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# A multi-agent system approach to dynamic ridesharing for older people – State-of-the-art work and preliminary design

I. Lohja<sup>1,2</sup>, Y. Demazeau<sup>3</sup>, C. Verdier<sup>1</sup>

<sup>1</sup> Univ. Grenoble Alpes, LIG, 38000 Grenoble, France

<sup>2</sup> Mobicoop, 54000 Nancy, France

<sup>3</sup> Univ. Grenoble Alpes, CNRS, LIG, 38000 Grenoble, France

iris.lohja@univ-grenoble-alpes.fr

## Abstract

*Ridesharing has disrupted the entire transport sector in the last decade, causing a cultural shift in the general population, but not so much in the older generations. In a previous paper, we proposed a multi-agent systems (MAS) approach for modelling and building an innovative ridesharing service tackling this lack of utilisation by older people. After having identified the obstacles that are impeding this utilisation, we dealt with each through MAS techniques. In this paper, we investigate the state of the art around these MAS techniques and describe the competing models for modelling each component of our multi-agent system, IMOPOP.*

## Keywords

*ridesharing, multi-agent systems, agent-based modelling.*

## Résumé

*Le covoiturage a perturbé le secteur des transports au cours de la dernière décennie, provoquant un changement culturel dans la population générale, mais pas tant dans les générations plus âgées. Dans un article précédent, nous avons proposé une approche multi-agents (SMA) pour la modélisation et la construction d'un service de covoiturage innovant pour remédier à ce manque d'utilisation par les personnes âgées. Après avoir identifié les obstacles qui entravent cette utilisation, nous les avons traités à travers des techniques SMA. Dans cet article, nous étudions l'état de l'art autour de ces techniques SMA et décrivons les modèles concurrents pour modéliser chaque composant de notre système multi-agents, IMOPOP.*

## Mots-clés

*covoiturage, systèmes multi-agents, modélisation agents.*

## 1 Introduction

Ridesharing has seen a lot of new advancements over the recent years, introduced by companies such as Uber in the international scene, and BlaBlaCar in France. Ridesharing is a service that offers one-way or two-way transportation to multiple participants on short notice. There are various reasons to use ridesharing : to reduce financial costs, carbon dioxide ( $CO_2$ ) emissions and traffic congestion ; to

stay mobile ; to interact with other people ; all resulting in significant environmental and social benefits. Ridesharing has also provided a solution for the lack of car and public transport, and has increased the level of mobility independence. But unless there is willingness to participate and trust in ridesharing, a ridesharing service is not effective. We showed this to be true for the ridesharing service of French ridesharing company Mobicoop [33]. The company's data analysis revealed that older people<sup>1</sup> is the population *stratum* that uses its ridesharing service the least. Furthermore, researching the French ridesharing industry, we came to the conclusion that older people were not utilising<sup>2</sup> other ridesharing services either. Having said that, we define our research problem to be : how can we build a complete ridesharing service that older people will utilise ? To tackle this problem, we take on a multidisciplinary approach combining method engineering, artificial intelligence (AI), business models, public policies, and digital inclusion. In this paper, we address our research problem from the AI point of view, investigating the state of the art around the techniques that we consider in our work. We propose to construct a multi-agent system. Mobility services are inherently multi-agent, due to a large number of geographically distributed passengers, drivers, vehicles, and service providers. Moreover, a MAS approach allows for modularity, flexibility, autonomy, and scalability of the system.

We currently employ ridesharing as the only transport mode. What makes our context special is that older people do not generally have fixed daily activities, such as school or work, but rather sporadic and sometimes urgent activities. So, we are not dealing with conventional static ridesharing but with real-time or dynamic ridesharing<sup>3</sup>. Older people might also change their minds easily and often, especially if their confidence in the service, in the driver and in the co-riders is not ensured. Furthermore, other crite-

1. We consider older people to be people of 60+ years old.

2. Utilisation implies the action of making effective use of the service.

3. Dynamic ridesharing, unlike static ridesharing, includes single or recurring ridesharing trips with no fixed schedule, organised on a one-time basis, with a matching of participants taking place up until their departure time.

ria such as gender of and acquaintanceship with co-riders and smoking, which research have shown to be important constraints in ridesharing [31, 21], are amplified for older people.

