratiques professionnelles et, ainsi, de transformer les rues afin qu'elles puissent répondre aux besoins de tous et non seulement de l'automobile.

Toutefois, les outils cartographiques d'AMCD ne doivent pas être considérés comme une panacée qui réglera tous les problèmes d'intégration du transport durable au sein des municipalités en termes de planification. Ce genre d'outil répond à un type de problème particulier, soit celui de créer une vision commune pour arrimer différents plans, politiques et normes (PPN), puis de rassembler les données en lien avec les PPN au sein d'une même base de données et de visualiser le résultat sur une carte afin de faciliter la vulgarisation. Tout comme certains professionnels l'ont mentionné durant les rencontres, l'AMCD ne représente qu'un outil parmi d'autres. C'est une manière de répondre au besoin de faciliter le partage et la communication d'information entre des professionnels de divers domaines travaillant dans des départements différents au sein d'une municipalité.

Par conséquent, d'autres méthodes ou techniques qui n'ont pas été étudiées durant cette thèse pourraient permettre de développer des objets frontières pour aider à venir changer les processus décisionnels et les comportements des professionnels afin de mieux intégrer le transport durable. Tout dépendant des contextes, un outil, une approche, une méthode ou un ensemble de ces derniers sera plus approprié qu'un autre pour aider à mettre en œuvre le transport durable. Les rencontres avec les 11 municipalités ont permis de documenter les caractéristiques d'un processus décisionnel idéal, mais aussi certaines des différences organisationnelles qui font qu'un objet frontière pourrait mieux répondre aux objectifs et aux contraintes de certaines municipalités. Par exemple, dans une municipalité où les élus exercent un contrôle très fort sur le choix des projets de réhabilitation, il serait peut-être difficile de mettre en œuvre un outil cartographique d'AMCD qui vient enlever des aspects plus

subjectifs à la décision alors que, dans une municipalité où le politique désire baser ses décisions sur des aspects plus techniques, le développement d'un tel outil serait plus facile.

D'autre part, les rencontres avec les professionnels des municipalités ont montré que le principal défi pour mieux intégrer le transport durable dans les pratiques des municipalités n'est pas tant technique que comportemental. En effet, c'est le changement de comportement des professionnels qui permettra d'améliorer l'intégration du transport durable. Un constat similaire a été fait dans les rencontres de suivi de projet quant au changement de comportement. Les principaux avantages que les professionnels ont trouvés à l'AMCD ne sont pas techniques, mais reliés aux changements de pratiques et de comportements que l'AMCD occasionnait au sein de la Ville de Québec, comme l'instauration de discussions multidisciplinaires et l'amélioration du processus décisionnel. Il en est de même pour les principaux défis, soit les problèmes de communication et la nécessité de travailler avec des professionnels de différents domaines. Conséquemment, si les mesures de gestion du changement ne sont pas présentes pour assurer le développement et s'il n'y a pas une volonté de changer au sein de l'organisation, il sera difficile de mettre en œuvre des outils et plus globalement des nouvelles pratiques favorisant le transport durable.

Ces résultats mettent en valeur le besoin d'effectuer un suivi post-projet dans le domaine de l'AMCD, mais également la nécessité de mieux comprendre les différents comportements entourant le développement et l'utilisation de modèle d'AMCD, tel que le suggère le domaine de la recherche opérationnelle comportementale. De plus, ces constats valident une des prémisses de cette thèse. Les gouvernements et les organismes publics ont besoin d'aide pour définir de nouveaux processus décisionnels et pour créer de nouveaux outils d'aide à la décision qui assurent une meilleure communication et une collaboration accrue des différents domaines afin de mieux intégrer les notions de transport durable dans les processus décisionnels.

Somme toute, le développement d'outils d'AMCD est un excellent moyen pour mieux intégrer le transport durable dans la planification du réaménagement et de la réfection de rues, sans pour autant être obligatoire. Cependant, une meilleure communication, une collaboration multidisciplinaire et une gestion du changement semblent être des éléments incontournables pour assurer la mise en œuvre et une meilleure intégration du transport durable au sein des municipalités que ce soit avec ou sans le développement d'outils d'AMCD.

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Annexe A General analysis of the reviewed articles

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Ambrasaite et al.	MCDA and Risk Analysis in Transport Infrastructure Appraisals: the Rail Baltica Case	Procedia - Social and Behavioral Sciences	2011	Combination	Denmark	Rail	Yes	No
Anagnostopoulos et al.	Multicriteria evaluation of transportation infrastructure projects: the case of Eastern Macedonia and Thrace region	Transaction on the Built Environment	2001	Combination	Greece	Infrastructure	Yes	Yes
Annema et al.	Cost-benefit analysis (CBA), or multi-criteria decision-making (MCDM) or both: politicians' perspective in transport policy appraisal	18th EURO Working Group on Transportation, EWGT 2015	2015	Comparison	Netherlands	Policy	No	No
Babashamsi et al.	Sustainable Development Factors in Pavement Life-Cycle: Highway/Airport Review	Sustainability	2016	Comparison	Malaysia	Infrastructure - Highway	No	Yes
Balm et al.	A city distribution impact assessment framework	Towards Innovative Freight and Logistics	2014	Combination	Netherlands	Freight	Yes	Yes, implicitly
Barfod and Sailing	A new composite decision support framework for strategic and sustainable transport appraisals	Transportation Research Part A: Policy and Practice	2015	Combination	Denmark	Infrastructure - Tunnel	Yes	Yes
Barfod et al.	Composite decision support by combining cost-benefit	Decision Support Systems	2011	Combination	Denmark	Infrastructure - Bridge	Yes	Yes, implicitly

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
	and multi-criteria decision analysis							
Bekefi et al.	Multicriteria analysis of the financial feasibility of transport infrastructure projects in Hungary	INFOR	2003	Combination	Hungary	Infrastructure	Yes	No
Beria et al.	Multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility	European Transport Research Review	2012	Comparison - Combination	Italy	General	No	Yes
Beukers et al.	Why Cost Benefit Analysis is perceived as a problematic tool for assessment of transport plans: A process perspective	Transportation Research Part A: Policy and Practice	2012	CBA	Netherlands	General	No	No
Bristow and Nellthorp	Transport project appraisal in the European Union	Transport Policy	2000	Comparison	United Kingdom	General	No	No
Browne and Ryan	Comparative analysis of evaluation techniques for transport policies	Environmental Impact Assessment Review	2011	Comparison	Ireland	Policy	No	Yes
Bueno Cadena and Vassallo	Setting the weights of sustainability criteria for the appraisal of transport projects	Transport	2015	MCDA	Spain	Infrastructure - Highway	Yes	Yes

