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Investigating the Conversion of a Signalized Intersection to a Turbo Roundabout

Vyshnavi Shetty   Mykola Sauciur   Anurag Pande, PhD

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Vyshnavi Shetty

Mykola Sauciur

Anurag Pande, PhD

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16. Abstract

Turbo roundabouts are multilane roundabouts with helical pavement markings and raised structures. While they have seen widespread use in Europe, California is only the second state in the U.S. (after Florida) to have installed a turbo roundabout. Turbo roundabouts separate the ingress and circulating roadways. The concept was proposed and implemented in the Netherlands to mitigate congestion by improving traffic flow efficiency and addressing safety concerns on conventional multilane roundabouts. This research evaluates the first-ever turbo roundabout in California and compares its safety and operational performance with the previously existing 4-legged signalized intersection. The research team obtained safety and operational performance measures using well-calibrated simulation models and video analytics of the real-world conditions recorded before and after the installation of the turbo roundabout. The safety metrics include surrogate safety measures defining traffic conflicts between vehicles that enabled a quicker safety evaluation compared to multi-year collision data. The results show that the turbo roundabout effectively reduced crash potential and queuing delays at this site, meaning smoother, safer traffic flows. The real-world conflict data shows that more severe crossing and head-on conflicts (situations that could lead to collisions) of the previous 4-legged signalized intersection have all but been eliminated. The rear-end conflicts that do occur on the roundabout involve vehicles traveling at meaningfully reduced speeds compared to similar conflicts observed on the signalized intersection. The results show that turbo roundabouts may be an effective option at rural routes where the siting criteria for multilane roundabouts are satisfied. Given the timeline for this research project, the evaluation was conducted within months of the construction completion. It is therefore advised that Caltrans continue to monitor traffic crash data to ensure that the long-term crash data shows the expected improvement of safety. To support such evaluation, the counterfactual estimate of annual crash counts (i.e., the number of crashes that would have been expected had the intersection left as a signalized intersection) is provided in this study. The estimate provides a basis for comparison with future crash data to Caltrans. This study underscores the potential of turbo roundabouts to enhance roadway safety and operational performance, supporting their consideration in traffic management strategies across California and the nation.

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Mineta Transportation Institute
College of Business
San José State University
San José, CA 95192-0219

Tel: (408) 924-7560
Fax: (408) 924-7565
Email: mineta-institute@sjsu.edu

transweb.sjsu.edu/research/2233

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Executive Summary

This study evaluates the operational and safety benefits of a turbo roundabout built on State Route 25/Highway 156 in the City of Hollister, CA (Caltrans District 5). Turbo roundabouts are multilane roundabouts with helical pavement markings and raised structures to separate the ingress and circulating roadways. The concept of the turbo roundabout was proposed and first implemented in the Netherlands to mitigate congestion by improving traffic flow efficiency and addressing safety concerns present in conventional multilane roundabouts. The turbo roundabout studied in this research is the first-ever turbo roundabout in CA (and only the second in the US, with the other being in Jacksonville, FL).

The study used detailed vehicle trajectory data to assess the performance of the newly installed turbo roundabout vis-à-vis the formerly used signalized intersection. The trajectory information was estimated in two ways: one using detailed microscopic simulation models, and the other using analysis of video recordings of the real-world movement of traffic through the signalized intersection and roundabout. The trajectory data were then used to estimate the number and nature of conflicts, i.e., potentially dangerous interactions that may lead to collisions between vehicles traversing the intersection. The measures used to define these conflicts are called surrogate measures of safety. Surrogate measures of safety were used in this study in lieu of collision data because crash data-based safety evaluation requires multiple years (at least three) of collision data for both the before- and after-installation periods, and this evaluation was conducted within a few months of turbo roundabout installation. To enable the agency, i.e., Caltrans, to conduct this collision data-based evaluation when future crash data are available, this study also used the method recommended by the Highway Safety Manual to estimate a baseline of expected crashes for the counterfactual scenario, i.e., one where the intersection was left as a 4-legged signalized intersection.

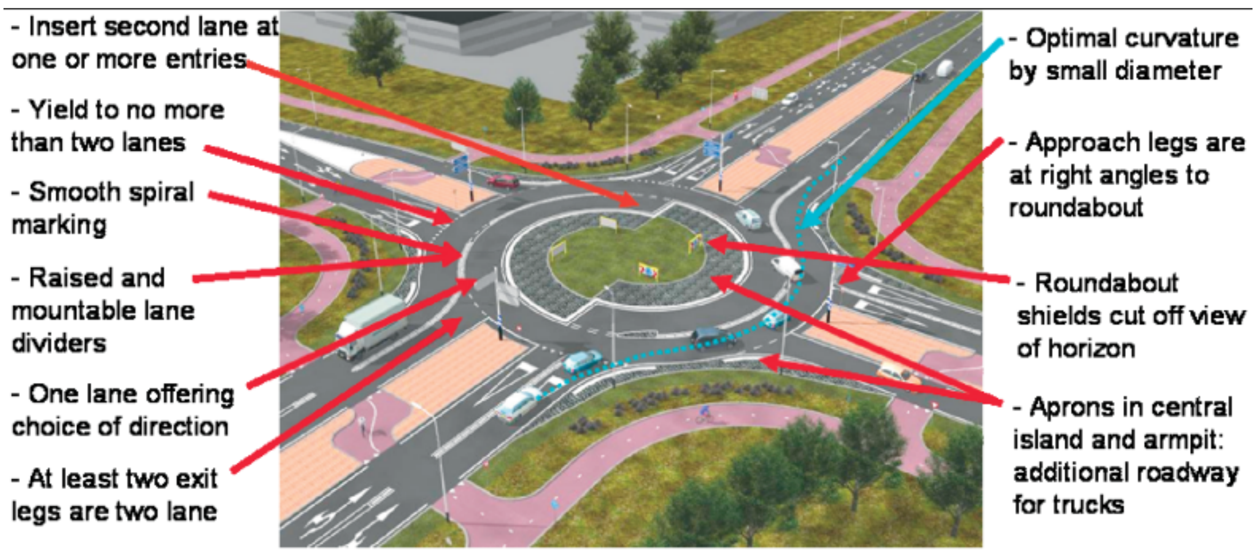
The simulation model showed a meaningful reduction in queuing-related delay for all approaches to the intersection after installing the turbo roundabout. On the approaches to the intersection, the queuing delay reductions ranged from 82.20% to 99.02% during morning and afternoon peak hours. While the real-world trajectory analysis showed higher interactions between vehicles at the turbo roundabout compared to the signalized 4-legged design, the most dangerous of interactions (with speed differential between interacting vehicle(s) more than 40 MPH and/or time to collision less than 1.5 seconds) were substantially reduced. The turbo roundabout also eliminated dangerous high-speed crossing conflicts that lead to the most severe T-bone type (also referred to as broadside collisions) crashes on 4-legged signalized intersections. The empirical Bayes method from the Highway Safety Manual also provided an estimate of ~15.38 crashes per year for the counterfactual scenario. In the future, Caltrans can monitor the crash data and compare the long-term annual frequency of crashes at the turbo roundabout with this counterfactual estimate of ~15.38 crashes per year to conduct a crash data-based safety evaluation.

Turbo roundabouts should be considered alternatives wherever a multilane roundabout is used. Also, since the real-world vehicle trajectory data used in this research was collected soon after roundabout installation, long-term safety performance using crash data should be examined as soon as three years of post-installation collision data become available.

1. Introduction

Modern roundabouts reduce approach speed at at-grade intersections and reduce conflict points. Therefore, they lead to fewer severe crashes than traditional 4-legged at-grade intersections. According to FHWA documentation on Turbo roundabouts, converting a traditional at-grade signalized intersection to a modern roundabout is expected to reduce the number of injury crashes by 78 % (Porter et al., 2019). On multilane roundabouts, same-direction sideswipe crashes are often a safety concern. Turbo roundabouts separate the ingress and circulating roadways. The concept of the turbo roundabout was proposed and first implemented in the Netherlands to mitigate congestion by improving traffic flow efficiency and addressing safety concerns in conventional multilane roundabouts (Silva et al., 2014). Turbo roundabouts are multilane roundabouts with helical pavement markings and raised structures (Silva et al., 2014). Figure 1 shows the key features of a turbo roundabout. These features help address lane selection and lane changing and improve entering and exiting behaviors.

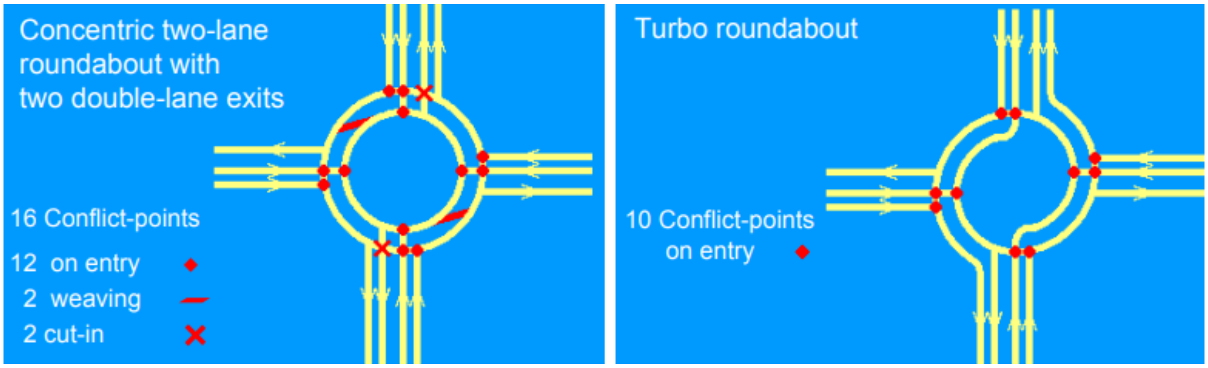
Figure 1. Distinctive Features of a Turbo Roundabout



(Porter et al., 2019)

From a safety perspective, turbo roundabouts have fewer conflict points than conventional roundabouts, as shown in Figure 2. In addition to the reduced weaving conflict points, there are slower travel speeds through the roundabout thanks to the raised dividers. This feature potentially results in fewer crashes and lower crash severity (Porter et al., 2019).

Figure 2. Conflict Points at Multilane Conventional and Basic Turbo Roundabouts

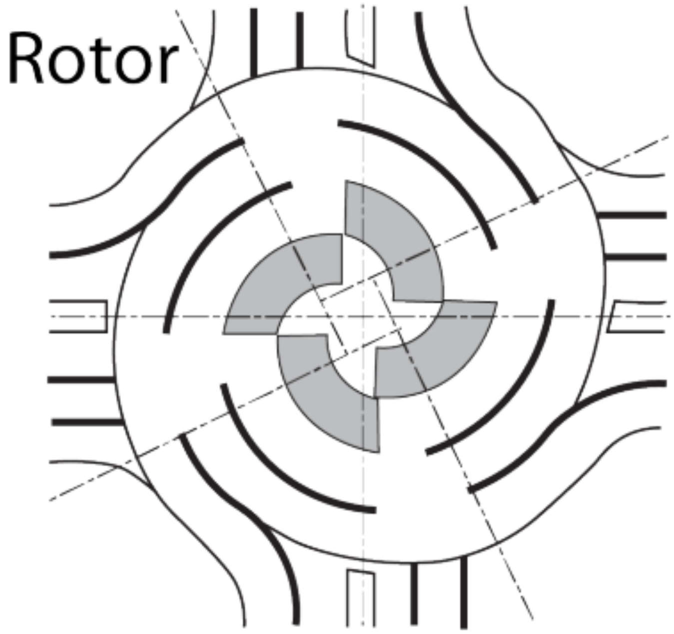


(Porter et al., 2019)

From an operational point of view, turbo roundabouts have a higher capacity due to the spiral road surface markings and the dividers limiting lane changes. The traffic volume is also well dispersed throughout the circulating lanes in the turbo roundabout as opposed to the conventional roundabout (Porter et al., 2019).

