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Impact of Access Management on Driver Behaviors

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16. Abstract

This project started with a broad question: What can new, rich naturalistic driver data such as in the Second Strategic Highway Research Program's Naturalistic Driving Study (SHRP2-NDS), tell us about how drivers react to roadway designs and access management techniques? To address this question, the project team reviewed and analyzed 6,209 trips that drivers in the NDS took through 40 circular intersections across five States. Coders flagged several types of driver behavior and captured a broad range of contextual variables. The analysis team used traditional statistics and machine learning methods to understand (1) when driver hesitation or uncertainty is most likely, and (2) general patterns and trends in driver hesitation or uncertainty. The team found that driver age is the most important predictor of hesitation or uncertainty with drivers' engagement in secondary tasks being a strong second. The findings presented here suggest further development and dissemination of educational or informational materials could mitigate drivers' hesitation or uncertainty in circular intersections and thereby improve traffic safety.

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Executive Summary

This report features the results of the project, “Impact of Access Management on Driver Behaviors,” which the U.S. Department of Transportation’s Volpe Center (Volpe) conducted for the National Highway Traffic Safety Administration and Governors Highway Safety Association (GHSA) under the National Cooperative Research and Evaluation Program . This project started with a broad question: What can new, rich naturalistic driver data such as in the Second Strategic Highway Research Program’s Naturalistic Driving Study (SHRP2-NDS), tell us about how drivers react to roadway designs and access management techniques (AMTs)? Access management is defined by the Federal Highway Administration (FHWA) as “a set of techniques that State and local governments can use to control access to highways, major arterials, and other roadways. Access management includes several techniques that are designed to increase the capacity of these roads, manage congestion, and reduce crashes” (FHWA, 2022a).

The project team reviewed the literature on roadway designs and access management and then reviewed the SHRP2-NDS metadata to determine which techniques were most suitable to study. The list included road diets, roundabouts, speed humps, bulbouts, and left-turn conflict intersections. After reviewing the possibilities, Volpe selected circular intersections (including roundabouts and similar traffic calming circles but not rotaries) for study largely based upon feasibility; they have already been identified in the NDS.

The project team partnered with analysts at the Virginia Tech Transportation Institute (VTTI) to review and analyze 6,209 trips that drivers in the NDS took through 40 circular intersections across five States. Coders flagged instances of driver behavior that could be characterized as hesitation or uncertainty and captured a broad range of contextual variables. The signs of hesitation could include sudden, unnecessary, and/or lack of deceleration, acceleration, or steering maneuvers in a place or at a rate that the analyst deems to be inappropriate or unsafe for conditions. It also could include apparent indecisiveness as to how or when to enter or exit the circle or which lane to be in. However, maneuvers that were part of an evasive response to a safety critical incident are not considered inappropriate or unsafe.

The analysis team used inferential statistics and “Random Forest” machine learning to understand the factors that predict hesitation or uncertainty. The team also identified patterns and trends in driver behaviors across the entire data sample. Driver age was a primary predictor of driver behaviors consistent with hesitation or uncertainty, and drivers’ engagement in secondary tasks—such as eating or cell phone usage—was a strong second. Circular characteristics, including the number of lanes and circle diameter, had smaller effects on driver behaviors. The findings suggest further development and dissemination of educational or informational materials regarding driving in circular intersections could mitigate drivers’ hesitation or uncertainty and thereby improve traffic safety.

Background

In keeping with its mission, NHTSA partners with traffic safety organizations to engage in cooperative research programs. Volpe conducted a study evaluating roadway designs and AMTs for NHTSA and GHSA under the National Cooperative Research and Evaluation Program. GHSA selected this project with the original problem statement of identifying roadway designs and AMTs and quantifying their impacts on driving behaviors using available naturalistic data.

Selection of Roadway Designs and AMTs

In the first step, Volpe developed a list of prioritized roadway designs and AMTs for potential analysis using the SHRP2-NDS dataset. Two questions guided the development of the list.

1. How likely is this roadway design or AMT to be proposed for future installations?
2. Is there evidence of driver behavior-related issues when drivers navigate the roadway design or AMT?

The following sections summarize the major findings from the literature review and interviews with subject matter experts (SMEs). The nine SMEs interviewed for this study were experts in the deployment of roadway designs and AMTs that included roundabouts and road diets. The purpose of these interviews was to get an initial orientation to the main issues often faced by State Departments of Transportation when installing roadway designs and to receive expert guidance on the relative importance of findings expressed in the literature.

Road Diets

A road diet or roadway reconfiguration typically involves converting an existing four-lane undivided roadway to a three-lane roadway consisting of two through lanes and a center two-way left-turn lane (FHWA, 2022b; Knapp et al., 2014). Figure 1 shows the before and after design of a road diet.

