Do drivers self-regulate their engagement in secondary tasks at intersections? An examination based on naturalistic driving data

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Abstract: Using naturalistic driving data, this study explored the prevalence of engagement in secondary tasks whilst driving through intersections, and investigated whether drivers manage and self-regulate such behaviour in response to variations in roadway and environmental conditions. Video recordings of in-vehicle and external scenes were coded for precisely defined categories of secondary tasks and related contextual variables. The findings indicated that nearly one-quarter of the total driving time at intersections was spent on secondary activities and that lower engagement occurred within intersections compared to phases immediately upstream or downstream. Drivers were less likely to occupy themselves with secondary tasks when their vehicles were moving than when they were stationary. Elderly drivers showed less inclination to perform secondary tasks than did younger drivers. Lastly, drivers tended to perform secondary tasks less frequently at intersections managed by traffic signs than those controlled by traffic lights, when they did not have priority compared to when they had priority, and in adverse weather conditions compared to fine weather conditions. In conclusion, drivers appeared to self-regulate secondary task engagement in response to roadway and environmental conditions. Specifically, they exercised self-regulation by reducing their secondary task engagement when the driving task was more challenging. The findings from this study provide preliminary evidence for targeting the education and training of drivers and media campaigns related to safe driving strategies and managing distractions.

1. Introduction

Driver distraction occurs when the attention of drivers is diverted away from safety-critical driving activities towards a competing activity (Regan et al., 2011). Such distractions might result in a range of outcomes, from minor errors to more serious safety consequences, if attention is misdirected at some crucial period during driving (Victor et al., 2015; Regan et al., 2009). Driver distraction is widely recognised as a primary traffic safety concern and a leading contributor to road crashes (Dingus et al., 2016; TRL, 2015; Beanland et al., 2013; Kircher, 2007; Stutts et al., 2001; Wang et al., 1996).

The introduction and widespread adoption of in-vehicle and portable technologies has presented drivers with numerous secondary activities that can divert attention from the primary driving task (e.g. mobile phone use)—a development that has directed the spotlight on the issue of driver distraction (e.g. Kircher et al., 2011).

Everyday driver behaviour has been examined using an observational research method known as the Naturalistic Driving Study (NDS), which involves collecting data through unobtrusive recording using equipment installed in vehicles, and refraining from imposing experimental interventions (van Schagen et al., 2011). The NDS methodology has been widely used to study the safety consequences of driver distraction. Many previous NDSs were devoted to estimating the relative risk of a crash or near-crash when drivers perform secondary tasks. For example, US drivers who engaged in secondary activities were exposed to twice the crash risk compared with attentive drivers (Dingus et al., 2016). Determining the relative likelihood of a crash whilst drivers perform secondary activities without considering how drivers self-regulate or manage these activities addresses only part of the safety problem.

In the current study, by contrast, the focus is not towards risk estimation but towards illuminating how drivers self-regulate secondary task engagement (also called behavioural adaptation in road safety research), with attention paid particularly to when drivers choose to execute secondary tasks, what categories of tasks they perform, which drivers engage and whether they make adjustments in response to variations in the demands imposed by the primary driving task (Carsten et al., 2017). Gaining an improved understanding of this self-regulatory behaviour can improve the crash risk evaluation and augment knowledge regarding the safety impacts of driver distraction (Dingus et al., 2011).

Several studies have implemented various techniques and methods of elucidating how drivers self-regulate their secondary task engagement behaviour. For example, Lamble et al. (2002) found in a survey study that elderly drivers report being less willing than younger drivers to use their mobile phones whilst driving as a strategic self-regulatory behaviour. Furthermore, Young and Lenné (2010) discovered in a survey study that drivers report being unwilling to perform secondary activities in bad weather conditions, heavy traffic situations and school areas. Similarly, Sayer's (2005) early NDS revealed that drivers infrequently perform secondary tasks when braking, driving at night, travelling on curved roads and driving on wet road surfaces. Some other NDSs indicated that drivers more frequently occupy themselves with secondary activities when they are stationary than when they are moving (Metz et al., 2014; Funkhouser and Sayer, 2012; Stutts et al., 2003). A Swedish NDS reported that drivers were less inclined to initiate visual-manual mobile phone tasks during sharp turns, at high speeds and in the presence of a passenger. The study also showed that drivers managed the timing of secondary task engagement by holding off activities until the completion of overtaking and lane-changing manoeuvres (Tivesten and Dozza, 2015).

Although the above-mentioned findings demonstrate a degree of positive self-regulatory behaviour, some other studies found inconclusive results relating to this self-disciplinary tendency. For example, a recent simulator study found that drivers delayed the initiation of secondary tasks during increased workload but that this delay was inadequate to mitigate the effects of the workload. That is, the drivers were willing to perform secondary activities even when workload conditions had not reverted to the baseline condition (Teh et al., 2018). In addition, an NDS performed in the European context illustrated that drivers regulate their engagement in secondary activities in accordance with task duration but not with task complexity. Drivers were found to perform all secondary task complexity levels independently of the driving task complexity (Carsten et al., 2017).

The results of the above-mentioned studies suggested that engagement in secondary tasks is not random, at least to a certain extent, with the drivers leveraging a variety of strategies in deciding on whether, where and when to engage. This observation aligns with a previously proffered explanation wherein drivers are regarded as active receivers and processors of distraction-related information. They are seen capable of effectively adjusting their behaviours in accordance with changes in demand situations, thereby mitigating the effects of distraction on safety and driving performance (Lee and Strayer, 2004; Regan et al., 2009; Haigney et al., 2000). Despite the positive application of self-regulation in a range of contexts, a deficiency in this area of knowledge is the lack of studies that focus on such behaviour at intersections and areas near these intersections.

Intersections impose additional demands on drivers as they have to properly assess numerous visual stimuli, including several and diverse moving objects (e.g. pedestrians and other vehicles) (Tawari et al., 2016). Moreover, intersections feature heavily in crash statistics. To illustrate, crashes that occur at intersections represent almost 60% of the total number of injury crashes in the UK (Simon et al., 2009) and approximately 50% of those in Germany and Australia (Streubel et al., 2015; Young et al., 2011). Yet, the prominent involvement of intersections in crash statistics has rarely motivated direct investigations of real-world driving behaviours at these sites. This work addresses self-regulation of distraction at these safety-critical locations.

