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A Cooperative Framework for Universal Basic Mobility System: Mobility Credits Approach

Miloš N. Mladenović, Montasir Abbas, Claudio Roncoli, and Sanaz Bozorg Chenani

Abstract— Development of integrated mobility and traffic management strategies is an important aspect of the ongoing transition of urban mobility systems. Extending from existing credit schemes, this research presents a system design and evaluation of a framework based on the principle of Universal Basic Mobility. In particular, using premises of long-term cooperation and hierarchical self-organization, the system design includes user-based Mobility Credits interrelated with Priority Levels. To complement the cooperation framework, system architecture is formulated in line with the distributed ledger technology. The proposed framework is tested using web-based interaction in the form of stated-preference experiment. Results are analyzed through statistical distributions and a discrete-choice model of user decision-making within the proposed framework. This research concludes that this framework could nudge users towards reciprocity and altruism in their travelling behavior. In addition, experiment participants have provided a range of comments related to positive features, potential for failure, and further development. Finally, the paper ends by raising several implications for wider citizen participation in the integrated mobility system design and evaluation.

I. INTRODUCTION

Intelligent Transport Systems (ITS) are entering a new era of digitalization and servitization driven by advances in information and communication technologies (ICT). On the one hand, there are significant technological advances in data collection, processing, storage, and communication, using a range of user-based or infrastructure devices. On the other hand, there is an ongoing development of different mobility services, driven by the idea of Mobility-as-a-Service, including ridesourcing and micromobility services [1, 2]. As the landscape of urban mobility systems is undergoing these changes, the importance of developing innovative principles for operation is growing. The increasing multi-modality and integration of urban mobility systems requires designs that can successfully coordinate different aspects of intrinsically distributed sub-systems. Thus, such efforts require combination of traffic and mobility management strategies, if we are to manage potentially adverse effects of ongoing development in vehicle automation [3]. In particular, technological development needs to incorporate human behavior dimension in the foundational principles, especially taking into consideration technological capability to accept user input, using various hand-held and in-vehicle devices.

Combination of urban traffic and mobility management strategies had been under a range of previous considerations. For example, dynamic road pricing techniques have been one of the most often implemented schemes in the field [4]. In contrast to road pricing, one of the dominant alternative approaches has focused on cap and trade schemes, based on permits, often related to CO₂ emissions [5, 6]. This field of studies has advanced significantly after Yang and Wang (2011) have analytically formulated tradable driving credit scheme [7]. Highlighting that tradeable credit scheme is revenue neutral and much fairer than conventional road

pricing, there has been significant advancement in theory and models, using different traffic patterns and formulation assumptions about human behavior [8-11]. However, the research on empirical evaluation of tradable credit schemes is still in its infancy, with only a handful of case studies [12]. In addition, there have been other alternative proposals for combined traffic and mobility management schemes, such as booking and reservation [13, 14], and auction schemes [15].

From a system design perspective, main questions raised by earlier research in integrated traffic and mobility management schemes are still open (e.g., target, geographical domain, distribution, enforcement and monitoring, and degree of differentiation) [5]. Another important point that has recently been highlighted is that mobility systems result in a distribution of specific positive and negative effects on users, bringing about inevitable distributive justice questions [16, 17]. Question of distributive justice requires consideration of user's rights, especially paying attention to the least advantaged, and not just average or aggregate effects. In relation, principles of distributive justice should be designed into the system operation principles [16, 18]. In particular, the idea of user's rights translates into the principle of Universal Basic Mobility (UBM). Following the idea of Universal Basic Income (e.g., [19]), the idea of UBM assumes that a certain level of access to mobility system should be guaranteed to each individual. Following the UBM principle, there is a need for system design for accessing common mobility resources in the urban environments, accounting simultaneously for changes in travel patterns and transport supply.