Multiple types of turbo roundabouts exist. These include the basic turbo roundabout, the egg turbo roundabout, the knee turbo roundabout, the spiral turbo roundabout, and the rotor turbo roundabout (Džambas et al., 2017; Porter et al., 2019). Figure 3 shows the rotor turbo roundabout layout. It is larger than the spiral turbo roundabout, with all approaches having three entry lanes. Note that the rightmost entry lanes are right-turn lanes. This design is of interest since this research evaluated the performance of a rotor turbo roundabout in Hollister, CA, recently installed by Caltrans District 5.

Figure 3. Rotor Turbo Roundabout Design



(Džambas et al., 2017; Porter et al., 2019)

1.1 Research Objectives

This research aims to evaluate the operational and safety benefits of the turbo roundabout on State Route 25/Highway 156 intersection in the City of Hollister, CA (Caltrans District 5), which finished construction in February 2024. It is the first turbo roundabout in the state and the second in the US, with the other being in Jacksonville, FL (Tovar, 2024). Since the roundabout has only been operational for a few months, it is impossible to quantify its safety impacts using a collision data-based before-and-after analysis. Furthermore, safety evaluation using collision data is reactive and can only occur after collisions are documented and archived in the databases, relying on police reports and sometimes with considerable delay.

Therefore, the authors adopted surrogate measure-based safety analysis approaches in this research, including microscopic simulation and video analytics. The study establishes an expected annual crash frequency estimate for all crashes as well as for crashes with fatalities or injuries in a counterfactual scenario, which assumes that the turbo roundabout was never installed and the intersection retained its 4-legged design and signalized traffic control. The counterfactual estimate is based on the Empirical Bayes (EB) methodology recommended by the Highway Safety Manual (HSM) (American Association of State Transportation Officials, 2010) and is obtained using the Highway Safety Software development by McTrans Center (McTrans, n.d.). The estimate provides Caltrans with a baseline for future collision-based evaluation when multi-year post-installation crash data for the turbo roundabout become available.

Specific project objectives for this research are as follows:

- Calibrate detailed microscopic simulation models for the existing signalized intersection geometry as well as the proposed rotor turbo roundabout to estimate operational and safety improvements before and after the installation.

- Use video analytics data of the State Route 25/Highway 156 intersection operation before and after the construction of the turbo roundabout to conduct traffic conflict-based safety analysis.

- Synthesize the performance evaluation framework for congestion mitigation and safety improvements at the State Route 25/Highway 156 intersection so that other Caltrans Districts may also implement this evaluation framework when considering turbo roundabouts as an alternative to multilane roundabouts.

1.2 Report Organization

The report is organized as follows. The next chapter provides a review of literature relevant to turbo roundabouts and surrogate safety assessments. Chapter 3 provides site information and context for the intersection location, while Chapter 4 provides detailed findings from simulation modeling and real-world video analytics. Chapter 5 provides conclusions from this work and recommendations for future evaluations.

2. Literature Review

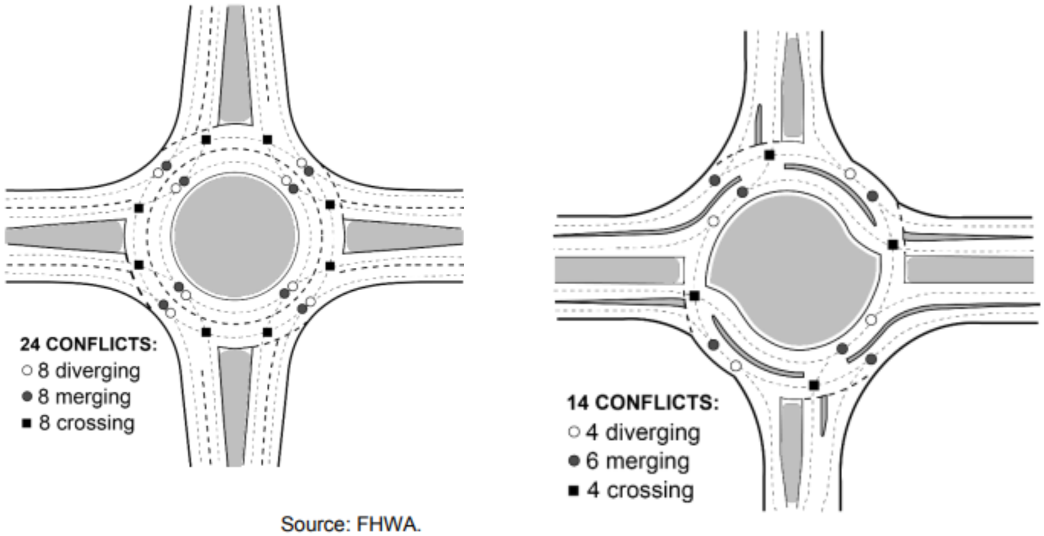
This chapter reviews the relevant literature on turbo roundabouts and the use of surrogate safety measures obtained via vehicle trajectories from microsimulation models and real-world video analytics to evaluate roadway performance. The review on turbo roundabouts is primarily from other countries since neither of the two turbo roundabouts in the US, including the one in Hollister, CA, is more than two years old.

2.1 Turbo Roundabouts

Compared to conventional at-level intersections, roundabouts are usually associated with reduced crashes due to reduced conflict points (compared to a typical 4-legged intersection). They also homogenize and lower approach speed profiles (Silva et al., 2014). Depending on the geometric characteristics and geographical locations of the intersections, past research has reported up to a 70% reduction in crash frequency and more than a 90% reduction in fatalities (Rodegerdts et al., 2010; Silva et al., 2014).

As roundabouts became common in North America, Rodegerdts (2007) showed that appropriately designed and built roundabouts can improve both safety and operational performance measures at an intersection. Specific to the turbo roundabout, FHWA reported that conversion of an intersection from yield-control, signalized, or old-style rotary to a turbo roundabout is associated with a 76% reduction in injury crash frequency (Porter et al., 2019). The study was based on international collision data, primarily from Europe (Fortuijn, 2009). Similarly, the turbo roundabout design elements introduced in Chapter 1 help reduce multivehicle crashes by helping with lane selection prior to entering the roundabout (see Figure 4).

Figure 4. Potential Conflicts Within a Traditional Roundabout (Left) and a Turbo Roundabout



(Right) (Porter et al., 2019; Vasconcelos et al., 2014)

Based on the literature, critical features of turbo roundabouts that provide the biggest benefits include:

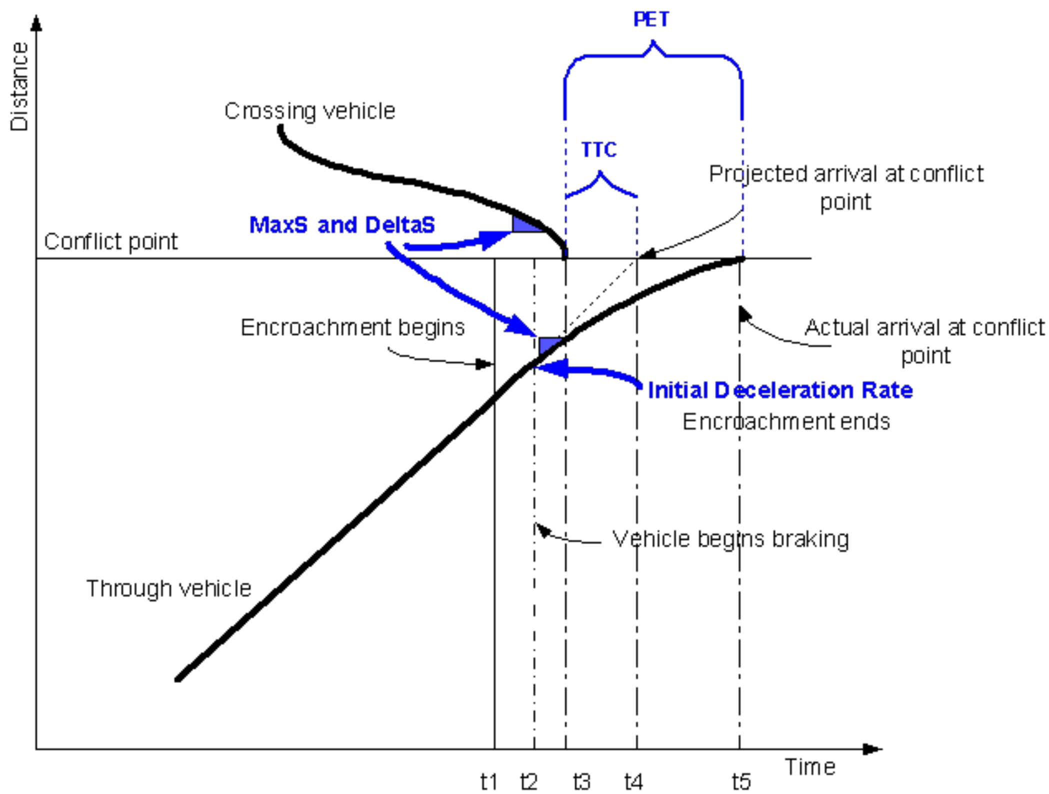
- Radial entry, which improves sight distance.
- Minimized central island radius and entry radius to reduce vehicle speeds.
- Raised lane divider to prevent weaving in the circulatory roadway.
- Roundabout shields that block the horizon and direct drivers to turn into the roundabout.
- Mountable aprons on the central island and the beginning of the raised lane divider to ease navigation by heavy vehicles.
- Spiral design so vehicles do not have to cross lanes to exit the roundabout.

With these design features and associated benefits, turbo roundabouts may be considered at any intersection where a roundabout is a potential alternative, particularly where traffic demand indicates the need for a multilane roundabout.

2.2 Surrogate Safety Assessment

In recent years, Surrogate Safety Measures (SSMs) have gained traction as a proactive alternative to traditional crash-based safety evaluations. Unlike crash data, which can take years to collect and leave road users at risk while data is still being assembled, SSMs predict crash likelihood by analyzing near-miss events—scenarios where vehicles come dangerously close but do not collide (Wang et al., 2021). This proactive approach helps engineers design safer intersections and evaluate traffic safety without relying on historical crash data, which can take years to collect (Ozbay et al., 2008; Tarko, 2018).

Figure 5. Surrogate Safety Measures on a Conflict Point Diagram



(Gettman & Head, 2003a)

SSMs include several indicators for measuring traffic conflicts, including:

- Time to Collision (TTC): The time remaining before two vehicles collide if they continue their current speed and path.
- Post Encroachment Time (PET): The time between one vehicle leaving a conflict area and another vehicle entering it.
- MaxS: The maximum of the speeds of the two vehicles involved in the conflict event.
- DeltaS: The maximum relative speed of the two vehicles involved in the conflict event.

These measures are depicted in Figure 5, which shows a graph with two vehicle trajectories in a time-space diagram. There is a “through vehicle” and a “crossing vehicle” approaching a conflict point at an intersection, where the two trajectories can potentially intersect unless one or both of the vehicles involved change their trajectories (Gettman & Head, 2003a). These metrics are particularly valuable for intersection safety analysis, and past research has shown that TTC and PET can be reliably used to proactively estimate an intersection's safety (Gettman et al., 2008; Gettman & Head, 2003b). Hasanvand et al. (2023) noted that there are two approaches to obtaining vehicle trajectory data that can be used to estimate TTC and PET: microscopic models developed using simulation tools (e.g., VISSIM) and video recordings of the real-world conditions.

The following subsections present a review of the applications of these two approaches for evaluating the safety performance of turbo roundabouts.