The paper is organised as follows : next section gives a brief overview on the approaches for transport demand modelling and agent-based modelling. Section 3 presents our multi-agent model of the ridesharing system. Section 4 concludes the paper and discusses perspectives for future work.

## 2 Related Work

The study of transport systems has started with the analytical modelling methodology [24]. Analytic models are based on mathematical programming and continuous approximations., what makes these models too abstract for expressing some elements of various transport systems. To deal with the abstract nature of these models, simulation modelling was introduced [39]. Simulations are a powerful tool for analysing the behaviour of transport systems, but centralizing it, limits the interactions and negotiations among individual actors. The agent-based simulation paradigm [30] is used to overcome this shortcoming.

One important aspect of transport system modelling is the modelling of travel demand and behaviour. Travel behaviour research studies the physical movement of people outside their reference locations, i.e., the place a person returns to at the end of the day, for any activity. Two types of approaches to understanding travel behaviour that have prevailed over the years include trip-based approaches [35] and activity-based approaches [23]. The conventional trip-based approaches place trips as the fundamental unit of analysis and include four steps : trip generation, trip distribution, mode choice, and route choice. These approaches explicitly ignore the spatial and temporal constraints of travel behaviour, along with the fact that travel demand derives from the demand for activity participation. These weaknesses make trip-based approaches not adapted to our context. Activity-based approaches, on the other hand, consider decisions concerning the activities that trigger the demand for travel. These decisions include decisions on participation, place, time, duration, and co-riders. This type of approaches has begotten several conceptual frameworks and mathematical models, but it has failed to get the attention of empirical transport research.

Agent-based simulation and activity-based modelling are popular approaches in transport research [5]. Some relevant tools include MATsim [1] and STARCHILD [41]. However, because these simulations treat travellers as passive data structures updated synchronously at infrequent time intervals, they fail to take account of frequent within-the-day decisions and negotiations which are necessary for a dynamic system such as the ridesharing system. In order to cover for these drawbacks, the fully agent-based approach is used. The AgentPolis platform uses this approach for modelling multi-modal transport systems [26] and for implementing ridesharing models [19, 27]. In the former,

AgentPolis provides support for modelling the environment and agent-environment interactions, but the support for modelling agent behaviour is relatively basic; in the latter, machine learning methods are used to quantify the potential of ridesharing in reducing traffic load and total vehicle miles travelled.

Related work in ridesharing has been mainly on ride-matching problems [20, 25], inter-modality and multi-modality [38, 44, 46], risks associated with ridesharing [17, 32], and privacy issues [3, 49]. Others opted for Decision Support Systems (DSS). [13] proposed a DSS for the organisation of the transportation of cruise passengers in a touristic city, addressing multiple goals simultaneously : limiting traffic congestion, maximizing tourism penetration, limiting the impact on the city transportation capacity.

## 3 Multi-agent model of a ridesharing ecosystem

A ridesharing ecosystem is composed of humans interacting through a software application. Typically, a user in a ridesharing application could be both a driver and a passenger, even at the same time, but for different rides. This adds a dynamic organisation to our ecosystem. Additionally, a driver and a passenger could have different objectives when offering or requesting a ride. These include mainly the need for transport and lower costs for passengers, and lower costs, environmental issues and desire to help for drivers.

In this section, we take on a MAS approach and represent our ecosystem as a multi-agent system, which we call IMOPop, where the agents represent the users of the ecosystem. In Subsection 3.1, we first describe shortly the obstacles that we have found to be blocking older people from using ridesharing services. Then, in Subsection 3.2, we investigate existing MAS techniques to deal with the identified obstacles, and MAS models to model each component of IMOPop.

