ADP : An Argumentation-based Decision Process Framework Applied to the Modal Shift Problem

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Abstract
This article introduces an argumentation-based decision process framework specifically designed to model context-based decisions and its application to the challenge of promoting responsible modal choices in transportation. Despite the growing demand for sustainable transportation options, many urban travelers continue to rely heavily on private cars. We show that our argumentation model can be used to understand how the traveler context influences the transportation modal choice decisions of the travelers. To validate the efficacy of our framework, we deploy it within a simulator of multimodal transportation networks, utilizing formal argumentation to represent various behaviors. By examining the underlying reasons behind individuals' car usage and investigating potential avenues for influencing their modal choices, we aim to contribute to the advancement of sustainable transportation solutions.

Keywords
Argumentation, decision model, multi-agent simulation, transportation modal shift

1. Introduction

The growth of cities is accompanied by an increasing transportation demand, resulting in heightened pollution and congestion. This is primarily attributed to travelers' preference for using private vehicles over other modes of transportation. The shift from private vehicle mode to alternative modes such as collective or non-motorized modes has become a significant concern for transportation authorities. To discourage private vehicle usage, authorities have implemented low-emission zones (LEZ) as a new measure. LEZ restricts access to certain parts of the city exclusively to vehicles with low emissions.

However, defining the boundaries of these zones is a challenge as it requires striking a balance between travelers' mobility needs and the traffic implications. Unfortunately, when the definition is solely based on traffic flow analysis, only the traffic consequences are taken into account. This approach is unfair as it places the burden solely on excluded travelers or those who can afford low-emission vehicles.

Neglecting the impact on travelers' needs presents two risks. Firstly, there is a high likelihood of non-compliance, resulting in additional costs to enforce the rule. Secondly, there is a limited effect on modal shift, as most travelers simply adjust their car routes to avoid the LEZ. Finally,

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to align with the users' needs, cities may introduce exceptions that make the rule unclear[1][2]. The LEZ definition problem emphasizes the necessity of conducting a more comprehensive analysis of travelers' decision-making processes to grasp the rule's impact on travelers and, consequently, assess its effectiveness.

Agent-based simulations focus on individual decision-making processes, making them valuable tools for analyzing the modal shift problem [1, 2]. However, these works often limit the traveler's context to their activities and locations, while the decision process of the agents is primarily guided by a single criterion, such as price impact [1] or the utilization of shared autonomous vehicles [2]. As a result, the diverse contexts of travelers are not adequately considered.

Modal shifting is determined by a whole range of factors that are interrelated to a larger or smaller extent. For instance, [3] conducted a study involving 205 Australian university students to examine the relative importance and correlation between psychological and situational factors in predicting commuter transport mode choices. The study's findings include: (1) individuals' values influence their commuting behavior through their corresponding beliefs regarding the environmental impact of cars, (2) factors such as cost, time, and accessibility contribute to individuals' choices of commuting mode, and (3) both situational and psychological factors jointly influence pro-environmental behavior. For a comprehensive review of the modal choice concept, interested readers can refer to [4].

To address this complexity, this article aims to propose a framework that captures the various contexts within which travelers make their travel decisions.

In this article, we argue that formal argumentation, such as the Dung framework [5], can be used to represent the decision-making context of travelers. Arguments and attacks pertain to specific situations for the traveler and elucidate the support or refutation of a modal choice. In this sense, argumentation seems particularly relevant to represent complex multi-criteria decisions structures, in opposition to numerical functions or simple logical rules. An additional benefit of argumentation is its similarity to how we, humans, reason, as it has been suggested by Mercier and Sperber [6], which makes it easier to understand and use for humans. Furthermore, argumentation gives us an explicit justification about the decision while it is not necessarily the case for other AI techniques, especially the numeric-based reward functions.

The contributions of this article are:

- An argumentation framework to represent context-based decisions,
- An application of argumentation to the problematic of the modal shift.

This paper is organized as followed: Firstly, Section 2 proposes a state of the art on argumentation-based decisions frameworks. Secondly, Section 3 introduces the case study dedicated to represent urban travelers behaviors within a simulator of multimodal transportation networks. Thirdly, Section 4 presents the formal framework and recalls basics notions. Finally, Section 5 presents the first results of the proof-of-concepts and Section 6 proposes conclusion and perspective of future work.

