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Electronic Notes in Theoretical Computer Science 343 (2019) 103–116

Electronic Notes in Theoretical Computer Science

www.elsevier.com/locate/entcs

Exploiting Gamification to Improve Eco-driving Behaviour: The GamECAR Approach

Stavros Nousias[1], Christos Tselios[1], Dimitris Bitzas[1], Dimitris Amaxilatis[2], Javier Montesa[3], Aris S. Lalos[1,4], Konstantinos Moustakas[1] and Ioannis Chatzigiannakis[5]

[1] *Department of Electrical & Computer Engineering, University of Patras, Greece*
{*nousias, tselios, bintzas, aris.lalos, moustakas*}*@ece.upatras.gr*

[2] *Spark Works ITC Ltd, UK*
{*d.amaxilatis@sparkworks.net*}

[3] *Brainstorm Multimedia, Spain*
{*jmontesa@brainstorm3d.com* }

[4] *Industrial Systems Institute, ATHENA Research and Innovation Center, Platani-Patras, 26504, Greece*
{*e-mail: lalos@isi.gr*}

[5] *Sapienza University of Rome, Italy*
{*ichatz@diag.uniroma1.it*}

Abstract

GamECAR aims to develop a highly innovative and interactive Serious Games platform that will empower and guide users to adopt an eco-friendly driving style. This will be achieved, without distracting them from safe driving, through a multidisciplinary approach aiming at the development of a user friendly, unobtrusive multi-player gaming environment, where the users will not only play collaboratively/competitively using their mobile device but also use the car itself and their own bodies, thus turning eco-driving into an immersive and highly motivating experience. The sensing infrastructure of GamECAR will acquire data related to driving from an OBD sensor that will capture a complex set of parameters related to eco-driving, and will also sense environmental and physiological parameters of the driver, so as to better position the state of the system (car) in context (environment, user). The GamECAR system will be quantified and evaluated in test campaigns with drivers in three different sites that will serve system development and will also demonstrate usefulness and exploitation potential.

Keywords: Gamification, Human-centric design, Transportation

1 Introduction

Road transport is one of the major causes of the environmental pollution, being responsible for about 30% of the total emissions of CO_2 into the atmosphere [18]. Recent studies have shown that a driver's driving style can result in more efficient

https://doi.org/10.1016/j.entcs.2019.04.013
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engine operation saving up to 35% of fuel. Thus, by motivating drivers to adopt a more eco-friendly driving can have substantial ecological, economic impact and promote safety in road transport. According to WHO, accidents cause the premature deaths of more than 1.25 million people every year [15] with the leading cause being aggressive driving. Specifically, the driving style is defined by a series of technical, social, psychological and cultural factors. More significant factors are the driver's age, values, social position, concentration, stress and risky behaviour. The most important factor in changing a driver's behaviour is the positive feedback from taking a certain action [7]. Behavioural theory strongly confirms that unless the individual can see or feel the results of his/her actions, on an immediate and continuous basis, that individual is unlikely to alter his/her behaviour over time. To this end, innovative approaches are required, that promote the drivers' motivation towards changing their driving style. Serious gaming and gamification have been proven to be powerful tools, that guide targeted behaviour change and are able to improve the way various activities are performed. The term gamification refers to a designed behaviour shift through playful experiences and became popular in the past years. In order to effectively motivate users to adopt desired behaviours, the games should provide information so that the user themselves will be able to evaluate their behaviour and increase their awareness on the negative consequences that it may have.