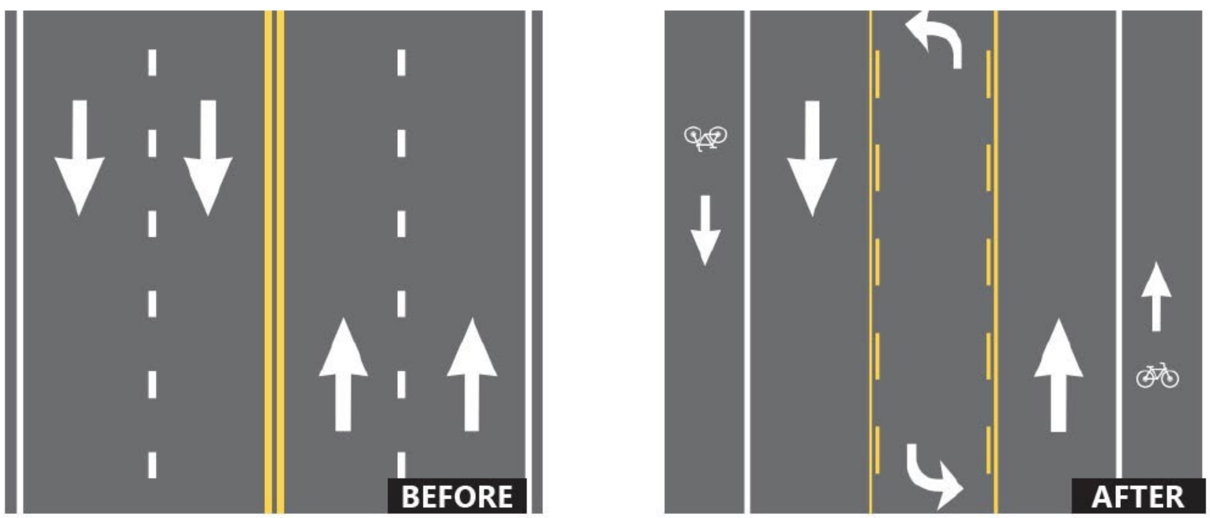

Figure 1. Before and after design of road diet

(Source: FHWA, 2022b)

Likelihood of Use in the Future

The road diet is an FHWA "Proven Safety Countermeasure," and the safety benefits may include reductions of "rear-end and left-turn crashes due to the dedicated left-turn lane" and "right-angle crashes as side street motorists cross three versus four travel lanes" (FHWA, 2022b). Therefore, they are likely to be used in the future.

Driver Issues

The research, including the input from the experts, did not identify any clear or common driver issues related to road diets.

Roundabouts

A roundabout is a circular intersection design featuring channelized, curved approaches that reduce vehicle speed, entry yield control that gives right-of-way to circulating traffic, and flow around a central island that minimizes conflict points (FHWA, 2022c). Figure 2 shows a multi-lane roundabout.

Figure 2. Illustration of a multi-lane roundabout

(Source: FHWA, 2022c)

Likelihood of Use in the Future

The roundabout is an FHWA Proven Safety Countermeasure, and the safety benefits from lower speeds and reduced conflicts at roundabouts substantially reduces crashes that cause injury or fatality (FHWA, 2022c). Therefore, they are likely to be used in the future.

Driver Issues

Research, including input from the experts, identified few concerns regarding roundabouts for drivers in the U.S., and crash rates for roundabouts are widely known to be low.

Speed Humps

A speed hump is a paved traffic calming design with raised road at the center and extending the full width of the street (FHWA, 2022d). Unlike speed bumps, speed humps tend to extend in length four or more feet in the direction of travel, leading to a relatively smooth ride over them. Speed humps are designed to reduce vehicle speeds, thereby improving the pedestrian environment and sense of safety. Figure 3 illustrates the difference between a speed hump and a speed bump.

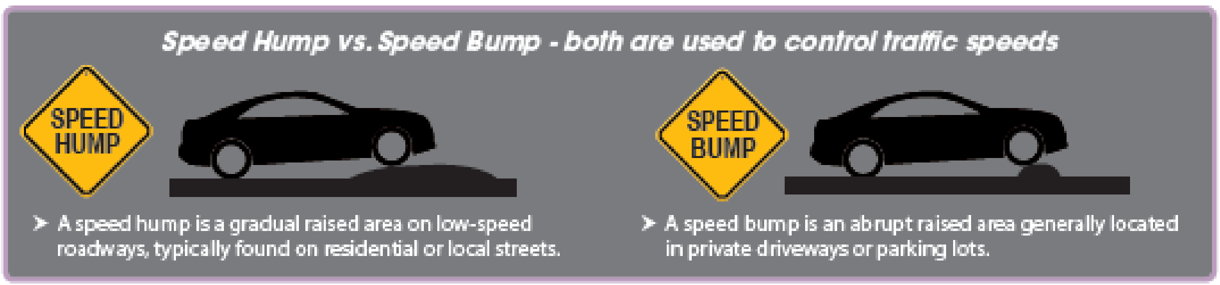

Figure 3. Speed hump versus speed bump

Source: (FHWA, 2022d)

Likelihood of Use in the Future

Speed humps are included in the FHWA Traffic Calming ePrimer (FHWA, 2017), but they were not listed as an FHWA Proven Safety Countermeasure (FHWA, 2021a).

Driver Issues

Issues associated with speed humps include the following:

- Diversion to side streets or travel outside of travel lanes by drivers to avoid the traffic device (Garcia et al., 2011),
- Sudden braking and accelerating, which can increase the likelihood of rear-end crashes (Pau, 2002),
- Diverting driver attention from other road users to the speed bump itself (Pau, 2002), and
- The possibility of drivers speeding between speed humps to make up time when the spacing between consecutive speed humps is not designed properly.

Bulbouts

Bulbouts, also known as curb extensions, are horizontal extensions of the sidewalks into the streets resulting in narrower roadway sections. They reduce street width to improve pedestrian crossing abilities, increase driver visibility at corners, and reduce vehicle speeds (FHWA, 2017).

Likelihood of Use in the Future

Bulbouts are included in the FHWA Traffic Calming ePrimer (FHWA, 2017), but they are not listed as FHWA Proven Safety Countermeasures (FHWA, 2021a). As such, they are less likely to be used than the other designs and techniques.

Driver Issues

Design tradeoffs of bulbouts identified in the project team's research did not include safety-related driver issues. Research suggested that previous studies tried unsuccessfully to find such effects, which would suggest that deeper study would not be fruitful.

Reduced Left-Turn Conflict Intersections

Reduced left-turn conflict intersections are geometric designs that alter how left-turn movements occur. These intersections simplify decision-making for drivers and minimize the potential for higher severity crash types, such as head-on and angle. Two highly effective designs that rely on U-turns to complete certain left-turn movements are known as the Restricted Crossing U-turn (RCUT) and the Median U-turn (MUT). The RCUT intersection, also known as a J-turn, Superstreet, or Reduced Conflict Intersection, modifies the direct left-turn and through movements from cross-street approaches. The MUT intersection modifies direct left turns from the major approaches (FHWA, 2021b).