[1] https://ec.europa.eu/transport/themes/urban/studies_cs
[2] https://ec.europa.eu/transport/sites/default/files/uvar_final_report_august_28.pdf

2. Agumentation-based decisions systems

Argumentation has been identified as an effective tool for decision-making and decision-support systems, particularly in situations where the recommended decisions need to be explained [7, 8]. Multiple studies [9, 10, 11, 12] have investigated the introduction of argumentation capabilities in decision-making and emphasized the importance of presenting arguments in favor or against possible choices to the user of a decision-support system. For instance, argumentation has been applied to justify a multiple criteria decision or represent decisions taken by a group of agents as in vote systems [13]. In a context of computer simulations, argumentation has been applied into agent-based simulations to model the opinion of agents [14], or [15] considers a case study in which argumentation is used to assess and compare cultural options available to farmers. However these approaches in agent-based models do not consider argumentation to make agent taking decisions. In [16], they use argumentation to represent knowledge of agents and their reasoning about alternatives in an automata framework, nammed as Action-based Alternating Transition Systems (AATS) framework. Some approaches in the literature in decision-support systems used argumentation to justify an option w.r.t. a goal. In [15], they consider a case study in which argumentation is used to assess and compare cultural options available to farmers. In their approach a system is a set of variables X and a set of states which is an instantiation of each variable of X, as e.g. $X = X_{out} \cup X_{in}$, where X_{out} is the observation, and X_{in} is human control values. An argument is a triplet $Arg = (option, goal, justification)$ which is associated with an option, a goal and a justification.

In this article, we are interested in the model proposed in [17]. They proposed an abstract argumentation model that defines an argumentation-based decision framework as tuple (A, D, R, F_f, F_c) where A is a set of arguments, D is a set of decisions, R is an attack relation, F_f is a mapping (resp. F_c) between pros (resp. cons) arguments and their associated decisions. Their model has several advantages:

- The simplicity of the model for linking arguments and decisions without having to change the abstract structure of arguments
- It provides the possibility of extending it easily to other argumentation models like e.g. Value-based Argumentation Frameworks (VAF) [18]

3. The simulated environment

The proposal presented in this paper is evaluated using a multiagent simulator available in the *Plateforme Territoire*[3]. This simulator enables agent travelers to access multimodal shortest itineraries between their origin and destination and simulates their movement along the chosen itinerary at a speed corresponding to the selected transportation mode. Itineraries can be evaluated using pre-trip indicators that influence the itinerary choice of the traveler agents. These indicators can be based on factors such as distance or traffic-related aspects like noise, which depends on the number of vehicles along different parts of the itinerary. Additionally, the

[3]https://territoire.emse.fr

simulator calculates global traffic indicators for each transportation mode to assess the system, such as the number of late travelers.

Application. *Each agent has to decide about one alternative which corresponds to choose a particular transportation network. In this simulator, we consider the following set of alternatives* $\mathcal{A}lts$ *and* $\mathcal{N}$ *be a set of agents :*

D1 $p.t. :=$*"go by public transport"*
D2 $bike :=$*"go by bike"*
D3 $walk :=$*"go by foot"*
D4 $car :=$*"go by car"*

Each agent decides based on indicators. For each agent $i \in \mathcal{N}$*, we consider the following indicators* $\mathcal{I}nds$*. We first define the indicators based on alternatives* $\mathcal{A}lts$*:*

- $t : \mathcal{A}lts \to \mathbb{D}^+$ *for a given alternative, it returns the duration for this alternative*
- $d : \mathcal{A}lts \to \mathbb{D}^+$ *for a given alternative, it returns the distance for this alternative*
- $pol : \mathcal{A}lts \to \mathbb{D}^+$ *for a given alternative, it returns the pollution rate associated with this alternative*
- $noi : \mathcal{A}lts \to \mathbb{D}^+$ *for a given alternative, it returns the noise generated by this alternative*
- $cos : \mathcal{A}lts \to \mathbb{D}^+$ *for a given alternative, it returns the cost of this alternative*

Indicators based on the agent state:

