

Impact of S-Curves on Speed in a Modern Roundabout



SAFER RESEARCH USING **SIMULATION**

UNIVERSITY TRANSPORTATION CENTER

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Abstract

According to the United States Department of Transportation (USDOT), around 20 people per day die at signalized intersections, with most of these caused by angle or head-on crashes. The USDOT's Federal Highway Administration (FHWA) has identified modern roundabouts to be substantially safer than signalized intersections, due in part to the reduction in conflict points from 32 for a traditional signalized intersection to 8 for a modern roundabout [2]. Despite the increased adoption of modern roundabouts across the US, there are a number of specific design elements for which the direct impact they have on operational and safety-related performance of the roundabout remains unknown. To be specific, there is currently no conclusive research on the direct speed effects related to the introduction of a reverse curve (S-curve) and its geometric characteristics on the approach to a roundabout. This research employed a series of microsimulation-based analyses to investigate the speed-related impacts related to the introduction to S-curves on the entry of a roundabout. An existing roundabout in Amherst, MA, USA, was used as a case study for this experiment. The existing geometry was initially modeled, after which the conventional linear approach was modified to an S-curve and evaluated. Field data from the locations were used to calibrate microsimulation models developed in AIMSUN. The resulting trajectory data was analyzed for both the base case as well as three levels of experimental S-curves (ranging from 30 to 60 degrees) on each roundabout approach (16 total). The results provide evidence to suggest that a significant reduction in speed can be realized with a minimal amount of reverse curvature on the roundabout approach.

1 Introduction

Minimizing traffic congestion while improving traffic safety within the roadway network has consistently presented a challenge for roadway designers. Both operational efficiency and improved safety have been the focus of numerous efforts over the years. In order to improve safety and preserve operational efficiency, roundabouts have been introduced in place of signalized intersections.

Despite the increased adoption of modern roundabouts across the US, there are a number of specific design elements for which the direct impact they have on operational and safety related performance of the roundabout remains unknown. Among the more critical factors in roundabout operations is the speed of vehicles at the point of entry. Several specific design strategies, ranging from traffic control devices to physical design alterations, have been employed to manage speed at roundabouts.

Among the most common countermeasures employed at roundabouts are signage and pavement markings. A 2011 study by Montella [3] in Italy analyzed the crash history of 15 roundabouts from 2003 to 2008, while also taking an annual inventory of field conditions. The study found that missing or faded yield lines contributed to 68 crashes. Furthermore, this research also revealed that absent, faded, or poorly located yield signs were major factors in 50 crashes during the same time period.

Unlike at conventional intersections, where drivers are not required to reduce their speeds when they proceed through an intersection, roundabouts require drivers to slow down. They accomplish this through the strategic design of deflection angles at roundabout entrances. The physical constrictions formed by the splitter island on the left and the curb on the right require drivers to slow down in order to remain in their lane. The magnitude of this deflection is a key factor in deceleration and speed selection. The reduced speeds achieved necessitating this maneuver serve to prevent many crashes and make occurring crashes less severe. Baranowski [4] provides an illustration of deflection at the entrance to a roundabout.

A study by Robinson et al. [5] showed that roadway curvature influenced the approach speed at roundabout entrances. The increase in the central angle of the vehicle path curvature was found to decrease the relative speed between entering and circulating traffic. This study recommended that the entry path radius should not be much larger than the circulatory radius. Zegeer et al. [6] found that the deflection at roundabout entrances should be set to control speeds between 15 and 18 mph. Troutbeck [7] stated that "adequate deflection through roundabouts is the most important factor influencing their safe operation." The Maryland Department of Transportation published roundabout design guidelines [8] that recommend a deflection angle that causes the driver to reduce speed as the curve enters the central island. This paper asserts that adequate deflection of the vehicle entering a roundabout is the most important factor in facilitating safe operations. The Washington State Department of Transportation roundabout design guidelines [9] state that the chicanes (Figure 1.1) are a type of horizontal deflection that has significant impact on traffic calming and reducing the speed of the vehicles at high speed approaches.