At this stage, UBM is only a concept, without detailed proposals for system design. With this in mind, this research proposes and evaluates one alternative approach. The proposed framework has been developed based on the principles of human cooperation [20, 21] and hierarchical self-organization [22-25]. The central component of this UBM framework is Mobility Credit system integrated with Priority Level assigned to each trip. Section 2 of this paper provides theoretical background and explains the proposed UBM framework, elaborating the argument for simultaneously taking into account the social and technical perspective. Section 3 presents methodology focused on data collection using web-based experiment, discrete choice modeling, and development feedback. Section 4 presents the results from web-based experimentation, including a discrete-choice decision-making model within the proposed UBM framework. In addition, results include a summary of open-ended comments about positive and limiting features of the framework, with ideas for further development. Section 5 includes a discussion of the results. The last section 6 concludes the paper, and provides recommendations for further research directions.

II. FOUNDATIONS OF THE COOPERATIVE FRAMEWORK

A. Principles of Cooperation

In order to design the proposed framework, it is important to understand principles of long-term and large-scale human cooperation, which is present in urban transport systems. In fact, users are present in urban mobility system throughout their lifetime, and they are expected to gain by accumulating benefits in the long term as opposed to seeking short-term gains. The premise here is that setting up individual agent's objective as cooperative versus competitive should result in improved system-wide results. Consequently, proposed framework should use human tendency to cooperate, especially at a group level, under several conditions [26]. First, people cooperate when there is direct [27] and indirect reciprocity [28], and because they care about the outcome other people in the system receive or because of greater social goals [29, 30]. Second, people cooperate if they perceive that other people cooperate [31], or if the payoff from the cooperation and the degree of the common interest increase [32, 33]. Third, people cooperate if the cooperation structure can be modified by the agreement among members [31, 34]. Fourth, people cooperate if there is more and better communication among members [31, 35], if there is an opportunity to build reputation [28, 31, 36], and finally, if there is a sanctioning system [26, 30, 31, 37-43].

Considering underlying relations in urban mobility systems, the proposed framework is envisioned as mutually advantageous long-term and large-scale cooperation that relies upon end-user reciprocity and altruistic behavior. In particular, in order to establish cooperation among users, a system of *non-monetary* Mobility Credits ($\mathbb{C}$) has been developed. In comparison to previous frameworks, one major difference is that these Mobility Credits do not involve trading, in order to prevent the dominant influence of economic inequalities. Another major difference is that $\mathbb{C}$ are explicitly related to traffic management mechanisms through the selection of Priority Level (PL) per trip. Basically, user can select a PL for each trip, as integer value from one to four, with PL four being of the highest importance. The idea of certain user priority at intersections already exists in traffic engineering community. However, in addition to determining the right-of-way at an intersection, PLs can be used for various other aspects of traffic management, such as route assignment or even destination choice. In the initial assignment, each user receives identical amount of 20 $\mathbb{C}$. Spending/gaining (indicated with + and - sign) of $\mathbb{C}$ occurs only through PL selection, with uniform rules for all users (Table 1). In addition, in this proposed alternative, there is a $\mathbb{C}$ ceiling (25 $\mathbb{C}$), being a maximum number of $\mathbb{C}$ that individual user can accumulate over time. The combination of $\mathbb{C}$ and PL is supposed to prevent either user or central control usurpation in determining the aggregate and distributive effects achieved in the particular mobility system.

TABLE I. RELATION BETWEEN CREDITS AND PRIORITY LEVELS

PL	1	2	3	4
$\mathbb{C}$	+2	0	-2	-10

B. Principles of System Architecture

For technical formulation, we propose a decentralized control approach that relies on cooperative communication and computation performed by distributed ITS components. If we were to develop a framework with a centralized control principle, we would need to have perfect information and high intelligence [24, 25]. Contrary to the centralized control principles, incorporating principles of self-organization can enable higher computational efficiency, robustness against failure, scalability for expansion, and smaller communication capacity requirements [24, 25, 44, 45]. Here, an important technical component would be to implement this framework using distributed ledgers (Figure 1), for establishing "smart contracts" [46, 47]. Such contracts mean that binding digital agreement can be implemented without the need of trusted intermediary. In practice, this means that agreement only executes when both parties, either human or ITS devices, have fulfilled all necessary requirements for completing the transaction. Potential of distributed ledger technology for ITS applications have already been recognized [48-50]. Therefore, the advantages would be in line with requirements for cooperation mentioned before, such as identity management, consensus and consistency over long-term interaction.