- $em : \mathcal{N} \to \{\top, \bot\}$ *is a function that represents if one agent has a medical emergency*
- $isOld, isFemale, isReadyToModalShift : \mathcal{N} \to \{\top, \bot\}$ *are functions that represent if one agent is old, is female, or is ready to modal shift*[4]
- $hasCar, hasECar, hasBike : \mathcal{N} \to \{\top, \bot\}$ *are functions that represent if one agent has a car, or has an electric car, or has a bike and are s.t. for each agent* $i \in \mathcal{N}$*, if* $hasCar(i) = \bot$ *then* $hasECar(i) = \bot$

Indicators based on the state of the environment:

- $isHealthCrisis, isRushHour, isTheNight \in \{\top, \bot\}$ *translate if there is a health crisis, if this is the rush hour, or if it is the night*

We formally define the state space (based on previously defined indicators) such as :

$$\mathcal{S}pInds = ((\mathbb{D}^+)^{\mathcal{A}lts \times \mathcal{N}})^4 \times (\{\top, \bot\})^{\mathcal{A}lts \times \mathcal{N}} \times (\{\top, \bot\}^{\mathcal{N}})^7 \times \{\top, \bot\}^3$$

In the sequel we consider the following notation :

$$\forall s \in \mathcal{S}pInds, \forall ind \in \mathcal{I}nds, s_{[ind]} = ind$$

This last notation translates for all $s \in \mathcal{S}pInds$, $s_{[t]} = t$ i.e. we return the part of the value of the component of vector that assigns the function which evaluates the duration of each alternative.

[4]For a sake of simplicity, we reduce to a small set of characteristics of the agent.

4. Argumentation-based framework for Decision Making

In this section we give the model of Amgoud and Prade [19] and their definitions of extensions w.r.t. their model. Secondly, we present our framework called ADP (Argumentation-based Decision Process) which extends their model. The main advantages of our framework are:

- The decision of an agent is contextualized w.r.t. the state thanks to its argumentation graph.
- The notion of arguments is abstract so that it can be easily extended to approaches that consider and explicit goals, or other argumentation approaches as e.g. logic-based argumentation [20].

4.1. Argumentation Framework for Decision Making

In order to map arguments to decisions, [17] extends the standard argumentation framework [5] to decisions. Arguments are mapped to supported decisions (i.e. pro arguments) and unsupported decisions (i.e. con arguments).

Definition 1. *An Argumentation Framework for Decision Making (AFDM) is a tuplet* $AFDM = (\mathcal{A}, \mathcal{R}, \mathcal{D}, \mathcal{F}_f, \mathcal{F}_c)$ *such that:*

- $\mathcal{A}$ *is a set of arguments*
- $\mathcal{R}$ *is a binary relation called* *attack relation*
- $\mathcal{D}$ *is a set of decisions (or actions)*
- $\mathcal{F}_f : \mathcal{D} \rightarrow 2^{\mathcal{A}}$ *is a function that assigns from* $\mathcal{D}$ *the set of pro arguments*
- $\mathcal{F}_c : \mathcal{D} \rightarrow 2^{\mathcal{A}}$ *is a function that assigns from* $\mathcal{D}$ *the set of con arguments*

We note $ADF(\mathcal{A}, \mathcal{D}) = 2^{\mathcal{A}} \times 2^{\mathcal{A} \times \mathcal{A}} \times 2^{\mathcal{D}} \times (2^{\mathcal{A}})^{\mathcal{D}} \times (2^{\mathcal{A}})^{\mathcal{D}}$ *the set of Argumentation-based Decision Framework based on a set of arguments* $\mathcal{A}$ *and a set of decisions* $\mathcal{D}$ *and consider:*

$$\forall a \in \mathcal{A}, \mathcal{F}_f^{-1}(a) := \{d \in \mathcal{D} : a \in \mathcal{F}_f(d)\}, \mathcal{F}_c^{-1}(a) := \{d \in \mathcal{D} : a \in \mathcal{F}_c(d)\}$$

A semantics of argumentation frameworks is given by the notion of extensions [5]. Extensions characterize which arguments are considered as admissible in regard to the argumentation graph.

