FIELD STUDY OF THE LEVEL 2 SUPER CRUISE USING TELEMATICS DATA

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ABSTRACT

Over-the-air data was captured from thousands of vehicles in natural driving across the United States to evaluate the GM production Level 2 (L2) Super Cruise, Front Pedestrian Braking, and camera-based Adaptive Cruise Control (ACC) features. This research mainly focused on how often, when, and where customers used Super Cruise, and examined safety surrogate measures. Super Cruise allows hands-free driving on compatible GPS-mapped roads, which, at the time, included only limited-access freeways and trunk roads. Super Cruise uses a driver monitoring system that includes a face camera and a series of escalating alerts to prompt the driver to pay close attention to the road ahead and to take steering control when takeover requests are issued.

Two Cadillac fleets were used, including 2642 model year 2018/2019 vehicles equipped with Super Cruise, as well as 1196 similar fusion ACC-equipped model year 2017-2019 vehicles. During the 14-month data collection period the Super Cruise fleet accumulated 24M miles and the ACC-only fleet accumulated nearly 14M miles. Telematics data was retrieved each ignition cycle using GM's OnStar system, including Super Cruise state changes, harder braking events, and GPS traces. This research examined contextual influences on Super Cruise use and compared crashes, braking levels, and vehicle speeds across Super Cruise, ACC, and manual driving modes.

Super Cruise engagements occurred on 72% of equipped vehicles, totaling 1.7M miles of engaged driving. Engagements accounted for 18% of the driven distance on system compatible roadways, with a median engagement duration of 2.6 minutes. Relative to manual driving, Super Cruise and ACC were generally used when there is less surrounding traffic (i.e., free-flow, nighttime) and the roadway environment is less complex (e.g., rural, non-rain, non-curved roads). Drivers frequently interacted with Super Cruise via steering overrides (e.g., to change lanes), receiving and responding to driver attention prompts, and responding to takeover requests. Approximately 57% of Super Cruise engagements included driver attention reminder(s), with 91% of such reminders resolved without further escalating alerts. Takeover request results indicated 58% were due to Operational Design Domain limits, and 24% were driver-attention related.

No Advanced Automatic Crash Notification events were observed on Super Cruise compatible roads for either the Super Cruise or the comparison ACC fleet. Modeling analyses under matched driving conditions indicated that harder braking (exceeding 2.6 m/s^2) events were 1.7 times more likely during ACC/manual driving than during Super Cruise driving, and that median and top speeds during Super Cruise engagements did not exceed those of ACC/manual driving during free-flow traffic conditions, which was found to be the dominant use case for Super Cruise. Together with the relatively modest median Super Cruise engagement duration of 2.6 minutes, these findings suggest drivers use Super Cruise selectively, have generally fewer harder braking events when Super Cruise is engaged, and appear comfortable with the interactive Super Cruise feature.

Front Pedestrian Braking automatic braking events occurred approximately once per 590,000 miles, mostly on lower-speed private and residential roads. For the camera-based ACC feature, results indicated usage and the incidence of harder braking levels are similar to fusion-based ACC.

INTRODUCTION

A large telematics-based data collection effort was undertaken to capture information to support the analyses of driver usage, driver interaction, and safety-relevant events for three GM production features. These features included Super Cruise, which is a SAE Level 2 feature [1], camera-based Front Pedestrian Braking[1] (FPB), and camera-based Adaptive Cruise Control (ACC). This study leveraged carefully selected sets of high-priority data captured using the GM OnStar telematics system. The analyses and results reported here are based on data from 8,893 GM production customer-owned vehicles operating across the continental United States (US) over a 14-month period from February 2020 into April 2021. This paper is a companion to the complete study report [2] which provides additional details on the data collection and analyses.

The work described here is the third telematics-based field study of Advanced Driver Assistance Systems (ADAS) features in natural driving performed by the same research team from the University of Michigan and GM, with support from the National Highway Traffic Safety Administration (NHTSA). This work follows previous studies examining Lane Departure Warning (LDW) and Forward Crash Alert (FCA) with over 1000 vehicles [3], and an assessment of Automatic Emergency Braking (AEB) and Intelligent Brake Assist (IBA) with more than 2500 vehicles [4].

METHOD

This study involved 8,893 GM production vehicles (30% equipped with Super Cruise) operating in 48 states across the entire US, as illustrated in Figure 1. Telematics (over-the-air) data transfers provided the research team with data, which was collected by means approved in vehicle owner data agreements. Data collection captured 103,940,946 miles of data. Each vehicle fleet provided its own unique set of data drawn from various data types, which included event-based data (including Super Cruise operating state changes), ignition cycle information (including GPS location/time and distance traveled), and continuous GPS location data to assess travel exposure and provide driving context for the event-based data. The OnStar data did not contain video or audio data, nor did it include remote sensing data (e.g., distances to nearby vehicles). In addition, the OnStar data was anonymized at the vehicle level for analyses, without information on driver identity or demographics. Figure 2 illustrates the path of the data from the vehicle to the analysis stage. During the analysis stage, the telematics data was augmented with publicly available digital maps, census data, and weather data to support analyses examining the influence of driving environment context.

[1] This type of feature is sometimes referred to as Pedestrian Automatic Emergency Braking (PAEB).

