Risk Factors, Monitoring Techniques, and Intervention Strategies: Experiences and Lessons from Different Transport Sectors

Amir Pooyan Afghari[1], Eleonora Papadimitriou[1], Sally Maynard[2], Rachel Talbot[2], Ashleigh Filtness[2], Geert Wets[3]

[1]*Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2628 BX, Delft, the Netherlands*

[2]*Transport Safety Research Centre, Loughborough University, LE11 3TU, Loughborough, United Kingdom*

[3]*Hasselt University, School for Transportation Sciences, Transportation Research Institute (IMOB), Agoralaan, 3590 - Diepenbeek, Belgium*

Abstract

Operator's behaviour accounts for the majority of accidents in various transport sectors (road, rail, aviation and maritime) and thus identifying human factors associated with increased risk, monitoring operators, and applying remedial interventions, are paramount in reducing risk across transport entities. Operator's mental state (fatigue, sleepiness, stress, emotions, illness, distraction), speeding, tailgating and illegal maneuvering are among human factors associated with increased risk. Although similar risk factors exist in all transport sectors, monitoring operators and applying interventions is more widespread in the road sector and there is a lack of knowledge sharing that could potentially provide insight for reducing human factors among all transport sectors. As the first step in establishing such a guideline, this paper aims to investigate the possibility of transferring knowledge about operator monitoring and intervention strategies between different transport sectors, i.e. road, rail, aviation and maritime. This transfer of knowledge is investigated from three perspectives: (i) most important risk factors that are common among sectors, (ii) monitoring technologies that are used in each sector, and (iii) intervention strategies that could be implemented in reducing risk in each sector. To achieve this objective, the most important risk factors in rail, aviation, and maritime sectors are first reviewed from the literature. The iDREAMS naturalistic driving study is then selected as a case study from the road sector and the risk factors, monitoring technologies and intervention strategies are reviewed and compared with the ones identified in the other sectors from the literature review. Results indicate that heart-rate measurements, eye tracking techniques, and speech recognition are used for monitoring workload, drowsiness/fatigue, stress, and situational awareness in the aviation sector. However, a complementary use of unobtrusive sensors seems necessary to enhance the reliability of monitoring. Proactive treatments such as taking a nap, caffeine intake, proper sleep environment, sufficient hours of uninterrupted sleep per night, consecutive nights recovery sleep are used for monitoring the operator's fatigue, sleepiness, and situational awareness in the maritime sector. Furthermore, in-cabin collision alert systems and blue light exposure are used as real-time interventions in this sector. None of the rail, aviation, or maritime sectors make use of systematic post-trip interventions to achieve a sustainable behavioural change over time.

Keywords: transport risk; monitoring operator; human factors; rail, aviation, maritime.

1 Introduction

Transport accidents induce a high cost; there is immediate cost at the point of accident, but also longer term impact such as through serious injury. Within road transport, for example, serious injuries as a result of crashes result in an average of 3.2 years lived with disability (*1*). Therefore, managing transport risk to reduce accidents will have individual and socioeconomic benefits. Human factors and operator's behaviour contribute towards many accidents in various transport sectors (road, rail, aviation and maritime). Previous research has shown that human factors contribute to about 95% of roadway accidents, and are the preliminary contributing factors in about 65% of these accidents (Treat et al., 1979). Within aviation, there are fewer overall accidents compared with road, however, when aviation accidents occur consequences are often severe. Despite the introduction of automation it has been estimated that approximately 75% of aircraft accidents have some human cause (*2*). Within maritime, there is a similar figure of 60% of shipping accidents being due to human error (*3*). The rail industry too is subject to human errors which can lead to accidents, however, it is acknowledged that the degree to which error leads to accidents depends on the tools used to assess the accident (*4*). Although all transport modes rely on human engagement, the risk for accident differs, in part due to time pressure; rail and road have shorter time windows for human response than aviation and maritime (*5*). These findings indicate that identifying human factors associated with increased risk, monitoring operators, and applying remedial interventions, are paramount in reducing risk across transport entities.

In seeking methods to manage the relevant human factors as contributors to accidents, it is necessary to also consider the system in which the human is operating. Management approaches should improve the operational environment so that the chance of a human factors error occurring is reduced (*6*). Monitoring techniques are an important component with the potential to reduce transport risk. However, such approaches may fail to reach there expected benefit if they are not implemented within an open culture. Professional operators are often wary of monitoring and may perceive it as a threat (*7*). Ultimately monitoring will be most effective if coupled with intervention strategies; for drivers and operators to engage with the intervention, they must trust the monitoring system.