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Bueno Cadena et al.	Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods	Transport Reviews	2015	Comparison	Spain	Infrastructure	No	Yes
Chowdhury et al.	Multiobjective Methodology for Highway Safety Resource Allocation	Journal of Infrastructure Systems	2000	MCDA	United States	Safety	No	No
Cornet et al.	Engaging Multiple Actors in Large-Scale Transport Infrastructure Project Appraisal: An Application of MAMCA to the Case of HS2 High-Speed Rail	Journal of Advanced Transportation	2018	MCDA	Denmark	Rail	Yes	Yes
D'Este	Capturing different viewpoints in multi-criteria analysis	Proceedings of the 32th Australasian Transport Research Forum	2009	MCDA	Australia	General	Yes	No
Damart and Roy	The uses of cost–benefit analysis in public transportation decision-making in France	Transport Policy	2009	CBA	France	Policy	No	No
De Brucker et al.	The Applicability of Multicriteria-Analysis to the Evaluation of Intelligent Transport Systems (ITS)	Research in Transportation Economics	2004	MCDA - Comparison	Belgium	Intelligent transport system	No	No
Dhir et al.	Application of the analytic hierarchy process to identify the most suitable manufacturer of rail vehicles for High Speed 2	Case Studies on Transport Policy	2015	MCDA	United Kingdom	Rail	Yes	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Dimitriou et al.	Presenting the case for the application of multi-criteria analysis to mega transport infrastructure project appraisal	Research in Transportation Economics	2016	MCDA - Comparison	United Kingdom	General	Yes	Yes
Galves	Supporting decision processes related to transport: from CBA (cost benefit analysis) to MCDA (multi-criteria decision analysis)	Proceedings of ETC 2005	2005	MCDA - Comparison	Brazil	Rail	Yes	Yes
Gamper and Turcanu	On the governmental use of multi-criteria analysis	Ecological Economics	2007	MCDA	Austria	Policy	No	Yes
Ghaeli et al.	Multicriteria Project Portfolio Selection: Case Study for Intelligent Transportation Systems	Transportation Research Record	2003	MCDA	Canada	Intelligent transport system	Yes	No
Griskeviciute-Geciene	The Evaluation of Investment Projects within the Territory of Development	Transport	2010	Comparison	Lithuania	Infrastructure	No	Yes
Guehnemann et al.	Combining cost-benefit and multi-criteria analysis to prioritise a national road infrastructure programme	Transport Policy	2012	Combination	United Kingdom	Infrastructure - Highway	Yes	No
Gwee et al.	International Variation in Cost–Benefit Analysis of Urban Rail Projects: Impact on Outcomes	Transportation Research Record: Journal of the Transportation Research Board	2011	CBA	Australia	Rail	No	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Hickman and Dean	Incomplete cost – incomplete benefit analysis in transport appraisal	Transport Reviews	2018	CBA - MCDA	United Kingdom	Infrastructure	Yes	Yes
Hüging et al.	Need for a Holistic Assessment of Urban Mobility Measures - Review of Existing Methods and Design of a Simplified Approach	Transportation Research Procedia	2014	Comparison - Combination	Germany	Infrastructure	Yes	Yes
Jong and Geerlings	Exposing Weaknesses in Interactive Planning: The Remarkable Return of Comprehensive Policy Analysis in The Netherlands	Impact Assessment and Project Appraisal	2005	CBA	Netherlands	General	No	No
Kang and Lee	A policy decision process for construction of public transportation city model: Case study of Jeju, Korea	2007 International Conference on Multimedia and Ubiquitous Engineering	2007	MCDA	United States	Public transport	Yes	Yes, implicitly
Kelly et al.	Ex Post Appraisal: What Lessons Can Be Learnt from EU Cohesion Funded Transport Projects?	Transport Policy	2015	CBA	United Kingdom	Infrastructure	No	No
Kim et al.	Advanced Traffic Management System: Integrated Multicriterion System for Assessing Detour Decisions During Nonrecurrent Freeway Congestion	Transportation Research Record	2012	Combination	United States	Infrastructure - Highway	Yes	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Leleur et al.	The COSIMA approach to transport decision making–combining cost-benefit and multi-criteria analysis for comprehensive project appraisal	Improving Public Investment Management for Large-Scale Government Projects: Focusing on the Feasibility Studies–Lessons and Challenges	2007	Combination	Denmark	Infrastructure	Yes	Yes, implicitly
Leviankangas and Lahesmaa	Profitability Evaluation of Intelligent Transport System Investments	Journal of Transportation Engineering	2002	Comparison	Finland	Intelligent transport system	Yes	No
Macharis et al.	A stakeholder-based multicriteria evaluation framework for city distribution	Research in Transportation Business & Management	2014	Combination	Belgium	Freight	Yes	Yes, implicitly
Mackie et al.	Transport appraisal revisited	Research in Transportation Economics	2014	CBA	United Kingdom	General	No	No
Mouter et al.	Attitudes towards the role of Cost–Benefit Analysis in the decision-making process for spatial-infrastructure projects: A Dutch case study	Transportation Research Part A: Policy and Practice	2013	Comparison	Netherlands	Policy	No	No
Munda	On the use of Cost-Benefit Analysis and Multi-Criteria Evaluation in ex-ante Impact Assessment	Publications Office of the European Union	2017	Comparison	Italy	Policy	No	Yes
Nadafianshahamabadi et al.	Differences in Expertise and Values: Comparing Community and Expert Assessments of a Transportation Project	Sustainable Cities and Society	2017	MCDA	United States	Infrastructure - Highway	Yes	Yes, implicitly

