Maintenance of Traffic for Innovative Geometric Design Work Zones

Final Report
December 2015

SWZDI
Smart Work Zone Deployment Initiative

Sponsored by
Smart Work Zone Deployment Initiative
Federal Highway Administration
(TPF-5(081))

About SWZDI

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) in 1999 and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work.

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16. Abstract

Currently there are no guidelines within the Manual on Uniform Traffic Control Devices (MUTCD) on construction phasing and maintenance of traffic (MOT) for retrofit construction and maintenance projects involving innovative geometric designs. The research presented in this report addressed this gap in existing knowledge by investigating the state of the practice of construction phasing and MOT for several types of innovative geometric designs 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).

This report provides guidelines for transportation practitioners in developing construction phasing and MOT plans for innovative geometric designs. This report includes MOT Phasing Diagrams to assist in the development of MOT strategies for innovative designs. The MOT Phasing Diagrams were developed through a review of literature, survey, interviews with practitioners, and review of plans from innovative geometric design projects. These diagrams are provided as a tool to assist in improving work zone safety and mobility through construction of projects with innovative geometric designs. The aforementioned synthesis of existing knowledge documented existing practices for these types of designs.

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MAINTENANCE OF TRAFFIC FOR INNOVATIVE GEOMETRIC DESIGN WORK ZONES

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EXECUTIVE SUMMARY

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. The Manual on Uniform Traffic Control Devices (MUTCD) (FHWA 2009) provides general guidelines and typical applications for the maintenance of traffic (MOT) of construction projects; however, no specific guidelines are currently in place to aid transportation practitioners in organizing this process for projects with innovative geometric designs.

The goal of this research is 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. MOT phasing diagrams showing phasing sequencing and construction work areas were developed for initial construction and maintenance of 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.

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. 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. 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. 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 MUTCD, 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.

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. Survey respondents were also 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.

To help fill gaps in existing knowledge and meet the need for guidance regarding development of MOT plans for projects with innovative geometric designs, MOT phasing diagrams were produced 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 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. Since each project is unique, the suggested MOT phasing diagrams are intended to serve as a starting point for transportation practitioners. Other factors such as driver experience, availability of detours, traffic counts, adjacent land use, buffer spaces, and anticipated impacts of a possible closure could be considered when developing MOT plans for a given project. A total of 37 MOT phasing drawings were developed 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.

A total of 31 MOT drawings were developed for maintenance of the facilities with innovative geometric designs as shown in Table ES.1.

Table ES.1 Maintenance drawings for each facility type

Facility Type	Maintenance Drawing
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. Maintenance of the innermost lane. 7. Maintenance of the exit ramp right turn lane. 8. Maintenance of the intersection center.
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.

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 important recommendation for maintenance projects on these facilities is that lane closures for through movement should extend throughout the limits of the intersection or interchange to help avoid driver confusion.

The results of the study indicate that each design examined in this project is capable of organized phased construction with little to no effect on movement access throughout construction. In general, the maintenance of traffic seems to be more straightforward for innovative designs in which traffic movements are separated (such as the RCUT or MUT) than for innovative designs in which traffic movements are grouped together (such as the DDI, SPUI, or roundabout). Some key recommendations of this report include:

1. Avoid using temporary movements through construction which would be considered an illegal movement for the final traffic movement configuration. If drivers are experienced with the final traffic configuration due to 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 channelizing islands before construction is complete to ensure drivers travel the intersection correctly.
3. For MUT, use appropriate signage to inform drivers about the median U-turn presence 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, providing median crossover points near the roundabout could prove to be useful by significantly shortening the flagging zone and thus allowing for more efficient flagging operations.
6. For any innovative geometric design, doubling the number of channelizers used through the extents of the work zone can prove valuable in preventing drivers from weaving.
7. Sequential lighting can provide valuable aid to drivers through the work zone for both daylight and nighttime periods.
8. Final conversion of some of these innovative designs, such as DDI, should be done under full closure which should occur when traffic volumes are low, such as weekend periods. The conversion could occur either through the middle or at the end of the project. A short full closure period also ensures that drivers acknowledge the change in intersection configuration.

