MOBILITYCOINS - TRADEABLE CREDIT SCHEME IN TRANSPORT PROJECT APPRAISAL

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ABSTRACT

Tradable mobility credits are considered a promising economic instrument for traffic and travel demand management; their possible role in the appraisal of transport projects, however, has not been in focus so far. Mobility credits not only have a monetary value attached, but they also carry utility information of travelers. Thus, they can moderate between the (short-term) travel demand and the (long-term) cost-benefit-analysis of supply-side measures. This role also implies that credits can express travel demands that would only emerge only if the project gets implemented. These travel demand could be different from the already familiar concepts of induced demand and rebound effects. Thus, if such a scheme gets implemented, this moderating role could further lead to the co-benefit of increased public participation and acceptance of transport projects. In this paper, we illustrate this role of tradeable mobility credits with a simple mathematical model. Travelers can spend their initially allocated credit budget for mobility, sell them to others, or redeem them as additional benefit in the appraisal of a transport project. If the benefits exceed the costs, the project gets implemented.

Keywords: tradeable mobility credit, transport appraisal, cost benefit analysis

INTRODUCTION

Transport sector requires economic instruments to achieve climate targets and limit traffic externalities. However, economists have had only limited success in promoting effective economic measures (*1*). Tradable credit schemes (TCS) are considered promising instruments. As cap-and-trade systems, they allow to set outcomes overall emission targets and people collectively distribute those resources efficiently. TCS, as they can be found in literature so far, cover mobility and market features. Those measures reflect short-term decisions by users. Either credits are used to fulfill mobility demands or are traded on the market to get another currency in return for a specific market price. Thus, TCS remain a traffic and travel demand management scheme so far (*2, 3*). The link of TCS to long-term decisions in the transportation system, e.g., infrastructure projects, has so far received little attention.

In this paper, we are presenting a link between TCS and the cost-benefit appraisal for transport projects. We extend the canonical TCS idea (*3, 4*) to the MobilityCoins System (*5*). The latter argues to use credits not only for charging for externalities, but also to use them as incentives for sustainable travel choices and to use credits to partially fund transportation projects. The economic and social motivation of this link is that travelers not only state their preferences on how the transportation system be designed, but also can travelers inform decision makers about where to prioritize measures to improve their lives, not only traffic. We establish the link by allowing travelers to *crowdfund* the funding gap between costs and benefits of an otherwise not realized transport project, e.g., a new bus line, through redeeming their credits for the project instead of travel or trading them on the market. In this regard, MobilityCoins can be considered as a moderator between the short-term traffic and travel demand management on one side and the long-term cost-benefit-appraisals for transport projects on the other hand. The policy oriented research question is thus whether a TCS scheme is capable of creating sufficient benefits due to crowdfunding of credits to close the funding gap of (smaller) transport projects without interfering too much with the performance of the transportation system. To explore this research question, we develop in this paper a mathematical model of the MobilityCoin System, formulated as a mixed complementarity problem (MCP).

This paper is organized as follows. We first review the literature on TCS and project appraisal in the transport sector. Thereafter, we introduce the mathematical model for the MobilityCoin system formulated as mixed complementarity problem (MCP). We then demonstrate the basic mechanism of using TCS to close the funding gap using a policy proof of concept in the Sioux Falls network. We close this paper with a discussion and a outlook for future research.

STATE OF THE ART

Based on the idea of TCS, first introduced by (*2*), we propose an extended generic policy instrument. As depicted in Figure 1, every user receives an initial credit budget at the beginning of each period which can be utilized in three main ways: mobility (demand), market (trading) and crowdfunding (supply). First, for mobility, credits can be used for a trip while charges depend on expected externalities. Second, instead of spending credits on mobility, they can be traded among users of the system. Due to the limited supply of credits, a market price is established that serves as an economic incentive to encourage the adoption of environmentally friendly, less expensive modes of transportation. Once users run out of credits, they have the choice to buy additional credits on the market, while users with a surplus in credits can monetize them. Third, credits can also be invested in supply-side measures defined by the agency to improve the travelers' generalized cost of travel, e.g. free flow speed improvements. The latter also gives users the opportunity to actively participate in the supply-side design, which can improve public support for such a policy tool (*6*)(*7*). Public acceptability of carbon pricing can be further improved through a tangible application and proper utilization of the revenues raised, e.g. for the crowdfunding of infrastructure (*8*). However, the idea of crowdfunding public infrastructure is not new and already present in the sustainable energy sector (*9, 10*). It has also been reported a few times in transport, e.g., public transport (*11*) or for bicycle infrastructure (*12*), but as yet it remains a niche.

Tradable credit schemes

As mentioned before, the novel approach goes back to the idea of a tradable credit schemes (*13*). It is a cap-and-trade system for mobility, which originally refers to (*14*). (*2*) were the ones who originally suggested using tradable credits in road traffic management. In general, a distinction can be made between tradable credit schemes and mobility permit schemes. The former entails that qualified users receive an initial credit budget from which they pay the charges for any of their trips (*13*). The latter requires that travelers have to bid for or buy the necessary permits for a specific link (e.g. a bottleneck) within a specific time period (*15*). (*16*) was one of the first using tradable permits to control vehicle emissions, congestion and urban decentralization and (*3*) were the first to algebraically express tradable credit schemes in small transportation networks. In recent years, numerous methodologies with varying characteristics in terms of user heterogeneity, validity, or allocation emerged and were applied to various kinds of networks. While certain schemes permit the transfer of remaining credits to the upcoming period, the majority of schemes contemplate a smaller period of expiration. Above all, in theory, tradable credits proved successful in achieving a congestion reduction goal (*3*)(*17*), and could also help to meet climate targets (*18*). While describing it as a potential promising (theoretical) instrument, (*19*) highlight that a TCS for mobility is still far from applicable to our present mobility system. Incorporating the transportation supply side, (*20*) applies a TCS with steps to increase road capacity and (*21*) combined a TCS and link capacity improvement measures in a bi-objective bi-level model to compare economic growth and environmental management. (*22*) analyzed travel demand management for an autonomous vehicle enabled TCS and lane management strategies to reduce overall travel time under user equity constraints.