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Nahmias–Biran and Shiftan	Towards a more equitable distribution of resources: Using activity-based models and subjective well-being measures in transport project evaluation	Transportation Research Part A: Policy and Practice	2016	Comparison - Combination	Singapour	Equity	Yes	No
Panou and Sofianos	A Fuzzy Multicriteria Evaluation System for the Assessment of Tunnels vis-à-vis Surface Roads: Theoritical Aspects - Part I	Tunnelling and Underground Space Technology	2002	Combination	Greece	Infrastructure - Tunnel	Yes	No
Popovic et al.	Application of new decision making model based on modified cost-benefit analysis - A case study: Belgrade tramway transit	Asia-Pacific Journal of Operational Research	2012	Combination	Serbia	Public transport	Yes	No
Prokopowicz and Dabrowska	A methodological and practical approach to multidisciplinary assessment of the expansion of EU transport network: a strategic case for the republic of Croatia	Transport Research Arena 2016	2016	Combination	United States	Infrastructure	Yes	Yes
Prosser et al.	Strategic option assessment: an alternative approach to multi-criteria analysis for transport / land use corridors	Proceedings of State of Australian Cities Conference 2015	2015	Combination	Australia	Rail	No	No
Quinet and Meunier	CBA § Darwin: The Case of Transport Infrastructure in France	Procedia - Social and Behavioral Sciences	2012	CBA	France	Infrastructure	No	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Rogers	Deciding on Dublin's Integrated Transport Polict: the Case For Heavy Rail	Proceedings of European Transport Conference 2000	2000	Combination	United Kingdom	Rail	Yes	No
Rudolph et al.	Evaluation and Appraisal of Sustainable and Integrated Urban Transport Projects	Proceedings of ETC 2015	2015	Comparison	Germany	General	No	Yes
Salling and Landex	Computer based ex-ante evaluation of the planned railway line between Copenhagen and Ringsted by use of a Decision Support System named COSIMA-DSS	Computers in Railways X	2006	Combination	Denmark	Rail	Yes	No
Salling et al.	Modelling decision support and uncertainty for large transport infrastructure projects: The CLG-DSS model of the Oresund Fixed Link	Decision Support Systems	2007	Combination	Denmark	Infrastructure - Bridge	Yes	Yes
Salling and Pryn	Sustainable transport project evaluation and decision support: indicators and planning criteria for sustainable development	International Journal of Sustainable Development & World Ecology	2015	Combination	Denmark	Infrastructure - Bridge	Yes	Yes
Sayers et al.	Multi-criteria evaluation of transport options—flexible, transparent and user-friendly?	Transport Policy	2003	MCDA	United Kingdom	Infrastructure - Highway	Yes	No
Scanella	Valuation of road projects with uncertain outcomes	Transport Reviews	2003	MCDA	Belgium	Infrastructure - Highway	Yes	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
Shiau	Evaluating transport infrastructure decisions under uncertainty	Transportation Planning and Technology	2014	Combination	China	Infrastructure - Highway	Yes	Yes
Spiekermann and Wegener	Evaluating Urban Sustainability Using Land-Use Transport Interaction Models	European Journal Of Transport And Infrastructure Research	2004	Combination	Germany	Policy	Yes	Yes
Thomopoulos and Grant-Muller	Incorporating equity as part of the wider impacts in transport infrastructure assessment: an application of the SUMINI approach	Transportation	2013	MCDA - Comparison	United Kingdom	Equity	Yes	Yes
Tischler	Finding the Right Way - A New Approach for Route Selection Procedures?	Transportation Research Procedia	2017	Combination	Austria	Rail	Yes	Yes, implicitly
Tsamboulas and Kopsacheili	Methodological framework for strategic assessment of transportation policies: Application for Athens 2004 Olympic games	Transportation Research Record	2003	MCDA	Greece	Policy	Yes	Yes, implicitly
Tsamboulas and Mikroudis	EFECT - evaluation framework of environmental impacts and costs of transport initiatives	Transportation Research Part D - Transport and Environment	2000	Combination	Greece	Infrastructure - Highway	Yes	Yes, implicitly
Tudela et al.	Comparing the output of cost benefit and multi-criteria analysis - An application to urban transport investments	Transportation Research Part A: Policy and Practice	2006	Comparison	Chili	Infrastructure - Highway	Yes	No

Authors	Title	Journal	Year	Category	First author's country	Transport field	Case study	Sustainable transport
van Wee	How suitable is CBA for the ex-ante evaluation of transport projects and policies? A discussion from the perspective of ethics	Transport Policy	2012	CBA	Netherlands	Equity	No	Yes, implicitly
van Wee et al.	Policies for synchronization in the transport–land-use system	Transport Policy	2014	CBA	Netherlands	Policy	Yes	No
Weisbrod	Incorporating Economic Impact Metrics in Transportation Project Ranking and Selection Processes	TRB 90th Annual Meeting Compendium	2011	Comparison	United States	Infrastructure - Highway	No	No
Yu et al.	An Importance Segregation Based Multi-objective Optimization Model for Traffic Safety Improvement Countermeasure Selection	International Journal of Transportation Science and Technology	2012	MCDA	China	Safety	Yes	No
Yu and Prevedouros	Risk assessment: method and case study for traffic projects	Journal of Modern Transportation	2017	MCDA	United States	Traffic	Yes	No

Annexe B Articles with a case study

Authors	Category	Type of decision	MCDA aggregation method used	CBA integrates social and environmental aspects
Ambrasaite et al. (2011)	Combination	Strategic	AHP	Not specified
Anagnostopoulos et al. (2001)	Combination	Strategic	AHP	Yes
Balm et al. (2014)	Combination	Strategic	PROMETHEE and AHP	Yes
Barfod (2018)	MCDA	Strategic	AHP and SMART or SMARTER and Swing weight	N/A
Barfod and Sailing (2015)	Combination	Strategic	AHP and SMART or SMARTER and Swing weight	Yes
Barfod et al. (2011)	Combination	Strategic	AHP and SMART	Yes
Bekefi et al. (2003)	Combination	Strategic	ELECTRE II	Yes
Bueno Cadena and Vassallo (2015)	MCDA	Strategic	Qualitative scale and REMBRANDT	N/A
Cornet et al. (2018)	MCDA	Strategic	AHP and direct weight	N/A
D'Este (2009)	MCDA	Strategic	AHP	N/A
Dhir et al. (2015)	MCDA	Strategic	AHP	N/A
Galves (2005)	MCDA Comparison	Strategic	Not specified	N/A
Ghaeli et al. (2003)	MCDA	Strategic	AHP	N/A
Gühnemann et al. (2012)	Combination	Strategic	Linear weighted summation	Yes (air pollution, noise, accident reduction)
Hickman and Dean (2018)	CBA MCDA	Strategic	N/A	Yes
Hüging et al. (2014)	Comparison Combination	Strategic	AHP	Yes
Kang and Lee (2007)	MCDA	Strategic	AHP	N/A
Kim et al. (2012)	Combination	Tactic	AHP	Yes
Leleur et al. (2007)	Combination	Strategic	AHP or SMARTER	Yes
Leviankangas and Lahesmaa (2002)	Comparison	Strategic	AHP	N/A

