

Little Falls, Gorham

Reconstruction to a Modern Roundabout

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ABSTRACT

Older American traffic circles can typically handle high traffic volumes, but they often have poor safety records. Modern roundabouts are similar to traffic circles in the sense that the traffic 'circles' around a central island, but many other design concepts differ.

The first modern roundabout in Maine was opened to traffic in July 1997. The total accident rate after sixteen months of operation is slightly below that which would be expected if the junction had been signalized. There has still not been a single injury accident, and the injury rate is expected to stay significantly below that of a signalized intersection.

The one-lane design will be able to handle traffic growth for years to come. Vehicle exhaust has been reduced significantly and delay on the minor approaches has been reduced by approximately 80% during morning and afternoon peak hours. In total, the reconstruction will annually save 5,000 to 10,000 hours of travel time. This by itself pays for the investment in about five years. Maine should have many junctions converted into roundabouts within the next few years.

Key words: Roundabout, safety, Maine, delay

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INTRODUCTION

The first modern roundabout in Maine was opened to traffic in early July 1997. This paper presents an analysis of the effect of this reconstruction.

Location

The junction (U.S. 202 and State Route 237) is located about 5 km north of the Gorham town center, and about 13 km northwest of central Portland, the largest city in Maine. In 1997, on average, 13,210 vehicles enter per day. Approach distribution is shown in Figure 1.

An elementary school and a town recreation center are located just south of the intersection. There is a gas station/mini mart at the southwest corner of the junction and several other businesses and numerous residences within a few hundred meters.

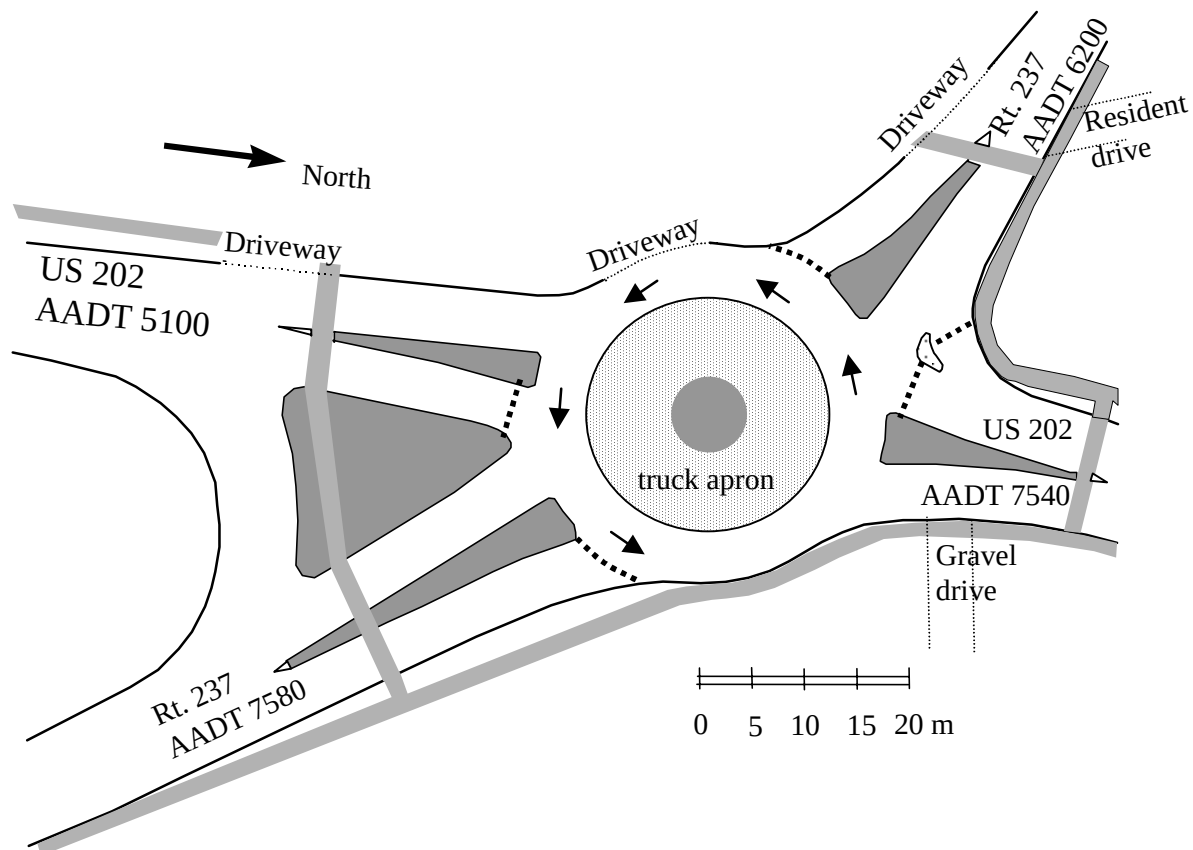


Figure 1. Layout after reconstruction.

GEOMETRIC DESIGN

Lay-Out Before

Prior to reconstruction, the junction was controlled by two-way stop signs with traffic on U.S. 202 having priority. Flashing red/yellow lights augmented the stop signs. The speed limit was 35 mph (56 km/h) on U.S. 202 and 30 mph (48 km/h) on Rt. 237.

