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Playing it safe: A literature review and research agenda on motivational technologies in transportation safety

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ABSTRACT

While motivation affects safety-related decision-making and human reliability, technologies to promote it are scarcely used. We have only recently witnessed how motivational technologies, including serious games, gamification, and persuasive technologies have emerged on the palette of methods for enhancing transportation safety. However, the research on these technologies for transportation safety is fragmented, preventing future studies and practical efforts. This paper describes the state-of-the-art through a systematic review to address this issue. Analyzing 62 studies, we perceive that motivational technologies focus on reducing the accident likelihood and mitigating their consequences. While these technologies can induce positive psychological change and improve learning, the evidence of behavioral change is mainly limited to simulation settings, lacking examination of the long-term benefits and potential adverse effects. Our results highlight the importance of aligning motivational design with the cognitive demand of the transportation task and the means for improving safety. Future research should explore how motivational technologies can enhance safety from the system design perspective, cover a broader scope of transportation modes, compare their effects to conventional approaches while considering social aspects in their design and evaluation. Beside providing an overview of the area and future directions, this paper also introduces design recommendations to guide practitioners.

1. Introduction

Transportation accidents, which result from diverse contributory factors, claim more than a million lives yearly [1]. Some of these factors include the uncertainties arising from environmental conditions, hardware and software, which can cause failures in transportation systems and are mitigated through measures such as testing, inspections and maintenance [2,3]. However, transportation systems are socio-technical systems, where humans play a central role. It is widely acknowledged that in such systems the human factors, such as errors and failures in operationalizing safe practices due to fatigue, stress or inadequate skill levels constitute a prominent source of uncertainty [3–5]. In the human factor domain, one of the most pertinent hurdles relates to motivation as humans tend to make inappropriate decisions in relation to safety, such as operating outside procedural guidelines, driven by expected short-term benefits (e.g., task simplification) [6].

A variety of approaches have been applied to mitigate the risks to transportation safety arising from human factors, including training [7], regulation [8] and awareness campaigns [9]. However, transportation accidents persist among the leading causes of death globally, especially for children and young adults [1] implying that despite the developments in the area, these strategies are inadequate in eradicating them. Safety training and public awareness campaigns are often non-engaging, and merely providing information does not necessarily translate to behavioral change [9–11]. Moreover, there are dangerous behaviors (e.g., speeding) motivated by expected social, utilitarian or hedonic benefits [12], that extrinsic regulation cannot adequately mitigate [13]. These caveats call for novel strategies to support positive motivation towards transportation safety.

To address the shortcomings of the conventional safety enhancement strategies, motivational technologies have been increasingly applied and researched in transportation safety domains. They do not merely inform users, but also engage and support psychological and behavioral change. The effectiveness of these technologies (i.e., serious and simulation games, gamification, and persuasive technologies) have been demonstrated in multiple domains, such as education, health and sustainability [14–17].

Despite the growing interest in the use of motivational technologies

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in transportation safety, the corpus of research on the topic lacks an overview. While transportation safety is an established field of study, research on motivational technologies is conducted in a very multidisciplinary manner, which contributes to understanding the multidisciplinary nature of the phenomenon. Although the importance of motivational factors on safety-related decision-making in socio-technical systems has been acknowledged [6], this lack of synthesis hinders future research and practical efforts as there is no comprehensive understanding of how technology can enhance safety by affecting human reliability through positive motivation, and what areas need additional investigation.

To address the lack of unified understanding, while aiding researchers and practitioners in attending to human factors through positive motivation, this article synthesizes the state-of-the-art of motivational technologies in transportation safety. In addition to providing an overview of the emerging topic by identifying and discussing the transportation domains that employ motivational technologies, types of motivational designs, approaches for enhancing safety and the outcomes of these technologies, the novel contributions of this study include design recommendations to guide practitioners in taking into account the characteristics of transportation tasks, safety improvement measures and different types of motivational technologies upon implementation. Moreover, a prominent contribution of this study is a comprehensive identification and description of thematic and methodological future research avenues towards a more holistic understanding of how motivational technologies can enhance the safety of transportation systems.

This study is organized as follows: Section 2 provides background information related to transportation safety, motivational technologies and prior literature reviews in adjacent domains. Section 3 details the materials and methods and Section 4 presents the results. Section 5 discusses the findings to explain why the solutions differ in safety improvement measures, technology types and affordances by transportation mode, provides design recommendations and proposes avenues for future research endeavors. Section 6 introduces the conclusions and limitations of this study.

2. Background

While there is no unambiguous definition for safety, it is commonly understood as a state of being free from harm or danger [18]. More specifically, safety often refers to the absence of accidents, defined as unplanned events causing unacceptable loss in relation to humans, distinguishing it from security which relates intentional threats, such as terrorism [19,20]. From a system viewpoint, safety emerges from the interactions of system components, including hardware and software, as well as humans and organization [3]. Safety is then enhanced by implementing barriers, which can either protect system components from failures, or mitigate the consequences of a failure event [3].

In transportation, ensuring safety is a major challenge due to the numerous deaths and injuries resulting from accidents [1]. However, transportation systems differ significantly in terms of accident occurrence. Globally, road accidents are among the leading causes of death [1] and are often closely related to human elements, such as individual judgment errors or violations [21,22]. Conversely, some transportation systems, such as aviation, are categorized as ultra-safe systems in which accidents are extremely rare and typically systemic as they depend on a combination of different factors, while their consequences are often catastrophic [21]. Nevertheless, even within such systems, ensuring safety is often dependent on human cognition and performance, while poor motivation can contribute to safety-eroding errors [23].

Motivation is defined as a “force or influence” which causes someone to take action [24]. According to the well-established self-determination theory, activities can be intrinsically or extrinsically motivated [25]. The former is performed for the sake of the activity itself, whereas for the latter motivation is derived from reasons that are external to the activity, such as incentives [25]. Activities that are intrinsically motivated are likely to satisfy the needs of competence (i.e., mastery), relatedness (i.e., social acceptance) and autonomy (i.e., freedom over one’s choices) [25]. A typical example of such activity is playing games, which people voluntarily undertake, while commonly experiencing feelings of mastery and connectedness to others [26].

Recently, the use of technologies to promote intrinsic motivation in mundane activities has gained increasing attention [14]. Instead of providing material incentives, these technologies employ motivational affordances, which are elements that support positive motivation and engagement towards desired behaviors [14]. In other words, motivational affordances aim to cultivate experiences that make engaging in an activity desirable for the sake of the activity itself. Technologies aiming to provide positive motivation can be seen to comprise three overlapping types: gamification, persuasive technology, and serious games. Whereas gamification draws inspiration from games and uses elements such as points or narratives outside of games, serious games are fully-fledged games with a utilitarian purpose [16]. Persuasive technologies use motivational affordances albeit they do not necessarily draw inspiration from game design [17].

