Motivational technology as a way of enhancing transportation safety – A systematic review of previous research

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Abstract. Motivational technologies have been studied and applied in various domains to encourage sustainable behaviors. One of such domains is safety of transportation systems. This paper presents a review of current research literature covering gamification, serious games and persuasive technology in the domain of transportation safety. A total of 46 records were reviewed, 32 of which were empirical records studying the effects or user perceptions of motivational technologies. Most of the current body of literature is in the area of road safety, followed by aviation. The results reported in the reviewed records indicate that applying motivational technologies is a promising approach for enhancing safety in different transportation domains. We have, however, identified shortcomings, thematic gaps and direction of future research which we discuss in this paper.

Keywords: motivational technology, gamification, persuasive technology, serious games, transportation safety, literature review.

1 Introduction

There is an increasing interest in academia and industry in how motivational technologies, i.e. gamification, serious games and persuasive technology, can be used to affect human behavior in various domains, such as in transportation, education or health management [9]. Transportation, be it of people or goods, is one of the cornerstones needed for the functioning of organizations and societies. There is a variety of different transportation systems such as land transport (e.g. roads, railways), aviation, maritime and inland waterway transport. One of the most persistent issues across all these domains of transportation is safety. While accidents related to transportation claim thousands of lives yearly in the EU alone, the differences between levels of safety in different modes of transportation are substantial (see e.g. [5]). Aviation and western railroads are considered highly regulated, ultra-safe systems with extremely low accident rates whereas road transportation is less regulated and has higher accident rates [1]. Typically, accidents in ultra-safe systems happen as a result of a combination of factors that alone could not cause an accident [1] while for example in driving, single factors, such as sleepiness, by itself can significantly increase the likelihood of a crash (see e.g. [3]). Also, the severity of accident consequences varies between different modes of transportation; whereas in road transportation, individual accidents typically do not claim multiple lives, the consequences of an aviation or a railroad accident can be catastrophic (see e.g. [5]).

Although safety is a systemic property, human behavior is one of the key factors when discussing the emergence of accidents. Safety measures, such as automation, information campaigns and safety trainings have been implemented as a way of enhancing transportation safety. However, as road transportation alone continues to claim more than a million lives yearly [12], there is a need for developing novel ways of enhancing transportation safety. To increase compliance with safety regulations, support safety behavior and enhance safety training, motivational technologies are increasingly applied in safety management to combat the issues stemming from the 'human factor'. Motivational technologies [9] primarily include gamification ([4], [6], [8]), serious games [2] and persuasive technology [10] that engage individuals with activities that are commonly considered mundane such as attending a safety training. Whereas gamification refers to transforming systems, services, products, organizational structures or practically any activities to afford similar experiences as games do using game design [6], serious games commonly represent full games designed for purposes other than pure entertainment [4]. Persuasive technology on the other hand, similarly to gamification, commonly refers to the addition of a type of design onto an existing practice. However, persuasive design as a term did not emerge from game research.

Although research on the use of these motivational technologies in the transportation safety domain has started to appear, the body of literature remains fragmented. This review aims at synthesizing the existing research that has been conducted on motivational technology in the domain of transportation safety. We present a comprehensive, descriptive review including various modes of transportation, safety measures and types of motivational technologies. The results implicate that most of the current body of research focuses on road safety, followed by aviation. Moreover, gamification in transportation safety is mostly aimed at enhancing safety at an individual level (gamifying or teaching safety behavior). However, transportation safety is affected by a variety of behaviors of different stakeholders making it thus a prominent context for further gamification research.

2 Materials and methods

In order to compile a comprehensive body of literature on the use of motivational technology in transportation safety we conducted a systematic literature search. Scopus database was chosen for the literature search since it indexes most other relevant databases. Moreover, the search was conducted only in one database for clarity and replicability of the search and selection process. The search was conducted in August 2019 over records' titles, abstracts and keywords in order to include only records which focus was improving safety using motivational technologies. The used search terms were (gamif* OR "persuasive technolog*" OR "simulation gam*" OR "serious gam*") AND (safety OR accident OR emergency OR security OR "risk management"). Types of records included in the search were conference papers, articles and book chapters.