In the past years, several behavioural and psychology based frameworks emerged, aiming to describe and comprehend the motivational features that drive players and can be utilized as a basis for successful gamification approaches. Gamification combines several different components including game mechanics, motivational psychology, behavioural economics, technology platforms, neurobiology, user interface and user experience design guidelines combined with business logic [10]. Ryan and Deci self-determination approach [11, 17] theorized that players are not merely motivated by reward systems to follow through a task but there are three main core drives, namely "competence", "relatedness" and "autonomy". Daniel Pink [16] replaced the competence core drive with "mastery" and added "purpose" as another significant coefficient. Nicole Lazzaro [13] introduced the four keys to fun gamification framework focusing on gameplay types with different motivational features. Hard fun calls the player to overcome difficulties and frustration facing reasonably hard obstacles and goals with strategy and determination. Easy fun focuses on exploration and creativity. People fun is based on socializing, communication, cooperation and competition, while the serious fun calls for self-improvement and for making a difference in the real world. Another study [6] made distinctions between player types recognizing four main categories: killers heading for the top, achievers aiming to conquer all available challenges, socializers aiming to build alliances or groups of players and finally, explorers, that head for exploring all the available options provided by the game without focusing on achieving high score or position. Amy Jo Kim in Gamification 101 [12] developed a game mechanics approach that makes distinctions between intrinsic and extrinsic rewards and introduces a three-phase game including on-boarding where the "Newbie" player learns the rules and commences the journey, habit-building including the main phase where activity loops and feedback systems turn "Newbies" into "Regulars". Mastery comes to "Enthusiasts" who have mastered the system and want to go deeper. Yu-Kai Chou proposed the octalysis actionable gamification framework [10] incorporating and analyzing further previous approaches, aiming to determine the core drives that make games more meaningful and fun. Eight core drives were recognized namely, epic meaning and calling, development and accomplishment, empowerment of creativity and feedback, ownership and possession, social influence and relatedness, scarcity and impatience, unpredictability and curiosity and finally loss and avoidance.

In this context, the GamECAR project aims to develop a highly innovative and interactive serious game platform that will motivate users to adopt a more eco-friendly driving style without distracting them from safe driving. Aiming to utilize this multitude of behavioural frameworks towards gamification of eco-driving behaviours, GamECAR employed the octalysis actionable gamification framework as a more complete, all-around and comprehensive approach without ignoring the benefits of other gamification methodologies. Furthermore, GamECAR aims to marry the different driving activities along with a set of desirable behaviours stimulated by the gamified environment. The developed playful interventions will be adapted to the user's characteristics through an intelligent unobtrusive sensing platform that will utilize late-breaking personalized user models, so as to optimize the individuals driving behaviour shift through playful experiences.

2 GamECAR platform

The overall GamECAR platform can be divided into (i) the data retrieval and processing platform and (ii) the gamified environment. The former collects and pre-processes all data related to vehicle and driver status (e.g. fuel consumption, gear change, acceleration, braking, heart/respiration rate) and extracts informative indicators, such as the eco-score and the aggressiveness score. The gamified environment is the actual game that processes all available data so as to assess the players' score and ranking.

2.1 Data retrieval and processing platform

As stated above, GamECAR platform is partially based on the design and deployment of a sensing prototype which will unobtrusively record physiological, behavioural, environmental and vehicle parameters thus composing an eco-driving index and then provide personalized and proactive hints to the drivers on how to adjust their current driving style to a more eco-friendly way. Figure 1 presents some of the basic hardware components of the aforementioned sensing prototype, namely (i) an OBD II device, attached to the car for retrieving vehicle-oriented data, (ii) a specialized wearable device, which collects the drivers heart rate, (iii) the Spire respirator sensor [1], which also obtains information related to the drivers vitals by

[1] https://spire.io/pages/stone

monitoring the respiration rate on any given time, (iv) an Android smartphone [2], which acts as the main coordinating node through a custom-made application capable of connecting to all other sensors as well as third-party repositories available online, collect and locally store data before transmitting them to (iv) the Spark Works Cloud Storage Repository, an online platform with the ability to process and analyze large data sets using custom algorithms and dedicated processes, in the most efficient manner. The Spark Works Cloud storage repository has already been used in different use cases, where different datasets were retrieved [2–5].

