A Framework for Gamification to Encourage Environmentally Friendly Driving Habits

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Abstract. In recent years, modern society has been facing more traffic jams, higher fuel prices and an increase in Carbon Dioxide emissions. According to NASA Global Climate Change, the current warming trend is extremely likely (greater than 95% probability) to be the result of human activity since the mid-20th century. Although general awareness in sustainability issues has improved in recent years through mass media coverage, this knowledge is not always translated into actual sustainable practice. The transportation sector consumes more petroleum than any other sector, and that share has increased over time from about 50% in 1950 to about 70% in 2018. In 2016, light-duty vehicles accounted for 58.5% of transportation energy use while medium/heavy-duty trucks and buses accounted for 23.9%. Vehicle miles travelled was seven times higher in 2017 than in 1950. In the transportation sector, the Fourth Industrial Revolution (Industry 4.0) emphasizes advances in communication and connectivity with breakthroughs in emerging technologies in fields such as fully autonomous vehicles sector. Small to mid-sized cities are not always wealthy enough to adopt these infrastructure changes so sustainable transportation falls on the decision of commuters. This paper shows how gamification can be linked to the components of Industry 4.0 to encourage drivers to drive less aggressively and, thus, more environmentally friendly. The gamification approach is illustrated using a sample of nine college-aged drivers but can be extended to fleet drivers.

1 Introduction

Sustainable development focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs [5]. Sustainable practices support ecological, human and economic health and vitality. This work defines sustainable driving as a set of driving techniques that saves fuel, is environmentally friendly and safe and hypothesizes that eco-driving is a sustainable driving technique.

The Fourth Industrial Revolution consists of many components including: mobile devices, location detection technologies, advanced human-machine interfaces, smart sensors, big analytics and advanced processes, augmented reality/wearables, and data visualization and triggered "live" training to name a few. Relative to the transportation sector, emerging technologies include self-driving cars, driver assistance systems or intelligent transportation systems [6].

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The definition of gamification varies between researchers such as "*The use of game elements in non-game contexts*" [8] or *"Incorporating game elements into non-gaming software applications to increase user experience and engagement"* [9]. Combining elements of Industry 4.0 and gamification to encourage environmentally friendly driving habits ("eco-driving"), in its simplest form, would require equipment to access data, cloud computing to store and analyze data and data visualization to communicate relevant information to the drivers. Effective data communication to the drivers is where gamification becomes relevant.

In 2018, there were 4,166,086 licensed drivers in Minnesota. Within the age groups 15–19, 20–24 and 25–29 who were involved in crashes, driving in a careless, negligent, or erratic manner was listed most often (10.9%. 3.5% and 15.2%) by officers at the scene [18].

In 2018, transportation activities were the largest source of emissions at 28% of total GHG emissions with 59% of CO2 emission from light-duty vehicles [25]. Improvements in vehicle fuel economy since 2005 has slowed the rate of increase of CO2 emissions; however, electric vehicles make up only a small percentage of vehicles sold at 1.9% in 2019 [20]. Although self-driving cars will help save lives, collecting data for self-driving cars is expensive and require billions of hours of footage of real driving for training Artificial Intelligence (AI) algorithms. Therefore, supporting the human driver in sustainable driving habits is still necessary [1, 15].

A variety of efforts have been undertaken to improve fuel economy and reduce emissions of on-road vehicles, including more stringent automotive emission standards, new engine and vehicle technologies, better fuel quality and renewable fuels. However, an important factor which is often overlooked and may improve vehicle fuel economy significantly is eco-driving technology. The investment for new vehicle technologies and fuels is usually significant and long-term, and an improvement of a few percentages may be considered significant. It was estimated that potential efficiency improvements of advanced engine and vehicle technologies were only about 4–10% and 2–8% respectively.

Behavioral approaches known as "eco-driving", can improve fuel economy by 15–25% along with promoting safety in road transport [3, 7, 14]. Eco-driving encourages drivers to anticipate traffic flow and maintain a steady speed with minimal braking and acceleration. Even with the benefits of eco-driving, studies have shown that drivers are still hesitant to change their driving style with motivation being the deciding factor when it comes to changing driver behavior [2, 17]. The objective of this paper is the development of tools to evaluate the behavior of drivers in order to make driving analysis to promote eco-friendly driving.

According to Self-Determination Theory, performing tasks that satisfy basic human needs for competence (feeling of proficiency), autonomy (control of one's actions), and relatedness (belonging or connectedness to others) enhances intrinsic motivation [21]. One way to engage and motivate people is through games. Elements of game design such as points, badges and leaderboards, have been applied to non-gaming contexts to enhance user engagement and experience [8].