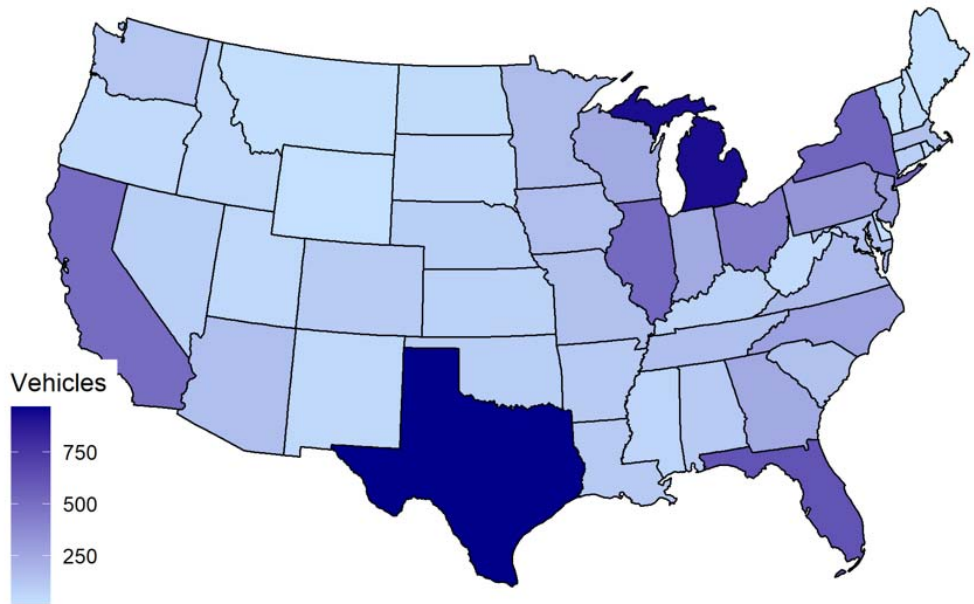

Figure 1. Vehicle count by state for all study vehicles.

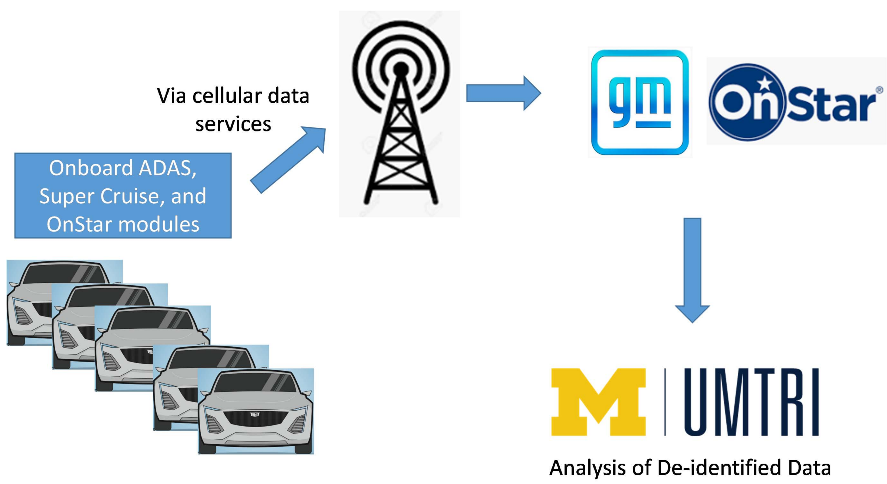

Figure 2. Data Collection Process.

This research mainly focused on how often, when, and where customers used Super Cruise, and examined safety surrogate measures. Super Cruise combines ACC and lane centering functionality, allows hands-free driving on compatible GPS-mapped roads, and uses a series of escalating alerts (e.g., a flashing green steering wheel light bar, as illustrated in Figure 3) to prompt the driver to pay close attention to the road ahead (monitored by a face camera). The system provides cues (including a flashing red steering wheel light bar) whenever the Super Cruise determines that the driver needs to take over steering control, referred to as "takeover requests". Examples of when such requests may occur include when there is a loss of system confidence that the driver is looking forward, when system limits are reached (e.g., leaving the system-compatible roads during a driver-initiated exit, or when lane markers are no longer detectable), or when system faults are detected (e.g., ice accumulating on a radar fascia). As advised in the Owner's Manual, when using Super Cruise, the driver is responsible for operating the vehicle in a safe manner and must remain attentive to traffic, surroundings, and road conditions, at all times. Note that Super Cruise uses a fusion-based ACC system employing both radar and camera sensors. ACC enhances conventional cruise control by allowing the vehicle to automatically follow a detected vehicle ahead at a driver-selected following gap, reducing the need for the driver to frequently brake and accelerate.