Definition 2 (Extensions)**.** *Let* $(\mathcal{A}, \mathcal{R}, \mathcal{D}, \mathcal{F}_f, \mathcal{F}_c)$ *be an AFDM,* $S \subseteq \mathcal{A}$ *be a set of arguments.*

- S *is an* *admissible extension* *iff* S *is conflict-free and all arguments* $A \in S$ *are acceptable w.r.t.* S*.*
- S *is a* *complete extension* *iff* S *is admissible and contains all acceptable arguments wrt* S*.*
- S *is a* *grounded extension* *iff* S *is a minimal complete extension wrt* $\subsetneq$ *i.e.* $\nexists S' \subseteq \mathcal{A}$ *s. t.* $S' \subsetneq S$*,* S' *is a complete extension.*
- S *is a* *preferred extension* *iff* S *is a maximal admissible extension wrt* $\subsetneq$*.*
- S *is a* *stable extension* *iff* S *is conflict-free, and* $\forall A \in \mathcal{A} \setminus S$*,* $S\mathcal{R}A$*.*
- S *is an* *ideal extension* *iff* S *is a maximal admissible extension wrt* $\subsetneq$ *that is included in all preferred extensions.*

Let us notice that in the general case there is no consensus about which extension semantics to use. However as suggested in [21] some extensions can be considered as more preferable due to their uniqueness, e. g. the grounded or the ideal extension.

4.2. Argumentation-based Decision Process

The Argumentation-based Decision Process (ADP) framework incorporates argumentation theory to model the decision-making process, enabling the selection of decisions based on argument extensions derived from the argumentation graph.

Thus, the system is fully described by a set of agents $\mathcal{N}$, a set of states $\mathcal{S}$, a set of arguments $\mathcal{A}$ and a set of decisions $\mathcal{D}$ or actions that agents can do. In the sequel, we define an argumentation-based decision process for one agent $i \in \mathcal{N}$. A function σ defines for each state $s \in \mathcal{S}$, an instance of Amgoud and Prade's model i.e. a subset of possible decisions $\mathcal{D}' \subseteq \mathcal{D}$ that in s the agent can do, a subset of arguments $\mathcal{A}' \subseteq \mathcal{A}$ which are verified in s, a set of (un)supported decisions $\mathcal{F}'_f$ ($\mathcal{F}'_c$), and a set of attacks $\mathcal{R}'$ that are generated by the semantics of each argument in $\mathcal{A}'$. Then, a function ϵ defines the extension semantics which is used by the agent to compute her stationary politics π. Since there is no concensus about how to compute the "winning" set of arguments based on a particular extension semantics (and so the decision), we let abstract and consider rather an heuristic function h which defines the computation method to choose a decision based on an extension semantics. Thus, we assume that the politic of the agent (which is stationary) is fully defined by this heuristic function i.e. $\pi = h$. The stationary policy function ensures that a decision is chosen from the available options for each state in a consistent manner w.r.t. the set of admissible arguments.

Definition 3. *An Argumentation-based Decision Process (ADP) is a tuplet* $ADP = (\mathcal{S}, \mathcal{A}, \mathcal{D}, \sigma, \epsilon, \pi)$ *such that :*

- $\mathcal{S}$ *is a no-empty set of states*
- $\mathcal{A}$ *is a no-empty set of arguments*
- $\mathcal{D}$ *is a no-empty set of decisions (or actions)*
- $\sigma : \mathcal{S} \to ADF(\mathcal{A}, \mathcal{D})$ *is a function s.t.* $\forall s \in \mathcal{S}, \sigma(s) = (\mathcal{A}', \mathcal{R}', \mathcal{D}', \mathcal{F}'_f, \mathcal{F}'_c)$ *where :*
  - $\mathcal{A}' \subseteq \mathcal{A}$ *is a subset of arguments associated with state* s *and we note* $\sigma_{[\mathcal{A}]}(s) = \mathcal{A}'$
  - $\mathcal{R}' \subseteq \mathcal{A}' \times \mathcal{A}'$ *represents the set of attacks between arguments in* $\mathcal{A}'$ *and we note* $\sigma_{[\mathcal{R}]}(s) = \mathcal{R}'$
  - $\mathcal{D}' \subseteq \mathcal{D}$ *is a subset of decisions associated in a state* s *and we note* $\sigma_{[\mathcal{D}]}(s) = \mathcal{D}'$
  - $\mathcal{F}'_f : \mathcal{D}' \to 2^{\mathcal{A}'}$ *and we note* $\sigma_{[\mathcal{F}_f]}(s) = \mathcal{F}'_f$ *and* $\sigma_{[\mathcal{F}_f^{-1}]}(s) = \mathcal{F}'^{-1}_f$ *is a function that assigns a set of pro arguments for each decision in* $\mathcal{D}'$ *in a state* s
  - $\mathcal{F}'_c : \mathcal{D}' \to 2^{\mathcal{A}'}$ *and we note* $\sigma_{[\mathcal{F}_c]}(s) = \mathcal{F}'_c$ *and* $\sigma_{[\mathcal{F}_c^{-1}]}(s) = \mathcal{F}'^{-1}_c$ *is a function that assigns a set of con arguments for each decision in* $\mathcal{D}'$
- $\epsilon : 2^{\mathcal{A} \times \mathcal{A}} \to 2^{2^{\mathcal{A}}}$ *is a function that, from an argumentation graph, returns the set of extensions*

