Maintenance of Traffic for Innovative Geometric Designs Work Zones

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ABSTRACT
In an effort to improve the safety and capacity of existing roads, many transportation practitioners are implementing innovative designs at intersections and interchanges. The development of construction phasing plans for these projects is a critical component to maintaining safety and mobility on the facility during construction. The goal of this paper is to address gaps in existing knowledge by presenting the state of the practice and providing guidance for transportation practitioners in developing construction phasing and MOT plans for projects with innovative geometric designs. Several types of innovative geometric designs were studied including the roundabout, single point urban interchange (SPUI), diverging diamond interchange (DDI), restricted-crossing left turn (RCUT), median U-turn (MUT), and displaced left turn (DLT). Example MOT phasing diagrams showing phasing sequencing and construction work areas were developed based on a review of literature, survey of practitioners, interviews with industry experts, and review of actual project plans. The example MOT phasing diagrams are intended to serve as a starting point for transportation practitioners, but project-specific factors such as driver experience, availability of detours, traffic counts, adjacent land use, elevation differences, barrier offsets, number of lanes, and anticipated impacts of a possible closure should be considered when deciding on the best MOT methods for a given project.

Key Words: Innovative Geometric Designs, Roundabout, Work Zone Traffic Control
INTRODUCTION
As the nation’s population continues to grow, the users of the highway network face increased safety risks, delays, and congestion. Budget constraints at many public agencies frequently make infeasible the construction of new facilities to improve the capacity and safety of the highway network. In an effort to improve the safety and capacity of the existing highway network, many transportation practitioners are implementing innovative designs at intersections and interchanges. These innovative designs provide many significant operational and safety benefits.

An important component pertaining to the design of these innovative highway facilities includes the development of construction phasing plans. Because these innovative design solutions are frequently retrofitted from an existing highway facility, the development of construction phasing plans for these projects is a critical component to maintaining safety and mobility on the facility during construction. No specific guidelines are currently in place to aid transportation practitioners in developing construction phasing for projects with innovative geometric designs.

The goals of this paper are to present the state of the existing practice and to provide guidance to transportation practitioners in developing MOT plans for both initial construction and maintenance projects with innovative geometric designs. The six types of innovative geometric designs examined in this research are roundabout, single point urban interchange (SPUI), diverging diamond interchange (DDI), restricted crossing U-turn (RCUT) intersection, median U-turn (MUT) intersection, and displaced left-turn (DLT) intersection. Figure 1 contains aerial photographs of examples of each of the six designs. Example MOT phasing diagrams showing phasing sequencing and construction work areas were developed for initial construction and maintenance for these facilities. These diagrams were developed through a review of literature, survey of practitioners, interviews of industry experts, and review of example plans from innovative geometric design projects. The research described in this paper was focused on practices used by agencies to develop MOT plans for these designs and not on investigating specific operational and safety impacts of the MOT for these designs.

LITERATURE REVIEW
A review of literature provided further insight into existing MOT techniques for both initial construction and maintenance of many of the intersection types. Roundabout facilities were found to be the most prevalent type studied. The Virginia DOT Work Area Protection Manual (2) contains operational guidelines for roundabout construction and maintenance projects. It includes drawings that show a typical work zone setup for maintenance of a single lane roundabout using flagger control, maintenance of a multi-lane roundabout with a temporary closure of the innermost lane, and maintenance of a multi-lane roundabout with a temporary closure of the outermost lane. FHWA (3) provides recommendations regarding various considerations when leaving uncompleted work in a roundabout overnight. The Wisconsin Department of Transportation (WisDOT) Roundabout Guide (4) suggests that detouring traffic away from roundabout construction is ideal for safety and operations and describes a typical roundabout construction staging organized in 6 phases for cases in which detours are not available.