Advanced operator assistance systems are common real-time monitoring and intervention technologies that aim to remediate human error and minimise the consequences of such errors. These aim to intervene in time to avoid an incident or crash occurring by changing either the behaviour or the operator or the vehicle. They range from warning systems that alert the operator to a hazard, to systems that intervene directly in the vehicle operation task, for example by automatically applying the brakes. A distinction should be made between operator assistance systems and autonomy as operator assistance systems still require the human to be in full control of the vehicle and are designed to assist in an emergency situation, but autonomous systems perform all or part of the dynamic driving task for a sustained period (*8*).

At one end of the spectrum, the of role of an advanced operator assistance system is to 'nudge' the operator into safer behaviour. A behavioural 'nudge' can be defined as a term to describe "deliberate and predictable methods for changing people's behaviour by modifying the cues in the physical and/or social context in which they act" (*9*) - for example a warning system that alerts the operator of a hazard ahead. At the other end of the spectrum, the advanced operator assistance system detects an error has occurred and automatically triggers a system that mitigates the consequences of an error. For example, in the rail mode, trains will automatically apply the brakes and bring the train to a hold if the driver passes a signal at danger (SPAD). For road, rail and maritime the level of intervention is generally limited to a warning or a vehicle-based intervention in response to a specific event/error however in aviation, autonomous systems are used in addition.

Although similar human factors exist in all transport sectors, monitoring operators and applying interventions is more widespread in the road sector. In the rail sector, operator monitoring is implicitly accounted for by the strict timetables and regulations. In addition, the difficulty of installing in-cabin technologies has largely prevented the use of these technologies so far. In the maritime sector, as the relatively low speed and density of maritime traffic leaves quite large reaction time margins for the navigating officers, the emphasis is put on alerting the operator for risks in the environment rather than their own steering behaviour. In the aviation sector, operator monitoring is mostly carried out within standard training, re-training and fitness screening processes by means of medical evaluations, neuropsychological tools, simulator sessions, etc. Meanwhile, automation and other advanced operator technologies are more common in the aviation sector than in other sectors. Overall and to the best of the authors' knowledge, there is no systematic knowledge sharing about operator monitoring and intervention strategies that can provide insight for reducing human factors that are common among all transport sectors.

To address this gap and as the first step to create such a systematic knowledge sharing, this paper aims to investigate the possibility of transferring knowledge about operator monitoring and intervention strategies between different transport sectors, i.e. road, rail, aviation and maritime. This research is carried out within the Horizons 2020 *i*-DREAMS project, which aims to develop novel monitoring and intervention strategies for road driving, in order to keep drivers within a 'safety tolerance zone'. While the transferability of these technologies and methods to other transport modes is not straightforward, the analysis of the current state-of-the-art in all transport modes may reveal opportunities for inter-sectoral knowledge transfer – also in terms of lessons learned from relevant interventions in other transport modes.

2 Methodology

To investigate the transferability of knowledge about operator monitoring and intervention strategies among different transport sectors, it is necessary to first review the most important risk factors that are common among road, rail, aviation, and maritime from the literature. A thorough review of important risk factors and the state of the art monitoring technologies and intervention strategies for the road sector was carried out in the *i*-DREAMS project (a summary of these reviews will be presented later in sections 3.1.1 and 3.2.1). As such, we aim in this study to make a related (although less extensive) review for the other sectors and transfer the findings between all sectors. This section presents the methodology for conducting the literature review for rail, maritime, and aviation transport sectors.

The literature review relating to maritime and aviation was carried out on the 30th and 31st March 2021, and the literature review relating to rail was carried out on the 8th and 9th June 2021, all through Scopus and Google Scholar. The search strategy was based on a combination of search terms in the title, abstract and keyword fields in a structured and iterative manner on the basis of the following general rule:

Rail:
<Train driver> AND <fatigue>, <Train driver> AND <SPAD>, <Train driver> AND <workload>, <Train driver> AND <situation awareness>, <Train driver> AND <distraction>, <Train driver> AND <stress>, <Train driver> AND <pedestrian detection>, <Train driver> AND <emotion>, <Train driver> AND <speeding>, and <Train driver> AND <depression>.

Maritime:
<ship> AND <risk factors>, <maritime> AND <risk factors>, <maritime> AND <safety>, <maritime> AND <fatigue>, <maritime> AND <sleepiness>, <maritime> AND <workload>, <maritime> AND <situation awareness>, <maritime > AND <distraction>, <maritime> AND <stress>, <maritime> AND <closest point of approach>.