A total of 873 records were obtained with the used search query. After the search, the titles and abstracts were examined. 11 records were excluded for not being available in English. A total of 103 records were identified as not being related to gamification, serious games or persuasive technology based on the titles and abstracts and thus excluded from further analysis. Of the remaining records, 715 were excluded based on

the titles and abstracts as they were not focused on transportation safety. Six records were not fully accessible to the authors using Scopus or Google Scholar. After screening the titles and abstracts, a total of 38 transportation or traffic safety related records were included in the review. Two additional records were identified using forward search and six using backward search. Thus, a total of 46 records were included.

3 Results

3.1 General description of the reviewed research

Although the differentiation between different types of motivational technologies can be ambiguous, we categorized the records according to whether the technology described in them matched with definitions of motivational technologies outlined in the introduction section. Papers that used parallel terms to serious games such as 'simulation games', or 'learning games' were categorized as serious games in this study. Furthermore, gamified simulators, learning platforms and training applications were categorized as 'serious games' as they provide a separate learning or training environment instead of gamifying behaviors, such as safe driving, in the 'field'. The categorization between persuasive technology and gamification was conducted according to the branding used by the authors of each manuscript. Of the 46 records included in this review, 28 focused on serious games, 15 on gamification and three on persuasive technology. Furthermore, we analyzed the contexts of all 46 records that met the inclusion criteria (table 1).

Table 1. Contexts of the records

	All records (n=46)		**Empirical records (n=32)**	
	Frequency	Records	Frequency	Records
Road safety	**35 (76.1 %)**		**24 (75%)**	
Driving	21 (45.7 %)	A1, A2, A4, A6, A7, A18, A20, A25, A30, A31, A32, A33, A35, A36, A37, A38, A39, A40, A41, A45 A46	14 (43.8 %)	A1, A4, A7, A18, A20, A25, A30, A33, A35, A39, A40, A41, A45, A46
Pedestrian	7 (15.2 %)	A3, A10, A17, A19, A28, A29, A43	6 (18.8 %)	A10, A17, A19, A28, A29, A43
Bicycle	3 (6.5 %)	A23, A24, A44	3 (9.4 %)	A23, A24, A44
Other	4 (8.7 %)	A5, A8, A22, A34	1 (3.1 %)	A8
Aviation safety	**9 (19.6 %)**	A9, A11, A12, A13, A14, A15, A16, A21, A27	**8 (25%)**	A9, A11, A12, A13, A14, A15, A16, A21
Maritime safety	**2 (4.3 %)**	A26, A42	**0**	-

The body of literature described various gamified safety measures and approaches for enhancing transportation safety. Records concerned with road safety mostly focused either on teaching safe or compliant behavior using serious games or gamifying safe driving such as not speeding, mostly with the aim of preventing undesirable outcomes, such as collisions. Also, other safety measures were considered; e.g. one of the records [A22] described a gamified application to make the reporting of road accidents more

engaging. Of the records that were in the context of driving safety, only one [A20] explicitly aimed at enhancing safety of freight transportation.

In the aviation context, the reviewed body of literature predominantly concentrated on safety measures that aim at reducing harmful consequences in case of an emergency. The emphasis on emergency management is understandable due to the nature of commercial aviation where accidents are typically extremely rare but can potentially have catastrophic consequences (see e.g. [1]). The records described gameful learning interventions that teach the passengers safety measures normally taught using safety cards or pre-flight demonstrations such as correct evacuation behavior, assuming brace position in case of forced landing and life preserver donning. One record [A21] described a solution which focused on training aircraft pilots instead of passengers. In the aviation context, serious gaming type of interventions were prevalent.

Two non-empirical studies related to maritime safety were identified and analyzed. In the maritime safety context, the reviewed records described serious game solutions which aimed at teaching situation awareness to submarine users using virtual reality [A42] and safe maritime cargo transportation to maritime specialists [A26].

