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The Dimondale Mini: America's First Mini-Roundabout

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ABSTRACT

America's first mini-roundabout opened to traffic May 30, 2001, at the corner of Creyts Road and East Road, in the Village of Dimondale, Michigan: a suburb of Lansing. This report describes Dimondale's project development effort, public involvement and acceptance, crash and delay performance, construction and maintenance issues, costs, and cost/benefit analysis. This paper is not intended as design guidance, but to share the lessons of this initial experience. We hope that other practitioners considering roundabouts in low-speed locations with constrained right-of-way - and constrained budget - will find this information helpful.

What is a Mini-Roundabout?

A mini-roundabout is an intersection developed in the 1960's by the British Transport and Road Research Laboratory (TRRL): a research branch of the UK Department of Transport. Under the leadership of Frank Blackmore, the TRRL conducted test track and field experiments on various sets of markings, eventually arriving at the current style. Today, a "mini-roundabout" (mini) is a circular intersection with an inscribed circle diameter of 14 to 28 meters and a central island usually 4 meters or less in diameter. The central island is traversable to facilitate circulation of large vehicles. Because signs cannot be installed on a traversable island, pavement markings (arrows) show the pattern of movement. Because minis rely primarily on pavement markings and lack the physical deflection provided by the central island in a "normal" roundabout, UK guidelines recommend minis for retrofit of existing intersections in locations with speed limits of 30 MPH or less.[1] Speed is constrained by the surrounding network. By 1990, the UK had about sixteen hundred mini-roundabouts.[2] As of this writing, the United Kingdom probably has more than two thousand, including hundreds with multiple lane entries. The US still has only one or two.

Where is Dimondale?

Dimondale, founded in 1848, is a village of about twelve hundred people, seven miles southwest of Michigan's state capitol in Lansing, in south-central Michigan. Originally an agricultural/trading settlement, Dimondale retains a vestige of that function, but is now mainly a bedroom suburb of Lansing. Much of Dimondale's 19th century architecture still stands, and the village's compact scale and mixed land use make it popular for walking and bicycling. New housing is being built in the surrounding area, and the resulting auto traffic conflicts with the village's historic layout, pedestrians, and bikes.

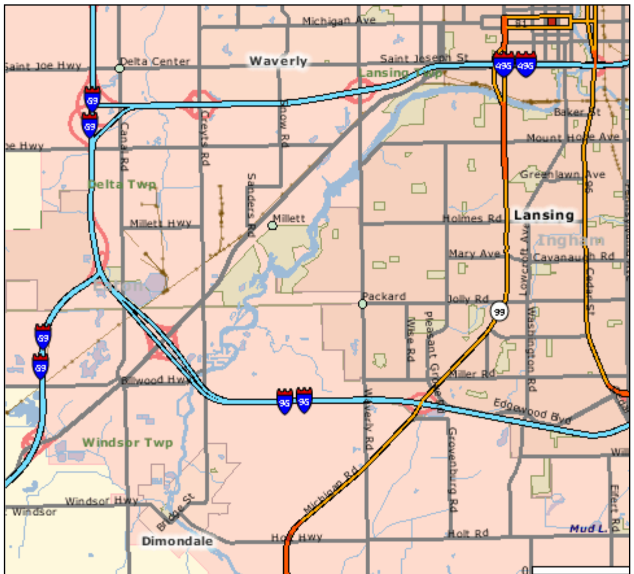

Figure 1 Southwest Metro Lansing & Dimondale

Project Background:
Dimondale first considered a roundabout in 1998, after an itinerant pedestrian advocate (Dan Burden) held a seminar on traffic calming. Dimondale's Street Administrator (co-author) attended the seminar, saw the potential of roundabouts, and informed the village council. The council directed him to collect more information, so he contacted the Michigan Department of Transportation (the other co-author) for information on roundabouts.

Downtown Dimondale's main four-leg intersection (Bridge at Washington Street) has limited lateral sight distance due to on-street parking. Speeding is common, and pedestrians are present day and night. These are all good indications for a roundabout, and the Village first considered that location, but they had recently rebuilt both Bridge and Washington Streets, and the pavement would not need reconstruction for some years. Large trucks also frequent the intersection, and a normal (raised-island) roundabout could not accommodate trucks in the available space. A mini would be needed.

Before converting the central point in the village, the village wisely decided to determine how well a mini-roundabout would perform at another location. The Village selected the three-leg intersection of Creyts/East Road, already scheduled for reconstruction, to demonstrate the mini-roundabout concept. The council deferred the Bridge/Washington intersection to future construction.

The Creyts Road/East Road Intersection:
East Road enters Dimondale from the east and runs due west toward the village center on Bridge Street. Creyts Road enters Dimondale from the north, and intersects East Road from the northeast, forming a WYE intersection at an angle of about 45 degrees. All approaches are two lanes and signed at 25 MPH. The northeast and east legs were previously stop-controlled, and the west leg was uncontrolled. The northeast corner lot has an 8-pump gas station/convenience store built in 2000, generating about 1300 trip ends on weekdays. The northwest corner lot has a residence with carpentry shop, and

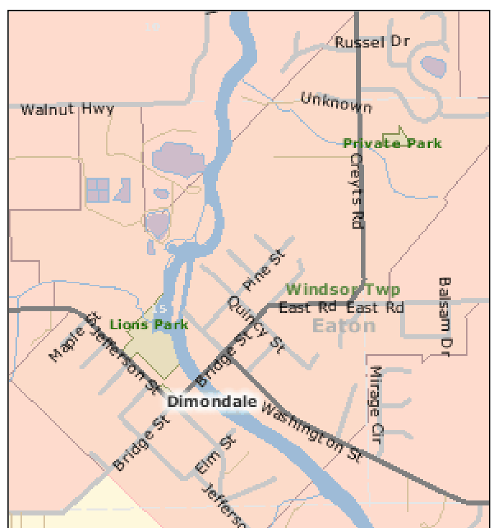

Figure 2: Dimondale Map

the south side of East Road is residential with an electrical substation immediately south of the intersection.