One of the few exceptions is the Australian NDS that analysed secondary task engagement at intersections amongst elderly drivers (65 years and older) and collected data from participants who were asked to drive an instrumented vehicle on their regular trips for two weeks. It was found that elderly drivers were significantly more willing to perform secondary activities in fully controlled intersections (signalised intersections) than in uncontrolled ones, in a stationary vehicle than in a moving situation and under low traffic density compared to moderate to high traffic density. Road type, turning direction and gender-related factors were non-significantly associated with involvement in secondary tasks (Charlton et al., 2013).

A number of limitations in Charlton et al.'s (2013) study are worth discussing. First, the drivers drove an instrumented vehicle rather than their own, thus presenting potential influence from the lack of familiarity with the vehicle. Second, the sample size was relatively small (10 drivers, each represented with 20 intersection manoeuvres), so care should be taken in generalising the findings to the wider population of elderly drivers. Third, the study centred only on an elderly sample and did not compare these drivers with a younger cohort. Studies that involve a broader age range are important in comprehensively disentangling changes across age groups. These limitations have been addressed in the present study and a wider array of driver-related and contextual factors were incorporated into analyses.

The examinations in this study used naturalistic driving data from the large-scale European project called UDRIVE (eUropean naturalistic Driving and Riding for Infrastructure & Vehicle safety and Environment). The current study was intended to determine the categories of secondary activities (e.g. smoking, mobile phone interaction, personal grooming) that drivers perform, their prevalence and whether engagement is affected by driver-related factors (e.g. age and gender) and contextual variables, particularly those associated with the complexity of the driving task at intersections (e.g. intersection control and weather conditions). Finally, the study involved a distraction-related comparison of three intersection phases: (1) the upstream phase (pre-intersection phase), (2) the intersection physical area (within-intersection phase) and (3) the downstream phase (post-intersection phase).

The primary hypothesis advanced in this study is that drivers exercise self-regulation by reducing engagement in secondary tasks during more challenging intersection-driving situations. Such reduction would be expected to take place specifically at areas falling within intersections rather than at upstream and downstream areas. It is also hypothesised that drivers will reduce secondary task engagement when their vehicles are in motion compared to when they are stationary, and when they do not have priority in passing through an intersection (which required more gap judgments) compared to when they have priority.

2. Methods

The naturalistic data from the UDRIVE project were sampled, viewed, annotated and analysed to ascertain whether and how drivers manage their engagement in secondary tasks as they travel through intersections. The data were supplemented with some driver-related factors (e.g. age) and driving information, which were collected by distributing forms to be filled out by the participant drivers during the recruitment stage. The study's protocols were ethically certified by the Research Ethics Committee of the University of Leeds (Ethics reference no.: AREA 16-193).

2.1. Participants

The study involved 163 car drivers who had at least 20 trip records stored in the dataset of the UDRIVE project. Amongst the participants, 85 were males (52.1%) and 78 were females (47.9%) with ages ranging from 18 to 80 years [mean = 43.9, Standard Deviation (SD) = 13.1, minimum = 18, maximum = 80]. The participants were distributed location-wise across five countries (the UK, Germany, France, Poland and the Netherlands). Table 1 shows the gender distribution of participants per country, and Table 2 displays some descriptive statistics of age per country.

Table 1. Participates by gender and country.

Country	Female	Male	Total
France	19	17	36
Germany	7	14	21
Netherlands	14	15	29
Poland	12	19	31
UK	26	20	46
Total	78	85	163

Table 2. Descriptive statistics of age per country (in years).

Country	Mean	SD	Minimum	Maximum
France	43.8	11.7	23	70
Germany	46.5	16.3	23	80
Netherlands	45.7	13.3	26	70
Poland	40.1	8.9	20	65
UK	44.6	14.5	18	69
Total	43.9	13.1	18	80

2.2. Data Acquisition System (DAS)

A DAS was installed in each driver's own vehicle to collect naturalistic data over a course of nearly 18 months. The DAS comprised (1) a combination of sensors that automatically and continuously recorded vehicular information, including speed, braking, acceleration and location coordinates, and (2) eight cameras that were positioned in such a way that enabled the wide video coverage of the drivers' forward, side and in-vehicle views but with minimal disruption to their lines of sight. These cameras included a MobilEye smart central forward-facing camera that detected other road users and measured frontward distances accordingly (Barnard et al., 2016). The camera arrangements are described below (Figure 1):

- Cameras 1, 2 and 3 were the three front-view cameras intended to provide forward visibility up to an angle of almost 180° (left, centre, right).
- Camera 4 was the driver's face camera designed to capture gaze directions and facial expressions.
- Camera 5 was the blind spot camera meant to detect other possible road users at the right side of the vehicle.
- Camera 6 served as the driver's action camera and was located over the shoulder to enable the recording of hand activity and engagement in secondary tasks.
- Camera 7 was the cabin camera, which was used to capture the presence of passengers, as well as their characteristic and activities.
- Camera 8 was the camera intended to record the driver's feet activity and movements.

The DAS had a feature that allowed the participants to deactivate the camera recording system temporarily by pressing a button below the rear view mirror (Eenink et al., 2014). The data obtained from the DAS were supplemented by some information from external databases. An example is map matching (with OpenStreetMap) which used the acquired time-series GPS coordinates to identify speed limits, intersection presence, and road type (Utesch et al., 2014).

Figure 1. Example shots of the camera channels in the UDRIVE project (Utesch et al., 2014); the driver appearing in the picture above was not a participant.

2.3. *Data sampling*

Given the magnitude of the UDRIVE project (close to 175,000 trips and over 1 million intersection cases identified through map matching), a sampling strategy was implemented to obtain a representative sample of the intersection cases. For each participant, 10 trips were randomly sampled without replacement across that participant's entire dataset (minimum trip distance = 1 kilometre). Within each trip, one intersection case was randomly selected for coding.