Some information regarding MOT was found for most of the other facility types; however, no existing studies were found pertaining to SPUI initial construction phasing or maintenance project traffic control. Most of the literature found discussed the conversion of an existing facility to an innovative design. For the DDI, the Diverging Diamond Interchange
(DDI): Informational Guide (5) suggests that the construction phasing for the conversion of a facility to a DDI should be based on many considerations, such as the possibility of a complete closure and the potential for use of existing pavement through the DDI. It provides an example DDI traffic phasing for a case in which no additional cross-section right-of-way is required and the existing bridge is utilized. For the RCUT and MUT intersections, the Alternative Intersections/Interchanges: Informational Report (AIIR) (6) suggests that the construction phasing and MOT require careful consideration whenever widening a two-lane road into a divided highway or retrofitting an existing intersection. The AIIR (6) provides an example of construction phasing for the retrofit of an existing multi-lane intersection to a RCUT intersection and a sample MUT construction phasing scheme for retrofitting an existing single-lane or multi-lane intersection through three construction phases. The Displaced Left Turn (DLT) Information Guide (7) describes three overall MOT strategies for the conversion of a conventional intersection to a DLT intersections: complete closure, closure of one cross road at a time, and providing full access of all traffic movements throughout construction. It also includes a general three phase construction approach for the DLT intersection for retrofitting an existing conventional intersection.

SURVEY
An online survey of industry experts provided knowledge on current practices pertaining to MOT at innovative geometric design intersection work zones. The survey was created online and distributed to practitioners throughout the United States, including representatives from state departments of transportation (DOTs), cities, counties, and private consultants. Contact information for industry experts originated from agencies such as the Missouri DOT and FHWA. The survey was also sent to the listserv of the TRB Roundabout Committee to allow committee members and colleagues to participate. The survey consisted of 16 questions, including multiple-choice and fill-in answers. The survey concluded by asking if the respondent would be willing to participate in a follow up interview and/or send project MOT plans for use as examples in developing MOT phasing diagrams.

The survey was completed by 48 industry experts across the United States from various state DOTs, cities, counties, consultants, and other agencies. There was a wide geographical distribution of participants as the survey responses originated from 28 states. Approximately 65% of the respondents were from state DOTs while the remaining respondents were from consultants and local agencies.

The survey results provided insights into the level of experience of practitioners with the various innovative geometric designs. The results showed that the survey respondents had the most experience with roundabouts followed by SPUIs for both initial construction and maintenance. This result conforms to expectations, since these two designs are more prevalent than the other alternative intersection and interchange types. Ninety percent of respondents indicated phased construction with partial closures was the predominant MOT method for initial construction across all facility types. Complete closure was the predominant method used for the initial construction of roundabouts by 20 percent of the respondents, and a temporary traffic signal was predominantly used for the initial construction of SPUIs by 10 percent of the respondents. Of the respondents, 89 percent indicated that phased construction with partial closures was also the predominant method for maintenance projects with other methods being used less frequently for maintenance than for initial construction. This result is expected since maintenance projects typically cause fewer traffic and ancillary impacts to the facility and
surrounding area than initial construction projects. Agencies were consistent in the methods used, as 90 percent and 91 percent of respondents indicated that they used the predominant MOT method “Always” or “Almost Always” for initial construction and maintenance projects, respectively. Other key survey findings include:

- 48% of respondents indicated that the use of a temporary bypass was less effective than other techniques. This could be due to the costs and temporary right-of-way requirements of a temporary bypass.
- Experience/knowledge, the Manual on Uniform Traffic Control Devices (MUTCD) (8), and state design manuals were the resources most commonly used by respondents to help develop MOT plans for innovative geometric designs.
- Traffic counts and availability of alternate routes were the factors used most frequently by respondents in developing MOT plans for innovative geometric designs.

INTERVIEWS
Survey respondents as well as additional contacts generated from the survey were asked to participate in an interview to share their experiences with MOT for initial construction and maintenance projects for innovative geometric designs. Individuals from various DOTs, cities, counties, and consultant agencies participated in these interviews. A total of 20 interviews were held with practitioners from 10 states. A majority (60%) of the interview subjects were from state DOTs. These interviews provided information on lessons learned, special considerations, and challenges faced in developing MOT plans. Interviews of industry experts also provided more knowledge regarding what factors should be considered and their effects on MOT.

Key findings of industry expert recommendations through the interview process are as follows:

1. Avoid using temporary movements through construction which would be considered an illegal movement for the final traffic movement configuration. If drivers are familiar with the final traffic configuration due to the presence other intersections of a similar type in the area, this application of MOT could prove beneficial without increased risk of future illegal movements.
2. For DDI, if possible, construct curbing for the channelizing islands before construction is complete to ensure drivers travel the intersection correctly.
3. For MUT, make sure drivers know there is a median U-turn after the intersection.
4. Agencies have tried using innovative geometric designs for MOT setup, such as the use of a quadrant DLT interchange or MUT to accommodate left turns during the construction of SPUIs in Utah and the use of a temporary DDI configuration for the conversion of a conventional interchange to a DDI in Missouri. Innovative geometric setups implemented for MOT could provide more effective work zone traffic management until construction is complete.
5. In roundabout construction, median crossovers on legs could prove to be useful on an as-needed basis.
6. For any innovative geometric design, doubling the number of channelizers through the extents of the work zone can prove valuable in preventing drivers from weaving.
7. Sequential lighting can provide a valuable aid to drivers through work zones for both daylight and nighttime periods.

