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Cycle4Value: A token-based incentive system to promote cycling

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1 ABSTRACT

Despite various measures to promote cycling, the overall proportion of journeys taken by bike in Austria has improved only slightly in recent years. As part of its mobility strategy, the Austrian Federal Government has set itself the target of doubling the proportion of journeys taken by bike in in 7 years. To this end, motivational or behavioural approaches should be preferred to costly infrastructural measures. In this context mobile apps for tracking but also for monetising users' own data - as a technological manifestation of the "quantified self" - are developing rapidly. Sweepstakes and even performance-related rewards are booming in many areas. At the same time, however, there is increasing awareness of data protection in Europe. In this respect, blockchain technology has great potential for handling user data due to its decentralisation, transparency and security (Buhl et al., 2017). Applications on the blockchain are disruptive innovators for a wide range of applications, from transaction processing to land register entries to logistics chains. In all these, data can be stored using decentralised, unforgeable blockchain records (Hopf & Picot, 2017). Applying such innovative measures can also support cycling promotion with all its associated benefits in reduced emissions, positive health effects and reduced infrastructural costs.

The solution envisaged in the project reward cyclists for regular cycling with so-called "Cycle Tokens". The key technologies - machine learning and blockchain - present an innovative solution for the validation of routing data and transaction processing. As proof of concept, it is tested whether and how a safe and transparent process of value generation for regular cycling can be created via a utility token, to translate the macroeconomic effects of cycling into value units.

2 INTRODUCTION

Ten years ago at the peak of the gamification hype, the research project “Nice Rides” targeted the promotion of bike commuting in the (sub-) urban area. While the primary goal was to implement a new routing algorithm allowing the choice between safe, time efficient and attractive routes, Nice Rides integrated a motivational framework with gamified elements to achieve a change in long established behavioural patterns (i.e. not choosing the car for commuting). The target group was directly involved in the design of the gamification framework as well as in the optimisation of the routing algorithm regarding the safety and attractiveness of bike routes. Users were encouraged to rate junction points and cycling pathways on an interactive map running on mobile and desktop clients. The gamification framework implemented mechanics like points, achievements and challenges such as “Cycle2Free” – thus enabling users to unlock premium features of the Bike Citizens app. Ten years on from Nice Rides we are working on the next iteration of a tokenised incentive model for sustainable mobility. In Cycle4Value, a transparent and low-threshold reward model for promoting cycling based on blockchain technologies is currently being tested in practice. The economic, health and ecological benefits/effects of cycling are presented simply and, after a plausibility check using machine learning, converted into a real value (Cycle Tokens). These value units are stored in a digital wallet and can be remunerated in a test marketplace. The research project surpasses conventional incentive systems because, on the one hand, both the storage of the value units and the redemption process are decentralised, tamper-proof and transparent and, on the other hand, the real economic benefit of active cycling is fairly monetised.

2.1 Practical Background

Despite various measures to promote cycling, the overall share of journeys made by bicycle in Austria has changed only slightly in recent years (Tomschy and Steinacher, 2017; Illek and Mayer, 2013). In line with its mobility strategy, the Austrian federal government aims to double the share of journeys made by bicycle in seven years. In addition to infrastructure, motivational and behavioural approaches in combination with technological innovations play a central role in achieving this ambitious goal. The positive effects of cycling on a collective and individual level (e.g. reduction of air and noise pollution, reduced land use, health-promotion, improved and socially just mobility), especially when substituting car journeys, have been proven in numerous studies (Bracher et al., 2002; Macdonald, 2007; Schäfer and Walther, 2008; Litman, 2003). Cost-benefit analyses, among others, proved to be a promising approach to quantify the ecological, economic, health and traffic benefits of cycling. While there are various incentive approaches to promote cycling, which primarily pursue an event character and are based on the distribution of prizes, Bike Citizens has already taken the first step towards a performance-based bike currency (Finneros) in the course of the research project Nice Rides. However, a transparent and tamper-proof solution for validation, storage and redemption has not yet been implemented. This is where the Cycle4Value framework comes into play, by utilising machine learning and blockchain technologies.