Authors	Category	Type of decision	MCDA aggregation method used	CBA integrates social and environmental aspects
Macharis et al. (2014)	Combination	Strategic	AHP	Yes
Nadafianshahamabadi et al. (2017)	MCDA	Strategic	AHP	N/A
Nahmias–Biran and Shiftan (2016)	Comparison Combination	Strategic	MAUT	N/A
Panou and Sofianos (2002)	Combination	Strategic	Fuzzy hierarchical analysis and NAIADE	No
Popovic et al. (2012)	Combination	Strategic	SMARTER	No
Prokopowicz and Dabrowska (2016)	Combination	Strategic	AHP	Not specified
Rogers (2000)	Combination	Strategic	MAVT (within VISA software)	Not specified
Salling and Landex (2006)	Combination	Strategic	AHP	Yes
Salling and Pryn (2015)	Combination	Strategic	Rembrandt and SMARTER	Yes
Salling et al. (2007)	Combination	Strategic	Not specified	Yes
Sayers et al. (2003)	MCDA	Strategic	MAVT	N/A
Scannella (2003)	MCDA	Strategic	MUSTARD	N/A
Shiau (2014)	Combination	Strategic	Utility function and AHP	Yes
Spiekermann and Wegener (2004)	Combination	Tactic	Not specified	Yes
Thomopoulos and Grant-Muller (2013)	MCDA Comparison	Strategic	AHP	N/A
Tischler (2017)	Combination	Strategic	Not specified	Not specified
Tsamboulas and Kopsacheili (2003)	MCDA	Strategic	AHP	N/A
Tsamboulas and Mikroudis (2000)	Combination	Strategic	Multi-objective using fuzzy sets	No
Tudela et al. (2006)	Comparison	Strategic	Compare AHP and MAUT	N/A

Authors	Category	Type of decision	MCDA aggregation method used	CBA integrates social and environmental aspects
van Wee et al. (2014)	CBA	Strategic	N/A	Not specified
Yu and Prevedouros (2017)	MCDA	Tactic	Fuzzy AHP and Utility function	N/A
Yu et al. (2012)	MCDA	Tactic	Multi-objective	N/A

Annexe C Number of reviewed papers according to different themes

Table 1: Number of papers including a case study according to the types of papers

Case study	CBA	CBA - MCDA	Combination	Comparison	Comparison - Combination	MCDA	MCDA Comparison	Total
No	8	0	1	10	1	2	1	23
Yes	1	1	21	2	2	13	3	43
Total	**9**	**1**	**22**	**12**	**3**	**14**	**4**	**66**

Table 2: Number of papers including sustainable transport/sustainable development considerations according to the types of papers

Include sustainability	CBA	CBA - MCDA	Combination	Comparison	Comparison - Combination	MCDA	MCDA Comparison	Total
No	8	0	9	6	1	8	1	33
Yes	0	1	7	6	2	4	3	23
Yes, implicitly	1	0	6	0	0	3	0	10
Total	**9**	**1**	**22**	**12**	**3**	**14**	**4**	**66**

Annexe D Detailed explanations to construct MACBETH attractiveness scales

The construction of MACBETH attractiveness scales for every criterion aims at translating a performance value on a given criterion into an attractiveness value that reflects the preferences and the concerns of the participants involved in the process. Since MACBETH produces an aggregated score based on a weighted average, it is crucial that scales are constructed as interval-level scales. These scales are, for each criterion, a function of: a preference direction (i.e. criteria values to be minimized or maximized), the "good" and "neutral" criterion reference levels, the criterion echelons, and the perceived difference of attractiveness between pairs of echelons. Interval-level scales are constructed numeric measurement scales that do not have an absolute zero and where the difference between two reference points is a fixed number of units of measure (e.g. Celsius temperature is an interval scale where the freezing point is the lower reference (value of 0) and the boiling point is the upper reference (value of 100), but the value may be lower than 0 and higher than 100), and a unit is a degree defined as one hundredth of the difference between the temperatures of boiling water and freezing water).

The good and neutral reference levels are essential to MACBETH because they allow for the criteria to be anchored in a realistic context and to build interval scales; without such information, the criteria weights (scaling constants) would be meaningless. Two reference levels are always needed in an evaluation method seeking to construct interval level-scales. In MACBETH, the "good" reference level represents a satisfactory level (i.e. a level that participants would like to achieve), while the "neutral" reference level refers to a level that is neither attractive nor unattractive (i.e. a level that participants find acceptable that they would not like to have performances lower than this level). As a rule of thumb, the value of 100 is generally assigned to the "good" reference level and the value of 0 is assigned to the "neutral" reference level. The scales are open, meaning that it is possible to have performances with an attractiveness score lower than 0 or higher than 100. Furthermore, the scales are generally not linear and may be bounded (i.e. no further increase in a performance will increase its attractiveness). For example, take the criteria of street width (Fig. 2.2): the group defined the "good" reference level as a street with a width of 15 m and the "neutral" reference level as one having a width of 10 m. The scale also has an upper and a lower bound. Anything below 6m would make it difficult to incorporate the different infrastructure for different modes, and anything above 24m would have sufficient room for sidewalks (e.g. 4m over both sides), bicycle paths (e.g. 4m for two-way plus barrier), public transport (e.g. 8m for two segregated lanes), and cars (e.g. 6m for a lane in each direction). Therefore, the difference of attractiveness below 6m and above 24m is null.

Once the two reference levels have been identified for a criterion, the participants are asked to rank the performances on the given criterion in order of decreasing attractiveness. Order of attractiveness implies that if value *X* on a given criterion is preferred to value *Y* on this criterion, then all other things being equal, an alternative with a value *X* would have a higher potential or priority to be chosen as an alternative compared to an alternative having a value *Y* on this same criterion. In the case of criteria with qualitative scales, all the possible performance steps are identified, whereas only major inflection points are identified for quantitative scales. Continuing with the street width example, the professionals identified seven steps apart from the two reference levels (i.e. 0 m, 6 m, 8 m, 12 m, 18 m, 24 m and 30 m or more).

Finally, participants are asked to express their perceived differences in attractiveness between any two criterion performances using a 7-point semantic scale. This difference in attractiveness can be *null, very weak, weak, moderate, strong, very strong or extreme*. For our example, the group estimated the difference in attractiveness between a width of 10 m and 8 m to be weak, whereas they were indifferent between a width of 6 m and of 0 m. The MACBETH scales are then computed with the software M-MACBETH (Fig. 2.2).