8. Final conversion of some of these facility types, such as DDI, should be done under full closure which should occur when traffic counts are lower, such as weekend periods. Depending on the circumstances of the project, the conversion could occur sometime from the middle to the end of the project. A short full closure period also ensures that drivers acknowledge the change in intersection configuration.

9. Use of innovative contracting techniques such as design build could be considered to allow contractors to determine methods used. However, care should be taken to ensure that any contractor modifications meet design guidelines and provide for work zone safety and mobility.

Additional findings through the interview process from interviewee opinion and recommendations include:
1. Other factors such as drainage, necessity of movements, and other situations can affect phasing.
2. Be cognizant of how to accommodate pedestrians.
3. With low speeds through the work zone, sharp angles in temporary traffic control are acceptable.
4. MOT plans should be continually reevaluated throughout the duration of the project.
5. Avoid the use of unwarranted temporary signals, because public pressure might make them permanent.

PROJECT PLAN EXAMPLES
Survey respondents were asked to provide project plans relating to MOT of innovative geometric designs to serve as examples of construction phasing and MOT. The obtained plans were examined for current MOT practices for each facility type. Respondents that provided plans and participated in the interview process were asked additional questions relating to the project plans. These questions involved the performance of specific methods of MOT through each facility type and what factors led to the chosen MOT and construction phasing method. Table 1 summarizes the project plans and other information received from state DOTs, consultants, cities, and counties. The following is the distribution of the number of plans by facility type: roundabout (19), SPUI (4), DDI (6), RCUT (6), MUT (2), and DLT (2). The plans represent a wide geographic distribution as they originated from 10 different states. The majority (59%) of the plans were obtained from state DOTs. Most of the plan examples showed phased construction with partial closures, although some plan examples with complete closures were also obtained. Additional information regarding the plan examples can be found in Brown et al. (9).

DEVELOPMENT OF MOT PHASING DIAGRAMS
To help fill gaps in existing knowledge and meet the need for guidance regarding development of MOT plans for projects with innovative geometric designs, the authors developed example MOT phasing diagrams for both initial construction and maintenance for each facility type based on engineering judgment and information compiled from the literature review, survey of industry experts, interviews of industry experts, and review of sample plans. The complete set of drawings can be found in Brown et al. (9). The information shown on the drawings includes the
intersection or interchange layout, lane configurations, work areas, lane closures, general layout of channelizers, general locations of traffic barricades, and general descriptions of phasing. For additional details regarding the layout of traffic control devices, practitioners are referred to Part 6c of the MUTCD (8). Since each project is unique, the provided MOT phasing diagrams are intended to serve as a starting point for transportation practitioners and should be further developed by an engineer based on site characteristics. Other factors such as driver experience, availability of detours, traffic counts, adjacent land use, extent of pavement removal, amount of grading and earthwork, elevation differences, barrier offsets, and anticipated impacts of a possible closure should be considered when developing MOT plans for a given project. Barrier offsets and vertical drop-offs were not explicitly considered in the initial work described in the paper, but they should be taken into consideration when developing MOT plans for these types of projects. A total of 37 MOT phasing drawings were developed by the authors for initial construction of the facilities with innovative geometric designs. Each drawing corresponds to a different phase of the initial construction of each intersection or interchange type.

For the roundabout, phasing drawings were developed for two MOT strategies: phased construction and complete closure of the intersection with a temporary bypass to accommodate traffic. The MOT phasing diagrams for roundabout phased construction include three phases as shown in Figure 2. In the first phase, half of the intersection is closed to allow for construction of half of the roundabout. One direction of traffic is maintained, or alternatively a flagger could be used to maintain both directions of traffic. In the second phase, the constructed half of the roundabout is opened to traffic, and one quarter of the remaining existing intersection is closed to allow for additional roundabout construction. In the third and final phase, the remainder of the existing intersection is closed for roundabout construction, and the final roundabout configuration is opened to traffic.

