A Preliminary Study for an Agent Blockchain-Based Framework Supporting Dynamic Car-Pooling

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***Abstract*—In the last decades, private cars caused an increasing growth of urban traffic flows all over the world with a consequent increase of environmental pollution and road congestion. In this context, Car-Pooling is an alternative car-based solution for private mobility that optimizes the car loading factor with respect to the number of passengers, although it requires that all the participants share trip origin and destination at the same time. To make the system more appealing, an on-demand service adopting variable fares on the basis of trip length and number of participants is proposed in this paper. Multi-agent, reputation and blockchain technologies are used and a suitable dynamic routing algorithm has been developed. Experiments on simulated data prove the potentiality of this approach.**

***Index Terms*—Car-Pooling, Multi-Agent System, Reputation System.**

I. Introduction

Nowadays, most part of urban traffic flows all over the world is due to private cars. In the last decades, they caused increasing costs for congestion, fuel consumption, travel time and health among the others [1]–[6], in a context where the majority of the vehicles move only their drivers.

To reduce the use of private cars, a wide range of strategies has been developed by local, national and overnational (e.g., the European Union) authorities. Most part of the actions adopted inside urban areas rely on policies for (*i*) discouraging the use of private cars by introducing restrictions as well as increasing their operational costs [7]–[13] and (*ii*) improving and promoting transit [14]–[16]. However, people continue to perceive private cars as more comfortable and flexible than transit thanks to the absence of constraints on time and space (e.g., fixed stops and timetables) that, conversely, characterize transit [17].

In the scenario above described, alternative forms of mobility still based on the use of cars are car-sharing (CS) and car-pooling (CP) systems. The CS is a *Pay-As-You-Use* modality mainly adopted for short trips in urban areas, while in the CP two or more users that make frequently the same journey, at compatible times, voluntarily agree to share a private car and the traveling costs. The business models of these forms of mobility belong to the "Sharing Economy" (SE) [18], [19], which promotes the temporary acquisition and shared usage of goods, services or knowledge as a possible and effective alternative to their ownership. The SE has gained relevance in recent years thanks to *i*) advancements in technological areas (e.g., computer science, communication, electronics and so on), which realize new ways to match demand and offer in real time [20] and *ii*) cultural changes in people's habits [21] included an increasing environmental awareness.

In this respect, a general consensus there is on CP as an efficient car-based solution for private mobility, which may optimize the car use with respect to the number of passengers [22]. Unfortunately, the common CP model lacks flexibility because it is generally applied among privates and for trips made on a regular basis. In other words, it requires that participants share the same time and the same origin and destination for the outward and (usually) for the return journeys. For such a reason, CP participants generally share also other characteristics like belonging to the same community, working in the same place, living in the same neighboring and so on. Currently, some Web-platforms mediate among demand and offer to reach an audience as larger as possible at low costs [19]. Such platforms enlarged the basis of potential CP users and have reached a fair popularity (also thanks to additional services like reputation systems, insurance, clear fares and so on) [23], [24] but have a low flexibility with respect to the trip origin and/or destination of the potential participants. Indeed, their main aim is to facilitate an agreement among unknown participants for a CP journey.

To give more flexibility in time and space to the traditional CP, dynamic issues have been introduced recently [25], [26], which try to match in real-time the mobility demand with the vehicles potentially able to satisfy it on-the-fly, if the new destination is compatible with those of the other passengers within prefixed time thresholds. Obviously, the other passengers accept a priori to adapt their route for a lower trip fare. In other words, when a ridesharing request is compatible with those of the other passengers, then the road path is modified to pick and drop the new passenger, like a shared taxi. Obviously, demand and offer must be processed in an automatic way as quickly as possible to provide a real-time service.

This study wants to contribute to this issue by proposing a framework based on software agents, reputation system and blockchain [27] technologies. More in detail, each user is supported by a personal agent associated with his/her smartphone (with suitable computation, storage, communication and GPS capabilities). These agents allow to identify and localize their

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users by exploiting the smartphone GPS. This information is periodically sent to the Agency that, by means of a dynamic routing algorithm, matches demand and offer for rides by taking into account, positions, seat availability and temporal constraints in terms of both departure and arrival times of all the participants.

For each ridesharing request coming from a personal agent, the Agency will return a list of the existing ride opportunities to that agent. From this list, the personal agent will select those rides considered as the most suitable for its user. Note that over time user's choices provide information about his/her preferences to its agent, which could allow a higher level of customization to be realized. After a ride is selected, and confirmed by the driver, a smart-contract [28] runs over a blockchain (like Ethereum [29]), to make the agreement public, irrevocable and for realizing safe payments in an automatic way by using a cryptocurrency (e.g., Ether).