While no previous systematic literature reviews comprehensively analyze motivational technologies to promote transportation safety, recent studies synthesized the state-of-the-art in adjacent areas.

For instance, Agnostopolou et al. [27] reviewed 44 papers on persuasive technology for sustainable mobility. The most used persuasive strategies were self-monitoring and feedback, gamification (referring to virtual rewards given for target behaviors), and social comparison. As a result, while persuasive technologies are a promising approach for promoting sustainable mobility behaviors (e.g., switching to more sustainable transportation modes), the authors explain that their long-term impacts remain unclear.

More recently, Warmelink et al. [28] reviewed the literature on gamification in production and logistics. The authors adopted a narrow definition of gamification, considering only studies that implemented elements often seen in games to other contexts [16]. By analyzing 18 studies, Warmelink et al. [28] conclude that the corpus mainly focuses on performance and efficiency in production execution and control.

Finally, the systematic literature review from Klock et al. [29] provided an overview of gamification in freight transportation. Based on [30] the authors used gamification as an umbrella term for various game-based approaches. Klock et al. [29] identified 40 studies that mainly focused on using simulation games to promote economic factors, whereas safety and sustainability were largely untouched.

As noted by previous literature reviews, the terminology regarding game-based and other types of behavioral change technologies is ambiguous. Whereas persuasive technology comprises all technologies designed to change attitudes and behaviors [27], gamification has been used either as a strict definition [28] or seen to encompass various solutions, including persuasive technology and serious games [29, 30]. To provide a comprehensive overview of the field, we consider the entirety of solutions aiming to promote motivation towards transportation safety (gamification, serious games and persuasive technology), while using the term “motivational technology”.

3. Methods

This systematic literature review aims to reveal trends within its research area [31]. More specifically, this review aims to synthesize the state of the art of motivational technologies in transportation safety, including publication details, transportation facets, safety improvement measures, types of motivational interventions, applied research methodologies and motivational technology effects. To achieve this, the methodology employed includes search conduction, studies screening, and data extraction.

Three keyword categories have potentially relevant results: (i) *motivational technologies:* serious or simulation games, gamification, and

Table 1
Classification scheme.

Category	Attribute	Possible values	
Publication details	Publication year	1989–2021	
	Publication type	Conference publication, Journal article	
	Number of citations	0–157	
Transportation facets	Transportation modes	Airway; Pipeline; Railway; Roadway; Waterway	
	Target audiences	Crew members; Cyclists; Drivers; Passengers; Pedestrians; Pilots	
Safety improvement measures	Injury prevention phases	Pre-event; During-event; Post-event	
	Human error management approaches	Person; System	
Motivational interventions	Technology types	Gamification, Persuasive technologies, Serious games	
	Affordances	Avatars or Characters; Badges or Rewards; Challenges or Goals; Cooperation or Teams; Feedback; Hints or Onboarding; Leaderboards or Rankings; Levels or Progression; Narratives or Storytelling; Points or Scores; Simulation or Virtual worlds; Time pressure	
Methodology and outcomes	Methodological designs	Framework or guidelines; Design proposals or Pilot studies; Empirical evaluations	Qualitative, Quantitative, Mixed
	Data collection method	Diary studies; Eye movement tracking; Interaction logs; Interviews and spoken tests; Physiological measurements; Questionnaires or surveys; User observations; Vehicle data, Written and drawing tests	
	Psychological outcomes	Engagement, flow or motivation; Enjoyment; Fatigue, monotony or strain; Locus of control or self-efficacy; Perceived alertness, distraction, arousal or boredom; Perceived learning, persuasiveness or efficacy; Perceived presence or reality; Perceived usability or usefulness; Perceptions of individual affordances; Risk awareness and perception or fear; Satisfaction or attitude; Willingness to use again	Negative; Neutral; Positive
	Behavioral outcomes	In-game performance; Knowledge acquisition or learning; Knowledge retention; Playing or usage time; Safer driving behavior	

persuasive technologies; (ii) *transportation:* road, rail, waterway, aviation, and transportation; and (iii) *safety*: security, emergency, accident, risk management, and safety. Given that transportation keywords prevented relevant studies from returning during searching tests, only motivational technologies and safety-related keywords were employed. The search was conducted on Scopus, which indexes many of the literature databases available, and considered conference papers, journal articles and book chapters that meet *("serious gam*" OR "simulation gam*" OR gamif* OR "persuasive technolog*") AND (security OR emergency OR accident OR "risk management" OR safety)* in their title, abstract or keyword fields.

Of the 873 studies returned in August 2019, 11 were not written in English, six were not accessible and 818 did not focus on motivational technologies aimed at enhancing transportation safety, which was expected given our search string did not include transportation keywords. Backward and forward searches of the 38 included studies identified eight additional records that met the selection criteria mentioned above. In December 2020, a search iteration using the same keywords was conducted in the Scopus database to identify studies published since the initial search. Of the 372 papers published in 2019–2021, 355 did not focus on motivational technologies aimed at enhancing transportation safety, four were not accessible and four already identified by the prior search. Thus, a total of seven new studies meeting the inclusion criteria were revealed. Backward and forward searches of these studies revealed one additional study. A third search iteration was conducted in January 2022 using the same keywords in the Scopus database to identify records published since the two prior searches. Of the 439 studies published in 2020–2022, 421 did not focus on motivational technologies aimed at enhancing transportation safety, seven were not accessible and four were already identified by the last search. Thus, a total of seven new studies that met the inclusion criteria were identified. Backward and forward searches of these studies revealed one additional study.

The 62 studies that met the criteria were analyzed using a concept matrix to capture relevant data [32]. While each study was analyzed by one researcher, two researchers took part in analyzing the studies and discussed ambiguous cases. An initial scheme for data analysis was created based on prior studies in related fields and iteratively revised during the analysis process. Finally, to provide a comprehensive overview of the corpus, the extracted data comprised publication details, transportation facets, safety improvement measures, motivational interventions, methodology and outcomes, as detailed in Table 1 and described below.

Transportation facets: The transportation modes can be divided into *airway, railway, roadway* and *waterway,* according to the type of infrastructure they use, while also *pipelines* are included in this categorization in some cases [33]. These modes comprise different audiences (i.e., stakeholders in transportation), including *crew members, cyclists, drivers, passengers, pedestrians* and *pilots*.