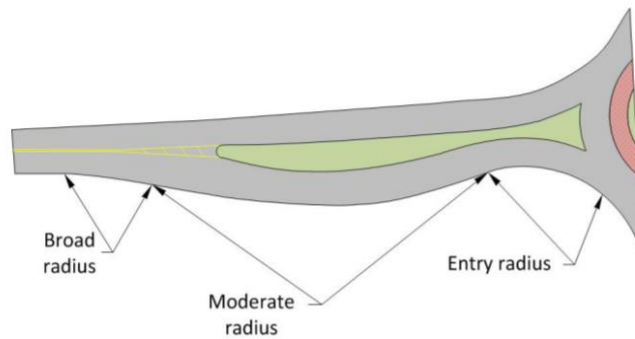


Figure 1.1 Chicane or S-curve at a roundabout approach

Isebrands [10] reports that traffic circles are characterized by little or no deflection angle. The author states that this particular aspect encourages high speeds. By comparison, the article states that at modern roundabouts, all drivers are deflected to the right, resulting in a 40% reduction in total crashes and an 80% reduction in fatal and injury crashes as compared to traffic calming circles. The variation in degree of deflection angle is not considered.

The objective of this study is to assess whether a reversed curve or S-curve approach decreases the speed of the vehicle entering a modern roundabout approach using microsimulation.

2 Methodology

The Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) microsimulation software was used to model a roundabout as well as three additional models with various angles for the S-curve in order to investigate the impact of those curves on approach speeds.

2.1 Site Selection

The single-lane modern roundabout in Amherst, MA, USA, was selected as a suitable case study for experimentation. The roundabout, pictured in Figure 2.1, is present at the intersection of North Pleasant Street (north and south), Eastman Lane (east) and Governor's Avenue (west). Situated in the UMass campus, the roundabout undergoes periods of sudden yet variable demand, with a mix of vehicular, pedestrian, and bicycle volumes.



Figure 2.1 An aerial photo of the roundabout test site

2.2 Traffic Data

Field data was captured at multiple time periods (both AM and PM peaks) as the base input for the microsimulation models. The data collected consisted of vehicular traffic demand, pedestrian traffic demand, and trajectories. Traffic flow was measured as the input to an OD-matrix for this project describing the total traffic flow entering the roundabout from each direction (Table 2.1).

Table 2.1 OD matrix for evening peak hour traffic

Entrance → Exit	<i>North Pleasant Street</i>	<i>Eastman Lane</i>	<i>GRC</i>	<i>Governor's Avenue</i>	<i>Total</i>
<i>North Pleasant Street</i>	0	126	158	345	629
<i>Eastman Lane</i>	121	0	294	64	479
<i>GRC</i>	98	78	0	72	248
<i>Governor's Avenue</i>	105	153	53	0	311
<i>Total</i>	324	357	505	481	1,667

2.3 Road Inventory

Since details about the geometric data and speeds were required for the modeling, specific geometric dimensions were obtained from a combination of design plans and field measurements. The campus roundabout was drawn in Auto-Cad Civil-3D in accordance with the existing layout and scale. Before changing the geometry of the approach, the stopping sight distance (SSD) for the roundabout was calculated from the first conflict point with the pedestrians at the roundabout. Since the main purpose of the S-curve was to reduce the speed and increase the line of sight for the drivers, the length of the SSD, i.e., 139-152 feet, was taken as the length of the S-curve. A set of three models was used to investigate the impact of S-curves on approach speeds at the roundabouts. Three models had varying central angles in the S-curve, ranging from 30, 45, and 60 degrees, as shown in Figure 2.2.