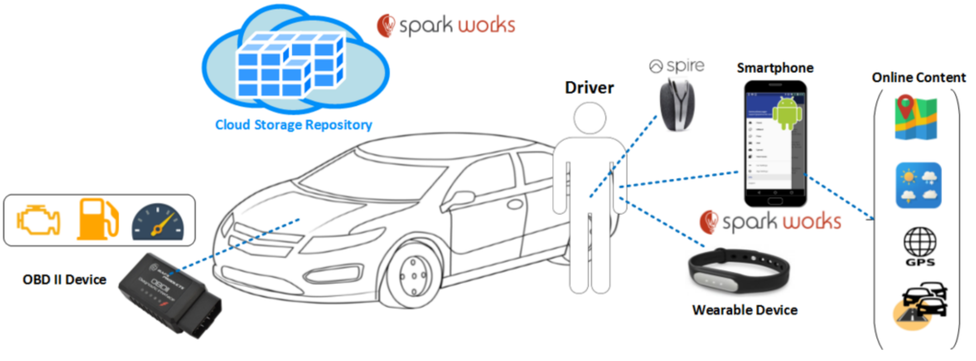

Fig. 1. GamECAR data retrieval and processing platform

Selecting a smartphone as the coordination node of the GamECAR data retrieval and processing platform provides significant flexibility due to the large number of available communication protocols and corresponding interfaces any contemporary smartphone supports, as well as the inherent caching and processing capabilities it incorporates [1,8,9]. In addition, the accumulated datasets may or may not undego a certain pre-process as described in [14].

2.2 Extraction of informative indicators

Eco-score penalizes high level of engine rounds per minute (RPM) values during gear shift-up, cruising, abrupt braking and high acceleration, while the aggressiveness score penalizes high lateral acceleration, abrupt braking and high variances in throttle position and RPM. Eco-score is comprised of five parameters, shift-up parameter, braking parameter, acceleration parameter, RPM parameter and cruising parameter. All parameters are computed within a 30 seconds temporal window. For each metric, we utilize a sigmoid function $\beta(x)$ and a weighted histogram function that assigns each event to a bin depending on the intensity of the event. $\beta(x)$ is defined as

$$\beta(x) = a_2 + \left(\frac{a_1}{(a_4 + exp\,[a_3 \cdot (x - x_0)])} \right) \tag{1}$$

where parameters a_1, a_2, a_3, a_4 defined experimentally for each case.

[2] https://www.android.com/

2.2.1 Braking

Given B the set of m braking events with B_i the i_{th} braking event. Then B_{i_S} is the amount for soft braking, B_{i_H} the amount for hard braking, B_{i_P} the amount of pedal braking and B_{i_E} the amount of emergency braking. Then the braking ecoscore parameter is defined as

$$E_B = \sum_{i=1}^{m} (10 \cdot B_{i_S} + 5 \cdot B_{i_H} - 5 \cdot B_{i_E} - 10 \cdot B_{i_P}) \tag{2}$$

2.2.2 Shift up event

Given S the set of m shiftup events with $S_{i_{RPM}}$ the peak RPM during a shiftup and S_{i_T} the duration of the event, each event is assigned to one of $N = 10$ bins. Each bin $H_S[n]$ corresponds to the set of shiftup events that satisfy the following:

$$H_S[n] = \{S_i| \, (S_{i_{RPM}} > 2000 + (n-1) \cdot 100) \, | \, (S_{i_{RPM}} \leq 2000 + n \cdot 100)\} \tag{3}$$

Then for each bin $H_S[n]$ a penalty factor $P[n]$ is defined as

$$P[n] = a \cdot \beta(n) \cdot \left(b + \left(\frac{\sum_{i \in H_S[n]} S_{i_T}}{m} \right) \right) \tag{4}$$