Every TCS system is targeting one or several objectives. It is not just congestion that is taken into consideration when determining the overall allocation and mobility pricing. In order to reduce greenhouse gas (GHG) emissions, the system can also be configured to influence emission externalities. (*23*) introduced market-based implementations for emissions standard attainment proposing origin-destination based pollution permits. (*24*) worked on a TCS system that redistributes link flow patterns to obtain minimum emissions for the whole network, and extend it to bi-objectives (low emissions and low travel times). (*25*) considered a vehicle type specific and OD-based credit allocation in a multi-period TCS framework. In addition, they suggested a pricing structure based on the type of vehicle (zero-emission versus internal combustion engine vehicles) and the links travelers are using linked to their vehicle type. The latter work encourages the use of zero-emission vehicles, while the former redistributes flows to achieve a dual goal of minimum emissions and minimum travel time.

Transport project appraisal

Public projects are required because of the strain on the current transportation infrastructure caused by the expanding global population and the rising transportation needs that go along with it. Due to their limitation, financial resources must be distributed wisely. It will be essential to distribute resources in the most effective way in order to accomplish more with less resources. A key component of evaluating transportation and other infrastructure projects are standard appraisal methods. Famous examples are the cost-benefit analysis (CBA), Multicriteria Analysis (MCA) or Environmental Impact Assessment (EIA). They offer a recognized and widely consistent framework for comparing the merits of various proposed projects by quantitatively evaluating project performance. CBA was invented by (*26*) in the 1840. He focused on willingness-to-pay and the consumer surplus that he called relative utility. Despite a wide application, it has also been criticized for restricting studies to those impacts that can be measured and monetized the easiest. The CBA technique is still evolving and guidelines are progressively mandating or promoting the inclusion of a greater variety of consequences in the analysis. This tendency is the outcome of a desire for a more thorough study as well as a reaction to those who have criticized the CBA's predominance. Comprehensive guides are available in various forms, like the 'Guide to cost-benefit analysis of investment projects' of the European Commission (*27*). In addition to analyzing quantitative options in value for money, which has traditionally been the emphasis of CBA, appraisal has gotten better over time. Now, analysis also concentrates on the stated strategic objectives of investment policy. There are several important needs for setting a clear method for appraisal. Under budget constraints evidence based priorities have to be met. Possible ramifications are shown to create transparency for decision makers and illustrate impacts on other policy objectives. Potential impacts of projects or policies are assessed as well as willingness to pay, actual payment and accepted valuation for societal impacts reflect society's preferences. Impacts on the transportation sector are assessed as a basis. Transport users' responses are estimated to proposed changes in the network by using an evidence-based models. Quantitative evaluation of transport user benefits in terms of time savings based on value of time, accident savings, changes in operating costs are planned over different time intervals. As aforementioned, the method of CBA is continuously under review. (*28*) draw the conclusion that the way residual value is handled is insufficient and needs more investigation since the current residual value calculations for both, the infrastructure's final project value and the asset's lifespan value, do not accurately represent the genuine value. Furthermore, externalities and societal or health impacts are considered, e.g., noise, land-use or air quality. Several scenarios are mapped including descriptions of "what-if" alternatives when implementing modified scenarios or not implementing certain measures. Wider economic measures beyond the transportation sector are also assessed. Associated with proper land use planning and labour market policies, different implications can be drawn, accelerating local investment, productivity increase and labour supply based on analytical tools and regional evidence. However, techniques are frequently data-intensive and typically call for involvement from industries other than transportation. (*29*) encourage the mutual use of Multi-Attribute Tradespace Exploration (MATE) and CBA in project selection to mitigate shortcomings of CBA. With MATE, it is possible to investigate how project costs and benefits are distributed as well as associated incentives for changing behavior. MATE is a method for system design selection and generation developed and matured at MIT. It is a value-based decision and design method for the conceptual design across domains (*30*). Different types of costs (such as tangible and intangible costs) are also kept separate, and a large number of designs are methodically explored early on in the concept phase. Another mutual use of two methods is evaluated by (*31*). By combining the two techniques MCA and CBA, the respective limitations might be overcome, resulting in a system that is both efficient and effective for evaluating sustainable mobility policies and initiatives. (*32*) was one of the first studies to look into the use of ideal-solution based Multicriteria Decision-making methodologies for sustainability evaluation of urban transport projects under uncertainty that chooses veto to identify the best option, overcoming the drawbacks of single Multicriteria Decision-making techniques. (*33*) include the equity dimension and assert that transportation projects serving the majority population are quite likely to outperform equivalent projects serving disadvantaged groups of the population in cost-benefit analyses. Furthermore, they investigate whether these equity impacts may be addressed by substituting accessibility improvements for travel time savings. (*34*) created a system for evaluating investments in public transportation for identifying transportation disadvantages and priorities for project creation. The method uses the notions of accessibility and affordability as a complimentary approach. By adding a function of impedance made up of the travel time budget and the proportion of income spent on transportation, that is based on the computation of accessibility levels to the labor market for different zones of a specific city. Changes in transportation expenses and time are typically employed to gain the benefits of the traveler instead using it in project assessment or appraisal. In the context of logit choice models, the logsum method serves as a measure of consumer surplus. Despite the fact that logit models are used in transportation fairly frequently, logsums are only occasionally used in project evaluation (*35*).