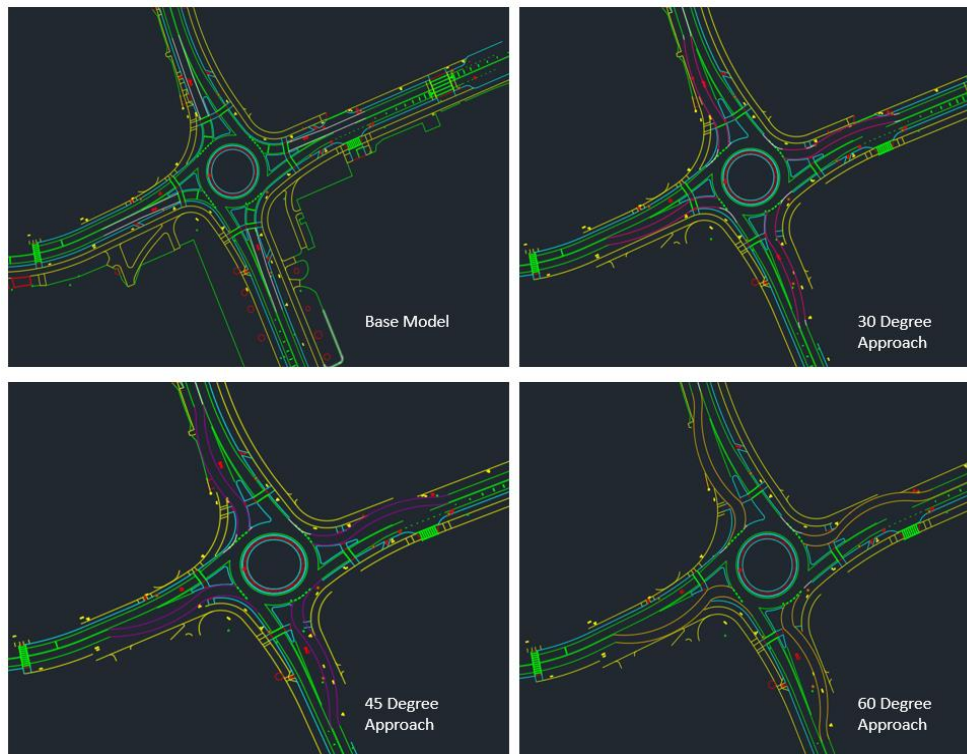


Figure 2.2 Aerial view of Auto-Cad figures for the base and three experimental S-curve models

2.4 Micro-Simulation

Data acquired from the video recording was utilized to develop and calibrate the microsimulation models using AIMSUN. Specifically, the models were developed in AIMSUN. Note that an attempt to model the roundabout using VISSIM was also completed, but the model was not able to account for the geometric conditions that were being manipulated within the current experiment. In AIMSUN, the roundabout feature played a significant role in reducing the speed at the modern roundabout approach.

In order to build the AIMSUN base model, data required included number and width of lanes, grades, roadway segment lengths, lane types, sight distance at approach, curves, super-elevations, radii, roundabout inscribed circle diameter, circulating lane width, and entry angles. The width of the pavement is 10 feet and pavement type is selected as roundabout for the approach and center island. The traffic volumes were assigned from the acquired evening peak hour data in the form of an OD matrix. Separate sets of vehicle parameters are used for passenger cars and heavy vehicles. The vehicle and segment speeds are set constant for both the base and S-curve models. The visibility to yield was calculated based on the horizontal stopping sight distance for all the models. The vehicles were set to run for a duration of 2 hours, and 10 replications were run on all the models.