CHAPTER 1. PROBLEM DESCRIPTION AND INTRODUCTION

Innovative geometric designs are considered to be a solution to many state department of Transportation (DOT) problems with utilizing limited funding to meet growing traffic demand that results in safety risks and congestion. These designs allow for unconventional traffic movements through intersections and interchanges. Implementing these designs requires work zones, and often requires MOT through work zones. Innovative geometric designs examined in this research include the 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.

Each intersection type provides various safety and operational benefits. The roundabout eliminates right-angle crossings and causes traffic to move continuously in a one-way circular motion (Figure 1.1). In eliminating right-angle crossings, the potential for serious crashes resulting from angle collisions is substantially reduced.

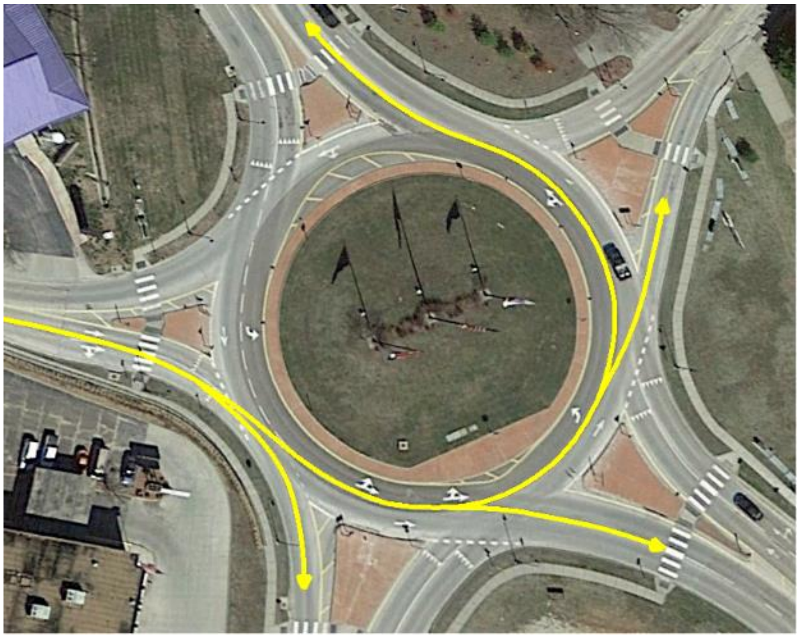

Image ©Google 2014

Figure 1.1 Roundabout intersection in Branson, Missouri, Business 65 and Branson Landing Boulevard

The SPUI utilizes a single signalized intersection which leads to a more simplistic signal phasing sequence and an increased capacity when compared to a conventional diamond intersection (Figure 1.2). SPUIs are typically used in urban areas with high traffic volumes.