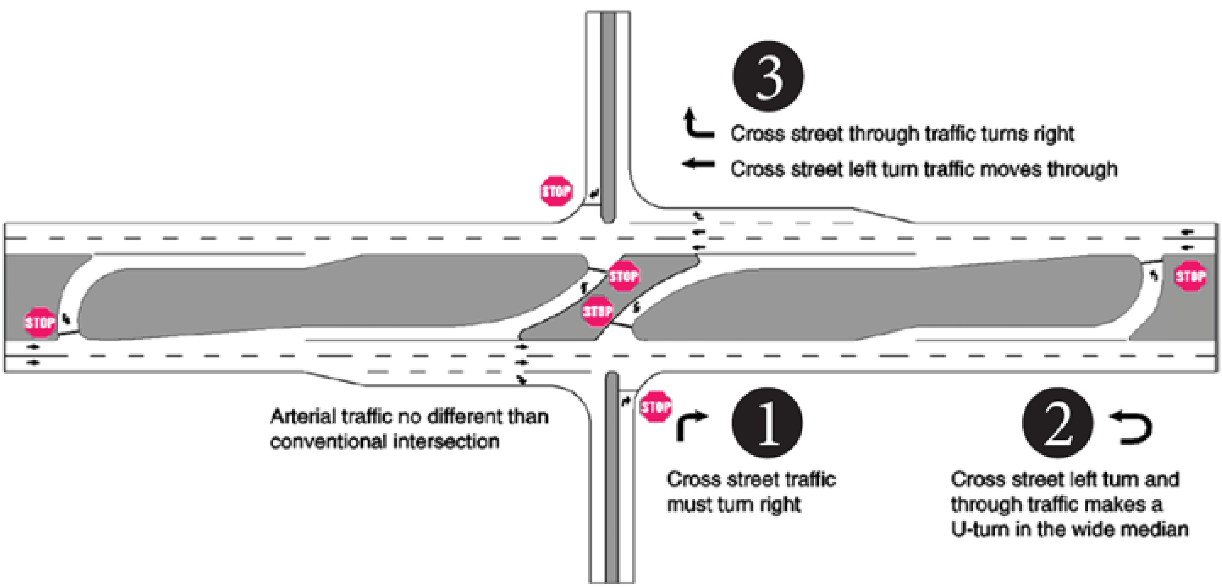

Figure 4. Example of an unsignalized RCUT intersection

(Source: FHWA, 2021b)

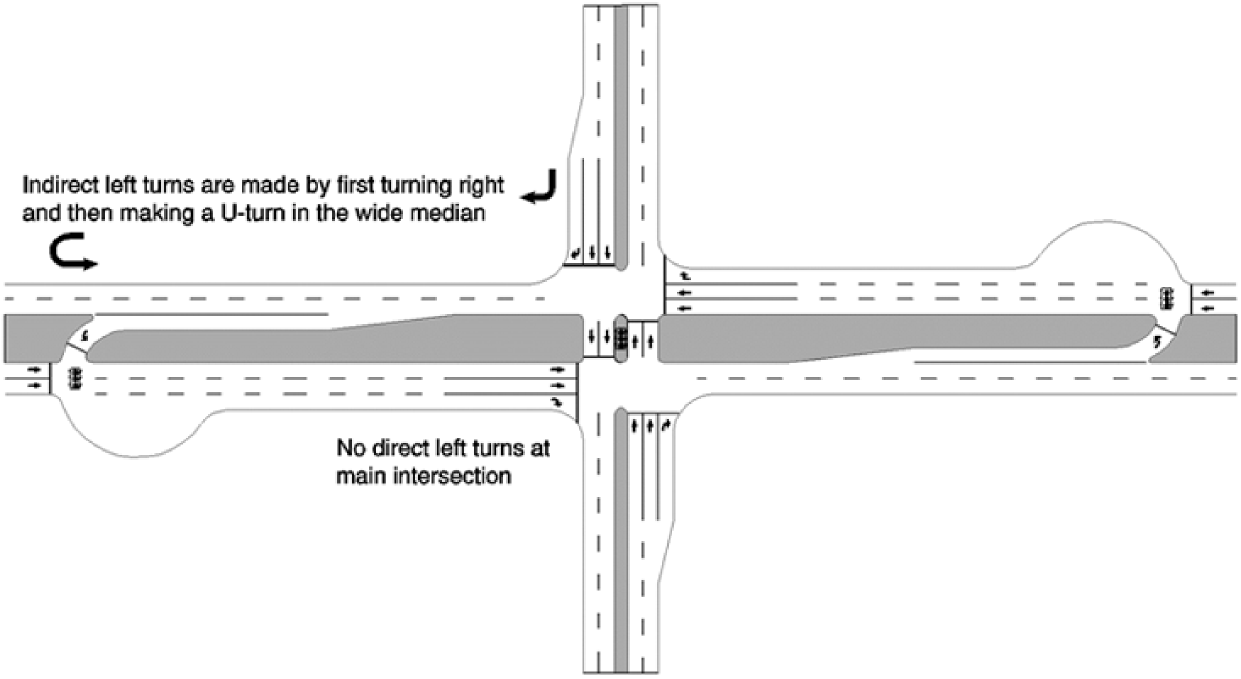

Figure 5. Example of a MUT intersection

(Source: FHWA, 2021b)

Likelihood of Use in the Future

FHWA identified the left-turn conflict intersection designs of RCUT and MUT as Proven Safety Countermeasures (FHWA, 2021b). According to FHWA, these intersections simplify decision-making for drivers and reduce fatalities and injuries by reducing higher severity crash types such as head-on and angle. Therefore, they are likely to be used in the future.

Driver Issues

No major or common issues were identified, and there were no safety-related concerns expressed by the experts.