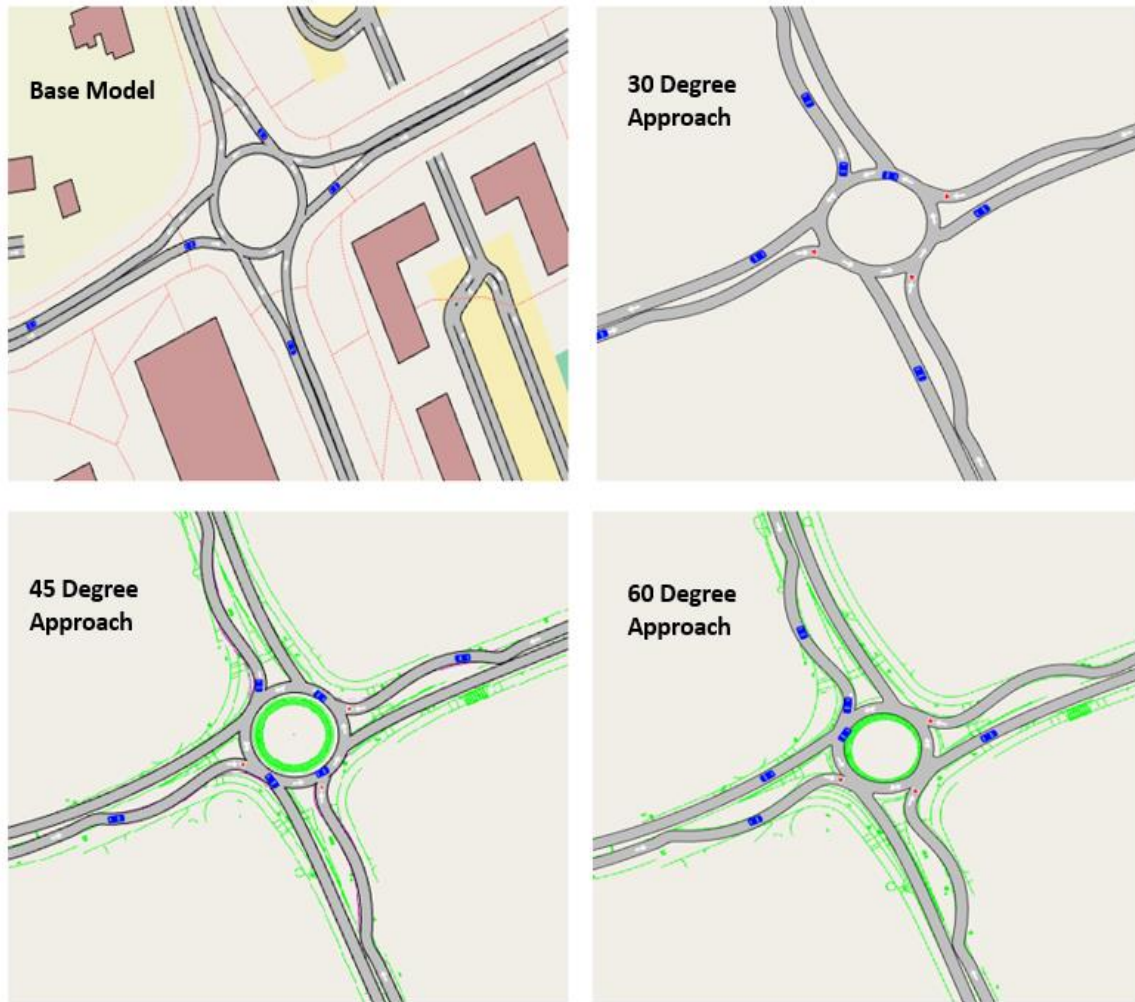


Figure 2.3 AIMSUN files for the base and three experimental S-curve models

3 Analysis and Results

3.1 Micro-simulation Analysis

Initially, the base model and three S-curve models were developed and tested in AIMSUN. Speed elements such as vehicle speed and section speed were constant for all models. The radius of curvature of the approach increased proportionally with the increase in the central angle of the approach.

Most microsimulation software programs do not consider the impact of horizontal curvature on vehicles' speeds. As a result, no matter how steep the central angle of the approach curve is, it does not have any effect on vehicles' speed. AIMSUN, on the other hand, has a roundabout feature, and it accounts for the impact of horizontal curvature but only at the approach of a roundabout. Hence, the chicanes at the approaches have a remarkable effect on vehicle speeds.

3.2 Speed Analysis

A total of 10 replications were performed, and the results were analyzed and are shown in Figure 3.1. The results show that there are statistically significant reductions in speed at all roundabout approaches when S-curves with different angles are introduced. In addition, the higher the angle of the S-curve, the higher the reduction in approach speeds.