Safety improvement measures: In transportation systems, injury prevention can occur at different phases of an accident. Injuries can be prevented (i.e., *pre-event*, such as teaching safe means for crossing a road), managed (i.e., *during-event*, such as ensuring correct evacuation behaviors), or treated (i.e., *post-event*, such as providing life support after an incident) [34]. These correspond to the view which sees that safety can be enhanced by implementing barriers that either protect the system from failures (i.e., pre-event) or limit their consequences (i.e., during-event and post-event) [3]. Two types of approaches for managing human errors can enhance safety. The *person approach* focuses on mitigating unsafe acts and violations (e.g., speeding) by focusing on individuals. The *system approach* changes the external conditions (e.g., transportation infrastructure, vehicles) under which people operate [35].

Motivational interventions: Motivational technologies comprise three technology types. *Gamification* reuses game elements outside games to promote psychological (e.g., attitude) and behavior change (e.g., effectiveness) [16]. *Serious games* (including simulation games) are games whose primary purpose is not entertainment [16]. *Persuasive technologies* are designed to change people's behaviors but do not necessarily draw inspiration from game design like gamification and serious games [17]. All motivational technologies employ motivational affordances (e.g., *Avatars or Characters; Badges or Rewards*), which are elements and mechanics that structure the system use to support one's motivational needs [36,14].

Methodology and outcomes: We categorized the methodological designs into *frameworks or guidelines, design proposals* or *pilot studies* without empirical evaluation, and *empirical studies* evaluating the effects of motivational interventions. Furthermore, we analyzed whether the evaluation was conducted using qualitative, quantitative or mixed methods [37], while quantitative and mixed studies were also identified as using descriptive (i.e., describing the dataset) or inferential (i.e., presenting relationships between variables) statistics. The data collection methods included *diary studies, eye movement tracking, interaction logs, interviews, physiological measurements, questionnaires or surveys, user observations, vehicle data* and *written and drawing tests*. Motivational technologies can have impacts on users that are either psychological (e.g., *Engagement, flow or motivation; Locus of control or self-efficacy*) or behavioral (e.g., *Knowledge acquisition or learning; Safer driving behavior*), while this effect can be negative, neutral or positive.

4. Results

Based on the data extracted from the 62 included studies, we describe synthesis of publication details, transportation facets, safety improvement measures, motivational interventions, as well as methodology and outcomes reported by the corpus.

As can be noted in Table 2, and visualized in Fig. 1, the topic is relatively new, and the corpus has mainly emerged during the last decade. Twenty-six of the studies were published in journals and 36 in conference proceedings. The relatively large number of conference publications implies that the corpus has yet to mature as conferences are typically venues for research-in-progress and early results.

Authors with the most studies included in this review were Chittaro (8 studies), Schroeter (5 studies), Steinberger (4 studies) and Buttusi (4 studies). As of January 2022, the most cited studies according to Scopus indexing were [58] (157 citations), [76] (151 citations), [53] (115 citations), [40] (86 citations), [44] (56 citations), [77] (45 citations), [73] (42 citations), [63] (30 citations), [38] (29 citations) and [55] (27 citations).

Most studies focused on roadway safety, mainly aiming to improve the safety of *drivers, pedestrians* and *cyclists*, as detailed in Table 3. One study [39] described a solution for accident scene investigation, one [44] for efficiently reporting road accidents and one [89] for citizen engagement in safety data collection. Moreover, two records described frameworks or design proposals for *any* road or street travel choices [82, 43,91], whereas two studies described a serious gaming solution for both *pedestrians* and *drivers* [84, 94] and one for both car *drivers* and *passengers* [96]. Airway safety studies mainly focused on aircraft *passengers,* and waterway safety studies on *ship* [81] and *submarine* [41] *crews*. No studies related to railway or pipeline safety were found.

Table 2
Publication years of the reviewed studies.

Year of publication	Records	Total
1989	[38]	1
2006	[39]	1
2007	[40]	1
2009	[41]	1
2010	[42,43]	2
2011	[44]	1
2012	[45]	1
2013	[46]	1
2014	[47–56]	10
2015	[57–59]	3
2016	[60–68]	9
2017	[69–73]	5
2018	[74–80]	7
2019	[81–87]	7
2020	[88–92]	5
2021	[93–99]	7

Regardless of the transportation mode, the person approach to managing errors was predominant (59 studies). Although the most common injury prevention phase was pre-event (47 studies), this varied by transportation mode. **Roadway safety studies** were mainly concerned with the **pre-event phase** while adopting the **person approach**. In other words, roadway safety studies focused on mitigating the unsafe acts of individuals (e.g., speeding) while promoting safe behaviors (e.g., safe means for crossing roads) to prevent accidents. For example, the solution proposed in [87] gamified driving tasks using challenges, points, rewards and ranking presented using in-car displays to prevent driving fatigue and improve reaction time. Exceptions regarding the injury prevention phase were found in three studies - two focused on the **post-event phase** as they proposed solutions for accident scene investigation [39] and reporting road accidents [44], whereas one proposed a serious game for promoting seat belt use (i.e., during-event - [96]). Moreover, [39] can be regarded as a **system approach** to error management as accident investigation typically aims to enhance the safety-related policies, practices, and conditions by identifying accident causes [100]. Other exceptions that used a system approach to error management is [89], which aimed to engage citizens in data collection to create safer cities and [95] which proposed a serious game to enhance engineering students knowledge on safe vehicle design.

Airway solutions focused on the **person approach** in the **during-event phase**. They mostly intended to teach content from safety cards or pre-flight demonstrations to passengers, such as evacuation behavior [83] and brace position [47], which aim at minimizing injuries. For example, Chittaro and Buttussi [83] described an arcade-type game where the user controls a character to evacuate an aircraft safely while facing various obstacles under time pressure. The proposed game aimed at improving aircraft passenger self-efficacy and knowledge regarding aircraft emergencies. The two airway studies that focused on pilots [69, 93] can still be regarded as person approach and during-event solutions, as they proposed design guidelines and serious game solutions to teach correct behavior for critical situations and emergencies.

Waterway interventions focused on the **person approach** while aiming to educate crews in planning and conducting safe cargo transportation (i.e., **pre-event phase** - [81]), as well as submarine crew spatial awareness for safety incidents (i.e., **during-event phase** - [41]). For example, Moyseenko and Meyler [81] proposed a game that simulates maritime cargo transportation and requires the players to assume different roles and make decisions to ensure safety.

Most studies defined the proposed solutions as **serious games** (55%) and **gamification** (39%). However, four cases described themselves as gamified driving simulators or training applications (i.e., fully-fledged games – [68,56,74,96] and one as a persuasive technology using game elements (i.e., gamification – [46]). Thus, considering descriptions, 61% of the studies can be regarded as serious games, 32% gamification, and 7% **persuasive technologies**. Nevertheless, serious games were predominant in all transportation modes and audiences, except for roadway drivers (Fig. 2), while both serious games and gamification have gained significant popularity over the last years (Fig. 3).