Summary

Table 1 summarizes the findings from the first step of the study. Based upon the results, the team decided to drop bulbouts from potential further study. The other four designs and treatments were considered for the second step of analysis using SHRP2-NDS.

Table 1. Summary of findings for roadway designs and AMTs

Roadway Designs and AMTs	Driver Behaviors of Note	Predicted Likelihood of Future Use
Road Diets	No major or common issues identified	High
Roundabouts	No major or common issues identified	High
Speed Humps	Maneuvering to avoid Attention focused on speed hump itself Hard acceleration between speed humps	Medium
Bulbouts	No major or common issues identified	Medium
Reduced Left-Turn Conflict Intersections	No major or common issues identified	High

Method

SHRP2 Naturalistic Driving Study

The NDS, performed by the Transportation Research Board's SHRP2, produced a uniquely rich data set about driving behavior. The NDS ran from 2010 to 2013 and involved collecting data from 3,400 participant drivers. Critically, the data includes four video feeds—driver hands and face, and front and rear views of the roadway. It also includes vehicle network data (e.g., braking) and sensors that were added to the vehicle for the purpose of the study, such as accelerometers and forward radar. VTTI collected these data in six metropolitan areas.

The SHRP2-NDS is complemented by the Roadway Inventory Database (RID), also collected as part of SHRP2. The RID's purpose was to provide quality roadway data that could be linked to the NDS to facilitate studies involving drivers, vehicles, and roadways. The RID provides comprehensive information about the roads that the NDS drivers used, such as the horizontal curvature, grade, characteristics of lanes, characteristics of shoulders, *Manual of Uniform Traffic Control Devices* (FHWA, 2009) signs, lighting presence, and intersection characteristics. As such, it enables researchers to match NDS trips to road segments with selected characteristics and to study associated driver behaviors (Smadi et al., 2015).

Framing the Data Plan

The data available in the SHRP2-NDS drove decision-making about whether it was feasible to detect the roadway design or AMT of interest and driver behaviors in the NDS. The two highest scoring were road diets and roundabouts.

In the end, the team excluded road diets from the study for several reasons. The primary challenge with detecting road diets is that they are defined by a ***change*** in the number of traveling lanes in one or both directions. As discussed above, a road diet refers to a situation where, typically, a four-lane road (two in each direction) is reduced to a two-lane road, often with left-turn lanes or bike lanes added. Merely identifying the presence of a two-lane road in the NDS or RID would not allow feasible identification of road diets. However, the RID has a coded intersection type for "roundabouts," which could have included modern roundabouts, rotaries, and traffic calming circles. Volpe restricted this category of circular intersections to include only modern roundabouts and traffic calming circles with stop signs by excluding rotaries as circular intersections with diameters of over 75 meters. Later visual inspection of the trips did not indicate the inclusion of any rotaries in the sample.

The selection of these circular intersections led to clarification of the research question in terms of what dependent variable to study, with an emphasis on the driver behaviors to be detected. As a result, the team selected indications of driver behaviors that could be characterized as hesitation or uncertainty as the dependent variable in this study. This decision was informed by feedback from roundabout SMEs and aligned with the purpose for this work as outlined in GHSA's original problem statement.

Sampling

Based upon the file provided to Volpe by VTTI, the SHRP2-NDS includes 57,205 traversals of 61 circular intersections. In this study, the project team analyzed a sample of those traversals.

Due to concerns that simple random sampling may not produce a sufficient sample size of driver behavior events, Volpe first:

- Excluded circular intersections that had few traversals, and
- Excluded traversals where there was no other vehicle or vulnerable road user (pedestrian, cyclist, or wheelchair user) present.

Of the traversals that remained, Volpe aimed to oversample lower-speed transversal, which were believed to be more likely to have hesitation, and to under-sample higher-speed traversals where vehicles did not slow down as much to navigate the roundabout. To achieve this goal, Volpe stratified the sample by traversals of 10 mph or less and those over 10 mph, and they drew a sample with 75% of traversals being lower-speed and 25% higher-speed. Following this sampling strategy, the final sample included 6,209 traversals from 40 circular intersections across five States. Table 2 summarizes the location of the circular intersections by NDS study site.

Table 2. NDS data with circular intersections

City Anchoring the Metropolitan Area	Circular Intersections Used in Study
Bloomington, Indiana	2
Buffalo, New York	10
Durham, North Carolina	8
Seattle, Washington	15
State College, Pennsylvania	0
Tampa, Florida	5
Total	*40*

Coding of Hesitation and Uncertainty

To capture information about driver hesitation and uncertainty, analysts at VTTI viewed segments of video captured by two cameras: one facing forward—capturing the scene in front of the vehicle—and one facing the driver's face and head. The video segments included the entirety of the circular intersection traversals selected by the sampling strategy. Volpe provided definitions and examples of "unnecessary hesitation, uncertainty, or discomfort" in the protocol. The information provided to the coders in the protocol was as follows:

> Signs of this [hesitation] may include sudden, unnecessary, and/or lack of deceleration, acceleration, or steering maneuvers in a place or at a rate that the analyst deems to be inappropriate or unsafe for conditions. May also include apparent indecisiveness as to how or when to enter or exit the circle or which lane to be in. Maneuvers that are part of an evasive response to a safety critical incident are not considered inappropriate or unsafe unless the maneuver was significantly more drastic than required or inappropriate for the conflict at hand (e.g., braking when accelerating was needed).

VTTI performed quality assurance (QA) checks on many of the events. They started the QA process by having experienced coders check 100% of another's coded events until they determined that the new coder was answering questions accurately and reliably. Once VTTI deemed a coder to be accurate/reliable, they checked 50% of their coded events rather than 100%. During the QA process, the person performing QA would suggest the original coder to make corrections. If there was ever a dispute during the QA process, a third person would review the event and resolve the dispute. At the end of the project, VTTI cleaned the data by performing logic checks and reviewing coder notes. If any of the events were flagged as having potential issues, those events were reviewed again to ensure accurate coding.