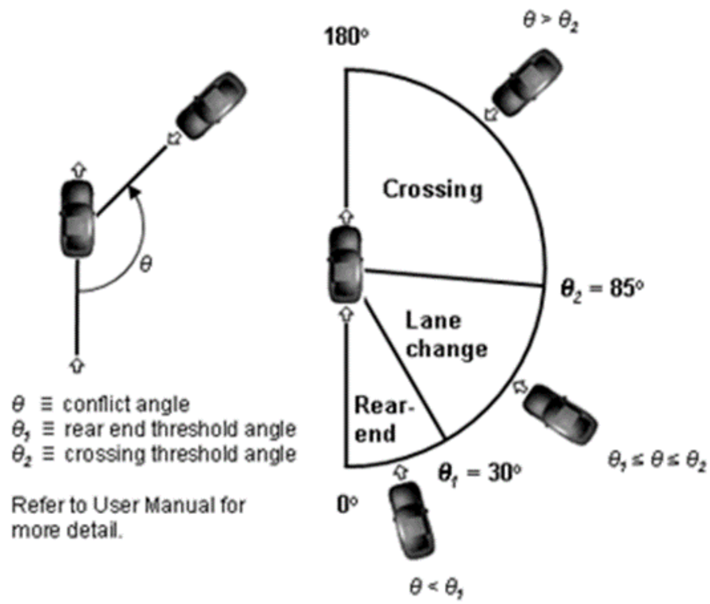
Surrogate Safety Assessment Using Simulation

One of the tools for estimating SSMs in a simulated environment is the Surrogate Safety Assessment Model (SSAM), developed by the Federal Highway Administration (FHWA). SSAM analyzes vehicle trajectory data to detect traffic conflicts. The groundwork for using surrogate safety measures in traffic simulations was laid by Gettman and Head (2003a), who were among the first to derive surrogate safety measures from simulation modeling. In a follow-up study, the first version of SSAM was released by the FHWA in 2008 (Gettman et al., 2008). The tool has since become widely adopted for proactive traffic safety evaluation, especially for new intersection designs such as roundabouts and other complex geometries (Gettman et al., 2008). SSAM is particularly useful for evaluating new intersection designs before they are implemented, providing a cost-effective way to predict safety performance.

In SSAM, conflicts are categorized based on vehicle trajectories and the angle at which the potential conflicts occur. The three primary conflict types (see Figure 6) identified in SSAM are:

- Crossing conflicts: Occur when two vehicles approach each other at perpendicular paths, such as at intersections.
- Lane change conflicts: Arise when vehicles move between lanes, potentially colliding with vehicles already in that lane.
- Rear-end conflicts: Result from sudden decelerations or slow-moving vehicles in front of faster-moving ones.

Figure 6. Conflict Angle Diagram in SSAM



(Gettman et al., 2008)

SSAM can estimate the frequency and severity of these conflicts by analyzing the trajectory data generated by microsimulation packages, including VISSIM. VISSIM is a widely used traffic simulation software that models detailed road user interactions at the microscopic level (Fellendorf & Vortisch, 2010). It generates vehicle trajectory data, which can then be exported to SSAM for conflict analysis. The use of microsimulation in safety assessments is particularly valuable because it allows traffic engineers to test multiple design alternatives and traffic conditions without waiting for real-world implementation.

According to Fan et al. (2013), the number of simulated conflicts at or near an intersection estimated using SSAM and VISSIM strongly correlates with real-world intersection crashes at the corresponding location. Past studies have noted that appropriately calibrating driver behavior models in VISSIM is critical, and trajectory data errors could be reduced by up to 50% using these processes appropriately, further improving the accuracy of safety predictions (Essa & Sayed, 2018; Fan et al., 2013; Huang et al., 2013). The ability to simulate various traffic scenarios and adjust parameters like speed, traffic volume, and road geometry in the microsimulation models makes SSAM a flexible tool for predicting and improving safety outcomes.

Turbo Roundabout Evaluation Using SSMs

Hasanvand et al. (2023) provided a detailed review of studies that used proactive trajectory data for evaluating roundabout safety performance. Several studies have analyzed turbo roundabout safety performance using trajectory data from microsimulation environments and surrogate safety measures (Gallelli et al., 2021; O. Giuffrè et al., 2018; T. Giuffrè et al., 2017; Leonardi & Distefano, 2023; Tesoriere et al., 2018; Vasconcelos et al., 2014). Most of these studies used VISSIM, with the exceptions of Vasconcelos et al. (2014), which used AIMSUN, and two studies by Giuffrè et al., which used both VISSIM and AIMSUN (O. Giuffrè et al., 2018; T. Giuffrè et al., 2017). It should be noted that these studies are distinct from studies that used simulation models to evaluate the operational performance of turbo roundabouts (Elhassy et al., 2021; Silva et al., 2015). Elhassy et al. (2021) simulated a future turbo roundabout in a US location (since built in Jacksonville, Florida). None of these past studies examined the safety of turbo roundabouts using both microsimulation models and real-world trajectory data. Furthermore, none of the turbo roundabouts evaluated for safety performance in these studies were located in the US.

Video Analytics of Real-World Trajectory Data for Safety Evaluation

Traffic conflict-based analysis represents a proactive approach to estimating traffic safety since it does not require multi-year collision data to make safety estimations. Given that the objective of this research involves the evaluation of a novel (in the US and California) roundabout design within months of its installation, a proactive approach is of interest. Real-world analysis of vehicle trajectories provides opportunities to observe traffic interactions that are similar to collisions even though they did not lead to one. These interactions are termed "traffic conflicts" and are indicative of the potential for serious traffic collisions (Levy et al., 2020). Recent developments in video analytics for road safety analysis can provide a cost-effective and time-efficient tool to assess road safety effectiveness as an alternative to the crash-based approach.

While simulation tools like VISSIM with SSAM provide powerful ways to predict future traffic conflicts, video analytics tools can collect surrogate safety data from existing real-world traffic conditions. By analyzing video footage from intersections, these systems can detect near-miss events and estimate surrogate safety measures, including the aforementioned measures TTC and PET. Zheng et al. (2019) noted that PET and TTC measures obtained from video analytics at intersections correlate well with the crash history of the intersections. Analysis of video data has been widely applied in field-based traffic studies for assessing potential crash risks at intersections (Sayed et al., 2013; St-Aubin et al., 2015; Stipancic et al., 2021; Tageldin et al., 2018).

Given recent advances in analytics and computational capabilities, commercial packages are now available to conduct this analysis, including TrafxSAFE (Navarro et al., 2022) and DataFromSky (Hasanvand et al., 2023). In the literature review conducted for this work, the authors found TrafxSAFE (TrafxSAFE, n.d.; formerly known as Brisk Lumina by Brisk Synergies, later acquired by Transoft Inc. and branded as TrafxSAFE) to be the most widely used package in peer-reviewed studies for analysis of real-world trajectory data (Fu et al., 2019; Scholl et al., 2019; Zangenehpour et al., 2017). TrafxSAFE has been used in similar studies that evaluated intersection and roundabout safety. These evaluations included a roundabout in MI (Levy et al., 2020), a series of intersections and roadway locations in Bellevue, WA (Samara et al., 2021), stop-controlled intersections (Navarro et al., 2022), and signalized intersections in PA (Sengupta et al., 2024) and

Toronto, Canada (Shangguan et al., 2024). The TrafxSAFE tool provides an estimate of the speeds of interacting vehicles and surrogate safety measures such as PET and TTC. If these measures fall below a certain threshold, the situation may be described as a more dangerous conflict. When analyzing trajectory data, PETs less than or close to 1.5 seconds are considered critically dangerous based on past research (Van der Horst & Hogema, 1994).

Kondyli et al. (2023) evaluated the TrafxSAFE tool for Kansas DOT and found that it provided reasonable estimates of TTC and PET, especially in clear weather conditions. Therefore, the TrafxSAFE tool may be considered state-of-the-art in video analytics for safety evaluation.

2.3 Conclusions from the Literature Review

Turbo roundabouts are likely to experience fewer crashes than traditional multilane roundabouts. FHWA notes that this may be due to the reduction of conflict points within the roundabout and the lower speeds required to navigate the smaller radii (Porter et al., 2019). Studies based on surrogate measures derived from microsimulation (Vasconcelos et al., 2013) and field observations (Chodur & Bąk, 2016; Kieć et al., 2019) suggest turbo roundabouts are expected to produce fewer and less severe crashes than a comparable multilane roundabout.

The literature also shows that video analytics and surrogate safety-based evaluations are maturing and can be effective ways to estimate safety in lieu of long-term crash data. While this research will provide a benchmark estimate for future crash data-based assessment of the effectiveness of the turbo roundabout, the literature shows that the video analytics results are reliable enough to measure safety performance.

Based on the findings from the literature review, this work is the first study to examine the real-world safety impacts of a turbo roundabout in a US context. On average, the U.S. vehicle fleet size is bigger than Europe, where previous evaluations of turbo roundabouts have been conducted partly due to a higher proportion of SUVs. Therefore, it is important to study the effects of one of the first turbo roundabouts in the country. Furthermore, applying SSAM with VISSIM and video analytics provides a robust framework for evaluating the roundabout performance. By simulating traffic scenarios, detecting potential conflicts, and validating results with real-world video data, this approach offers a practical, proactive approach to assessing intersection safety.

3. Site Information and Data Details

This chapter briefly describes the SR-25 and SR-156 highways and the signalized intersection in Hollister, CA (San Benito County) that was recently converted to a turbo roundabout. The intersection is situated in a rural setting, surrounded by farmland, and is located near Hollister airport. The airport does not have commercial passenger flight operations but is the location of the CalFire Air Attack Base, responsible for suppressing wildfires in six counties, making the intersection a strategically important location (*Hollister, CA*, n.d.). Turbo roundabout construction at this location began in June 2022, and the project was completed in February 2024. Final acceptance was confirmed by Caltrans shortly thereafter (Thompson, 2023). First, a description of previously existing conditions (i.e., signalized intersection) and collision patterns is provided, followed by details of the newly constructed roundabout based on a site visit conducted in April 2024.

3.1 Route Details

State Route 25 (SR-25) in Hollister, CA, is a major north-south highway that connects Hollister to Gilroy and the San Francisco Bay Area. SR-25 runs through rural areas, primarily serving agricultural regions and acting as a commuter route for residents traveling to jobs in the Bay Area. SR-25 is a vital route for both local and regional traffic, as it links with US Route 101 in Gilroy and intersects with State Route 156 near Hollister, providing access to various destinations. The highway is also popular for its scenic views of California's agricultural landscape. Within the study area, SR-25 is a two-lane undivided highway with farmlands on either side of the segments.

State Route 156 (SR-156) in Hollister, California is a key east-west highway that serves as a vital connector between Northern California's coastal and inland regions. It links US Route 101 near Prunedale to State Route 152 near Hollister and, further east, connects to Interstate 5. The route is critical in providing access to the city of Hollister, a growing agricultural and residential hub, and serves as a corridor for commuters and goods transportation.

In the San Benito County city of Hollister, SR-156 is often used to access local destinations and for regional traffic heading to destinations like San Juan Bautista, Monterey, and San Jose. This section of the highway sees considerable traffic, including heavy vehicles/trucks, and it intersects State Route 25, which leads to Gilroy and the Bay Area. Over time, concerns about traffic congestion, safety, and the need for upgrades have been raised to accommodate the area's growing traffic demands. Within the study area, SR-156 is a two-lane undivided roadway with farmlands on either side of the segments. The intersection of SR-25 and SR-156 was located at PM (Post Mile) 54.034 on SR-25 and had a signal traffic control. Caltrans provided signal timing and traffic volume data for the intersection. These data may be found in Appendices A, B, and C.

3.2 Collision Analysis

This section provides a brief collision analysis for the previously existing signalized intersection. Collision data for this analysis are from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS). A subset of this data in the proximity of the intersection is also used to obtain an EB (Empirical Bayes) estimate of the expected crashes that would have occurred had this intersection been left as a signalized intersection (see Chapter 4). The TASAS crash data summary, covering the period from January 1, 2015 to December 31, 2019, was obtained from Caltrans and reflects conditions prior to the start of the roundabout construction (i.e., a signalized intersection).