Creyts Road and its East Road intersection were scheduled for reconstruction in 2001 due to aging pavement. Creyts Road was two-lane asphalt with gravel shoulders, and would be rebuilt with two 11.5' asphalt lanes, 4' bike lanes, and curb and gutter. East Road west of Creyts had recently been rebuilt with that same cross section. East Road east of Creyts would stay as two 10.5' lanes with 2' shoulders and ditches. The intersection layout was yet to be determined. The relevant question was: over the 20-year project life, what intersection alternative was the best community investment?

Project Justification:
The previous two-way stop control intersection did not have a high crash history. However, the village council had received complaints about vehicles speeding eastbound through the intersection, or speeding through the left turn into Creyts Road and cutting off southbound Creyts traffic. The council was also concerned about pedestrian safety, because Creyts and East Road are the main pedestrian corridors to downtown, and a new convenience store had just opened on the corner.

Available alternatives were all-way-stop control (AWSC) and roundabout. The intersection did not meet signal warrants, and the village was concerned that adding a stop sign on the eastbound approach could induce crashes, because drivers were not accustomed to stopping there. The right-of-way, including the corner donated by the gas station, permitted only a 21-meter inscribed circle, which could not accommodate the

Figure 3 Looking Northeast at the Dimondale Mini-Roundabout

WB-50 design vehicle with a raised central island. This left two practical alternatives: AWSC and mini-roundabout. Land use was changing, traffic was increasing, and the Village wanted an intersection that would perform most effectively for the coming 20 years.

Creyts/East Traffic Forecast:
In 1998, the average daily traffic (ADT) entering the Creyts Road/East Road intersection was 5,550 vehicles with about 3-4% trucks. The 2020 forecast was approximately 9,550 vehicles. This growth rate was applied to a 1998 turn movement count to develop the 2020 forecast volumes shown in Table One:

Table One: Forecast 2020 Turning Movements						
	Southwest-bound Creyts		**Eastbound East Road**		**Westbound East Road**	
Hour	**Right**	**Left**	**Through**	**Left**	**Right**	**Through**
AM	89	56	111	203	103	60
PM	342	123	125	203	64	119
Off-peak	129	54	70	123	50	54

Safety Research and Expectations:
There were no mini-roundabouts in the United States to help predict the crash performance. However, several British studies suggested that safety would most likely improve after construction of a mini-roundabout, and no reports suggested otherwise. In a study of injury crashes at 20 mini-roundabouts in greater London, Lalani[3] 1975, stated that vehicle accidents within 50 meters declined 29.5%, and pedestrian crashes within 50 meters declined 37.5%. Total injury crashes declined 30.3% after construction of a mini-roundabout, which was statistically significant at the 90% confidence level. A 1977 study by Green[4] of 88 priority control intersections converted to small or mini roundabouts found a statistically significant reduction of 34% in all injury crashes, and 46% in fatal and serious injury crashes.

In their 1989 study of 139 three-leg, domed mini-roundabouts, Walker and Pittam stated that minis annually averaged 0.54 injury accidents within 20 meters, with 16.8% fatal or serious injuries. From 20-100 meters from the junction, the average was 0.66 injury accidents, with 21.1 percent fatal/serious. The accident rate for three-leg mini-roundabouts in 30 MPH zones was ten injury crashes per 100 million entering vehicles, or 0.1/MEV. This rate was lower than that of all other intersection types, including traffic signals, T-junctions, and other types of roundabouts. Based on this information, we estimated that a mini-roundabout would most likely improve safety at the intersection, and was not likely to create an unsafe condition.

Capacity and Delay Cost Calculations:
Highway Capacity Software 2000 was used to estimate delay for the all-way-stop. TRL Lab Report 942 equations (RODEL-1 set at 50% CL) were used to estimate delay for the mini-roundabout. Because the mini would allow U-turns, 1% of approach volumes were

added to each approach to estimate these moves. Average delay per vehicle for the year 2020 is shown in Table Two:

Table Two: Year 2020 Average Control Delay for All Way Stop vs. Mini-Roundabout				
	AM Peak	**PM Peak**	**Off-Peak**	**TOTAL 2020**
All-Way Stop	9.6 Seconds	14.7 Seconds	8.6 Seconds	**9,287 Hours**
Mini-Roundabout	3.4 Seconds	3.9 Seconds	3.3 Seconds	**3,291 Hours**
Time Savings	6.2 Seconds	10.8 Seconds	5.3 Seconds	**5,986 Hours**