An experienced VTTI research staff member oversaw the project. In addition, all coders who viewed videos also had extensive experience viewing naturalistic driving data and different driving scenarios. Through repeated observation of a variety of driving scenarios, coders gained a familiarity of how individuals may act in different situations. They were able to use this prior knowledge to make judgments on whether the subject displayed any signs of hesitation or uncertainty. Table 3 has the questions and responses for the coders.

Table 3. Driver behavior and maneuver codes

Driver Behavior	Driver Maneuver
Does the driver exhibit signs of unnecessary hesitation or uncertainty while entering, traversing, or exiting the traffic circle? (Check all that apply.) · None · While preparing to enter or entering · While traversing · While preparing to or exiting · Unable to determine	If yes, what maneuvers are performed that make the driver's unnecessary hesitation or uncertainty evident? (Check all that apply.) · None (only if "None" for behavior) · Acceleration · Deceleration · Steering · Lack of acceleration · Lane control/selection · Indecision (apparent indecisiveness regarding when or how to enter, when or how to exit, which lane they should be in, etc. May include 'doubling-back.') · Other · Unable to determine

Data Sets

In this study, the project team considered four datasets.

1. Traversal event data
2. Driver demographics
3. Driver behavioral tendencies questionnaire data
4. Circular intersections characteristics

The SHRP2-NDS data contain the first three. Volpe computed the fourth using aerial maps combined with the GPS coordinates of the roundabouts provided in the RID.

Initial analysis identified possible relationships between questionnaire responses (dataset #3) and driver hesitation likelihood. The team concluded, however, that countermeasures to mitigate these driver behaviors would unlikely be informed by risk perceptions, personality types, and behavioral tendencies measured by the questionnaire data. Therefore, the team chose not to use the driver behavioral tendencies questionnaire data for further analysis.

Results

The project team screened a range of independent variables for potential relationships with driver uncertainty and hesitation (listed in the Description of Coded Data). This section highlights findings related to the independent variables found to have the strongest predictive relationships with driver hesitation or uncertainty.

Traversal Event Data: Driver Behavior by Location in Circular Intersection

Driver behaviors characterized as hesitation or uncertainty were separately identified by coders during entry, traversal, and exit of the circular intersection, giving three moments when a driver would display these behaviors. Figure 6 shows the likelihood of these driver behaviors at each location. A mixed model logistic regression, controlling for repeated measures within person, indicated that the odds of these driver behaviors while entering are 2.64 times the odds while exiting ($p<.001$). The odds of these driver behaviors while traversing are 2.28 times the odds while exiting ($p<.001$). A post hoc Tukey test indicated the coefficients for these driver behaviors while entering versus while traversing were statistically different from one another ($p = 0.016$).

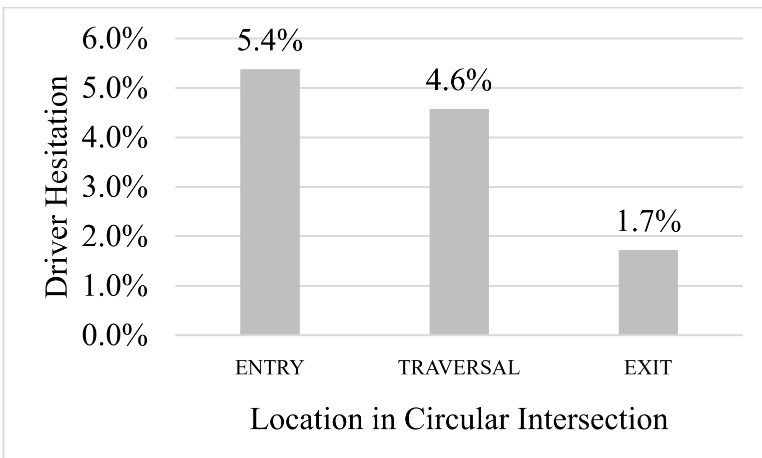

Figure 6. Likelihood of driver behavior characterized as hesitation or uncertainty by location

Driver Demographics: Driver Behavior by Age

Regarding age and driver uncertainty and hesitation, the data show a strong and positive correlation ($r = .95$) between proportion and age (see Table 4 and Figure 7). However, since this study did not examine driver behaviors at other types of intersections and oversampled circular intersections more likely to elicit hesitation or uncertainty, it is not appropriate to conclude that age is necessarily related to uncertainty and hesitation in all circular intersections.

Table 4. Number of traversals and percent with hesitation or uncertainty by age

Age Range	Number of Traversals	Percent of Traversals with Hesitation
16-19	809	3.3%
20-24	1652	3.2%
25-29	375	6.1%
30-34	369	3.8%

Age Range	Number of Traversals	Percent of Traversals with Hesitation
35-39	319	2.8%
40-44	270	3.3%
45-49	278	12.9%
50-54	266	5.6%
55-59	294	8.8%
60-64	225	13.8%
65-69	224	14.7%
70-74	289	17.0%
75-79	328	24.7%
80-84	246	23.6%
Subtotal	5,944	
Missing	265	
Total	6,209	