Finally, the shift up ecoscore parameter is defined as

$$E_S = \sum_{i=1}^{N} P[n] \tag{5}$$

2.2.3 Acceleration

Given A the set of m acceleration events, A_i is the i_{th} event, A_{i_a} is the recorded acceleration and A_{i_u} is the recorded velocity. Then each event is assigned to one of $N = 12$ bins. Each bin $H_A[n]$ corresponds to the set of acceleration events that satisfy the following:

$$H_A[n] = \left\{ A_{i_u} \middle| A_{i_a} > a_{min} + (n-1)\frac{a_{max} - a_{min}}{12} \middle| A_{i_a} \leq \frac{a_{min} + n\,(a_{max} - a_{min})}{12} \right\} \tag{6}$$

where a_{max} and a_{min} are personalized parameters. Finally, the acceleration ecoscore parameter is computed by the following expression:

$$E_A = \sum_{n=1}^{N} \left(a \cdot \beta(n) \cdot \frac{\sum_{i \in H_A[i]} A_{i_u}}{\sum_{i=1}^{m} A_{i_u}} \right) \tag{7}$$

2.2.4 RPM

Given R the set of m RPM events, R_i is the i_{th} event within a window of duration equal to w. Each event is recorded when the engine RPM value exceeds 2500 rpm.

$R_{i_{PEAK}}$ is the peak RPM value during the event and R_{i_T} is the duration of the event. Then, the RPM ecoscore parameter is computer as follows:

$$E_{RPM} = \sum_{i=1}^{m} \left(- \left(1 + \frac{R_{i_T}}{w} \right) \cdot \beta(R_{i_{PEAK}}) \right) \tag{8}$$

2.2.5 Cruising

For each temporal window the speed variance s_u^2 and throttle position variance s_{th}^2 are computed. The parameters for vehicle speed and throttle are computed

$$f_u = \frac{\bar{u}}{100} \cdot \beta(s_u^2) \tag{9}$$

$$f_{th} = \frac{\bar{th}}{100} \cdot \beta(s_{th}^2) \tag{10}$$

where $\bar{u}$ and $\bar{th}$ are the average speed and throttle position. Finally, the cruising ecoscore parameter is computed.

$$E_C = \beta(f_{th} + f_u) \tag{11}$$

2.2.6 Aggressiveness score

The aggressiveness ecoscore calculation is based on the following parameters: a) engine RPM variance parameter, b) braking intensity parameter, c) acceleration magnitude parameter. High variance of engine RPM indicates driver nervousness and improper vehicle handling. For example, significant fluctuations in engine RPM are the result of a driver who is not focused on smooth cruising and overall safe driving. Instead, they tend to accelerate many times for small duration, thus minimizing their fuel efficiency, eco-friendliness and safety for themselves and others. Given a $w = 30$ seconds temporal window the aggressiveness engine RPM related score A_{RPM} is

$$A_{RPM} = \frac{s_{RPM}^2}{\mu} \tag{12}$$

where s_{RPM}^2 is the engine RPM variance and μ is an experimentally defined parameter.

Braking intensity is computed during online analysis, based on the correlation between vehicle deceleration and braking duration. This is intended to contribute to the computation of aggressiveness score in a cumulative manner. Abrupt braking events indicate poor planning from the drivers part and a low level of situation awareness regarding road conditions and surrounding traffic. The braking intensity aggressiveness score A_B is equal to

$$A_B = \frac{\#A}{\#A + \#S} \tag{13}$$

where $\#A$ is the number of abrupt braking events and $\#S$ is the number of smooth braking events within the aforementioned temporal window. Lateral and directional acceleration obtained from the mobile devices accelerometer can provide a meaningful measurement of steering and overall driving aggressiveness. While abrupt braking and engine RPM variance are a good metric of aggressiveness in slow sections of the driving route, they fail to provide similarly robust information in faster sections. To alleviate this, the lateral and directional acceleration magnitudes are incorporated, which provides high sensitivity for assessing aggressiveness A_{ACC} in fast sections. More specifically, given a the acceleration magnitude timeseries of length N,

$$A_{ACC} = \frac{1}{\lambda} \cdot \frac{\sum_{i=1}^{N} a_i}{N} \tag{14}$$

where λ is an experimentally defined normalization parameter.