### 3.1 Analysis of the ridesharing ecosystem

Prior to the work presented here, we used a continual innovation method to analyse the ridesharing ecosystem with the objective of identifying, among others, the relevant actors and their functions [33]. Then, through interviews and focus groups, we diagnosed the ecosystem and found three major Blocking Points (BP) : trust, user preferences and accompaniment. The trust BP refers to older people's tendency to not trust strangers, which strongly affects their participation in ridesharing. The user preferences BP encompasses the very specific and well-determined preferences of older people, e.g., strong feelings against smoking in the car, preference of travelling with a female driver. The accompaniment BP deals with some older people's need for some level of assistance to e.g., get in and out of the car or to be accompanied to their place of origin and destination. Here, we deal only with the first two BPs, as addressing the accompaniment BP is not within the scope of this paper (this has been done in [33]). In the next sub-

section, we first present the methodology for building our multi-agent system, then we model each of its components.

## 3.2 IMOPOP – Architectural Design

### 3.2.1 Methodology

In [10], a population in a multi-agent system is described as consisting of the set of agents that inhabit it, along with the set of their possible behaviours and the set of interactions that they can have. We classify different types of actors in the ridesharing ecosystem into different agent populations in IMOPOP due to their different characteristics. As a result, we have three agent populations : drivers, passengers and intermediaries. Intermediaries include people, associations and organisations that act as an intermediary between the passenger (the older person) and the driver. The agents interact among them and with organisations in the MAS through coordination mechanisms. Coordination is defined as the management of dependencies between activities [34]. According to [48], these dependencies can be of various types, and the type of dependencies influences the choice of the coordination paradigm for the MAS. Most of the coordination paradigms are centred on one or some of the MAS components. In order to consider the dynamics at the level of each component, we use the Vowels paradigm [11], which offers a componential view of a MAS.

### 3.2.2 Modelling

One of the main elements of the ridesharing ecosystem is the Ridesharing Software (RS). Jennings and Wooldridge argue that taking on an agent-oriented approach is adapted to complex real-world software systems [28]. A well-known conventional software development paradigm is object-oriented programming, which found a specialisation in the agent-oriented paradigm coined by Shoham [42]. To identify the components of IMOPOP, we use the AEIO toolboxes approach to agent-oriented programming (AOP), which identifies four main components – Agents, Environments, Interactions, and Organisations [9]. Our purpose in this subsection is to find the most appropriate model for modelling each MAS component, starting with the agents.

#### *Modelling agents*

In literature, there are various definitions of an agent in a multi-agent system depending on the application. In this paper, we adopt the generic definition given in [14], which defines the agent as “An entity which is placed in an environment and senses different parameters that are used to make a decision based on the goal of the entity. The entity performs the necessary action on the environment based on this decision.” The main agent in IMOPOP is the older person. Thus, for modelling the agents, we focus on modelling older people. For this, we start our research in the social sciences.

One of the social science theories often used in socio-technical systems is Activity Theory (AT) [47]. AT has been developed in two schools of thought with the common objective of understanding human behaviour. In its origins in Russia, AT specifies that the behaviour of humans can be understood by examining the activities and the

actions constituting the activities wherein people engage. It has been used to understand individual human behaviour by examining the relationship between the Individual, the Object and the Mediating Artefacts (tools), whereby each component affects the other and the activity as a whole [47]. In the Scandinavian school of thought, AT was reformulated by Engeström [16] by adding an interacting entity to the original scheme of Individual, Object and Mediating Artefacts – the Community. Engeström’s scheme includes notions from human-computer interaction theory as well. It has been used for analysing individuals and groups, mainly to understand how technologies are adopted and adapted through use in complex social situations [22, 29]. The first AT school of thought inspired many works on modelling social behaviour, including Clancey *et al.*’s [8]. Here, they develop a cognitive model relating goals, knowledge, behaviours, and social concepts in the Brahms modelling and simulation system [7].

A Brahms model formalises observations in order to have a systematic way of relating different sources of information and use them in work system design. To get a Brahms model, participant observation is necessary. In our context, it would be fairly impossible to capture the many possible situations and the emerging diverse behaviours, which leads our work towards Situation Theory [2].