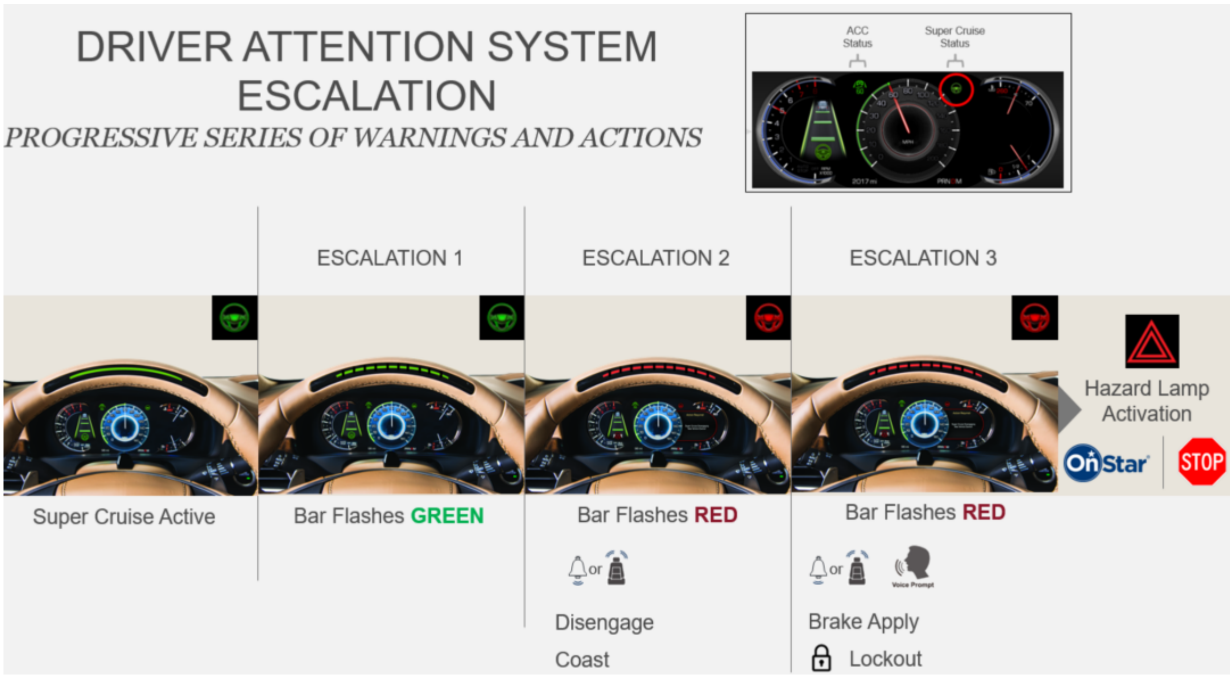

Figure 3. Illustration of Super Cruise driver-attention based cues (Note the Escalation 1 stage is bypassed for takeover requests not related to driver attention).

A secondary focus of this effort examined two camera-based features, FPB and camera-based ACC, the latter of which was compared to fusion-based ACC. FPB can help the driver avoid or reduce the severity of a front-end collision with a pedestrian the system detects directly ahead of the vehicle. The system provides pedestrian alerts and can automatically provide hard emergency braking or enhance the driver’s hard braking. The FPB is active at speeds below 50 mph and has limited performance at nighttime and in low visibility conditions. The driver can set the FPB system to “Off”, “Alert”, or “Alert and Brake”, with the latter factory default setting allowing automatic braking.

For studying Super Cruise, as shown in Table 1, two vehicle fleets were used. The Super Cruise “Equipped Fleet” consisted of 2,642 Cadillac CT6 sedans equipped with Super Cruise (model year 2018-2019) and the “Fusion ACC fleet” consisted of 1,196 CT6 vehicles (model year 2017-2019). This latter fleet was used for Super Cruise comparison purposes, sometimes referred to as the “Baseline Fleet”, was not equipped with Super Cruise but was otherwise similarly equipped with fusion-based ACC and high levels of ADAS feature content.

Table 1.

Vehicle fleets used to address research themes

	Super Cruise Fleet	**Fusion ACC Fleet**	**Camera ACC and FPB Truck Fleet**	**Camera ACC and FPB SUV Fleet**	**FPB without ACC Fleet**
Vehicles Used	2018-2019 Cadillac CT6	2017-2019 Cadillac CT6	2020 GMC Sierra, 2020 Chevrolet Silverado	2020 GMC Terrain, 2020 Chevrolet Equinox	2019 Chevrolet Cruze
Count	2,642	1,196	2,187	2,206	662
Super Cruise Analysis Role	Equipped Fleet	Baseline Fleet	n/a	n/a	n/a
Front Pedestrian Braking Analysis Role	n/a	n/a	Equipped Fleet	Equipped Fleet	Equipped Fleet
Camera ACC Analysis Role	n/a	Baseline Fleet	Equipped Fleet	Equipped Fleet	n/a

As shown in Table 1, the analysis of the camera-based Front Pedestrian Braking (FPB) system was based on a separate fleet totaling 5,055 vehicles, including a mixture of model year 2020-2021 GM truck, SUV, and sedans. Furthermore, the analysis of the camera-based ACC system involved three fleets composed of (1) 1,196 sedans with fusion ACC, (2) 2,187 trucks with camera ACC, and (3) 2,206 SUVs with camera ACC. This breakdown of the ACC fleets breakdown was done to address, to the extent possible, the issue that the different ACC sensing technologies examined (camera versus fusion) were confounded by vehicle types, which are also associated with different driver characteristics.

ANALYSIS AND RESULTS – SUPER CRUISE

The Super Cruise analyses was primarily restricted to the approximately 130,000 miles of Super Cruise-compatible roads associated with the early Super Cruise launch and known to be common across the Super Cruise fleet. The analyses used the open-source OpenStreetMap ("OSM") to define the road network, after it was established that the OSM's classification of "motorways" provided an appropriate surrogate for the early subset of Super Cruise-compatible roads (restricted to limited access freeways), as well as the subsequent "trunk road" expansion to a set of other divided highways with occasional at-grade intersections and driveways. The more limited amount of data gathered from "trunk roads" were included in the analyses reported below only when specifically mentioned.

Since the driving environment can importantly influence driver choices, five key environmental factors, listed below, were identified for use in statistical modeling.