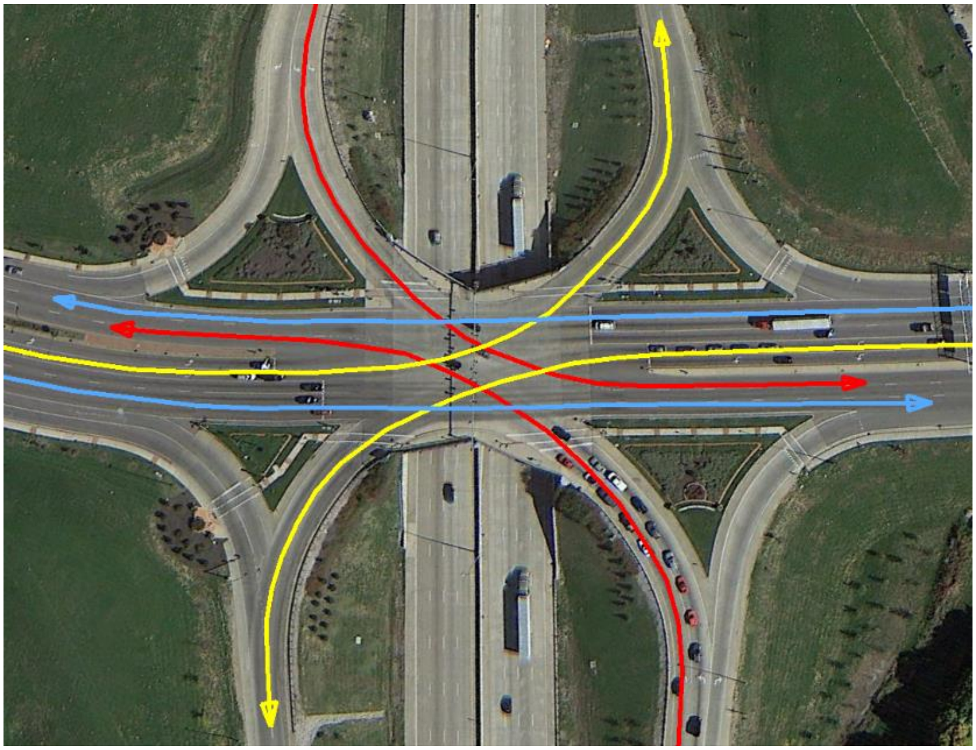

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Figure 1.2 Single point urban interchange (SPUI) in St. Louis, Missouri, I-64 and S. Kingshighway Boulevard

The DDI, also known as the double crossover diamond interchange, shifts cross-street traffic to the left side of the roadway (Figure 1.3). This design utilizes unrestricted left-turn movements for on-ramps leading to increased capacity and safety due to elimination of left-turn crossing conflicts.

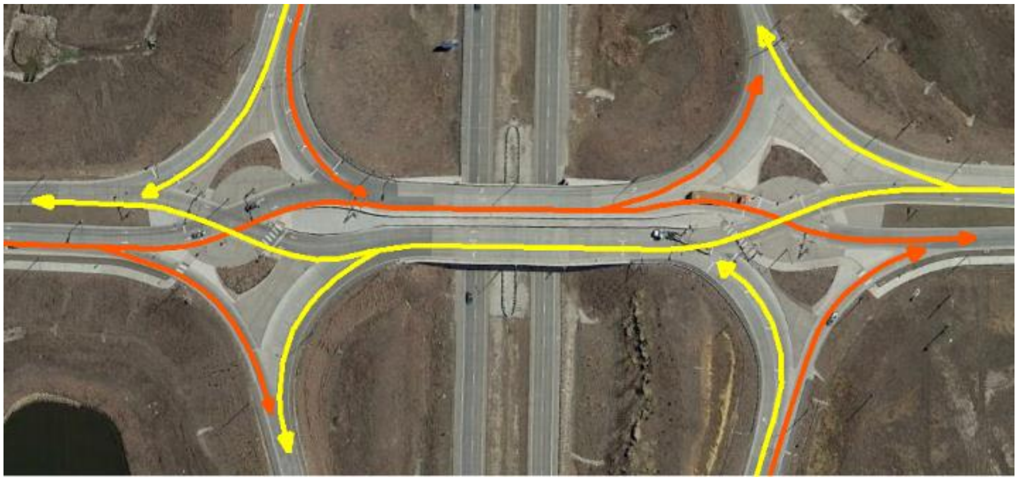

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Figure 1.3 Diverging diamond interchange (DDI) in Grandview, Missouri, Route 150 and Botts Road

The RCUT involves eliminating cross-street left and through movements through the use of median U-turns but allows for through movements on the major street and typically allows for left turns from the major street (Figure 1.4). The RCUT improves traffic safety and operations by eliminating minor movements with conflicts of high severity potential. The RCUT is also known as a superstreet intersection or J-turn intersection.