Annexe E Attractiveness scales for qualitative and quantitative criteria

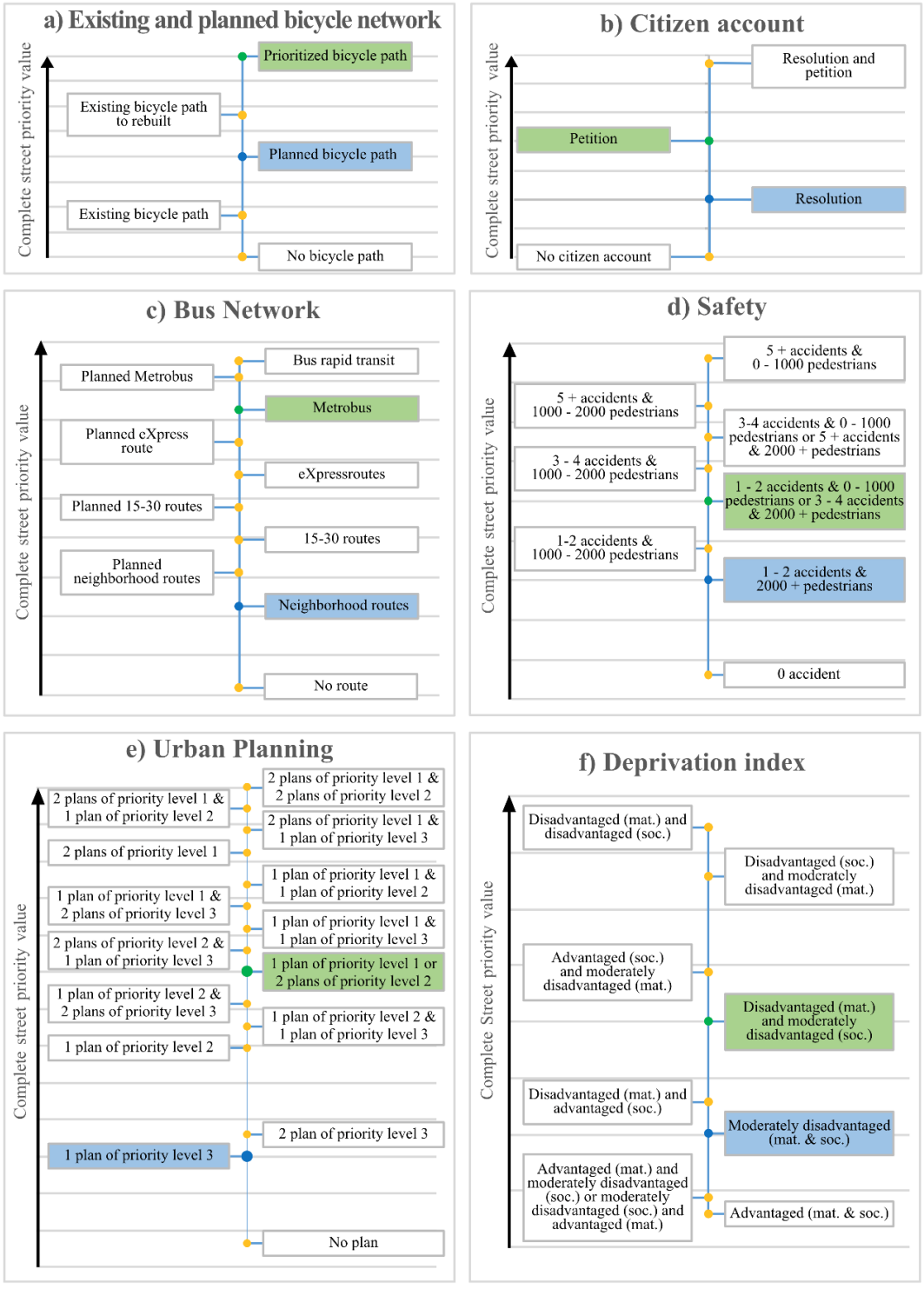


Figure 1. Constructed attractiveness scales for the qualitative criteria. The “good” and “neutral” references are respectively indicated by a green box and a blue box.

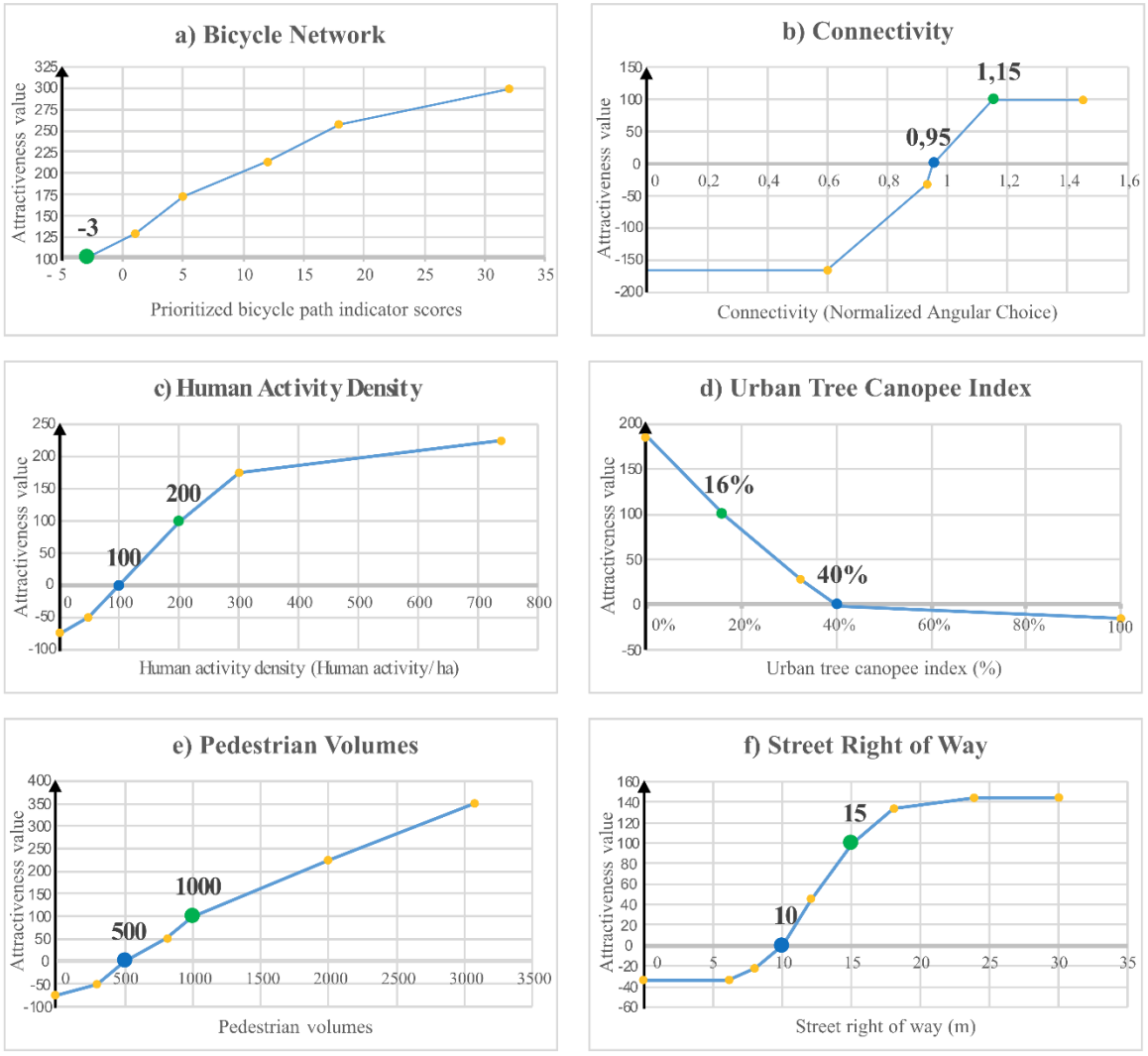


Figure 2. Constructed attractiveness scales for the quantitative criteria. The “good” and “neutral” references are respectively indicated by a green dot and a blue dot.