For each trip, it is also assumed a dynamic fare which depends both on how much long is the trip and how many riders share that trip because the higher the number of participants to a ride is, the lower the comfort is as well as the cost for passenger. It implies that in a dynamic CP, where the number of passengers can change along the trip if a new rider is added, the other participants receive a monetary compensation for both the loss of comfort and the decreased cost for passenger. This procedure is automatically carried out each time that a smart-contract for that ride runs on the blockchain.

The paper is organized as follows. Section II presents the proposed agent framework, while Section III describes the main characteristics of the dynamic routing algorithm. The reputation system is described in Section IV, while the results of a campaign of simulations are show in Section V. Section VI gives an overview on the related work and, finally, in Section VII some conclusions are presented.

II. The Multi-agent Framework

This section describes a multi-agent framework (F) able to support a dynamic CP. The framework consists of three components:

- the Agency (Ag), which is a trusted and safe centralized component, unique in F, that coordinates the CP service and collaborates with the other agents.
- A Personal Agent (PA), which supports the CP activities of a user and runs on his/her personal device (i.e., smartphone) equipped with suitable computational, storing and communication capabilities as well as with a pair of cryptographic keys [30] (for authentication and privacy issues). A PA is free of entering/leaving F at any time.
- A permissioned blockchain.

Briefly, the tasks carried out by Ag are:

- **Affiliation.** Ag manages the affiliation of each PA with F and provides each PA with an identifier, an initial reputation score, and a pair of cryptographic keys.
- **Support.** Ag manages its identity and all the CP service tasks. In detail, Ag: *i*) collects the position of all the PAs active on F at a certain time (see below); *ii*) manages and updates a reputation system based on the users' feedback about the travel mates; *iii*) collects all the PAs requests for rides. The Ag uses these information to search the best opportunities for rides that, suitably ordered, are sent to the PAs requiring them. Note that communication among PAs should occur via Ag by using a suitable tool. When a ride request/offer is accepted by the parts then commitment and payments (included compensations due to the dynamic nature of this CP service) are carried out via a smart-contract running on the permissioned blockchain platform.

Similarly, the tasks carried out by a PA are:

- **Affiliation.** In F each PA needs to be affiliated with Ag.
- **Activation.** Whenever a PA enters (i.e., it is active) on F then, periodically, it sends its GPS coordinates to Ag.
- **Search.** To search a ride, a PA sends to Ag time and position of both origin and destination point of its trip. Ag will answer with a list of opportunities, then the PA will order this list, on the basis of the preferences of its user, and will submit it to him/her for his/her choice (however, PA could perform this task also in an autonomous way [31]).
- **Commitment.** After the choice of a ride, the PAs of both driver and new passenger make public and irrevocable their agreement by means of a smart-contract which runs on a permissioned blockchain and also provides monetary payments and compensations with a cryptocurrency.
- **Feedback.** At the end of a ride each PA sends a feedback $f \in [0,1] \in \mathbb{R}$ (provided by its user) to Ag; the greater f is, the greater its appreciation about the ride is.

Finally, the third component of F is a permissioned blockchain which allows to trust anonymous and unknown actors and warranties data integrity and payments without exploiting other centralized third parties [32]. More in detail, each time that two users (i.e., a driver and a new potential passenger) agree for a ride, then a smart-contract starts on the adopted blockchain platform by using a permissioned approach. The smart-contract makes this choice irrevocable, publicly and realizes all the contractual obligations, payment and possible compensations to the included travel mates, in an automatic way. To this aim, the information about the PA positions provided by Ag is also exploited. The costs due to the blockchain management are assumed to be included in the CP fare. Note that this mechanism is not linked to a specific blockchain protocol[1].

III. The Dynamic Routing Algorithm

In this Section the algorithm for the dynamic route research running on the Agency is introduced. It is a variant of the Alpha-Beta Pruning algorithm [33] driven in the in-depth

[1]For sake of simplicity, in this preliminary phase we refer to the well known Ethereum blockchain platform for the advantages deriving by both the availability of documented API with the opportunity of adopting its cryptocurrency (i.e, Ether) and wallet service.