Value of Estimated Time Savings:
Typically, intersection evaluations consider only level of service (LOS) during the peak hours, with LOS "D" considered acceptable, but that method ignores the 80% of travel that occurs during off-peak hours. For our evaluation, we estimated the total cost of delay for each alternative over the 20-year life of the project. AM and PM peaks were each assumed to occur ten times each week, or 522 hours per year. The off-peak hour was assumed to occur 14 times on weekdays and 18 times on weekend days, or 5531 hours per year. Total delay was then summed for each year 2002-2021, based on the forecast turning volumes in that year. User delay was valued at $11.93 per hour, based on values in 1998: $11.58 for passenger vehicles (96%), $18.54 for single-unit trucks (2%), and $22.31 for combination trucks (2%).[5] Vehicle delay cost was discounted at 4% per year: a typical rate used for discounting highway investments.[6] Table Three compares the net present value of total life-cycle delay for the all-way-stop and mini-roundabout alternatives:

Table Three: 20-Year Life-Cycle Delay Cost All-Way-Stop vs Mini-Roundabout Alternative		
	Total Delay 2002-2021 (Hours)	**Net Present Value (2001 Dollars)**
Control Delay for All-Way-Stop:	144,060 Hours	$1,118,340
Control Delay for Mini-Roundabout:	53,956 Hours	$422,973
Net Savings due to Mini-Roundabout:	**90,104 Hours**	**$695,367**

Over the 20-year life of the project, the mini-roundabout eliminates about 90,000 hours of travel delay compared to the all-way stop. This delay reduction is equivalent to one vehicle and driver idling at the intersection - for ten years. In current dollars, that time savings is worth about $700,000 to the motoring public (mostly Dimondale residents and visitors). At a rate of .58 gallons per hour idling for passenger vehicles, and 1.0 gallons per hour idling for trucks, the mini will save 53,700 gallons of fuel over 20 years.[7]

We also found literature specifically on the economics of conversion of Tee intersections to offside priority (mini-roundabout) control. In a study of five projects that converted 3-leg major/minor intersections to mini-roundabout, Marlow[8] 1979 found that conversion was economically worthwhile in four locations with daily flows from 14,000 to 31,600 ADT, but not worthwhile in one location with 12,100 ADT. However, those projects were evaluated as an expense specifically to fix existing congestion and crash problems. In Dimondale, the intersection was neither congested nor a high crash location. It was to