Fig. 1: Proposed framework architecture

In addition, envisioned self-organization framework is developed using the principles of multi-layer hierarchy in system operation. The control architecture can have a large number of cooperation layers, such as those on the intersection, route, or whole network level (Figure 1). However, the system design still includes a system layer, which can be used to disseminate information on global network events of high importance, such as in case of emergency evacuations. Defining the system in a layered structure can allow fulfilment of different objectives, which on route or network level might be focused on formation of platoons, routing or destination choice based on PL value. Thus, in addition to PL being selected by the user based on the estimated importance of the trip, this value might also depend on the vehicle occupancy, vehicle type (e.g., emergency vehicle), users' and vehicle dynamics characteristics, or constraining network characteristics (e.g., approach grade, queuing capacity). In addition, cooperation does not have to

be limited solely to interaction in traffic, but can also include other elements, such as sharing computing load. This type of multi-layered self-organizing decentralization can acquire and maintain structure based on the relationships between the behavior of the individual agents (the microscopic level) and the resulting sophisticated structure and functionality of the overall system (the macroscopic level).

III. METHODOLOGY

Data collection was organized in the form of state-preference survey, using a web-based experiment. Web-based experiment is selected for data collection because of faster speed, lower cost, greater external validity, the ability to experiment around the clock, high degree of automation, and wider samples than in-person experiment [51], while being comparable with other types of experiments [52-54]. Web-based experiment was developed as a custom website (approved by Institutional Review Board VT IRB 14-542). The experiment setup included first the consent page, followed by the info page where details of the $\mathbb{C}$ and PL framework have been explained. Third web-page was the experiment page, where the subject is supposed to interact with the proposed framework (Figure 2), as long as they preferred. A minimum of ten interactions was used for determining eligibility for participating in the raffle. Experiment design aimed for anonymous data collection, while special attention has been paid to the user interface design, in order to minimize the effect on user's decision-making. For example, radio button was used for PL selection, allowing simultaneous overview of all PLs. The experiment setup also included the exit and contact page, allowing the subjects to provide additional comments about the proposed framework. Probing questions for respondents' feedback on the framework included such aspects as potential benefits, possibility for tricking the system, suggestions for different setup, and other more general concerns. This feedback was categorized in the analysis based on themes appearing.

Based on the previous surveys and interviews [55] and development of control algorithm architecture [56], experiment was designed so that the subject would receive information about a random trip purpose (e.g., shopping, holiday, social, entertainment, personal, work/school, medical). Trip purpose distribution has been approximated from National Household Travel Survey sample [57]. Second, setup included information about time obligation related to the trip, divided into three categories, being without time obligation (W/TO), with time obligation (WTO), and with strict time obligation (STO). Time obligation is a factor that takes into account cultural or psychological importance a subject assigns to certain events with certain trip purpose. Third, setup included estimates of time delay, would signify how much later or early, in minutes (e.g., 20 min), a user expects to arrive at the destination based on the previous experience (e.g., route or time of day) or additional sources of information (e.g., real-time traffic information). This information, in addition to conventional trip purpose

information, incorporates additional human perception and decision-making about individual trips. Based on this information, user's task was then to select a PL for each hypothetical trip. Framework experimentation used an assignment of stochastic trip information to each subject in order to test as many as possible combinations.