Aviation:
<flight> AND <risk factors>, <aviation> AND <risk factors>, <aviation> AND <safety>, <aviation> AND <fatigue>, <aviation> AND <sleepiness>, <aviation> AND <workload>, <aviation> AND <situation awareness>, <aviation> AND <distraction>, <aviation> AND <stress>, <aviation> AND <heart-rate>.

The results of the initial search for rail were quite limited. Any repeated sources were discarded and the resulting list was then checked for relevance, leading to a total of six articles. The results of the initial search for maritime and aviation, on the contrary, were quite high (around 100 articles and reports). However, articles were filtered first by their titles to eliminate irrelevant results for this research. Later, the process of filtering was continued by screening the abstracts of the remaining results. For the relevant literature, full body text was examined. Lastly, references present in the finally selected literature were reviewed and included ('backwards snowballing'). This resulted in 33 articles and reports (21 for aviation, and 12 for maritime).

3 Analysis and Results

The results of the systematic literature review are presented in Table 1. These results are used in this section to investigate the transfer of knowledge between transport sectors from three perspectives: (i) most important risk factors that are common between sectors, (ii) monitoring technologies that are used in each sector, and (iii) intervention strategies that could be implemented in reducing risk in each sector.

Table 1. Risk factors, monitoring technologies, and intervention strategies in rail, maritime, and aviation

Sector	Definition of risk	Risk factor	Technology	Purpose (Monitoring/Intervention)	Study	Finding
Aviation	control errors (e.g., airspeed and altitude deviations)	Fatigue/sleepiness/workload/spatial disorientation/hypoxia/sleep deprivation	Portable and wearable for heart rate (ECG, EEG)	Monitoring	Lehrer et al. (2020); Dehais et al. (2019); Suavet et al. (2014); Majumder et al. (2014); Cardwell (2012)	There are two methods for monitoring pilots' fatigue and situational awareness: (i) ECG and other heart-rate monitoring techniques are considered very reliable for monitoring workload, drowsiness/fatigue and stress, (ii) eye tracking techniques used to monitor fatigue, drowsiness and situational awareness.
			Portable and wearable for brain monitoring	Monitoring	Gateau et al. (2018);	
			Eye tracking tech and oculometer	Monitoring	Peissl et al. (2018); Thatcher & Kilingaru (2012); Lounis et al. (2020)	
			Short-acting hypnotics, caffeinated gum, Controlled in-flight rest breaks	In-cabine treatments	Cardwell (2012)	
		Stress	Chest strap sensor and voice recognition	Monitoring	Socha et al. (2016); Luig and Sontacchi (2014)	Speech recognition is used for monitoring stress. A complementary use of unobtrusive sensors would enhance the reliability of monitoring.
		Risk perception	Survey after simulator	Post-trip feedback	Molesworth et al. (2006)	Pilots' feedback on minimum altitude and their perception of risk were evaluated. Post-trip feedback was not that effective mostly because the feedback is helpful when it is in the temporal proximity of the behaviour.
		Situation awareness	Eye tracking	Real-time warning / alert	Chiara et al. (2019); Muehlethaler et al. (2016)	Real-time alerts and warnings improve situation awareness among pilots.
			In-cab display (simulator)	Real-time warning / alert	Sandys et al. 1997; Feary 2005; Creissac Campos and Harrison 2008; Pizziol et al. (2014)	
			Tactile and auditory warnings	Real-time warning / alert	Sklar et al. (1999)	Both tactile conditions resulted in higher detection rates for, and faster response times to, uncommanded mode transitions.
			Post-trip training	Post-trip feedback	Cowings et al. (2009)	Post-trip treatment and training is effective and can improve flying behaviour.

Table 1 – CNTD: Risk factors, monitoring technologies, and intervention strategies in rail, maritime, and aviation