SR-25 Roadway Segments

A total of 46 collisions occurred on the SR-25 northbound and southbound section between Post Mile (PM) 52.505 and PM 54.034 over a 60-month period. This section had a fatal collision rate of 0.016 per million vehicle miles (MVM), a fatal-plus-injury collision rate of 0.25 per MVM, and a total collision rate (including fatal, injury, and property damage) of 0.73 per MVM. For similar facilities, the average fatal collision rate is 0.025 per MVM, the average fatal-plus-injury rate is 0.33 per MVM, and the total collision rate is 0.78 per MVM.

A total of 94 collisions occurred on the SR-25 section between PM 54.034 and PM 55.132 over the same period. This section had a fatal collision rate of 0.021 per MVM, a fatal-plus-injury collision rate of 0.81 per MVM, and a total collision rate of 1.95 per MVM. For similar roadways, the average fatal collision rate is 0.025 per MVM, the fatal-plus-injury rate is 0.33 per MVM, and the total collision rate is 0.78 per MVM.

In summary, the study segment from PM 52.505 to PM 54.034 shows collision rates below average, while the segment from PM 54.034 to PM 55.132 has substantially higher fatal-plus-injury and total collision rates compared to similar roadway segments in the state.

SR-156 Roadway Segments

Based on TASAS data, 64 collisions occurred on the SR-156 northbound and southbound section between PM R10.122 and R11.378 over a 60-month period. This section had no fatal collisions (0.00 per MVM), a fatal-plus-injury collision rate of 0.62 per MVM, and a total collision rate of 1.47 per MVM. For similar facilities, the average rates are 0.013 per MVM for fatal collisions, 0.26 per MVM for fatal-plus-injury collisions, and 0.67 per MVM for total collisions.

In comparison, during the same period, eight collisions occurred on the SR-156 section between PM R11.378 and PM R12.528. This section also had no fatal collisions, a fatal-plus-injury rate of 0.07 per MVM, and a total collision rate of 0.27 per MVM. The average rates for similar roadways are 0.013 per MVM for fatal collisions, 0.26 per MVM for fatal-plus-injury collisions, and 0.67 per MVM for total collisions.

In summary, the section from PM R10.122 to R11.378 has higher-than-average fatal-plus-injury and total collision rates, while the section from PM R11.378 to R12.528 shows substantially lower collision rates compared to similar roadway facilities in the state. Note that PM 11.378 on SR 156 represents the intersection with SR 25.

Collision Summary: Injury Severity and Crash Type

TSAS Selective Accident Retrieval (TSAR) is a detailed report available from TASAS. This report provides specific data on traffic collisions within a study area based on selected criteria such as time period or crash type. This section of the report provides an overview of crash severity, types of collisions, and primary collision factors for four segments of SR-25 and SR-156 based on the TSAR generated from the TASAS over the five-year period before construction commencement.

Crash severity refers to the classification of collisions based on the level of harm or damage they cause. Severity has five distinct categories: Fatal, for collisions resulting in death; Serious Injury, for crashes causing severe, potentially life-threatening injuries; Minor Injury, for non-life-threatening injuries; Possible Injury, where injuries are not confirmed but suspected; and Property Damage Only (PDO), for crashes that result solely in damage to vehicles or property.

Table 1. Crash Frequency by Severity for SR-25 and SR-156 Segments

Segment	Property Damage Only (PDO)	Serious Injury	Minor Injury	Possible Injury	Fatal	Total
SR-25 PM 52.505 - 54.034	30	2	4	9	1	46
SR-25 PM 54.034 - 55.132	55	2	6	30	1	94
SR-156 PM R10.122 - R11.378	37	1	6	20	0	64
SR-156 PM R11.378 - R12.528	6	0	0	2	0	8
Total for the Study Area	128	5	16	61	2	**212**

Note. Data are from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS).

Table 2. Crash Percentage by Severity for SR-25 and SR-156 Segments

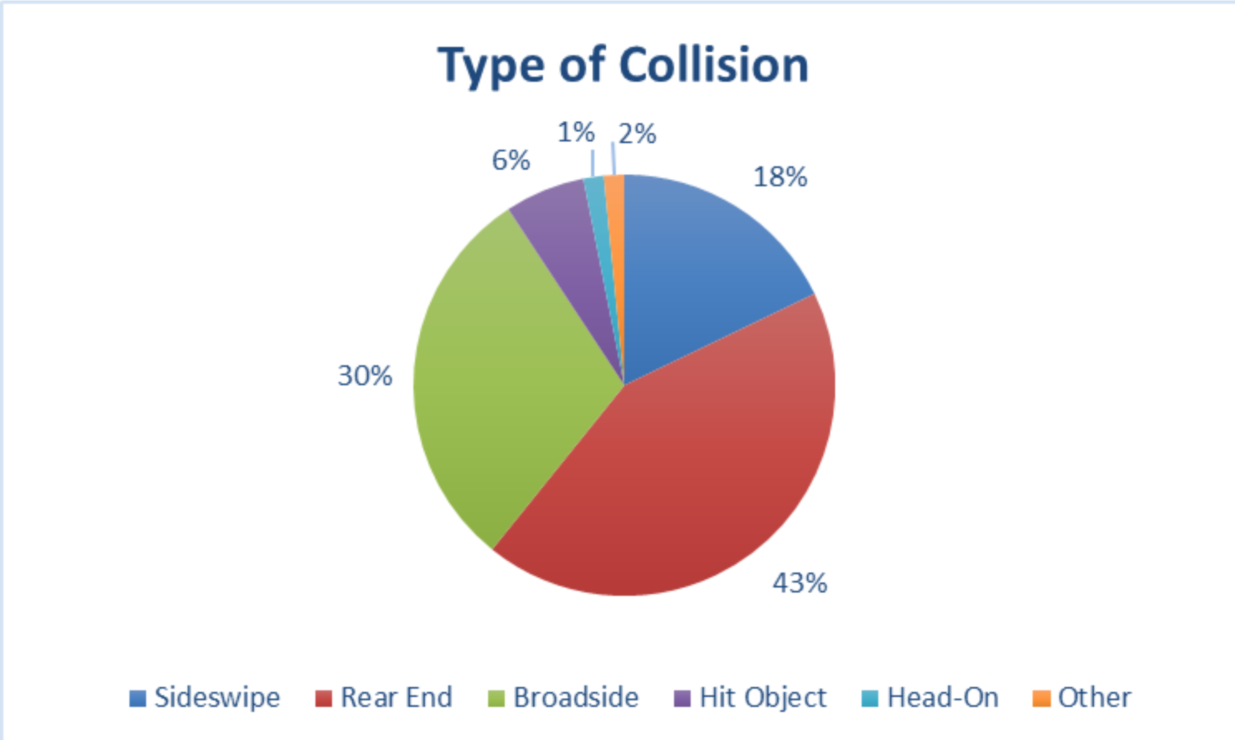
Segment	Property Damage Only (PDO)	Serious Injury	Minor Injury	Possible Injury	Fatal
SR-25 PM 52.505 - 54.034	65%	4%	9%	20%	2%
SR-25 PM 54.034 - 55.132	59%	2%	6%	32%	1%
SR-156 PM R10.122 - R11.378	58%	2%	9%	31%	0%
SR-156 PM R11.378 - R12.528	75%	0%	0%	25%	0%

Note. Data are from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS).

Table 1 summarizes the crash severity data for four segments of SR-25 and SR-156, followed by Table 2, which has the same data as percentages of each severity level on each segment. The segment from SR-25 PM 54.034 to 55.132 had the highest number of PDO crashes (55) and possible injuries (30). The SR-25 PM 52.505 to 54.034 segment observed one fatal collision alongside another fatal collision on the SR-25 PM 54.034 to 55.132 segment. Meanwhile, the SR-156 PM R11.378 to R12.528 segment had the lowest crash severity overall, with only 6 PDO incidents, two possible injury crashes, and no recorded fatalities or serious injury crashes. Across all segments, 128 PDO crashes were recorded, alongside five serious injury crashes, 16 minor injury crashes, 61 possible injury crashes, and two fatal crashes.

Different types of collisions provide insights into how crashes occur and the nature of the impact. Common collision types include sideswipe, rear-end, broadside, hit object, and head-on. Figure 7 illustrates the proportion for the type of collision in the study area.

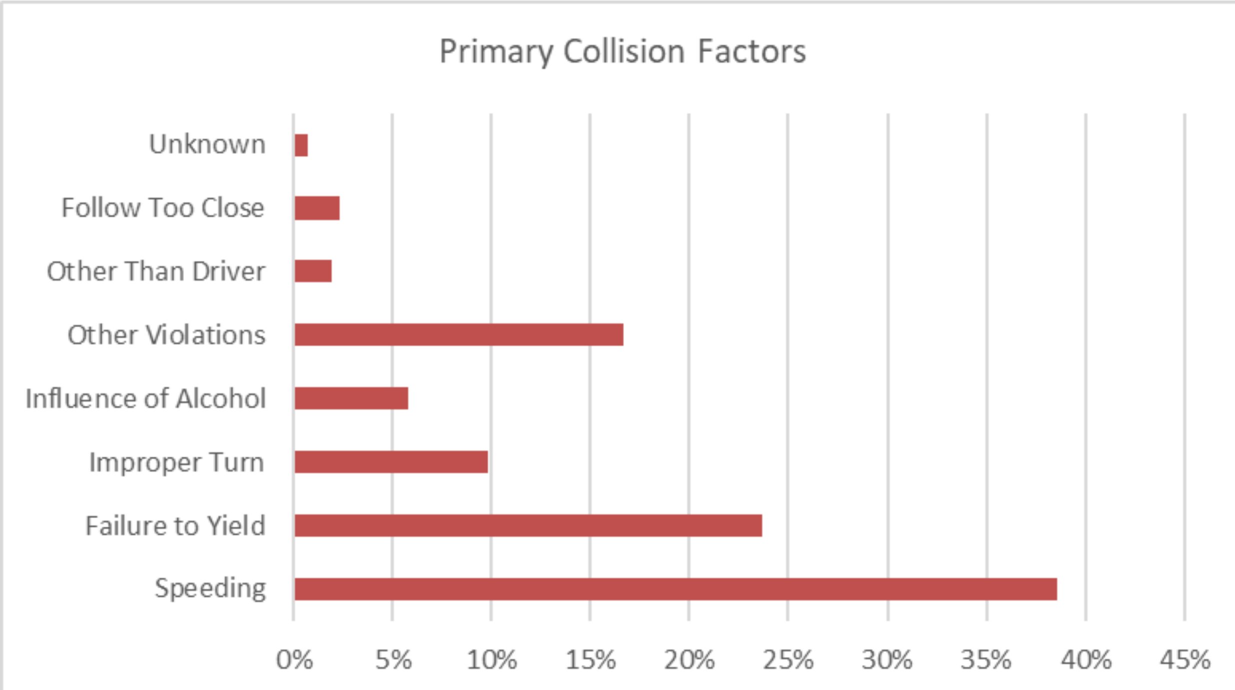
Figure 7. Types of Collisions for SR-25 and SR-156 Segments



As shown in Figure 7, rear-end collisions are the most common, making up 44% of all crashes, typically due to following too closely or sudden braking at the signalized intersection location. Broadside collisions (commonly called T-bone crashes) account for 30.7% of all crashes. These often occur at intersections when vehicles fail to yield. On signalized intersections, these collisions are likely to result in severe collisions. Sideswipe collisions contribute to about 18.3% of crashes, usually resulting from improper lane changes. Less frequent are hit object collisions (6.3%) and head-on collisions (1.6%), which, while rare, also tend to be severe.