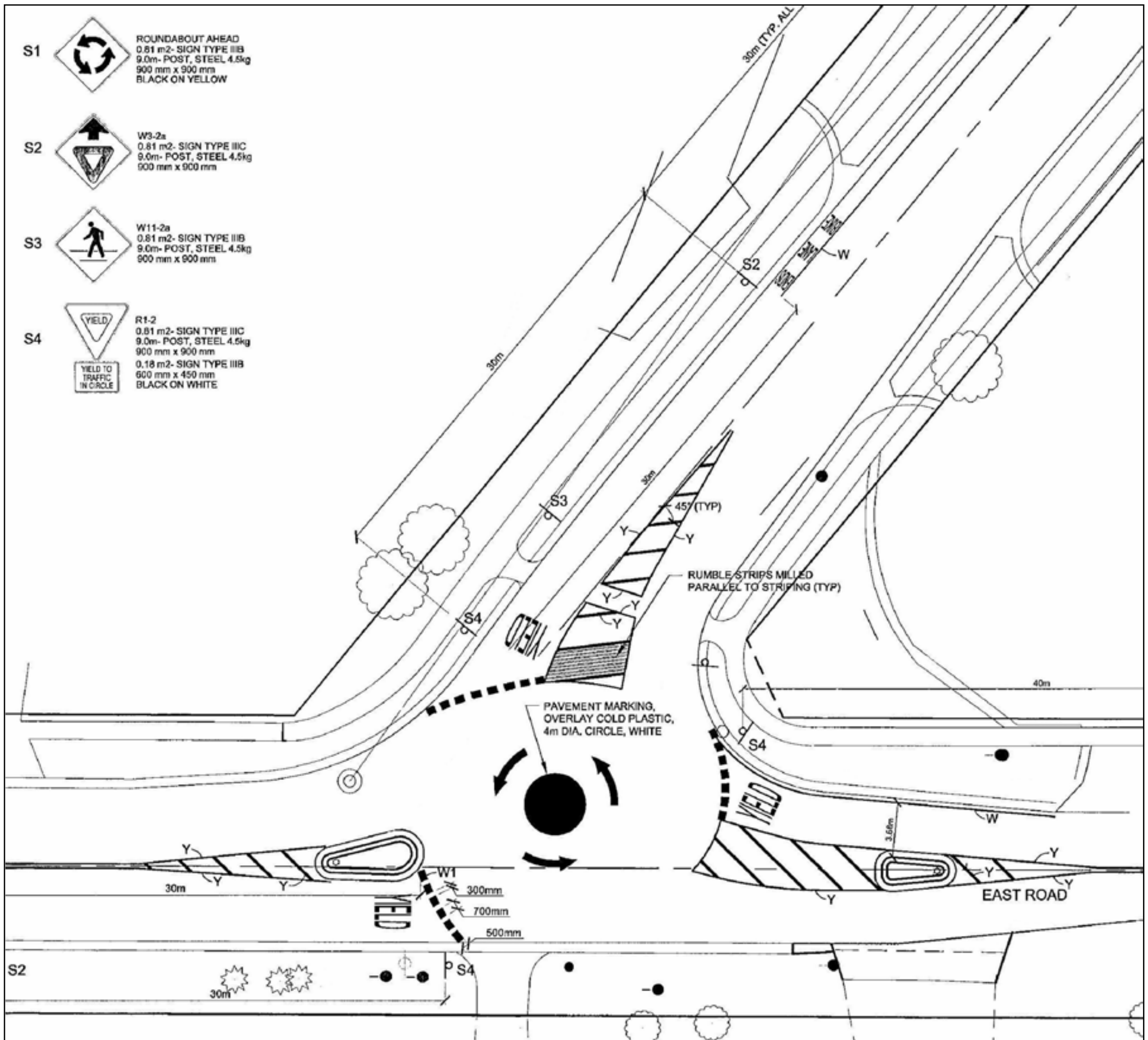

Figure 4: Mini-Roundabout Sign and Marking Plan (Fleis and Vandenbrinck Engrg.)

be rebuilt in some form to replace a worn out pavement, and the decision needed to be based on the most likely overall performance.

Based on the expected travel time savings, speed reduction, and safety performance over the project life cycle, the Village Council decided to build a mini-roundabout alternative. Village staff was directed to proceed with a mini.

Project Development and Design Effort:

At the beginning of the project, neither author had any experience with design of mini-roundabouts, and none was available in the United States. However, one of us (Ed) had been studying normal roundabouts for several years, so he reviewed the available literature and asked several knowledgeable contacts for advice. Fortunately, this was also during the development of the Northwestern Connector project near Detroit, and several prominent roundabout designers regularly visited Lansing during that project. Quick side trips to Dimondale allowed the Village - with their limited budget - to also receive design advice from world experts.

A literature search found a number of useful design materials, including a new book specifically on the design of mini-roundabouts: Mini-roundabouts: Getting them Right!, by Clive Sawers.[9] Mr. Sawers worked with Frank Blackmore at the TRRL during the late 1960's - at the time of the invention of the mini-roundabout - and had developed a simple design methodology. At the suggestion of Tony Redington of the Vermont Agency of Transportation, Michigan, Vermont and Maryland cooperated to bring Mr. Sawers to the United States and present a one-day seminar in each state. These seminars were a great success, and each was well attended by a cross section of road agencies that were impressed by Mr. Sawers informative presentation. Mr. Sawers visited Dimondale, met with their staff, and offered suggestions for the proposed mini-roundabout sites.

It is worth noting that Mr. Sawers and Mr. Crown - two British mini-roundabout designers - differed in two important recommendations. First, Mr. Sawers used an older, rule-of-thumb capacity analysis formula, whereas Mr. Crown uses formulas in TRL Lab Report 942 for capacity analysis. Because LR-942 is calibrated to the measured capacity and detailed geometry of mini-roundabouts in the field, we opted to use the LR-942 formulas (RODEL-1 set at 50% CL) for capacity estimation.

Using any capacity method, the Dimondale mini would operate below capacity for the life of the project. According to the LR-942 formulas, the worst-case forecast V/C ratios in the 2020 PM Peak period were 0.38 on the north leg, 0.26 on the west leg, and 0.22 on the east leg. Average queue lengths were in the fractions of a vehicle. Table Four shows the geometric parameters used for the capacity analysis:

Table Four: Geometric Capacity Parameters for the Mini-Roundabout

Capacity Parameter	Leg 1: N. Creyts Road	Leg 2: W. East Road	Leg 3: E. East Road
Entry Width (w)	5.0m	5.0m	4.0m
Flare Length (L)	15m	15m	15m
Approach Width (v)	3.5m	3.5m	3.2m
Entry Radius (r)	27m	100m	9m
Entry Angle (phi)	17 degrees	10 degrees	35 degrees
Inscribed Circle Diameter (D)	21m	21m	21m

Another point of disagreement between our experts did affect the layout. Mr. Sawers recommended advancing the YIELD lines to a point just outside the swept path of the circulating vehicles, so that entry width could be wider, the intersection would be more compact, and drivers would not tend to overrun the yield line. Mr. Crown advised against advancing that far, stating that as the diameter shrank the intersection would begin to behave as an American all-way stop instead of a roundabout. We decided to compromise on these two concepts, and place the YIELD line midway between the inscribed circle and the outer swept paths of circulating vehicles.

Mr Sawer's guide recommends adding a lane when the flare reaches four meters width, and UK guidelines recommend an extra lane when the entry width exceeds six meters. Because of the unfamiliarity of American drivers and the low volume at this intersection, we did not need to add a lane. Instead, we ended the bike lanes thirty meters (100') prior to the yield line (bikes either use the sidewalk or merge and circulate as a vehicle), and flared each approach to five meters, but left it striped as one lane. This would improve bike safety, add capacity, and accommodate farm machinery.

During the design process, the authors worked directly with the project engineer, Paul Galdes of Fleis and Vandenbrinck Engineering, on the design of the intersection. The design started with the principles outlined in Mr. Sawers' manual. We laid out the inscribed circle, drew the swept paths, established deflection, and gradually located the blob and splitter islands within the limits of the intersection. As our design began to look presentable, we E-mailed Barry Crown, a roundabout designer very experienced with minis, and asked him if he would assist us by reviewing our design. Mr. Crown graciously provided design review pro bono. Fortunately for us - and for Dimondale - Mr. Crown offered several critical improvements.