Gamified roadway studies mostly focused on promoting safe driving by intervening in users' psychological states to mitigate dangerous behaviors (e.g., speeding, lane deviations). Roadway serious games aimed to teach safe behaviors and safety-related skills (e.g., crossing the street safely, cycling situation awareness). Persuasive technologies were also designed to improve safe driving and other road travel choices through non-game-like interventions. Airway and waterway studies solely employed serious games.

Overall, the most applied motivational affordances were (textual, graphical or audible) **feedback, challenges or goals, simulations or virtual worlds**, and **points or scores**, as outlined in Table 4. In roadway domains, the most commonly applied affordances were feedback (31 studies), challenges or goals (24 studies), and points or score (24 studies). Airway studies predominantly applied simulation or virtual

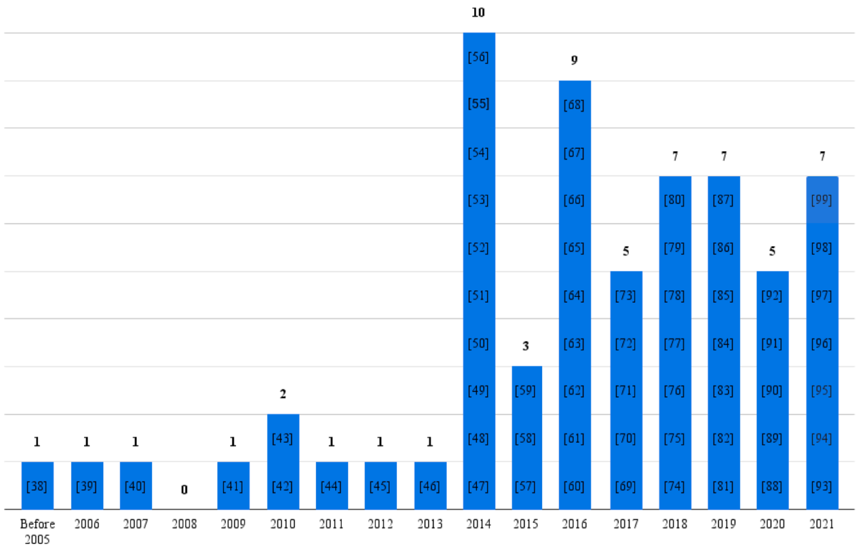

Fig. 1. Publication trend of the reviewed studies. The first and only study before 2005 was published in 1989.

Table 3
Transportation mode and target audience of the studies.

Transportation mode	Studies	Total (% of all studies)
Roadway		**49 (79%)**
Drivers	[68,80,60,53,46,87,56,94,95,48,99,52,85, 98,84,96,59,49,50,61,54,55,62,78,67,73, 71,75,90,65]	30 (48%)
Pedestrians	[92,42,66,40,51,94,97,84,38,86,79,57]	12 (19%)
Cyclists	[70,72,74]	3 (5%)
Passengers	[96]	1 (2%)
Any	[82,39,89,44,91,43]	6 (10%)
Airway		**11 (18%)**
Passengers	[76,88,83,47,63,45,58,77,64]	9 (15%)
Pilots	[69,93]	2 (3%)
Waterway	**2 (3%)**	
Crew	[81,41]	2 (3%)

worlds (8 studies), feedback (7 studies) and avatars or characters (7 studies). The two waterway solutions applied challenges or goals, simulation or virtual worlds, hints or onboarding, narratives or storytelling, and cooperation or teams.

A small part of the reviewed papers (11%) used a theoretical approach, presenting **frameworks or guidelines**, including a vignette survey study to explore the intentions to participate in gamified driving [82]. We also identified research-in-progress papers describing **design proposals** (22%). Most studies (66%) evaluated the outcomes through empirical approaches that described a design, followed by an **empirical evaluation**, as shown in Table 5. These evaluations were either **qualitative** (3 studies), **quantitative** (20 studies), or **mixed** (18 studies). A total of 22 quantitative or mixed-approach studies used data to make assumptions about an entire population and examine relationships between variables (i.e., inferential). In comparison, 16 studies used descriptive statistics.

Questionnaires or surveys, interaction logs, and **interviews and spoken tests** are commonly reported data collection methods, as shown in Table 6. It is notable that of the purely qualitative studies, only [46] reported the methods used for data gathering.

Of the 41 empirical studies, 32 examined psychological outcomes (Table 7). The most evaluated were: (i) **enjoyment or fun**; (ii) **perceived usability or usefulness**; and (iii) **engagement, flow or motivation**, the second one being evaluated by all three types of technologies. Some psychological outcomes (e.g., risk awareness, perception or fear, and locus of control or self-efficacy) were only studied in serious games interventions.

The examined outcomes also differed by transportation domain. In the roadway domain, the most evaluated were enjoyment (14 studies), perceived usability or usefulness (13 studies), and engagement, flow or motivation (6 studies). In the airway domain, the most evaluated ones were locus of control and self-efficacy (6 studies); risk awareness and perception or fear (5 studies); and engagement, flow or motivation (5 studies). Waterway studies did not evaluate any outcomes as they were non-empirical.

Overall, most studies reported encouraging results on psychological outcomes. Some neutral results, as well as types of outcomes which cannot be considered positive or negative, were described e.g., by Schneider and Mazur [54] *(enjoyment)*; [76] (*engagement, flow or motivation* - comparing the effects of different types of virtual reality displays); [39,76,74] (*perceived presence or realism)*; [83,47,63,45,58] (*risk awareness and perception or fear)*; [87] and [59] *(fatigue, monotony or strain)* and [60] and [51] (*perceptions of individual affordances)*. Results were exclusively positive regarding *perceived usability and usefulness; locus of control or self-efficacy; perceived alertness, distraction, arousal or boredom; perceived learning, persuasiveness or instruction efficacy; satisfaction or attitude*; and *willingness to use again*.

Thirty-two studies reported behavioral outcomes, especially related to **knowledge acquisition or learning** in serious games (including learning effects assessed using questionnaires, interviews and performance over time). Overall, these games tackled various topics, such as cyclist situational awareness [70], road rules [52], and aircraft evacuations [83]. Four studies assessed the transfer of learning on performance and, while three ([77,56,38]) found positive effects, the learning effect did not transfer to real-world driving behavior in [99]. **In-game performance** without learning effect assessment was reported in four studies. Gamified interventions statistically improved some driving behaviors in simulation settings (e.g., speeding, lane control - [87,73]) while negatively impacted others (e.g., off-road glances - [71]). No behavioral outcome was evaluated by persuasive technology interventions. Five studies compared behavioral outcomes from motivational technology interventions to conventional safety enhancement strategies, including aircraft safety cards and demonstrations ([83,63, 58,77]) and classroom learning [54]. As shown in Table 8, the studies reported behavioral results using descriptive statistics or inferential analysis while motivational technologies mainly positively impacted users' behavior.