2.2 Motivational Framework

Cycle4Value develops and evaluates a blockchain-based incentive system, based on complementary integration of the transtheoretical model (Prochaska et al., 2009). In order to change human behaviour, it is necessary to understand the underlying behavioural processes. Many theories of motivational psychology and behavioural science have attempted to describe and explain mobility behaviour, including the theory of planned behaviour (Fishbein and Ajzen, 1975), the norm-activation theory (De Groot and Steg, 2009) and the self-regulation theory (Bamberg et al., 2011). In line with (Prochaska et al., 2009), the self-regulation model (Bamberg et al., 2011) claims that behaviour changes through a time-ordered sequence of stages, each stage involving various cognitive and motivational difficulties.

Within our motivational framework monetarised incentives will be triggered using smart contracts powered by the Blockchain as a Service (BaaS) platform Ardor. By providing information and action-related knowledge (Staats et al., 2004), setting goals (Locke and Latham, 2002), comparison and competition with other users, and rewards and feedback (Fujii and Mackey, 2009; Froehlich, 2011), mobility behavior is influenced in a targeted, playful manner. In addition, incentives enhance behavioural control and support positive aspects of eco-mobility (Ajzen and Manstead, 2007). The major advantage of this token-based incentive system is that the individual interventions are fed directly to individual users, increasing motivation and the likelihood of voluntary and longer-term behavior change. The main goal is to achieve a change in established behavioural patterns by encouraging positive attitudes and awareness regarding the economic, ecological and health-related effects of cycling. Through the integration of modern ICT technologies such as a token-based incentive system and plausibility algorithms supported by artificial intelligence and machine learning, target groups will be rewarded with Euro pegged utility tokens for participating in field tests in Vienna, Graz and Krems (Austria) as well as Berlin (Germany). Based on a meta-analysis, the value for each token is defined as 1.37 Euro per kilometre (more details can be found on https://www.cycle4value.at and in our previous paper (Seewald et al., 2021).

2.3 Blockchain Technology

(Pfeiffer et al., 2020) show that blockchain technologies are a valid way to secure gamification frameworks and their ecosystems. The authors also provide insights into innovative consensus algorithms and their vital ability to monitor multi-chain processes. In this context (Komiya and Nakajima, 2019) examine consensus algorithms as a reward system. They introduce their Proof-of-Achievement (PoA) approach, an algorithm optimized for blockchain games which focusses on the number of tasks achieved in the game. Similarly, (Yuen et al., 2019) perceive consensus algorithms like Proof-of-Work (PoW) as a bottleneck for games. Their proposal is called Proof-of-Play with a focus on peer-to-peer solutions. Along with Proof of Stake (PoS) as the consensus algorithm featured by Ardor, an environmentally friendly consensus method is used within Cycle4Value to verify all transactions, while at the same time ensuring connectivity to ERC20 protocols. When using PoS a mixture of volume (stake), online time and random components determines whether a node validates transactions. This makes it possible to operate the blockchain in a more energy-efficient way. In fact, a Raspberry Pi Zero is enough to operate a node in the network.

2.4 Cryptoeconomics

Cryptoeconomics is an emerging field of economic coordination games in cryptographically secured peer-to peer networks (Voshmgir and Zargham, 2020). This field was bootstrapped following the appearance and popularisation of the Bitcoin network, which runs a protocol for a Peer-to-Peer Electronic Cash System (Nakamoto, 2019). Transactions in the Bitcoin network are based on a newly created unit of account inherent to the protocol and governed by a set of simple and deterministic rules. The detachment of this unit account from anything outside of the system and its rigid issuance policy led to the creation of a digital token, the value of which – when denominated in a commonly used unit of account like the e – is very volatile, with swings of sometimes more than 10% per day. The volatility of Bitcoin and many digital assets which followed led to a widespread belief that this characteristic is inherent to digital assets based on cryptoeconomic protocols. This is however not the case, as the emergence of stable coins such as Bank (2019) showed. The Ethereum protocol, first described in a 2014 whitepaper (Buterin et al., 2014), popularised the idea of cryptoeconomic systems with support for fully programmable smart contracts. This led to a plethora of innovations in the digital assets space and inspired the idea of mapping the economic benefits of cycling to such a digital asset.

