Outcome Evaluation of i-DREAMS (H2020 Project) Interventions: Multi-country Comparison of Driving Behavior

Muhammad Adnan[1](✉), Kris Brijs[1], Muhammad Wisal Khattak[1], Laurie Brown[2], Rachel Talbot[2], Christelle Al Haddad[3], Constantinos Antoniou[3], Virginia Petraki[4], George Yannis[4], and Tom Brijs[1]

[1] UHasselt, Transportation Research Institute (IMOB), Martelarenlaan 42, 3500 Hasselt, Belgium
muhammad.adnan@uhasselt.be

[2] Transport Safety Research Centre, School of Design and Creative Arts, Loughborough University, Loughborough LE11 3TU, UK

[3] Chair of Transportation Systems Engineering, Technical University of Munich, Arcisstrasse 21, 80333 Munich, Germany

[4] Department of Transport Planning and Engineering, National Technical University of Athens, 5 Heroon Polytechniou Street, 15773 Athens, Greece

Abstract. The i-DREAMS project introduced the concept of a 'Safety Tolerance Zone,' i.e., a context-aware safety envelope designed to assist drivers. Using an ecosystem of sensors, i-DREAMS technology monitors factors that determine driving task complexity and coping capacity and calculates risk levels. Real-time and post-trip interventions are tailored to keep drivers from unsafe driving. Real-time interventions are provided via in-vehicle display, while post-trip interventions are delivered via a smartphone app with gamification provisions. This study focuses on the effectiveness (i.e., outcome evaluation) of real-time and post-trip interventions that involve 4 phases, including the baseline measurement phase.

The paper presents a comparative analysis using the data collected from car drivers from three countries: Belgium (n = 48), the UK (n = 49), and Germany (n = 25). Overall, drivers showed a reduction in events per 100 km after exposure to the i-DREAMS technology. So, there was an improved safety outcome. However, differences were found between the countries analyzed. The highest number of events per 100 km was noted for UK drivers, with the reduction pattern consistent across 4 phases. The interventions were more promising for 'road sharing' and 'speeding' events for Belgian and German drivers. Driver-level analysis revealed that two-thirds of drivers in each country showed a consistent decrease in events/100 km.

Keywords: i-DREAMS · Safety Tolerance Zone · Outcome evaluation · naturalistic driving data · multi-country comparison

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1 Introduction

In the era of digitization, rapid steps in transport automation bring new challenging conditions, transforming the framework of operator/vehicle/environment interactions and the need for an increased understanding of the human factors affecting the behavior of operators/drivers. Simultaneously, technological advancements make vast and in-depth operator performance data easily accessible (e.g., new in-vehicle sensors that record precise driving behavior and contextual data, increased driver adoption and usage of information technologies, Internet of Things). This opens up new possibilities for detecting and designing tailored interventions to continuously and dynamically reduce hazards, raise awareness, and improve performance [1–3]. Two viewpoints for safety management (i.e., local and general) were offered by [3]. The local or "in real-time" perspective denotes a closed-loop procedure of sampling, evaluating, and responding to actual occurrences. The 'generic' perspective is founded on the holistic notion that a driver's response in a real-world scenario depends on variables that are more constant over time (such as personality, driving experience, safety attitudes, etc.). The i-DREAMS project introduced the 'Safety Tolerance Zone' (STZ) concept, a context-aware safety envelope designed to prevent drivers from getting too close to the boundaries of unsafe driving via both real-time and post-trip interventions. The formal working definition of STZ adopted within i-DREAMS is as follows: **"the time/distance available [for vehicle operators] to implement corrective actions safely [in the potential course towards a crash]"** [4, 5]. In-vehicle interventions inform or warn drivers in real-time (nudging), and post-trip interventions inform them after driving through an app-based (and web-based) gamified coaching platform to improve driving behavior (boosting).

This paper addresses the effectiveness (i.e., outcome evaluation) of real-time and post-trip interventions developed within the i-DREAMS project. Moreover, this study presents a comparative analysis of the intervention effectiveness based on the on-field trials conducted in the UK, Belgium, and Germany.