Primary collision factors refer to the driving behaviors or conditions that contributed to the crash. These factors include speeding, failure to yield, influence of alcohol, improper turn, and more. As shown in Figure 8, in terms of primary collision factors, speeding is the leading cause, contributing to 38.6% of all crashes. Failure to yield is another significant factor responsible for 23.7% of crashes. Other notable factors include improper turns and the influence of alcohol, which play smaller but important roles in collisions.

Figure 8. Primary Collision Factors for SR-25 and SR-156 Segments



The combined analysis of crash severity, types of collisions, and primary collision factors reveals that speeding and failure to yield are the dominant contributors to crashes. These collision patterns show that a roundabout may be an effective solution at this site since roundabouts reduce approach speeds and broadside conflicts that lead to severe crashes. The next section provides site details of the newly constructed roundabout based on a site visit conducted in April 2024.

3.3 Roundabout Details

Figure 9 shows the study location geometrics and traffic control after the construction of the turbo roundabout. The details of the turbo roundabout provided in this chapter are based on a site visit on April 21, 2024. The objective of the site visit was to observe the roundabout's traffic flow, signage, and safety features. The visit also helped ensure the fidelity of the model developed in VISSIM vis-a-vis the real-world conditions.

Figure 9. Turbo Roundabout in Hollister, CA

(Link to Additional Image/Videos)

The ground-level images were captured using an iPhone 14, and aerial photos were taken with a DJI Mini 3 drone at an elevation of 350 feet, allowing for comprehensive views of the roundabout and its approaches. Key observations relevant to traffic flow and safety from the site visit are provided below:

- **Signage:** All approaches to the roundabout were equipped with overhead signage, supplemented by clear markings and additional directional signs.
- **Traffic Speeds:** Traffic speeds varied based on whether drivers had to yield before entering the roundabout.
- **Driver Behavior:** Since the site visit was conducted soon after the roundabout installation, some instances of driver confusion were noted. Vehicles, especially larger trucks, occasionally mounted barriers and engaged in somewhat aggressive maneuvers.
- **Intersection Performance:** The turbo roundabout demonstrated visibly better traffic flow and reduced queues and delays compared to the 4-legged signalized intersection. However, instances of "cooperative yielding," where drivers already in the roundabout slowed or stopped to allow others to enter, were observed, indicating some uncertainty about the roundabout use.

The driver confusion observed during site visits within weeks of roundabout installation is consistent with findings from Joerger (2007), who noted that while US drivers may have some confusion in the immediate aftermath of a roundabout installation, over time, drivers' confusion gives way to improved navigation through the roundabout. Retting et al. (2007) also found that the proportion of drivers having favorable opinions of roundabouts in a community increases significantly after one year of installation of a roundabout in the community.

In the next chapter, the safety and operational performance of the turbo roundabout are examined in contrast with the signalized intersection control that preceded it. Note that the video data were collected in March 2024 due to the time constraints of this research project. As the drivers become more familiar with the turbo roundabout, one can expect an improvement in behavior, which may lead to a better operational performance at the turbo roundabout in the near future, beyond what is reported here. A future long-term evaluation will also be helpful for assessing safety performance which may also change once the drivers get used to navigating the turbo roundabout. For example, it would be worth watching if some of the speed reductions hold on the approach to roundabout over a longer term.

4. Modeling Results: Safety and Operations Analysis

The analysis in this chapter is based on (i) microscopic traffic simulation modeling and (ii) analysis of traffic conflict data from video analytics using the TrafxSAFE tool. Microscopic traffic models for the signalized intersection and roundabout were created in VISSIM. The VISSIM simulation models were calibrated to reproduce performance measures such as volumes, speeds, and headways observed in the field. The model calibration and validation processes were consistent with the guidelines provided in the latest version of the Traffic Analysis Toolbox Volume III (Wunderlich et al., 2019).

4.1 VISSIM Simulation and Operational Performance

The first set of analyses examines the operational performance of the simulated signalized intersection vs. the simulated turbo roundabout. The VISSIM simulation models were calibrated using field-observed speed profiles and traffic volumes for AM and PM peak hours. Table 3 shows the averages for operational performance measures, including approach speed and queue delays for both control types. These averages reported in Table 3 are based on 20 randomized runs of the simulation model.

Table 3. Operational Performance Measures for AM Peak Hour

		Signalized		Turbo Roundabout	
Approaches	Segment	Queue Delay (Seconds)	Average Speed (Miles per Hour)	Queue Delay (Seconds)	Average Speed (Miles per Hour)
		AM Peak Hour			
Westbound	25	171.68	37.6	2.71	36.79
Eastbound	25	70.05	41.51	1.9	36.95
Northbound	156	71.83	41.7	2.3	34.92
Southbound	156	72.06	41.68	12.84	36.56

Table 4. Operational Performance Measures for PM Peak Hour

Approaches	Segment	Signalized Queue Delay (Seconds)	Signalized Average Speed (Miles per Hour)	Turbo Roundabout Queue Delay (Seconds)	Turbo Roundabout Average Speed (Miles per Hour)
		PM Peak Hour			
Westbound	25	90.97	38.29	4.09	37.43
Eastbound	25	277.17	41.28	2.73	38.58
Northbound	156	82.59	40.39	14.32	40.86
Southbound	156	148.02	41.31	2.64	39.77

Tables 3 and 4 show that the turbo roundabout would essentially eliminate the queue delay that existed with the signalized traffic control during the morning (AM) and afternoon (PM) peak hours. During the AM peak hours, the queue delay reduction ranged from 82.20% on SR-156 Southbound to 98.42% on Westbound SR-25. During the PM peak hours, the reduction ranged from an 82.7% reduction in queue delay on Northbound SR-156 to a 99.02% reduction on Eastbound SR-25. Tables 3 and 4 show approach speeds either staying almost the same or reducing by as much as 7 MPH. Since the reduction in approach speeds also relates to safety, this reduction is further discussed in the section where surrogate safety measures are evaluated. The simulation model shows that the roundabout would be able to practically eliminate queuing at the approach to the intersection. The elimination of queues would also yield safety benefits, given that queues at signalized intersections lead to rear-end collisions, which tend to be more severe in rural environments such as the site of this intersection where higher speeds prevail compared to more urban settings.

4.2 VISSIM Simulation and SSAM

This analysis conducted 20 randomized simulation runs in VISSIM to evaluate traffic safety at the signalized intersection and turbo roundabout during morning (AM) and afternoon (PM) peak hours. The Surrogate Safety Assessment Model (SSAM) tool from FHWA was used to assess the safety of the two intersection designs at the same location. SSAM helps analyze simulated traffic conflicts (near-miss situations), such as rear-end collisions, lane-change conflicts, and crossing conflicts, which are indicative of potential crash risks. This section aims to assess comparative safety performance using simulation software for signalized intersections and turbo roundabouts during AM and PM peak hours.

Table 5. compares key safety metrics, the average number of three different conflict types, and total conflicts based on the vehicle trajectory data collected from the 20 simulation runs.

Table 5 SSAM Conflict Results for Signalized Intersection vs. Turbo Roundabout

Scenario	Total Conflicts	Crossing Conflicts	Rear-End Conflicts	Lane Change Conflicts
Signalized Intersection AM Peak Hour	80	0	45	35
Signalized Intersection PM Peak Hour	70	0	49	21
Turbo Roundabout AM Peak Hour	20	0	15	5
Turbo Roundabout PM Peak Hour	44	0	39	5

The average number of conflicts provides a balanced view of the typical performance of each traffic control type, signal, and turbo roundabout, smoothing out the peaks and troughs of individual simulation runs. The average value also provides insight into the expected number of incidents under normal peak-hour conditions.

Signalized Intersection: At the signalized intersection, the AM peak hours experience, on average, 80 conflicts per run, reflecting the frequent occurrence of rear-end and lane-change conflicts during heavy traffic periods. During the PM peak hours, the average number of total conflicts reduces to 70, but the continued prevalence of rear-end conflicts (49) underlines the safety challenges that signalized intersections face. It needs to be mentioned that while no crossing conflicts were observed in the simulation environment, it was likely because no signal violations were being simulated. In real-world conditions, those rare conflicts do have the potential to occur and lead to severe broadside collisions.

Turbo Roundabout: In contrast, the simulated turbo roundabout performed significantly better in terms of safety. On average, 20 incidents occured per run during the AM peak hours, a substantial reduction compared to the signalized intersection. For the PM peak hours, the number of conflicts rose, with the average number being 44. However, the conflict frequency for the PM peak hour was still far lower than the signalized intersection model at the same location.

It is to be noted that a few crossing conflicts (still rounded to zero on average over 20 runs) were observed in the simulated turbo roundabout model, particularly during the AM peak hour. This could occur because turbo roundabouts require vehicles to navigate more complex multilane configurations. As vehicles merge or cross lanes at the roundabout's entry points, there may be more opportunities for vehicle-vehicle conflicts, especially during high-demand hours. In turbo roundabouts, drivers may not anticipate these interactions as smoothly as they would with clear traffic signals, leading to potential conflicts at merge or crossing points. To ascertain the safety implications of these conflicts, the speeds of vehicles involved in the crossing conflicts in the simulation environment were examined. It was confirmed that these were all low-speed conflicts that would not typically result in a collision, let alone severe injury. Some of the key observations from the analysis are noted below:

- The signalized intersection at this rural location consistently exhibited a higher frequency of both rear-end and lane-change conflicts during both peak hours, highlighting their susceptibility to higher traffic conflicts, particularly those that may lead to collisions at higher speeds.

- The turbo roundabout would significantly reduce total conflicts, especially during the AM peak, suggesting a safer traffic environment and reduction in critical high-speed rear-end and lane-change conflicts.

- Even though the turbo roundabout showed a slight increase in incidents during the PM peak hour, it would still outperform the signalized intersection in total conflicts and the severity of incidents.

Overall, the model for turbo roundabouts demonstrates superior safety performance compared to signalized intersections, particularly during the AM peak hour, by effectively minimizing both the frequency and severity of conflicts. The comparison indicates that turbo roundabouts offer a safer alternative, especially for managing rear-end and lane-change conflicts during high traffic volumes, making them a more effective option for reducing overall traffic incidents.

4.3 Video Analytics

Video cameras were installed at the intersection location and data were collected for November 2 (Tuesday) through November 4 (Thursday), 2021, during the pre-construction phase. After the construction of the roundabout, the video recordings were obtained for March 19 (Tuesday) through March 21 (Thursday), 2024, to get post-treatment data. The video data for both before and after periods were processed using TrafxSAFE by Transoft (*TrafxSAFE*, n.d.) to extract road user trajectories through the signalized intersection and the newly installed turbo roundabout. We compared the pre- and post-installation data for the time frame for which data were available for the same time of day and day of the week. There were 13 hours on each of the Tuesdays, 8 hours on Wednesdays, and 8 hours on Thursdays (a total of 29 hours each) for which both pre- and post-installation data were available. Using the trajectory data, the conflicts were defined based on categorizing surrogate measures PET or TTC at various thresholds, differential speeds between vehicles involved in the interaction events (DeltaS), and/or speeds of the vehicle traveling the fastest during the interaction (MaxS). For details on these measures of surrogate safety, please refer to Chapter 2. Fifty randomly selected conflicts in the pre-roundabout install data were verified by checking back in the video data to ensure the validity of the trajectory and conflict information.

Drivers often face some confusion navigating a newly built roundabout as they negotiate for space. Some conflicts resulting from such behavior were also observed during site visits (see Chapter 3).

Therefore, it is essential to contextualize the conflicts characterized by TTC/PET below a threshold value with the speeds of the vehicles involved (either with DeltaS or MaxS).