Lay-Out After

The final design is shown in Figure 1. The roundabout is designed to accommodate the largest tractor-trailer combinations allowed in Maine (WB-19's) as well as oversized vehicles along U.S. 202. The alignment of the approaches was left unchanged, compared to the before situation, up to points around 30 meters upstream from the yield lines. The speed limit on U.S. 202 was lowered to 25 mph (40 km/h) while Rt. 237 kept its 30-mph limit. The reduction in speed limit was decided prior to and separately from the decision to build a roundabout.

There are still no national roundabout design guidelines. The roundabout was designed according to modern design principles as outlined by, for example, the Maryland Design Guide (1). But certain design criteria could not be met within the available right-of-way. For example, splitter islands could not be located so as to direct traffic to the edge of the truck apron without having to widen the approaches and cutting down several maple trees—see Figure 2.



Figure 2. Typical southbound vehicle traveling as desired around the truck apron rather than across it even though the splitter island does not clearly direct traffic that way.

Physical Characteristics

Approach lanes are 4.5 meters wide, and exit lanes are 5.5 meters wide. The circulating lane is 5 meters wide. The central island has a 7-meter diameter and is surrounded by a truck apron that is slightly oval—21 x 23 meters. The plans called for the apron, which is made out of ultra-thin white topping, to be raised 60 mm above the circulating lane with a 1:1 bevel. In the actual construction it was elevated by only about 40 mm. The reason is that the contractor was not familiar with the limited compaction of the stone-matrix asphalt mix used for the travel lane. The small island in the northwest corner is fully traversable.

Striping and Signs

The roundabout has double yield signs at each approach and yield lines consisting of 15-cm wide skip stripes (30 cm marks + 30 cm skips). It also has painted arrows in the circulating roadway. These arrows, together with arrow signs on the central island, are supposed to ensure that all drivers go counterclockwise around the central island.

Each approach has a warning sign with a symbol of a roundabout located about 300 meters prior to the roundabout. Another sign is at about half that distance. It has the legend ROUNDABOUT AHEAD combined with a yellow speed limit sign recommending 15 mph.

Design Speed

The most important characteristic of a modern roundabout is probably its design speed. That is the maximum speed with which a driver can travel with reasonable comfort. Reasonable comfort is here defined as a side-force around 0.3 g. This is a higher centrifugal force than AASHTO assumes in design of curves, but it is not the highest force accepted by aggressive drivers. Available side friction on dry, clean pavement is around 1.0 g. This means that a skilled driver in ideal conditions may be able to go up to 80% faster than the design speed without losing control. But very few drivers will aim for such speeds. In inclement weather, the available friction may not even allow a driver to achieve the design speed.

A design speed around 29 km/h (18 mph) seems reasonable for the Gorham environment. An acceptable range for different movements may be 25 to 37 km/h (16 to 23 mph). (1, 2)

Fitting templates and using a 1.8 meter wide path shows that the design speed for a passenger car in the *northbound* direction of U.S. 202 is around 40 km/h (25 mph) at entry, as illustrated in Figure 3a.

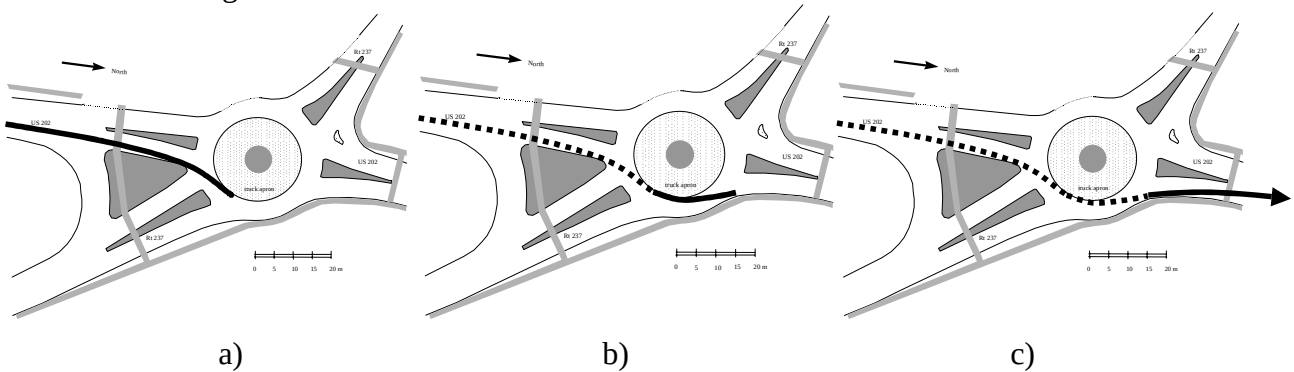


Figure 3. Path for northbound traffic a) Entry path, b) circulating path, c) exiting path.

The design speed is then reduced to around 29 km/h (18 mph) where the vehicle is circulating, see Figure 3b, but then increases to around 43 km/h (27 mph) when the vehicle is exiting if going straight through the junction, see Figure 3c. Northbound left turn has a circulating design speed around 26 km/h (16 mph). The right turn is excluded from the roundabout and has a design speed of approximately 26 km/h (16 mph).