2 Methods

Part of the i-DREAMS project was a longitudinal field operational test conducted in a real-world setting, comprising four phases, as given in Table 1. The participants for the field trials were selected based on several inclusion criteria to ensure a diverse and representative group. These criteria included factors like driving experience, road exposure, age (minimum 18 years), balanced representation of gender, vehicle type (to accommodate the i-Dreams technology), smartphone usage, multi-driver access (i.e., one vehicle, many drivers), etc. To ascertain effective participation, an incentive of 250€ was paid to each driver incrementally during the data collection. More information on the experimental protocol can be found in [6]. The naturalistic driving data collected in i-DREAMS concerns various data about safety promoting goals (SPG) and performance objectives (PO). Table 2 defines these SPGs and POs and their inter-relationship.

According to the STZ, a driver can be in three different stages: 1) Normal Driving, 2) Danger (medium severity level), and 3) Avoidable Accident (high severity level). No real-time interventions are necessary if a driver is within the first stage (i.e., normal

Table 1. Phases and their definitions

Phase	Definition
1	*The baseline Phase* corresponds to the initial monitoring period after the installation of i-DREAMS technology when interventions were not active) – Duration: 4 weeks
2	Phase 2 corresponds to the monitoring period when only real-time interventions were active within a vehicle- Duration: 4 weeks.
3	Phase 3 corresponds to the monitoring period when in-vehicle real-time interventions were active, and drivers also received feedback (scores and events per trip) on their driving performance through the app; duration: 4 weeks.
4	Phase 4 corresponds to the monitoring period when in-vehicle real-time interventions were active along with feedback, but at the same time, gamification elements were also active. Duration: 6 weeks

Table 2. SPG and PO and their inter-relationship.

Safety Promoting Goals (SPG)	Performance Objectives (PO)
Vehicle Control	Acceleration, Deceleration, Steering control
Speed Management	Speed
Road Sharing	Headway, Illegal Overtaking, Lane Discipline, Forward Collision Warning, and Pedestrian Collision Warning
Driver Fitness	Fatigue and handheld mobile phone use (during driving)

driving). On the contrary, an alert is offered if a driver is within the stage of danger. In contrast, in the avoidable accident stage, an intrusive warning signal (either or not accompanied by an instruction) is offered. The device developed in i-DREAMS issues warnings on the following risk indicators: Headway, Speed, Fatigue, illegal overtaking, Lane departure, and Pedestrian collision [7]. Within post-trip interventions, more details are given to the driver with the help of a smartphone application [8]. This smartphone application features general driving performance scores and gamification elements like a leaderboard, goals, and pros and cons for certain driving behaviors. Data used for this study comes from 48 Belgian, 49 UK, and 25 German car drivers and covers around 4.5 months. The analysis is based on determining changes in a number of normalized events (i.e., events/100 km) for the two highest risk stages of STZ (i.e., danger stage and avoidable accident risk stage). The analysis method includes comparison using descriptive statistics and standard statistical tests (repeated measures ANOVA (in case the data is normally distributed), and an equivalent non-parametric test is used (such as the Friedman test)). Results of the Generalized Linear Mixed Model (GLMM) estimated for total events/100 km are also provided. Additionally, individual driver-level analysis is performed to investigate the differences which are not detectable in group-level analysis.

3 Results

Table 3 provides the general idea of the effectiveness of the interventions as total events/100 km occurred in danger and avoidable accident stages are indicated along with the standard deviation. UK drivers generate more events/100 km, with a consistent reduction pattern compared to other countries. This is mainly due to higher urban trips that may have resulted in higher vehicle interactions.

Table 3. Total events/100 km concerning intervention phases

Phase	Belgium (n = 48)		UK (n = 49)		Germany (n = 25)	
	Events/100 km	St. Deviation	Events/100 km	Std. Deviation	Events/100 km	St. Deviation
1	180.8	94.5	275.3	249.6	152.2	153.7
2	185.7	97.5	261.3	223.8	151.0	114.7
3	188.0	107.0	251.0	225.2	137.3	123.6
4	177.2	105.6	240.7	219.2	149.6	126.2

Table 4 provided the events/100 km for each phase for each SPG (especially Vehicle Control (VC), Road Sharing (RS), and Speed Management(S)). Driver fitness-related events/100 km were relatively lower compared to other SPGs. The UK's statistical test results show improved behavior in almost all SPGs, with Belgian drivers showing better results for RS-type events. For German drivers, results do not seem promising. However, it was noted that German drivers' speeding events/100 km belonging to the avoidable accident stage decreased consistently, which is statistically significant.