When examining the behavioral outcomes by transportation domain, the most reported ones in roadway studies were knowledge acquisition

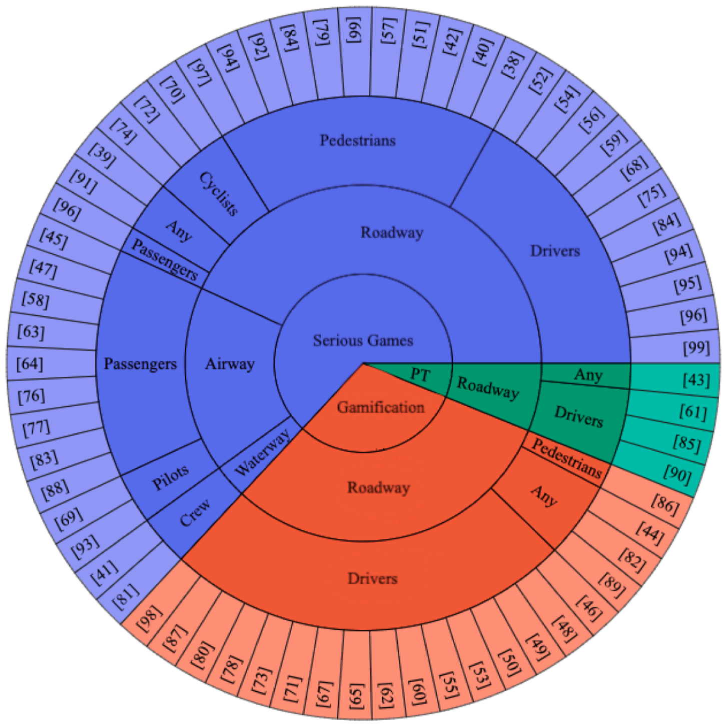

Fig. 2. Transportation modes and target audiences by motivational technologies.

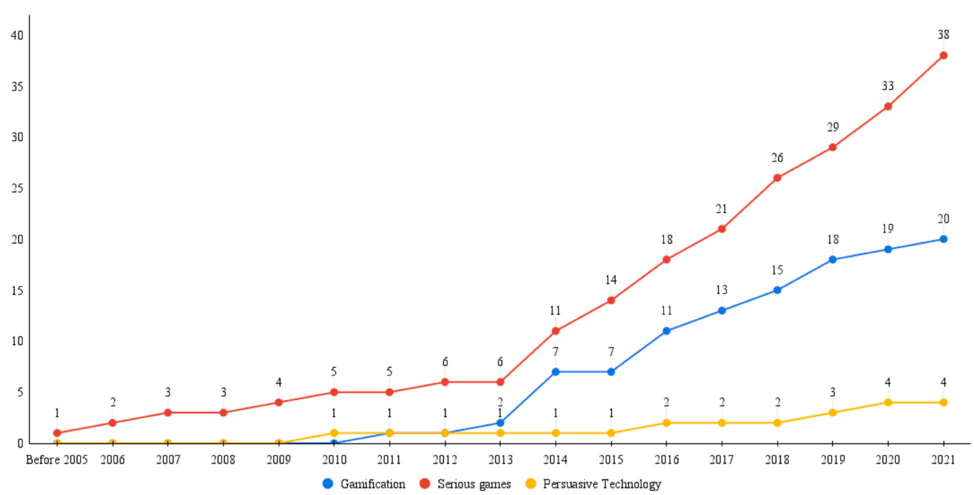

Fig. 3. The development of different motivational designs.

or learning (15 studies), safer driving behavior (5 studies), in-game performance (3 studies), playing or use time and knowledge retention (2 studies each). In the airway domain, the most reported ones were knowledge acquisition or learning (8 studies), playing or usage time (3 studies) and knowledge retention (2 studies).

5. Discussion

While the corpus addressed three of the five main transportation modes, no studies focusing on railway or pipeline safety were found. This could be related to high levels of automation and professionally controlled operations, which potentially reduce the need for psychological and behavioral change [101,102]. In addition, the lack of motivational interventions in pipeline and railroad transportation might be due to the complexity they would add to such safety critical systems. Introducing novel safety measures can make systems more opaque, vulnerable and lead to emergent undesirable outcomes [103,35]. For example, gamifying practices related to safely controlling a pipeline would introduce an additional system for the operators to master, potentially increasing their workload while being detrimental to the demanding tasks consisting of complex data monitoring [104].

Most studies understandably targeted roadway safety, as road accidents claim more lives than other modalities combined [105,106]. Roadway studies mostly focused on drivers, which is expected as industrial societies have been car cultures for decades and many of the world's most populous countries are increasingly adopting motorized vehicles, leading to a rise in traffic-related trauma [107]. Beside drivers, unsafe driving poses risks to vulnerable road users (i.e., pedestrians, cyclists), further emphasizing driving safety [108]. Unlike in the roadway domain, airway safety studies focused on passengers, instead of vehicle operators. This target audience was also expected, given that commercial aviation is highly regulated, automated, and exclusively

Table 4
Motivational affordances by transportation mode.

Motivational affordance	Roadway	Airway	Waterway	Total (% of all studies)
Feedback	[92,53,87,40,56,94,95,97,70,99,72,91,85,98,38,86,59,49,50,61,55,78,67,73,71,79,74,75,90,57,65]	[76,88,47,63,45,58,77]		38 (61%)
Challenges or Goals	[68,80,42,82,46,87,56,51,94,95,48,44,70,72,98,49,50,43,54,78,67,73,71,57]	[83,69,64,58]	[81]	29 (47%)
Simulation or Virtual worlds	[92,68,42,39,40,51,94,95,97,44,91,84,38,96,59,54,79,74]	[76,88,47,63,45,58,77,69]	[41]	27 (44%)
Points or Scores	[68,80,42,60,82,53,46,87,56,51,89,95,97,48,44,70,99,72,85,84,86,71,74,75]	[69,88]		26 (42%)
Avatars or Characters	[92,39,66,51,97,44,84,38,86,96,50,49,54,57,65]	[76,83,47,63,45,77,64]		22 (35%)
Levels or Progression	[68,82,46,66,56,89]	[88,83,45,69]		19 (31%)
Badges or Rewards	[92,42,60,82,46,87,51,97,48,44,85,86,50,78,74,57,65]	[88]		18 (29%)
Hints or Onboarding	[92,68,40,55,79]	[76,88,47,63,58,77]	[81]	12 (19%)
Narratives or Storytelling	[39,51,52,54,79,65]	[76,88,58,69,64]	[81]	12 (19%)
Leaderboards or Rankings	[82,46,87,51,97,48,44,49,50,78]			9 (15%)
Cooperation or Teams	[80,60,82,51,38,55,78]		[81]	8 (13%)
Time pressure	[68,39,94,99,72,86]	[83,77]		8 (13%)

Table 5
Methodological approaches.