The MOT phasing diagrams for roundabout construction with a temporary bypass are shown in Figure 3. The MOT phasing diagrams for this roundabout construction strategy include three phases. In the first phase, the temporary bypass is constructed while the existing intersection remains open to traffic. The existing intersection is closed during the second phase of construction, and traffic is diverted to the temporary bypass. In the final phase, traffic is shifted onto the final roundabout configuration, and the temporary bypass is removed.

The example MOT phasing diagrams for a SPUI (cross road over the freeway and salvage of the existing rectangular bridge) include five phases as shown in Figure 4. In the first phase, the existing bridge is widened as needed. Construction of the left turn ramps begins in the second phase. A temporary closure of the innermost lane for both the entrance and exit ramps may be required. In Phase 3, one side of roadway widening is constructed, and connections between the newly constructed ramps and the existing roadway are made. The temporary closure of one lane for newly constructed ramps and existing ramps may be required, and a temporary traffic signal is installed. Construction of the right turn facilities also begins in the third phase. In the fourth phase, the remaining roadway widening is constructed, and the conventional diamond interchange approaches are removed. Finally, in Phase 5, traffic is shifted onto the final SPUI configuration, and the final traffic signal is installed.

These MOT phasing diagrams are for the cross road over the freeway and salvage of the existing rectangular bridge. Cases in which the cross road goes under the freeway or a new bridge is being constructed likely require modifications to this phasing. In addition, there are tradeoffs between using a rectangular bridge and an hour-glass shaped bridge. The rectangular bridge typically costs more than an hour-glass shaped bridge and has significant amounts of
empty space on the structure. However, its expanded footprint allows for easier MOT for both initial construction and maintenance than an hour-glass shaped bridge.

The example MOT phasing diagrams for a DDI (cross road over the freeway and salvage of the existing bridge) include five phases as shown in Figure 5. In the first phase, the existing bridge is widened as needed. In Phase 2, the bridge deck on the opposite side is reconstructed, if necessary. The portions of the crossovers that are located outside of the existing roadway are constructed. In the third phase, one direction of traffic is shifted onto the newly constructed bridge deck, and widening of the existing bridge deck continues. This phase also includes reconstruction of the innermost lane and median on the bridge deck and the approaching roadways. Traffic is shifted from the existing bridge deck onto the newly constructed innermost lane in Phase 4. The bridge deck widening and construction of the medians through the bridge deck and approaching roadway continue during this phase. In the fifth and final phase, traffic is shifted to the final DDI configuration. A short complete closure of the interchange is typically required for the final conversion to the DDI configuration. In addition, the final traffic signal control is installed, and the raised medians at each of the crossovers are constructed. These example MOT phasing diagrams are for the cross road over the freeway with the salvage of the existing bridge. Cases in which the cross road goes under the freeway or a new bridge is being constructed likely require modifications to this phasing.

The MOT phasing diagrams for a RCUT include two phases as shown in Figure 6. In the first phase, the median U-turns on the main roadway are constructed. This work is completed with minimal impact on traffic. In Phase 2, traffic is shifted from the main roadway left-turning movements and minor roadway through movements onto the newly constructed median U-turns. Measures should be taken to ensure that travelers are aware of the U-turn. The RCUT intersection center and minor road medians are also constructed during this phase. Upon completion of the second phase, traffic is shifted onto the final RCUT configuration.

The MOT phasing diagrams for a MUT are similar to the MOT phasing diagrams for a RCUT and are shown in Figure 7. In the first phase, the median U-turns on the main roadway are constructed with minimal impact on traffic. In Phase 2, the left-turning traffic on the major road is shifted onto the newly constructed median U-turns. The intersection center and original left-turn bays are removed. A full closure of the intersection for a short duration of time may be required. Finally, traffic is shifted onto the final MUT configuration.

The MOT phasing diagrams for a DLT include three phases as shown in Figure 8. In the first phase, the pavement for the minor roadway movements outside of the future left-turn bays and the major roadway right-turn movements is constructed. In Phase 2, the newly constructed right-turn movements are opened to traffic, and construction of the displaced left-turn bays and major roadway crossovers begins. During the third phase, traffic is shifted to the displaced left-turn bays. The original left-turn bays from the original intersection are removed. Upon completion of the third phase, the DLT intersection is fully opened to the final traffic configuration.