To be annotated and included in the analysis, an intersection case should have synchronised video data and time-series vehicular information and fully functional properly directed camera views.

2.4. *Data coding and analysis*

The selected intersection cases were coded manually using a coding scheme developed specifically for this work. The scheme involved the categorisation of observed secondary tasks and the identification of intersection-related contextual factors. The key variables in the study were as described below:

Secondary tasks: From previous NDSs (Carsten et al., 2017; Dingus et al., 2006; Stutts et al., 2003), the current study identified eight secondary task categories for annotation (both single- and multi-task situations were coded):

- Mobile phone-related tasks (i.e. any type of interaction with a mobile phone)
- Writing/reading-related activities (e.g. reading a paper material or packaging)
- Drinking/eating-associated activities
- Interactions with in-vehicle control systems (e.g. climate control adjustment)
- Smoking-related activities
- Grooming-related activities
- Singing/talking in the absence of passengers
- Passenger conversations (i.e. any exchange with a passenger, at the minimum, a one-word utterance).

Intersection layout: The intersections were coded as either roundabouts or intersections (non-roundabouts).

Intersection priority: The intersection approaches were coded in accordance with the priority given to the subject vehicle (SV) in passing through an intersection (i.e. an SV has priority versus an SV has no priority).

Intersection control: The intersections were coded as managed with traffic signs and road markings or controlled by traffic lights.

Turning direction: Turns made at the intersections were classified into three groups, namely, left turns, right turns and straight on (no turn). Note that the UK is the only left-side driving country amongst the sampled countries, hence left and right turn categorisation was reversed to match the type of manoeuvre made in the other countries.

Intersection locality: The intersection approaches were classified as either rural or urban based on map matching data.

Weather conditions: Weather conditions at the intersections were coded as no adverse weather conditions (good weather) or adverse weather situations (including rain, snow or fog).

Vehicle motion status: The motion statuses of vehicles were classified as either moving or stationary. A vehicle was considered stationary when it was at a complete stop (i.e. when speed dropped to zero).

Because this study was also designed to carry out a distraction-related comparison of the pre-intersection, within-intersection and post-intersection phases, an important requirement was to delineate the boundaries of these phases. According to Stover (1996), the intersection functional area refers to the distance-based influence zone that extends both before and after the boundaries of the physical intersection area. This distance-based influence zone depends considerably on the initial speeds of vehicles and can be derived by adding the following: (1) the distance travelled during the perception-reaction time, (2) the distance travelled whilst braking and moving laterally, (3) the distance travelled during full deceleration after moving laterally, and (4) the length required to store vehicles (i.e. queue length) (Stover, 1996). The current study adopted the physical length values of the pre- and post-intersection phases published by Stover (1996). These length-based values were wide-ranging functions of the speed limit at intersections, as shown in Table 3.

Table 3. Distance-based zone of the intersection functional area (excluding queue length)

Speed (km/h)	Physical distance (m)
30	30
40	45
50	65
60	85
70	115
80	140
90	175
100	205

To facilitate the data viewing and coding process, this study used a visualisation and processing tool developed by the UDRIVE team known as the Smart Application for Large-Scale Analysis (SALSA). The duration of secondary tasks was annotated to $1/10^{th}$ of a second accuracy (given a video frame rate of 10 frames/second). It should be noted that the full secondary task engagement is not necessarily covered, if the engagement initiated before the intersection zone or ended after the intersection zone.

Inter-rater checks were performed to examine the reliability of the coded data, for which a random selection of 10% of the intersection cases were coded by a second independent coder. Inter-rater reliability was examined using Intraclass Correlations coefficient for the continuous variables (e.g. the time at which secondary tasks was initiated) and Cohen's Kappa coefficient for the categorical variables (e.g. weather conditions) (Hallgren, 2012). The inter-rater reliability was 92% for the continuous variables and 96% for the categorical variables.

The data analyses were performed using the Statistical Package for the Social Sciences (version 24). Various descriptive and inferential examinations were conducted to determine the frequency and prevalence of engagement in secondary activities with consideration for the driver-related and contextual variables. The percentage of total driving time at intersections in which the driver was engaging in secondary tasks was the major metric used to evaluate prevalence. The other metrics employed were the percentages of time spent at the pre-intersection, within-intersection, and post-intersection phases, and the total stationary and moving times during which secondary tasks were performed. A paired-samples t-test was carried out for the distraction-related comparison of the motion status conditions, and one-way repeated measures ANOVA were conducted for the comparison of the three intersection phases. Multiple linear regression modelling was used to model the driver-related and contextual determinants of the percentage of total intersection time associated with secondary task engagement.

3. Results

A total of 1630 intersection cases (10 intersection cases per participant) were analysed. The total observation time across all these cases was 678.8 minutes, and the average duration of an intersection case was 25 seconds. With regard to the intersection phases, the total observation time was divided into 373.2, 161.2 and 144.4 minutes for the pre-, within- and post-intersection phases, respectively. For vehicle motion status, the total observation time was segmented into 536 minutes for the moving condition and 142.8 minutes for the stationary condition. Table 4 breaks down the 1630 intersection cases with reference to the coded contextual factors.

Table 4. Contextual factors acquired from coding.

Contextual factor	% of 1630 intersection cases
Intersection layout	
Roundabouts	26.0
Intersections	74.0
Intersection priority	
Priority allocated to SV	49.4
No priority allocated to SV	50.6
Intersection control	
Traffic signs and road markings	62.9
Traffic lights	37.1
Turning direction	
Turning left	32.5
Going straight	35.9
Turning right	31.6
Intersection locality	
Rural	24.7
Urban	75.3
Weather condition	
No adverse conditions	86.7
With adverse conditions	13.3

3.1. How prevalent is secondary task engagement?

The analyses revealed that nearly one-half of the intersection cases had engagement in at least one form of secondary task (47.7%). Almost all drivers (97.5%) engaged in a secondary task in at least one out of the 10 intersecting cases coded for them. A total of 1050 secondary task instances were observed, which represents 26.5% (179.9 minutes) out of the total intersection time (678.8 minutes). Amongst the intersection cases, drivers undertook a single secondary activity in 543 cases (33.3%), two secondary activities in 198 cases (12.1%) and more than two secondary activities in 37 cases (2.3%).