Study type			Total (% of all studies)
Empirical evaluation	Descriptive	Inferential	41 (66%)
Mixed	[68,66,94,97,69,84,59,61,74,90]	[39,40,56,51,70,67,73,71]	18 (29%)
Quantitative	[60,95,96,54,75,86]	[87,76,47,63,45,58,83,88,77,99,72,52,38,65]	20 (32%)
Qualitative	[46,48,79]	3 (5%)	
Design proposals or Pilot studies	[92,42,53,89,44,91,85,64,98,49,50,78,41,57]	**14 (23%)**	
Framework or Guidelines	[80,82,93,81,43,55,62]	**7 (11%)**	

Table 6
Data collection methods in empirical evaluations.

Data collection methods	Evaluation type			Freq. (% of studies)
	Quantitative	Mixed	Qualitative	
Questionnaires or surveys	[60,87,76,88,83,47,63,45,58,77,99,72,52,96,54,65]	[68,39,56,51,69,70,84,59,61,67,73,71,74]	[46]	30 (48%)
Interviews and spoken tests	[76,83,47,63,58]	[66,40,56,51,69,61,67,73,71]	[46]	15 (24%)
Interaction logs	[88,99,72,86]	[39,56,51,70,67,73,71,74]		12 (19%)
User observations	[87,77,38]	[68,40,69,59,90]	[46]	9 (15%)
Eye movement tracking	[87,65]	[70,67,73,71]		6 (10%)
Physiological measurements	[87,58]			2 (3%)
Written and drawing tests		[39,97]		2 (3%)
Diary studies			[46]	1 (2%)
Vehicle data	[99]			1 (2%)

Table 7
Psychological outcomes.

Psychological outcome	Roadway	Airway	Total (% of studies)
Enjoyment	[68,46,66,56,51,97,70,99,72,59,54,67,73,71]	[69]	15 (24%)
Perceived usability or usefulness	[46,56,51,94,97,48,99,84,59,61,67,71,79]	[69]	14 (23%)
Engagement, flow or motivation	[56,51,59,67,73,71]	[76,83,58,77,69]	11 (18%)
Perceived presence or realism	[68,39,97,59,74]	[76,58,69]	8 (13%)
Perceived learning, persuasiveness or instruction efficacy	[94,97,84,61,90]	[63,77]	7 (11%)
Locus of control or self-efficacy		[76,83,47,63,45,77]	6 (10%)
Risk awareness and perception or fear		[83,47,63,45,58]	5 (8%)
Perceived alertness, distraction, arousal or boredom	[87,59,67,73]	[58]	5 (8%)
Willingness to use again	[56,70,72]		3 (5%)
Fatigue, monotony or strain	[87,99,59]		3 (5%)
Satisfaction or attitude	[97,38,59,61]		3 (5%)
Perceptions of individual affordances	[60,51]		2 (3%)

operated by highly trained professionals [109]. In waterway studies, the emphasis on crew members is justifiable, given that crew behavior and communication are central to safety in this domain [110].

Based on our results, motivational technologies are applied to accident prevention (i.e., pre-event) and trauma mitigation in case of an accidental event (i.e., during-event, post-event). Road user psychological and behavioral states have a major role in the emergence of road accidents, which makes their prevention (i.e., pre-event) a reasonable approach for motivational technology interventions in the roadway domain [111,22]. Unlike roadway solutions, airway studies predominantly targeted the during-event phase, attempting to mitigate the harm caused by adverse events, such as aircraft emergencies. This emphasis might be explained by the nature of modern commercial aviation, where accidents are not frequent but potentially have catastrophic consequences, especially if emergency procedures have not been implemented [21,11]. Moreover, commercial aviation accident prevention potentially requires little motivational change, as the operations are conducted by highly trained professionals under strict regulation and automation [109]. Aircraft passenger behavior, on the other hand, plays a crucial role in emergencies (i.e., during-event), while the commonly applied means for promoting passenger safety (e.g., safety-cards, demonstrations) are ineffective [11]. Therefore, in aviation, the highly regulated and automated operations together with the passenger role in emergencies further explain the focus on passenger safety during accidental events.

Beside the means for injury mitigation, the studies in different transportation domains differed in the intervention types they applied.

Table 8
Behavioral outcomes.

Behavioral outcome	Descriptive statistics	Inferential statistics Statistically Significant Negative	Negative	Neutral	Positive	Statistically Significant Positive
Knowledge acquisition or learning	[68,97,59,54,74]				[56]	[39,76,88,47,63,45,58,77,40,70,99,72,52]
Safer driving behavior		[67,71]	[87]		[65]	[67,71,87,73]
Playing or usage time						[63]
In-game performance	[66,83,95,75]					
Knowledge retention					[40]	[76,58,52]

In the roadway domain, gamification was predominant, whereas airway and waterway studies only applied serious games. One possible explanation for the applicability of gamification in roadway safety is the pre-event emphasis. Many roadway gamification studies aimed to enhance safe driving by intervening driver psychological states (e.g., boredom or tiredness) and mitigating dangerous behaviors (e.g., lane deviation, speeding) by gamifying the driving task using affordances such as feedback, challenges and points. Gamifying safe driving in day-to-day life is reasonable, given that driver behavior and psychological states play a crucial role in road safety. For example, by increasing the cognitive demand, gamification can reduce monotony, and decrease accident risk. In such situations, gamification can have a similar effect on driving behavior as driving with a passenger, for example [87].

Instead of gamifying day-to-day behaviors, airway studies focused on teaching aircraft passengers correct behavior for emergencies (i.e., during-event phase). This makes serious games a viable option as they aim to provide engaging learning experiences and a safe space for exploring the consequences of various choices and actions, which cannot be easily achieved using real-life safety drills. These solutions can also utilize error-based educational approaches, leading to improved learning when combined with the feedback of the negative consequences of incorrect actions [88]. Beside the well-known benefits of serious games, their advantage in the transportation safety domain is threat appeal, given their ability to communicate risks to the user vividly is likely to increase the attention level and lead to improved outcomes regarding behavioral change [88,112]. Overall, unlike traditional safety measures (e.g., pictorials, safety demonstrations), serious games effectively promote learning towards emergency situations [63,58].