- Urban environments were defined as driving within the 497 most populated urbanized areas across the US, as determined from the 2010 Census geometry file. These urbanized area polygons were smoothed into convex hull shapes for more efficient mapping of the driving data. This classification divided driving in these urbanized areas versus all other driving, irrespective of whether the "other driving" was truly rural or within an urban cluster (population of 2,500-49,999). Using this classification, driving segments were classified as "fully urban", "fully non-urban" or a "mixture" of urban and non-urban driving.
- The presence of rain was determined from calculations using a vehicle's location and nearby Meteorological Terminal Aviation Routine Weather Reports (METAR), which are available from the US National Oceanic and Atmospheric Administration. This data consists of weather station reports from several hundred locations across the United States.

- A free-flow traffic condition was defined as whenever the vehicle speed is travelling faster than 5 mph below the speed limit ([5], [6]). (Put in another way, the vehicle speed never falls more than 5 mph below the speed limit.)
- Speed limit was determined from OpenStreetMap data. For Motorway segments without this attribute, when available, a posted speed value was assigned from the closest preceding road segment.
- Light condition (i.e., day versus night) was defined here as a characteristic of ambient illumination without consideration of street lighting, which is not known from the data or maps. Driving segments were classified as "fully daylight", "fully night" or a "mixture" of day and night.

See [2] for further details of how these contextual variables are computed.

Analyses of Super Cruise

It should be noted that not all the analyses reported below use the entire set or same subset of driving data. For example, while the overall exposure data generally includes all driving data, analyses examining driving environment eliminated data from consideration when the telemetry data was not adequate to map the entire trip which is needed to identify driving on compatible roads.

Super Cruise usage descriptive results: Results indicated Super Cruise was engaged in 1,721,398 miles of driving (25,489 hours) in 304,376 separate system engagement events. The median vehicle in the Super Cruise fleet travelled 8,178 miles with Super Cruise engaged. Of the Super Cruise vehicles which had at least 100 miles of travel and were driven at least once on a motorway, 72% engaged Super Cruise at least once. When the various enabling conditions required for Super Cruise use were met (e.g., driving on a compatible road, ACC enabled, lane lines detected, vehicle centered in the lane, etc.), the system was engaged for 45% of the distance travelled. When only considering if the Super Cruise-equipped vehicle was on a motorway (irrespective of other enabling conditions required for use), Super Cruise was engaged for 18% of motorway travel distance. Furthermore, as shown in Table 2, for vehicles with at least one Super Cruise engagement, 54% of such vehicles had the system engaged for more than 10% of motorway travel, whereas 14% had the system engaged for more than 50% of motorway travel.

Table 2.

Fraction of motorway distance with Super Cruise engaged for vehicles with at least one Super Cruise engagement (irrespective of various enabling conditions required for use)

Percent distance engaged, compared to all motorway distance traveled (irrespective of various enabling conditions required for use)	Vehicles with this engagement level	Percent of vehicles with motorway engagements
Engaged greater than 0 % of distance	1838	100%
Engaged greater than 10 % of distance	996	54%
Engaged greater than 25% of distance	651	35%
Engaged greater than 50% of distance	265	14%
Engaged greater than 75% of distance	42	2%

Driving context influence on Super Cruise usage: The influence of driving context on Super Cruise usage on motorways was examined using two different measures. The first measure, "engagement rates", captures whether Super Cruise was engaged at any point during a motorway driving segment, defined as driving from the time the vehicle entered a Super Cruise-compatible motorway to the time it was no longer on a system compatible motorway.

A second measure, “usage proportion”, captured the proportion of time Super Cruise was engaged during motorway driving segments including Super Cruise engagements.

Results within the Super Cruise fleet indicated a consistent pattern of reduced Super Cruise engagement rates, as well as reduced system usage proportions, when driving during the daytime, in the rain, on urban or mixed urban/rural roads, in non-free flow traffic, and in traffic congestion. Table 3 shows the odds ratios comparing the fixed effect to its corresponding baseline (e.g., the second row indicates the odds of engagement in daytime is 0.76 times the odds of engaging at night). A second analysis indicated that, when compared to manual driving, Super Cruise engaged and ACC engaged driving were similarly influenced by the environmental factors examined above. In addition, this second analysis also examined road curvature, with results indicating that Super Cruise and ACC were less likely to be engaged on curved roads, with curved roads defined as those in the top 20% of curvature (which generally were for curve radii of less than 1780 meters).

Overall, the pattern of these driving context findings suggests that drivers tend to engage Super Cruise more often, and leave the system on longer once engaged, when there is less surrounding traffic (e.g., free-flow and night effects), and the roadway environment is less complex (e.g., rural, non-rain). As shown in Table 3, the magnitude of effect for free-flow and congestion are much larger than the other factors, suggesting that traffic was a major factor in determining Super Cruise use. This observation was corroborated by the second analysis, which further indicated that free-flow was the dominant condition for Super Cruise use, with 73% of engaged driving occurring without encountering any non-free-flow conditions during the engagement. Results from the engagement analysis also suggested substantial vehicle-to-vehicle variability in the driver choice to use Super Cruise at all. In addition, while vehicles that made multiple trips per day were more likely to engage Super Cruise at least once, results indicated that system usage proportion (when engaged) was not affected by the number of trips per day.

Table 3.