	BF	DFS	M	αP	A^*	G	DR
Time complexity	b^d	b^d	b^m	b^m	b^d	b^d	$d \div b^m$
Space complexity	b^d	bd	bm	bm	b^d	bd	bm
heuristic boundary nodes			✓	✓			✓
heuristic search					✓	✓	✓
heuristic B&B							✓
optimal solution	✓	✓	✓		✓		✓
complete search	✓	✓	✓		✓		✓
partial solution			✓	✓			✓
global path minimization					✓		✓
tree cuts		✓		✓			✓

TABLE I
COMPARISON WITH BRUTE FORCE (BF); DEPTH FIRST SEARCH BRANCH&BOUND (DFS); MINIMUM (M); αPRUNING (αP); A^+; DYNAMIC ROUTING (DR) - (B- BRANCHING FACTOR, M - MAX DEPTH).

search by suitable heuristics capable to improve the cut-off technique and to evaluate boundary nodes (if the chosen depth horizon does not allow to reach the optimal solution).

The main features of this algorithm (see Table I) are:

- if the solution is contained into the fixed search depth (horizon) then the optimal solution is provided, otherwise the more promising one is provided. At each node, the algorithm optimizes a function (e.g., cost, number of passengers), positive and depending on one or more parameters;
- if the search ends in advance (e.g., for time or resource limits) the temporary optimal solution is provided;
- If cycles are allowed, the nodes generating them are examined last, otherwise discharged if the solution cannot admit cycles;
- when boundary conditions change, then the optimal route is recomputed;
- heuristic functions are adopted to estimate partial solutions, optimize the Branch & Bound and drive the in-depth search (the order of optimal expansion of nodes is chosen based on the closeness of nodes to the optimal solution);
- any list of expanded nodes for the Depth-First-Search (DFS) or for a temporary tree is stored.

In Figure 1, the pseudo-code (in form of flow-chart) of the algorithm is depicted. For sake of clarity, it is represented in an iterative form even if the algorithm is recursive. Note that the variables are appropriately initialized, the functions and the adopted heuristic are known and the term “root” refers to the node from which the search starts.

When an intermediate node to be served is added, as in the dynamic CP, the algorithm starts a new search to find a new path if the request is compatible with existing constraints (e.g., time and reputation), otherwise the request is rejected. The algorithm solves a route problem linking more nodes by considering (without loss of generality) the problem of searching (on the basis of the adopted heuristic) the best path between two consecutive nodes as independent from all the other paths linking the other nodes belonging to the route (i.e., local solution). Even though in the CP problem the cycles should be avoided, the algorithm can also find solutions

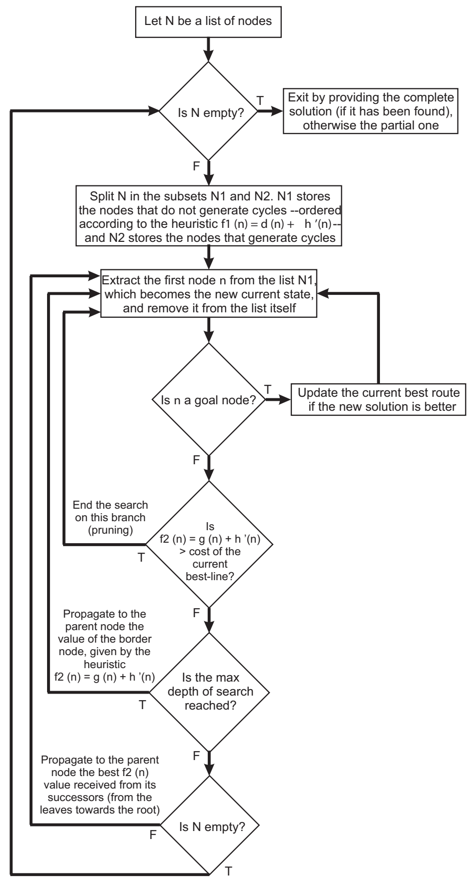

Fig. 1. The Dynamic Routing Algorithm in an iterative version.

containing cycles, but these paths are examined last because the priority in expanding nodes is given to those nodes not present in the current path. Moreover, if it is impossible to find the optimal solution with respect the initial constraints (e.g., search time), the best solution found at the set depth search is provided. Note that the fixed search depth does not affect the algorithm performance if it is greater than the depth where the optimal solution is.

IV. THE REPUTATION MODEL

The proposed reputation model considers the whole past history of each CP actor on the basis of the feedback assigned to him/her by his/her counterparts [34]–[36]. Note that each user has an initial reputation, set to 0.5, to contrast whitewashing strategies [37] without penalizing too much the newcomers with a low initial reputation value [38].