In the *southbound* direction, a passenger car can enter at speeds around 43 km/h (27 mph) whereas the circulating speed for through traffic is around 30 km/h (19 mph) with an exiting speed around 40 km/h (25 mph). The right turn has a design speed around 26 km/h (16 mph).

Traffic on Rt. 237 going *eastbound*, has a design speed just above 40 km/h (25 mph) at entry. If the car turns left, it needs to reduce its speed to around 24 km/h (15 mph) while cir-

culating whereas the exit design speed is above 40 km/h (25 mph). Through traffic has a circulating speed around 29 km/h (18 mph) and an exit speed above 40 km/h (25 mph). Right-turning vehicles have a design speed around 40 km/h (25 mph).

Westbound traffic on Rt. 237 has a theoretical entry speed above 100 km/h (60 mph). If the vehicle turns right its design speed is around 56 km/h (35 mph). If the vehicle turns left, the circulating speed is around 23 km/h (14 mph); and if it goes straight, the design speed is around 31 km/h (19 mph) while circulating and quite a bit higher while exiting.

Ideally, the design speed should be within the given range for all movements from the time a vehicle enters the roundabout until it exits, and the design speed should be the lowest at entry (2). To have the lowest design speed at the circulating point is deemed acceptable only if the approach speeds are low for other reasons than that caused by the geometry of the entry. Rt. 237 carries commuters from west of Little Falls towards Portland and most traffic is through traffic, but Rt. 237 still has a local character when going through the town (narrow, winding, no shoulders, continuously surrounded by houses). This may keep speeds reasonably low in the vicinity of the roundabout. But, the design speed for the westbound entry and for the right turns in both directions of Rt. 237 are higher than desired. The entry speeds on U.S. 202 are also above the recommended range, and travel speeds on U.S. 202 are often well above 40 km/h (25 mph).

Above design speeds have been calculated under the assumption that no vehicles encroach onto the truck apron. If the apron is not built in such a way that it effectively keeps passenger cars off it, then the design speeds for through movements are well above those given here.

Visibility and Sight Characteristics

An important characteristic of a roundabout is that it is visible to drivers. That is addressed adequately with vegetation on the central island and ‘arrow’ signs facing each approach. The red apron also helps. There seems to be adequate lighting to illuminate the junction at night.

Sight distances are acceptable for all approaches. Drivers entering can see circulating traffic within the roundabout as well as traffic entering from the approach closest to the left. Adequate stopping sight distances are available throughout the roundabout.

Crosswalks

Marked crosswalks are located approximately 15 to 20 meters upstream from the yield lines.

SAFETY

General

Besides safety, security may also be a factor to consider. Security concerns the risk of being attacked, having one’s vehicle car-jacked, etc. The feeling of security may be as important a factor as actual security. In large urban areas, most people are less afraid to be in a car that is moving—e.g., through a roundabout—than stopped—e.g., waiting at a red light. And their fears have a basis. More or less all car jackings—based on a review of crime-prevention tips and incidents described on Internet in October 1998—involve a stopped vehicle.

Nominal safety refers to conformance to warrants, guidelines, and standards. For example, if an intersection is designed to meet AASHTO and state standards it is “nominally safe”

no matter how many accidents has occurred or will occur there. On the other hand, an intersection with an experimental design may be considered “nominally unsafe” even if it has only one-tenth the accident experience of the first intersection. Liability may be a concern at the second location, but still nominal safety is of limited interest.

Subjective or *perceived safety* refers to a person’s feeling about accident risk. Typically, it refers to an ordinary road-user’s perception when driving. It can, however, also refer to an expert’s opinion—e.g., the opinion of a traffic engineer, police officer, or motor journalist. Subjective safety—especially the perception of the ordinary road-user—is by itself of interest. If a location is perceived to be unsafe, drivers may avoid it and that may cause them to use routes that are less desirable from a community’s perspective. And, even if they do not avoid the location, it may cause stress. On the other hand, drivers who perceive a location to be unsafe may be more careful at that site. This may lead to fewer accidents than if people view the location as safe. Some safety advocates therefore argue that engineers should try to design locations so that they are safe but look unsafe.

Objective safety refers to the final result on safety as measured through a “count” of accidents. This count is *not* the random outcome that a location has experienced or will experience but the long-term expected number of accidents if traffic volumes and all other parameters could be held constant. It would make little sense to state that the safety of a location has deteriorated by 50% from 1997 to 1998 because the number of accidents went from two to three. The objective safety may be estimated on the basis of reported accidents as well as be based on the result of accident models, indirect measures such as conflict studies, or a combination of these. It is the objective safety that will be the focus of comparisons below. It is important to consider possible regression-to-the-mean effects as well as trends when comparing the objective change in safety before and after a reconstruction.

Roundabouts

The average accident rate of signalized intersections in Maine is around 0.8 police-reported accidents per million entering vehicles (3). European data show that well designed modern roundabouts have accident rates between 0.2 and 0.6 (2). But it is with respect to accident severity that roundabouts really excel. European experience shows that modern roundabouts have injury-accident rates (number of injury accidents involving motorists per million incoming vehicles) ranging from 0.03 to 0.09. That is well below the typical injury-accident rate of a signalized intersection. In Maine, the average injury-accident rate of signalized intersections was 0.25 for the 1987 to 1993 period (3).