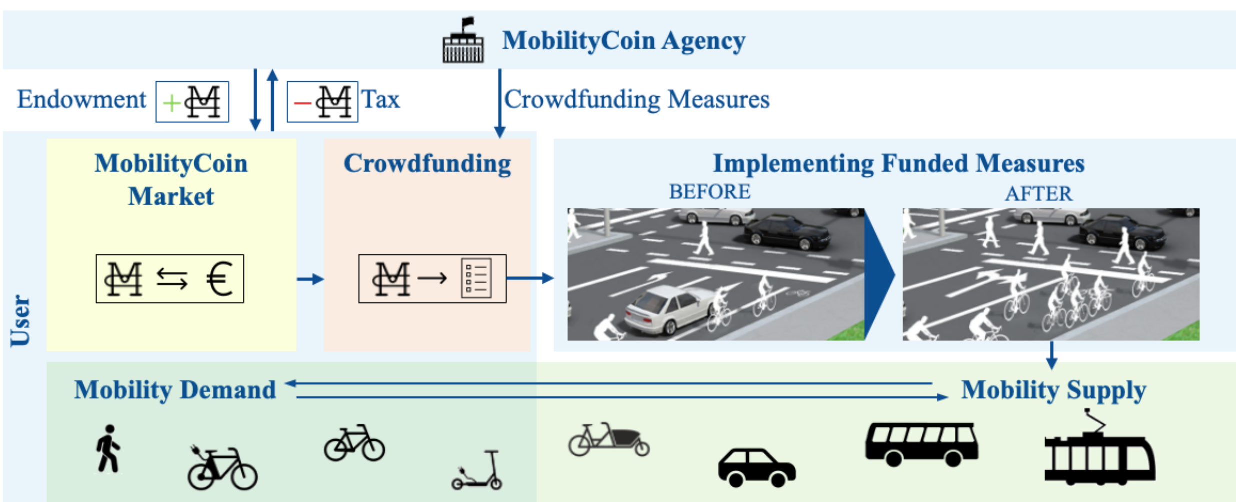

FIGURE 1: Major building blocks of the MobilityCoin System (*5*).

A MATHEMATICAL MODEL FOR AN INTEGRATED CREDIT SCHEME

To investigate and illustrate the fundamental behavior of the MobilityCoin System, we describe the system mathematically. Table 1 summaries the indices, parameters and variables. We use basic and well-known building blocks for establishing the linkage between TCS and cost-benefit appraisals to demonstrate the scheme as a proof of concept. Originating from the model proposed by Yang and Wang (*3*), we formulate the MobilityCoin System as an equilibrium problem in mixed complementarity problem (MCP) representation (*36, 37*). This equilibrium problem is embedded into the modeling sequence shown in Figure 2 to model the interactions between TCS and crowdfunding of the benefit gap of a proposed transport project. In the following, we discuss each building block before discussing the policy scenario.

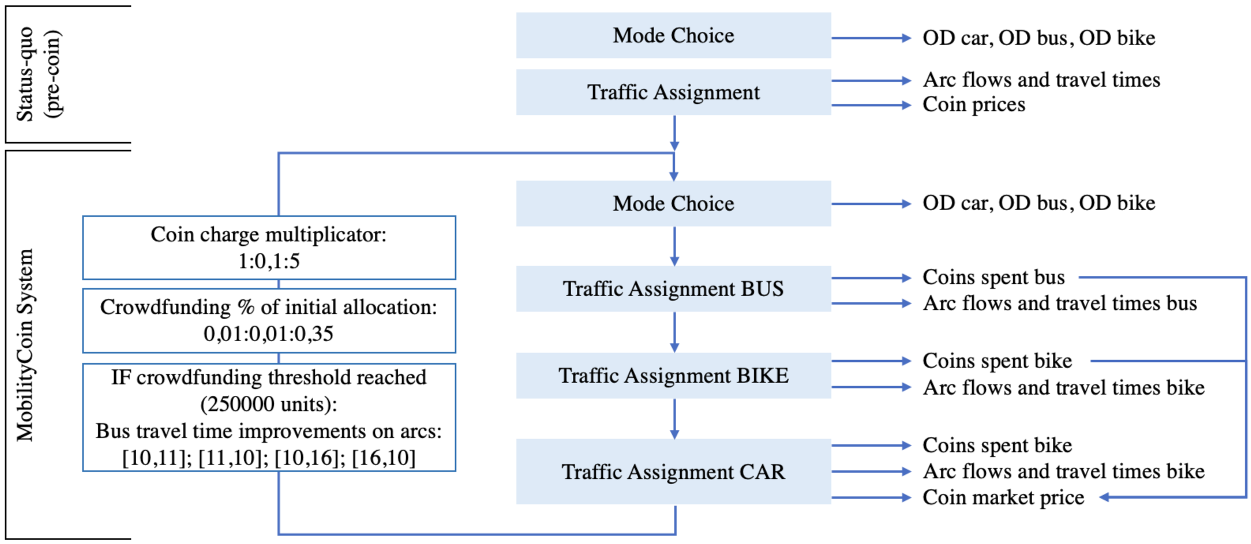

FIGURE 2: Mathematical model for the integrated system.