Annexe F Interview Guide for Post-Project Evaluation

The original interview grid was written in French and subsequently translated and adapted for this publication. Although the interview guide is well structured, the guide served mainly as a support for the interviewer and was adapted from an interview to another. Moreover, the spatial decision-support system (SDSS) is referred to as "the tool" in this guide since it was the vocabulary used by Quebec City professionals.

1 Introduction to the Research Project

In 2016, many workshops were organized in collaboration with our research team to develop a cartographic tool allowing to prioritize Quebec City interventions from a Complete Streets' perspective. At the time, the objective was to create a shared Complete Streets vision between the professionals from urban planning, environment, transport and urban design through the creation of multicriteria decision aiding tool. The project was completed two years ago, and I am currently conducting a follow-up on the project. The objective of my approach is to document the different perspectives and perceptions of the actors involved in the Complete Streets strategy to understand which circumstances were favorable and which circumstances were barriers to the development and adoption of the tool. This is why I wish to conduct an interview with you.

2 Questions to the workshop participants

2.1 Previous experiences with MCDA

The first series of questions that I will ask you are related to the development of the tool and multicriteria decision aid group workshops.

2.1.1 Before this project, had you ever participated in multicriteria decision aiding group (MCDA)workshops?

a. If yes, in which contexts did you participate in MCDA workshops?
b. If not, did you participate in similar projects that were not linked to MCDA?

2.2 Process to develop the artifacts (model and the SDSS)

2.2.1 Can you share with me your experience and your impressions about your participation in the project's workshops?

(Depending on the participants' previous answers, the following questions can be asked if the topic was not directly addressed in the previous question.)

Throughout the different workshops,

a. Were there any aspects of the projects that you appreciated more or that you found easier? If yes, what were they?
b. On the other hand, were there any aspects that you appreciated less or that you found more difficult? If yes, what were they?
c. Did you experience any limitations or constraints during the modeling process? If yes, what were they?
d. Halfway through the project, we added subgroup workshops to the modeling process, what do you think of this?
e. What do you think of the multidisciplinary character of the group workshops?

In research, we often say that there are usually two ways to develop a model : an expert mode and a facilitator mode. In the expert mode, the researchers develop the model on their own and present the results to the client. In the facilitator mode, the researchers support the client during meetings as facilitators and jointly construct the model.

2.2.2 Which mode do you think was used during the project?

2.2.3 Do you think that we used a facilitator mode to build the model rather than an expert mode?

2.2.4 Do you see any advantages or disadvantages to us using a facilitator mode rather than an expert mode?

2.2.5 From your point of view, was there an impact to involve the different professionals and departments from the project's beginning?

If we go back to the MCDA process from a more general perspective and the tool that we developed with Quebec City.

2.2.6 What were the reactions of the other persons in your department to the process and the results? What were the reactions of the elected officials?

2.2.7 How would you qualify your trust level in the results of the MCDA tool (low, moderate, high)? Why?

2.2.8 To summarize, could you describe the project in terms of one best move and one worst move?

2.3 Use of the SDSS

To follow up on the group workshops, I would like to ask few questions about the developed tool and the Complete Street strategy within which the tool is inserted.

2.3.1 How do you perceive the tool compared to the previous approach used in Quebec City? What are the differences between the tool and the previous approaches for street prioritization? How do you explain these differences?

(Depending on the participants' previous answers, the following questions can be asked if the topic was not directly addressed in the previous questions.)

2.3.2 The next series of questions is related to the strengths and the weaknesses of the tool.

a. Are there any aspects that you appreciate about the tool?
b. Are there any strengths that you attribute to the tool?
c. Are there any conditions that favor the use of the tool in your practices?
d. Are there any aspects that you do not appreciate about the tool?
e. Are there any weaknesses that you attribute to the tool?
f. Are there any limitations or constraints that you encountered when you were using the tool?

2.4 Questions about the future of the tool

If we consider the future use of the tool,

2.4.1 What would ensure the use of the tool in the future?

2.4.2 On the other hand, what would hinder or stop the tool's use in the future?

2.4.3 Are there any aspects that you would like, or have heard about, to see improved or modified in the tool (technical aspects or criteria in the model)?

2.5 Open questions about MCDA

In closing, I have a few questions of a more general nature that are not specifically about the tool or the Complete Street strategy, but that are linked to multicriteria decision aid.

2.5.1 Following your experience, would you consider an MCDA process for other projects in the future?

2.5.2 Would you suggest to Quebec City the use of an MCDA process for projects in other departments or fields?

a. If yes, for which other types of projects would a similar process be relevant?
b. If not, why do you think that a multicriteria process would not be appropriate?

2.5.3 If in the future, one of your colleagues has to participate in an MCDA process for the first time, which advice would you give her/him to prepare him/herself?

2.5.4 In conclusion, do you have a last comment or something to add that we did not discuss?

3 Questions to the tool users about the SDSS

3.1 Previous experiences with MCDA

To begin, I will ask you questions about the Complete Streets strategy and the tool to prioritize the redesign of streets as Complete Streets.

3.1.1 How long have you been working with the Complete Street strategy or the tool to prioritize the redesign of streets as Complete Streets?

3.1.2 Can you share your first impressions of the Complete Streets strategy?

3.1.3 Can you share your first impressions of the multicriteria tool to prioritize the redesign of streets as Complete Streets?

The tool to prioritize the redesign of streets as Complete Streets was developed according to a multicriteria decision aiding approach.

3.1.4 Are you familiar with the multicriteria decision aiding approach?

3.1.4.1 If yes, did you ever participate in a project using this approach?

3.1.4.2 If not, would you like to have more information about this approach?

3.1.5 What do you think about us having used such an approach to develop the tool?

3.2 Use of the SDSS (referred to as the tool)

To continue, my next question will be about the tool's uses in your practice and your perceptions of its uses.