Maryland and Vermont roundabouts are as safe as European (1). The question to be answered here is whether that is true for the Gorham roundabout too, in spite of less deflection and somewhat higher design speeds than desired.

Accident Analysis—Before

Before reconstruction, the stop controlled intersection had, on average, six police-reported accidents per year—six accidents in 1994, seven in 1995, and five in 1996. With 12,000 vehicles entering daily, the accident rate becomes 1.36 [per million entering vehicles]. Six of the eighteen accidents involved personal injury, giving an injury-accident rate of 0.45.

The expected accident rate for an average non-signalized intersection in Maine is around 0.5 (3). But the average intersection does not have as high traffic volume or as high a percentage of its traffic entering from the minor approaches—in this case 52%! Also, the typical

intersection does not have commercial driveways entering it, nor does it have skewed angles. Taking these factors into account, it would, in my estimation, not be unlikely that we would have similar numbers of accidents reported once more if these years could be repeated. In other words, a substantial regression-to-the-mean effect does not seem to be likely. That no particular year had a number much higher than the average also indicates that large regression effects are unlikely.

Traffic volumes have increased by approximately 9% between the [mid] before period and the after period (to AADT 13,210). The number of accidents per million entering vehicles can be assumed to be constant as long as changes in volumes are small. Thus, the best estimate of the objective safety level for the period after the reconstruction is that *the number of accidents would have been around 6.5 per year* ($1.09 \times 6 = 6.54$) *if the junction had been kept as a two-way stop intersection.*

Speeds—Before

Speeds of free-moving vehicles on U.S. 202 were measured during the daytime with a stopwatch. The average northbound velocity was 55.0 km/h (34.2 mph). The southbound velocity was, on average, 56.5 km/h (35.1 mph). Speeds around 70 km/h (45 mph) were not uncommon.

Accidents Analysis—After

Four accidents have been reported in the first 16 months, all minor with no injuries. This gives an accident rate of 0.62 per million entering vehicles. The first accident was of rear-end type on an approach. The second was caused by a southbound driver entering without yielding, striking a circulating car. The third accident was caused by ice. A circulating vehicle skidded over a splitter island into another vehicle. The fourth accident was also caused by ice. This was a single-vehicle accident with a vehicle skidding into a sign on the central island. Combined damages were estimated at less than \$1,500 for each of these accidents. The minimum damage for an accident to be reported in Maine is \$500.

An accident rate calculated on the basis of four accidents is obviously imprecise. Assuming that the observed number varies around the expected number according to the Poisson distribution means that there is a 5% chance that the ‘true’ accident rate is below 0.30 and a 5% risk that it is above 1.42 accidents per million vehicles. With the same reasoning, the ‘true’ injury rate is between 0.0 and 0.47 per million vehicles.

The observed [most likely] accident rate is almost exactly what we may expect. Models developed by VTI in Sweden (4) suggest that the accident rate of a roundabout with these flows should be 0.51, or 3.3 accidents in 16 months with 0.13 injuries per accident, i.e. 1.0 injured person every three years. The observed injury rate (0.0 so far) is of course exactly where we want it to be.

There is a British Injury Crash Prediction model developed by TRL. Edmund Waddell, Michigan Department of Transportation, helped me run this model. It predicts that the roundabout will have 0.55 injury accidents per year. There will, according to this model, be one serious injury every thirteen years and one fatality every 422 years. Most [injury] accidents will be single-vehicle crashes (once every 4.9 years), approach accidents (one every 6.5 years), entering/circulating accidents (once every 14.7 years) and pedestrian accidents (once every 20.7 years).

The average accident rate for older traffic circles in the United States is around 2.3 per million entering vehicles (2). The Maine circles, at 3.5, are worse than the average. With respect to accident rate, the Gorham roundabout has performed better than any of the older circles in the state.

Analysis of Conflicts—After

Conflict studies were carried out with the Swedish LTH technique (5), since the American FHWA technique isn't operational for drivers facing stop or yield signs. The Swedish technique looks at near misses. It uses the concept of time-to-accident (TA) which is calculated from the time a road-user starts avoiding a crash (by braking or swerving) until the accident would have happened had none of the drivers taken evasive action. If TA is less than a critical threshold value, then the situation is classified as a "serious conflict."

Conflict studies were done on four weekdays. The author carried out the observations himself. This ensured that the observer had extensive training and experience with the technique, in excess of 500 hours of field and video observations over the last two decades.

Two basic types of conflicts were observed, rear-end conflicts and conflicts caused by drivers on U.S. 202 not yielding when entering. The rate of "non-yielding conflicts" was approximately one serious conflict for every 1,500 vehicles entering. That equals 8.8 conflicts per weekday or about 3,000 conflicts per year.

The Swedish technique is not validated for U.S. conditions. That means that there are no exact conversion factors between conflicts and accidents. Based on Swedish validation studies (5), Maine conditions, including reporting criteria, and French, British, and Finnish experiences with the technique, I estimate the conversion factor for this milieu to be roughly one reportable accident for every 1,000 serious conflicts. We should then expect around three accidents of this type per year. Similar calculations for rear-end accidents predicts a much lower rate, around one accident per year. Single-vehicle crashes are not covered by the Swedish technique.