Charging scheme

Each mode is charged individually. Bus and bike are charged link-wise. Bus is charged 0.05 coins while users receives 0.01 coin as an incentive for using the bike. The pricing function of the car follows Equation 1. The resulting charge per link for the car is p_{ij}. It combines the basic coin price κ with a price policy multiplier ϕ to accommodate a congestion oriented scheme. It is grouped into three categories based on the status-quo traffic flows $Q_{\text{ij,m=car}}$. That allocation persists during the development of the model based on the policy scenario, assuming that agents are not aware about current traffic. The multiplier ϕ can be altered in policy scenarios.

$$p_{\text{ij,m=car}} = \kappa_{\text{ij,m=car}} * \phi = \begin{cases} 1 * \phi * \kappa_{\text{ij,m=car}}, & \text{if } Q_{\text{ij,m=car}} \geq 10000 \\ 0.5 * \phi * \kappa_{\text{ij,m=car}}, & \text{if } Q_{\text{ij,m=car}} \geq 5000 \& < 10000 \\ 0.1 * \phi * \kappa_{\text{ij,m=car}}, & \text{if } Q_{\text{ij,m=car}} < 5000 \end{cases} \tag{1}$$

Mode-choice

The overall demand is distributed across modes based on a logit model. In the first run, the mode specific utilities are expressed as deterministic components of a parameter function of modal attributes of travel time t_{ijm}. After introducing the coin system, the utility function gets extended by the mode specific link prices p_{ijm}. The choice probabilities are established through a maximum-likelihood estimation in a logit-modeling framework, assuming that users are aware about the coin charges a priori (*38*). Following the generic utility function 2 and probability function 3, the OD-pair values for each mode are computed. For the utility function, the coefficients of modal attributes β are based on estimates provided in (*39*). Altogether we get mode specific utilities U_{ijm} for each OD-pair i, j. Note that p_{ijm} is the credit price for the OD-pair.

$$U_{\text{ijm}} = \beta_{0,\text{m}} + \beta_{\text{time,m}} * t_{\text{ijm}} + \beta_{\text{cost,m}} * p_{\text{ijm}} \tag{2}$$

Indices	Definition
i, j, k	Node identifier
m	Mode (car,bus,bike)
Parameter	**Definition**
p_{ijm}	Link price by mode m from node i to j in coins.
κ_{ijm}	Basic coin charge by mode m from node i to j.
ϕ	Price policy multiplier.
β_m	Mode-choice coefficients of modal attributes.
I	Initial MobilityCoin endowment.
K_{ijm}	Link capacity by mode m from i to j.
OD_{jkm}	Demand by mode m from node j to k.
CF_{coin}	Collected funding for crowdfunding measure.
t_{ijm}	Free flow travel time by mode m from node i to j.
a_m, b_m	Mode-specific parameters of the BPR function.
Variable	**Definition**
U_{ijm}	Utility by mode m from i to j.
T_{ijm}	Travel time by mode m from i to j.
C_{ijm}	Travel costs by mode m from i to j.
MC_{ijm}	Minimum path costs by mode m from i to j.
Q_{ijm}	Link flow by mode m from i to j.
Y_{ijkm}	Link flow by mode m from i via j to destination k.
MP_{coin}	MobilityCoin market price.

TABLE 1: Model indices, parameters and variables.

The mode-choice is connected upstream to the traffic assignment (*40*). Once the mode is chosen, the demand matrix is link-wise allocated in three mode-specific demand matrices. Thus, agents are taking the same mode for the entire origin-destination trip, means a change in modes within one trip is generally excluded.

$$P_{\text{ijm}} = \frac{e^{U_{\text{ijm}}}}{e^{U_{\text{ij,car}}} + e^{U_{\text{ij,,bus}}} + e^{U_{\text{ij,bike}}}} \tag{3}$$

In the presented model in Figure 2, mode choice is updated at every iteration. In the first iteration, however, utilities are computed solely based on travel time. The resulting mode choice probabilities are then used to update the origin-destination matrices that are used in the subsequent traffic assignment.

Traffic assignment

The traffic assignment module of the model refers to the algebraic TCS description of (*3*). The BPR function 7 is applied as volume delay function for the means of transport car. Bus and bike mode is not affected by congestion. The user equilibrium (UE) is described and computed as a link-flow mixed complementarity problem (MCP) (*36, 37, 41*). The governing Equation is Wardrop's condition for the user equilibrium (*42*) shown in Equation 4. On the left hand side of Equation 4 we have the sum of the travel costs C_{ijm} starting at node i to any adjacent nodes j and the minimal costs MC_{jkm} for travelling from any adjacent node j to destination node k with mode m that should be greater than or equal to the minimal costs MC_{ikm} travelling from node i to node k. The non-negative flow variable Y_{ijkm} is associated to this time minimization equation and is only positive for those neighboring nodes where the generalized costs are minimal.