Fig. 2: Experiment web interface

Considering that PLs are true categorical outcomes, mutually exclusive and collectively exhaustive, the research team decided to use ordinal logistic regression [57]. However, the ordinal nature of the outcomes does not have implications for differences in the strength of the outcomes. As a result, the ordinal logit model is used to determine the probability of outcome falling in a reference category (i.e., probability of selecting certain PL based on the information about the trip and $\mathbb{C}$ available). This approach takes into consideration the inherent differences and variability in individual human decision-making. For example, assume that the probability of selecting PL 1 is $P(Y = 1)$. This value must lie between zero and one, but considering the nature of categorical data, predicted values may be smaller than zero and higher than one. To solve this, probability is replaced with odds that $Y = 1$. The odds, or $\Omega(Y = 1)$, is equal to $P(Y = 1)/[1 - P(Y = 1)]$. Taking a natural logarithm of the odds, logit, is represented as $\Lambda(Y)$. In the case of natural logarithm of the odds, estimated probability of dependent variable cannot exceed maximum or minimum values. Consequently, the equation for the relationship between the dependent and independent variables (X) becomes

$$\Lambda(Y) = \alpha + \beta_1 X_1 + \dots + \beta_k X_k \quad (1)$$

This relationship can be converted by exponentiation into odds.

$$\Omega(Y = 1) = e^{\alpha + \beta_1 X_1 + \dots + \beta_k X_k} \quad (2)$$

Finally, we can convert from odds to the probability of selecting PL 1 as

$$P(Y = 1) = \frac{e^{\alpha + \beta_1 X_1 + \dots + \beta_k X_k}}{1 + e^{\alpha + \beta_1 X_1 + \dots + \beta_k X_k}} = \frac{1}{1 + e^{-(\alpha + \beta_1 X_1 + \dots + \beta_k X_k)}} \quad (3)$$

where α is an intercept parameter and $\beta_1, \dots, \beta_k$ are coefficients associated with k-th variable. At the end, it is important to emphasize that probability, odds, and logit are three different approaches for expressing exactly the same data relationship. Furthermore, modeling human decision-making using logistic

regression results in threshold values (θ) of cumulative probabilities, which determine what PL will be selected for specific set of dependent variables. For cumulative logit model, all categories at and below a given threshold value are compared with all the categories above the threshold. In this case, separate models are developed for different trip purposes and different time obligations. Considering that there are seven different trip purposes and three different time obligation variables, the following equations represent a generalization of the cumulative probability value (CPV) for logistic regression models, where subscripts $k = 1, 2, \dots, 6$ are index predictors, and $i = 1, 2, 3$, are index categorical values of the dependent variable..

$$CPV(PL \leq 1) = \frac{1}{1 + e^{-(\alpha_1 + \beta_1 \cdot ED + \beta_2 \cdot AC + \beta_4 \cdot TO \cdot ED + \beta_5 \cdot TO \cdot AC + \beta_6 \cdot ED \cdot AC)}} \quad (4)$$

$$CPV(PL \leq 2) = \frac{1}{1 + e^{-(\alpha_2 + \beta_1 \cdot ED + \beta_2 \cdot AC + \beta_4 \cdot TO \cdot ED + \beta_5 \cdot TO \cdot AC + \beta_6 \cdot ED \cdot AC)}} \quad (5)$$

$$CPV(PL \leq 3) = \frac{1}{1 + e^{-(\alpha_3 + \beta_1 \cdot ED + \beta_2 \cdot AC + \beta_4 \cdot TO \cdot ED + \beta_5 \cdot TO \cdot AC + \beta_6 \cdot ED \cdot AC)}} \quad (6)$$

where:

ED – estimated delay

TO – time obligation

AC – available $\mathbb{C}$

Model evaluation is performed using whole model test, which determines if the specified model is significantly better than the reduced model without any effects, not including intercepts, i.e., if all the slope parameters are zero or not. In addition, model evaluation is performed using lack of fit tests, which tests determine if a saturated model is significantly better than the proposed model, i.e., if the model has parameters that should be used in the model. Finally, model evaluation is also performed using effect tests, which determine if the specified model is significantly better than a model without a given effect, i.e., if the model parameters have significant predicting power.