Situation Theory is a theoretical approach, according to which a system is defined as the composition of situation-related concerns. To collect information about these concerns and to address the user preferences BP, we use the Hodges’ Health Career Model (H2CM) [15]. It is a model centred around the person, based on the situation, considering all contexts (or as many as possible), and allows for simple modelling. One of the main reasons why this model is adapted to our context is that it allows for individualism and holism at the same time.

We use H2CM to structure knowledge or features of older people around two axes – the vertical axis of individual and group and the horizontal axis of humanistic and mechanistic – which create four knowledge domains – Interpersonal, Sciences, Sociology, and Political. The vertical axis indicates our primary focus on the older person as an individual and as a group. The horizontal axis separates features into humanistic – related to the social aspect of the older person/people – and mechanistic – related to the technical aspects concerning the older person/people. Figure 1 shows the H2CM model for the passenger population, where we can see some features identified and classified into the four knowledge domains.

Modelling the passenger population with H2CM in IMOPOP helps to identify and include in the system their preferences and constraints, thus addressing the user preferences BP. A UML representation of a passenger agent is shown in Figure 2.

Table 1 compares the approaches we have considered for the modelling of the agents, according to our main criteria.

#### *Modelling the environment*

The environment in a multi-agent system is the place where

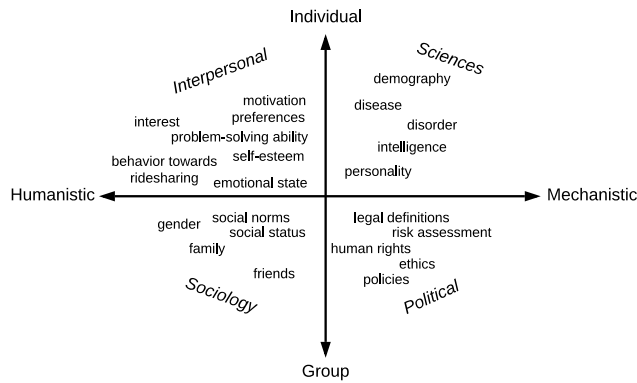


FIGURE 1 – Hodges' Health Career Model for older people. The positioning of features within a quadrant is irrelevant.

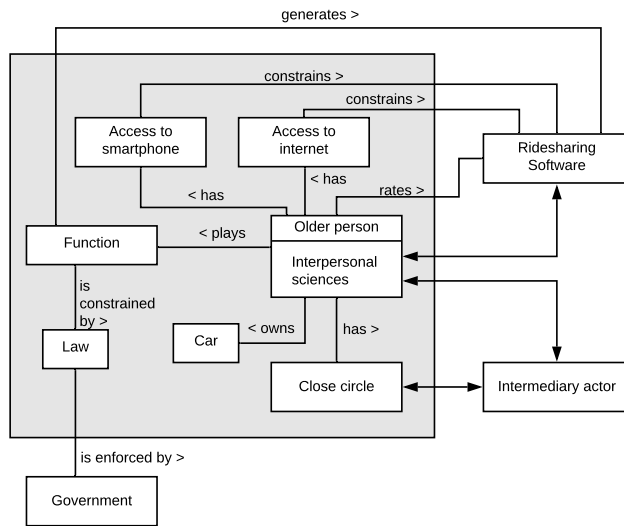


FIGURE 2 – UML representation of an older person agent in IMOPOP. The agent itself is shown in the grey square.

the agents are located [14]. An agent gathers information from the environment through its senses, which helps it in decision making. Different features of the environment affect the complexity of the MAS [48] – accessibility, determinism, dynamism, and continuity. The environment in IMOPOP is the physical world, where users interact through the RS. It is : inaccessible because agents sense incomplete and noisy data; non-deterministic because the outcome of agent actions cannot be entirely predictable; dynamic because the environment can change not only as a result of the actions of the agents; and continuous because the agents can enter any unlimited state. The different types of data that the agent can sense from the environment are referred to as parameters in our definition of an agent. These parameters concern Points Of Interest (POIs) for the agents, such as pharmacies, general practitioners, supermarkets, leisure time venues, and so on. They include

|                    | individual-focused | group-focused | situation-focused | user participation required |
|--------------------|--------------------|---------------|-------------------|-----------------------------|
| Activity Theory    |                    |               |                   |                             |
| - Russian SoT      | ✓                  | ✗             | ✗                 | ✓                           |
| - Scandinavian SoT | ✓                  | ✓             | ✗                 | ✓                           |
| Situation Theory   |                    |               | ✓                 | ✗                           |
| H2CM               | ✓                  | ✓             | ✓                 |                             |

TABLE 1 – Comparison between different approaches for the agent modelling on the basis of several criteria.