One important consideration for such a token-based incentive system which rewards cyclists with theoretically cash-equivalent tokens is, of course, fraud. Especially for large stakeholders like cities, it is very important that incentives not be misallocated as otherwise the expected benefits may not materialise. In fact, one of the main obstacles to wide distribution of such incentive systems is exactly this capacity for fraud, and large stakeholders have taken this issue as an argument against the wide deployment of such systems. We will describe our approaches to deal with this issue in section 3.4.

3 METHOD

3.1 Research Questions

The primary aim of the Cycle4Value research project is to increase the awareness of the positive effects of cycling, the acceptance of cycling as a means of mobility and the implementation of cycling as a habit, which will primarily support the subsequent ambitious transport and health policy strategies.
The research questions are as follows:

1. Is a tokenised incentive framework able to alter attitudes towards cycling and improve awareness of the positive effects, as well as alter behaviour (cycling as a habit)?
2. Do users and stakeholders see the monetised value of cycling as a fair reward?
3. Can the legacy ad-hoc plausibility model of the Bike Citizens Beta App be replaced by a machine learning system trained on similar data?
4. Can the legacy ad-hoc plausibility model of the Bike Citizens Beta App be replaced by a pre-trained transport-mode-detection model?
5. Can such a system be made and kept cheat-proof indefinitely by leveraging artificial intelligence and machine learning techniques, as well as continuous retraining?
6. Can such a system be made and kept cheat-proof more simply (using captchas or similar techniques), by preventing automated generation of large numbers of accounts by bots?
7. How can cheating detection techniques be improved "on the ground", when it is unlikely that ground truth data on cheating techniques is available in a timely manner (excepting deliberate challenges to the user base)?

Research questions (1) and (2) are addressed within this paper (e.g. in Section 3.1); (3) and (4) were already addressed in (Seewald et al., 2021) and will be summarized and slightly extended in Sections 2.4 and 3.2; (5), (6), (7) will be only partially addressed here and are to some extent left open for future work as a definitive evaluation is not yet possible within our project.

3.2 Research Material

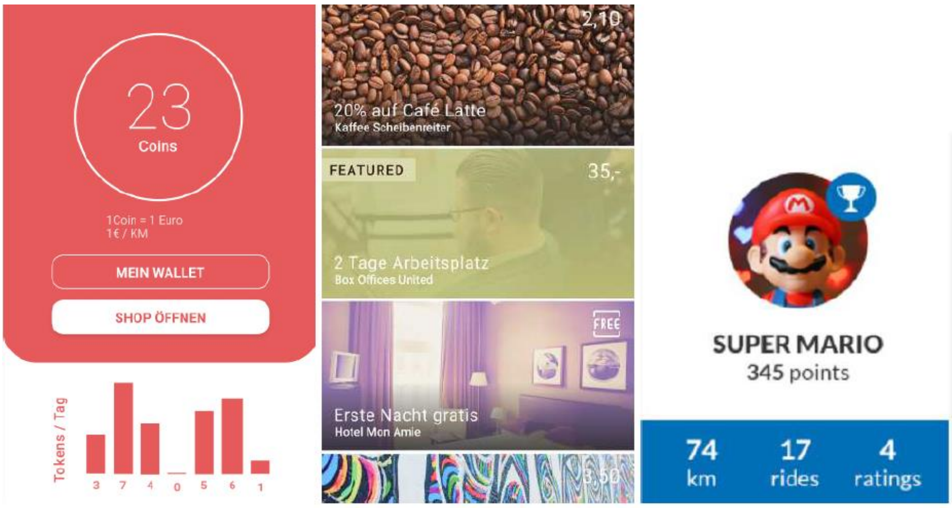

Fig. 1: Left, Centre: Cycle4Value dashboard and marketplace; Right: Nice Rides dashboard.

