Outcome Evaluation of i-DREAMS (H2020 Project) Interventions: Multi-Country Comparison of Driving Behvavior

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Abstract. The i-DREAMS project introduced the concept of a 'Safety Tolerance Zone', i.e., a context-aware safety envelope designed to assist drivers in maintaining self-regulated control within the boundaries of safe operations. Using an ecosystem of sensors, i-DREAMS technology continuously monitors factors determining driving task complexity and available coping capacity and calculates risk levels in real-time. Based on this information, both real-time and post-trip interventions are tailored to keep drivers from getting too close to the boundaries of unsafe driving. Real-time interventions are provided via in-vehicle display, while post-trip interventions are delivered via a smartphone app (and web-dashboard) with provisions for gamification. This study focuses on effectiveness (i.e. outcome evaluation) of real-time and post-trip interventions that involves 4 phases including the base line measurement phase.

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

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

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 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 the detection and design of 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).

2 Objectives

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

3 Methods

Part of the i-DREAMS project was a longitudinal field operational test conducted in a real-world setting, comprising four phases: phase 1: Baseline measurement with no intervention (4 weeks), phase 2: real-time intervention only (4 weeks), phase 3: real-time intervention + post-trip feedback (4 weeks), and phase 4: real-time intervention and post-trip feedback + gamification (6 weeks). The participants 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. The naturalistic driving data collected in i-DREAMS concerns a variety of data about safety promoting goals (SPG) and performance objectives (PO). Table 1 defines these SPGs and POs and their inter-relationship.

Table 1. 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)

According to the STZ, a driver can be in three different stages: 1) Normal Driving, 2) Danger (medium severity level) , 3) Avoidable Accident (high severity level). In case a driver is within the first stage (i.e. normal driving), no real-time interventions are necessary. On the contrary, in case a driver is within the stage of danger, an alert is offered, while in the case of 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, i.e. Headway, Speed, Fatigue, illegal overtaking, Lane departure and Pedestrian collision[6]. Within post-trip interventions, signals are given to the driver after driving, with the help of a smartphone application[7]. This smartphone application has two major elements: general scores based on driving performance (Overall and specific to each SPG), and gamification elements (e.g. leaderboard, goals, pros and cons for certain driving behavior). Data used for this study comes from 48 Belgium, 49 UK, and 25 German car drivers and covers around 4.5 months (i.e. comprising all 4 phases of interventions). The analysis is based on determining changes in number of normalized events (i.e. events/100km) 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 if the data is normally distributed), otherwise equivalent non-parametric test is used (such as Friedman test)). We also presented results of the Generalized Linear Mixed Model (GLMM) estimated for total events/100km. Additionally, individual driver level analysis is performed to investigate the differences which are not detectable in group level analysis.

4 Results

Table 2 provides the general idea of effectiveness of the interventions as total events/100km occurred in danger and avoidable accident stages are indicated along with the standard deviation. It is very clear that UK drivers generated more events/100 km, however, their reduction pattern is consistent over the subsequent intervention phases compared to the other two countries. Upon further investigation it was also revealed that the higher number of events for UK drivers is mainly attributed to the higher number of trips in urban areas, which means higher interactions with other vehicles.

Table 2. Total events/100km with respect to intervention phases

Phase	Belgium (n=48)		UK (n=49)		Germany (n=25)	
	Events/100km*	St. Deviation	Events/100km	Std. Deviation	Events/100km	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

*Events/100km are mentioned as total events occurred for all risk indicators (POs) in danger and avoidable accidents stages of STZ

Table 3 provided the events/100km for each phase for each SPG (especially Vehicle Control (VC), Road Sharing (RS) and Speed Management(S)). Driver fitness related events/100km were quite lower compared to other SPGs. Results from the statistical test (i.e. test significance) are also provided, which indicate that UK drivers show improved behavior in almost all SPGs and for Belgium drivers better results were only noted for RS type events. For German drivers, at this level results seems not promising. However, we have further separated these events for danger and avoidable accident stages of STZ. It has been noted that German drivers speeding events/100km belonging to avoidable accident stage was decreased consistently and that decrease is also statistically significant. These results indicated that i-DREAMS interventions were effective not for all SPGs but for specific SPGs.

Table 3. Events/100km with respect to 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	

*Events/100km are mentioned as events occurred for all risk indicators (POs in specific SPG) in danger and avoidable accidents stages of STZ

Additional statistical analysis was carried out on the combined countries data (BE, GER and UK), to determine significant differences between Phases, and also between countries. GLMM analysis was used, 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. We applied negative binomial (NB) GLMM to the data, since our independent variable (events per 100km) is a count variable, and it exhibits overdispersion. Table 4 provides the results of the GLMM, where total events/100km (danger and avoidable accident stages of STZ, only danger STZ and only avoidable accidents STZ) is considered as dependent variable. Phase (Phase 1 as reference) and Country (BE as reference) are considered as independent variable.

Table 4. 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	

For combined case of 'total' events, the expected log count of events per 100km 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 indicates there were more events in the UK compared to Belgium for all cases. Variance between drivers was found more for avoidable accident stage than 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 labelled as Type A (i.e. outcome is improved) and other drivers are labelled as Type B (outcome did not improve). The results are given in Table 5. For Belgium and Germany, around two thirds of drivers showed improved outcomes after exposure to the technology, but in the UK this figure increased to three quarters. Type A and Type B drivers are further analyzed in relation to several demographic and other characteristics, in all three countries Type B drivers were found more confident.

Table 5. Drivers type and summary statistics

Country	Type A (Events/100km Decreased)		Type B (Events/100km 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%

5 Discussion & Conclusion

When data is combined for Belgium, Germany and the UK, who experienced the full system, there was a statistically significant decrease in events 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 had a positive impact on the measured safety outcomes and succeeded in keeping drivers in the first level of the STZ for more of their journey. For the combined data the most significant results were seen from Phase 3 to Phase 4. This suggests that the addition of the gamification elements had a significant impact on safety outcomes, and further supports the conclusion that the full system provides the most effective results. Looking at the different safety promoting goals, the interventions appeared to have the greatest and most consistent impact on ‘road sharing’ events. However, these data were only available for Belgium and the UK, so it would be useful to collect further data for other countries to support this finding. ‘Vehicle control’ events were least significantly impacted, which could be due to the fact that there are no real-time warnings in relation to this SPG. The UK drivers had the largest number of events; therefore, one suggestion could be that the technology has the greatest impact on more ‘risky’ drivers. There were little demographic differences between the two types of drivers, and where there were differences, they generally were not consistent across countries. There is some data to suggest the drivers who worsened were more confident relative to the drivers who improved, so it is possible they had less desire to change their behavior, though this cannot be concluded for sure. Further work is needed to understand why the system has such varied effects on different drivers.

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