Effect of the Wye Intersection:
Because of the Wye intersection of Creyts Road, trucks turning right from westbound to northeast bound cannot make that turn without using the southbound lane. For that reason, we could not use a raised curb for the north splitter island, and instead used rumble strips. This works acceptably, because few trucks make that move, and truck speeds are very slow. Although the splitter is traversable, the lanes follow the natural vehicle paths and entering and exiting drivers keep right of the splitter. The TEE layout of the intersection provides deflection of the southbound approach.

For the opposite movement, trucks turning left from southwest bound to eastbound must overrun both the central island and the west end of the east splitter island. However, the westbound approach needed raised splitter and bollard to provide entry deflection and approach visibility. At Mr. Crown's recommendation, we built raised curb on the east end of the splitter, but used yellow paint to delineate the west end of that splitter. This is less than ideal, but it was necessitated by the 45-degree wye. In operation, it has not been a significant problem. Initially, some disgruntled drivers chose to drive directly over the central island (or blob) but this happens infrequently now that the stripes have been repainted and local drivers have become accustomed to the mini.

Locating "The Blob" (Central Island) and Arrows:
With the basic layout determined, we brought some cones and a spray can to the intersection and laid out the mini on the pavement, with cones where the splitters and central blob would be. (The "blob" is a spherical section of asphalt 4 meters across and 120 millimeters high, covered with thermoplastic.) Then, we took turns driving through to see how it felt. That turned out to be a valuable step, and we recommend it. On the

drawing board, we placed the central island dead center of the inscribed circle. When we drove it, that location gave good deflection on the westbound through movement, and also easily accommodated the southbound left turn, although it did not affect that natural path at all. But, the eastbound-to-northbound left turn felt very awkward, and required backtracking to get out of the intersection. If the cones hadn't prevented it, we would have preferred to drive straight over the central island, and most drivers probably would have if we had left the blob in that location.

Based on the feel of it, and after consulting with Mr. Crown, we relocated the blob one meter to the west of center. This greatly reduced the awkward feel of the eastbound left turn, and reduced our tendency to drive over the blob. This turned out to be correct, as almost all eastbound-to-northbound drivers do now drive around the blob.

Each of the three pavement arrows surrounding the blob was located in front of an approach. This was so that drivers at each yield line would see an arrow pointing around the blob.

Illuminated Bollards:
Bollards were a point of discussion within the design team. Bollards are translucent plastic shells about one meter high, illuminated by a fluorescent lamp in the base (see photo). Bollards are not in the US manual, but without them, Mr. Crown strongly advised against building a mini. He pointed out that, without bollards, the blob and arrows (flat to the pavement and without any signs on a central island) would not be visible to drivers, and they would not recognize the intersection until it was too late to react properly.

The bollards required extra cost and electrical work, but were worth the effort. The bollards are visible two blocks away during day and night. They are also attractive, and have elicited favorable public comments. We recommend including them in US highway design manuals.

Signs, Markings, and Yield Emphasis:
ROUNDABOUT AHEAD signs were placed 60 meters from each yield line. YIELD AHEAD signs were placed 30 meters from the yield line, and a YIELD sign was placed at each yield line.

The dashed yield lines are 500mm x 700mm thermoplastic marks with 300mm gaps, per UK standards described in Roundabout Design Guidelines.[10] The yield lines begin at the end of each splitter island, and roughly follow the curve of the swept paths to the outflow point of the entry, although the eastbound splitter was constrained by an access drive to the electrical substation. Yield lines are essential to show entering drivers where to yield, and to guide circulating drivers toward the exits.

Yield signs are uncommon at Michigan intersections, so we further emphasized yielding by adding a thermoplastic YIELD legend in front of the yield line. We debated using paint instead. In addition to reducing cost, a painted legend may have performed better in some aspects. The thermoplastic became broken and distorted after a year or so, and it reduces stopping friction slightly, which may be important in some instances. Paint would offer more friction and would not break or distort, but it would be less visible and wear away more quickly. The authors have not agreed whether thermoplastic or paint would be better, but we agree that the yield legend is helpful.

We also offered extra directions to explain who entering drivers should yield to. Beneath each YIELD sign, we added the explanation: YIELD TO TRAFFIC IN CIRCLE, as a temporary training aid. In retrospect, Ed thought this phrasing might lead people to think they should yield in the circle. "YIELD TO CIRCLE TRAFFIC" may have been clearer.

The team also debated whether to install additional YIELD signs on the splitter island(s). However, there is no splitter island on the north leg, and the east splitter is set back from the yield line, so those two splitters do not offer good locations for yield signs. The west splitter island offers a good location, and because that approach was previously uncontrolled, extra emphasis on yielding was appropriate. Ultimately, the village decided not to install a yield sign on that splitter because it would not conform to the other approaches. It could be added later if necessary.

The village originally installed pedestrian crossing signs at the crosswalks. We do not know if these were helpful, and there were no pedestrian crashes before or after construction. Ultimately, the Village decided the signs added clutter, potentially distracting drivers' eyes from pedestrians and the yield sign. The crosswalk signs were removed in 2002.