Sector	Definition of risk	Risk factor	Technology	Purpose (Monitoring/Intervention)	Study	Finding
Maritime	Distance Closest Point of Approach (DCPA)	Equipment	Cabin monitoring system	Monitoring	Feng et al. (2020)	Real-time alerts are helpful in reducing the secondary risk of the equipment in the cabin.
		Fatigue/sleepiness/sleep deprivation	Blue light expsoure, caffeinated drinks and naps	In-cabin proactive and reactive treatment	Jepsen et al. (2015) Starren, van Hooff et al. 2008; Anund et al. (2015) Grech (2016)	The treatments are effective in supporting the long hours of work and rest requirements.
		Tailgating/overtaking/speed/distance	Collision alert system	Real-time warning / alert	Goerlandt et al. (2015); Zhang et al. (2015); Yamin et al. (2020); Wang et al. (2017); Wu et al. (2019)	The alert systems are effective in reducing the risk based on speed, proximity, and collision course in various scenarios like overtaking, crossing, etc.
		Situation awareness	Visualization software display / real-time alerts	Monitoring & real-time warning / alert	Riveiro et al. (2008); Rhodes et al. (2005)	The visualization tool can help decrease the discrepancy between the perception of environmental elements with respect to time and/or space, the comprehension of their meaning, and the projection of their status after some variable has changed, such as time.

Table 1 – CNTD: Risk factors, monitoring technologies, and intervention strategies in rail, maritime, and aviation

Sector	Definition of risk	Risk factor	Technology	Purpose (Monitoring/Intervention)	Study	Finding
Rail	SPAD (Signal Passed at Danger)	Fatigue/sleepiness/workload	In-cab DAS (Driver Advisory Systems)	Real-time warning/alert	Large et al. 2014	DAS potentially requires additional, possibly conflicting, control actions in addition to those required by speed and signals, and therefore must involve extra physical and cognitive effort. There may be additional benefits that are realised, such as enhancing driver arousal and keeping them in-the-loop.
			Wireless Wearable EEG	Real-time warning/alert	Zhang et al. 2017	A fatigue detection system for high-speed trains based on the driver's vigilance using wireless wearable EEG (around the head) is a valid proposition.
			Heart Rate and Galvanic Skin Response	Real-time warning/alert	Crowley & Balfe 2018	None of the workload measures (task load, subjective, or physiological) was sufficient on its own to measure driver workload, but each has its own strengths and applications.
		Stress/illness	Multimedia	Monitoring	van Vark et al. 1995	Automated stress assessment system was applied to professionals such as air traffic controllers and train drivers. The model consists of several subsystems each of which is based on one medium only and is designed to derive hypotheses about the amount of stress based on that particular medium. Most of the research relates to 'person under the train' incidents.
		Situation awareness/pedestrian detection	PDAs providing DAS	Real-time warning/alert	Tschirner et al. 2013	Of the three DAS considered, none creates comprehensive SA of the current traffic situation. The research shows that drivers have strong interest in the surrounding traffic, need up to date information about the traffic plan, and have valuable information that could improve operative planning. DAS which implements the concepts listed could significantly improve train drivers' SA of current traffic situation and planning.
			In-cab display	Real-time warning/alert	Young & Grenier 2012	New technologies such as ERTMS suggest that the information needs of the future train driver will have a more significant impact upon situation awareness (SA) and performance. Anticipates the cognitive issues faced by future train drivers and posits a new model of display design to support performance. Puts forward field and simulator trials to test and validate the designs.

3.1 Most important risk factors

3.1.1 Road

The definition of risk on the road is typically based on the number of crashes that occur, in terms of frequency or probability (e,g, rate of number of accidents per amount of traffic exposure). However, crash data are not always available or sufficient to proactively identify risk, therefore a family of other metrics and indicators is often used, namely surrogate measures of safety. These may include indicators such as headways, time-to-collision, harsh accelerations or braking etc., which in many cases correlate very well with actual crashes. Risk factors on the road sector include a broad range of vehicle, environment and human factors. Driver behaviour factors in particular receive a lot of attention, because the majority of road drivers are not professional drivers and may exhibit a variety of risk factors, with most prominent ones being speeding, alcohol impairment, mobile phone distraction, but also age and inexperience. The i-Dreams project has identified the following risk factors (safety goals) as factors to be tackled with priority by means of driver monitoring and intervention: speeding, tailgating, illegal overtaking, pedestrian collision, fatigue and sleepiness, distraction and harsh acceleration/deceleration.

3.1.2 Rail

Collisions are very rare for rail where traffic (particularly in the case of trains) is largely controlled by the use of signals across the network. As a result, the definition of risk for this literature review was the train driver experiencing a SPAD (Signal Passed at Danger); this is where a train passes a stop signal when not permitted to do so, which is a potential precursor to an accident on the railway. The risk factors which were identified for the rail context due to their potential for leading to a SPAD were fatigue, sleepiness and workload; stress and illness; and situation awareness and pedestrian detection. The importance of avoiding train drivers becoming sleepy or fatigued is clear, since they are driving on a daily basis in large vehicles with many passengers. Issues related to fatigue, sleepiness and workload were considered together due to their connections (e.g. a high workload may contribute to the development of fatigue and illness whilst low workload may also be linked to fatigue and error rates) (*10–12*). Stress and illness are similarly linked to the previous risk factors and attempts have been made to monitor these (*13*). Situation awareness and pedestrian detection are important in train driving with events around the train and relating to the remainder of the network of particular importance (*14*). Increasing use of technology in train cabs has led to concerns around its effects on the situation awareness of drivers (*15*).