Considering all modalities, affordances such as feedback and challenges, which can be considered achievement and progression-based, as well as simulation and virtual worlds, which aim to immerse the user into the game world, were common [14]. The relative absence of social affordances (e.g., leaderboard, cooperation) may be related to the single-player approach predominantly adopted by these interventions. Studies in the roadway domain mainly applied challenges, points and feedback, focusing on achievement and progression [14].This might be explained by roadway studies focusing on gamification, as achievement and progression affordances are easily applied to existing practices and tasks, such as driving [113]. Moreover, as roadway gamification involves day-to-day scenarios (i.e., gamified driving), feedback and challenges are suitable affordances as they can be provided real-time through ambient colors or audio, avoiding distractions and excess cognitive effort, which might detriment safe driving [65]. Beside feedback, studies in the aviation domain commonly applied immersion-based affordances, including simulation or virtual worlds as well as avatars or characters. The prevalence of these affordances in aviation might be explained by the emphasis on serious games solutions, which often aimed to simulate real-world scenarios while allowing the user to feel like being in dangerous environments and situations. Moreover, portraying adverse consequences through avatars can effectively alter individual risk perceptions, which was one of the commonly examined outcomes in aviation studies [114]. While only two waterway studies were identified and analyzed, they implemented various affordances, including challenges or goals, simulation or virtual worlds, hints or onboarding, narrative or storytelling and cooperation or teams.

In terms of methodological approaches, most of the reviewed studies were mixed or quantitative and described the design of a motivational intervention followed by an empirical evaluation. This approach corresponds to the broader corpus of existing research on motivational technologies (e.g., gamification [14]). As such, the corpus mainly focuses on understanding whether motivational technologies achieve their predetermined, quantifiable goals.

In general, the most evaluated psychological outcomes were *enjoyment or fun, perceived usability or usefulness* and *engagement flow or motivation*, which were also most common in the roadway domain. However, beside *engagement, flow or motivation*, airway studies mostly investigated the effects of *locus of control or self-efficacy* and *risk awareness and perception or fear.* The differences might again be explained by the airway focus on emergencies, as these psychological states have a central role in determining the outcomes of such situations [47]. Regarding behavioral outcomes, *knowledge acquisition or learning* was predominant given the prevalence of serious games, which typically have educational purposes, making learning a natural way to assess them [115].

5.1. Design recommendations

Based on the results of this review, we provide three recommendations to guide motivational technology design in transportation safety:

Designers should consider the injury prevention phase to find a suitable motivational intervention type. While motivational technologies are suitable for accident prevention as well as limiting their consequences, the approaches for these two differ in terms of applicable designs. Gamifying everyday transportation tasks *in-situ* is suitable for preventing accidents (i.e., pre-event) as it can provide motivation for adhering to safety rules and engaging in safe practices (e.g., [73]). However, implementing motivational affordances *in-situ* is not generally a viable approach for limiting accident consequences (i.e., during-event), as people typically do not lack motivation in situations, such as emergencies, where the outcomes are immediate and evident [116]. On the other hand, serious games are a suitable means for the during-event phase due to their capability to motivate users to learn correct behaviors for the unlikely accident events, while supporting users' self-efficacy and internal locus of control which play a key role in emergency situations (e.g., [76,47,63]).

Designers should choose the motivational affordances according to the applied safety improvement measures. On the one hand, for the *in-situ* gamification approaches for accident prevention, achievement-based affordances are suitable, as they are easily applied to existing practices and can be implemented using different forms of ambient feedback [49,50,67], allowing the user to focus on the main task. On the other hand, immersive affordances allow the users to feel part of a game world in which they can practice safety-related skills in emotionally intense scenarios (related to e.g., aircraft emergencies), potentially replacing the need for costly real-life drills [45] thus being suitable for the during-event interventions. However, even in such immersion-based interventions, sufficient feedback should be provided to the user by detailing the consequences of correct and incorrect actions to ensure learning and avoid enforcing incorrect behaviors [88].

Designers should consider the cognitive demand of the transportation *task, the tradeoff between distraction and potential safety benefits, and provide the feedback in a way that takes little attention away from the task itself.* Due to the growing levels of automation, monotony is becoming an increasingly prevalent issue in transportation safety, whereas motivational technologies can reduce the accident risk by increasing the cognitive demand in monotonous transportation tasks, such as driving long distances [87]. However, implementing the motivational system in order to reduce the monotony poses a risk of distraction by taking the attention away from driving, increasing the reaction time and increasing the likelihood of collisions [87,67]. One approach to address this issue was to present repeated questions about the vehicle environment [87], thus motivating the driver to pay attention to it, whereas some of the gamified driving solutions used ambient colors and ambient sound to avoid distraction [49,67]. Some of the transportation tasks, however, are cognitively demanding as they require efficient information processing and decision making [104]. In such cases, introducing an *in-situ* motivational intervention might add an extra layer of complexity and be detrimental to safety, while a learning intervention that is used outside of the daily operations might be suitable.

5.2. Future avenues

The reviewed studies indicate the motivational technologies potential for enhancing transportation safety by promoting psychological and behavioral change. However, there are limitations and shortcomings to overcome, many of which relate to the motivational technologies research legacy, such as the lack of comprehensive theory-driven designs and evaluation of the effects of individual affordances as well as the incomplete descriptions of interventions [14,28]. Additional thematic and methodological gaps and corresponding future research directions are further discussed below.

Future research should cover a broader scope of transportation modes. Literature predominantly examined roadway transportation, which is the most accident-prone mode [21], while 11 out of 62 studies targeted airway safety. Surprisingly only two non-empirical studies focused on waterway safety, whereas no studies related to railway safety were found. While accidents occurring in these modalities do not pose a prominent global problem similarly to roadway transportation, human behavior is still essential to ensure their safety. On the one hand, the risks of maritime accidents become prevalent especially under complex waterway traffic and environmental circumstances, and similarly to airway emergencies, appropriate passenger and crew behavior is crucial in maritime disasters, making it a prominent context for motivational technology interventions that aim to educate and bring about attitudinal change [117,118]. Additionally, maritime shipping is becoming increasingly autonomous, posing novel challenges, such as lack of training and experience of daily operations, which motivational technologies could tackle [110]. On the other hand, in the railroad safety domain, motivational technologies could support the sustained alertness of train operators who perform highly monotonous tasks in their daily work.