2.3 Gamification methodology

This section analyzes the gamification approach employed in GamECAR project incorporating several state-of-the-art elements described briefly in Section 1. Elements of storytelling contribute significantly towards engaging the player during discovery and on-boarding phases stimulating an epic meaning call towards the importance of eco-driving and the subsequent environmental impact. Goals set by the game environment, achievable within a reasonable time frame with a reasonable amount of effort are associated with a sense of development and accomplishment in the case of success or with a sense of loss in the case a milestone is missed. Short-term challenges and their mid-term counterpart, quests, are similar to goals, but usually, have a much more limited scope. In contrast to the aforementioned goals, which are meant to highlight long-term performance and commitment to desirable behaviours, challenges and quests exploit also socializing aspects. Furthermore, customization options of the game environment allow the player to have a sense of ownership or possession over game elements. A clear and well-defined progression through the game stages should be provided. The player should be continuously motivated to progress further into the game by creating a sense of disappointment in the case that progress stalls. Subsequently, and especially in educational contexts, feedback is of crucial importance in order to not only achieve the ultimate purpose of the game but also help the player stay engaged and make progress. Finally, besides the direct rewards, other rewards can be offered in a randomized fashion in order to promote the act of playing. This can be done via occasional, unexpected positive rewards, referred to as "loot-boxes", inside the gamified environment. Levelling up can also have a similar effect if it involves new content being accessible by the player. In this way, the player has extra motivation for unlocking the new contents by making progress, such as advanced game-play data analytic tools or cosmetic elements.

A comprehensive overview of the core drives promoted by the game engine is presented in Figures 2 and 3. The game design mainly promotes epic meaning, accomplishment, empowerment of creativity, and social norms based on positive motivation gamification approaches [10]. The game design also takes into account separate player types, classified into 3 predefined classes, namely "constant improver", "safety enthusiast" and "smart saver". Figure 3 shows the core drives that

Fig. 2. Distribution of GamECAR core drives

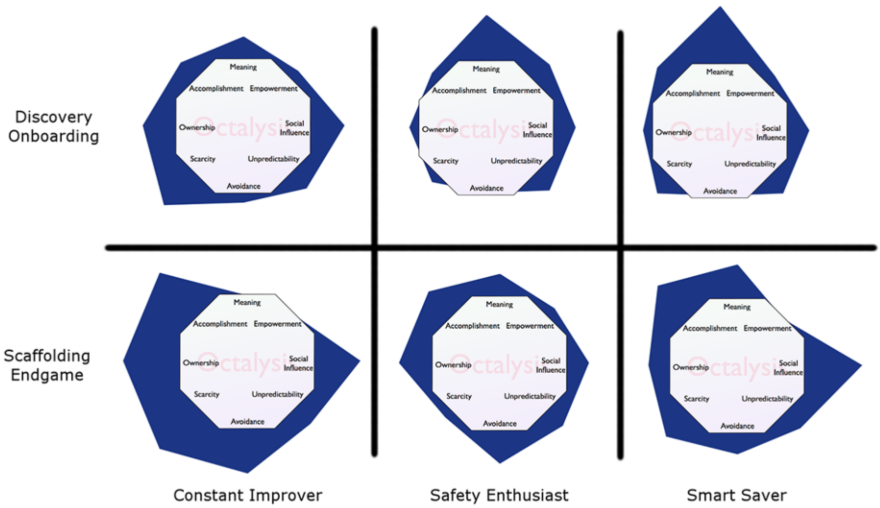

Fig. 3. Player types core drive distribution for each phase of the game

gamification features should take advantage of in order to be most effective depending on each players type and game phase. The figure is separated in two rows, representing early and late phases of the game and three columns, corresponding to the three aforementioned player types. During early phases, the focus is on core drives like Epic Meaning, while later the focus shifts to Loss and Avoidance, Accomplishment and Social Influence. Similarly, Accomplishment and Ownership are key drives for the Constant Improver, as are Loss and Avoidance and Ownership for the Safety Enthusiast and Social Influence and Scarcity for the Smart Saver.