3.1.3 Maritime

In the maritime sector, risk is commonly defined based on the concept of the Distance to Closest Point of Approach (DCPA) which is analogous to the time to collision approach (TTC) in the road sector. DCPA is defined as the closest distance of two encountered ships or one ship and one object passing by according to the current state of navigation (*16*). Based on this definition, many risk factors have been identified in this sector including fatigue, sleepiness, tailgating, overtaking, speed and situational awareness. Fatigue is one of the most important risk factors which is related to spending very long periods of time at sea and can have serious consequences bearing in mind that heavy vehicles and vessels carry passengers and dangerous cargo (*17*). Sleepiness, on the other hand, is related to lack of sleep due to shift work and is common in the maritime sector because maritime working hours occur during night time. In addition, tailgating and overtaking are common among ships (*18*) and resemble the traffic conflicts in the road sector (*19*). Finally, situational awareness –the constant updated situational picture about the observed maritime environment or set of entities to the operator, has been shown to be a critical risk factor is this sector (*20*).

3.1.4 Aviation

In the aviation sector, risk has been mostly defined in terms of the control errors related to the ability of maintaining the dynamics of flight (e.g., airspeed and altitude deviations) (*21*). With this definition, many studies have shown that fatigue, spatial disorientation, hypoxia, and sleepiness are among the most important risk factors in this transport sector (*22*)(*23*)(*24*). Aviation fatigue (also referred to as cognitive fatigue in aviation) is mostly caused by workload as a consequence of excessive flying task demand under high pressure or over prolonged period of time. Spatial disorientation is the inability of the brain to keep the body's position relative to the earth's position and hypoxia is oxygen deficiency in the body. These two factors are common among pilots and astronauts. Sleepiness is mostly caused by sleep deprivation and \ or circadian time of the body among flight crew. A few studies have shown that stress and risk perception are also among other important risk factors in the aviation sector (*25*). These studies have shown that pilots' stress in the cockpit can influence their speech and communication during the flight which in turn can increase the risk of losing control. Last but not the least, situational awareness has been constantly shown to be an important risk factor in aviation too (*26*, *27*). This risk factor is related to the distinction between understanding of flight status and actual flight status, and results from failure to correctly perceive information, failure to comprehend the situation, or failure to project situation into future status (*28*).

3.2 Monitoring technologies and intervention strategies

3.2.1 Road

Despite the progress in developing advanced operator (driver) assistance systems, the monitoring of several driver factors is not sufficiently tacked by existing technologies. While speeding, lane departure warning and tailgating are addressed by several in-vehicle systems (e.g. intelligent speed assistance, lane departure warnings, forward collision warnings), these technologies do not offer individualised support and feedback to the drivers. Several systems (e.g. Mobileye) offer headway monitoring and pedestrian detection and collision avoidance warnings. On the other hand, driver state factors such as fatigue, sleepiness and distraction / inattention have received less attention in the development of technologies, especially for non-professional drivers. The most common ways of monitoring these are eye-tracking technologies, which analyse the gazing and blinking behaviour of drivers through cameras or eye glasses. Fatigue and sleepiness may also be yielded by means of physiological indicators (e.g. heart rate) (29). Distraction by mobile phone can be detected through dedicated telematics applications analysing the movement of the device itself.

There are several emotions categories (e.g. anger, stress, fear/anxiety) that have been analysed in previous studies – although no systematic monitoring of these takes place in practice. These are mostly monitored by means of electrodermal activity and cardiac measurement, such as electrocardiogram, heart rate or heart rate variability. These physiological indicators can be measured in a completely unobtrusive way, by means of recent technologies such as steer-wheel covers or wearables (e.g. smartwatches). For a full review of driver monitoring technologies of these risk factors, the reader is referred to (23) and (24). While monitoring drivers can change their behaviour if they know they are monitored (40), it can have adverse effects on their behaviour too. Previous studies have shown that there are several limitations related to monitoring drivers such as increased complexity of the monitoring devices, distraction (41).