Future research should go beyond the person approach to error management. The reviewed corpus mainly focuses on enhancing transportation safety by attempting to mitigate dangerous behaviors of individuals while promoting safe ones. While addressing individual safety behavior is fundamental, focusing solely on it provides a narrow view of the motivational technologies' applicability. Thus, we encourage future research to explore how these technologies can support citizen and worker engagement in improving transportation infrastructures safety and work practices alike. Only one design proposal study [89] described a gamified system for transportation safety-related crowdsourcing. Hence, a prominent direction for future research is to empirically investigate such systems that encourage citizen participation, including reporting of potential dangers and other forms of safety initiatives. Moreover, transportation infrastructure has a significant impact in disaster response and recovery, while damages and blockages disrupt disaster and emergency management activities [119,120]. Therefore, to enhance disaster preparedness, motivational technologies could aid policymakers and designers by enhancing data collection for evaluating different disaster management strategies [119]. Similarly, future research in transportation organizations should examine how motivational technology can support employee safety participation to maintain and improve safety, as well as in collecting data for analyzing the human and organizational factors of safety incidents and emergencies, which is currently lacking in some modalities, such as maritime transportation [110].

Future research should consider social aspects in design and evaluation. The literature examined the psychological and behavioral effects of interventions implementing motivational affordances that are typical of single-player settings, which translates to transportation safety being regarded as a solitary endeavor. However, social influence is a crucial aspect in enhancing regulatory compliance [121], which is a prominent aspect of enhancing safety. Additionally, the safety of complex transportation systems depends on the interactions of multiple stakeholders who share responsibility for managing it [122]. Therefore, to enhance compliance and to reflect the idea of safety as a systemic property arising from complex interactions, social motivational affordances (e.g., teams, shared goals, cooperation) should be included to a greater extent in future research as they could enhance communication, shared situational awareness and lead to attitudinal change in transportation, which are also outcomes that should be explored in-depth.

Future research should investigate the learning effect of the motivational intervention when compared to the traditional approach. Instead of acknowledging motivational technologies as a silver bullet to safety learning and training, researchers could clarify situations where these interventions are helpful. As an example, most empirical studies assessed learning effects without comparing the proposed intervention to conventional safety training. Meanwhile, four out of the five studies that made this comparison need further discussion, as the intervention was compared with in-flight cards, which are an ineffective way to deliver information [11]. Therefore, future studies should compare motivational technologies to approaches, such as corporate safety training, safety onboarding of new employees and safety awareness video presentations.

Future research should examine the emergent effects of motivational interventions using qualitative approaches. While quantitative research is essential for understanding the premeditated causal effects of motivational technologies on safety, the field of motivational effects is still rather young and can still greatly benefit from more inductive approaches that can uncover and tease out other nuanced phenomenon beyond the investigation of a priori assumed effects; they are unlikely to uncover the emergent effects motivational technology interventions can have on users or organizations when implemented. For example, an intervention might lead to safer behavior, but be detrimental to individual well-being if perceived as a form of control. To uncover such emergent effects, we encourage future studies to employ qualitative approaches which consider outcomes beyond those that focus on the design goals. Moreover, future qualitative studies should report and justify the methodological process (e.g., sample selection, data collection and analysis, credibility/reliability checks - [123]) more rigorously as only one reviewed qualitative study ([46]) provided a description of the used data collection methods.

Future research on serious games should verify the transfer of knowledge into safety behavior. While providing information is an essential aspect of transportation safety management, knowledge does not always transfer into real-world behavior [10]. Whereas learning was one of the most commonly examined outcomes in the reviewed corpus, only four studies provided evidence on the transfer of knowledge into behaviors, including life preserver donning, driving behavior and pedestrian behavior. Moreover, only one [99] examined knowledge transfer in naturalistic settings by collecting forklift driving data. While examining behavioral change in non-controlled settings might be problematic due to ethical concerns which might arise from the possible adverse effects that might occur when motivational technologies are implemented, laboratory scenarios do not provide sufficient evidence due to the biases resulting from the experimenter and setting effects. Therefore, an avenue for future research is to verify the knowledge transfer and learning of safety-related procedures in non-controlled scenarios and real-life events to provide more reliable evidence of their effectiveness.

Future research should address the long-term effects of motivational interventions. Although most behavioral outcomes presented by the corpus were favorable in short-term simulation settings, long-term effects are still unclear. Given some adverse effects found even in simulation-based evaluations, such as off-road glances, more research is required to conclude whether motivational technologies are effective ways to improve safety and if these results are also reproducible in the long run. Further examination is also needed on how the feedback should be presented in different contexts as, e.g., auditory and visual information can influence behavioral patterns differently [124]. As the corpus matures and the possible detrimental effects of motivational technologies are profoundly understood and mitigated, future research should also examine the effects of motivational technology interventions on safety indicators, such as accident rates, for more concrete evidence on their actual impact on safety.

6. Conclusions

This article synthesized the state-of-the-art of motivational technologies in transportation safety, provided design guidelines and identified promising avenues for future research through a systematic review. Targeting roadway, airway and waterway domains, these technologies have been predominantly harnessed to enhance individual safety behavior as a means for preventing transportation accidents as well as limiting their consequences. By using mainly quantitative and mixed evaluations, the corpus demonstrates motivational technologies' potential to induce psychological change and lead to safety-related knowledge acquisition, while the evidence of behavioral change beyond learning is mostly limited to driving behaviors in simulation settings. Based on these results, we recommend designers to consider the injury prevention phase, approach for safety improvement, and the cognitive demands of the tasks when designing motivational technologies.

We acknowledge that this literature review has some limitations. We used the key terms derived from gamification, serious games, simulation games, and persuasive technology in our search. Although these keywords represent the main concepts that constitute motivational technology, records that have not used the previous terms to describe their research focus were not included even if it could be considered motivational technology. Moreover, as we used safety-related search terms, records that did not explicitly use them to describe their focus were not included, although the difference between, e.g., 'eco-driving', 'collaborative driving', and 'driving safety' can be ambiguous.

Limitations of the analysis phase relate to the incomplete descriptions of the interventions applied in the reviewed studies, as only the affordances mentioned in the manuscripts were considered. Moreover, in the analysis phase, some details of the reviewed studies have inevitably been lost since the purpose of this study is to provide an overview of the corpus, leading to a necessity to generalize the contents of individual studies that were reviewed. As an example, types of affordances (e.g., Levels or Progression) and outcomes (e.g., *engagement, flow or motivation*) were grouped together to avoid excessive complexity of the analysis.

We suggest future work in the domain to cover a broader scope of transportation modes, go beyond the person approach to error management by exploring how motivational technologies can aid in enhancing transportations safety thorugh system design, and consider the role of social aspects in both design and evaluation of motivational technologies. Methodologically, future studies should investigate the learning effect of motivational interventions when compared to the traditional approach, verify the knowledge transfer of serious games into safety behavior, explore the emergent effects using qualitative approaches and address the long-term effects of motivational interventions on safety indicators.

CRediT authorship contribution statement

Eetu Wallius: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Ana Carolina Tomé Klock:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Juho Hamari:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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