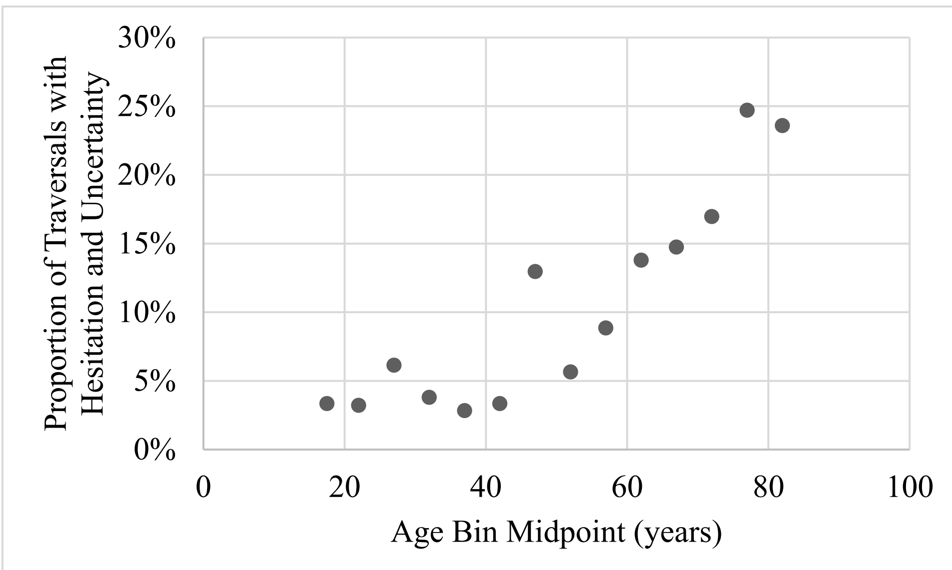

Figure 7. Percent of traversals with driver hesitation or uncertainty by age of driver

Circular Intersection Characteristics: Driver Behavior by Number of Entry Lanes

In this step, the analyses focused on the location with the highest likelihood of driver hesitation or uncertainty: the entry to the roundabout. Figure 8 shows that there is a greater proportion of these driver behavior events at entries with two lanes than for those entries with one lane. A mixed model logistic regression, controlling for repeated measures within person, indicated that the difference is statistically significant at conventional levels ($p = 0.036$). The odds of uncertainty while entering are 1.38 times higher for two entry lanes compared to one entry lane.

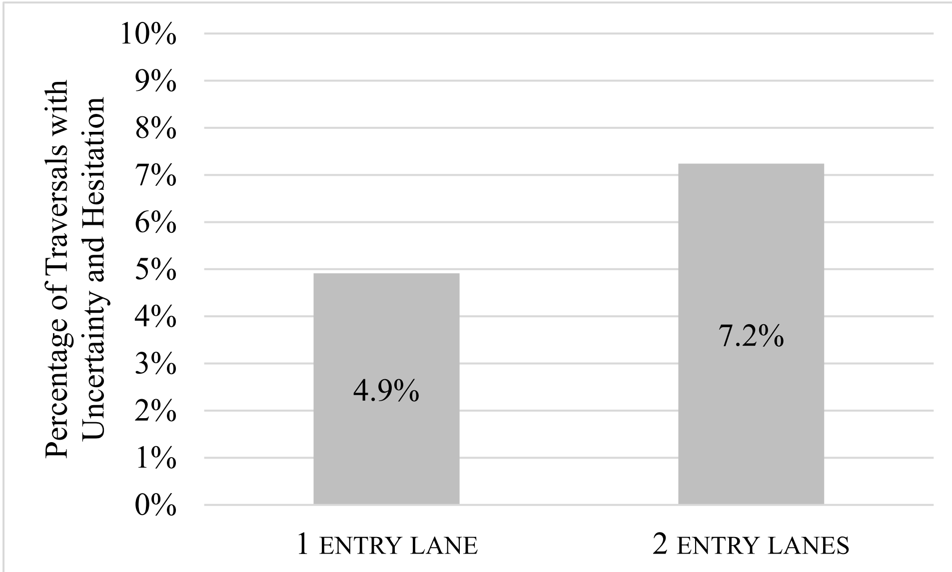

Figure 8. Percentage of traversals with hesitation or uncertainty at entry by number of lanes

Multivariable Model Findings

In addition to the analyses described in the preceding sections, the team analyzed these driver behaviors using Random Forest modeling. Random Forest modeling is a type of machine learning-based statistical modeling that is generally preferred for this class of modeling problem: a "categorization" problem where a set of scenarios must be sorted into one of several categories (Yiu, 2019). As a machine learning-based modeling approach, Random Forest does not require any assumptions about the structure of the data being analyzed. The independent variables contained in the model are described in Table 5.

Table 5. Independent variables predicting driver hesitation

Type	Summary	Description
Main Effects		
Driver demographics	Age	What is the age of the driver (based on birthdate)?
Traversal event data	Secondary tasks	What secondary tasks are observed during the entrance, traversal, or exit maneuvers? (Check all that apply.) (Coded from video)
Roundabout characteristics	Diameter	What is the diameter of the roundabout?
Roundabout characteristics	Entry – number of lanes	Number of lanes available on entry road at entry point to roundabout
Controls		
Driver demographics	Household size	How many people live in the driver's household?
Driver demographics	Household income	What is the driver's annual household income?
Traversal event data	Time of day	At what time did the vehicle enter the roundabout?
Traversal event data*	Vehicle present	Were any other vehicles present in the roundabout during the subject's entrance, traversal, or exit maneuvers? (Coded from video)

The Random Forest method estimates the impact of each independent variable on the dependent variable (Molnar, 2021). In the typical approach for this impact estimation, the estimated impact of each variable is computed for each event (or in this case, a traversal) defined by a set of values of the independent variables. Average estimated impact values for the independent variables in the final model are shown in Table 6. Driver age is excluded from Table 6 and is instead treated separately in Figure 9.

Table 6. Predicted impact on likelihood of driver behaviors characterized as uncertainty

		Variable Level		**Percentage-Point Increase in Likelihood as Variable Moves From Low to High Level**	
Variables Expected to Have an Impact		**Low**	**High**	**Entry**	**Traversal or Exit**
Secondary tasks		No	Yes	9.1%	6.1%
Roundabout diameter		<110 ft	>110 ft	2.5%	8.4%
Number of entry lanes		1	2	1.4%	2.2%
Controls					
Household size		2 or fewer	3 or more	-9.8%	-8.7%
Household income		<$68,455	>$68,455	-5.2%	-0.7%
Time of day		Before 2:25 p.m.	After 2:25 p.m.	-1.5%	-0.3%
Vehicle present at entry		No	Yes	-0.8%	
Vehicle present at exit		No	Yes		-0.9%

Table 6 shows how the likelihood of uncertainty and hesitation changes when the independent variable changes from the value listed as “Low” to the one listed as “High.” For example, the row labeled “Household size” indicates that, on average across all traversals in the set, the difference in the likelihood of uncertainty and hesitation at entry between a driver who is in a 3-or-more-person household and a driver in a 2-or-fewer household is -9.8 percentage points.