As a first step in analysing category of task engagement, the frequency of engagement in each secondary task category was counted (Table 5). The most frequently observed task category was passenger conversation (n = 456), followed by talking/singing with no passengers onboard (n = 149), mobile phone-related tasks (n = 132) and interactions with in-vehicle control systems (n = 100). The tasks in which the drivers least frequently engaged were reading- and writing-related activities (n = 6). Table 5 also presents the percentage of drivers performing each type of task. 82.8% of drivers were observed talking to a passenger, while only 2.5% of drivers were observed to perform reading or writing activities.

Table 5. Secondary task engagement as determined from data coding.

Secondary task	Frequency	Percentage of drivers performing task (%)
Passenger conversations	456	82.8
Talking/Singing with no passengers present	149	46.0
Mobile phone-related tasks	132	33.7
Interactions with in-vehicle control system	100	39.3
Smoking-related activities	74	7.4
Personal grooming activities	73	33.1
Food/drink activities	29	12.3
Reading/writing activities	6	2.5
Other	31	16.6
Total	1050	97.5

Second, the amount of time that the drivers spent on performing each secondary task was compared with the total observed intersection time (678.8 minutes). The tasks performed for the most time were passenger conversations (13.2%), followed by mobile phone-related (6.6%) and smoking-related (3.7%) activities. The lowest represented tasks were reading- and writing-related activities, accounting for only 0.2% of the total observed intersection time (Figure 2).

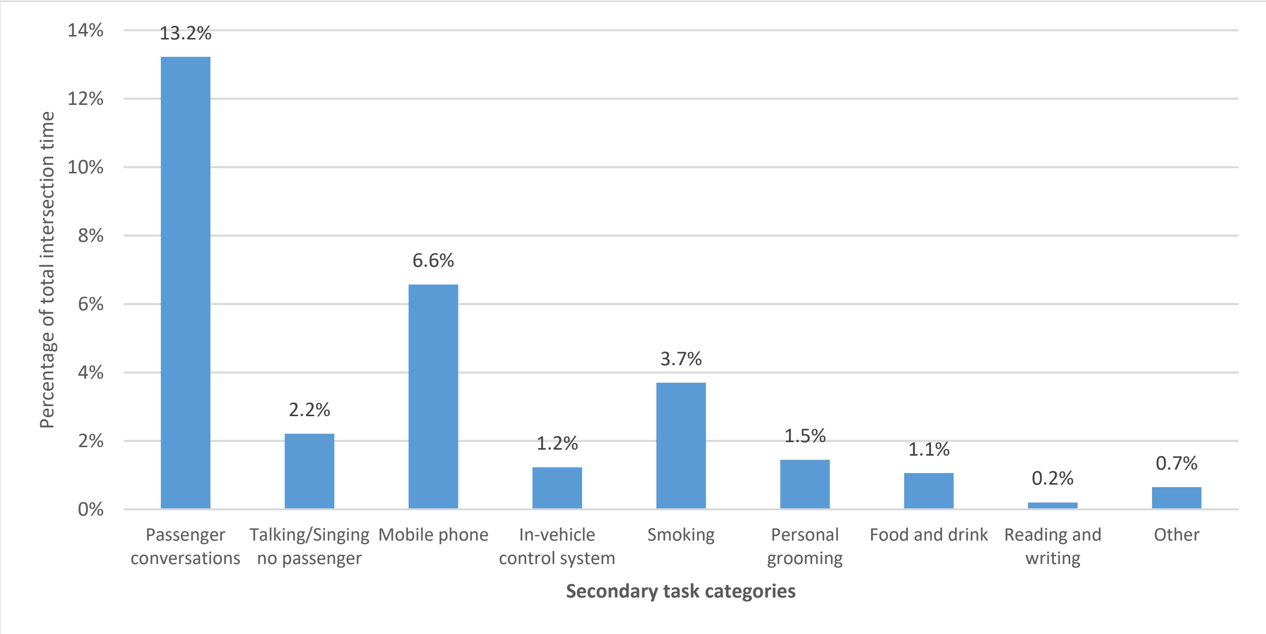

Figure 2. Percentage of total intersection time per secondary task categories.

Third, the relationship between mean percentage of total intersection time and task frequency was investigated (Figure 3). Both mobile phone-related and smoking-associated tasks were performed for the longest mean percentage of total intersection time (71.6% and 72.9%, respectively). Conversely, the lowest mean percentage of total intersection time involved interactions with in-vehicle control systems (14.3%). Passenger conversation occupied a moderate percentage of time (45.7%), but were by far the most frequently observed task.