POIs' position, opening and closing hours; the distance of the agent from the nearest public transportation; and other additional information. Furthermore, we include in the environment the ridesharing market represented by the main (competitor) players.

#### Modelling organisation

Demazeau and Rocha Costa [10] use the process-oriented notion of organisation, defining an organisation in a multi-agent system as a set of organisational roles and organisational links. An organisational role is the set of the agent's behaviours which are part of the processes performed by a group of agents, while an organisational link is the mutual influence between agents in the group of agents performing a specific process in the system.

The agent organisation in IMOPOP is Mobicoop – the organisational roles of the agents in Mobicoop's global processes and the organisational links among them.

#### Modelling interactions

Agents in a multi-agent system interact in order to achieve an ultimate goal – a shared ride, in the case of IMOPOP. During interactions, agents are in contact with each other directly (e.g., a driver and a passenger agree, in person, on sharing a ride), through another agent (e.g., a driver and a passenger are put into contact with each other through an intermediary), or through the environment (e.g., through Mobicoop's RS). Agents can participate in different kinds of interactions [18]. According to goal compatibility, agents cooperate when their goals are compatible, or compete when their goals are incompatible. According to resource availability, agents are in conflict when resources are insufficient. According to agent ability, agents can collaborate when they have insufficient ability to reach their goals. Agents in IMOPOP have insufficient resources and skills to achieve their compatible goals. For this reason, they coordinate and collaborate with each other. We use an interaction model separately from the agent internal architecture. Beer *et al.* [4] discuss about the different forms that negotiation between agents can take – protocols, auctions and argumentation. Considering that our target group is older people, agents in IMOPOP should follow a very simple communication line, which should result in a mutually acceptable agreement. For this, the most appropriate form of negotiation are negotiation protocols, and the one that accomplishes this result with the minimum amount of communication is the Contract Net Protocol (CNP) [43]. CNP allocates tasks among autonomous agents in a typi-

cally spatially-distributed application, aiming to provide higher speed, reliability and extensibility in the application. The main problem in our application is the connection between agents with rides to be executed and the most appropriate agents to execute those rides. The contract net in our system is the set of agents in IMOPOP. Similarly to the user who can act as either a passenger or a driver, each agent can take on one of two roles, manager or contractor, but not both for a single interaction. For a particular interaction, one agent assumes the role of the manager – responsible for monitoring the execution of the ride – and another agent the role of the contractor – responsible for the actual execution of the ride. Typically, the manager announces the trips for which the passenger needs a ride. Then the contractor evaluates announcements for rides and bids on the ones suited to it. The manager receives the bids, evaluates them and awards a contract to the most pertinent contractor. The contract could be passed at the end of the first interaction, or the manager and the contractor can continue exchanging request and information messages, such as for adding a stop during the trip, once a contract has been awarded. The interaction is done by sending messages via the RS. These messages can be ride announcements, ride bids, ride contract awards, and others.

An example of an interaction between users in a ridesharing platform is given in Figure 3.