Additional statistical analysis was carried out on the combined countries' data (BE, GER, and UK) using GLMM analysis, as this allows for the analysis of data when (a) random effects are present (e.g., the case of repeated responses from study subjects/participants or multi-level data structure), and (b) it has a non-normal distribution. Negative binomial (NB) GLMM was applied to the data since the independent variable (events per 100 km) is a count variable exhibiting overdispersion. Table 5 provides the results of the GLMM, where total events/100 km, only danger STZ, and only avoidable accidents STZ) are considered as the dependent variable. Phase (Phase 1 as reference) and Country (BE as reference) are considered independent variables.

For the combined case of 'total' events, the expected log count of events per 100 km decreases from Phase 1 (baseline) to each of Phase 2, Phase 3, and Phase 4 (indicated by the -ve sign of the estimates). The country variable estimate suggests there were more events in the UK compared to Belgium for all cases. The variance between drivers was found to be more for avoidable accidents than for the danger stage. Because of the large variance in the data, it is useful to analyze differences between drivers. The average number of total events per phase was calculated for each driver, and drivers who showed overall improvement from Phase 1 to Phase 4 are labeled as Type A, and other drivers are labeled as Type B. For Belgium and Germany, around two-thirds of

Table 4. Events/100 km concerning intervention phases

SPG	Phase	Belgium (n=48)		UK (n=49)		Germany (n=25)	
		Events/100 km	test Significance	Events/100 km	test Significance	Events/100km	test Significance
VC	1	101.5	0.070	136.7	0.060	96.8	0.691
	2	107.9		131.7		94.1	
	3	109.9		130.7		89.5	
	4	102.7		130.6		97.3	
RS	1	65.4	0.017	119.7	<0.001	N/A	
	2	62.3		113.8			
	3	61.8		106.0			
	4	59.4		96.2			
S	1	13.9	0.122	18.8	<0.001	55.8	0.218
	2	15.5		15.8		56.8	
	3	16.2		14.3		47.9	
	4	15.1		13.9		52.3	

Table 5. GLMM estimation results

Fixed Effects	Combined (danger + Avoidable accidents)		Avoidable accidents STZ		Danger STZ	
	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	5.114	<0.001	3.652	<0.001	4.835	<0.001
Phase 2	-0.026	0.277	-0.055	0.064	-0.019	0.433
Phase 3	-0.071	0.003	-0.140	<0.001	-0.045	0.072
Phase 4	-0.116	<0.001	-0.195	<0.001	-0.088	<0.001
GER	-0.316	0.020	0.058	0.725	-0.457	0.001
UK	0.234	0.039	0.140	0.308	0.264	0.002
Random Effects: Variance User_ID	0.281		0.445		0.294	

drivers showed improved outcomes after exposure to the technology, but in the UK, this figure increased to three quarters (see Table 6). Type A and Type B drivers were further analyzed regarding demographic and other characteristics; in all three countries, Type B drivers were more confident.

Table 6. Drivers type and summary statistics

Country	Type A (Events/100 km Decreased)		Type B (Events/100 km Increased)	
	No. of Drivers	Percentage Decrease	No. of Drivers	Percentage Increase
BE	31 (65%)	−17.0%	17 (35%)	26.1%
UK	37 (76%)	−23.5%	12 (24%)	10.8%
GER	16 (64%)	−26.4%	9 (36%)	22.2%

4 Discussion and Conclusion

When data was combined for Belgium, Germany, and the UK, events decreased statistically significantly from Phase 1 to Phase 4. This was for both medium and high severities, for 'total,' 'vehicle control,' 'speeding,' and 'road sharing' events. This suggests that the i-DREAMS system positively impacted the measured safety outcomes and kept drivers in the first level of the STZ for more of their journey. The most significant results from Phase 3 to Phase 4 were seen in the combined data. This suggests that adding the gamification elements significantly impacted safety outcomes and supports the conclusion that the system provides the most effective results. Looking at the different safety-promoting goals, the interventions appeared to have the most significant and consistent impact on 'road sharing' events. However, these data were only available for Belgium and the UK, so it would be helpful to collect further data for other countries to support this finding. 'Vehicle control' events were least significantly impacted, which could be because there are no real-time warnings about this SPG. There were little demographic differences between the two types of drivers, and where there were differences, they generally were inconsistent across countries. There is some data to suggest the drivers who worsened were more confident than those who improved, so it is possible they had less desire to change their behavior, though this cannot be concluded. Further work is needed to understand why the system has varied effects on drivers.

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