The result of the conflict studies supports the findings of the accident analysis. More important, the conflict studies show that the problems still exist in June of 1998. Drivers still have not learned appropriate yielding behavior, and maybe they never will unless the design is modified. However, all conflicts occurred at low speeds indicating that the risk of personal injury is very low, unless motorcyclists, bicyclists, or pedestrians are involved. So design modifications of this site may not be a high priority.

Analysis of Behavior—After

Apron encroachment

Almost all heavy trucks use the apron and they are supposed to use it. But 66% of the vehicles that encroached onto the apron were not heavy trucks. These drivers obviously found it more convenient to go across the apron than to go around it. Approximately 14% of all passenger cars, vans, and pickups encroached.

Speed Reduction and Potential Safety Effect

The average speed of through traffic on U.S. 202 was 23.3 km/h (14.5 mph). The 95-percentile speed was 42 km/h (26 mph). One reason speeds were more or less within the legal limit of 25 mph may be that only daytime speeds were measured. The radar gun that

was used may also have caused speed compliance. Aggressive drivers often have radar detectors and such devices would obviously warn them.

The average speed for through traffic on U.S. 202 was reduced from 56 km/h to 23 km/h. Research from VTI, Sweden, indicates that once a conflict occurs, the risk of a collision varies with the actual speed to the power of two, the risk of injury with the speed to the power of three, and the risk of a fatality with the speed to the power of four. Using those relationships, the risk of a collision has been reduced by 83%, the risk of an injury by 95% and the risk of a fatality by 97%. These reductions refer to situations where vehicles on U.S. 202 suddenly face a car entering in front of them. The actual effect of the reconstruction will be influenced by several other factors besides the speed reduction.

Yield Behavior

The fact that drivers fail to yield to traffic in the roundabout appears to be a safety problem. Observational studies show that ‘only’ about 1% of drivers (12 out of 1055 entering cars) fail to yield. But many other drivers would not have yielded had there been a conflicting vehicle in the roundabout. And even if it is only 1% who do not yield, that is around 150 potential accidents per day! The reason some drivers do not yield may be a lack of understanding rather than not observing the signs. Public education may be needed.

Approximately one in fifty drivers stop when reaching the yield line even if there are no vehicles to yield to. This may cause rear-end collisions.

It is sometimes observed that a ‘circulating’ driver with the right-of-way stops and yields to let a driver enter the roundabout. This ‘polite’ behavior causes excessive delay because many drivers do not accept the invitation, or do so after hesitating a few seconds. But worse than delay is that this behavior may cause accidents. Drivers should follow the rules as stipulated. Else there will be misunderstandings resulting in accidents.

It is also noted that there are ‘impatient’ drivers behind drivers who stop and yield, typically when entering along U.S. 202. These impatient drivers sometimes blow their horns, ‘forcing’ the driver in front to enter gaps that are very short. And if the circulating vehicle slows down as a result of this, then some of these impatient drivers push their way ahead as well. They obviously do not think that U.S. 202 traffic ever should have to yield.

Use of Indicators

Most drivers do not signal turns in any way. Only about 10% of those making a turn indicate their intent. This is probably safer than if 90% did it. In order to trust that a car is turning, all drivers would need to use their indicators in a consistent way.

Wrong Way

In the early fall of 1997, vehicles were observed going the wrong way around the central island a couple of times a day. These maneuvers were typically made by left-turning dump trucks. A trucker was approached about this already in July of 1997. He responded that he would keep doing it until the roundabout was destroyed and replaced by a signal. However, it seems as if he has stopped doing it since no such maneuvers were observed in May or June of 1998. Yet, many bicyclists continue to ride on the wrong side through the roundabout.

Pedestrians

Observations of pedestrian behavior when crossing the roadway at the roundabout shows that about 77% of the crossings occurred along the shortest path rather than at the marked crosswalks. Only 'older' pedestrian seem to use the crosswalks.

The safety of pedestrians is probably less influenced by whether they cross at a marked crosswalk or not than by the conditions of the place where they cross. A study by Herms (6) actually shows that the safety of pedestrians is compromised by marking crosswalks since the crosswalks install a false sense of security among pedestrians without influencing the behavior of many drivers. In my judgement, based on extensive research (7), the most important safety characteristics are speeds, vehicle volume, crossing distance, existence of refuge island, and sight conditions.

The Gorham roundabout scores high on these characteristics compared to the before situation and compared to the typical signalized intersection as well as the older rotaries in the state. For example, the older Windham rotary has typical vehicle speeds around 45 km/h (28 mph). The likelihood a pedestrian would be killed if involved in an accident with a car at that speed is around one in two (8). The risk of death at typical Gorham speeds is around one in seven (8). And, typically, a driver has some time to react and brake before he hits a pedestrian who unexpectedly steps out in front of a car. The actual collision speed in Gorham should therefore be quite a bit lower than the typical speed. In Windham, the higher initial speed means that there is a greater risk that the driver will not have time to start braking.

Safety Effect of Reconstruction

If we assume that the observed accident numbers are the best estimates of the expected numbers, and take traffic volume growth into account, then we get an overall reduction in accident rate of 54% (1.36 to 0.62). But numbers are so small that there is actually a 9% chance that there is no reduction in accident rate (Binomial test).