Initial Public Skepticism and the Public Meeting:
As luck would have it, a highly skeptical retired state highway engineer lived in Dimondale, and as rumors began to spread of a proposed roundabout, he explained the perils of traffic circles to his neighbors. This generated some anxiety, and some residents began to oppose the project. In response, the Village arranged a public meeting to present the project and allow people to ask questions. Some citizens arrived with misconceptions about the size of the circle, concerns about cost, or fears of crashes. Some had seen the recent roundabout in nearby Okemos and feared it would require similar right of way. We explained the project and answered everyone's questions, but some probably still felt as if they had unfairly lost an argument.

Construction:
For the most part, construction went smoothly. One design error on our part caused a problem. (We had never designed a mini-roundabout.) Due to our inexperience with computer aided design (CAD), and the numerous construction lines used to develop the roundabout geometry, we asked our CAD operator to turn off the utility layer so that we could more clearly see the curb layout. As a result, we failed to notice a manhole on the curb line. During construction, the contractor (who had never built a roundabout) found that manhole, and decided to fix the design by simply curving the curb around it. This left a "dent" in the NE curb that has collected tire rubber. We have mitigated that by painting a pavement edge line to direct vehicles around it.

During painting, the paint crew (who had never painted a roundabout) painted the entry side of the east splitter one foot to the left, and the error was not caught until later. As a result, the westbound approach appeared to be aimed straight at the central island, and about 40% of drivers obediently drove straight over the blob. After we spotted the problem, the authors repainted the east splitter island and pavement edge line to the right: re-aiming that lane to the right of the central island. This resulted in much better driver compliance: i.e., the vast majority now drove around the island instead of over it. We also concluded that many drivers drove over it intentionally at first, because they did not do it when other drivers were present.

Final Cost Estimate:
Compared to normal raised island roundabouts, the mini was very inexpensive, but a couple of things complicate the cost calculation. The intersection was to be rebuilt anyway, so portions of the construction cost (milling, asphalt, outer curbs, some striping, etc.) would have been incurred no matter what intersection was built. Costs attributable to the roundabout are primarily the islands, bollards, signs, electrical, and markings. Charges for final design were also mixed with the design of the Creyts Road reconstruction, so $7,000 is just an estimate. To provide a conservative cost estimate, all cost components were included in the benefit/cost analysis. Table Five shows the costs for the Dimondale Mini-roundabout:

Maintenance Issues and Costs:
The Dimondale street crew now has three years of experience maintaining a mini. Winter snow plowing tends to skin the thermoplastic of the central blob, requiring repair in the spring. Drivers have also knocked bollards loose from time to time, however the Village anticipated this and ordered two spare bollards at the outset. (Hint: During initial bollard installation, make sure the bollards will pop out properly without damaging the base unit.)

Maintenance Costs, June 1, 2001 through May 30, 2004:

Bollard Repair	$ 68.00
Thermoplastic Repair	$204.54
Line Painting	$ 51.14
Electricity (Estimated)	$100.00/yr*3years
TOTAL	$623.68 (Approximately $208/year in 2003 dollars)

For the benefit cost analysis, maintenance costs were assumed to continue at $200 per year (2001 dollars) for the life of the project. The net present value of maintenance cost was included as a disbenefit for benefit/cost calculations.

Table Five: Creyts/East Mini-Roundabout Project Cost Tabulation (2001 Dollars)					
Item	**Description**	**Unit**	**Quantity**	**Unit Price**	**Amount**
	PRELIMINARY ENGINEERING and RIGHT OF WAY				
A	Traffic Forecast/Capacity Analysis		1	Donated	0
B	Environmental Analysis		0	N/A	0
C	Public Meeting lump sum		1	$250 (est)	~$250
D	Roundabout Geometric Design		1	Donated	0
E	Geometric Design QA/QC		1	Donated	0
F	Detailed Design (part of Creyts Rd.)	lump sum	1	~$7,000	~$7,000
G	Right of Way	sq. meter	~20	Donated	0
	Pre-engineering & ROW Subtotal				**$7,250**
H	**CONSTRUCTION (Tom's Advance Paving)**				
1	Mobilization	lump sum	1	$500	$500
2	Pavement, remove	sq. meter	236	$15	$3,420
3	Bit Cold Mill, 50 mm depth	sq. meter	700	$6	$4,200
4	Sand Subbase, 300mm, CIP	sq. meter	10	$40	$400
5	Aggregate Base, 200mm, CIP	sq. meter	10	$40	$400
6	Adjust Structure	each	2	$225	$450
7	Bituminous surface mixture, 13A	metric ton	220	$45	$9,900
8	Bituminous base, islands, butt joints	metric ton	40	$80	$3,200
9	Rumble strip	sq. meter	50	$20	$1,000
10	Curb and gutter, conc., islands	meter	40	$55	$2,200
11	Post, steel, 4.54 kg	meter	25	$8	$200
12	Sign, type IIIC	sq. meter	5	$80	$400
13	Sign, type IIIB	sq. meter	4	$80	$320
14	Remove sign	each	3	$50	$150
15	Overlay, plastic, yield line, 500mm	meter	35	$40	$1,400
16	Overlay, cold plastic, yield legend	each	3	$175	$525
17	Marking, 100mm, yellow	meter	20	$8	$160
18	Marking, waterborne, 150mm, white	meter	20	$9	$180
19	Overlay cold plastic, arrow	each	3	$150	$450
20	Overlay, cold plastic, center island	each	1	$700	$700
21	Remove existing pavement markings	lump sum	1	$500	$500
22	Traffic detour	lump sum	1	$500	$500
23	Flag control	lump sum	1	$500	$500
24	Aggregate shoulder adj., 22A, 50mm	sq. meter	200	$8	$1,600
25	Marking, 100mm, yellow	meter	300	$4.50	$1,350
	Construction Subtotal:				**$34,725**
I	**BOLLARDS, (Forest City Signs Ltd., Cheshire, England)**				
1	Superflex bollard (Keep Right!)	each	4	$62.48	$250
2	Universal city base, 2*11-watt	each	2	$62.48	$125
3	Air freight, handling, security (UK)	lump sum	1	$390	$390
4	US Customs Clearance and Bond	lump sum	1	$190	$190
5	Delivery and handling (US)	lump sum	1	$105	$105
	Bollard Subtotal:				**$1,060**
J	**ELECTRICAL**				