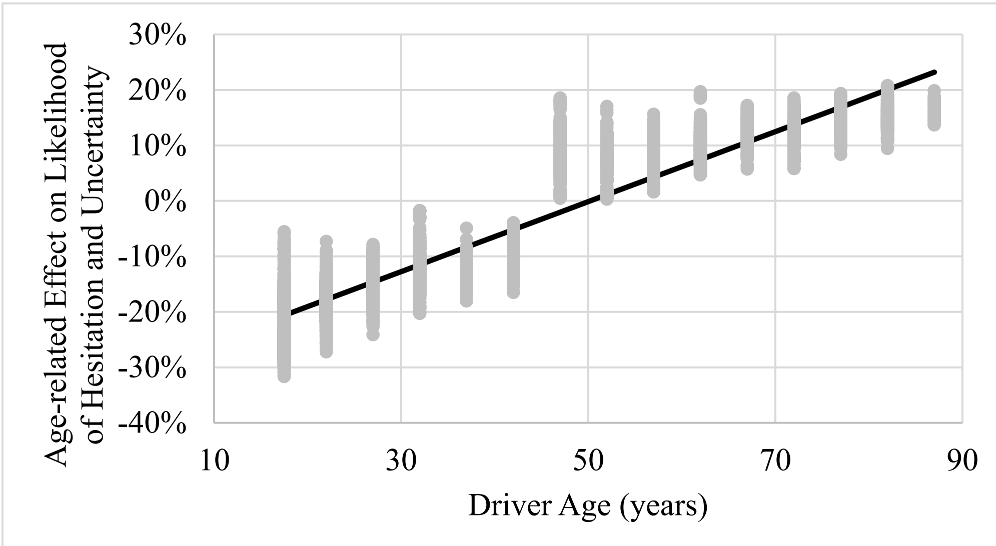

Figure 9. Estimated effect of driver age on likelihood of driver behaviors characterized as hesitation or uncertainty at entry

Figure 9 shows the estimated effect of driver age on the likelihood of driver behaviors characterized as hesitation or uncertainty while entering the roundabout. The estimates in Figure 9 were computed using the same model that generated the estimates in Table 6; the presentation is different to illuminate the relatively continuous effect of driver age. The thick vertical lines are comprised of individual data points, one for each traversal in the sample data. The drivers’ ages are represented as the midpoints of the 5-year bins into which the age falls.

The sloped line illustrates the nearly linear effect of age on driver behavior likelihood as a function of driver age ($r^2 = 0.89$). The line has a slope of 0.63 percentage points per year, indicating that if Driver B is 10 years older than Driver A (and the two drivers are otherwise similar), then the likelihood of Driver B exhibiting these driver behaviors while entering a roundabout is 6.3 percentage points higher than for Driver A. Figure 9 shows a significant increase in the effect of age when going from the 40-to-44 age group (which shows up as 42, the midpoint, on the chart) and the 45-to-49 age group. The average age effect for the 40-to-44 age group is -0.092 whereas the average age effect for the 45-to-49 age group is 0.088. The model suggests that a 47-year-old driver is 18% more likely to exhibit driver behaviors characterized as hesitation or uncertainty on entering a roundabout than a 42-year-old driver. In sum, older drivers navigating circular intersections in the NDS appeared to exhibit driver behaviors characterized as hesitation or uncertainty more than the younger drivers with the most substantial increase between the 40-to-44 age group and the 45-to-49 age group.

Conclusions

This analysis used human observation and coding of videos of drivers during circular intersection traversals to identify patterns of driving behaviors that could be characterized as hesitation or uncertainty. The team analyzed a sample of 6,209 traversals and identified factors that predicted driver behavior characterized as hesitation or uncertainty in circular intersections. First, these driver behaviors occurred at higher rates while entering the roundabout as opposed to during traversal or exiting. This finding is consistent with the observation that entering an intersection is generally more challenging than exiting an intersection. Second, these driver behaviors occurred at higher rates at circular intersections with two-lane entries versus one-lane entries.

In addition to intersection characteristics, driver characteristics also predicted the likelihood of driver behaviors characterized as hesitation and uncertainty. Age was a strong and significant predictor of these driver behaviors; older drivers were more likely to show hesitation or uncertainty in a circular intersection than younger drivers. Furthermore, hesitation and uncertainty also related to engagement in secondary tasks while driving; drivers who were engaged in secondary tasks were more likely to show hesitation or uncertainty than drivers who were not. This finding is consistent with the observation that distracted driving related to secondary task engagement can cause challenges for a variety of driving tasks.

By understanding the characteristics associated with hesitation and uncertainty, more useful and effective strategies can be developed to mitigate these behaviors and promote the use and safety benefits of circular intersections. Older drivers may particularly benefit from such campaigns. In addition to exhibiting higher likelihood of hesitation or uncertainty when driving through circular intersections, older drivers are less likely to know how to correctly negotiate a roundabout (McKnight et al., 2008). Therefore, communication or education campaigns that focus on helping older drivers learn how to correctly navigate circular intersections or provide experience to increase familiarization and support could improve safety (Retting et al., 2007). Some groups such as the American Association of Retired Persons (AARP) and the Roadway Safety Foundation currently produce materials that familiarize drivers with various roadway scenarios (AARP, 2020; Roadway Safety Foundation, 2023). The study findings suggest the need to distribute and use these types of educational materials.