32 of the reviewed records were empirical studies (i.e. studies involving data composed of observation of reality and its analysis), while 14 were non-empirical (i.e. retorted to conceptually treat the phenomenon). Design science papers were not considered empirical unless they included a type of evaluation that would inform about the effect of motivational technology. Moreover, studies that included secondary data or data that was used as background information in design science projects were not considered empirical as these studies do not inform us about the effects of the intervention on psychological states or behavioral and organizational outcomes. Therefore, the reviewed non-empirical records were mainly conceptual or framework papers and preliminary descriptions of gamified applications without an evaluation of the effects of motivational intervention. Additionally, one record [A2] studied perceptions related to safe gamified driving.

The reviewed empirical records included a description of a design process or developed application followed by a user evaluation or an experimental study to test the designed solution. 24 of the 32 empirical records applied a serious game solution. Eight of the empirical records described a gamification or persuasive technology approach that does not take the user to a separate learning or training environment. All such solutions were applied to enhance safe driving by reducing boredom and fatigue or by persuading for safe driving and making it more engaging. In order not to distract the driver, the feedback in gamified driving solutions was often implemented using ambient colors and audio or given post-drive.

3.2 Motivational affordances and outcomes in empirical studies

We examined the motivational affordances reported in the reviewed empirical manuscripts (table 2). Most applied affordances were forms of performance feedback, which include e.g. visual demonstration of in-game behavior consequences, textual feedback, praise or rebuke by in-game characters, forms of ambient audio or visual feedback and performance reports. The ‘Other, misc.’ category includes rarely applied affordances, such as avatar levels, motion tracking, physical boards and puzzles.

Table 2. Motivational affordances in empirical studies

Affordance	Records	Frequency
Performance feedback	A9, A12, A13, A14, A15, A16, A17, A18, A23, A24, A29, A30, A33, A39, A40 (solutions 1 & 2), A41, A43, A44, A45, A46	21
Game world, 3D world, virtual world, simulation world	A1, A8, A9, A12, A13, A14, A15, A16, A17, A19, A21, A30, A35, A43, A44	15
Challenges, quests, missions, tasks, clear goals, objectives	A1, A7, A11, A15, A16, A18, A19, A21, A23, A24, A35, A39, A40 (solution 1), A41	14
Avatar, character	A8, A9, A10, A11, A12, A13, A14, A16, A19, A28, A29, A35, A46	13
Score, points	A1, A4, A7, A18, A19, A20, A21, A23, A24, A29, A44, A45	12
Game levels, scenarios, sections	A1, A10, A11, A14, A18, A20, A21, A25, A35, A43	10
Narrative, storytelling, plot	A8, A9, A15, A19, A21, A25, A35, A43, A46	9
Assistance, helpers, instructions, hints	A1, A9, A12, A13, A15, A16, A17, A43	8
In-game rewards, virtual items	A4, A7, A19, A20, A44, A46	6
Timer, time pressure	A1, A8, A11, A16, A29	5
Increasing difficulty	A1, A10, A11, A21, A43	5
Co-op, teams, social collaboration, social networking	A4, A7, A19, A28	4
Badges, achievements, medals, trophies	A4, A20, A29, A46	4
Progress visualization	A7, A18, A29, A40 (solution 1)	4
Leaderboard, high score list, ranking	A7, A18, A20	3
Quiz, questions	A18, A29, A45	3
Other, misc.	A7, A10, A19, A25, A28, A43, A45	7

27 of the empirical records reported studying one or more psychological outcomes (table 3). Outcomes related to usability, perceived enjoyment and perceived usefulness or effectiveness of the gamified system were the most studied similarly to gamification research generally [9].