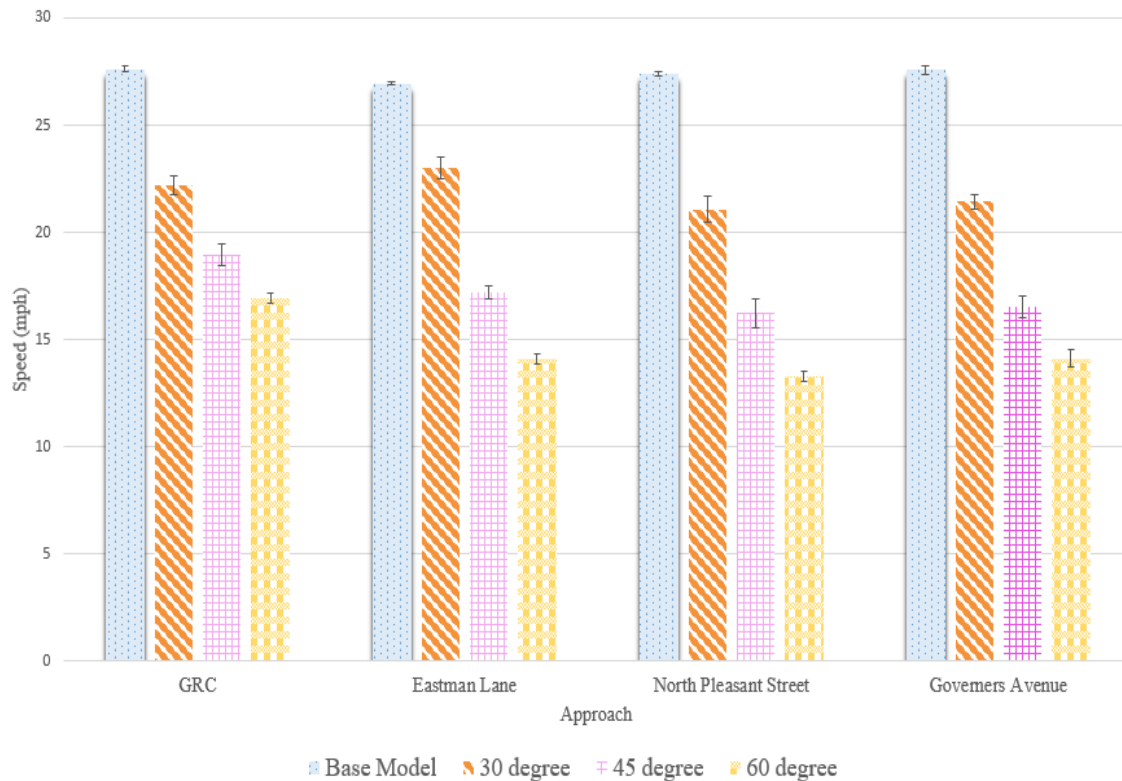


Figure 3.1 Mean speed plot for each approach for all S-curves tested.

3.3 Trajectory Analysis

The trajectory data of each approach was extracted from AIMSUN for all four models. The primary reason for this trajectory-based analysis was to get a clear understanding of speed reduction at different parts of the S-curve approach. Trajectory data were obtained every 10 seconds. The approach length for all models ranged from 138 feet to 150 feet. The approach length was split into three segments to allow for a comparison of the vehicle trajectories among different models. Figure 3.2 depicts the location of the segment transitions at the GRC approach. The first segment is the furthest from the approach and is within 0-75 feet from when the S-curve starts, the second segment lies between the beginning of the approach and the roundabout and has a length of 76-90 feet, and the third segment is closest to the roundabout with a length of 91-150 feet.



Figure 3.2 Illustration of segment definitions for the GRC approach

The trajectory data collected from AIMSUN were aggregated based on the 10 replications for each vehicle that approached the roundabout, and their average speed at all three segments was calculated. This was plotted as a curve with speed on the Y-axis and distance on the X-axis. Moreover, the average speed of all vehicles at each segment was also computed and plotted along with the curves as the mean speed curve. This was carried out for each of the four models—the base model, the 30-degree model, the 45-degree model, and the 60-degree model—at each of the roundabout approaches: Eastman Lane, Governor’s Avenue, GRC, and North Pleasant Street.