The use of gamification has shown positive results in encouraging eco-drive habits [13, 17, 23]. Gamified eco-driving applications can be found in many cars including

Ford's SmartGauge with EcoGuide, the color-switching eco-gauge of the *Chevrolet Volt*, or *Kia's ECOdynamics* system. *Fiat's eco:Drive* is a computer application that Fiat promises will cut fuel costs and reduce a driver's carbon footprint. It requires a USB stick, a computer and either the Fiat Grande Punto, 500 or Bravo [11].

Recent studies in using gamification for driver behavior modification defines metrics based on the golden rules of eco-driving. The level of complexity of these metrics differ. The GamECAR consortium developed an eco-score that 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 [19]. This work also uses an eco-score and an Eco-Driver Grid based on the decision-making grid from maintenance literature.

In the maintenance of equipment, the allocation of maintenance strategies to various machines is analogous to prescribing drugs for different patients [13, 17, 22, 24]. The decision-making grid (DMG) acts as a map on which the performances of the worst machines are located according to downtime and failure frequency. Downtime is defined as the mean time to repair (MTTR) and failure frequency is the number of failure events (Fig. 1).

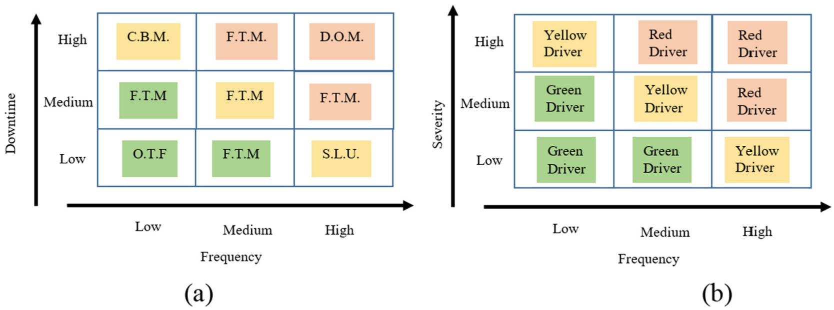

Fig. 1. (a) Decision making grid and (b). Proposed eco-driver grid

The DMG allocates one of five possible maintenance strategies for a failure event depending on its location in the DMG; Operate to failure (O.T.F.), Skills level upgrade (S.L.U.), Condition-based Maintenance (C.B.M.), Fixed-Time Maintenance (F.T.M.) and Design-Out Maintenance (D.O.M.). Assets that fall in the *O.T.F.,* section of the grid represent machines with low failure frequency and low downtime. This is the optimal state and is the area of the grid towards which all asset performance figures should aspire.

The goal of this work is to develop an eco-driver grid in a manner similar to the DMG where drivers are now identified as a green-, yellow- or red-driver. A long-term goal of this work would be to tailor feedback and training to "move" the driver toward the "green driver" section of the grid.

2 Methods

Participants were recruited using online postings at the University of Minnesota Duluth. Nine drivers (7 males and 2 females) between the ages of 18 to 30 years old were recruited to observe their driving habits in Duluth and develop the game elements. A telematics device that plugs in the on-board diagnostic post (OBD II) port of the study participants' personal vehicle collects engine and GPS data. The data collected is uploaded to a portal to which only the principal investigator and approved student researchers have access. Study participants do not have access to this portal in order to protect privacy. The goal of this study was to develop and test the eco-score and sustainable grid game elements.

2.1 Description of Data

The telematics device records GPS and engine data for each driver. From the engine data, acceleration forward and braking, acceleration side to side, acceleration up and down, GPS location, trip distance and number of times the driver "speeds" along with the distance and time spent speeding. For acceleration, this data is recording at small increments in time as shown in Table 1. Speeding, on the other hand, is a user-defined "rule" within the portal. A sample speeding report is shown in Table 2.

Table 1. Sample of acceleration data collected from the telematics device.

Vehicle	Date	Engine data	Value
CRV	Oct 27, 2020 6:14:03 PM	Acceleration forward or braking	0 m/s^2
CRV	Oct 27, 2020 6:14:03 PM	Acceleration side to side	0 m/s^2
CRV	Oct 27, 2020 6:14:03 PM	Acceleration up down	9.610517 m/s^2
CRV	Oct 27, 2020 6:14:05 PM	Acceleration side to side	−3.0204482 m/s^2
CRV	Oct 27, 2020 6:14:05 PM	Acceleration up down	10.483309 m/s^2
CRV	Oct 27, 2020 6:14:07 PM	Acceleration side to side	0 m/s^2
CRV	Oct 27, 2020 6:14:07 PM	Acceleration up down	9.7183895 m/s^2
CRV	Oct 27, 2020 6:14:34 PM	Acceleration forward or braking	0 m/s^2
CRV	Oct 27, 2020 6:14:34 PM	Acceleration side to side	0 m/s^2
CRV	Oct 27, 2020 6:14:34 PM	Acceleration up down	9.845877 m/s^2

2.2 Game Elements

Game elements include points, badges, leaderboards, performance graphs, meaningful stories, avatars and teammates [8]. Game elements in this pilot study included avatar names (chosen by drivers), the eco-score (points and leaderboard) and the eco-driver grid (badge and leaderboard).