IV. RESULTS

A. Web-Based Experiment Results

In total, 266 anonymous individuals have participated in the experiment, with 8311 cumulative PL selections, average of 31.24, and median of 20 PL selections per participant. An example of results is shown in the Figure 3. This figure shows number of PL selections for shopping, entertainment, work/school, and medical trip purpose. Shopping trip purpose was without time obligation, entertainment trip purpose is with some time obligation, work/school trip purpose is with strict time obligation, and medical trip purpose did not have related time obligation, as this trip was supposed to be an emergency case. For these selected trip purposes and time obligations, the figure shows the number of PL selections for different delay in travel time, with negative values representing being early, and positive values representing being late.

Fig. 3: Examples of responses per trip purpose

In general, web-experiment results have shown that users have tendency to use $\mathbb{C}$ and select PL depending on the trip purpose, time obligation, and expected delay. First, users tend to select lower PL for shopping, social, entertainment, compared to holiday, personal business, work/school, and medical trip purpose. Second, users tend to select lower PL if the estimated delay is negative in contrast to being positive, i.e., if the estimate was that they would be late. Similarly, for time obligation, users select lower PLs when there is no time obligation, as opposed to trips with time obligation. As designed, selection of PL 4 does not occur at below 10 $\mathbb{C}$, and selection of PL 3 does not occur at 0 $\mathbb{C}$. One can observe that most of the selections were done at 24, 22, and 20 $\mathbb{C}$, but that users were selecting at all $\mathbb{C}$ values (Figure 4). In addition, the ratio of PL selected is similar for great majority of available $\mathbb{C}$ values, where the frequency of PL selection is inverse to PL

value. However, only 4.7% of all the selections were at zero €, having in mind that the framework was envisioned to deter users from reaching the minimum. Moreover, average and median PL selected were 1.8 and 2, respectively, highlighting previous observation about often selection of PL 1 and 2.

Fig. 4: Number of PL selections based on Priority Credits available

B. Model of Human Interaction with PS

Following several tables (Table 2 to Table 9) show ordinal logistic regression analysis for each of the models, and model evaluation parameters. From Table 2 to Table 8 one can observe different influencing parameters for each model, with the most significant parameters identified with asterisks. Each of these tables shows parameter estimate given by logistic model, standard error of each parameters estimate, Wald Chi-square which tests for the hypotheses that each of the parameters is zero, and finally observed significance probabilities for the Chi-square tests. Different influencing parameters relate to the individual perceptions of relationship between trip purpose, time obligation, time delay, and PL parameters. Clear difference can be observed between trip purposes that are performed more often (e.g., work/school, shopping, personal). Decision-making for PL selection in the case of these trip purposes has higher complexity than decision-making for trip purposes that are not as regular (e.g. holiday, entertainment, and social). In the case of medical trip purpose, main influence originates from the number of available €. For medical trip purpose, most of the subjects tend to select PL 4 by default, unless they are restricted by the number of available Priority Credits.

TABLE II. MODEL FOR SHOPPING TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.1495	0.1191	1.57	0.2097
Intercept[2]	1.7080	0.1293	174.43	<.0001*
Intercept[3]	4.1836	0.2398	304.40	<.0001*
Time Obligation - w/strict (STO)	-0.6134	0.0716	73.46	<.0001*
Time Obligation - w/ (MTO)	-0.1304	0.0739	3.12	0.0775
Delay	-0.0484	0.0039	158.12	<.0001*
Available	0.0363	0.0068	28.35	<.0001*
(STO) * (Available-16.3694)	-0.0239	0.0094	6.51	0.0107*
(MTO) * (Available-16.1214)	0.0090	0.0097	0.85	0.3552
(STO) * (Delay-0.2416)	-0.0028	0.0051	0.30	0.586
(MTO) * (Delay-0.2416)	-0.0116	0.0053	4.75	0.0293*