Statistically significant odds ratios for fixed effects predicting probability of Super Cruise engagement and proportion of time Super Cruise was engaged given an engagement occurred)

Fixed Effect	Odds Ratio for Probability of Engagement	Odds Ratio for Proportion of Time Engaged
Segment Duration (log)	2.10	1.22
Daytime - Day (vs. Night)	0.76	0.88
Daytime - Mix (vs. Night)	0.77	0.93
Rain - Low level (vs. None)	0.93	0.94
Rain - Med level (vs. None)	0.80	0.92
Rain - High level (vs. None)	0.75	0.81
Urban - Urban (vs. Not urban)	0.81	0.88
Urban - Mix (vs. Not urban)	0.84	0.89
Proportion of Time in Free-flow[2]	2.57	1.34
Proportion of Time Congested[1,3]	0.38	0.34
Driver Trips/Day 2-4 (vs. 1)	1.29	--
Driver Trips/Day >4 (vs. 1)	2.06	--

Effects of Super Cruise on travel speed: Within the Super Cruise fleet (which allows ACC use without Super Cruise engaged), travel speeds relative to the speed limit were examined across vehicle control modes (Super Cruise engaged, ACC engaged, manual driving) using median and maximum speed measures (while controlling for vehicle and road segment effects). As shown in Table 4, results for the median speed measure indicated that speeds in free-flow traffic were approximately the same in all three vehicle control modes, and near the speed limit. In non-free flow traffic, median speeds during Super Cruise engagements were almost 2 mph faster relative to manual driving. The corresponding maximum speed analysis (again, relative to the speed limit) indicated that, relative to manual driving, maximum speeds during Super Cruise engagements were lower in free-flow traffic (-1.15 mph for Super Cruise, -1.50 mph for ACC), with this pattern reversing in non-free-flow traffic (+0.81 for Super Cruise, +0.61 mph for ACC).

Overall, it should be noted that Super Cruise engagements were more common in free-flow traffic (as reported above), where median and maximum speeds did not exceed those of manual driving. It should also be kept in mind that, while statistically significant, the speed differences reported are smaller than the observed vehicle/driver and road segment effects. Put in another way, the variability in driver behavior and road segment environment produced greater differences in the travel speed than the vehicle control mode.

[2] These factors are continuous rather than binary/categorical like the other factors. As such, the listed effects are for a shift from none (0.0) to all (1.0) of the segment meeting the stated criteria. For example, a 10% increase in free-flow traffic produces an odds ratio of 1.1.
[3] Time congested is defined as the time during which the vehicle speed is less than half the posted speed limit.

Table 4.

Estimated change in median and maximum speeds (mph) relative to speed limit for both ACC and Super Cruise driving relative to manual driving

Fleet	Control Level	Median Speeds Relative to Speed Limit		Maximum Speeds Relative to Speed Limit	
		Free-flow	Not Free-flow	Free-flow	Not Free-flow
Super Cruise	Super Cruise	+0.10	+1.99	-1.15	+0.81
	ACC	-0.19	+1.92	-1.50	+0.61
Fusion ACC	ACC	-0.31	+3.40	-1.92	+1.41

Super Cruise engagement durations: The mean duration of a Super Cruise engagement was 5.1 minutes, with 15^{th}, 50^{th}, 85^{th} percentile values of 24 seconds, 2.6 minutes, and 9.4 minutes, respectively. (At the individual vehicle level, the corresponding 15^{th}, 50^{th}, 85^{th} percentile engagement duration values were 2.8, 4.8, and 8.3 minutes, respectively.) The median time between successive Super Cruise engagements in the same ignition cycle was 49 seconds. A Super Cruise takeover request (TOR) was observed every 8.8 minutes of engagement time. Overall, these findings suggest that there is considerable variation in the duration and nature of Super Cruise engagements.

Steering over-ride events: In 57% of Super Cruise engagements, one or more Super Cruise steering override events occurred with an 85^{th} percentile duration of 9 seconds. These events occur when active driver steering is detected during a Super Cruise engagement (e.g., the driver is steering to make a lane change) and Super Cruise acknowledges the override to the driver and temporarily does not provide automatic steering control. (Note the model years in this study did not include an automatic lane change feature, which has been offered on Super Cruise vehicles since model year 2021.)

Driver attention cues: In 47% of Super Cruise engagements, one or more times the driver attention system prompted the driver with alert cues to pay more attention to the forward scene. (These cues could also occur if the system lacked confidence in tracking eye/head position.) If the driver did not respond appropriately to this first stage attention reminder, a subsequent takeover request (TOR) required the driver to take active steering control of the vehicle. When an attention reminder was given, the driver was observed to resolve 91% of these reminders without further Super Cruise escalation alert prompts.

Takeover requests (TORs): In order to gain insights into transfers of vehicle control, particularly those from Super Cruise to the driver, the source of TORs was examined using all TOR cases where high quality data (e.g., vehicle location) were available during motorway travel, which resulted in 137,548 cases. TORs may occur for a variety of reasons, all of which require the driver to take steering control of the vehicle. Results indicated that:

- 58% of TOR disengagements were due to a detected system limit condition (e.g., lane markers are no longer detected, the vehicle is no longer on a GPS-mapped compatible roadway)
- 24% of TORs occurred after a driver attention reminder had been issued
- 12% of TORs occurred during a detected steering override mode (e.g., if drivers steer onto an exit ramp)
- 4% of TORs were due to detecting drivers disengaging Super Cruise (e.g., pressing the brake) without taking control of steering
- 2% of TORs were associated with system faults detected by an internal system health check