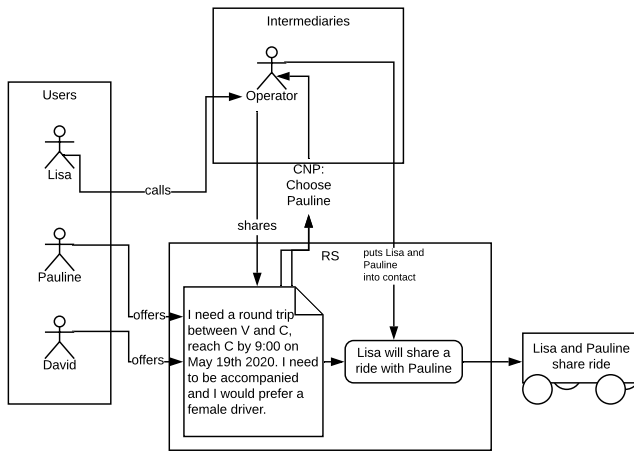


FIGURE 3 – Example of an interaction between users

Following, in Figure 4, we give the negotiation between the agents using CNP. Figure 4a shows a ride announcement message, where the Manager (for Operator) broadcasts its message for a ride to all the users of the RS, describing what Lisa needs (task abstraction), the criteria that a driver must meet in order to be able to submit a bid (eligibility specification), the expected form of a bid (bid specification), and the deadline for receiving bids from drivers (expiration time). We see in this message Lisa’s constraint and preference for the driver – willingness to accompany and female gender, respectively – which result from the modelling of Lisa as a passenger agent through H2CM. Figure 4b shows the bid message of the Contractor (for Pauline)

for the Manager’s announced ride. The same format follows the other contractor’s (representing David) bid message. These messages preserve the same bid format specified by the Manager in Figure 4a. The Manager, after considering both ride bids, determines that the one made by the Contractor (for Pauline) satisfies its constraint and preference, and awards a ride contract to it (Figure 4c). The Operator is notified about the contract award and subsequently puts Lisa and Pauline into contact.

**To: \***  
**From:** Manager (for Operator)  
**Type:** RIDE ANNOUNCEMENT  
**Contract:** 29-02-2020

**Task Abstraction:**  
 share ride  
 from V to C  
 round trip  
 accompaniment

**Eligibility Specification:**  
 must have proposed a ride  
 must be leaving from or through V  
 must be going to or through C  
 must arrive in C around 9:00

**Bid Specification:**  
 origin of the ride  
 destination of the ride  
 time of arrival at destination  
 willingness to accompany  
 gender

**Expiration time:**  
 28 February 2020, 23:59

(a) Ride announcement.

**To:** Manager (for Operator)  
**From:** Contractor (for Pauline)  
**Type:** BID  
**Contract:** 29-02-2020  
**Node Abstraction:**  
 origin is V  
 destination is C  
 arrival at 9:00  
 round trip  
 I am female  
 I can accompany

(b) Ride bid.

**To:** Contractor (for Pauline)  
**From:** Manager (for Operator)  
**Type:** AWARD  
**Contract:** 29-02-2020  
**Task Specification:**  
 origin is V  
 destination is C  
 arrival at 9:00  
 round trip  
 accompaniment

(c) Ride contract award.

FIGURE 4 – Three messages in the example of the contract net of users negotiating for a ride through a ridesharing software

### Modelling time

A passenger and a driver start negotiating for a ride at the time of negotiation. The negotiation can last for a short time or up until expiration time (as shown in Figure 4a). From the time of negotiation until the award of a ride contract, both passenger and driver could change their minds, availabilities, preferences, or constraints. For this reason, we add a clock in IMOPOP, which ensures that agents are intrinsically real-time. This concept comes from [42], where an agent is considered to have a mental state made of beliefs, capabilities, decisions, and obligations. At regular intervals, agents update their mental state based on previous changes (e.g., as a result of an interaction), and execute the commitments (e.g., a ride) for the current time. The clock makes sure that this two-step loop is initiated repeatedly at regular intervals. When a ride contract has been awarded, it means that at the time of execution, i.e., when the ride happens, the passenger, the driver, and either the driver’s or the passenger’s car are available<sup>4</sup>.

### Modelling urgency and importance

There could be many various activities why older people (and people in general) need a ride. We categorize these activities into five main groups : health (e.g., for a medical appointment), family (e.g., to visit their child), leisure

4. We consider the case when the passenger has her/his own car but does not drive it, for various reasons. In such a case, the person acting as driver can drive the passenger’s car.