The effect on injury risk cannot be established with any precision. If we—in accordance with the Swedish model—assume that 10% of the accidents at the roundabout will cause injuries, then the reduction will be 87% (from 0.45 to 0.06). This compares favorably to published injury accident reductions from conversion of conventional intersections to roundabouts (9):

- Australia	75%
- Britain	34%
- Denmark	36%
- France	78%
- The Netherlands	55%
- Norway	74%
- Switzerland	38%

CAPACITY

Roundabouts typically have higher capacity than conventional stop or signal controlled intersections with the same number of approach lanes (10).

Practical capacity at a given conflict point can be estimated according to Australian data as indicated by the solid line in Figure 4 (11). Observations of actual flows at Gorham are also plotted in Figure 4 (1). The fact that some drivers hesitate—and doubt that they have the

right-of-way—while circulating may explain that the observed values are a bit lower. The capacity will probably increase to the level already experienced in Australia when Maine drivers get more used to roundabouts.

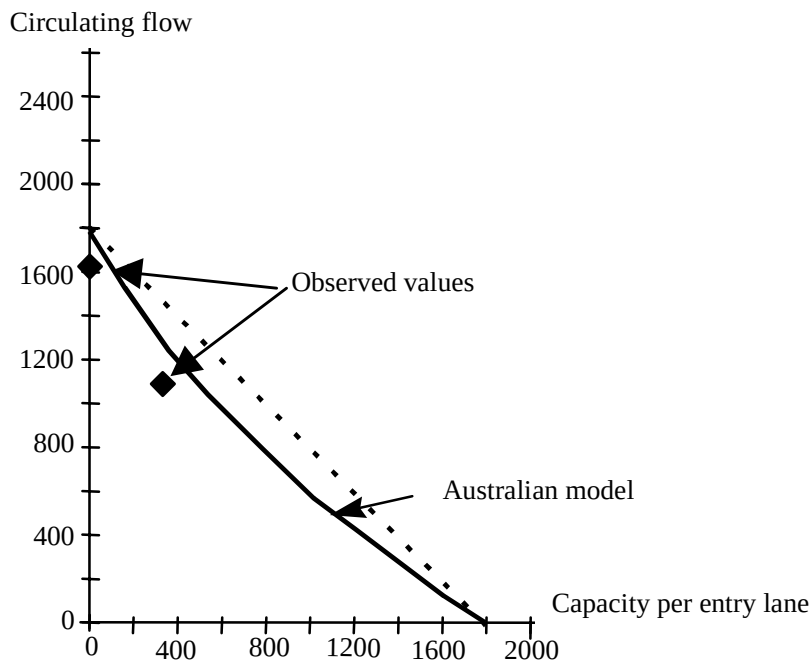


Figure 4. Observed capacity vs. Australian prediction.

DELAY

Delay when passing through a junction typically consists of two components, geometric delay and delay caused by traffic. The latter consists of stopped delay and delay while driving slower than desired.

Before

Throughout the day, straight through and right-turning traffic on U.S. 202 had negligible delays. Through traffic could pass on the right side of vehicles stopped waiting for a gap to make a left turn except when there were large trucks waiting. Left-turning cars from U.S. 202 would sometimes have to wait a few seconds for a gap in the opposing direction. Observational studies during the afternoon peak hour show that the average stopped delay for southbound left-turning vehicles was 1.9 seconds. Left turning vehicles in the opposing direction had to wait on average 1.3 seconds for a gap.

Drivers approaching the junction on Rt. 237 experienced substantial delays during peak hours, especially in the eastbound direction during the morning and in the westbound direction during the afternoon. A license-plate observational study of 451 matched vehicles shows that delay (calculated as the difference between observed travel time and ideal travel time) on average was 55.8 seconds in the eastbound direction during the morning rush hour. In the afternoon peak, 597 westbound vehicles were observed. The arithmetic mean delay was 39.1 seconds. One reason delay is shorter in this direction is that a higher percentage of drivers turn right.

After

The reconstruction has made Rt. 237 and U.S. 202 'equal' with respect to priority and delay. The roundabout slows down all vehicles. But, the times until gaps are found for traffic from Rt. 237 is shortened dramatically.

Morning rush-hour data was collected for traffic heading east on Rt. 237 and north on U.S. 202, while westbound traffic on 237 and southbound on U.S. 202 was studied during the afternoon peak hour. The average delay of eastbound traffic was 5.1 seconds in the morning. The average delay of northbound traffic was 3.2 seconds. The average delay in the afternoon for westbound traffic was 7.4 seconds. Southbound traffic on U.S. 202 had on average a delay around 2.8 seconds.