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Appendix A: Description of Coded Data

VTTI coders generated these data by viewing video footage of traversals.

Variable	Description
EVENT_ID	Traffic circle event identifier?
FILE_ID	Video file ID?
VALID	Does the subject vehicle traverse through a traffic circle during the identified epoch and does the traffic circle contain either a vulnerable road user or another vehicle at the time of the traversal? · Yes · No traffic circle traversal (Stop and save.) · No vulnerable road users (VRUs) or other vehicle (Stop and save.) · Unknown (Stop and save. Leave notes for review in log.)
EPOCHSTART	Timestamp at which the subject begins the maneuver to enter the traffic circle of interest
EPOCHEND	Timestamp at which the subject has completed the maneuver to exit the traffic circle of interest
EPOCHSEVERITY	During the traversal (including entrance, traversal, and exit), is the subject vehicle involved in or affected by any safety-critical events (SCEs)? · None · Crash · Near-crash · Crash relevant · Non-subject conflict · Multiple
EPOCHTYPE	If an SCE is coded above, indicate the type of conflict here. None (if none above) · Rear-end, striking · Rear-end, struck · Road departure (does not include use of ‘apron’) · Sideswipe, same direction (left or right) · Opposite direction (head-on or sideswipe) · Pedestrian-related · Pedal cyclist-related · Animal-related · Other · Multiple · Unable to determine
UNCERTAINTY	Does the driver exhibit unnecessary hesitation or uncertainty while entering, traversing, or exiting the traffic circle? (Check all that apply.) · None · While preparing to enter or entering · While traversing · While preparing to or exiting · Unable to determine
UNCERTAINTYMANEUVER	If yes above, what maneuvers are performed that make the driver’s hesitation or uncertainty evident? (Check all that apply.) · None (only if “None” for UNCERTAINTY)

Variable	Description
	· Acceleration · Deceleration · Steering · Lack of acceleration · Lane control/selection · Indecision (Apparent indecisiveness regarding when or how to enter, when or how to exit, which lane they should be in, etc. May include “doubling-back.”) · Other · Unable to determine
LANESENTRYRD	Number of lanes available on entry road at entry point to traffic circle. · 1 · 2 · 3 · 4 · 5+ · Unknown
LANEASSIGNMENTENTRY	Which lane of the entry road is the subject vehicle in at the entry point of the traffic circle? · 1 · 2 · 3 · 4 · 5+ · In transition (subject changes lanes while entering the traffic circle) · Unknown
LANESEXITRD	Number of lanes available on exit road at exit point from traffic circle. · 1 · 2 · 3 · 4 · 5+ · Unknown
LANEASSIGNMENTEXIT	Into which lane of the exit road does the subject vehicle exit the traffic circle? · 1 · 2 · 3 · 4 · 5+ · In transition (subject changes lanes while exiting the traffic circle) · Unknown
GLANCEPATTERN	Does the driver glance left prior to/when entering the traffic circle and then return glance to forward prior to exiting the traffic circle? · Yes – glances left then forward · No – glances left but not back to forward (until after EpochEnd) · No – never glances left
GLANCEFORWARDTIME	If YES above, enter the timestamp at which the driver’s glance returns to forward after looking left to enter the traffic circle. · Timestamp (text box)

Variable	Description
VRUPRESENT	Were any VRUs present during the entrance, traversal, or exit maneuvers? (Check all that apply.) · None present · While preparing to enter or entering · While traversing · While preparing to exit or exiting · Present and traveling with traffic (at any point in the traversal) · Unable to determine
VRURESPOND	Did the subject respond appropriately to the presence of the VRU(s) coded above? · Yes, responded appropriately to all · No, insufficient response to at least one (describe in notes) · Response not needed · Unable to determine · Not applicable (no VRU present as coded above)
VEHICLEPRESENT	Were any other vehicles present in the traffic circle during the subject's entrance, traversal, or exit maneuvers? (Check all that apply.) · None present · While preparing to enter or entering · While traversing · While preparing to exit or exiting · Unable to determine
VEHICLERESPOND	Did the subject respond appropriately to the presence of the other vehicles coded above? · Yes, responded appropriately to all · No, insufficient response to at least one (describe in notes) · Response not needed · Unable to determine · Not applicable (no other vehicle present as coded above)
SECONDARYTASKS	Secondary tasks that are observed during the entrance, traversal, or exit maneuvers. (Check all that apply.) · No secondary tasks · Talking/singing (to self or unknown) · Dancing · Reading/Writing · Passenger interaction (any seat) · Insect (in vehicle, interaction) · Pet (in vehicle, interaction) · Reaching for object (other than included in other options) · Object in vehicle, other (other than included elsewhere, not just holding something, searching through purse, etc.) · Cell phone talking (not just holding) · Cell phone visual/manual (reaching, viewing, texting, or other visual/manual task – not just holding) · Other electronic device (reaching, viewing, or manipulating, e.g., tablet device or nomadic GPS, not just holding) · Center stack adjust (radio, HVAC, touch screen) · Integral device adjust (adjust window, seatbelt, mirror, etc. – not driving essential tasks like turn signals, wipers, etc.) · External distraction (not driving-related scanning) · Food/drink (reaching, eating, drinking, cleaning up, etc. – not just holding) · Smoking or tobacco (reaching, lighting, smoking/holding,

Variable	Description
	extinguishing, expectorating, actively vaping not just holding, etc.) · Personal hygiene (reaching for relating, fixing hair/make-up, shaving, tooth care, adjust clothing/jewelry/glasses/contacts – not just holding) · Other non-specific internal glance · Other known secondary task (to be described) · Unknown type (secondary task present) · Unknown (unknown if task present)
NOTES	Enter any notes relevant to the traffic circle traversal to describe any unique characteristics, behaviors, or maneuvers. Also, define any "other" options selected in the previous variables. · Text box, free text

Appendix B: Additional Information

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