$$C_{\text{ijm}} + MC_{\text{jkm}} \geq MC_{\text{ikm}} \perp Y_{\text{ijkm}} \tag{4}$$

For the number of agents travelling from every node j to a destination k is given by the flow conservation on the left side of Equation 5. This equation is associated with the minimal costs variable MC_{jkm}.

$$\sum Y_{\text{ijkm}} - \sum Y_{\text{jikm}} = OD_{\text{jkm}} \perp MC_{\text{jkm}} \tag{5}$$

We add a third condition to the MCP for integrating the MobilityCoin Market in the traffic assignment module. Therefore, we first have to add the MobilityCoin trip charge p_{ijm} and market price MP_{coin} to the generalized travel costs, as shown in Equation 6.

$$C_{\text{ijm}} = T_{\text{ijm}} + p_{\text{ijm}} * MP_{\text{coin}} \tag{6}$$

The travel times T_{ijm} are defined according to the BPR function as shown in Equation 7.

$$T_{ijm} = t_{ijm}\left(1 + b_m\left(\frac{Q_{ijm}}{K_{ijm}}\right)^{a_m}\right) \tag{7}$$

Subsequently, we associate the market clearing condition shown in Equation 8 with the market price which is only positive if and only if all coins of the initial endowment I are charged for mobility purposes by using all three modes. In Equation 8, $\mathscr{A}$ defines the set of arcs in the network.

$$I - \left(\sum_{ij\in\mathscr{A}} Q_{\text{ij,car}} * p_{\text{ij,car}} + \sum_{ij\in\mathscr{A}} Q_{\text{ij,bus}} * p_{\text{ij,bus}} + \sum_{ij\in\mathscr{A}} Q_{\text{ij,bike}} * p_{\text{ij,bike}}\right) = 0 \perp MP_{\text{coin}} \tag{8}$$

The coins used for funding in crowdfunding measures, which is explained in more detail in the next section, are not part of the market clearing condition, since we suppose a percentage-wise increase in funding and reduce the amount of coins before the initial allocation for this proof of concept.

Crowdfunding

Clearly, the intention of individuals to crowdfund or invest parts of their mobility budget into transport projects can follow various mixed patterns, e.g., egoistic or altruistic motives. Ultimately, users want to fulfill their needs and invest in the best assumed benefits. To comprise this uncertainty, we introduce an induced randomness of 3% to the crowdfunding volume in each period. Here, we define that ΔB is the benefit gap that equals the benefits (e.g., travel time savings) minus costs (e.g., the construction costs).

In this scheme, a so far unrealized project gets only implemented if and only if Equation 9 holds. In other words, the monetary value realized by crowdfunding, i.e., market price MP_{coin} times funding volume CF_{coin}, must be greater or equal to the benefit gap.

Indices	Definition
$b_{car} = 0.15$	B parameter for mode car.
$a_{car} = 4$	Power of BPR function for mode car.
$b_{bus} = b_{bike} = 0$	B parameter for modes bus and bike.
$a_{bus} = a_{bike} = 1$	Power of BPR function for mode bus and bike.
$v_{bus} = 25$ [km/h]	Constant travelling velocity for bus.
$v_{wbus} = 6$ [km/h]	Constant walking velocity to bus stop.
$d_{busstop} = 0.1 * l_{ij}$	Walking distance to bus stop.
$v_{bike} = 10$ [km/h]	Constant travelling velocity for bike.

TABLE 2: Model indices, parameters and variables.

$$MP_{coin} \cdot CF_{coin} \geq \Delta B \tag{9}$$

We assume for simplicity that in case this condition is not met that CF_{coin} is not returned to the market, as it has been redeemed, e.g., the validity period of coins is over. However, other market designs are possible too. For instance, coins can be returned to the users making them available again for mobility or crowdfunding purposes. We leave this for future research. Arguably, crowdfunding is evaluated at the end of the validity period and credits cannot be used for other purposes anymore.

DATA: MULTIMODAL SIOUX FALLS

Prior to introducing the assumed policy scenario, we give an overview about the underlying data. We extend the renowned Sioux-Falls network to the multimodal case. The Sioux-Falls networks sees much use for illustrating and discussing contributions on traffic assignment and network design problems (*36, 43*). It consists of 76 links connecting 24 nodes as shown in Figure 3. The parameters for the car network are obtained from a Github repository on transportation networks (*44*).

We extend the provided model to the multimodal case as follows. On the demand side, we simply use the existing demand for cars provided in (*44*) and distribute it across the three modes using a mode choice model. On the supply side, we set the parameters for the BPR functions of buses and bicycles as shown in Table 2, while using the BPR function parameters as provided in (*44*). We make the simplifying assumption that all modes use the same network, while not interfering each other, i.e., the volume-delay functions are separated.

POLICY SCENARIO

In the first step, we add the MobilityCoin System to the status-quo and assess the change in flows when increasing the coin price multiplier continuously for the car mode following Equation 1. The resulting and expected shift to the modes bus and bike intended by the agency can be seen in graph 4, which is emphasizing that the credit system is acting as travel demand management scheme.

Suppose that the agency identified that on links 27, 29, 32, and 48, which are highlighted in red in Figure 3, a transport project was not able to reach the required equality of benefits and costs; nevertheless, the agency considers the benefit gap small enough to put the project up for crowdfunding of the benefit gap. The agency quantifies the gap with $\Delta B = 250000$ monetary units.