The main tool for customizing the game experience and stimulating the appropriate core drives are mission objectives, which are customized according to the aforementioned approaches. For example, a mission for the Constant Improver should challenge him to beat his/her previous performance or invite him to exceed the scores of his/her peers. Similarly, a player in the Safety Enthusiast should face missions that are somewhat easier than the corresponding missions for the other two categories, but place a heavy focus on consistent performance and calm/eco-friendly road behaviour. Finally, missions posed to the Smart Saver should feature as either objective or highlight the benefits of ecodriving regarding reduced fuel consumption and positive environmental impact.

The main activity that the user will undertake as part of their interaction with GamECAR is driving. After each trip, an overall eco-score for the trip is calculated and presented to the user. As a part of the overall experience, other more concrete behaviours and parameters related to specific driving skills will be also calculated and stored. These include a) fuel consumption b) gear change c) acceleration d) braking e) aggressiveness score denoting how many times a driver breaks and accelerates in a minute. All of these parameters and scores are in fact related to the specific desired behaviours pursued in GamECAR. And there is also an implicit aspect to this, just using the GamECAR app while driving is one of the desired behaviours and therefore just by following this behaviour, the user should improve his or her status within the gamified system. For a given eco-score above a certain threshold, other gamified elements are also earned or achieved during each active driving session. These include a) driving skill awards, b) badges c) avatar outfits and d) knowledge cards, as presented in Figures 4 to 6. Figure 5 presents the flowchart describing the process that facilitates the driver to gain driving medals and trophies. The driver earns knowledge cards that he/she has to respond to. Completing a set of cards forms and album enabling missions. Consequently, completing missions the driver earns trophies. Likewise, Figure 6 presents the flowchart describing the process that facilitates the driver to gain driving skills. Game elements are customized behind the scenes in order to appeal to different types of players during the different phases of the game. GamECAR drivers will gain levels in the game, which require progressively more experience points (XP). Specifically, the game becomes harder in the main phase of the game corresponding to levels 15 to 35. Figure 7 presents the progression of required experience points from the user to level-up. The level system also determines the game phases, with each phase having distinctive characteristics, features and objectives:

- Discovery phase. In levels 1 to 4 after completion of 90-120 minutes of driving depending on eco-score, the participant familiarizes with the games elements, scoring features, feedback, levelling system and driving statistics extraction. To this end, the user gets introduced to levels, eco-score, heads-up display (HUD) alerts and basic driving statistics.
- On-boarding. In levels 5 to 14 that corresponds to an estimate of 6-8 hours of driving, approximately 9-16 days with 30 minutes of daily driving the player is exposed to more advanced features of the game. Apart from the discovery phase elements, this phase includes leader-boards and leader-board points (LP), daily missions with loot-box rewards, large-scope missions with XP/LP, knowledge cards, loot-boxes. The drop likelihood depends on eco-driving performance, up