TABLE III. MODEL FOR HOLIDAY TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.6793	0.0934	52.82	<.0001*
Intercept[2]	0.8958	0.0963	86.54	<.0001*
Intercept[3]	2.8615	0.1539	345.77	<.0001*
Time Obligation - w/strict	-0.5456	0.1076	25.72	<.0001*
Time Obligation - w/	-0.3029	0.1066	8.08	0.0045*
Delay	-0.0395	0.003	173.65	<.0001*
(Delay-0.15314)*(Available-16.3155)	-0.0013	0.0004	12.66	0.0004*

TABLE IV. MODEL FOR SOCIAL TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.6069	0.1278	22.58	<.0001*
Intercept[2]	1.5419	0.1364	127.73	<.0001*
Intercept[3]	4.3471	0.2703	258.72	<.0001*
Time Obligation - w/strict	-0.5759	0.0756	58.08	<.0001*
Time Obligation - w/	-0.0201	0.0773	0.07	0.7953
Delay	-0.0622	0.0041	223.19	<.0001*
Available	0.0330	0.0073	20.65	<.0001*
(Delay+0.1308) * (Available-15.9448)	-0.0019	0.0005	14.65	0.0001*

TABLE V. MODEL FOR ENTERTAINMENT TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.4617	0.2322	3.95	0.0468*
Intercept[2]	1.709	0.249	47.12	<.0001*
Intercept[3]	4.2653	0.4611	85.56	<.0001*
Time Obligation - w/strict	-0.5504	0.1400	15.45	<.0001*
Time Obligation - w/	-0.1812	0.1409	1.65	0.1984
Delay	-0.0766	0.0099	60.25	<.0001*
Available	0.0247	0.0129	3.69	0.0548

TABLE VI. MODEL FOR PERSONAL TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.7281	0.1219	35.66	<.0001*
Intercept[2]	1.2685	0.1252	102.69	<.0001*
Intercept[3]	4.2480	0.2201	372.37	<.0001*
Time Obligation - w/strict (STO)	-0.6534	0.0700	87.21	<.0001*
Time Obligation - w/ (MTO)	-0.1762	0.7000	6.34	0.0118*
Delay	-0.0800	0.0050	260.16	<.0001*
Available	0.0136	0.0066	4.26	0.0390*
(STO) * (Available-16.3694)	-0.0145	0.0092	2.48	0.1153
(MTO) * (Available-16.3694)	-0.0142	0.0095	2.24	0.1343

TABLE VII. MODEL FOR WORK/SCHOOL TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.8167	0.0482	287.49	<.0001*
Intercept[2]	0.9848	0.0498	390.56	<.0001*
Intercept[3]	3.9186	0.1169	1122.6	<.0001*
Time Obligation - w/strict (STO)	-0.519	0.0553	88.20	<.0001*
Time Obligation - w/ (MTO)	-0.1712	0.0549	9.72	0.0018*
Delay	-0.0782	0.0038	426.16	<.0001*
(STO) * (Delay-1.8427)	-0.0128	0.0049	6.74	0.0094*
(MTO) * (Delay-1.8427)	-0.0082	0.0051	2.64	0.1042

TABLE VIII. MODEL FOR MEDICAL TRIPS

Term	Estimate	Std. Error	χ^2	Prob > χ^2
Intercept[1]	-0.3819	0.408	0.88	0.3493
Intercept[2]	0.2123	0.3889	0.30	0.5851
Intercept[3]	2.0604	0.4371	22.22	<.0001*
Delay	-0.0289	0.0537	0.29	0.5901
Available	-0.1564	0.0248	39.81	<.0001*