In particular, when a ride ends, each user entrusts his/her appreciation in terms of feedback ($f \in [0, 1] \subset \mathbb{R}$) to his/her PA that, in turn, sends f to Ag which manages the reputation system. When a feedback $f_{x,y}$, released by the user u_x about the user u_y, is received by the Ag, this latter computes the parameter $Q_{x,y} = \left[\left(\widehat{P}_{x,y} + r_{x,y}\right) \cdot a_x \cdot f_{x,y}\right]/2$, where: *i*) P is the final cost of the ride; *ii*) $r_{x,y}$ is the number of past rides between u_x and u_y; *iii*) a_x is the accuracy of u_x in providing a feedback; *iv*) $f_{x,y}$ is the feedback given by u_x

about u_y. To hinder malicious behaviors, Ag will update the current reputation score of u_y (i.e., ${R_y}^{old}$) as ${R_y}^{new} = \alpha \cdot {R_y}^{old} + (1-\alpha) \cdot Q_{j,i}$ only if $Q_{j,i} > 0 \vee R_y^{old} \geq 0.5$ is true, conversely R_y will not be updated (e.g., ${R_y}^{new} = {R_y}^{old}$). The parameter $\alpha \in [0,1] \subset \mathbb{R}$ gives more or less relevance to ${R_y}^{old}$ with respect to the new contribution $Q_{x,y}$.

To avoid alternate behaviors, the parameter $\widehat{P}$ takes into account the cost P of the ride, where P_{Max} is the maximum cost threshold, such that $\widehat{P} = Min(1, P/P_{Max})$. The parameter r is effective against collusive behaviors occurring among two or more users that frequently exchange positive feedback to increase maliciously their reputation scores. To this aim, let $T_{x,y}$ be a parameter depending on the time occurring between two consecutive interactions between u_x and u_y evaluated positively, the variable $r_{x,y}$ is computed as $r_{x,y} = 1/(e^{(1-T_{x,y})})$ if $f_{x,y} \geq 0.5 \wedge T_{x,y} > 1$, otherwise $r_{x,y} = 1$. To compute $T_{x,y}$, let t_l and t_p be the timestamps of the last two positive feedback and let ΔT be a time threshold. At the first positive feedback $T_{x,y} = 1$ while, for each further positive feedback, *i)* if $(|t_l - t_p| < \Delta t$ then $T_{x,y} = T_{x,y} + 1$, otherwise *ii)* $T_{x,y} = Max[1, T_{x,y} - \lfloor |t_l - t_p|/\Delta t \rfloor]$.

The accuracy degree of u_x in providing a correct feedback is taken into account by the parameter $a_x \in [0,1] \in \mathbb{R}$ where $1/0$ stands for maximum/minimum accuracy. More specifically, a_x is computed as ${a_x}^{new} = \beta \cdot {a_x}^{old} + (1-\beta) \cdot \big(1 - |f_{x,y} - R_y|\big)$, where the parameter $beta \in [0,1] \subset \mathbb{R}$ weights a_x^{old} with respect to the new contribution given by the difference between $f_{x,y}$ and the reputation of the target user (i.e., R_y).

V. Experiments

This section presents the results of two experiments testing the reputation system and the dynamic routing algorithm.

To test the reputation system, a population of 1000 users randomly distributed on 5 behaviors (e.g., very unpleasant, unpleasant, neutral, pleasant, very pleasant), has been simulated for unvarying (case A) and alternate[2] (case B) modalities. In the simulations, the reputation system parameters α and β have been set both to 0.2 and P_{max} has been set to 5€. The number of ride mates and cost of the ride have been randomly generated respectively in the ranges $2 \div 5$ and $[1.00€, 7.50€]$. Moreover, in the case B, the cost of the CP services has been set $> 5€$ for the 25% of the rides. The simulation has been arranged for epochs, so that the reputation parameters t_l and t_p have been set to the respective epochs and Δt has been set to 3 epochs. Each feedback has been randomly generated coherently with the user's behavior. All the users received an initial reputation score of 0.5 and for each *epoch* only a population share of 20% has been randomly selected. Obviously, the higher the percentage of users correctly identified, the higher the accuracy of this reputation system.

Figure 2 shows the results obtained for the two cases A and B on the basis of the user's behavior correctly recognized. A common aspect is represented by the ability to recognize the users' nature very quickly (e.g., 90% of users is correctly classified in less than 11 and 18 epochs for the cases A and B, respectively). With respect to similar systems, this is also due to the fact that each user receives more feedback for the same ride, depending on the (random) number of participants to the ride. Note that, all the "neutral" users' behavior, receiving an initial reputation set to 0.5, are correctly recognized from the first to the last epoch. However, also by setting a different value for the initial reputation, these users are quickly recognized like the other.