- *$\pi : \mathcal{S} \rightarrow \mathcal{D}$ is a stationary politic s.t. $\forall s \in \mathcal{S}, \pi(s) = h_s(\epsilon(\sigma_{[\mathcal{R}]}(s)))$ where $h_s : 2^{2^{\mathcal{A}}} \rightarrow \mathcal{D}$ is a function s.t. each chosen decision belongs to the set of extensions given by the AFDM:*

$$\forall \mathcal{E} \subseteq 2^{\mathcal{A}}, h_s(\mathcal{E}) \in \{d \in \mathcal{D} : d \in \sigma_{[\mathcal{D}]}(s)\}$$

We now present how this model is applied in our proof-of-concept. The implemented model has 22 arguments, and for a sake of readability, we do not present all of these arguments in this article but only 4 of them.

Application. *Let consider the following $ADP = (\mathcal{S}, \mathcal{A}, \mathcal{D}, \sigma, \epsilon, \pi)$ where $\mathcal{S} = \mathcal{S}pInds$ and $\mathcal{D} = \mathcal{A}lts$. We consider a set of arguments $\mathcal{A}$ and we assume in our study case that σ is such that for all $s \in \mathcal{S}$ and for each agent $i \in \mathcal{N}$:*

- *A. hC := "agent i has no car" ; C. hB := "agent i has no bike",*

  ***Activation** : $hC \in \sigma_{[\mathcal{A}]}(s)$ iff $s_{[hasCar]}(i) = \bot$ and $hB \in \sigma_{[\mathcal{A}]}(s)$ iff $s_{[hasBike]}(i) = \bot$*

  ***Pros** : $\sigma_{[\mathcal{F}_f^{-1}]}(s)(hC) = \sigma_{[\mathcal{F}_f^{-1}]}(s)(hB) = \emptyset$*

  ***Cons** : $\sigma_{[\mathcal{F}_c^{-1}]}(s)(hC) = \sigma_{[\mathcal{F}_c^{-1}]}(s)(hB) = \emptyset$*

  ***Attacks** : $\forall(a, d) \in \{(hB, bike), (hC, car)\}, \{(a, x) : x \in \sigma_{[\mathcal{F}_f]}(s)(d)\} \subseteq \sigma_{[\mathcal{R}]}(s)$*

  ***Meaning** : If she has no car (resp. no bike), then hC (resp. hB) is verified. It is not in favor, or against any alternative and attacks all verified arguments that supports one of these alternatives.*

- *iAE := "it is a medical emergency"*

  ***Activation** : $iAE \in \sigma_{[\mathcal{A}]}(s)$ iff $s_{[em]}(i) = \top$*

  ***Pros** : $\sigma_{[\mathcal{F}_f^{-1}]}(s)(iAE) = \{d \in \sigma_{[\mathcal{D}]}(s) : \neg\exists x \in \sigma_{[\mathcal{D}]}(s), s_{[t]}(i)(x) > s_{[t]}(i)(d)\}$*

  ***Cons** : $\sigma_{[\mathcal{F}_c^{-1}]}(s)(iAE) = \sigma_{[\mathcal{D}]}(s) \setminus \sigma_{[\mathcal{F}_f^{-1}]}(s)(iAE)$*

  ***Attacks** : $\{(iAE, x) : x \in \sigma_{[\mathcal{A}]}(s), \sigma_{[\mathcal{F}_f^{-1}]}(s)(x) \cap \sigma_{[\mathcal{F}_c^{-1}]}(s)(iAE) \neq \emptyset\} \subseteq \sigma_{[\mathcal{R}]}(s)$*