These results clearly suggest that care needs to be taken not to treat TORs identically in safety-related analyses, since TORs may be triggered by driver behavior or system limitations/faults, and such TORs may be anticipated by the driver or occur unexpectedly. Irrespective of the cause of the TOR, if the driver does not take steering control promptly, Super Cruise TORs can lead to a higher-level alert escalation where a driver detected to be non-responsive is locked out of Super Cruise use for the entire ignition cycle. Such lock-outs were observed in 32% of vehicles with one or more Super Cruise engagements. If the driver still does not take control promptly during this higher-level alert escalation, Super Cruise will eventually bring the vehicle to a stop in its travel lane. Six such stopped cases were observed. In four cases the vehicle was at a low travel speed (below 14 mph) in the minute prior to the event, suggesting 'stop and go' driving. In the remaining two cases the travel speed was over 60 mph. In all cases, driving continued after the event for at least three miles. The underlying reasons for these cases are unknown and cannot be determined with the available data. For example, these events could have occurred due to the driver not responding to the TOR (e.g., due to distraction, falling asleep, impairment, or other health reasons), unsuccessfully responding to the TOR (e.g., steering takeover attempted but not detected by the system), or choosing not to respond to the TOR (e.g., experimenting with system functionality).

TOR duration times: TOR durations are defined as the time between the TOR request and when Super Cruise detected the driver had taken over steering control. By Super Cruise design, the system requires that a TOR lasts at least 1 second. Additionally, since TOR durations were based on 1 Hz reporting of Super Cruise state changes, there were inherent limitations on duration accuracy. Consequently, the approach taken here was to focus on larger differences in durations while avoiding over-interpretation of the absolute duration values.

A linear regression model was fitted to predict the duration of the TOR types described above, the log of the time into the trip (to capture any trip duration effects), and a modeling of the vehicle/driver as a random effect in order to consider individual differences. The modeled TOR durations at 45 minutes into a trip is shown in Table 5using the five TOR categories introduced earlier. The 45-minutes value was used since it corresponded to the average time that a TOR occurs in a trip. Results indicated that TOR durations associated with driver steering overrides and driver disengagements were shorter than those TORs associated with attention reminders, system limit, and system fault conditions. This pattern may be explained by the driver more readily anticipating driver-initiated TOR types. Results also indicated that the TOR durations were slightly shorter for longer trips. For example, a TOR occurring 15 minutes into a trip is approximately 0.2 sec longer than one occurring 56 minutes into a trip.

Table 5.

Modeled average TOR duration (in seconds) at 45 minutes into a trip across TOR types

TOR Type	Driver Steering Override	Driver Disengagement	Attention Reminder	System Limit	System Fault
Average Duration at 45 minutes into Trip	1.73	1.75	2.66	2.77	2.72

Advanced Automatic Crash Notification (AACN) events: No AACN events were observed on Super Cruise compatible roads for either the Super Cruise or baseline fusion ACC fleets during data collection.

Effects of Super Cruise on harder braking events: To further explore safety-related measures beyond actual crash events, the presence of longitudinal decelerations exceeding 2.6 m/s^2 (defined as “harder braking”) was compared between Super Cruise engaged driving versus a combined set of manual and ACC driving for location- and time-matched driving segments. A conditional logistic regression analysis was used, under which matched driving segments were identified by finding segments of continuous Super Cruise engaged driving, and then identifying “matched” passes over the same segments of road in continuous manual/ACC driving that was at approximately the same time of day (within four hours). Table 6 shows the results in terms of odds ratios for four comparisons. The analysis indicated that the presence of harder braking exceeding 2.6 m/s^2 was 1.7 (or 1/0.58) times more likely in manual/ACC driving than Super Cruise engaged driving, indicating Super Cruise use is associated with fewer cases of harder braking relative to a combined set of ACC/manual driving. Likewise, the increase in the proportion of free-flow decreases the likelihood of harder braking events (i.e., each 10% increase in free-flow driving decreases the odds of an event by 0.65), and the likelihood is 4.24 times more likely for passes in daytime versus nighttime (possibly related to surrounding traffic levels).

Table 6.

Estimated Super Cruise (versus ACC/manual) driving effect magnitude from conditional logistic regression model for harder braking events exceeding 2.6 m/s²

Factor	Estimated Odds Ratio
Super Cruise (vs. ACC/Manual)	0.58
10% increase in proportion of free-flow	0.65
Day/Night mixture (vs. nighttime)	0.52
Fully daytime (vs. nighttime)	4.24

Peak deceleration events after disengagements: In addition to examining harder brake events under general driving, a focused analysis was conducted to examine peak longitudinal decelerations immediately following a Super Cruise disengagement. This analysis compared the likelihood of peak longitudinal decelerations exceeding a sequence of thresholds (from 0.5 m/s^2 to 2.6 m/s^2) five seconds after a disengagement for different disengagement types~~,~~ relative to location- and time-matched combined manual/ACC driving segments.

Disengagements were divided into five mutually exclusive categories. The first two "No TOR" categories, shown in rows 2 and 3 of Table 8, identified Super Cruise disengagements that did not result in a TOR. These "No TOR" cases were further divided into cases based on the presence of a highway exit within 30 seconds following the disengagement. The remaining three categories shown in Table 7 separately distinguished between disengagements that produced a TOR, including attention-based disengagements (that were preceded by a flashing-green attention reminder) and non-attention disengagements (which were further divided as indicated above into highway exit and no exit categories). Highway exits were distinguished from non-exits since highway exiting can create a distinctly different deceleration profile than general (non-exit) highway driving, and furthermore, highway exiting while in Super Cruise initiates a handoff of control from the system to the driver (whereas a non-exit disengagement can be due to variety of other reasons). In summary, the disengagement categorization approach used here was based on the joint consideration of the presence of attention reminder escalations, exit-related disengagements, and the presence of a TOR.