TABLE IX. WALD AND LIKELIHOOD RATIO TESTS

Predictor	DF	Holiday		Shopping		Social		Entertainment		Personal		Work/School		Medical	
		Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2	Wald χ^2	L-R χ^2
Time Obligation	2	57.78	60.89	105.03	114.11	74.12	76.73	29.01	30.04	146.47	154.33	161.45	167.30	N/A	
		<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*		
Delay	1	173.65	196.37	158.12	170.18	223.19	249.68	60.25	67.04	260.16	285.17	426.15	463.49	0.29	0.29
		<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	0.5901	0.5873
Available	1	N/A		28.35	29.36	20.65	21.36	3.69	3.79	4.26	4.43	N/A		39.81	49.44
				<.0001*	<.0001*	<.0001*	<.0001*	0.0548	0.0516	0.0390*	0.0353*			<.0001*	<.0001*
Delay x Available	1	12.66	13.03	N/A		14.65	14.99	N/A		N/A		17.11	16.65	N/A	
		0.0004*	0.0003*			0.0001*	0.0001*					0.0002*	0.0002*		
Time Obligation x Delay	2	N/A		7.31	7.10	N/A		N/A		N/A		9.63	10.01	N/A	
				0.0258*	0.288*							0.0081*	0.0067*		
Time Obligation x Available	2			6.62	6.93										
				0.0366*	0.0313*										

C. Open-ended comments

Respondents have provided feedback on a range of positive features, such as the ability to plan and prioritize trips. Majority of respondents have provided feedback that framework prevents abuse, that $\mathcal{C}$ is fair, including the ability to save. In addition, some participants have noted that low number of $\mathcal{C}$ available in combination with long estimated travel time and less important activity can influence people to change their departure time. On the contrary, respondents noticed that framework might be favoring individuals with more planning skills, that there is an incentive to spend $\mathcal{C}$ when one has them, and that some people might alternate between PL 1 and 3. More interestingly, participants provided many suggestions for further development. First, PL could be adjustable during the trip, as the need arises. Second, there could be a mechanism for post-activation verification for highest PL and for spending/gaining $\mathcal{C}$ (e.g., medical emergency). Similarly, PL 4 should only be available for selection if trip destination is on the predefined list (e.g., hospital). Third, some participants suggested that there should be a separate emergency $\mathcal{C}$ or more starting $\mathcal{C}$ for people that need frequent medical care. Fourth, some participants suggested that there should be different mechanism for gaining $\mathcal{C}$ (e.g., reporting incidents, using zero emission vehicle, using active or public transportation). In relation, many participant suggested adjustments to the framework, such as that gain of $\mathcal{C}$ for lowest PL should have higher value, that spending and gaining $\mathcal{C}$ based on the number of $\mathcal{C}$ that user has (e.g., as $\mathcal{C}$ number increases, gaining less $\mathcal{C}$), and that there could be dynamic $\mathcal{C}$ ceiling to enable reputation building.

V. DISCUSSION

Results from the web-experiment show us that PL selection was altruistic and PL 4 was not selected often for trip purposes different from medical. Consequently, the frequency of PL selection is inverse to PL value, confirming the intended cooperative feature of PS. Although one can notice inevitable variability in human decision-making, potentially originating from different interpretation individuals have related to trip information or PL, the conclusion is that people have a common understanding about PL intention and are willing to cooperate. The data from web-experiment enabled the development of discrete-choice models of human decision-making within the proposed framework.

Models were developed per trip purpose, and these models were capable to include variability of human decision-making, providing probabilities of selecting specific PL based on trip information and $\mathcal{C}$ number. Moreover, PL selection depends on time obligation and estimated delay. A clear distinction can be made in parameters for more frequent (e.g., work) in comparison to less frequent trip purposes (e.g., holiday). This informs us that most of the users tend to have a common understanding of trip purposes with higher and lower priority. Moreover, most of the participants were successfully nudged towards altruistic behavior. For example, this would not only mean selection of lower PL, but also potentially effects on choosing trip destination and departure time. These factors might be especially important in the context of automated vehicles, where there could be a potential to constraint energy or emissions effects through defining starting and maximum $\mathcal{C}$ number. Furthermore, one can notice inevitable randomness in human decision-making, potentially originating from different interpretation individuals have related to trip information or the operation of this framework. However, it is important to note that the results were probably influenced by the short-term and virtual interaction influenced by the web-experiment. Although in long-term system operation, more users might arrive to zero $\mathcal{C}$, there is a learning process involved with long-term interaction, potentially resulting in better $\mathcal{C}$ management.