Table 6. Frequency of Interactions Per Hour at Various Levels of Safety Indicators

Range	Interactions/Hour Signalized Intersections			Interactions/Hour Turbo Roundabout Intersections		
TTC/PET in seconds	Rear-End (TTC)	Head On TTC	Crossing (PET)	Rear-End (TTC)	Head On TTC	Crossing (PET)
0<x<1.5	25.1	11.0	0.0	210.5	0.0	0.0
1.5<x<2.5	21.4	4.0	0.3	213.7	0.0	0.0
2.5<x<4	14.8	3.8	0.9	76.7	0.0	0.0
>4	2.3	1.1	37.0	7.9	0.0	0.0
DeltaS in MPH						
<20	54.3	12.8	13.5	503.3	0.0	0.0
20<x<40	8.9	6.3	16.5	5.4	0.0	0.0
>40	0.5	0.7	8.2	0.0	0.0	0.0
MaxS in MPH						
<20	20.0	2.2	0.5	459.0	0.0	0.0
20<x<40	40.5	15.8	15.4	49.8	0.0	0.0
>40	3.2	1.8	22.3	0.0	0.0	0.0

Table 7. Percentage of Interactions Per Hour at Various Levels of Safety Indicators

Range	Interactions/Hour Signalized Intersections			Interactions/Hour Turbo Roundabout Intersections		
TTC/PET in Seconds	Rear-End (TTC)	Head On TTC	Crossing (PET)	Rear-End (TTC)	Head On TTC	Crossing (PET)
0<x<1.5	39.4%	55.4%	0.1%	41.4%	NA	NA
1.5<x<2.5	33.7%	20.2%	0.8%	42.0%	NA	NA
2.5<x<4	23.3%	19.0%	2.4%	15.1%	NA	NA
>4	3.7%	5.4%	96.7%	1.5%	NA	NA
DeltaS in MPH						
<20	85.2%	64.8%	35.3%	98.9%	NA	NA
20<x<40	14.0%	31.9%	43.2%	1.1%	NA	NA
>40	0.8%	3.3%	21.5%	0.0%	NA	NA
MaxS in MPH						
<20	31.3%	11.1%	1.4%	90.2%	NA	NA
20<x<40	63.6%	80.0%	40.3%	9.8%	NA	NA
>40	5.1%	8.9%	58.3%	0.0%	NA	NA

Table 6 shows the number of interactions between vehicles, and Table 7 shows the same information as the percentage of interactions. The thresholds used to categorize the surrogate measures and speed values are consistent with the existing literature (Hasanvand et al., 2023; Souleyrette & Hochstein, 2012). The tables show that the turbo roundabout had a higher number of interactions per hour compared to the 4-legged signalized intersection. In fact, the number of rear-end interactions where TTC <1.5 seconds was also higher for the turbo roundabout. However, 98.9% of interactions had a speed differential (DeltaS) less than 20 MPH for the turbo roundabout, and 90.2% had MaxS less than 20 MPH. This indicates that interactions captured by TrafxSAFE were overwhelmingly lower-speed interactions on the turbo roundabout. On the previously existing signalized intersection, 68.7% of rear-end interactions, 88.9% of head-on interactions, and 98.6% of crossing interactions had MaxS over 20 MPH for the vehicles involved. Furthermore, no head-on or crossing conflicts were observed on the turbo roundabout.

Safety Scores

In this section, safety scores (ranging from 1 through 6) are estimated for each interaction, and the frequency and percentage of interactions with each of the six scores are reported for both the signalized intersection and the turbo roundabout. The safety score aims to combine the MaxS/DeltaS categories with the TTC/PET categories. The higher speed (or speed differential) interactions receive a higher safety score, e.g., MaxS (or DeltaS)> 40MPH corresponds to a safety score of 3. Lower values of TTC/PET receive a higher safety score, e.g., 0<TTC<1.5 corresponds to a safety score of 3. The total safety score is obtained by adding the safety scores corresponding to speed and TTC/PET. Hence, an interaction with MaxS>40 MPH and TTC<1.5 seconds will receive a safety score of 6 (worst possible). The full schema to define the safety score for each interaction is shown in Table 8.

Table 8. Schema to Define Safety Score for Each Interaction

DeltaS or Max S Range (MPH)	Safety score contribution (Speed)	TTC/PET range	Safety score contribution-(TTTC/PET)	Total Safety score (Sum of two score contributions)
< 20	1	0<x<1.5	3	4
		1.5<x<2.5	2	3
		2.5<x<4	1	2
		>4	0	1
20<x<40	2	0<x<1.5	3	5
		1.5<x<2.5	2	4
		2.5<x<4	1	3
		>4	0	2
> 40 MPH	3	0<x<1.5	3	6
		1.5<x<2.5	2	5
		2.5<x<4	1	4
		>4	0	3

Interactions with scores 1–2 are considered low-risk, 3–4 are considered moderate risk, and 5–6 are considered high-risk. The risk score is color-coded in Table 8.

Tables 9 and 10 provide the number/hour and percentage of interactions falling within each risk category based on speed differential (DeltaS) for each traffic control type (signalized intersection and turbo roundabout). The rows corresponding to Safety Scores 5 and 6 are highlighted since those represent the most dangerous conflicts.

Table 9. Frequency of Interactions Per Hour by Risk Score Categorization

	Signalized Intersection				Turbo Roundabout
Safety Score	Rear-End	Head On	Crossing	Total	Rear-End
1	2.3	0.5	15.0	17.8	7.9
2	14.2	2.7	14.6	31.5	76.7
3	18.8	3.9	8.4	31.1	212.4
4	**23.0**	**9.6**	**0.2**	32.8	**207.6**
5	5.1	2.6	0.0	7.7	4.2
6	0.3	0.5	0.0	0.8	0.0

(Based on Speed Differential DeltaS)

Table 10. Percentage of Interactions Per Hour by Risk Score Categorization (Based on Speed Differential DeltaS)

	Signalized Intersection			Turbo roundabout
Safety Score	Rear-End	Head On	Crossing	Rear-End
1	3.6%	2.4%	39.2%	1.5%
2	22.2%	13.6%	38.3%	15.1%
3	29.4%	19.9%	22.0%	41.8%
4	36.2%	48.2%	0.5%	40.8%
5	**8.0%**	**13.2%**	**0.1%**	**0.8%**
6	**0.5%**	**2.6%**	**0.0%**	**0.0%**

Even though the total number of interactions on the turbo roundabout is substantially higher if one considers those with safety scores 5 and 6, the turbo roundabout had close to 50% fewer such interactions (based on deltaS). Specifically, conflicts with the highest safety score (5 or 6) were down by almost 51% (8.5 interactions per hour to 4.2 per hour for turbo roundabout). Even those 4.2 conflicts per hour were rear-end types, typically leading to the lowest-severity collisions.

Tables 11 and 12 provide the same information as Tables 9 and 10 (number and percentage per hour interactions with the corresponding safety scores) based on MaxS.

Table 11. Frequency of Interactions Per Hour by Risk Score Categorization (Based on Speed Differential MaxS)

	Signalized Intersection				Turbo roundabout
Safety Score	Rear-End	Head On	Crossing	Total	Rear-End (and Total)
1	1.3	0.4	0.4	2.1	7.9
2	7.1	1.9	14.8	23.8	75.4
3	15.8	2.8	22.6	41.0	200.2
4	**18.1**	**3.7**	**0.4**	22.2	**191.2**
5	19.7	9.4	0.1	29.2	34.0
6	1.6	1.6	0.0	3.2	0.0

Table 12. Percentage of Interactions Per Hour by Risk Score Categorization (Based on MaxS)

	Signalized Intersection			Turbo Roundabout
Safety Score	Rear-End	Head On	Crossing	Rear-End
1	2.1%	2.1%	1.0%	1.5%
2	11.2%	9.8%	38.6%	14.8%
3	24.8%	14.1%	59.1%	39.4%
4	28.4%	18.5%	1.1%	37.6%
5	**31.0%**	**47.7%**	**0.2%**	**6.7%**
6	**2.5%**	**7.8%**	**0.1%**	**0.0%**

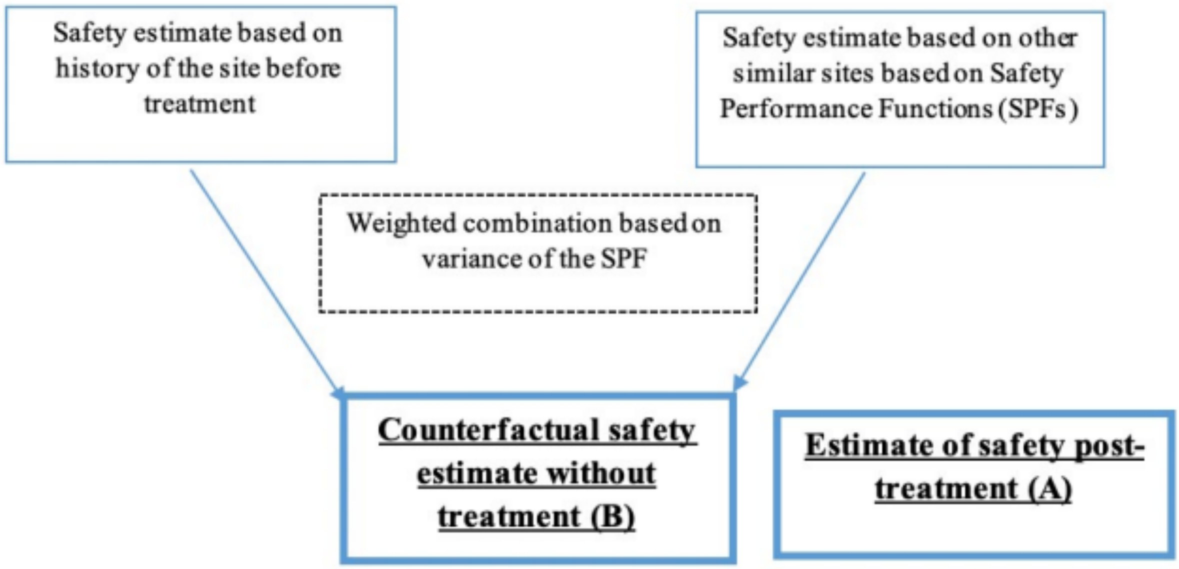
Based on MaxS, 33.5% of interactions on the signalized intersection may be considered high-risk (safety scores 5 and 6), while only 6.7% are severe for the turbo roundabouts.

The data also show that the turbo roundabout has eliminated crossing and head-on conflicts occurring at the signalized intersection. Note that these conflicts lead to the most severe injury crashes. While the overall rear-end interactions are higher, they are mostly low- to moderate-risk interactions. These higher numbers of interactions at the turbo roundabout also need to be contextualized by the fact that video data were collected within weeks of the full opening of the roundabout, and one may expect these interactions to further reduce over time.

4.4 Expected Crashes from the Counterfactual Analysis

The last set of analyses is provided for Caltrans to monitor long-term safety performance with future crash data as it becomes available. Toward that end, we applied the Empirical Bayes analysis recommended by the HSM to estimate how many crashes would be expected to occur at this location if the intersection remained a signalized intersection. Figure 10 shows the framework used to estimate the counterfactual (Estimate "B" in the figure below). When it becomes available, future collision data can be used to estimate post-treatment safety (i.e., "A" in Figure 10).

Figure 10. EB Before/After Evaluation Framework



(Source: (Molan et al., 2020))

Highway Safety Software (HSS) Results

Since the roundabout has only been in place for a few months, this study only provides a counterfactual estimate that may be compared with future collision data. According to the Empirical Bayes analysis, the site would have been expected to experience ~7.21 Fatal and Injury crashes, ~8.17 PDO crashes, and a total of ~15.38 crashes per year. This estimate is based on the 4-legged signalized intersection characteristics and collision data reported in Chapter 3. The estimate was obtained using the Safety Performance Function (SPF) and the empirical Bayes methodology from the HSM implemented in the HSS (Highway Safety Software). The total of 15.38 crashes annually provides a baseline for Caltrans to compare long-term collision data as it becomes available for the turbo roundabout. The output from the HSS is shown in Appendix D.