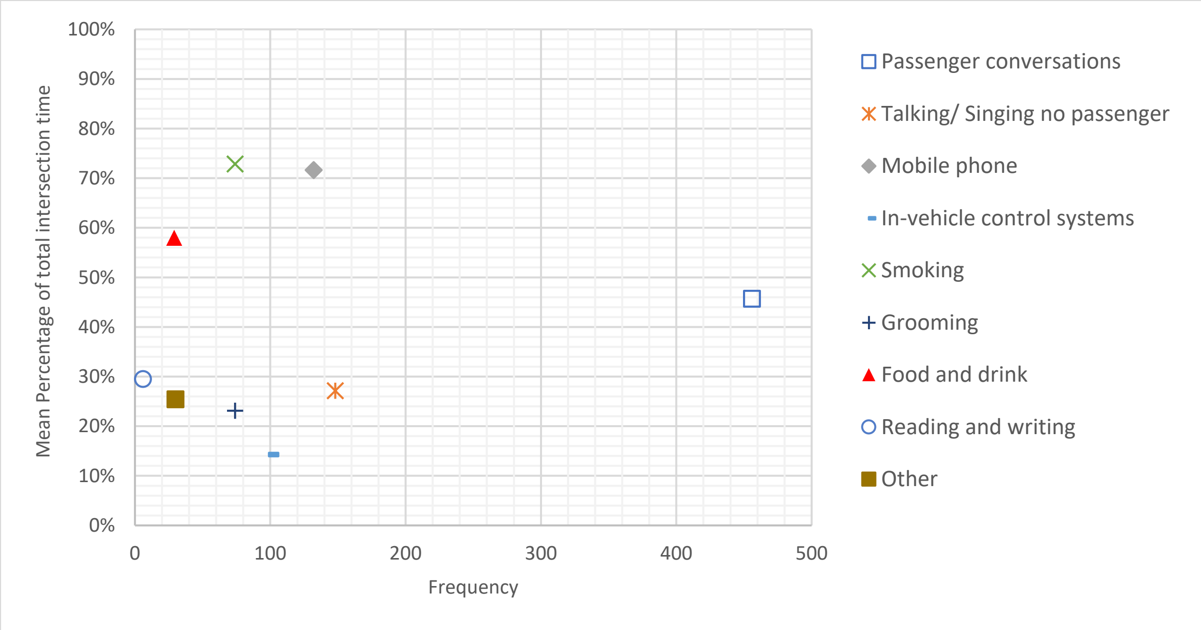

Figure 3. Mean percentage of total intersection time vs. frequency by each task category.

3.2. How do drivers regulate their secondary task engagement across intersection phases and motion statuses?

The drivers performed secondary tasks on average for 26.5% of the total intersection time. Figure 4 shows a breakdown of secondary task time by intersection phase (upstream, within and downstream), and Figure 5 presents the secondary task time by vehicle motion status (stationary and moving).

A one-way repeated measures ANOVA was conducted to look into the differences in the percentages of time associated with secondary task engagement between the intersection phases. Pairwise comparisons were carried out with Bonferroni correction for multiple comparisons. The percentages were statistically significantly different across the intersection phases, $F(1.795, 2924.593) = 37.258$, $p < 0.0005$. The post-hoc analysis showed a significantly lower level of secondary task engagement during the within-intersection phase (mean = 22.1%) than during the upstream (mean = 26.8%) and downstream phases (mean = 27.2%) ($p < 0.0005$), but no significant difference was found between the upstream and downstream phases (Figure 4).

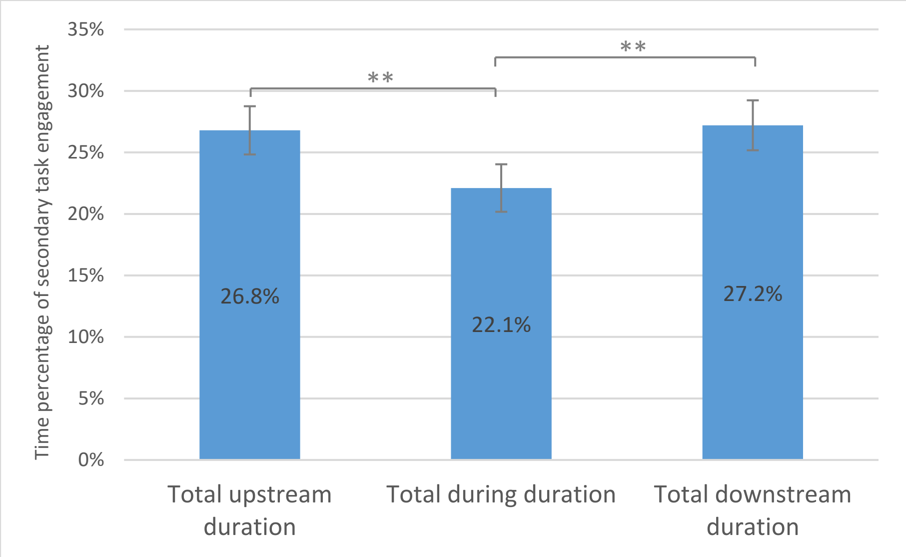

Figure 4. Secondary task engagement by intersection phase (**p < 0.0005).

With respect to the comparison of the stationary and moving periods, the paired-samples t-test indicated a significant increase in the percentage of time performing secondary tasks whilst stationary (mean = 34.8%) compared with moving (mean = 25.1%), $t(434) = 8.958$, $p < 0.0005$ (Figure 5).

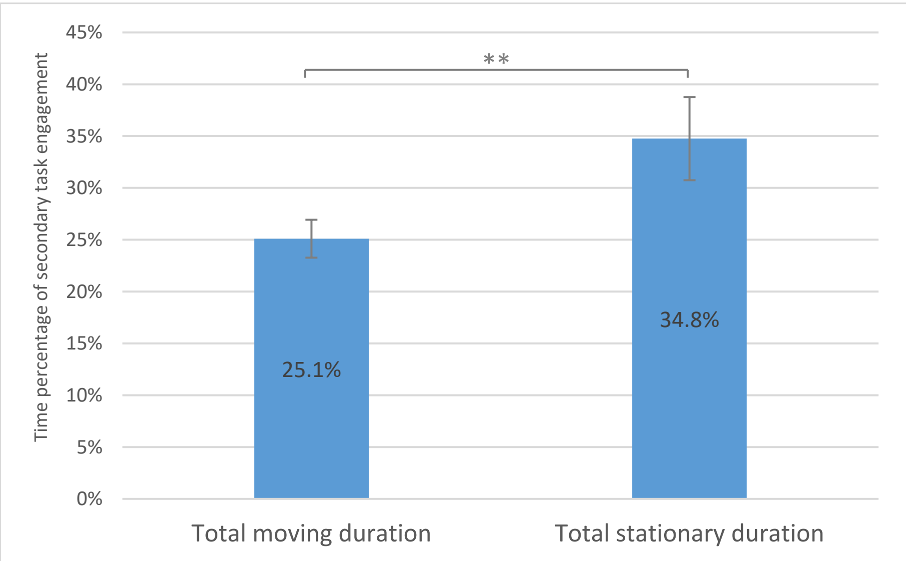

Figure 5. Secondary task engagement by motion status (**p < 0.0005).