  ***Meaning** : If there is a medical emergency, then iAE is verified. It is in favor of all alternatives that are the quickest, against the others and attacks all verified arguments that are in favor of at least one alternative that is not the quickest.*

- *cRA := "the car alternative crosses the regulated area"*

  ***Activation** : $cRA \in \sigma_{[\mathcal{A}]}(s)$ iff $s_{[reg]}(i)(car) = \top$, $s_{[hasCar]}(i) = \top$ and $car \in \sigma_{[\mathcal{D}]}(s)$*

  ***Pros** : $\sigma_{[\mathcal{F}_f^{-1}]}(s)(cRA) = \emptyset$*

  ***Cons** : $\sigma_{[\mathcal{F}_c^{-1}]}(s)(cRA) = \{car\}$*

  ***Attacks** : $\{(cRA, x) : x \in \sigma_{[\mathcal{F}_f]}(s)(car)\} \subseteq \sigma_{[\mathcal{R}]}(s)$*

  ***Meaning** : cRA is verified when the alternative car crosses a regulated area while it should be forbidden. It attacks all arguments in favor of car.*

- *iEx := "it is too much expensive for agent i when $s_{[cos]}(i)(d) > \theta_i^c(s)(d)$" with $d \in \mathcal{D}$ and $\theta_i^c(s) : \mathcal{D} \rightarrow \mathbb{D}^+$ a function to set a threshold for what the agent considers as too much expensive*

  ***Activation** : $iEx \in \sigma_{[\mathcal{A}]}(s)$ iff $\exists d \in \sigma_{[\mathcal{D}]}(s)$ s.t. $cos(i)(s)(d) > \theta_i^c(s)(d)$*

  ***Pros** : $\sigma_{[\mathcal{F}_f^{-1}]}(s)(iEx) = \{d \in \sigma_{[\mathcal{D}]}(s) : \theta_i^c(s)(d) > s_{[cos]}(i)(d))\}$*

  ***Cons** : $\sigma_{[\mathcal{F}_c^{-1}]}(s)(iEx) = \{d \in \sigma_{[\mathcal{D}]}(s) : s_{[cos]}(i)(d) > \theta_i^c(s)(d)\}$*

  ***Attacks** : $\{(iEx, x) : \exists d \in \sigma_{[\mathcal{F}_c^{-1}]}(s)(iEx), x \in \sigma_{[\mathcal{F}_f]}(s)(d)\} \subseteq \sigma_{[\mathcal{R}]}(s)$*

Meaning *: iEx is verified when at least one alternative is above the threshold of acceptability of agent i in regard to her budget. It attacks all arguments that supports one alternative which is not in the threshold of acceptability.*

It is worth noting that attacks hold more weight in the decision-making process compared to simply considering a list of pros and cons. This is because a single attack can invalidate an argument and subsequently remove it from the extensions, thus impacting the agent's deliberation process for making choices.

Furthermore, this model could be easily extended to get a more realistic models by considering other arguments as e.g. "I'm relocating", "I'm the police", "I prefer biking", "There is no bicycle network", "There is no bus at this hour", etc.

5. Experimental results

In this section, we provide an application of the framework to simulate the modal shifting. We present the results obtained from our experiments, starting with an explanation of the various scenarios tested. Then, we provide an example of an argumentation graph generated for one agent. Finally, we demonstrate how decision-making based on argumentation can be utilized to evaluate the evolution of the overall transportation network.

5.1. Implemented scenarios

We aim to enhance the simulation of regulating a multimodal transportation networks, consisting of a car, bus, walk, and bicycle network, each with distinct characteristics such as average speed, environmental impact, financial cost, and noise level. Specifically, we focus on regulating the car network, which involves determining certain areas where cars are either allowed or prohibited from accessing. We present the parameters considered in two network configurations: namely, a configuration without regulated areas and another with regulated areas (LEZ). In both, we assume there are 5000 traveler agents, no health crisis, and it is rush hour. The objective of a traveler agent is to choose the most appropriate transportation mode. We also establish some thresholds based on these assumptions e.g. 90% have a bike and 100% a car, 30% of them have an electric car, 40% are ready to modal shift, 20% are senior, 10% are emergencies. The threshold for the acceptability w.r.t. time i.e. $\theta_i^t(s)(d)$ is set arbitrary as the following : if the travel time is greater than $1.2 \times t_{min}$ then it is unacceptable. The noise threshold $\theta_i^n(s)(d)$ should not exceed 1.0. The quantity of pollution, θ_i^p should not exceed 9.0, the cost becomes unacceptable when the cost is greater than $\theta_i^c(s)(d) = 0.2$ and the distance is unacceptable when it is greater than $\theta_i^l = 200.0$. We consider 6 scenarios:

- Without LEZ: the objective is to evaluate the impact of taking into account the context in the distribution of the travelers per networks considering a classical multimodal network.
  - s_1: the traveler agents decide by considering the quickest alternative, i.e. a monocriteria decision process.
  - s_2: the traveler agents decide with the proposed ADP.

- With LEZ: the objective is to evaluate if our model is efficient to understand the traveler decision process for the transportation modal shift.
  - s_3: the traveler agents choose the quickest alternative. The comparison with s_1 will give information about the quality of the decision criteria to understand the consequences of the LEZ definition.
  - s_4: the agents decide with an ADP. The comparison with s_2 will give information about the quality of the decision criteria to understand the consequences of the LEZ definition.
  - s_5: the traveler agents decide with the ADP defined in s_4 but the distance acceptance has been reduced. The comparison with s_4 should show an increase of the modes with the shortest distance.
  - s_6: the traveler agents decide with the ADP defined in s_5 but the pollution acceptance has been reduced. The comparison with s_5 should show an increase of the least polluting modes.

5.2. From the point of view of one agent

After running the scenario s_4 (ADP+LEZ), we illustrate an argumentation graph of one agent. Its characteristics are given by : $s_{[em]}(i) = \bot$, $s_{[isOld]}(i) = \bot$, $s_{[isRTMS]}(i) = \bot$, $s_{[hasCar]}(i) = \top$, $s_{[hasECar]}(i) = \bot$, $s_{[hasBike]}(i) = \top$.

Application. *If $\mathcal{G}rd(\sigma_{[\mathcal{R}]}(s))$ is the computed grounded extension from the argumentation graph $\sigma_{[\mathcal{R}]}(s)$ where s represents the current state, then, we define the scoring function $scr_1 : \sigma_{[\mathcal{D}]}(s) \rightarrow \mathbb{R}$ such that for all decisions $d \in \sigma_{[\mathcal{D}]}(s)$:*

$$pros(d) = |\mathcal{G}rd(\sigma_{[\mathcal{R}]}(s)) \cap \sigma_{[\mathcal{F}_f]}(s)(d)|$$
$$cons(d) = |\mathcal{G}rd(\sigma_{[\mathcal{R}]}(s)) \cap \sigma_{[\mathcal{F}_c]}(s)(d)|$$

$$scr\ (d) = \begin{cases} \frac{pros(d)}{pros(d)+cons(d)} & \textit{if } pros(d) + cons(d) \neq 0 \\ 0 & \textit{otherwise} \end{cases}$$

We compute the scores by considering the argumentation model given in Application 4.2. The result of the computed argumentation graph is depicted in Table 2. Then, by computing the grounded extension, we get: $\mathcal{G}rd(\sigma_{[\mathcal{R}]}(s)) = \{\{5, 17\}\}$. To deal with equalities, we assume the following order for agent i: $Bus > Bike > Walk > Car$. For a sake of simplicity we decided to set this order arbitrary. In this setting, the agent chooses the car alternative by avoiding the regulated area since $scr(Car) = 1$ while for other alternatives X, we have $scr(X) = 0$.

5.3. From a global perspective: how individual explicit decision processes may be manipulated to influence the system

We analyze the impact of a LEZ on agents considering scenarios s_1, s_2 (ADP), s_3 (LEZ), s_4 (ADP+LEZ), s_5 (ADP+LEZ), s_6 (ADP+LEZ). The Table 1 presents the distribution of the travelers between the transportation modes according to several scenarios. Here we compare the scenarios to illustrate three advantages of our approach. In each of them, travelers have to choice the transportation modes corresponding to their preferences with or without considering LEZ.