Table 2. Sample speeding report.

Device	Location	Date	Start time	Duration	Distance (miles)
CRV	I-35, Pine City, MN 55063, USA	Nov 02, 2020	10:10:00 AM	0:01	1.98
CRV	I-35, Pine City, MN 55063, USA	Nov 02, 2020	10:11:33 AM	0:04	5.70
CRV	I-35, Rush City, MN 55069, USA	Nov 02, 2020	10:16:10 AM	0:09	12.65
CRV	5747 340th St, Stacy, MN 55079, USA	Nov 02, 2020	10:26:54 AM	0:02	3.75
CRV	30225 Fir Trail, Stacy, MN 55079, USA	Nov 02, 2020	10:29:42 AM	0:01	2.57
CRV	I-35W, Columbus, MN 55025, USA	Nov 02, 2020	10:40:14 AM	0:00	0.77
CRV	I-35W, Lino Lakes, MN 55038, USA	Nov 02, 2020	10:41:18 AM	0:02	2.72
CRV	5320 Main St NE Door, 70 Main St NE, Fridley, MN 55421, USA	Nov 02, 2020	10:56:29 AM	0:00	0.58
CRV	1701 James Cir N, Brooklyn Center, MN 55430, USA	Nov 02, 2020	10:58:01 AM	0:00	0.87
CRV	3319 67th Ave N, Minneapolis, MN 55429, USA	Nov 02, 2020	10:58:56 AM	0:00	0.53
CRV	12289 97th Ave N, Maple Grove, MN 55369, USA	Nov 05, 2020	9:09:56 AM	0:06	7.54

The eco-score was calculated based on four metrics – acceleration, braking, cornering and speeding. Thresholds were chosen based on previous research on the effect of hard acceleration on vehicle fuel economy and passenger safety [4]. Three levels were created for acceleration, braking and cornering to incorporate mid-range driving. Based on how data was collected from the telematics device, a mid-range level for speeding could not be designed. The scoring system for each metric is shown in Table 3. The relevant variables are defined as follows

AllAcc is the set of all AccX > 0; $N_{acc} = |AllAcc|$
AllBrk is the set of all AccX < 0; $N_{brk} = |AllBrk|$
AllCrn1is the set of all AccY > 0; $N_{crn1} = |AllCrn1|$
AllCrn2 is the set of all AccY < 0; $N_{crn2} = |AllCrn2|$
SpdFreq is the number of times a driver was recorded as speeding in one day

$L_S^{'}$ is the length of a trip not spent speeding (miles)
L is the length of a trip (miles)
g is the acceleration due to gravity

Table 3. Scoring system for eco-score

Range	Score	Metric	Level
$\boldsymbol{A_{CC}X_i} > 0.4$ g	0	Acceleration ("AccScore")	Hard
0.29 g $< \boldsymbol{A_{CC}X_i} \leq 0.4$ g	1		Medium
$0 < \boldsymbol{A_{CC}X_i} \leq 0.29$ g	2		Soft
$\boldsymbol{A_{CC}X_i} < -0.38$ g	0	Braking ("BrkScore")	Hard
-0.38 g $\leq \boldsymbol{AccX_i} < -0.28$ g	1		Medium
-0.28 g $< \boldsymbol{AccX_i} < 0$	2		Soft
$\boldsymbol{AccY_i} < -0.38$ g	0	Left Cornering ("CrnScore1")	Hard
-0.38 g $\leq \boldsymbol{AccY_i} < -0.19$ g	1		Medium
-0.19 g $\leq \boldsymbol{AccY_i} \leq 0$	2		Soft
$\boldsymbol{AccY_i} > 0.38$ g	0	Right Cornering ("CrnScore2")	Hard
0.19 g $< \mathbf{AccY}_i \leq 0.38$ g	1		Medium
$0 < \mathbf{AccY}_i \leq 0.19$ g	2		Soft
If Speed > 8 mph over speed limit for more than 30 s	0	Speeding ("SpdScore")	Speeding
If Speed < 8 mph over speed limit	2		Not Speeding