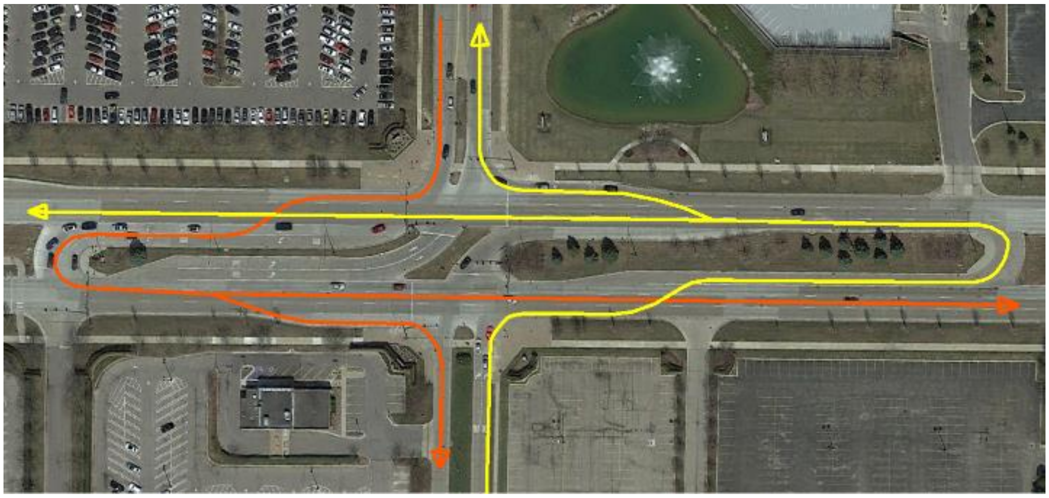

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Figure 1.4 Restricted crossing U-turn (RCUT) intersection in Troy, Michigan, W. Big Beaver Road and Lakeview Drive

The MUT eliminates left turn movements within an intersection and provides median U-turns after the street crossing (Figure 1.5). This configuration is utilized in both rural and urban settings.

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Figure 1.5 Median U-turn (MUT) intersection in Clawson, Michigan, W. 13 Mile Road and Stephenson Highway

The DLT moves left-turn traffic of an intersection to the opposite side of opposing lanes in advance of the intersection (Figure 1.6). This eliminates the left-turn phase at the intersection signal, resulting in more efficient phasing and safer operations.

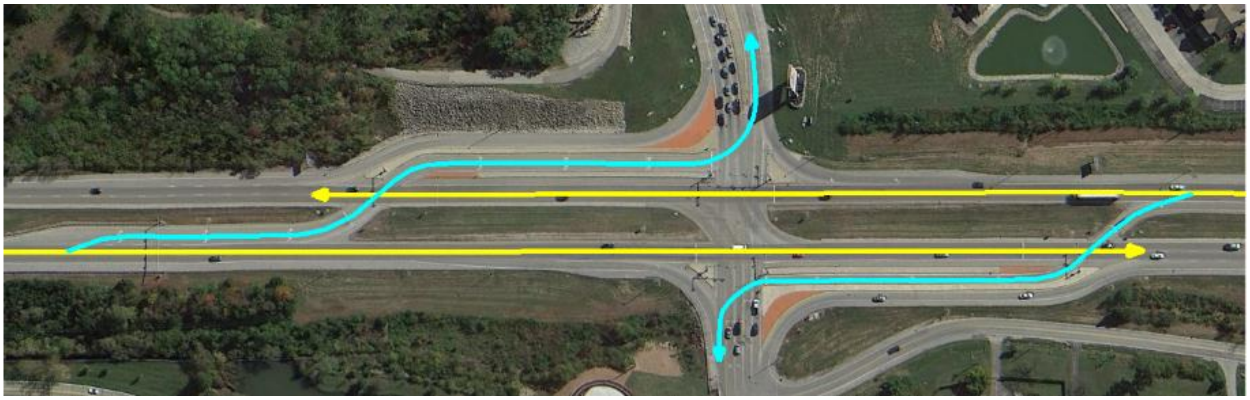

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Figure 1.6 Displaced left turn (DLT) intersection in Fenton, Missouri, Route 30 and Summit Road

Several challenges are faced when implementing these intersections. This research focuses on the challenge of initial construction phasing and maintenance of traffic (MOT) through retrofit construction of these intersections. Because these innovative designs eliminate and re-direct certain traditional traffic movements, the proper phasing and MOT are critical. The MUTCD provides guidelines and typical applications for the MOT through construction projects; however, no specific guidelines are currently in place to aid transportation practitioners in organizing this process for projects with innovative geometric designs. Some construction phasing suggestions will be discussed in the literature review.