The second experiment verified the performance of the dynamic routing algorithm with different graphs (even large ones) generated randomly by adopting on the parameters compatible with the considered scenario. For each new admissible request the route is modified by rejecting the requests incompatible with both pre-existing time constraints and minimum reputation and by choosing among: i) minimizing the cost; ii) maximizing the number of served users; ii) maximizing the Users/Cost ratio. The computing time is always negligible, some milliseconds. From an operational point of view, note that when the new passengers are collected at a node, the requests on the previous node is reset to avoid the insertion of loops between the two nodes.

[2]With respect to the ride cost.

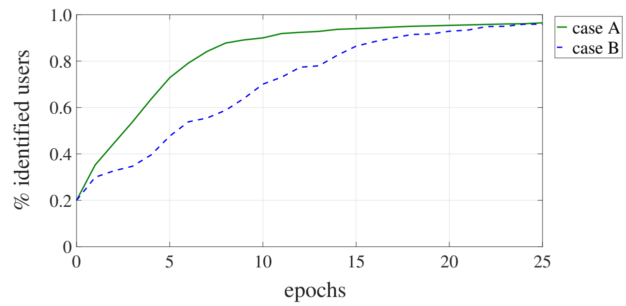

Fig. 2. Percentage of users correctly identified. Cases A and B.

VI. Related Work

In recent years, Intelligent Transport Systems (ITSs) received a great impulse from advancements occurred in com-

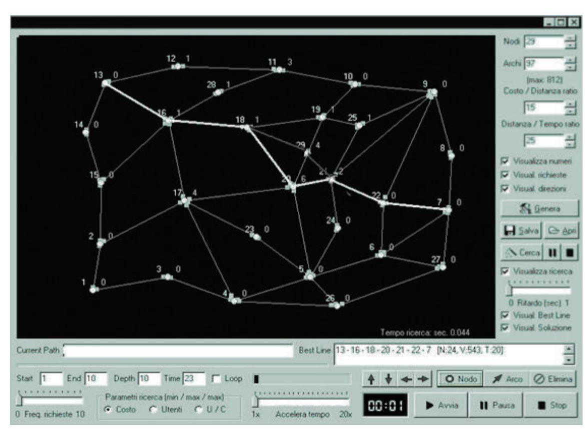

Fig. 3. Random network 29 Nodes, 51 Links, path from 13 to 7, depth 6.

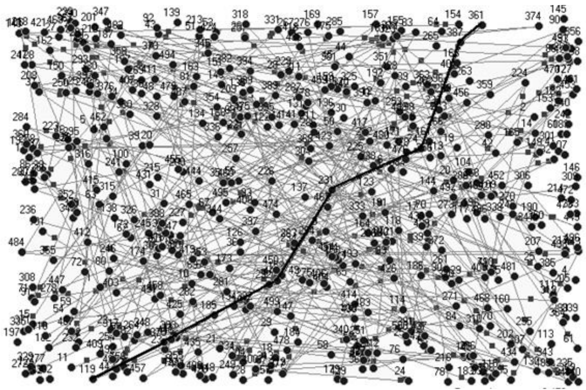

Fig. 4. Random Network 500 Nodes, 306 Links, path from 119 to 361, depth 10.

puter science, electronic and communication above all. In this context, an increasing attention is given to the adoption of the intelligent software agent technologies [39]–[42] thanks to their learning and adaptive capabilities [43], the attitude to cooperate by sharing their knowledge [44]–[47] and to deal with large, uncertain and/or dynamic systems in a centralized or distributed way.

Also trust and reputation systems are adopted in the ITS area, mainly because in larger and larger dynamics environments information about counterparts is often necessary [48], [49] to evaluate the trustworthiness of potential counterparts. Note that to assure integrity of both trust/reputations and identities, also cryptographic techniques are often exploited.

In the CP scenario, reputation systems are worthy to be implemented [50], [51] and several models exist. For instance, in [52] a reputation system is used to refuse undesirable passengers to avoid having unpleasant rides. Similarly, the authors of [53] and [54] propose to implement reputation systems, respectively named *Smart Rider Seeker* and *SmartShare*, that allow drivers and commuters to offer and request rides by also permitting to reject potential participants. However, all these approaches do not describe any specific reputation model, differently from our proposal. CS activities too can benefit from reputation information, as in [55] where agents assist users in improving their driving behavior by means of individual reputation measures, also used to obtain both the access to CS services and personalized fares. Some experiments on real and simulated data show the potentiality of this approach.