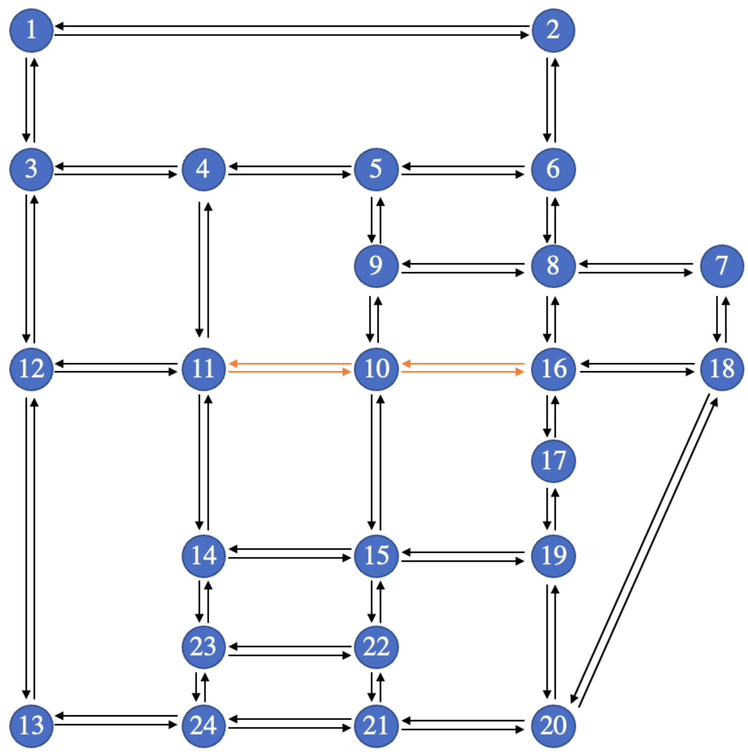

FIGURE 3: Sioux Falls network with selected links for crowdfunding (*45*).

A summary of the crowdfunding measure is shown in Table 3.

Links	27, 29, 32, 48
Travel time improvement	30%
Capacity improvement	50 %
Costs	250000

TABLE 3: Model crowdfunding indices, parameters and variables.

As mentioned before, we added the charging mechanism to the model as a first step. Now, we want to evaluate the additional crowdfunding feature. Therefore we assume that users of the system spent a certain percentage of coins in crowdfunding measures, instead of using it for mobility purposes. As shown in Figure 5, the initial endowment of the agency is constant at 100000 coins. Starting with a crowdfunding share CF_{coin} of 0%, we now continuously raise the withdrawal for the crowdfunding feature by $0,01\%$ for the following periods. As soon as the crowdfunding threshold of 250000 monetary units is reached, the measure gets funded and implemented.

IMPLICATIONS FOR POLICY MAKING

The novel idea of spending coins for an increased benefit in the transport system extends the original idea of a TCS. So far, credits were used to fulfill short-term decisions in mobility. With the introduced crowdfunding application, users can balance their own value for said short-term decision with an additional long-term invest in travel time or capacity improvements, for instance.

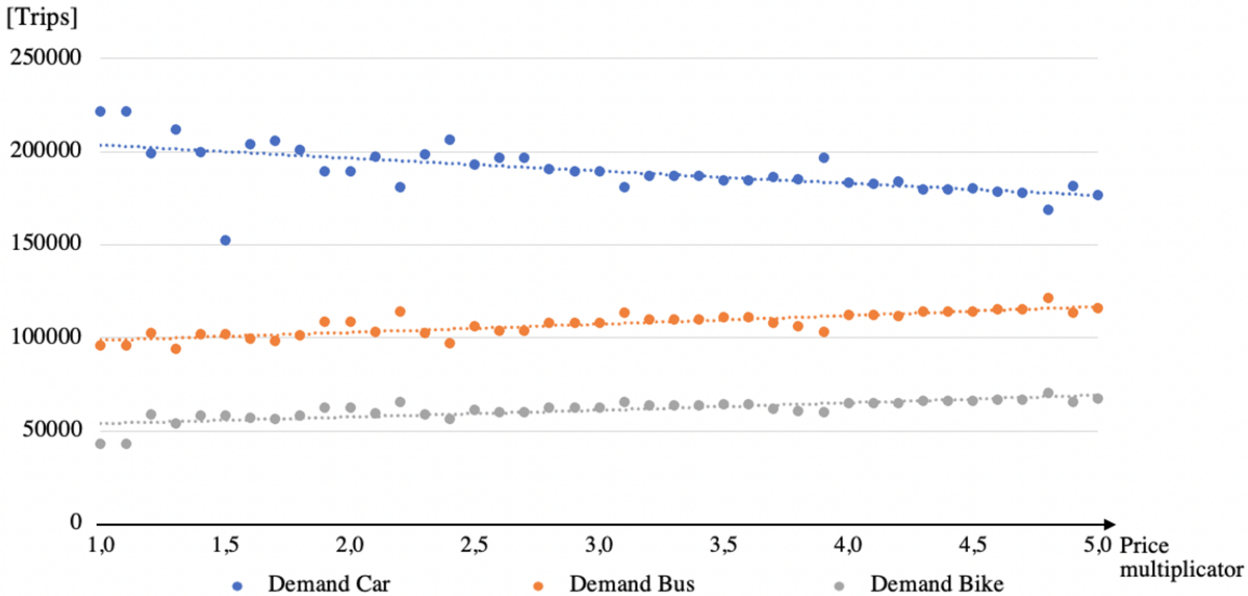

FIGURE 4: Development of demand of all modes when raising coin charge.