3.2.1 How do you perceive this tool in comparison to the previous approaches in the City? What are the differences between this tool and the previous approaches? How do you explain these differences?

3.2.2 How did you use the prioritization tool in your practice?

3.2.3 What facilitated or complicated the use of this tool in your practice?

3.2.4 Do you perceive any advantages of using this tool in your practice or in that of your colleagues?

3.2.5 Do you perceive disadvantages or barriers to using this tool in your practice or in that of your colleagues?

(Depending on the participants' previous answers, the following questions can be asked if the topic was not directly addressed in the previous questions.)

a. Are there aspects that you appreciate about the tool?
b. Are there strengths that you attribute to the tool?
c. Are there aspects that you do not appreciate about the tool?
d. Are there weaknesses that you attribute to the tool?

3.2.6 How would you qualify your level of trust in the results of the multicriteria tool? (low, moderate, high) Why?

3.2.7 To summarize, could you describe the project in terms of one best move and one worst move?

3.3 Questions about the future of the tool

If we consider the future use of the tool,

3.3.1 Are there any other uses of the tool that you would like to see in the future or some features that you have not mentioned so far?

a. In your view, what would be the favorable conditions for implementing these future uses?
b. And, what would be some hurdles to these future uses?

3.3.2 What would ensure the use of the tool in the future? And, what would hinder or stop the tool's use in the future?

a. Are there any aspects that you would like, or heard about, to see improved or modified in the tool (technical aspects or criteria in the model)?

3.4 Open questions about MCDA

In closing, I have a few general questions that are not specifically about the tool or the Complete Street strategy, but that are linked to multicriteria decision aid.

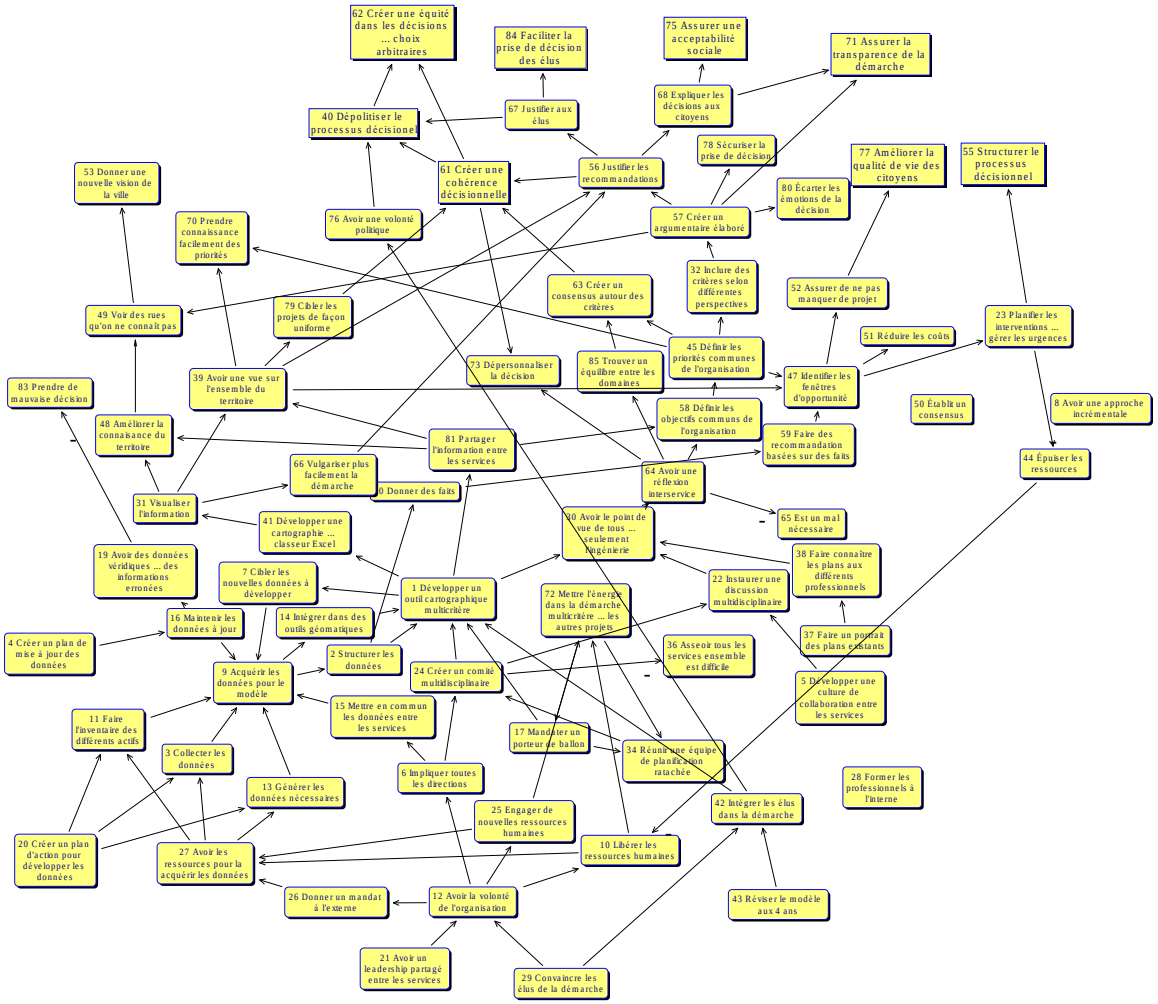
3.4.1 Following your experience, would you consider an MCDA process for other projects in the future?