In addition to the lessons about this particular framework, one of the important lessons is that system design needs to pay close attention to the societal values built into the technology and explicate them from the early stages of the design process. Thus, technology designers cannot lack the conscious reflections on the social component of technology, because technology shapes the context of human actions and consequently shapes humans themselves. In particular, further development will need to take into consideration local culture and values. For example, value of time punctuality and acceptable arrival window for activity might vary upon such aspects as the type of social event, level of relationships with activity participants, or overall system congestion. Similarly, $\mathcal{C}$ valuations might depend on the relative importance of the destination activity, or next obligation during the day (e.g., shopping might not be important, but might become based on the next activity). In addition, the current framework bases on the consideration of individualized decision-making, while

many travel decisions might be influenced by the other people travelling together, or by other people involved in the destination activity. Finally, we have to highlight that despite the fact that conventional management schemes do sometimes distinguish between different types of users (e.g., emergency vehicle, public transport vehicle), the specific needs of all the users are not directly considered. The consequence is that current frameworks cannot detect the least advantaged user, and do not protect the inviolability of the individual user in contrast to the aggregate effects. Contrary to conventional management mechanisms, this framework allows the input from individual users into the control process. For example, a user travelling to the hospital can get shorter travel time in comparison to the user travelling to vacation. This line of individual input is certainly a direction worthy of further understanding.

VI. CONCLUSION

In order to cater for the inherent complexity of urban mobility systems, this research design has been inspired by the idea of Universal Basic Mobility, and developed into a framework with non-monetary mobility credits and priority levels, based on the principles of human cooperation and systemic self-organization. The framework introduced the notion of end-user responsibility in the control process, relying on principles of large-scale and long-term human group cooperation. From the technical standpoint, this framework introduced a hierarchically distributed structure aiming for multi-level self-organization. The proposed approach relies on utilizing distributed but connected computing and sensing power. Information on human decision-making within the proposed modeling framework has been collected with a stated-preference web-based experiment. This information from web-experiment was used to develop discrete-choice models of human decision-making within the proposed framework. Models were developed per trip purpose, accounting for variability in human decision-making based on trip information and priority credits. In addition, web experiment setup has enabled users to provide a range of comments related to positive features, potential for failure, and further development.

In addition to these results, we would like to underline limitations and future research needs. The framework presented here includes one potential perspective, which can be included in the development of UBM-based mobility technology. In addition, this is the first attempt to use in the system design the principles of large-scale and long-term human cooperation. Therefore, the contribution here is not providing a final solution, but a proof that such an endeavor is possible. The insights in this paper stimulate several new and important questions. First, there is a need to further investigate the framework potential, by exploring human decision-making within different credit and priority level schemes. In particular, the framework can be further improved using knowledge on human decision-making relating fairness and cooperation. Here, we can draw methodological lessons from research on road pricing [59] and emerging mobility services

[60, 61]. Second, there is a need for further formulation of decentralized system operations strategies, for different traffic situations or network routes. This topic relates to an important issue of scalability and robustness to handle nonrecurring events. A practical benefit for further development is the available logit models, which can be used to develop agent-based system model. Ultimately, there is a need for a broader discussion on the objectives and parameters for future development of sustainable urban mobility systems based on principles of Universal Basic Mobility. However, this effort will never be successfully accomplished without a wider discussion on technological development alternatives, including not just engineers, but a range of other experts and public as well [62-64].

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