Figure 3.3 through Figure 3.6 show the trajectories for all four models at each approach. The scatter plots represent the average speed of each vehicle over the range of distance, and the bold lines represent the mean speed of all the vehicles at that distance. As also indicated by Figure 3.1, Figure 3.3 through Figure 3.6 clearly show that the S-Curve approach has a significant impact on reducing speed at the approach of a roundabout.

The speeds of vehicles for the base model are generally higher for all approaches and all ranges of distances compared to those of the models that include the S-curves. It is also observed that for the base model the average speed remains constant for the entire distance that is traveled as a vehicle is approaching the roundabout.

For the models that include the S-curves, the speed behavior was different at the four approaches, but there was an overall reduction of speeds as the vehicles were approaching the roundabout. Note that vehicles adopted different initial speeds at the four approaches due to differences in further upstream geometry and/or operational conditions. For all of the approaches and S-curves, however, the reduction in speeds was directly related to the magnitude of the S-curve.

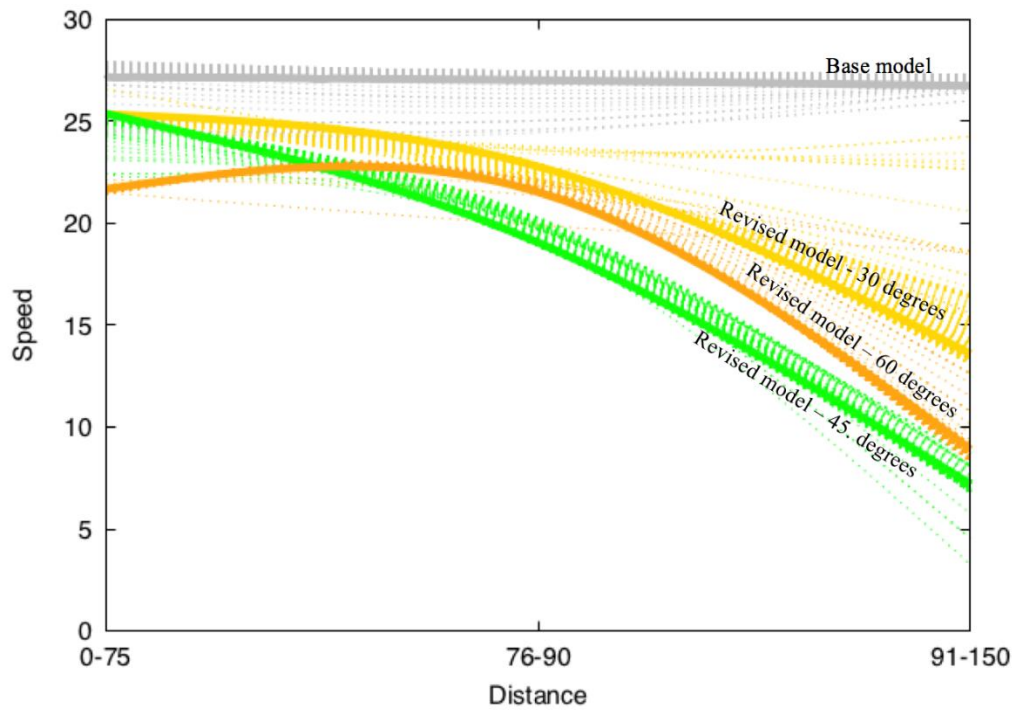


Figure 3.3 Individual vehicle trajectories and an average trajectory as a function of distance from the beginning of the approach (GRC approach)