For each Super Cruise disengagement, matched baseline passes in manual/ACC driving were required to (1) come from the same vehicle, (2) follow the same sequence of OSM road segments (current, previous, and following), (3) share the same exiting behavior in the next 30 seconds and (4) occur at approximately the same time of day. For each baseline pass, a "phantom" disengagement was placed at the point in the pass closest to the location of the disengagement associated with the matching Super Cruise pass. Next, the presence of peak decelerations exceeding five different thresholds during the five seconds following the actual or phantom disengagement was recorded. Conditional logistic regression was then used to evaluate whether the passes with Super Cruise disengagements had a higher likelihood of exceeding deceleration thresholds than the baseline passes (distinguishing between the type of disengagement and controlling for travel speed, the presence of rain, and weekday versus weekend travel). Since disengagements do not occur randomly and are often associated with some level of deceleration (e.g., disengaging due to stopped traffic ahead and slowing to a stop), a large odds ratio for disengagement type might not actually be indicative of a potential safety concern. To address this issue, the disengagement type odds ratios for each deceleration threshold were standardized against the matching odds ratio for the -1.0 m/s^2 case, as shown in Table 7. If the normalized odds ratios remained near one, then the braking profile in the disengagement cases was interpreted to be similar to normal human braking under "matched" conditions. For normalized odds ratios greater than one, braking above that threshold was interpreted to be more prevalent after a disengagement relative to matched baseline cases controlling for the braking characteristic associated with disengagements. Similarly, odds ratios less than one were interpreted in the opposite fashion.

The results shown in Table 7 indicated that for disengagements categorized as related to either exiting the motorway onto a ramp (where Super Cruise is designed to disengage) or a driver attention escalation, the pattern of results was similar to the combined set of manual and ACC driving, except for a higher concentration of low-level decelerations. This latter finding is consistent with the use of a throttle off disengagement cue, which is intended Super Cruise design. For the "TOR, Non-Exit" condition, there was a significantly higher probability of exceeding the 1.5, 2.0, and 2.6 m/s^2 criteria than in manual/ACC driving (compared to the -1.0 m/s^2 case). (A similar non-significant trend can be observed in the "No TOR, Non-Exit" condition.) The cause of this trend is presently not clear, because the data available do not distinguish between driver and system braking. Plans are in place to further examine this finding in an ongoing follow-on study using the telematics-based data collection approach employed here.

Table 7.

Normalized odds ratios for likelihood of Super Cruise driving passes exceeding various deceleration thresholds compared to baseline passes across disengagement types (asterisks indicate confidence intervals do not overlap with the corresponding interval for the 1.0 m/s^2 estimate)

Disengagement Type	Deceleration Threshold				
	-0.5 m/s^2	-1.0 m/s^2	-1.5 m/s^2	-2.0 m/s^2	-2.6 m/s^2
No TOR, Highway Exit	1.45 *	1.00	0.83	0.76	0.97
No TOR, Non-Exit	0.90	1.00	1.07	1.09	1.16
TOR, Driver Attention Escalation	10.13 *	1.00	0.81	0.57	0.70
TOR, Highway Exit	1.50 *	1.00	0.90	0.88	0.73
TOR, Non-Exit	1.02	1.00	1.22 *	1.56 *	2.21 *

ANALYSIS AND RESULTS – FRONT PEDESTRIAN BRAKING (FPB)

Results indicated that 98.3% of the vehicles kept FPB set to "Alert and Brake" for the entire study duration (which is the factory default setting allowing automatic braking), suggesting widespread acceptance of the feature. FPB alert and FPB automatic braking events were observed at a rate of 25.8 and 0.17 per 100,000 miles, respectively. While 67% percent of the FPB-equipped vehicles issued at least one FPB alert, only 1% of the vehicles issued a FPB automatic braking event. An examination of these latter events indicated 45% occurred away from public roads (e.g., in parking lots or car dealerships), 22% occurred on residential roads, and 9% occurred on motorways.

The mean speeds at FPB alert and FPB automatic braking onsets were 21.8 mph and 14.9 mph, respectively, with associated 85th percentile speeds of 36.2 mph and 25.4 mph, respectively. While the observed peak decelerations near FPB alert and automatic braking events support that driver braking and/or FPB automatic braking occurred, only 4.8% of the FPB automatic braking events exceeded -4.0 m/s^2 deceleration levels.