3.3. Does being stationary influence self-regulation behaviour?

Figure 6 compares secondary task engagement over the three intersection phases for the cases with (n = 436) and without (n = 1194) stationary time on the intersection approach (knowing that stationary time was most likely in the upstream phase). The one-way repeated measures ANOVA test revealed a significant difference amongst the intersection phases, both with stationary time, $F(1.752, 761.911) = 45.854$, $p < 0.0005$; and without stationary time, $F(1.786, 2131.066) = 28.484$, $p < 0.0005$. Where no stationary time occurred, there was significantly higher time spent performing secondary tasks in the downstream phase (mean = 28.7%) compared to the within-intersection phase (mean = 23.1%) ($p < 0.0005$). Where the vehicle stopped in the upstream phase, there was significantly higher time spent engaging in secondary tasks in the upstream phase (mean = 31.4%) compared to the within-intersection (mean = 19.3%) and downstream phases (mean = 23.1%) ($p < 0.0005$) (Figure 6).

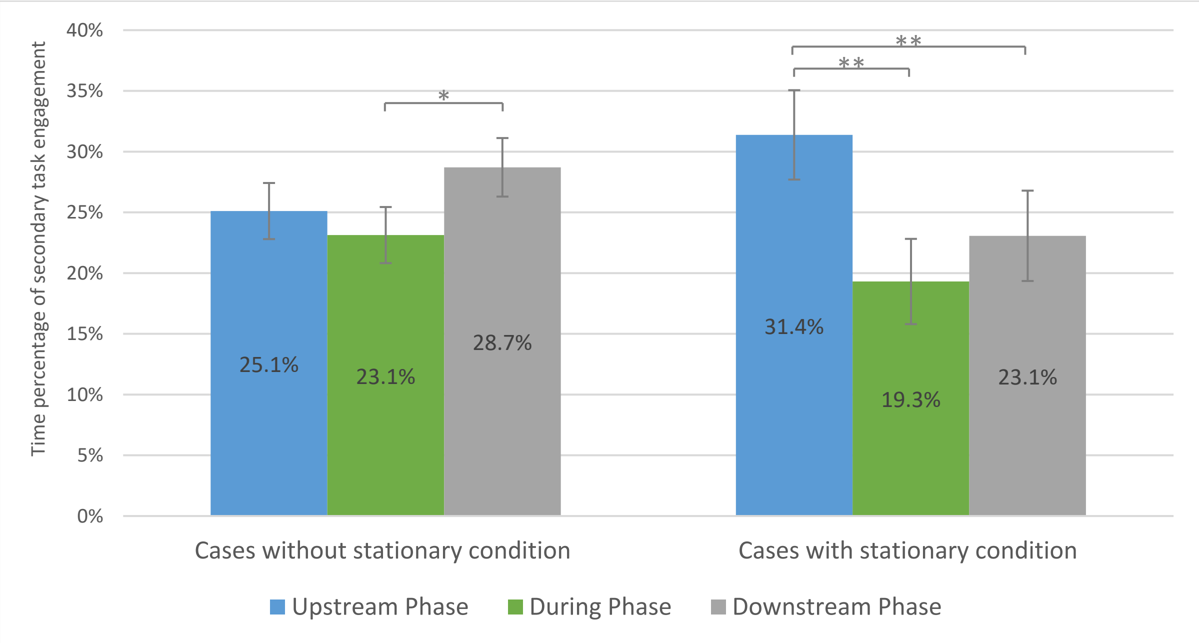

Figure 6. Secondary task engagement on the basis of stationary presence (*$p < 0.05$, **$p < 0.0005$).

3.4. What are the effects of driver-related and contextual factors?

Two multiple linear regression models were developed to identify the contextual and driver-related predictors of the percentage of total intersection time involving secondary task engagement. The first model included all of the predictors, while the second model included only predictors that had a significant association with the dependant variable (parsimonious model). A comparison of the fit statistics between the two models suggested that the parsimonious model accounted more of the variance (see Table 6), and therefore it was selected for the subsequent discussions. Table 7 summarises the models' outcomes, including the estimated unstandardised coefficient (*b*), the standardised coefficient (β) and the statistical significance of each factor.

Table 6. Model fit statistics for the two models.

Model type	F	p	Adjusted R^2
All predictors	32.352	0.000**	0.174
Significant predictors only	35.580	0.000**	0.175

**p < 0.0005

This study focused on interpreting β alongside with *b* coefficients because not all the factors were measured with a common scale. The β coefficients were based on variables that were measured using a common metric (z-scores) so that they could be directly compared using a standardised scale ranging from –1 through 0 to +1. A factor with a large β magnitude is a strong determinant, whereas one with a small β magnitude is a weak determinant.

The strongest and most consistent predictor of the percentage of secondary task engagement time (indicated by the highest magnitude β) was driver age. Hence, age was entered into the model as a continuous variable, the percentage of secondary task engagement decreased by an unstandardised coefficient of 0.4% for every one-year increase in age ($p < 0.0005$). The next most consistent predictor was country. The German sample registered the lowest percentage of secondary task engagement (8.9% to 14.4% lower than other countries). The trend was that the Polish sample had the highest percentage of secondary task engagement, followed by the Dutch, the UK and the French samples; the lowest engagement was observed amongst the German sample.

The significant β coefficients were smaller in relation to intersection control, intersection priority and weather conditions. The percentage of secondary task engagement decreased by an unstandardised coefficient of 5.3% at intersections with traffic signs compared with intersections managed by traffic lights ($p = 0.035$); this percentage increased by 6.0% when SVs had priority versus the cases where SVs did not have priority ($p = 0.006$); and it declined by 5.6% when adverse weather conditions existed compared with driving in good weather ($p = 0.040$).

Gender, intersection layout, turning direction (left/right/straight) and locality (urban/rural) exerted no significant impact on the level of engagement in secondary tasks ($p > 0.05$) (Table 7).

Table 7. Summary of the multiple linear regression results on predicting secondary task engagement.