3.4.2 Would you suggest to Quebec City the use of an MCDA process for projects in other departments or fields?

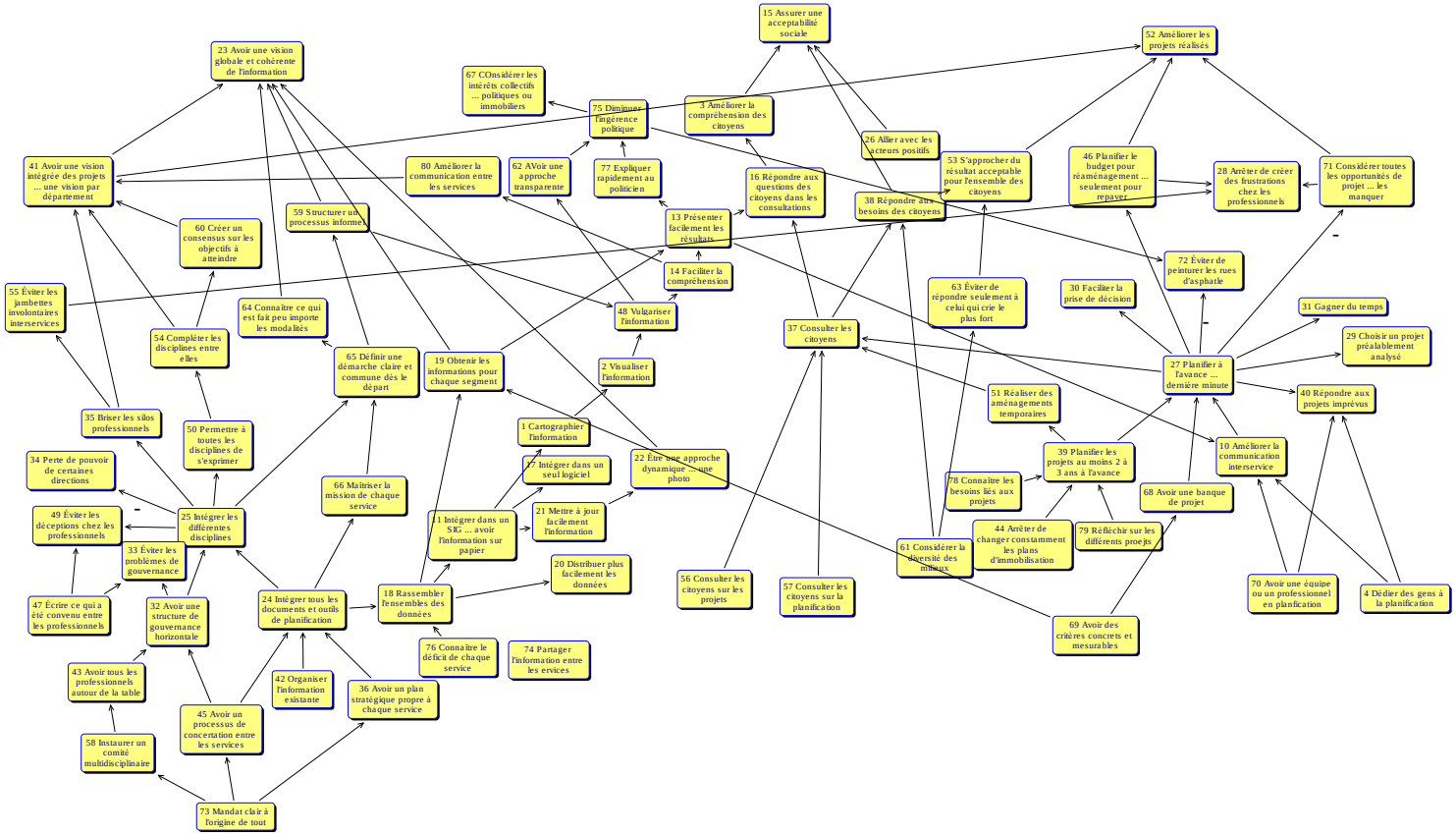
a. If yes, for which other types of projects a similar process would be relevant?
b. If not, why do you think that a multicriteria process would not be appropriate?

3.4.3 To conclude, do you have anything to add that we did not discuss or a last comment?

Annexe G Causal maps about the advantages, issues and challenges to develop an MC-SDSS and about the characteristics of an ideal decision process to plan street redesign and rehabilitation



Goal standard


15 Assurer une acceptabilité sociale
52 Améliorer les projets réalisés
23 Avoir une vision globale et cohérente de l'information
67 COnsidérer les intérêts collectifs ... politiques ou immobiliers
75 Diminuer l'ingérence politique
3 Améliorer la compréhension des citoyens
26 Aller avec les acteurs positifs
41 Avoir une vision intégrée des projets ... une vision par département
80 Améliorer la communication entre les services
62 AVoir une approche transparente
77 Expliquer rapidement au politicien
16 Répondre aux questions des citoyens dans les consultations
53 S'approcher du résultat acceptable pour l'ensemble des citoyens
46 Planifier le budget pour réaménagement ... seulement pour repaver
28 Arrêter de créer des frustrations chez les professionnels
71 Considérer toutes les opportunités de projet ... les manquer
59 Structurer un processus informel
38 Répondre aux besoins des citoyens
13 Présenter facilement les résultats
60 Créer un consensus sur les objectifs à atteindre
72 Éviter de peinturer les rues d'asphalte
14 Faciliter la compréhension
55 Éviter les jambettes involontaires interservices
63 Éviter de répondre seulement à celui qui crie le plus fort
30 Faciliter la prise de décision
31 Gagner du temps
64 Connaître ce qui est fait peu importe les modalités
48 Vulgariser l'information
37 Consulter les citoyens
54 Compléter les disciplines entre elles
29 Choisir un projet préalablement analysé
65 Définir une démarche claire et commune dès le départ
19 Obtenir les informations pour chaque segment
2 Visualiser l'information
27 Planifier à l'avance ... dernière minute
51 Réaliser des aménagements temporaires
40 Répondre aux projets imprévus
35 Briser les silos professionnels
1 Cartographier l'information
50 Permettre à toutes les disciplines de s'exprimer
10 Améliorer la communication interservice
34 Perte de pouvoir de certaines directions
17 Intégrer dans un seul logiciel
22 Être sur une approche dynamique ... une photo
39 Planifier les projets au moins 2 à 3 ans à l'avance
78 Connaître les besoins liés aux projets
68 Avoir une banque de projet
66 Maîtriser la mission de chaque service
49 Éviter les déceptions chez les professionnels
25 Intégrer les différentes disciplines
11 Intégrer dans un SIG ... avoir l'information sur papier
21 Mettre à jour facilement l'information
44 Arrêter de changer constamment les plans d'immobilisation
79 Réfléchir sur les différents projets
33 Éviter les problèmes de gouvernance
61 Considérer la diversité des acteurs
20 Distribuer plus facilement les données
56 Consulter les citoyens sur les projets
57 Consulter les citoyens sur la planification
70 Avoir une équipe ou un professionnel en planification
4 Dédier des gens à la planification
47 Écrire ce qui a été convenu entre les professionnels
32 Avoir une structure de gouvernance horizontale
24 Intégrer tous les documents et outils de planification
18 Rassembler l'ensembles des données
69 Avoir des critères concrets et mesurables
76 Connaître le déficit de chaque service
74 Partager l'information entre les ervices
43 Avoir tous les professionnels autour de la table
42 Organiser l'information existante
36 Avoir un plan stratégique propre à chaque service
45 Avoir un processus de concertation entre les services
58 Instaurer un comité multidisciplinaire
73 Mandat clair à l'origine de tout