The Bike Citizens Beta App, which has been extended by new features in relation to the token-based reward system, serves as the object of investigation. During the beta test, aspects of usability and acceptance by users and stakeholders were surveyed by means of an online questionnaire. In addition, users were recruited from the Bike Citizens network to actively try to outsmart the existing routing algorithm. After a previous marking, recorded tracks are marked as fake tracks. Figure 1 show the Cycle4Value dashboard as well as the marketplace, and on the right the dashboard that was implemented in Nice Rides. While we are currently pursuing the token-based reward approach, the previous project relied heavily on established gamification elements such as points - the so-called “bike impact score”, badges and challenges.

3.3 Framework

Figure 2 shows the incentivisation approach followed in Cycle4Value. Where Nice Rides used an abstract point system including digital badges, in Cycle4Value every kilometre cycled is converted into a cycle token, based on a formula that considers individual and collective benefits of cycling. Before being transferred to a digital wallet, the registered route data is checked for plausibility using machine learning. The wallet serves as a frontend, where the user can view the current status at any time. The Cycle Tokens earned in this way serve as vouchers for a marketplace supplied with incentives from various partners such as shops, public transport providers and cultural institutions.

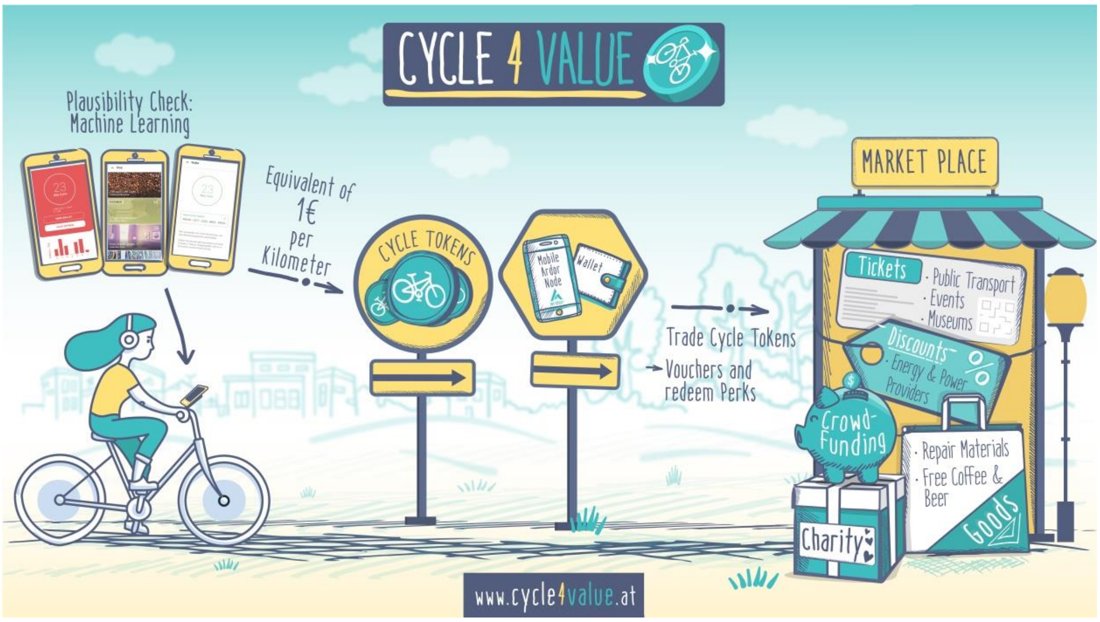

Fig. 2: Incentivisation approach followed in Cycle4Value

3.4 Cheat Proofing

To investigate cheating and fraud detection – and thus cheat-proof the system – we previously analysed an existing ad-hoc legacy system which tests for the related concept of track-based cycling plausibility – created mainly to prevent people uploading noncycling tracks. In (Seewald et al., 2021), we have shown that the results of a legacy model for plausibility detection of cycling tracks can to a moderate extent be reconstructed by a classically trained rule-learning model with handcrafted features, as well as to a somewhat lesser extent by a pretrained transport mode detection (TMD) model, even though the latter was trained on a completely different dataset.

To better compare both measures, we split the original plausibility values of 0-100 into five (almost) equally large intervals: [0;20); [20;40); [40;60); [60;80); [80;100] and computed arithmetic mean and standard deviation of the new plausibility measure over each interval. Fig 3 shows the results, and the same values averaged for each possible legacy model plausibility as a Raw Mean. The latter roughly corresponds to a ROC