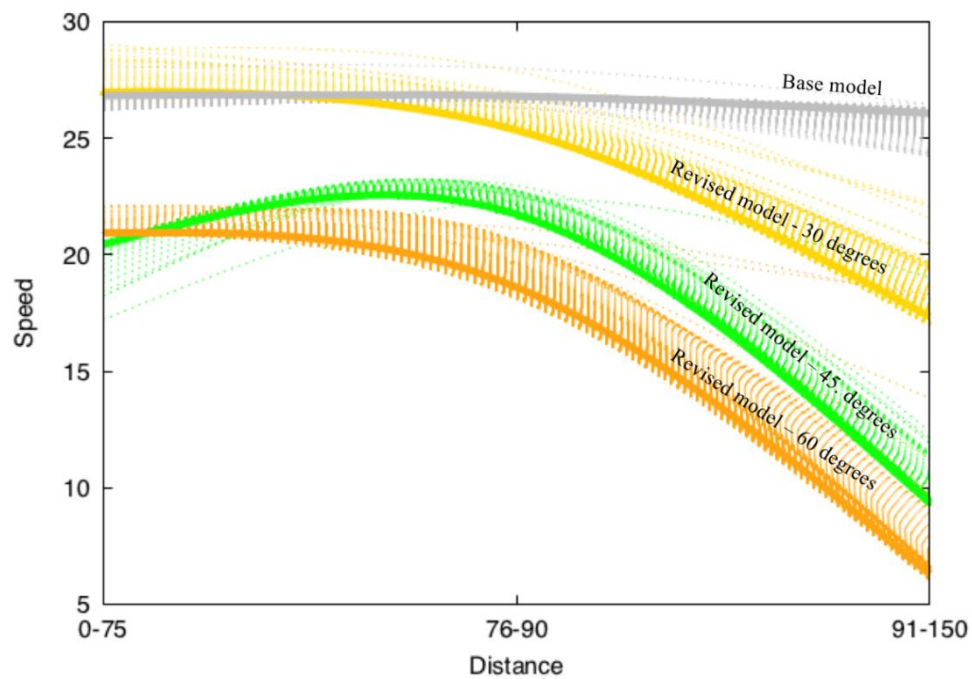


Figure 3.4 Individual vehicle trajectories and an average trajectory as a function of distance from the beginning of the approach (Eastman Lane approach)

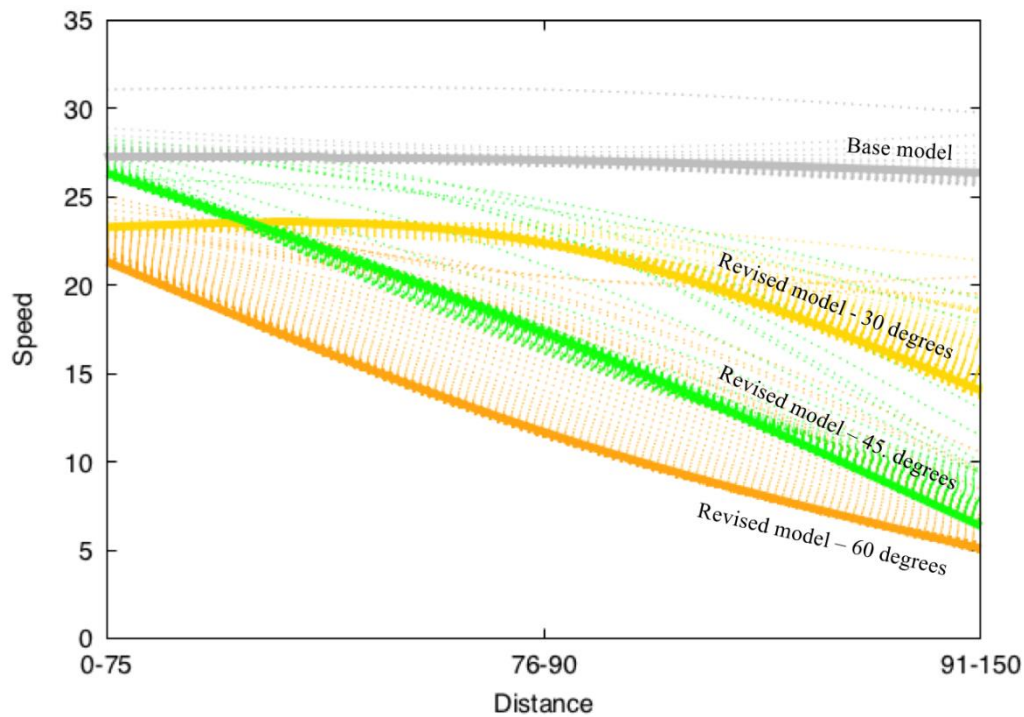


Figure 3.5 Individual vehicle trajectories and an average trajectory as a function of distance from the beginning of the approach (North Pleasant Street approach)