Blockchain [27] and smart-contracts are giving new opportunities both to multi-agent systems [56] and to the mobility ecosystem to act in sharing, insurances, payment activities and store publicly and permanently car profiles, maintenance, accident, transfer and other data [57]. A blockchain is a decentralized, distributed ledger of interconnected data block that once added, in a chronological way, are permanent and unchangeable. Before adding a data block, it has to be validated by a distributed consensus protocol [58] based on three steps (e.g., transaction endorsement, ordering, validation and commitment) after which it will be added and publicly accessible. Since the blochchain is replicated on more independent hosts, it cannot be easily controlled, tampered or deleted [59]. Note that blockchain performance are significantly affected by the adopted consensus protocol in terms of computational complexity, robustness, latency, scalability and safety. Behind the cryptocurrencies (like Bitcoin [27]) some blockchains can realize smart-contracts [28], i.e. computerized transactions that realize the terms of a contract. For instance. Ethereum [29] was the first blockchain for smart-contracts but, nowadays, other similar platforms exist (e.g., Ripple [60], Stellar [61] and Tendermint [62]) and, like Ethereum, most of them has their own digital coin (like Ether). This class of blockchains appears the most suitable for developing the sharing economy business.

VII. Conclusions

CP can contribute to support public and private mobility by reducing urban traffic and its environmental problems. To this aim, in this paper a dynamic form of CP potentially able to enlarge the number of CP users has been presented.

These issues have been addressed by exploiting multi-agent systems, reputation systems and blockchain technologies and tested by realizing some experiments on simulated data. The first experiment verified the capability of the proposed algorithm to manage the dynamic routing, while the second one, based on simulated data, verified the effectiveness of the proposed reputation system for two scenarios. The results of these preliminary experiments encourage further developments of this form of dynamic CP.

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References

[1] M. N. Postorino and G. M. L. Sarnè, "Mobility forecast in an urban area through the use of neural networks," in *Applications of advanced technologies in transportation engineering*. ASCE, 1995, pp. 213–217.

[2] C. A. M. Toledo, "Congestion indicators and congestion impacts: a study on the relevance of area-wide indicators," *Procedia-Social and Behavioral Sciences*, vol. 16, pp. 781–791, 2011.

[3] L. Chen and H. Yang, "Managing congestion and emissions in road networks with tolls and rebates," *Transportation Research Part B: Methodological*, vol. 46, no. 8, pp. 933–948, 2012.

[4] E. Cascetta and M. N. Postorino, "Fixed point approaches to the estimation of o/d matrices using traffic counts on congested networks," *Transportation science*, vol. 35, no. 2, pp. 134–147, 2001.

[5] A. Spickermann, V. Grienitz, and A. Heiko, "Heading towards a multimodal city of the future?: Multi-stakeholder scenarios for urban mobility," *Technological Forecasting and Social Change*, vol. 89, pp. 201–221, 2014.

[6] T. Fontes, S. Pereira, P. Fernandes, J. Bandeira, and M. Coelho, "How to combine different microsimulation tools to assess the environmental impacts of road traffic? lessons and directions," *Transportation Research Part D: Transport and Environment*, vol. 34, pp. 293–306, 2015.

[7] M. N. Postorino, G. Musolino, and P. Velonà, "Evaluation of o/d trip matrices by traffic counts in transit systems," in *Schedule-Based Dynamic Transit Modeling: theory and applications*. Springer, 2004, pp. 197–216.