curve. The mean TMD-derived plausibility measure increases strictly monotonically from the lowest to the highest interval. Although standard deviation is initially high, it shrinks for higher intervals. A recalibration of the TMD model or an adaptation of the threshold for plausibility could improve the match considerably. The Pearson’s correlation coefficient between legacy and TMD measure is 0.31, indicating a weak to moderate correlation. Note again that the TMD model has not been trained on any part of our datasets, so these results are quite surprising and indicate that TMD models are a good starting point for a trainable plausibility – and possibly also cheating – detection system. Note also that the legacy model was not explicitly designed to detect cheating and fraud, but rather to increase the quality of uploaded data by ensuring that only bicycle tracks were accepted. We are currently improving on this work to build the final track-level fraud detection system.

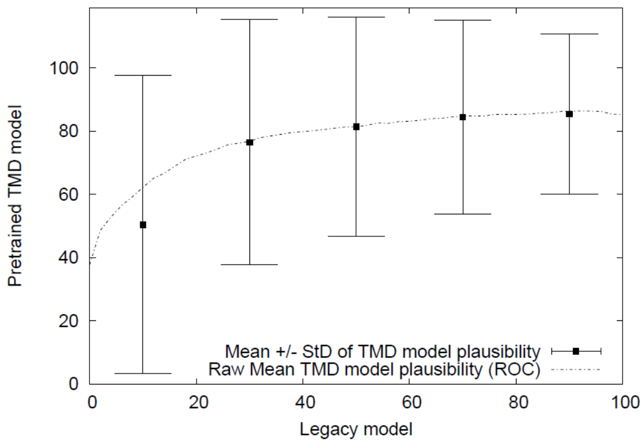

Fig. 3: Comparison of the ad-hoc plausibility (legacy) model with transport-mode detection (TMD) model.

However, as will be seen later in section 4.2 not all types of fraud are detectable at track-level. We also have to consider attacks involving multiple tracks, such as using multiple phones on a single bike, which can only be detected at multiple-track level. It is necessary to build a multiple-track-level fraud detection system as well.

4 RESULTS

4.1 Expert Survey

14 experts from the city administration, technical universities and transport planning took part in an online survey. 37% of the participants considered gamification to be “over”, and alternative incentivisation approaches as preferable when promoting cycling. Vouchers, giveaways and initiatives such as “Cycle2Work” were given as examples. None of the stakeholders currently use a blockchain-based incentive system. Regarding the value of a cycled kilometre as basis for a cycle token, values between 0.26 and 0.5 Euro were seen as most appropriate (57%) followed by 0.51-0.75 Euro (29%). Considering that the sum of 1.37 Euro as derived in Cycle4Value includes both individual and collective benefits, there is a good match with this expert view, if 50% of the value is granted to the user and eligible for collecting rewards (= 0.68

Euro which take into account the collective benefit). In terms of the positive impact of cycling, the greatest relevance was attributed to environmental benefits (67%). However, the meta-analysis carried out showed that the greatest benefit actually comes from health-related effects, although the ratio can shift flexibly depending on the CO_2 price per ton. 83% see the incentive system as valid means to promote cycling.