ANALYSIS AND RESULTS: CAMERA-BASED ADAPTIVE CRUISE CONTROL (ACC)

The first ACC analysis examined the probability of ACC engagement during a trip, and if engaged, the proportion of the trip for which ACC was engaged. Similar to the corresponding Super Cruise analysis reported above, ACC was more likely to be engaged in contexts with less surrounding traffic (e.g., free-flow, nighttime) and less complex roadway environments (e.g., rural, non-rain). Results also demonstrated a preference for ACC use on motorway trips, likely reflecting greater use during high-speed travel. As in the Super Cruise analysis, the presence of free-flow traffic was a large factor in determining engagement. Note that in Table 8 the effects for free-flow, congestion and motorway travel are for 10% increases in the proportion of the trip meeting the criterion for that factor. This was done here to improve the interpretability given that the analysis was at the trip rather than driving segment level (fully free-flow travel being less plausible across an entire trip). Furthermore, results indicated ACC was more likely to be engaged during a trip for both the camera-based ACC fleets (SUVs and trucks) compared to the fusion-based

ACC sedan fleet. However, the proportion of the trip for which ACC was engaged was not different across the three groups examined. In addition, within the two camera-based ACC fleets, SUVs (compared to trucks) were less likely to engage ACC and had a greater proportion of complete non-ACC users, likely due to vehicle type and/or driver characteristics rather than ACC technology type.

As shown in Table 9Table 9, the second ACC analysis indicated all three ACC groups showed the odds of harder braking (i.e., exceeding 2.6 m/s^2 longitudinal deceleration) were reduced relative to manual driving, providing evidence similar to the Super Cruise findings reported earlier that ACC systems helped avoid motorway situations in which harder braking may be required. Although this data trend was less true for camera ACC SUVs, there was not significant evidence of a difference in this ACC effect between vehicle types, and this trend does not appear to be attributable to ACC technology type when accounting for the confounding of vehicle and ACC technology types in this analysis.

Table 8.

Estimated odds ratios for fixed effects predicting probability of ACC engagement and proportion of time that ACC was engaged given an engagement occurred (NS indicates non-significance in the difference)

Fixed Effect	**Odds Ratio for Probability of ACC Engagement**	**Odds Ratio for Proportion of Time Engaged**
log-Trip Duration	2.10	1.22
Camera ACC SUV (vs. fusion ACC Sedan)	1.70	*1.11* (NS)
Camera ACC Truck (vs. fusion ACC Sedan)	2.26	*1.01* (NS)
Daytime - Day (vs. Night)	0.56	0.79
Daytime - Mix (vs. Night)	0.61	0.87
Rain - Low (vs. None)	0.84	0.89
Rain - Med (vs. None)	0.60	0.89
Rain - High (vs. None)	0.51	0.85
Urban - Urban (vs. Rural)	0.14	0.47
Urban - Mix (vs. Rural)	0.89	0.83
10% Increase in Prop. of Time in Free-flow[4]	1.52	1.18
10% Increase in Time Congested[3]	0.98	--
10% increase in Time on Motorways[3]	1.38	0.99
Rush Hour – Yes (vs. No)	0.87	0.93
Weekday – Yes (vs. No)	0.84	0.92

[4] These factors describe the probability of engagement and time engaged per 10% increase in proportion of time rather than a binary comparison like the other factors.

Table 9.

Estimated odds ratios for ACC/vehicle type effect on harder braking (-2.6 m/s^2) from conditional logistic regression model

ACC technology/ Vehicle Type	Estimated ACC Effect (Odds Ratio vs. Manual Driving)
Fusion ACC Sedan	0.60
Camera ACC SUV	0.73
Camera ACC Truck	0.59

CONCLUSION

The primary aim of this effort was to evaluate aspects of the Super Cruise feature, which is consistent with SAE Level 2 automation terminology. This telematics-based effort, coupled with recent efforts to examine Super Cruise field effects using police-report data [7], represent groundbreaking approaches for understanding the real-world usage and the safety impacts of emerging L2 systems.

Drivers' use of Super Cruise largely mirrored their use of the well-established fusion-based (radar and camera technology) ACC feature, with usage levels similarly reduced under heavier traffic and more complex roadway environments relative to manual driving. This selective use pattern is generally consistent with the vehicles' owner's manual which cautions that Super Cruise should not be used in complex or uncertain conditions. The data also indicated that some drivers use Super Cruise substantially (14% of vehicles were engaged more than half of their motorway travel distance) and that drivers generally experienced frequent transitions and interactions with the system, including executing short-lived steering overrides (e.g., to change lanes), receiving and responding to driver attention prompts, and responding to takeover requests. Together with the relatively modest median Super Cruise engagement duration of 2.6 minutes, these findings suggest drivers use Super Cruise selectively and have generally fewer harder braking events when Super Cruise is engaged. As a follow-on to the Super Cruise effort reported here, a second similar study is being conducted with model year 2021 Super Cruise-equipped vehicles which includes lane change on demand functionality and other system enhancements.

As a secondary focus of this effort, findings for the newer camera-based ACC feature indicated usage patterns and lower rates of harder braking (relative to manual driving) similar in nature to those observed for the fusion-based ACC feature. This comparison, however, was complicated by the confounding of ACC technology with vehicle type (sedan, truck, or SUV). For the camera-based FPB feature, results indicated extremely high feature usage (acceptance), that automatic braking events occurred once per 590,000 miles and mostly on lower-speed private and residential roads, with 4.8% of such events were associated with braking exceeding -4.0 m/s^2.

This was the latest in a series of NHTSA-funded large-scale telematics-based studies aimed at characterizing the usage, performance, and safety-related events surrounding production ADAS features under real-world, customer use conditions [3,4]. The findings in this paper continue to illustrate the distinct advantage of this telematics-based approach for studying infrequent safety-related events. These telematics studies can provide timely and cost-efficient understandings of driver usage and safety under real-world driving conditions without influencing the driver behavior through experimental artifacts that can appear in corresponding smaller instrumented vehicle, on-board data acquisition system (DAS) studies.

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