Effect of Reconstruction

During *periods with light traffic*, almost half of all vehicles in the before situation could just sail through the junction whereas traffic on Rt. 237 had to, or at least was meant to, come to a full stop. For these times of day, traffic on U.S. 202 now slows down to speeds around 24 km/h (15 mph). Also, the distance traveled has increased some. With normal acceleration/deceleration behavior, the change created by the roundabout translates into a delay of about 2 seconds per vehicle on U.S. 202 compared to a before situation with a 25 mph speed-limit. (Lowering the speed limit to 25 mph was decided prior to and separately from deciding to build the roundabout. All drivers may not have complied with this limit if the roundabout had not been constructed, but, in my mind, timesavings obtained from driving above the speed limit ought not to be included in a comparison of this type.) On Rt. 237, traffic had to stop in the before situation. Now it only has to slow down. This saves about 2 seconds per vehicle assuming vehicles are driven at the speed limit away from the junction. Almost exactly half of all traffic at the junction enters from Rt. 237. Therefore, the construction of the roundabout has not changed total delay during off-peak hours. (1)

The before study of *morning peak hour* shows that eastbound traffic on Rt. 237 had an average delay of 55.8 seconds. Other approaches had shorter delays. The overall delay was around 24 seconds per vehicle. In the after period's morning peak, the average eastbound delay was 5.1 seconds. The delay on all other approaches was shorter than that. Giving a weighted delay of 4 seconds. Besides these delays, we have geometric delay. However, as shown for off-peak, the added delay of about 2 seconds per vehicle on U.S. 202 is fully compensated for by reduced deceleration/acceleration time for traffic on Rt. 237. In other words, the calculated 4-second delay per vehicle seems to be an unbiased comparison value. The reconstruction of the junction has meant that the average morning-peak-hour delay was reduced by about 83%. Approximately 1,200 vehicles enter the intersection during this hour. The total morning-peak delay is therefore reduced by 6.7 hours per day, or by over 2,000 hours per year.

The before study of *afternoon peak hour* found that westbound traffic on Rt. 237 had an average delay of 39.1 seconds. About half of all vehicles enter on this approach. This gives a conservatively estimated weighted overall delay of 21 seconds per vehicle (1). In the after period, the overall delay is estimated to be around 5 seconds per vehicle. This means that the reconstruction reduced the average afternoon-peak delay by about 76%. Approximately 1,250 vehicles enter during this time period. The annual reduction in afternoon-delay amounts to just over 2,000 hours.

Total Change in Delay

There is no difference in total delay between the before and after situation during low-volume periods. During peak hours, delay has been reduced significantly. During “half-busy times,” delay has also been reduced. My estimate is that the roundabout saves drivers more than 5,000 hours per year, maybe the double. Assuming time is valued at \$5 per hour, the annual savings in time alone is around \$25,000 to \$50,000.

In summary, the construction of the roundabout saves significant times for the road-users, but more important is the fact that all longer delays have been eliminated. It is these longer delays that make drivers frustrated, contributing to road-rage in general (12) and, in particular, to decreased safety at the intersection where the delay is experienced. After waiting in a queue for a minute or more, many drivers enter shorter gaps than they do otherwise (13).

Delay on the minor approaches could also have been reduced through signalization. I tested this with HCS analyses. Overall, even a modern traffic actuated signal, with separate left-turn lanes, would give delays that are at least double as long as those given by the roundabout (1).

ENVIRONMENTAL EFFECTS

Percent Stopped Vehicles

Modern cars have low emissions when driven at constant or nearly constant speeds. An accelerating vehicle, on the other hand, produces significant amounts of exhaust. Traffic slowing down and keeping that speed through a junction and then accelerating back up to normal travel speed will cause much less pollution than a vehicle which is repeatedly forced into stop-and-go conditions.

Before Period

Before reconstruction, more than half of all traffic had to stop because they entered from the approaches with stop signs. During busy hours, a driver often had to stop and start twenty or thirty times before reaching the stop sign. The total number of stops, seen over the whole day, exceeded the total number of vehicles entering the junction in spite of the fact that most drivers on U.S. 202 did not have to stop at all.

After Period

In the after period, few drivers have to stop during times when traffic is light. Only during heavy traffic flows do a substantial percentage of vehicles have to come to a complete stop. Field studies between 3:30 and 4:00 p.m. show that 26% of all vehicles came to a full or nearly full stop. Very few vehicles had to stop more than once. Around 4:30, the queue on the westbound approach sometimes grew to around seven or eight cars, but few cars had to stop more than once. Even during peak flow, around 5 p.m., traffic in the westbound direction of Rt. 237 kept moving during long time periods. However, roughly 66% of the vehicles on this approach had to come to a full stop during the peak-minutes.

A rough estimate is that over the full day less than one in four vehicles have to come to a full stop. This would mean that there are no more than 3,000 stops per day. In the before situation, that number is estimated to be above 12,000.

Fuel Consumption and the Environment

There are many factors influencing fuel consumption as well as emissions, e.g., distribution of speeds, percentage of cars stopped, driver behavior while stopped, grade. There is typically less gasoline consumption and less emission at vehicle-actuated signals than at roundabouts as long as traffic volumes are low. But during busy hours, even quickly responding, modern, vehicle-actuated signals tend to operate like fixed-time ones, and the percentage of cars that must stop becomes high. (1) I am convinced that the loss during busy hours would be greater than what would be gained during low-volume conditions compared to the roundabout.

From an environmental perspective, two-way stop control is typically preferable to any alternative control as long as the share of traffic coming from the minor road is not too high. In Gorham, that share was above 50% and obviously too high.