4.2 Cheating and Attack Modes

The semi-monetary compensation in form of tokens which are potentially convertible to cash makes cheating the system (respectively fraud) much more likely. While the number of false negatives (Type II errors, undetected cheaters) should be small, the number of false positives (Type I errors, i.e. people wrongly classified as cheaters) should also be small to prevent disillusionment and reduced trust in the reward system. To some extent this can be optimised by using learning algorithms that output confidence values and by choosing appropriate thresholds. In our latest model, the number of tokens generated corresponds to the square root of cycling kilometres per track and is cut-off at two levels: at most 4 tokens per track, and at most 8 tokens per day, yielding some buffer against attacks by limiting payoff for a single user. However as this is probably not sufficient, we have collected six types of possible attacks on the system. This list may be of course be incomplete and is intended only as a starting point.

1. Uploading tracks from sports events (e.g. cycle racing)
2. Uploading tracks from delivery services
3. Uploading tracks made with other vehicles (may include e-bikes)
4. Using more than one phone on a bicycle
5. Uploading automatically generated fake tracks
6. Uploading modified real-life tracks

Attacks (1), (2) and (3) are not a large problem. In (1), the restriction of the maximum number of tokens per track and day – mentioned above – severely restricts the possible gain per user. (2) should not yield any payoff as these bike rides would happen anyway even without incentives. However if only a single person profits, it remains a minor problem. We could address it by either filtering out common bike routes which could be applied to attack (1), should too many similar tracks be uploaded. Attack (3) should be easily detectable by the fraud detection system although the differentiation of e-bikes is still an open problem.

The more interesting cases are attacks (4) to (6): (4) should be detectable – especially once we have gyroscope and accelerometer sensors – by aligning multiple tracks and determining their similarity. The local sensor movements on these tracks will be extremely similar, but this can only be detected on the level of multiple tracks, and not from a single track. We will address this in future work as such data has just become available.

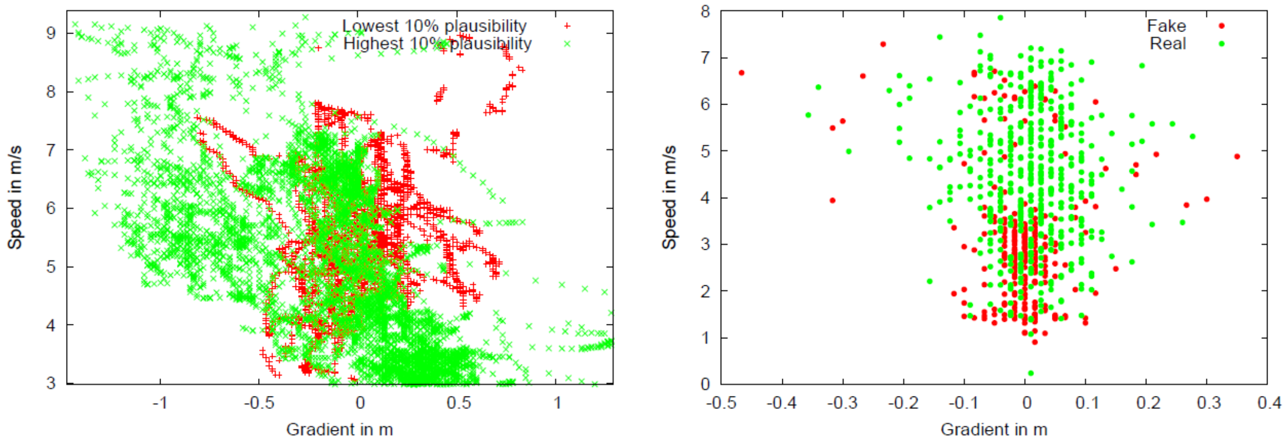

Fig. 4: Left: Scatterplot of gradient vs. speed, coloured by 10% lowest and highest plausibility, on historical data; Right: Same scatterplot on first batch of competition data with by-track user-defined classification Real and Fake.