Table 4. The equations to calculate the score for each metric

Metric	Equation
AccScore	$\frac{\sum_{i=1}^{N} \mathrm{AccX_i}}{2 \times \mathrm{N_{Acc}}}$
BrkScore	$\frac{\sum_{i=1}^{N} \mathrm{AccX_i}}{2 \times \mathrm{N_{brk}}}$
CrnScore1	$\frac{\sum_{i=1}^{N} \mathrm{AccY_i}}{2 \times \mathrm{N_{crn1}}}$
CrnScore2	$\frac{\sum_{i=1}^{N} \mathrm{AccY_i}}{2 \times \mathrm{N_{crn2}}}$
SpdScore	$\frac{\mathrm{L_S^{'}}}{\mathrm{L}}$

$$\mathbf{EcoScore} = \left(\frac{\mathbf{AccScore} + \mathbf{SpdScore}}{2}\right) \quad (1)$$

In the preliminary study, the EcoScore was calculated for one day of driving. In future studies, the EcoScore will be calculated over a set distance (Table 4). Further research on the best distance to use is ongoing. Table 5 shows an example of the eco-scores obtained for each driver for one day.

Table 5. An example of the eco-Score for each driver from the study

Driver	Total
CRV	9.51
HW	9.34
Iron Man	9.50
Link	9.46
Liverpool1127	9.38
Pete	9.27
Universitario	9.33
Voldemort	9.20
Yung Modulus	9.40

The eco-driver grid was designed to display the relationship between severity and frequency of aggressive driving habits. The severity is calculated using Eq. (2).

$$\mathbf{Severity} = 1 - \mathbf{EcoScore} \tag{2}$$

Frequency is the number of times an aggressive driving habit was recorded.

$$\mathbf{Frequency} = |\{\mathbf{AccX_i} > 0.29\boldsymbol{g}\}| + |\{\mathbf{AccX_i} < -0.28\boldsymbol{g}\}| + |\{\mathbf{AccY_i} < -0.19\boldsymbol{g}\}| + |\{\mathbf{AccY_i} > 0.19\boldsymbol{g}\}| + \mathbf{SpdFreq} \tag{3}$$

In the grid, a lower frequency and lower severity is best. The goal is to move the driver towards the green section of the grid. Thresholds were defined based on the group driving performance and matches the decision making grid of the maintenance strategies literature. Let h be the highest value in the list and l the lowest value in the list.

$$\text{Medium/High boundary} = \boldsymbol{h} - \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{h}) \tag{4}$$

$$\text{Medium/High boundary} = \boldsymbol{h} - \frac{\mathbf{2}}{\mathbf{3}}(\boldsymbol{h}) \tag{5}$$

$$\text{Low boundary} = \boldsymbol{l} \tag{6}$$

Figure 2 shows an example of the grid for a day of driving.

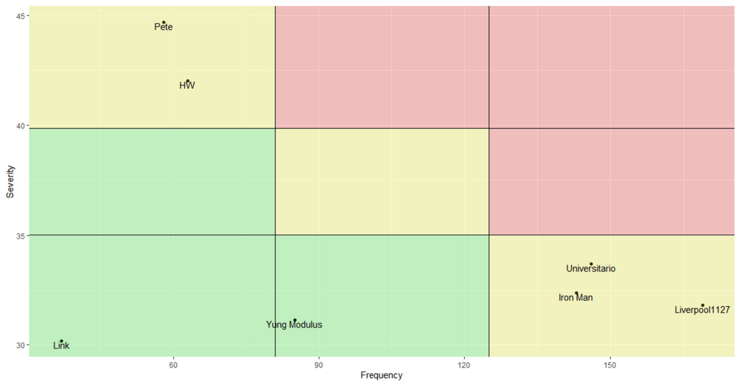

Fig. 2. Eco-driver grid.

This study developed the EcoScore and Eco-Driver Grid using data collected from a telematics device plugged into the OBD II port of the study participants' vehicles. Work is ongoing to optimize the EcoScore calculation and grid design.

2.3 Summary and Conclusion

This paper presents a framework of using game elements and components of Industry 4.0 to encourage drivers to adopt less aggressive and more environmentally friendly driving habits. The game elements include identification of drivers via avatars to protect privacy, a leaderboard is used to show the driver's position relative to others to encourage some friendly competition. The grid, developed based on the maintenance strategies literature, provides another data visualization technique to rank the drivers based on two dimensions of their driving metrics – severity and frequency of the non-eco-friendly driving habits. At the moment, drivers are informed of their performance at the end of the day via email. Work is ongoing to improve communication to the drivers, test peered driving and a longitudinal study to test the impact of gamification on over a longer period of time.

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