COST

Installation

Several studies have concluded that roundabouts save money by increasing an intersection's capacity, making it unnecessary to widen the road between intersections (10). The Gorham roundabout confirms that concept. No additional right-of-way had to be purchased. If the junction had been signalized, separate left-turn lanes would have had to be provided, and additional right-of-way would have had to be acquired. The only right-of-way costs associated with this project had to do with relocation of utilities—\$992.

Preliminary engineering costs amounted to \$39,948. Another \$49,259 were debited to this project as construction engineering costs. These costs are much higher than would be typical if roundabouts were a standard type of junction.

The construction cost was \$169,554. This can be compared to the Lisbon roundabout in Maryland that cost \$194,000 and the Keck Circle in Montpelier, Vermont that cost \$150,000 (14). The total cost of the Gorham roundabout was \$259,682.

Maintenance

Roundabouts do require regular winter maintenance, restriping and repaving if ruts occur, but so do all other intersections. The Gorham public works director reports that there were no problems with winter maintenance during the 1997/98 winter. Standard equipment was used.

AESTHETICS

Highway beautification is desirable. And aesthetics is an aspect that should not be forgotten when choosing intersection type. The Gorham roundabout is beautiful, at least in my opinion. That does not mean that future roundabouts cannot be made even more pleasing. All beautification does not necessarily cost a lot of money. And public art money ought to be available in some instances. Roundabouts can be used as focal points for landscaping efforts, including flower beds, trees, artistic water fountains, brick work, display of granite blocks, etc. In France, many towns use roundabouts for beautification of their main ports of entry. They also work as town gates, telling people that they are leaving the rural highway and entering a low-speed area. Adding speed humps, chicanes, etc. to existing roads can be seen as design failures whereas roundabouts may be perceived as aiding drivers through points of interactions.

Placing big boulders, a fountain, or a statue in the middle of the central island can give a roundabout its own character. People will recognize it as a landmark and be pleased with the aesthetic addition to the landscape/cityscape. But solid objects may also block views and cause injuries if they are hit. The perceived risks of such objects are well documented (2). But actual injuries are rare. There should be little risks of injuries—or litigation—if the roundabout is well designed with splitter islands deflecting traffic away from the central island.

ACCEPTANCE

Students using a questionnaire gathered the opinions of 68 motorists in the area. Just over 40% knew about the roundabout project before construction started. Out of these, about 60% claim they were skeptical or outright opposed the idea. About 20% were in favor of the roundabout.

The typical male states that the construction of the roundabout definitely hasn't improved the safety of the location. Women are less certain. The majority of females do not think that safety is diminished.

The final question, "would you at this point rather have seen the intersection signalized?" was answered with "yes" by 69% and "no" by 28%. Obviously, most people do not appreciate the roundabout. But at least, the 28% figure is somewhat higher than the 20% support prior to construction. It was noted that residents adjacent to the roundabout were more positive than those living further away.

DESIGN MODIFICATIONS FOR FUTURE SITE

The first modern roundabout built in Maine is not without its problems even if it overall performs well. One problem is that some drivers do not yield when entering. This has already caused accidents. Informing drivers that they have to yield ahead is obviously important. Maybe too many drivers do not notice the signs. Flashing yellow lights in combination with the signs may be an option until roundabouts are more common. Rumble strips is another option for commanding the attention of drivers. However, they cause noise and couldn't be used in this environment.

Another problem is that some drivers go across the apron rather than around it. This could be remedied by making the apron less comfortable to traverse. A higher apron certainly would increase the discomfort of entering it at high speeds. However, it still has to be low enough so that low-riding trailers do not get stuck when traversing it, and the edge has to be smooth enough not to make motorcyclists lose their balance. Also, the PCC-apron could be textured (resembling paving stones). Textured aprons are used in Scandinavia in regions with heavy snowfall. However, the most important reason drivers go across the apron is that they are not directed away from it. A modern roundabout should have splitter islands deflecting traffic to the edge of the apron, not to the edge of the central island as here. Right-of-way restrictions in combination with oversized vehicles traveling through the junction caused this 'flaw' in design. Traversable island extensions could be added.

A third problem is that some drivers go too fast, and some do it without going across the apron, indicating that design speed is too high.

OVERALL CONCLUSIONS

The Gorham roundabout has reduced delay by 5,000 to 10,000 hours per year. This by itself will pay for the reconstruction in approximately five years.

The roundabout has reduced the accident rate, and so far there hasn't been a single reported injury accident. According to a British model, a roundabout with these traffic volumes and design characteristics will have one slight injury accident every second year, a serious injury accident every thirteen years and a fatality every 422 years. The Swedish model predicts one injury every three years. Conflict studies also shows that there will be few injury accidents. The Gorham junction used to have two injury accidents per year prior to reconstruction. The injury reduction by itself should pay for the reconstruction within a couple of years.

The roundabout has also improved the aesthetics of the location and reduced fuel consumption and emissions.

What more can drivers and residents ask for? Surveys show that the majority of those living adjacent are happy with the solution but that a majority of other users still do not feel that the design is as good as a traditional signalized intersection. I think that people eventually will accept this type of control as a standard design, and learn to appreciate the smooth flow of traffic at low speeds and the absence of injuries and deaths. But I also acknowledge that the roundabout does have a few design characteristics that are not fully compatible with those of the optimal modern roundabout. Design of future roundabouts should take the lessons learned from this site into consideration.

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