5. Conclusions and Future Scope

This study provides the safety and operational evaluation of a newly installed turbo roundabout. The evaluation was conducted in the immediate aftermath of the opening of the roundabout. The performance of the roundabout was evaluated vis-a-vis the 4-legged signalized intersection that existed at the location. This turbo roundabout evaluation is noteworthy since this is the first turbo roundabout in CA and the second in the US. Hence, this is the first study to evaluate a turbo roundabout in a US context. For evaluation, both a simulation-based approach and a video analytics-based approach are used, and the use of both methods for turbo roundabout performance evaluation also makes this study the first of its kind.

5.1 Summary of Findings

The results of the study may be summarized as follows:

- The roundabout reduced the queue delay at the intersection by a substantial amount and reduced approach speeds by a moderate amount.
- The SSAM analysis of simulated trajectories showed that most dangerous traffic conflicts would be reduced due to the new roundabout.
- The real-world trajectory data analyzed using the TrafxSAFE tool showed more interactions between vehicles as the road users negotiated for space on the turbo roundabout compared to previously existing signalized intersections. However, these interactions involved vehicles approaching and entering the intersection at a slower speed than when the intersection was signalized. The highest-risk interactions (defined based on surrogate measures TTC and DeltaS) were reduced by more than 50% on the roundabout compared to the signalized intersection.
- The study also provides a framework for future evaluations of roundabout performance for agencies. Key steps of the framework are as follows:
    - Step 1: Analyze existing intersection and future design(s) using simulation in the decision-making and pre-construction phase.
    - Step 2: Collect appropriate collision history and data relevant to the application of the EB methodology recommended by HSM to estimate counterfactual crash counts.
    - Step 3: Collect real-world trajectory data on existing intersections prior to the commencement of construction.

- Step 4: Within a few months of construction, collect and analyze video trajectory data to ensure and document the change in conflicts.

- Step 5: In the long term, collect post-construction collision data and compare it with the EB baseline estimate of collisions for the counterfactual scenario (obtained in Step 2).

- This study completed Steps 1 through 4 and provided Caltrans with the counterfactual annual crash frequency estimate to complete Step 5 of the evaluation framework as multi-year post-construction collision data becomes available. Note that HSM recommends a minimum of three years of collision data.

5.2 Future Work

While this study provides evidence of reduced severe high-speed conflicts due to turbo roundabouts, there is room for improvement. Due to the timeline of this research effort, the post-construction data were collected in the immediate aftermath of project delivery. For roundabouts, drivers typically get better at negotiating the intersection after a few months, and we expect that future video data will show an even more substantial reduction in conflicts. In other words, the safety improvements reported herein may be an conservative estimate of the safety benefits of the turbo roundabout.

On a related note about driver comfort and familiarity, sometimes the approach speeds at roundabouts have been observed to increase in the long run. In other words, the speed reductions observed in the immediate aftermath are not retained, and approach speeds tend to increase. For example, Hydén and Várhelyi (2000) studied 21 roundabouts and found that a reduction in speeds was observed in the data collected four months after roundabout installation, but these gains in speed reduction were often lost after four years. While the study is older and focused on urban areas, the turbo roundabout site in Hollister should be continuously monitored to ensure that speed reduction benefits are still being observed. On rural roundabouts with a small number of VRUs (Vulnerable Road Users, i.e., bicyclists and pedestrians), most of the safety gains are from the elimination of T-Bone conflicts, and therefore, on this roundabout, we do expect safety to improve over the long-term. Regardless, the counterfactual estimate of crash frequency provided in this report should allow Caltrans to quantify the long-term safety performance improvements.

Appendix A: Signal Timing Information

California Department of Transportation, Caltrans | 2070 Controller TSCP Timing Chart | TSCP: 2.21 | PAGE 1

Location: SBt - 156 PM 11.37 & Rte 25 - TSS
Designed By: AP
System:
District: 5
Installed By: AP
Master At:
I/C:
Service Info:

Timing Change:	Date Start:	Date End:	Designed:	Installed:
11/9/2022	10/26/2022			

PHASE		FLASH
1)	SB 156 LT to Rte 25	[ ]
2)	NB Rte 156	[ ]
3)	WB LT to Rte 156	[ ]
4)	EB Rte 25	[ ]
5)	NB Rte 156 LT to 25	[ ]
6)	SB Rte 156	[ ]
7)	EB LT to Rte 156	[ ]
8)	WB Rte 25	[ ]

OVERLAP	FLASH
A)	[ ]
B)	[ ]
C)	[ ]
D)	[ ]
E)	[ ]
F)	[ ]

Intersection Layout

Comments and Notes:
Video Detection for all phases.

RAM Checksum

Page 2: E1B6	Page 8: 85AF
Page 3: AB2A	Page 9: 8D70
Page 4: 0BF4	Page 10: DF52
Page 5: 191A	Page 11: 8647
Page 6: 191A	Page 12: 8D98
Page 7: B5E7	Page 13: 86F7

Post Mile: SBt-156 PM 11.37 & Rte 25 - TSS

Printed: 6/9/2023

Cabinet
332
Configuration
CALTRANS

CONFIGURATION PHASE FLAGS

Phases (2-1-1-1)	
Permitted	1 2 3 4 5 6 7 8
Restricted	. . . .

Phase Features (2-1-1-4)	
Double Entry	. 2 . 4 . 6 . 8
Rest In Walk	. . . .
Rest In Red	1 . 3 . 5 . 7 .
Walk 2	. . . .
Max Green 2	. . . .
Max Green 3	. . . .

Startup (2-1-1-5)	
First Green Phases	. 2 . . . 6 . .
Yellow Start Phases	. . . .
Vehicle Calls	1 2 3 4 5 6 7 8
Pedestrian Calls	. . . .
Yellow Start Overlaps	. . . . . .
Startup All-Red	10.0

Phase Recalls (2-1-1-2)	
Vehicle Min	. . . . 5 . . .
Vehicle Max	. . . .
Pedestrian	. . . .
Bicycle	. . . .

Phase Locks (2-1-1-3)	
Red	. . . .
Yellow	. . . .
Force/Max	. . . .

Call To Phase (2-1-2-1)		Omit On Green	
1	. . . .	1	. . . .
2	. . . .	2	. . . . 5 . . .
3	. . . .	3	. . . .
4	. . . .	4	. . . . . . 7 .
5	. . . .	5	. . . .
6	. . . .	6	1 . . . .
7	. . . .	7	. . . .
8	. . . .	8	. . 3 . . . . .

Flashing Colors (2-1-2-2)	
Yellow Flash Phases	. . . .
Yellow Flash Overlap	. . . . . .
Flash In Red Phases	. . . .
Flash In Red Overlap	. . . . . .

Special Operation (2-1-2-3)	
Single Exit Phase	. . . .
Driveway Signal Phases	. . . .
Driveway Signal Overlaps	. . . . . .
Leading Ped Phases	. . . .

Protected Permissive (2-1-2-4)	
Protected Permissive	. . . .

Pedestrian (2-1-3)	
P1	. . . .
P2	. 2 . . . . . .
P3	. . . .
P4	. . . 4 . . . .
P5	. . . .
P6	. . . . . 6 . .
P7	. . . .
P8	 8

Overlap (2-1-4)				
Overlap	Parent	Omit	No Start	Not
A	. . . .	. . . .	. . . .	. . . .
B	. . . .	. . . .	. . . .	. . . .
C	. . . .	. . . .	. . . .	. . . .
D	. . . .	. . . .	. . . .	. . . .
E	. . . .	. . . .	. . . .	. . . .
F	. . . .	. . . .	. . . .	. . . .

Post Mile: SBt-156 PM 11.37 & Rte 25 - TSS   PAGE 2   CHECKSUM: E1B6   Printed: 6/9/2023

PHASE TIMING

Phase (2-2)	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-
--- Walk 1 ---	0	0	0	0	0	0	0	0
Flash Don't Walk	0	0	0	0	0	0	0	0
Minimum Green	8	10	5	10	8	10	5	10
Det Limit	10	35	10	25	10	35	10	25
Max Initial	0	40	0	35	0	40	0	35
Max Green 1	12	75	6	70	18	70	6	70
Max Green 2	4	105	50	90	12	105	50	180
Max Green 3	50	60	50	180	50	60	50	75
Extension	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum Gap	3.0	5.0	3.0	4.0	3.0	5.0	3.0	4.0
Minimum Gap	1.5	1.0	1.5	1.0	1.5	1.0	1.5	1.0
Add Per Vehicle	0.0	2.3	0.0	2.0	0.0	2.3	0.0	2.0
Reduce Gap By	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Reduce Every	1.0	1.5	1.0	1.0	1.0	1.5	1.0	1.0
Yellow	3.9	6.0	3.9	5.8	3.9	6.0	3.9	5.8
All-Red	1.5	2.5	1.5	2.5	1.5	2.5	1.5	2.5
Ped/Bike (2-3)	**-1-**	**-2-**	**-3-**	**-4-**	**-5-**	**-6-**	**-7-**	**-8-**
--- Walk 2 ---	0	0	0	0	0	0	0	0
Delay/Early Walk	0	0	0	0	0	0	0	0
Solid Don't Walk	0	0	0	0	0	0	0	0
Bike Green	0	0	0	150	0	0	0	60
Bike All-Red	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

OVERLAP TIMING

Overlap (2-4)	A	B	C	D	E	F
Green	0.0	0.0	0.0	0.0	0.0	0.0
Yellow	5.0	5.0	5.0	5.0	5.0	5.0
Red	0.0	0.0	0.0	0.0	0.0	0.0

Red Revert

Red Revert (2-5)	
Time	3.0
All-Red Sec/Min (2-6)	
All-Red Sec/Min:	OFF

Max 2 Extension

Max/Gap Out (2-7)	
Max Cnt	0
Gap Cnt	0

Appendix B: Morning (AM) Peak Hour Traffic Counts

Leg	SBt-25					
Direction	Northbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 07:15:00	6	287	3	0	1	**297**
2021-11-02 07:30:00	1	214	4	0	1	**220**
2021-11-02 07:45:00	4	207	2	0	1	**214**
2021-11-02 08:00:00	5	207	2	0	0	**214**
Grand Total	16	915	11	0	3	**945**
% Approach	1.7%	96.8%	1.2%	0.0%	0.3%	
% Total	0.7%	41.8%	0.5%	0.0%	0.1%	**43.1%**
PHF (Nov 02 2021 7:15AM - 8:15 AM)	0.667	0.797	0.688	0	0.75	**0.795**
Motorcycles	0	3	0	0	0	**3**
% Motorcycles	0.0%	0.3%	0.0%	0.0%	0.0%	**0.3%**
Lights	7	894	7	0	1	**909**
% Lights	43.8%	97.7%	63.6%	0.0%	33.3%	**96.2%**
Single-Unit Trucks	4	11	0	0	0	**15**
% Single-Unit Trucks	25.0%	1.2%	0.0%	0.0%	0.0%	**1.6%**
Articulated Trucks	5	7	4	0	2	**18**
% Articulated Trucks	31.3%	0.8%	36.4%	0.0%	66.7%	**1.9%**
Buses	0	0	0	0	0	**0**
% Buses	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Bicycles on Road	0	0	0	0	0	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Leg	SBt-25					
Direction	Southbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 07:15:00	4	98	7	0	5	**114**
2021-11-02 07:30:00	6	112	11	0	1	**130**
2021-11-02 07:45:00	6	138	11	0	7	**162**
2021-11-02 08:00:00	6	130	15	0	6	**157**
Grand Total	22	478	44	0	19	**563**
% Approach	3.9%	84.9%	7.8%	0.0%	3.4%	
% Total	1.0%	21.8%	2.0%	0.0%	0.9%	**25.7%**
PHF (Nov 02 2021 7:15AM - 8:15 AM)	0.917	0.864	0.733	0	0.679	**0.867**
Motorcycles	0	0	0	0	1	**1**
% Motorcycles	0.0%	0.0%	0.0%	0.0%	5.3%	**0.2%**
Lights	18	454	41	0	17	**530**
% Lights	81.8%	95.0%	93.2%	0.0%	89.5%	**94.1%**
Single-Unit Trucks	0	10	1	0	0	**11**
% Single-Unit Trucks	0.0%	2.1%	2.3%	0.0%	0.0%	**2.0%**
Articulated Trucks	4	12	2	0	1	**19**
% Articulated Trucks	18.2%	2.5%	4.5%	0.0%	5.3%	**3.4%**
Buses	0	1	0	0	0	**1**
% Buses	0.0%	0.2%	0.0%	0.0%	0.0%	**0.2%**
Bicycles on Road	0	1	0	0	0	**1**
% Bicycles on Road	0.0%	0.2%	0.0%	0.0%	0.0%	**0.2%**