Model	Predictor	Referent	*b*	SE $_b$	β	*p*
All predictors	(Constant)		46.767	7.492		.000**
	Driver age in years (continuous)		-.444	.074	-.153	.000**
	Country: France	Germany	9.845	3.312	.108	.003*
	Country: Poland	Germany	14.569	3.389	.151	.000**
	Country: UK	Germany	11.050	3.171	.131	.001*
	Country: Netherlands	Germany	12.290	3.398	.124	.000**
	Driver gender: Male	Female	1.947	1.904	.026	.307
	Intersection layout: Intersections	Roundabouts	-4.105	2.363	-.052	.083
	Intersection Control: Traffic signs	Traffic lights	-6.833	2.684	-.079	.011*
	Intersection Priority: With priority	No priority	5.572	2.789	.073	.046*
	Intersection Locality: Rural	Urban	-.053	2.205	-.001	.981
	Turning direction: Left	Going straight	2.956	2.557	.036	.248
	Turning direction: Right	Going straight	.394	2.259	.005	.862
	Weather Conditions: Bad	Good	-5.424	2.725	-.049	.047*
Significant predictors only	(Constant)		43.062	5.576		.000**
	Driver age in years (continuous)		-.436	.072	-.151	.000**
	Country: France	Germany	8.866	3.277	.097	.007*
	Country: Poland	Germany	14.383	3.382	.149	.000**
	Country: UK	Germany	10.203	3.126	.121	.001*
	Country: Netherlands	Germany	11.982	3.378	.121	.000**
	Intersection Control: Traffic signs	Traffic lights	-5.278	2.499	-.061	.035*
	Intersection Priority: With priority	No priority	6.038	2.180	.080	.006*
	Weather Conditions: Bad	Good	-5.604	2.722	-.050	.040*

*$p < 0.05$, **$p < 0.0005$

4. Discussion

In contrast to earlier NDSs that delved into the sources of driver distraction and the associated crash risk arising (e.g. Klauer et al., 2006; Hickman et al., 2010; Dingus et al., 2016), the present study investigated the prevalence of secondary task engagement at intersections and drivers' attempts to self-regulate this behaviour across different roadway and environmental conditions.

For the 1630 intersections coded, approximately half of the intersections (47.7%) and one-quarter of the total observation time (26.5%) contained a secondary task interaction, showing that secondary task engagement is common and frequent occurrence. The one-quarter time percentage outcome is inconsistent with the findings of the UDRIVE project (Carsten et al., 2017) and Dingus et al. (2016), who discovered 10.2% and 51.9% levels of engagement, respectively. These differences are likely due to coverage—the present analyses were restricted to intersections, whereas the aforementioned investigations were aimed at the full range of driving contexts. Moreover, the different coding schemes applied in these studies rendered solid comparisons difficult. For example, the current study included passenger conversations as a category of secondary task engagement, but this classification was not covered in the UDRIVE project.

Across the 1630 intersection cases, the most frequently observed tasks were passenger conversations, followed by talking/singing in the absence of passengers and mobile phone activities. Notably, the least frequently observed activities were those associated with reading/writing which was unsurprising because these tasks would require taking eyes completely off the road. Smoking also was not widespread observed among drivers, however it had the longest mean duration throughout the entire intersection zone. This result was unsurprising because smoking tasks were annotated as long as the cigarette is burning independently from the position of the cigarette (e.g. hand, mouth). Conversely, interactions with in-vehicle control system task was the shortest average duration distraction which was expected given the short period required to accomplish this kind of task.

Passenger conversations as the most prevalent secondary task category is consistent with the findings of earlier NDSs (Dingus et al., 2016; Stutts et al., 2003). In the UDRIVE project, mobile phone usage and talking/singing tasks were the most frequent, whereas reading/writing was the lowest-frequency task (Carsten et al., 2017), in line with the findings of the current study (accounting for the absence of passenger conversations from their coding scheme). The only dissimilarity between the outcomes of the two studies is the relative frequency of drink/food activities and grooming tasks. These two secondary task categories were observed to a lesser extent in the current intersection-focussed work, relative to the full trip analysis in the UDRIVE study. This leads to the possibility that abstinence from food-, drink- and grooming-tasks is a form of self-regulation exercised by drivers. Overall, this study provides evidence that drivers refrain from carrying out certain secondary activities as they travel through intersections.

The percentage of time with secondary task engagement was greater during upstream and downstream phases than during the within-intersection phase. There is a V-shaped self-regulation relationship between secondary task engagement and progress through the intersection phases, with a suggestion that drivers respond to the higher demand or risk associated with the within-intersection phase (where conflicts with other streams of traffic are more likely to occur) by reducing their secondary task engagement. This V-shaped relationship varies depending on whether the upstream phase involved the vehicle being stationary at some point. Where the vehicle did not stop in the intersection, the drivers were more willing to postpone initiating secondary activities until the driving task demand was lower at the downstream phase. Where stopping occurred, the drivers were more likely to perform secondary tasks during stationary at the upstream phase and then relinquish activities to keep pace with the growing demand/risk encountered after moving. These outcomes implied that being stationary highly influences drivers' decisions on when to initiate or abandon secondary tasks across the intersection phases. Ultimately, then, this behaviour can be deemed another form of self-regulation.

The comparison of moving versus stationary behaviour likewise suggested that the drivers reduced secondary task engagement when their vehicles were moving compared to when they were stationary—consistent with previous NDSs (Metz et al., 2014; Funkhouser and Sayer, 2012; Stutts et al., 2003). This result points yet again to self-regulatory discipline by drivers, this time in response to the high demand of their vehicle being in motion compared to stationary.

A multiple linear regression model was estimated to explore the relative importance of several determinants of the percentage of intersection time allocated to secondary tasks. Driver age was the most powerful predictor of involvement in secondary activities, with task engagement decreasing as the drivers became older. This trend indicated that elderly drivers were less likely to occupy themselves with secondary tasks than younger drivers—a result that coincides with the findings of several studies on the general driving context (e.g. Sullman, 2012; Stutts et al., 2003). It was also an expected outcome given elderly drivers' reduced abilities (e.g. visual and information processing abilities) (Eby et al., 1998) and the complexity of the driving task within intersections and its surrounding areas. With respect to task engagement by age across the three intersection phases, the analysis revealed that the V-shaped relationship holds over the different age groups.