(e.g., to go to the theatre), shopping (e.g., for groceries), and sports (e.g., for a walk). Furthermore, they could determine a sequence of activities to be done during one single ride (tour). When there is only one passenger in a ride, the driver accommodates to the passenger's prioritised list of activities (in the case of a tour). Two more complicated cases include : when two or more passengers ask for different rides with the same driver at the same time, and when two or more passengers ask for the same ride with one driver. In these cases, we set priorities to the activities according to their urgency and importance [12]. These concepts are, however, subjective. As a result, the driver cannot satisfy everybody's priorities, so he chooses one out of the passengers in the first case, and the order of destinations (corresponding to the passengers' activities) in the second. Here comes into play the concept of trust.

#### Modelling trust

Trust is a subjective belief. Trust, in our context, concerns mainly the passenger and includes trust in the ridesharing service, in the driver and in the co-riders.

Work on trust in ridesharing is still limited : [50] designs a ridesharing system allowing people to gain information on their co-riders through social media, [37] embeds a ridesharing system within an organisation to incorporate a basic level of trust, [6] deals with drivers' trust in passengers, [36] tackles the trust in the platform.

In the ridesharing industry, we have found various elements employed by companies for building trust. Companies such as Citygo<sup>5</sup> and Covoit'ici<sup>6</sup> incorporate a rating system. Even though they are used in many human-computer applications, rating systems suffer from two main shortcomings : insufficient ratings at the system's start and ratings' biased nature. Some companies go a step further : Citygo<sup>7</sup> rewards its users for giving their ratings, Keepmove<sup>8</sup> provides trust by allowing users to create customised communities, and Smiile<sup>9</sup> includes neighbours in the system while certifying that the ones on the platform are indeed neighbours in real life.

In MAS, passenger trust in the co-riders and the ridesharing platform are conceptualised as individual-level trust and system-level trust, respectively [40].

In IMOPop, we deal with the trust BP in four ways : by rating drivers and co-riders, a passenger can decide to either trust them or not based on their ratings ; by creating ridesharing communities with passengers and drivers, a passenger can (almost) completely trust members of her/his own community ; through the recommendation of her/his entourage, who is not necessarily a ridesharing participant, it becomes easier for a passenger to trust ; and through intermediaries, which are informed about the trustworthiness of ridesharing participants. Trust levels tend to differ in time. But depending on the means mentioned above, we can say that trust remains relatively static when built

through intermediaries (people will always trust intermediaries) ; trust built through communities is semi-dynamic ; trust built through ratings and people's recommendations is dynamic. Moreover, the dynamic evolution of the system brings along a possible change in the passenger trust in the ridesharing platform.

## 4 Conclusion and Future Work

The main objective in our work is to provide a ridesharing service that will be effectively used by older people. In another paper [33], we have shown that the older population hesitates to use ridesharing services and we have put forth three main blocking points for this utilisation – lack of trust in the service, driver and/or the co-riders ; very specific preferences which are sometimes difficult to be met ; and need for assistance. We have proposed to innovate in a ridesharing service by adopting MAS techniques. We have also proposed to model the ridesharing ecosystem as a multi-agent system, which we called IMOPop.

In this paper, we discussed about various MAS techniques for dealing with the first two blocking points. Viewing our multi-agent system as componential, we considered various models for modelling each of its components. We used the socio-technical Hodges' Health Career Model, which originates from the social care domain but we still described as it is crucial for IMOPop. It is used to model the older people as the agents in the system, addressing the user preferences blocking point. Given that we consider ridesharing as activity-based, we discussed about activities and proposed modelling the urgency and importance of these activities in the system. In the environment, we modelled agents' points of interest and the main players in the ridesharing market. Agents in IMOPop interact using the Contract Net Protocol. Time dynamics is modelled through a clock which makes agents intrinsically real-time. Finally, we addressed the trust blocking point by proposing four different means for building trust in IMOPop.

Future work includes the formalisation of IMOPop with a meta-model, the agent-based simulation using various scenarios and ultimately their validations. Afterwards, we will incorporate a business model into the multi-agent system and run other simulations.

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