Real-time warnings, apart from those issued by commercial advanced operator (driver) assistance systems mentioned above, are not common for the driver state risk factors. An emerging field, however, is post-trip interventions in the form of individual driver star rating, personalised feedback and coaching through smartphone or web-based applications.

3.2.2 Rail

Fatigue, sleepiness and workload in train drivers have been monitored using wireless wearables, heart rate and Galvanic skin response. In addition, in-cab Driver Advisory Systems (DAS) have been investigated in relation to both fatigue and situation awareness, in the latter case in the context of the potential future dominance of new technologies such as ERTMS (European Rail Traffic Management System) which rely on situation awareness and the appropriate display designs. A multimedia assessment system for stress and illness has also been investigated and found to be transferable to other industries such as air traffic control.

For train and tram drivers, real-time warnings and alerts are key to fatigue detection and also to situation awareness. Keeping drivers informed about the traffic around them is of significance and helps them to drive effectively. Mixing and augmenting strategies may also be of benefit in the rail context.

3.2.3 Maritime

Monitoring technologies in the maritime sector have mostly dealt with tailgating, overtaking, speed and situational awareness. Collision alert systems are among the common technologies in this sector to first monitor the navigation performance of the crew (in terms of speed, proximity, and collision course in various scenarios) and then provide relevant warnings to the crew (*32–34*)(*18*). Visualization software displays and real-time alerts have been used to monitor and increase the crew's situational awareness (*35*, *36*). These technologies aim to decrease the discrepancy between the perception of environmental elements with respect to time and/or space, the comprehension of their meaning, and the projection of their status after some variable has changed, such as time. Additional in-cabin monitoring has also been used to keep track of the technical equipment in the cabin that could be a secondary risk to the crew (*37*). Such technologies, however, are not in the scope of this study.

Surprisingly, no monitoring approach has been used in the maritime sector for fatigue and sleepiness. Instead, proactive and reactive in-cabin treatments have been commonly used to treat fatigue and sleepiness. These treatments which may include blue light exposure to the crew in the cabin (*38*) caffeinated drinks, and naps (*39*), aim to support the ship crew in long hours of work and their rest requirements.

3.2.4 Aviation

Heart-rate measurements, eye tracking techniques, and speech recognition are used for monitoring workload, drowsiness/fatigue, stress, and situational awareness in the aviation sector. However, a complementary use of unobtrusive sensors seems necessary to enhance the reliability of monitoring. Proactive treatments such as taking a nap, caffeine intake, proper sleep environment, sufficient hours of uninterrupted sleep per night, consecutive nights recovery sleep are used for monitoring the operator's fatigue, sleepiness, and situational awareness in the maritime sector. Furthermore, in-cabin collision alert systems and blue light exposure are used as real-time interventions in this sector.

4 Conclusions

The comparison between risk factors across different transport sectors show that many risk factors are common among these sectors. Yet, there is no systematic way of dealing with these risk factors. This highlights the gap between the road sector and the other three transport sectors, and identifies the potential benefits that could be gained from transferring knowledge between these sectors. In the first step of addressing this gap, this study first reviewed the most important risk factors in rail, aviation, and maritime sectors from the literature. The iDREAMS naturalistic driving study was then selected as the case study from the road sector and the risk factors, monitoring technologies and intervention strategies were reviewed and compared with the ones identified in the other sectors from the literature review.

Our findings indicated that heart-rate measurements, eye tracking techniques, and speech recognition are used for monitoring workload, drowsiness/fatigue, stress, and situational awareness in the aviation sector. However, a complementary use of unobtrusive sensors seems necessary to enhance the reliability of monitoring. Proactive treatments such as taking a nap, caffeine intake, proper sleep environment, sufficient hours of uninterrupted sleep per night, consecutive nights recovery sleep are used for monitoring the operator's fatigue, sleepiness, and situational awareness in the maritime sector. Furthermore, in-cabin collision alert systems and blue light exposure are used as real-time interventions in this sector.

While the road sector has been investigating systematic post-trip interventions (in the form of providing feedback about driving behaviour and giving scores to drivers in gamified platforms) to achieve a sustainable behavioural change over time, none of the rail, aviation, or maritime sectors make use of such post-trip interventions. Our literature review in the aviation sector, however, indicated that the potential effectiveness of such post-trip treatment when it is in the temporal proximity of the behaviour, has been recognized in this sector. Future research should be dedicated to investigating the sustainable effects of these treatments on human factors in all sectors.

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