[8] S. Ison and T. Rye, "Implementing road user charging: the lessons learnt from hong kong, cambridge and central london," *Transport Reviews*, vol. 25, no. 4, pp. 451–465, 2005.
[9] N. Paulley, R. Balcombe, R. Mackett, H. Titheridge, J. Preston, M. Wardman, J. Shires, and P. White, "The demand for public transport: The effects of fares, quality of service, income and car ownership," *Transport Policy*, vol. 13, no. 4, pp. 295–306, 2006.
[10] S. Liu, K. P. Triantis, and S. Sarangi, "A framework for evaluating the dynamic impacts of a congestion pricing policy for a transportation socioeconomic system," *Transportation Research Part A: Policy and Practice*, vol. 44, no. 8, pp. 596–608, 2010.
[11] M. N. Postorino, "A comparative analysis of different specifications of modal choice models in an urban area," *European journal of operational research*, vol. 71, no. 2, pp. 288–302, 1993.
[12] A. de Palma and R. Lindsey, "Traffic congestion pricing methodologies and technologies," *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 6, pp. 1377–1399, 2011.
[13] M. Gibson and M. Carnovale, "The effects of road pricing on driver behavior and air pollution," *J. of Urban Economics*, vol. 89, pp. 62–73, 2015.
[14] J. D. Harford, "Congestion, pollution, and benefit-to-cost ratios of us public transit systems," *Transportation Research Part D: Transport and Environment*, vol. 11, no. 1, pp. 45–58, 2006.
[15] M. N. Postorino and V. Fedele, "The analytic hierarchy process to evaluate the quality of service in transit systems," *WIT Transactions on The Built Environment*, vol. 89, 2006.
[16] C. Winston and V. Maheshri, "On the social desirability of urban rail transit systems," *Journal of urban economics*, vol. 62, no. 2, pp. 362–382, 2007.
[17] B. Caulfield, "An examination of the factors that impact upon multiple vehicle ownership: The case of dublin, ireland," *Transport Policy*, vol. 19, no. 1, pp. 132–138, 2012.
[18] J. Parsons, "Remix: Making art and commerce thrive in the hybrid economy," *Journal of Teaching and Learning*, vol. 7, no. 1, 2010.
[19] R. Belk, "You are what you can access: Sharing and collaborative consumption online," *J. of Business Research*, vol. 67, no. 8, pp. 1595–1600, 2014.
[20] K. Dervojeda, "Accessibility based business models for peer-to-peer markets," *Business Innovation Observatory: The Sharing Economy, Case study*, vol. 12, 2013.
[21] J. Agyeman, D. McLaren, and A. Schaefer-Borrego, "Sharing cities," *Friends of the Earth Briefing*, pp. 1–32, 2013.
[22] B. Cohen and J. Kietzmann, "Ride on! mobility business models for the sharing economy," *Organization & Environment*, vol. 27, no. 3, pp. 279–296, 2014.
[23] https://www.blablacar.it, 2019.
[24] https://www.singucarpooling.com, 2019.
[25] J. Friginal, S. Gambs, J. Guiochet, and M.-O. Killijian, "Towards privacy-driven design of a dynamic carpooling system," *Pervasive and mobile computing*, vol. 14, pp. 71–82, 2014.
[26] J. Alonso-Mora, S. Samaranayake, A. Wallar, E. Frazzoli, and D. Rus, "On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment," *Proc. of National Academy of Sciences*, vol. 114, no. 3, pp. 462–467, 2017.
[27] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2008.
[28] N. Szabo, "Smart contracts," *Unpublished manuscript*, 1994.
[29] https://www.ethereum.org, 2019.
[30] C. Adams and S. Lloyd, *Understanding PKI: concepts, standards, and deployment considerations*. Addison-Wesley Professional, 2003.
[31] M. N. Postorino and G. M. L. Sarne, "A neural network hybrid recommender system," in *Proceedings of the 2011 conference on neural Nets WIRN10*, 2011, pp. 180–187.
[32] M. A. Khan and K. Salah, "Iot security: Review, blockchain solutions, and open challenges," *Future Generation Computer Systems*, vol. 82, pp. 395–411, 2018.
[33] D. E. Knuth and R. W. Moore, "An analysis of alpha-beta pruning," *Artificial intelligence*, vol. 6, no. 4, pp. 293–326, 1975.
[34] P. De Meo, F. Messina, M. N. Postorino, D. Rosaci, and G. M. L. Sarné, "A reputation framework to share resources into iot-based environments," in *2017 IEEE 14th International Conference on Networking, Sensing and Control (ICNSC)*. IEEE, 2017, pp. 513–518.
[35] P. De Meo, F. Messina, D. Rosaci, and G. M. L. Sarné, "Combining trust and skills evaluation to form e-learning classes in online social networks," *Information Sciences*, vol. 405, pp. 107–122, 2017.