	Street Lights (Consumers Energy Corporation)				
1	1 street light installation, 1 upgrade	each	2	$100	$200
	Wiring Installation (John R. Howell, Inc.)				
2	Buried wiring and bollard, install	lump sum	1	$4,500	$4,500
	Electrical Subtotal:				**$4,700**
	TOTAL MINI-ROUNDABOUT:				**$47,735**

Speed Effects:
The posted speed limit on all approaches remained 25 MPH before and after construction. Prior to the mini, the northeast and east legs of the intersection were stop controlled, and the west leg was uncontrolled. On the west leg, the 85th percentile approach speed was measured at 32 MPH. After construction of the mini, the 85th percentile speed was measured at 24 MPH at the same location. The NE and E legs have not been measured, but we observe that these approaches operate at a slightly lower speed than the west approach.

Crash Effects:
The following tables list all crashes reported within 300' of the intersection during the three years before and three years after the roundabout opened. We appreciate that this includes the period of construction and the immediate period after opening, during which times we might expect an unusual crash pattern. But, this is the data available as of this writing:

Before Period: Table Six lists reported crashes within three hundred feet during the "Before" period, from June 1, 1998 to May 30, 2001. During the before period, there were five crashes within 300 feet, with one class "B" injury. Using National Safety Council comprehensive crash costs, [11] the annual crash cost equals five property damage collisions and $2,000 each, and one class B injury at $46,200 each, in three years. **Annual Crash Cost Before: $18,733.**

Table Six: Crashes in the "Before" period: June 1, 1998 to May 30, 2001
Jul 08, 1998, 1 PM, daylight, dry, cloudy, westbound, 250' west of intersection, rear-end, PDO . Driveway related.
Sep 27, 1998, 1AM, dark, dry, clear, northbound, 50' north of intersection, fixed object, PDO. Driver had just turned left from eastbound East Rd to northeast-bound Creyts. Alcohol reported.
Jun 19, 2000, 4PM, daylight, dry, clear, eastbound, 150' west of intersection, fixed object, 1 Class B injury.
Jul 30, 2000, 4 AM, dark, dry, cloudy, southbound, in intersection, fixed object, drove due south across the intersection and onto the curb. PDO. Alcohol reported.
Oct 26, 2000, 3 PM, daylight, dry, clear, southbound, 200' north of intersection, rear end, (driveway related) PDO

After Period: Table Seven lists reported crashes within three hundred feet during the "After" period, from June 1, 2001 to May 30, 2004. During the after period, there were five crashes within 300 feet, with two class "C" injuries. Two drivers also struck bollards, but did not report these to police. Again using National Safety Council cost figures, the annual crash cost equals five property damage collisions and $2,000 each, and two class C injury at $22,000 each, over three years. **Annual Crash Cost After: $18,000.**

Table Seven: Crashes in the "After" Period: June 1, 2001 to May 30, 2004
Dec 19, 2001, 12 PM, daylight, wet, cloudy, eastbound, 300' east of intersection, rear end, PDO, (driveway related).
July 4, 2002, 4 AM, dark, dry, clear, westbound, 250' west of intersection, rollover, 1 Class "C" Injury. Speeding and lost control after turning right from Creyts to East. Alcohol reported.
Oct 15, 2002, 11 PM, dark, dry, clear, eastbound, 100' east of intersection, fixed object (phone pole), 1 class C Injury. Driver lost control after going east through rdbt. Alcohol reported.
Dec 9, 2003, 1 PM, daylight, wet, cloudy, southbound, 20' north of intersection, rear end, PDO. A southbound driver hit a car stopped at the yield line.
Jan 1, 2004, 10 PM, dark, dry, cloudy, westbound, 200' west of intersection, fixed object (telephone pole), PDO. Driver lost control after turning right at roundabout.

The crash data suggests that the average annual cost of crashes within 300' of the intersection declined by $733 (3.9%) during the after period. Alcohol was reported in each injury crash. Volumes also increased, so the total crash rate would show some improvement. However, this is a small sample, so we do not observe or claim any significant change. The US needs more data to evaluate crash effects of mini-roundabouts.

Benefit/Cost Ratio and Time of Return:
Tangible transportation project benefits typically include delay reduction (vehicle expense, driver time), and crash reduction. The delay reduction has been observed at Dimondale. There was no significant change in crashes, so we did not include crashes in the benefit/cost analysis. All benefits and costs were discounted at 4% and shown in 2001 dollars.