Table 3. Empirically studied psychological outcomes

Outcome	Records	Frequency
Enjoyment, fun, entertainment, flow	A1, A10, A11, A18, A21, A23, A24, A30, A35, A39, A40	11
Perceived usefulness/effectiveness/learning/performance	A7, A13, A16, A18, A19, A20, A23, A30, A33, A41	10
Ease of use, perception of use, user experience	A1, A4, A7, A21, A30, A39, A40, A41, A43	9
Engagement, motivation	A9, A11, A15, A16, A18, A21, A40	7
Self-efficacy, locus of control	A9, A11, A12, A13, A14, A16	6
Perceived vulnerability	A11, A12, A14	3
Perceived severity	A11, A12, A14	3
Presence	A8, A9, A30	3
Perceived challenge, effort, gameplay difficulty	A23, A24, A35	3
Behavior agreement, attitude	A11, A19, A28	3
Perceived reality, realism, parallels with reality	A1, A21, A44	3
Fatigue, boredom, arousal	A15, A30, A41	3

25 of the records reported studying one or more behavioral or learning outcome. 17 records reported studying forms of learning or knowledge gain. Four records studied forms of safe behavior, all of which were related to the task of driving. Other studied behavioral outcomes were related to e.g. game performance and system usage time.

Most of the empirical records (26 records) reported mainly positive results in the forms of knowledge acquisition or positive learning outcomes resulting from motivational technology interventions (14 records), positive user feedback (9 records) and increase in compliant or safe driving (4 records). However, in many of the records that reported positively oriented results, they were mixed with null results.

4 Discussion and avenues for further research

Most of the reviewed studies approach transportation safety from a perspective that equates safety with compliance or safe behavior of individuals and the body of research is leaning towards a single player serious gaming approach. However, safety is often dependent on the interaction between multiple actors and includes e.g. successful teamwork and communication (see e.g. [7]). Thus, in future research, especially social aspects of gamification and their effects on safety-behavior should be studied. Additionally, a prominent direction for future research is to examine how gamification can be utilized at societal level, e.g. by encouraging participation in traffic safety related crowdsourcing, such as reporting potential dangers, in order to effectively collect and analyze early-warning indicators and further enhance transportation infrastructure safety e.g. by urban planning and policymaking.

Majority of the reviewed research is related to road safety which is understandable as road transportation is more accident prone than e.g. aviation and railroad transportation [1]. However, other modes of transportation offer distinct settings and safety-related problems that gamification could potentially tackle. For example, the absence of research in the domain of railroad safety is surprising as operating a train is a highly automated and monotonous task which yet requires a high level of sustained attention (e.g. [11]) thus making it a prominent target for studying gamification aimed at enhancing task engagement or alertness. Moreover, railroads are complex systems in which safe functioning requires seamless co-operation of multiple actors and thus we suggest that railroad safety might be a suitable context for studying collaborative aspects of gamification which according to our findings are rarely studied in transportation safety contexts.

All the empirical records that studied gamification in the ‘field’ were related to the task of driving. The nature of driving, where single factors such as sleepiness can have a significant effect on safety (see e.g. [3]), makes it a natural context for such interventions. However, more research is needed on how the feedback in gamified driving should be presented in order not to distract the driver. Feedback given post-drive does not distract the driver but might however have limitations as it does not provide the driver a possibility to adjust the behavior real-time based on the feedback.

Moreover, the reviewed studies examined the effects of gameful interventions on short-term outcomes such as engagement, learning or forms of safe driving. The body

of research thus lacks long-term studies that examine the effect of gamification on safety metrics, such as accident rates. Future research should also further address the issue of technology acceptance and integration of gameful interventions to work and other practices in organizational settings, which is a topic barely covered by the current body of research.

5 Limitations

In this study, we reviewed research that studied various forms of motivational technology in the context of transportation safety. In the literature search, we used the key terms derived from gamification, serious games, simulation games and persuasive technology. Thus, records that have not used the previous terms to describe their research focus were not included even if they studied motivational technology. Moreover, as we used safety-related search terms, records that did not use these terms to describe their focus were not reviewed. We limited the literature search to Scopus database and although it indexes most relevant databases, using only one database might have resulted in missing out some relevant records. Moreover, we analyzed the applied affordances based on the descriptions of applied motivational technologies reported by the authors of each manuscript. However, it is possible that some of the implemented affordances remained unreported and therefore not included in our manuscript.

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