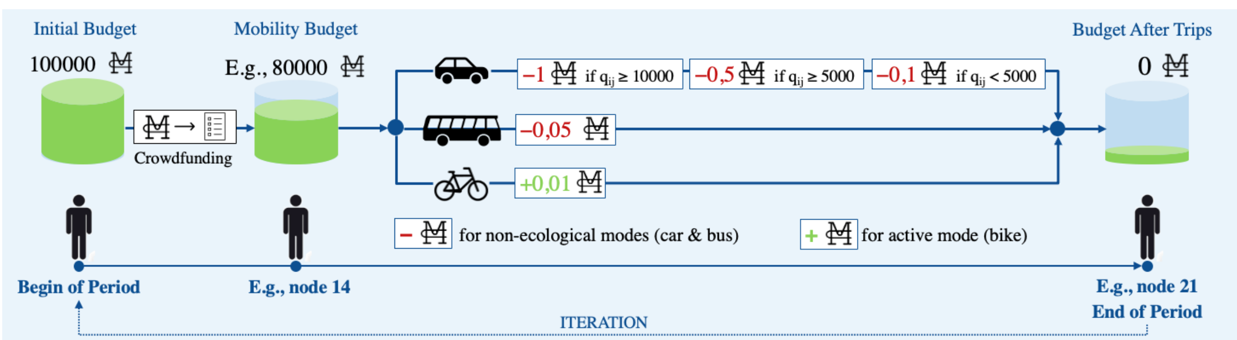

FIGURE 5: MobilityCoin flow within one period.

This can be seen as a vote of the users which in return grants feedback towards the agency. In this paper, we illustrate first results for the MobilityCoin System's pricing and crowdfunding feature. As shown in Figure 6 and as intended by the agency, the mode specific demands steadily shift away from car towards bus and bike. This development is observed along the entire funding raise.

The impression of effectiveness is reinforced by the development of the system travel time before and after the crowdfunding measure is implemented, which is shown in Figure 7. We assume, that the effectiveness of the MobilityCoin System increases by adding a pull mechanism (crowdfunding) to the initial push mechanism (pricing).

The withdrawal of coins off the system keeps less coins for expensive modes, additionally urging users to shift modes. At the same time investing in these ecological modes can lead to a two-way improvement of the transportation system. The agency can instantaneously quantify the benefit by connecting the coins with the travel time improvements in order to define the benefit gap.

Starting from an optimal traffic flow pattern in a static case with homogeneous travelers, a favorable behavior of the presented cost-benefit approach is only observed in a multimodal case.

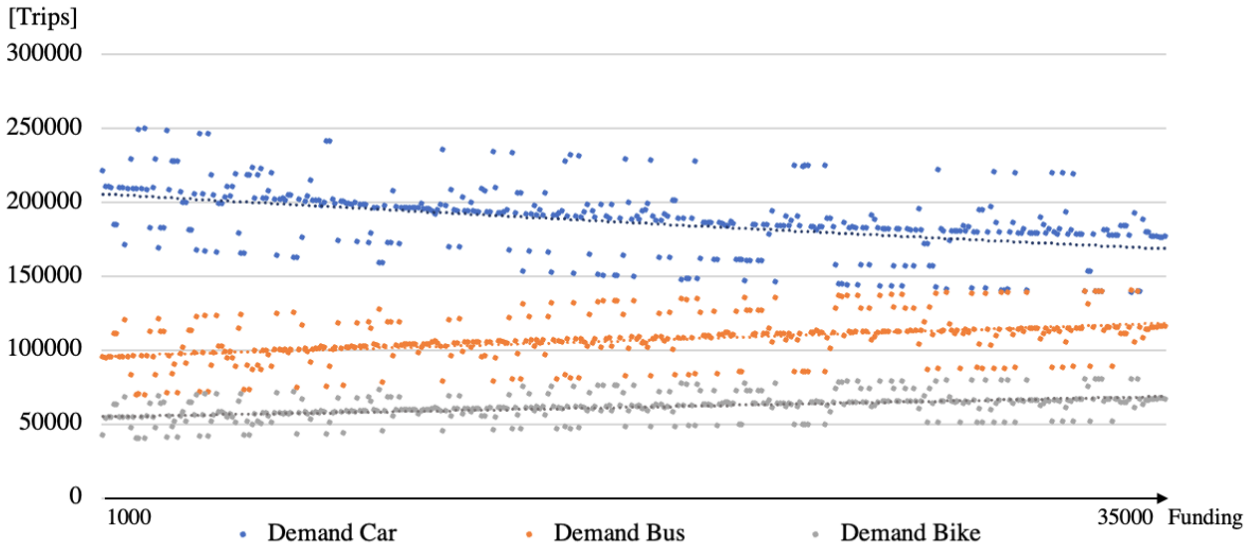

FIGURE 6: Development of demand of all modes when raising coin charge and crowdfunding.

Otherwise system travel time increases steadily which does not lead to a beneficial outcome, respectively reaching the benefit gap ΔB. That leads to the assumption that a favourable development is only achieved if alternatives exist. Furthermore, the results of the model show that pricing is effective to change travel behavior towards more sustainable modes and the number of allocated coins has a direct impact on the market price, which, in our case, is important for an investment by the agency in crowdfunding measures. The crowdfunding measure is the distinctive feature of the MobilityCoin System. In the second step we could observe that this feature can have an additional beneficial effect on the travel behavior.