A total of 31 MOT drawings were developed by the authors for maintenance of the facilities with innovative geometric designs as shown in Table 2. The drawings do not show a sequence of phasing as was shown for the initial construction drawings. Instead, each drawing shows the general configuration for maintenance work on a different part of the facility including locations of work areas, lane closures, and channelizers. One maintenance drawing for each facility type is provided as an example in Figure 9. Lane closures for through movements should extend throughout the limits of the intersection or interchange to help avoid driver confusion.
MOT for maintenance work such as deck replacement on SPUIs can be especially challenging and may require that the interchange be temporarily operated as a diamond interchange. The use of a rectangular bridge instead of an hour-glass shaped bridge on a SPUI can help to facilitate MOT during maintenance work.

CONCLUSIONS
Example MOT phasing diagrams were developed by the authors for both initial construction and maintenance of these innovative geometric designs based on a synthesis of current practices gathered through literature review, surveys and interviews of industry experts, and examination of project plans. Each facility type is capable of organized phased construction which involves little to no effect on movement access throughout construction. The MOT phasing diagrams were developed to serve as an aid to transportation practitioners looking to implement these designs through a retrofit construction from a conventional intersection while needing to maintain access throughout construction and maintenance. The MOT phasing diagrams should be used in conjunction with project specific characteristics such as driver experience, detour availability, adjacent land use, barrier offsets, elevation differences, extent of pavement removal, amount of grading, number of lanes, and possible closure impacts to determine the best construction phasing and MOT methods for a given project.

There are many ways in which the research presented in this paper can be expanded. The MOT phasing diagrams could be expanded and refined to take into account other considerations such as barrier offsets, vertical drop-offs, and placement of signs. Other configurations such as the cross road under the freeway, the construction of a new bridge for the DDI and SPUI, and the use of an hour-glass shaped bridge for a SPUI could be explored as well. Finally, the safety and operational impacts of the MOT for these designs could also be investigated.

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Closure of right turn lanes may be needed

Shifting the bridge deck traffic onto westbound lanes

Shifting the traffic onto the newly constructed bridge deck (eastbound lanes)

Work area

Channelizer

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| Roundabout    | 1. Maintenance of portion of circulating roadway. Temporary closure of circulating roadway of roundabout on one approach. One-way traffic or flagger on one pair of approaches.  
2. Maintenance of half of the roundabout. Temporary closure of one pair of approaches. One-way traffic or flagger on other pair of approaches. |
| SPUI          | 1. Temporary closure of the outside left turn lane.  
2. Temporary closure of the inside left turn lane.  
3. Temporary closure of right turn entrance ramp.  
4. Temporary closure of the outermost through lane.  
5. Maintenance of the center lane. Temporary closure of the two outermost lanes.  
6. Temporary closure of the innermost through lane.  
7. Temporary closure of the exit ramp right turn lane.  
8. Maintenance of the intersection center. Temporary closure of left turn lanes on exit ramps and outer left turn lanes and innermost through lanes on cross road. |
| DDI           | 1. Temporary closure of the left turn lane for entrance ramp.  
2. Temporary closure of the left turn exit ramp.  
3. Temporary closure of the outermost DDI lane. Shifting left and right turn traffic onto the through lanes.  
4. Maintenance of the outside through lane of the DDI. Temporary closure of both the outside DDI through lanes and turning lane.  
5. Temporary closure of the innermost through lane. |
| RCUT          | 1. Temporary closure of the center of the intersection.  
2. Temporary closure of the median U-turn without a temporary U-turn.  
3. Temporary closure of the median U-turn with a temporary U-turn.  
4. Temporary closure of the outermost RCUT through lane.  
5. Maintenance of the center RCUT through lane. Temporary closure of the center and outside RCUT through lanes.  
6. Temporary closure of the innermost RCUT through lane. |
| MUT           | 1. Temporary closure of the median U-turn without a temporary U-turn.  
2. Temporary closure of the median U-turn with a temporary U-turn.  
3. Temporary closure of outermost through lane.  
4. Maintenance of the center MUT through lane. Temporary closure of both the center and outermost MUT through lanes.  
5. Temporary closure of the MUT innermost through lane. |
| DLT           | 1. Temporary closure of the DLT right turn lane.  
2. Temporary closure of the DLT left turn lane without provision of temporary left turn bay.  
3. Temporary closure of the DLT left turn lane with temporary left turn bay.  
4. Maintenance of outside through lane. Temporary closure of outside through lane and cross street outside left turn lane.  
5. Maintenance of inside through lane. Temporary closure of inside through lane and cross street southbound inside left turn lane. |