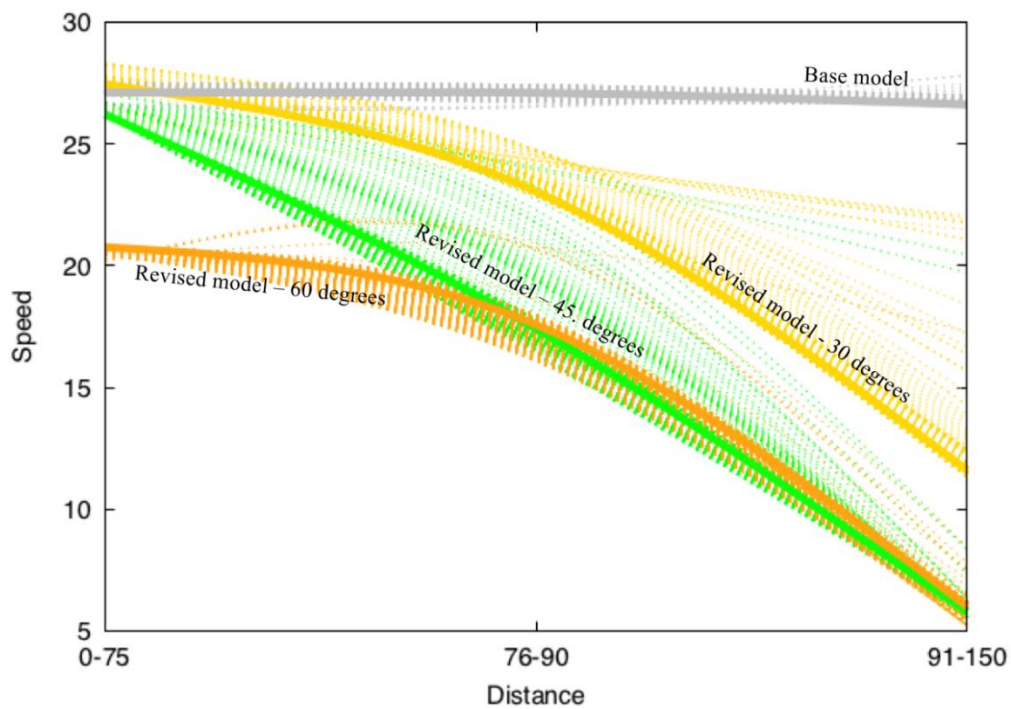


Figure 3.6 Individual vehicle trajectories and an average trajectory as a function of distance from the beginning of the approach (Governor's Avenue approach)

4 Conclusion

Overall, the results of this study suggest that a significant reduction in speed can be realized with a minimal amount of reverse curvature on the roundabout approach.

The introduction of reverse curvature on the approach to the modern roundabout produces significantly reduced speeds over a greater distance than that of a traditional roundabout with a linear approach. In the existing roundabout, the speed of the vehicle as it approaches the roundabout remains relatively constant, even when it is nearing the entry of the roundabout. For the roundabout models with S-curves, a reduction in speeds is observed as the vehicles approach the entry of the roundabout. This may be because the visibility of vehicles circulating in the roundabout and pedestrians is improved when S-curves are introduced. This is not only a safer design for pedestrians, bicyclists, and visually impaired pedestrians, but also reduces vehicle-to-vehicle conflicts.

Future work will determine the S-curve angle that achieves the optimum speed for a vehicle approaching the roundabout. In some instances, extreme reductions in approach speed may not be warranted, due to the impact they can have on queueing and delays at roundabouts. A further analysis could include simulation of pedestrian behaviour and analysis for the impact of pedestrians on vehicle operations when S-curves are present. Finally, the study can be repeated in a driving simulator environment, and the results can be compared against the microsimulation results.

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