DISCUSSION AND CONCLUSIONS

This paper provided a first mathematical formulation of the MobilityCoin System that is a systematic link between tradable credit schemes (TCS) as a mean for (short-term) traffic and travel demand management on one side and the cost-benefit-analysis approach for (long-term) transport project appraisals on the other hand. We established the link by allowing travelers to *crowdfund* the positive gap between costs and benefits of an otherwise not realized transport project, e.g., a new bus line, through redeeming their credits for the project instead of travel or trading them on the market. The economic and social motivation of this link is that travelers not only state their preferences on how the transportation system should be in their area, but also does this link give users the possibility to inform decisions makers on where to alter the infrastructure to improve their daily activities and not only traffic.

The presented equilibrium model of the MobilityCoin System serves an illustration purpose of the basic mechanism; from there the idea must be developed in various ways in future research. First, the model and its components will be further developed to capture more choice variety, e.g., heterogeneous users (low vs. high income), multi-period aspects like departure-time choices and banking credits over several periods (e.g., speculation), and stochastic traffic assignment. We will further explore the integration into existing dynamic schemes (*46*). In addition, we will explore the model stability and under which parameters the system has a solution at all. Second, identification

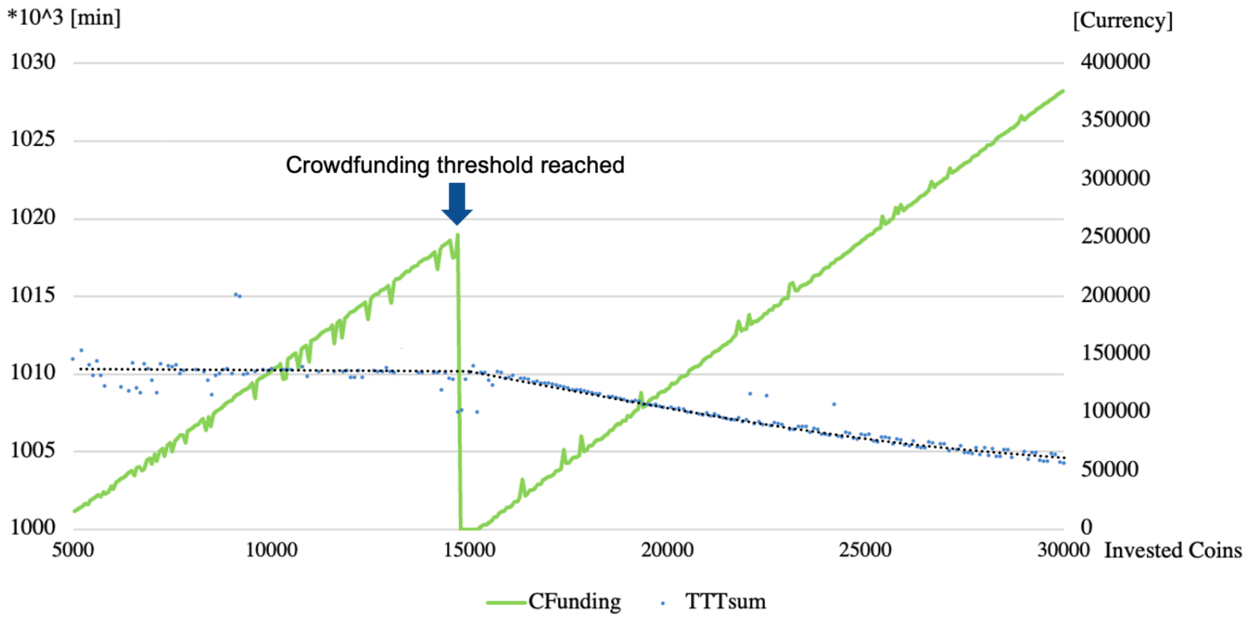

FIGURE 7: Development of funding and system travel time.

of reasonable parameters. For this purpose, we will build on an existing and calibrated multimodal transport model to explore further the feasibility and applicability of the MobilityCoin System, implemented in a real-world transportation network. We will further use stated preference surveys to obtain behavioral parameters under a TCS scheme. Third, the TCS market place that will quite likely see a transaction tax to avoid hoarding (*47*) creates a revenue stream for the agency. We will explore in future research to which extent this revenue stream can be used in funding infrastructure.

In closing, the proposed link between the TCS for traffic and travel demand management and cost-benefit appraisal can deliver potential advantages into transport policy. First, TCS are considered promising for traffic management. Adding a pull factor to the original pricing mechanism of TCS opens further opportunities for efficiency and effectiveness of such schemes. Second, TCS are by definition supposed to be economically self-sufficient. An extension of this self-sufficient peculiarity to a crowdfunding feature offers the possibility to directly quantify cost-benefits of (smaller) supply-side measures. Depending on the design of the funding mechanism and the system objective, the MobilityCoin System can enclose various push and pull mechanisms with a self-sufficient nature to improve mobility for everyone, while reducing external costs of transportation.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: P. Blum, A. Loder, K. Bogenberger; data collection: P. Blum; analysis and interpretation of results: P. Blum, A. Loder, K. Bogenberger; draft manuscript preparation: P. Blum., A. Loder. All authors reviewed the results and approved the final version of the manuscript.

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