In terms of cross-country comparison, the highest task engagement percentage was observed amongst the Polish sample, followed by the Dutch, the UK and the French samples. The German sample registered the lowest engagement. This trend is compatible with the findings reported in the UDRIVE project (even with the absence of the Dutch sample from their analysis) (Carsten et al., 2017). These cross-country differences may be attributed to variations in traffic culture as drivers in some countries are more law-abiding, more sensitive to risk (Nordfjærn et al., 2011) and more conscious about the danger of distracting activities than others. The results for the Polish sample accounting for the highest engagement is unsurprising owing to the fact that Poland had the worst road safety record (highest road traffic fatality rate) amongst the five countries (WHO, 2018). Therefore, an association may exist between engagement in secondary tasks and the road traffic crashes occurrence. Further investigation of the between-country differences that underpin these results is required. With reference to the German sample, further investigation is needed to explore why these drivers exhibited the lowest engagement in secondary tasks. Gaining the best lessons from the German experience can be a gateway to refine distraction-related prevention strategies (e.g. regulation and enforcements) in other countries.

The multiple linear regression modelling also cast light on a number of contextual factors, particularly those associated with the complex aspects of driving at intersections. The analysis revealed that the percentage of secondary task engagement was significantly influenced by intersection control, intersection priority and weather conditions. Secondary task engagement was higher at traffic light intersections than at traffic sign intersections, suggesting that drivers were less willing to perform secondary activities at intersections that require more gap judgment and where the potential conflicts between vehicles moving in different directions are not separated in time. This finding aligns with the results of an earlier NDS (Charlton et al., 2013). With reference to intersection priority, the drivers were more likely to perform secondary activities when they had priority in passing through an intersection compared to cases when they did not. This result is plausible considering that drivers in non-priority locations are compelled to evaluate gaps and choose the best option for crossing an intersection (high decision-making demand). In terms of weather conditions, the drivers were more reluctant to perform secondary tasks in poor weather situations than in good weather situations, which agrees with previous general driving studies (Young and Lenné, 2010; Sayer, 2005). All these findings demonstrated positive self-regulatory behaviour, wherein drivers realised the greater driving task demands associated with certain environmental contextual factors and consequently adjust their involvement in secondary tasks. This phenomenon is in agreement with previous studies that showed the reluctance of drivers to undertake secondary activities under challenging driving scenarios (e.g. Funkhouser and Sayer, 2012; Tivesten and Dozza, 2015).

Neither intersection locality nor intersection layout significantly influenced the percentage of time allocated to secondary tasks. The latter outcome suggests that drivers perceived roundabouts the same way as non-roundabout intersections. Also, no significant difference was explored in secondary task engagement between female and male drivers—a finding that aligns with many studies within the literature (e.g. Charlton et al., 2013; Sullman, 2012). Similarly, no significant association was discovered between turning directions (straight/right/left) and the percentage of secondary task engagement. This outcome, although unexpected, is consistent with the outcome derived by Charlton et al. (2013), albeit their analysis did not involve straight drives through intersections. A lower level of secondary task engagement during left turns (across traffic flow with many conflict points) compared with right turns was hypothesised. This unexpected outcome can be attributed to the method adopted in the current analyses; that is, the percentage of total intersection time was used as a dependent variable in the comparison, even though turning manoeuvres occur mostly within the physical area of intersections (within-intersection phase). Closer scrutiny is needed to determine if different dependent variables are suitable for the examination of turning manoeuvres.

Some of the findings in the present study implied that drivers, at least to some extent, reduced the relative risk associated with secondary tasks by deciding to perform more tasks when their vehicles were stationary and when traversing intersections typified by relatively lower decision-making demands. Nevertheless, this does not mean that such behaviour is a safe practice. The concern arising from this, is that drivers may underestimate the danger related to secondary task engagement, specifically when driving at intersections. As discussed earlier, intersections pose more demands on drivers than do other types of roadways and figure prominently in crash statistics (Simon et al., 2009). In these distracting situations at intersections, drivers are required to use additional cognitive resources to process different sources of information, which in turn, may reduce situation awareness or slow down driver decision making to risky levels and eventually lead to safety errors and increase crash risk.

The outcomes of the current work should be seen in light of several limitations. First, the drivers in each of the countries do not constitute a representative sample of the driving population. For this reason, the cross-country comparisons should be viewed with caution. Second, the sample size of intersection cases within each driver was small (10 intersections per driver). Further research is needed to demonstrate whether the findings of this study are robust for a larger sample of cases.

5. Conclusion

This study illustrated a novel application of the naturalistic driving method in analysing secondary task engagement at intersections. The results on prevalence revealed that secondary task engagement is common among drivers. Drivers exercised self-regulation by reducing their engagement during certain roadway and environmental conditions, assumed/considered to be more challenging. This self-regulatory discipline was shown by the drivers' lower willingness to perform secondary tasks when their vehicles were moving and the V-shaped relationship between the percentage of time engaged in secondary task activities and the three intersection phases (before, within and after). Self-regulatory behaviour was also represented by the reduced willingness of drivers to perform secondary tasks as they travelled along intersections managed by traffic signs, when they did not have priority and when adverse weather conditions existed. A particularly important finding is that the young drivers were more willing to engage in secondary tasks than the elderly participants.

The study results provide some preliminary information that can be useful in refining driver education, training and awareness programmes on managing distractions and safe intersection driving strategies. This can be achieved, for example, by directing media campaigns towards groups of drivers most engaged in distraction activities at intersections (e.g. younger drivers). The study results also offer preliminary evidence for targeting enforcement. For example, the location of the distracted driving enforcement system—new technology developed by Acusensus (Australia) that provides automated recognition to detect illegal mobile phone actions—can be prioritised at intersections and areas near intersections. In addition, the results should be helpful in the creation of guiding principles for categorising intersections in relation to the self-regulation and prevalence of secondary task engagement. Such principles can be determined on the basis of the insight gained into when/where secondary activities are carried out and what types of activities drivers will undertake.

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