Benefits:	Net present value of Delay Reduction:	$695,367
	Net present value of Maintenance:	- $2,718
	NET BENEFIT:	**$692,649**
Costs:	Total Project Development Cost:	$ 47,735
	NET COST:	**$ 47,735**
	Benefit/Cost Ratio:	**14.5 : 1**

Estimated time of return is the length of time that future benefits must accrue to recoup the initial investment. Because traffic is increasing, the amount of time saved by the mini-roundabout relative to an all-way-stop increases each year. In the first year, the estimated value of time saved is $34,065, giving a time of return for the project of 1.4 years. The mini-roundabout was therefore a sound community investment. It has already paid for itself.

Public Opinion and Driver Behavior After Three Years:
Years ago, one of us (Ed) stumbled across a mini-roundabout in England, and his initial reaction was to laugh at it. Who would bother to drive around the thing? We stopped

laughing after we read the engineering reports. It turns out that minis are an exceptionally safe and cost-effective traffic management tool - useful at many thousands of intersections. We felt confident that, once folks saw the mini, drivers would recognize it as a serious traffic management device - not to be snickered at.

Folks made fun of our mini. One popular proposal suggested a rubber statue of one of us (Jim) on the central island, so drivers could run over it or slap it as they drove by. Some who had opposed the project drove over the central island in protest. (Most stopped doing that after we told them it was OK, and they gradually got bored and annoyed by the hump.) Immediately after it opened, the principal complaints we heard were: “It was a big waste of money.” “It confuses people.” “They should have just installed a stop sign.” Now, after three years, the vast majority of drivers use the mini with skill, and the most common complaint we hear is that “those other drivers” don’t know how to drive it. Some still do stop unnecessarily. Nevertheless, most Dimondale drivers have gotten very good at driving it, delay is exceptionally low, and as before the roundabout, crashes have involved speeding, careless, or inebriated drivers. But, it has become a local tradition to make fun of the mini.

Conclusions:

1. A mini-roundabout has been demonstrated in the United States. Delay is greatly reduced. Crashes were low before conversion, and did not increase after conversion. Dimondale is a typical Midwestern locale with no prior driver experience using roundabouts. Other US locations can expect similar results.

2. Delay at mini-roundabouts compares very favorably to all-way-stop control. Over the life of the project, the Dimondale mini eliminates 90,000 hours of delay - equivalent to one vehicle and driver idling for ten years. UK reports show that conversion of three-leg major/minor junctions to mini roundabout is most beneficial at volumes from >12,000 to >30,000 ADT.

3. Mini-roundabouts reduce fuel consumption and emissions. Many thousands of stop and signal controlled intersections in the US could benefit from conversion. This could significantly reduce US energy consumption and related vehicle emissions.

4. Mini-roundabouts cost much less than a normal raised island roundabout. The $47,000 cost of the Dimondale mini built in 2001 compares to approximately $300,000 for the nearby Okemos normal roundabout built in 2000. This cost can be further reduced.

5. Absence of a publicly-perceived problem at the intersection prior to construction diminished public support. A location where the public perceives existing crashes or delays would probably gain greater public acceptance. Public information efforts could also improve public acceptance.

Suggestions and Recommendations:
An attractive mini-roundabout is possible for less cost. Practitioners may wish to consider using prefabricated splitter islands to reduce installation time and cost. Pre-fabricated splitter islands, available in the UK, are bolted in place in existing intersections. Installation is fast and cheap, but shipping them from England would be expensive. Alternatively, it would be possible to graft hot asphalt splitters and blob onto existing asphalt, and then paint the splitters and cover the blob with thermoplastic. Once drivers become accustomed to roundabouts, it will be possible in mild climates to provide a mini using only paint, signs, and lighting.

The authors cannot agree whether the temporary instruction YIELD TO CIRCLE TRAFFIC or YIELD TO TRAFFIC IN CIRCLE is preferable. A better solution would be to adopt the international roundabout symbol (blue circle with white arrows) which means: "Roundabout. Traffic on left has priority." This symbol, used in conjunction with the yield sign, tells drivers that they have arrived at a roundabout. In snow, drivers cannot see pavement markings, so this sign is the only indication drivers receive showing the circulation pattern. The US has no comparable sign, so it is necessary and reasonable to adopt the international symbol.

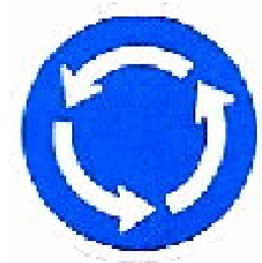

Figure 5: International Roundabout Symbol

Last Minute Pointers:
Minis are exceptionally efficient and save time and fuel.
Uncle Sam needs you to build them.
Seek experienced design advice, and heed it.
Use a manual.
We recommend The Purple Guide, and Mini-roundabouts: Getting them Right!
TRL Lab Report 942 is based on measured capacity at minis. Use the TRL-942 formulas in ARCADY or RODEL for capacity analyses.
Triple-check trucks swept paths and provide a little extra space.
Double check the utility layer when laying it out.
Before building the islands, lay out the mini with chalk and cones. Drive it and see how it feels. Adjust the design as necessary.
Use a YIELD legend.
Illuminated bollards are essential for visibility, and look very sharp.
Assure the construction engineer is familiar with roundabout design issues.
Monitor contractors and painters closely.
Monitor performance to assure drivers behave as intended. Adjust the design if needed.

Disclaimer:
The views expressed in this paper are those of the authors, and do not represent official statements or policies of the State of Michigan or the Village of Dimondale.

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