[36] M. N. Postorino and G. M. L. Sarnè, "A neural network to identify driving habits and compute car-sharing users reputation," in *Italian Workshop on Neural Nets*. Springer, 2017, pp. 207–216.
[37] G. Zacharia and P. Maes, "Trust management through reputation mechanisms," *Applied Artificial Intelligence*, vol. 14, no. 9, pp. 881–907, 2000.
[38] S. Ramchurn, D. Huynh, and N. Jennings, "Trust in multi-agent systems," *Knowledge Engeenering Review*, vol. 19, no. 1, pp. 1–25, 2004.
[39] B. Chen and H. Cheng, "A review of the applications of agent technology in traffic and transportation systems," *Intelligent Transportation Systems, IEEE Trans. on*, vol. 11, no. 2, pp. 485–497, 2010.
[40] C. Adam and B. Gaudou, "Bdi agents in social simulations: a survey," 2016.
[41] J. P. Müller and K. Fischer, "Application impact of multi-agent systems and technologies: a survey," in *Agent-Oriented Software Engineering*. Springer, 2014, pp. 27–53.
[42] M. N. Postorino and G. M. L. Sarné, "Agents meet traffic simulation, control and management: A review of selected recent contributions," in *Proc. of the 17th Workshop from Objects to Agents, WOA 2016*, ser. CEUR Workshop Proceedings, vol. 1664. CEUR-WS.org, 2016.
[43] L. Busoniu, R. Babuska, and B. De Schutter, "A comprehensive survey of multiagent reinforcement learning," *Systems, Man, and Cybernetics (C): Appl. and Reviews, IEEE Trans.*, vol. 38, no. 2, pp. 156–172, 2008.
[44] V. Tomás and L. Garcia, "A cooperative multiagent system for traffic management and control," in *Proc. of the 4th Int. Joint Conf. on Autonomous agents and multiagent systems*. ACM, 2005, pp. 52–59.
[45] F. Wang, "Agent-based control for networked traffic management systems," *Intelligent Systems, IEEE*, vol. 20, no. 5, pp. 92–96, 2005.
[46] B. Chen, H. Cheng, and J. Palen, "Integrating mobile agent technology with multi-agent systems for distributed traffic detection and management systems," *Transportation Research Part C: Emerging Technologies*, vol. 17, no. 1, pp. 1–10, 2009.
[47] S. Sen, A. Biswas, and S. Debnath, "Believing others: Pros and cons," in *Proc. of the 4th Int. Conf. on Multi-Agent Systems, ICMAS'2000*. IEEE, 2000, pp. 279–286.
[48] D. Rosaci, G. M. L. Sarné, and S. Garruzzo, "Integrating trust measures in multiagent systems," *International Journal of Intelligent Systems*, vol. 27, no. 1, pp. 1–15, 2012.
[49] M. N. Postorino and G. M. L. Sarné, "An agent-based sensor grid to monitor urban traffic," in *Proc. of the 15th Workshop "from Objects to Agents", WOA 2014*, ser. CEUR Workshop Proceedings, vol. 1260. CEUR-WS.org, 2014.
[50] D. Graziotin, "An analysis of issues against the adoption of dynamic carpooling," *arXiv preprint arXiv:1306.0361*, 2013.
[51] C. Caballero-Gil, P. Caballero-Gil, J. Molina-Gil, F. Martín-Fernández, and V. Loia, "Trust-based cooperative social system applied to a carpooling platform for smartphones," *Sensors*, vol. 17, no. 2, p. 245, 2017.
[52] D. B. Nagare, K. L. More, N. S. Tanwar, S. Kulkarni, and K. C. Gunda, "Dynamic carpooling application development on android platform," *International Journal of Innovative Technology and Exploring Engineering*, vol. 2, no. 3, pp. 136–139, 2013.
[53] S. Abdel-Naby and P. Giorgini, "Smart ride seeker (srs) an introductory plan," University of Trento, Tech. Rep., 2006.
[54] H. Packer and L. Moreau, "A methodology to take account of diversity in collective adaptive system," 2016.
[55] E. Picasso, M. N. Postorino, and G. M. L. Sarné, "A study to promote car-sharing by adopting a reputation system in a multi-agent context." in *Proc. of the 18th Workshop from Objects to Agents, WOA 2017*, ser. CEUR Workshop Proceedings, vol. 1867. CEUR-WS.org, 2017, pp. 13–18.
[56] G. Ciatto, A. Maffi, S. Mariani, and A. Omicini, "Towards agent-oriented blockchains: Autonomous smart contracts," in *PAAMS 2019*, 2019.
[57] D. Namiot, O. Pokusaev, V. Kupriyanovsky, and A. Akimov, "Blockchain applications for transport industry," *International Journal of Open Information Technologies*, vol. 5, no. 12, pp. 130–134, 2017.
[58] N. Chalaemwongwan and W. Kurutach, "State of the art and challenges facing consensus protocols on blockchain," in *Information Networking (ICOIN), 2018 International Conference on*. IEEE, 2018, pp. 957–962.
[59] M. Pilkington, "11 blockchain technology: principles and applications," *Research handbook on digital transformations*, p. 225, 2016.
[60] https://ripple.com/, 2019.
[61] https://www.stellar.org, 2019.
[62] https://tendermint.com, 2019.