Leg	SBt-156					
Direction	Eastbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 07:15:00	64	42	2	0	7	**115**
2021-11-02 07:30:00	57	47	18	0	4	**126**
2021-11-02 07:45:00	38	40	15	0	9	**102**
2021-11-02 08:00:00	45	53	8	0	9	**115**
Grand Total	204	182	43	0	29	**458**
% Approach	44.5%	39.7%	9.4%	0.0%	6.3%	
% Total	9.3%	8.3%	2.0%	0.0%	1.3%	**20.9%**
PHF (Nov 02 2021 7:15AM - 8:15 AM)	0.797	0.858	0.597	0	0.806	**0.909**
Motorcycles	0	1	0	0	0	**1**
% Motorcycles	0.0%	0.5%	0.0%	0.0%	0.0%	**0.2%**
Lights	198	119	41	0	27	**385**
% Lights	97.1%	65.4%	95.3%	0.0%	93.1%	**84.1%**
Single-Unit Trucks	2	8	1	0	0	**11**
% Single-Unit Trucks	1.0%	4.4%	2.3%	0.0%	0.0%	**2.4%**
Articulated Trucks	4	54	1	0	2	**61**
% Articulated Trucks	2.0%	29.7%	2.3%	0.0%	6.9%	**13.3%**
Buses	0	0	0	0	0	**0**
% Buses	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Bicycles on Road	0	0	0	0	0	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Leg	SBt-156						
Direction	Westbound						
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**	**Int Total**
2021-11-02 07:15:00	3	44	0	0	3	**50**	**576**
2021-11-02 07:30:00	1	53	1	0	1	**56**	**532**
2021-11-02 07:45:00	0	35	4	0	1	**40**	**518**
2021-11-02 08:00:00	2	70	4	0	3	**79**	**565**
Grand Total	6	202	9	0	8	**225**	**2191**
% Approach	2.7%	89.8%	4.0%	0.0%	3.6%		
% Total	0.3%	9.2%	0.4%	0.0%	0.4%	**10.3%**	
PHF (Nov 02 2021 7:15AM - 8:15 AM)	0.5	0.721	0.563	0	0.667	**0.712**	**0.952**
Motorcycles	0	0	0	0	0	**0**	**5**
% Motorcycles	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**	**0.2%**
Lights	1	130	9	0	5	**145**	**1969**
% Lights	16.7%	64.4%	100.0%	0.0%	62.5%	**64.4%**	**89.9%**
Single-Unit Trucks	0	7	0	0	0	**7**	**44**
% Single-Unit Trucks	0.0%	3.5%	0.0%	0.0%	0.0%	**3.1%**	**2.0%**
Articulated Trucks	5	65	0	0	2	**72**	**170**
% Articulated Trucks	83.3%	32.2%	0.0%	0.0%	25.0%	**32.0%**	**7.8%**
Buses	0	0	0	0	1	**1**	**2**
% Buses	0.0%	0.0%	0.0%	0.0%	12.5%	**0.4%**	**0.1%**
Bicycles on Road	0	0	0	0	0	**0**	**1**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**	**0.0%**

Appendix C: Afternoon (PM) Peak Hour Counts

Leg	SBt-25					
Direction	Northbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 15:00:00	6	127	0	0	0	**133**
2021-11-02 15:15:00	10	104	1	0	0	**115**
2021-11-02 15:30:00	15	138	0	0	0	**153**
2021-11-02 15:45:00	13	103	1	0	0	**117**
Grand Total	44	472	2	0	0	**518**
% Approach	8.5%	91.1%	0.4%	0.0%	0.0%	
% Total	1.8%	18.8%	0.1%	0.0%	0.0%	**20.7%**
PHF (Nov 02 2021 3PM - 4 PM)	0.733	0.855	0.5	0	0	**0.846**
Motorcycles	1	0	0	0	0	**1**
% Motorcycles	2.3%	0.0%	0.0%	0.0%	0.0%	**0.2%**
Lights	34	450	1	0	0	**485**
% Lights	77.3%	95.3%	50.0%	0.0%	0.0%	**93.6%**
Single-Unit Trucks	3	10	0	0	0	**13**
% Single-Unit Trucks	6.8%	2.1%	0.0%	0.0%	0.0%	**2.5%**
Articulated Trucks	5	11	1	0	0	**17**
% Articulated Trucks	11.4%	2.3%	50.0%	0.0%	0.0%	**3.3%**
Buses	1	1	0	0	0	**2**
% Buses	2.3%	0.2%	0.0%	0.0%	0.0%	**0.4%**
Bicycles on Road	0	0	0	0	0	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Leg	SBt-25					
Direction	Southbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 15:00:00	3	283	28	0	17	**331**
2021-11-02 15:15:00	3	224	27	0	24	**278**
2021-11-02 15:30:00	9	262	38	0	17	**326**
2021-11-02 15:45:00	7	236	33	0	20	**296**
Grand Total	22	1005	126	0	78	**1231**
% Approach	1.8%	81.6%	10.2%	0.0%	6.3%	
% Total	0.9%	40.1%	5.0%	0.0%	3.1%	**49.2%**
PHF (Nov 02 2021 3PM - 4 PM)	0.611	0.888	0.829	0	0.813	**0.93**
Motorcycles	0	3	0	0	0	**3**
% Motorcycles	0.0%	0.3%	0.0%	0.0%	0.0%	**0.2%**
Lights	17	986	124	0	78	**1205**
% Lights	77.3%	98.1%	98.4%	0.0%	100.0%	**97.9%**
Single-Unit Trucks	2	8	1	0	0	**11**
% Single-Unit Trucks	9.1%	0.8%	0.8%	0.0%	0.0%	**0.9%**
Articulated Trucks	3	7	1	0	0	**11**
% Articulated Trucks	13.6%	0.7%	0.8%	0.0%	0.0%	**0.9%**
Buses	0	1	0	0	0	**1**
% Buses	0.0%	0.1%	0.0%	0.0%	0.0%	**0.1%**
Bicycles on Road	0	0	0	0	0	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Leg	SBt-156					
Direction	Eastbound					
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**
2021-11-02 15:00:00	29	73	2	0	3	**107**
2021-11-02 15:15:00	18	89	8	0	5	**120**
2021-11-02 15:30:00	24	72	4	0	1	**101**
2021-11-02 15:45:00	32	65	4	0	3	**104**
Grand Total	103	299	18	0	12	**432**
% Approach	23.8%	69.2%	4.2%	0.0%	2.8%	
% Total	4.1%	11.9%	0.7%	0.0%	0.5%	**17.3%**
PHF (Nov 02 2021 3PM - 4 PM)	0.805	0.84	0.563	0	0.6	**0.9**
Motorcycles	0	0	0	0	0	**0**
% Motorcycles	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Lights	102	204	12	0	10	**328**
% Lights	99.0%	68.2%	66.7%	0.0%	83.3%	**75.9%**
Single-Unit Trucks	0	15	4	0	1	**20**
% Single-Unit Trucks	0.0%	5.0%	22.2%	0.0%	8.3%	**4.6%**
Articulated Trucks	1	80	1	0	1	**83**
% Articulated Trucks	1.0%	26.8%	5.6%	0.0%	8.3%	**19.2%**
Buses	0	0	1	0	0	**1**
% Buses	0.0%	0.0%	5.6%	0.0%	0.0%	**0.2%**
Bicycles on Road	0	0	0	0	0	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**

Leg	SBt-156						
Direction	Westbound						
Start Time	Left	Thru	Right	U-Turn	Right on red	**App Total**	**Int Total**
2021-11-02 15:00:00	2	70	1	0	1	**74**	**645**
2021-11-02 15:15:00	0	73	0	0	2	**75**	**588**
2021-11-02 15:30:00	1	75	2	0	3	**81**	**661**
2021-11-02 15:45:00	1	88	3	0	1	**93**	**610**
Grand Total	4	306	6	0	7	**323**	**2504**
% Approach	1.2%	94.7%	1.9%	0.0%	2.2%		
% Total	0.2%	12.2%	0.2%	0.0%	0.3%	**12.9%**	
PHF (Nov 02 2021 3PM - 4 PM)	0.5	0.869	0.5	0	0.583	**0.868**	**0.947**
Motorcycles	0	0	0	0	0	**0**	**4**
% Motorcycles	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**	**0.2%**
Lights	4	205	6	0	6	**221**	**2239**
% Lights	100.0%	67.0%	100.0%	0.0%	85.7%	**68.4%**	**89.4%**
Single-Unit Trucks	0	11	0	0	1	**12**	**56**
% Single-Unit Trucks	0.0%	3.6%	0.0%	0.0%	14.3%	**3.7%**	**2.2%**
Articulated Trucks	0	88	0	0	0	**88**	**199**
% Articulated Trucks	0.0%	28.8%	0.0%	0.0%	0.0%	**27.2%**	**7.9%**
Buses	0	2	0	0	0	**2**	**6**
% Buses	0.0%	0.7%	0.0%	0.0%	0.0%	**0.6%**	**0.2%**
Bicycles on Road	0	0	0	0	0	**0**	**0**
% Bicycles on Road	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**	**0.0%**

Appendix D: HSM Safety Analysis

Highway Safety Software Rural Multilane Intersection Report				
Project Information				
Analyst	Nick Sauciur		Date	7/14/2024
Jurisdiction	Caltrans D5		Analysis Year	2024
Project Description	Turbo Roundabout Project Mineta			
Input Data				
Intersection Type	Four-leg, Signal (4SG)			
AADTmaj (veh/day)	24100		AADTmin (veh/day)	15400
Intersection Skew Angle	0		Lighting	Yes
Approaches with Left-Turn Lanes	4		Approaches with Right-Turn Lanes	2
Calibration Factor	1.00			
Predicted Intersection Crashes				
Crash Severity	Overdispersion Parameter	Nspf,rs by Severity	Predicted Crash Frequency	
Fatal and Injury (FI.)	-	9.790	9.790	
Property Damage Only (PDO)	-	18.780	18.780	
Total	0.277	28.570	28.570	
Expected Roadway Section Crashes				
Crash Severity	Average Observed Crashes	Weight	Expected Crash Frequency	
Fatal and Injury (FI.)	-	-	7.209	
Property Damage Only (PDO)	-	-	8.169	
Total	13.714	0.112	15.378	
Economic Analysis (Expected Crashes)				
Crash Severity	Per Crash Societal Crash Cost		Expected Annual Crashes	Total Societal Crash Cost
Fatal and Injury (FI.)	$158,200.00		7.209	$1,140,463.80
Property Damage Only (PDO)	$7,400.00		8.169	$60,450.60
Total	-		15.378	$1,200,914.40

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About the Authors

Vyshnavi Shetty

Ms. Shetty is a graduate student in the Department of Civil and Environmental Engineering at California Polytechnic State University, San Luis Obispo.

Mycola Sauciur

Mr. Sauciur is a graduate student in the Department of Civil and Environmental Engineering at California Polytechnic State University, San Luis Obispo.

Anurag Pande, PhD

Dr. Pande is a Professor in the Department of Civil and Environmental Engineering at California Polytechnic State University, San Luis Obispo. His research interests include traffic safety, microscopic simulation of transport systems, analysis of data to improve transportation decision-making, and service-learning.