Scenario	Car	Bike	Walk	Bus
s_1	1	0	0	0
s_2	0,4944	0,304	0,163	0,0386
s_3	0,9502	0,005	0	0,0448
s_4	0,4408	0,297	0,163	0,0992
s_5	0,48	0,2678	0,1632	0,089
s_6	0,4454	0,2348	0,1742	0,1456

Table 1
Distribution of the travelers per transportation mode

Is our approach adapted to reproduce the diversity of travelers' modal choices? The scenario s_1 considers that travelers choose the quickest trip without other parameters while the travelers in s_2 decide according to the argumentation model presented in section 5.1. Here, the result show that with the only decision criteria based on time it is not possible in this example to have a real multimodal system, the car alternative is always the fastest transportation mode. The argumentation model is closer to the reality.

Is our approach efficient to understand the consequences of the network regulation on multimodal travelers' modal choices? The scenarios s_3 and s_4 are respectively similar to s_1 and s_2 expected that a LEZ is deployed. We can observe for both the same evolution with the transfer of around 5% of travelers from the car mode to the bus mode. The advantage of our proposal is that this transfer being based on a more realistic initial distribution we observe a multimodal traffic that is more balanced between modes.

Is our approach adapted to understand the consequences of traveler behaviors on the transportation system? The scenario s_5 is based on s_4 (LEZ deployed and ADP) with the modification of the distance constraint argument (θ_i^l) which is reduced to 0. It means that travelers prefer the shortest trips. We observe that there is a shift of travelers towards the car mode to reach a value close to that of s_2. This illustrates that the decision is the result of a compromise, as the majority of travelers do not shift.

The scenario s_6 is based on s_5 with the reduction of the tolerance of the pollution (θ_i^p). This argument counter balances partially the one of the distance. The result is a percentage of travelers choosing the car mode that is similar to s_4 and an increase of the traveler choosing the bus mode. This last mode is a good compromise between the distance and pollution arguments.

6. Conclusion

In this article, we have presented an argumentation-based decision process framework for modeling the decision-making process of urban travelers. To demonstrate the feasibility of our framework, we have provided a proof-of-concept by instantiating the model with arguments that could be considered in a modal shifting.

It is important to highlight that our current model lacks of realistic data on real behavior of urban travelers, and we acknowledge that it represents a preliminary effort in this direction. In future research, we plan to enhance our framework by incorporating e.g. web-based data and considering more statistical data. We believe that it will provide more accurate insights into the decision-making process of agents and will provide more realistic results.

By combining our framework with comprehensive and up-to-date web data, we anticipate that our model will offer a deeper understanding of urban travelers' decision processes, ultimately leading to more effective strategies for promoting responsible modal choices in transportation.

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ArgID	Name	Attacks	F_f^{-1}	F_c^{-1}
1	AvoidAnyContactWhenThereIsHealthCrisis	$\{\}$	$\{D4, D2\}$	$\{D1\}$
5	TimeDurationAcceptability	$\{16, 9, 7, 6, 10, 12, 11\}$	$\{D4\}$	$\{D1, D3, D2\}$
6	CanAlwaysWalk	$\{\}$	$\{D3\}$	$\{\}$
7	CannotTravelLongDistance	$\{15, 16, 9, 13, 6, 12, 11\}$	$\{D4, D1\}$	$\{D3, D2\}$
9	BikeIsAnEfficientWayForTransportation	$\{\}$	$\{D2\}$	$\{\}$
10	NoiseAcceptability	$\{\}$	$\{D1, D3, D2\}$	$\{D4\}$
11	PollutionThresholdIsNotAcceptable	$\{5, 1, 20, 16, 7, 10\}$	$\{D3, D2\}$	$\{D4, D1\}$
12	TooMuchExpensive	$\{5, 1, 20, 16, 7, 10\}$	$\{D3, D2\}$	$\{D4, D1\}$
13	IsRushHour	$\{\}$	$\{D3, D2\}$	$\{D4\}$
15	BikingAndWalkingIsGoodForYourHealth	$\{\}$	$\{D3, D2\}$	$\{\}$
16	ItIsAResponsibleWayOfTransportation	$\{\}$	$\{D1, D3, D2\}$	$\{D4\}$
17	NotReadyToModalShift	$\{1, 15, 20, 16, 9, 7, 13, 6, 10, 12, 11\}$	$\{\}$	$\{\}$
20	TheWeatherIsNotGood	$\{\}$	$\{D4, D1\}$	$\{D3, D2\}$

Table 2
Argumentation graph for the agent i's decision

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