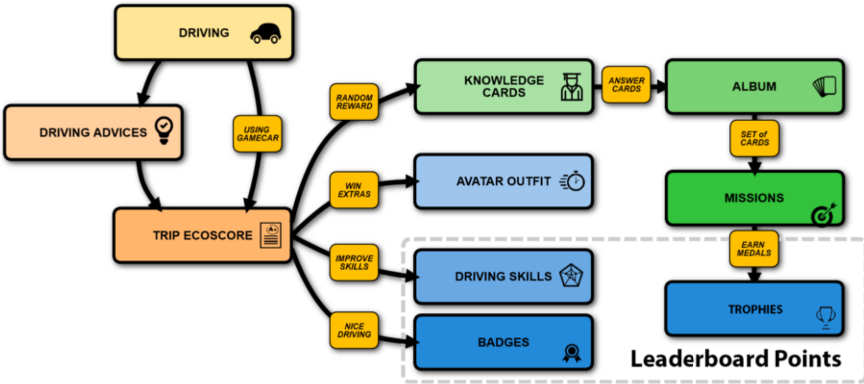

Fig. 4. GamECAR gamification design

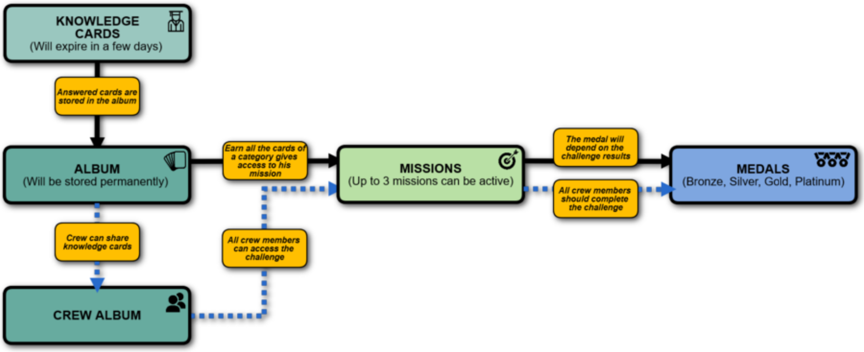

Fig. 5. Unlocking missions and earning trophies

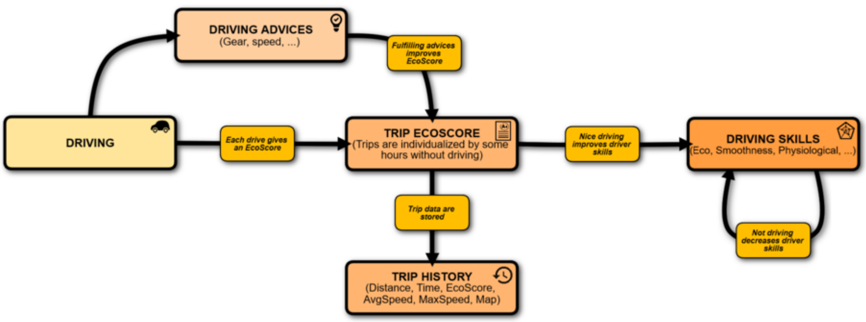

Fig. 6. Rewards

to 5 drops per month and profile customization.

- Scaffolding. In levels 15 to 39 that corresponds to an estimate of 45-57 hours of driving, approximately 2.5-4 months with 30 minutes of driving daily, the game that aims to create desirable habits for the player. Along with all the aforementioned features, the users are granted the ability to create their own crews in order to recruit other players as they gain a widely respected veteran status.
- Endgame. Levels 40 to 50 correspond to an estimate of 1.5-2 months with 30

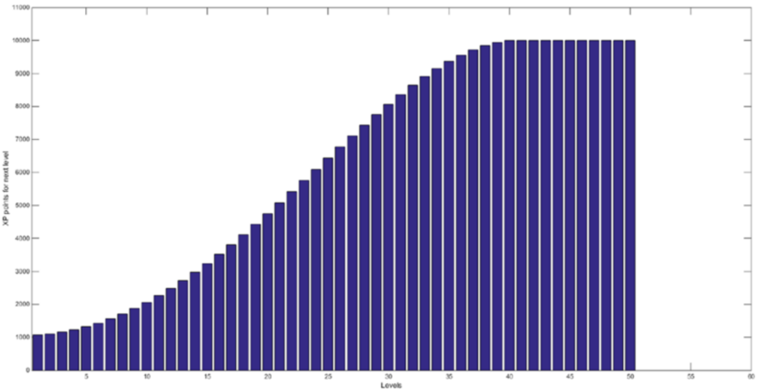

Fig. 7. Additional experience points required for the driver to reach a certain level

minutes of driving daily. In this final stage of the game, players start to receive personalized messages according to their weak driving aspects. They also gain access to advance information visualizations regarding their performance compared to global statistics. Finally, most of their visible status is subject to inactivity decay, meaning that it is gradually diminished while the player remains inactive. The features are then further customized based on the detected type of each player.