For attack (5), it is important that not all details of the system are known, otherwise engineering a reverse system is made correspondingly easier. However, since we focus on machine learning techniques throughout, it is likely that creating realistic fake tracks will be very hard, and people will mainly resort to replaying modified existing tracks (6), which should again be detectable by their similarity. Also, only (4) to (6) – and (3) when combined with (4) – ensure potentially unlimited payoff, which is surely the most tempting fraud scenario. It should also be noted that only attacks (3) and (5) can be addressed at single track level with models described here. The other four attacks must be addressed at the level of multiple tracks and will need a completely different approach, although likely one also partially based on artificial intelligence and machine learning techniques. As the most tempting attacks call for many users to be automatically created, another option may be to simply make user registration non-scriptable, e.g. by using captchas or requiring a short cycling sequence with pulse rate (for example, by using the front smartphone camera and pulse-by-face). As this list may be incomplete, we are currently running a competition for cheating with appropriate incentives before deploying the system widely. This should give us sufficient data on other scenarios not considered here. As first result, we obtained two fake tracks which the legacy plausibility system classifies with maximum plausibility.

Fig. 4 shows the results. It seems that for the competition tracks, the distribution of gradient vs. speed is much more similar than for historical data which indicates that new unique attack modes may possibly be found in the newer data.

5 DISCUSSION

New technologies (e.g. navigation and routing apps) in combination with incentive systems (e.g. gamification) are becoming increasingly popular within the cycling community. However, there are still many open questions – for example, how to leave the level of abstract and often gamified rewards and deliver real rewards; and what their underlying value could be. This is mainly related to the problem of quantifying the costs and benefits of cycling in monetary terms and ensuring the quality of tracking data. Privacy concerns also play a significant role here, as sprawling, unrestricted tracking & exploitation methods generate sceptical criticism.

Cycle4Value therefore explores the use of blockchain technologies based on digital tokens to translate track data into value units. In this way, the entire process of distribution, storage and redemption of Cycle Tokens can be mapped and automated. Thanks to blockchain technology, all accounts can also be secured against fraud and hacks. Since each “cycled” token appears once and uniquely as a public entry on the blockchain, it also has a unique, ideal value. This leaves behind the purely digital incentive level of common gamification approaches and gives cycling a real value.

Another innovation in the project is the use of machine learning for plausibility checks of registered cycling trips or cycling routes (“tracks”). In contrast to ad-hoc code, which typically uses highly predictive features (e.g. maximum acceleration and speed) and is thus relatively easy to circumvent by suitable countermeasures (e.g. driving slowly, controlled acceleration), in machine learning the learned model will typically use a large number of slightly predictive features, making it significantly more difficult to intentionally cheat the system. Another advantage of a machine learning system is that it can be retrained if new attack types are found and thus can remain useful much longer. However, as we mentioned a single-track prediction is not sufficient. It is also necessary to compare multiple movement patterns using appropriate distance metrics to prevent “multiplication” of “genuine” bike rides (e.g. using multiple smartphones in the backpack or on the bike). Cheating by using alternative means of transport with similar movement patterns is thus effectively prevented as far as possible. Care is taken here to ensure that “real” journeys continue to be recorded correctly (as small a false positive rate as possible). Towards this goal, we are currently running a competition for cheating with appropriate incentives and are researching fast algorithms for multiple track alignment. The solution presented in this paper is currently being implemented and piloted using the Bike Citizens Beta App. First reviews received by stakeholders suggest this approach has potential to shift mobility behaviour in the right direction.

6 ACKNOWLEDGEMENTS

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