2.4 Gamification elements

This section presents and analyzes gamified elements employed in GamECAR. These include ecoscore, driver avatar, driving skills and awards, knowledge cards, missions, trophies, badges, loot boxes, driver ranking. Ecoscore is the score that drivers receive once they have completed a GamECAR journey while using the app. It is generated from the various elements of data that the app captures in relation to acceleration, braking, gear changing, fuel consumption and driving style as described in Subsection 2.2. Driver avatar is given to the user upon the profile creation. This equips the drivers with a virtual version of themselves within the gamified platform. As they achieve certain objectives within the app, they are given the opportunity to upgrade their avatar in terms of the way it looks or additional features. Avatar outfits can be traded with other users in the Virtual Community Platform. The avatar is the virtual representation of the driver and will be viewed on various screens within the app. It will also be viewed by other drivers that the user is competing against, thereby meaning that drivers will want their avatar to be better than that of others.

Driving skill scores are given to drivers and reflect their specific abilities in relation to different aspects of their driving including fuel consumption, acceleration, breaking, gear changing and driving aggression. The driving skill scores are a key part of ensuring that users are able to improve and work towards their epic goals within the game by providing individualized scores for each driving element. The user is getting live feedback that they can react and respond to when they undertake a journey. The Driving Skills awards recognize the achievements of the driver in specific aspects of their driving, thereby highlighting the progress that they are making. Knowledge cards pop up at random times within the experience and give the user the chance to answer questions on specific aspects of eco-driving. Knowledge cards open a whole subsection in the system and represent several gamification aspects within GamECAR. If the drivers gather enough Knowledge Cards in a particular area, they can complete a page in an album. This then allows accessing missions. Missions represent an additional game layer that is designed to be accessed by more advanced or experienced app users. They are designed to keep users interested in GamECAR and to give them specific objectives to complete on top of keeping their scores up and gaining badges. Missions can also be opened and completed collaboratively with a crew referring to a set of drivers who are playing together.

Mission trophies are awarded to those who successfully complete a mission and are then displayed in much the same way as badges. Mission trophies demonstrate achievement in relation to the completion of a mission. As such, they are a demonstration of the achievements of that particular user. Driving badges demonstrate achievement in relation to specific driving skill areas and show the progress that is being made by individual drivers in relation to their own achievements and those of others. A loot box is a gamified gift that the app awards randomly to users at different points in the experience. As the name suggests, a Loot Box can contain a number of different elements from the GamECAR rewards system including Knowledge Cards, Avatar Outfits, Badges and Missions. The Driver Ranking will be an accumulated score based on the trip ecoscores that the driver has achieved during their GamECAR career. This ranking is a reflection of how well the driver is progressing towards being a high performing driver. A points-based scoring mechanism allows the driver to rank themselves against others and to target an increased driver ranking score. The Driver ranking is the most simple element of the gamified experience. This is the one aspect of the gamification that everyone will be able to understand and relate to.

3 Conclusion

This work presented the GamECAR approach towards developing an interactive serious game platform, for motivating players to adopt a more eco-friendly driving style, without distracting them from safety. The gamified ecosystem adapts to user characteristics along with the real environmental aspects, by obtaining information through an intelligent sensing platform. In addition, elements of storytelling contribute significantly towards engaging the player during all phases of the game, by constantly emphasizing towards the importance of eco-driving and the subsequent environmental impact. All goals set by the game environment, are achievable within a rather short period of time with a reasonable amount of effort and are always kept associated with a sense of development and accomplishment when successful or a sense of loss when a milestone is missed. This approach greatly optimizes the driver's in-game experience, which is now fully correlated with the actual driving as well as

(a) (b) (c) (d)

(e)

Fig. 8. a)Home screen, b)Profile overview screen, c)Avatar customization screen, d)Driving skills overview screen, e)Leaderboard

the proper environmental, traffic and route conditions. Preliminary results indicate that drivers were able to follow the provided instructions easily, they remain active and fully engaged in all gaming activity, while the ultimate goal of endorsing a more eco-driving behaviour is achieved.

Acknowledegment

Part of this work was funded by European Union's Horizon 2020 research and innovation programme GamECAR under Grant Agreement No 732068.

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