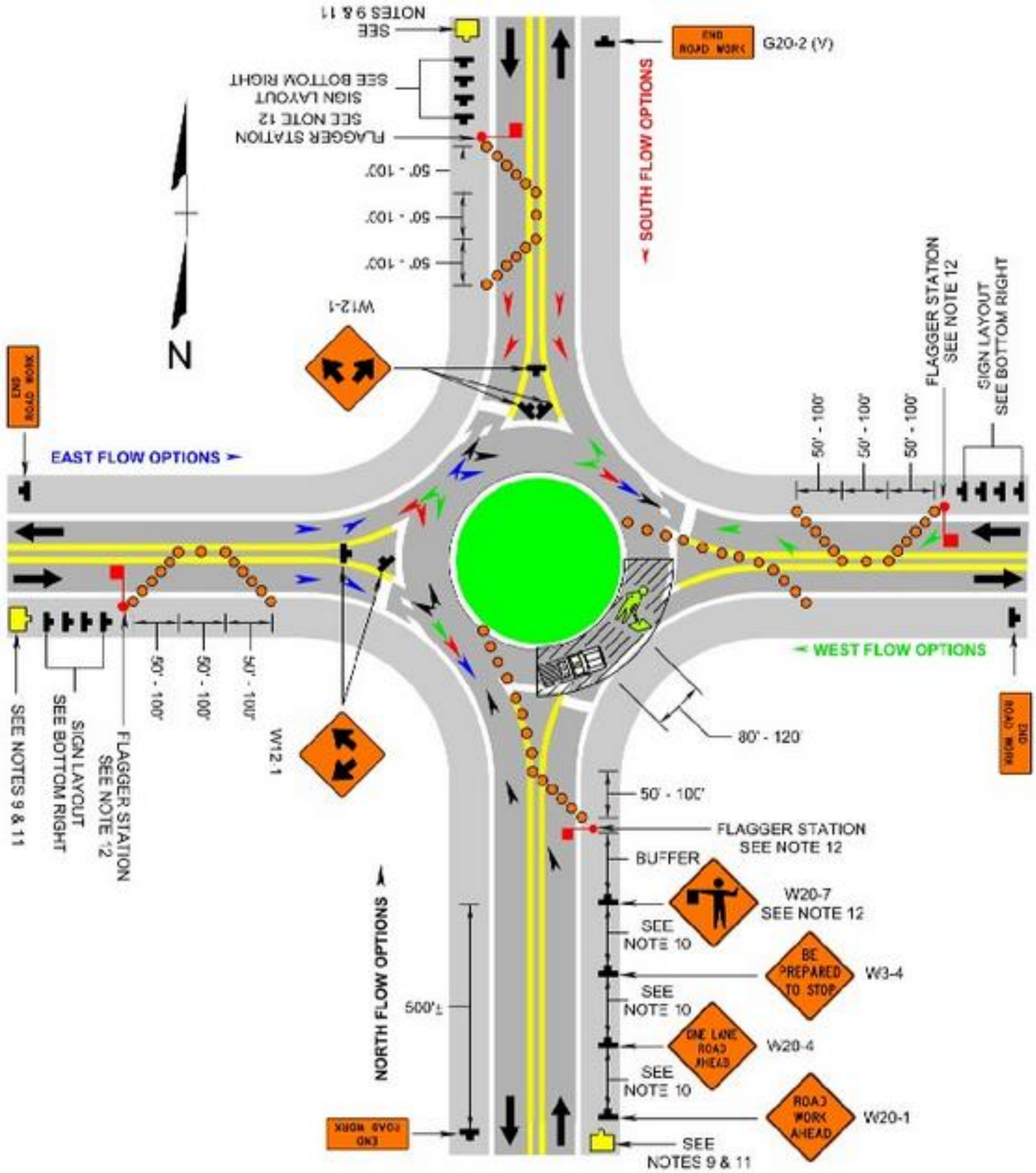
Goals for this report include providing guidance for transportation practitioners in developing MOT plans for both initial construction and maintenance for projects with innovative geometric designs. This involves providing guidance in developing an overall MOT strategy and MOT Phasing Diagrams for deploying traffic control measures such as barriers, delineators, and striping. Guidelines were developed for MOT through a review of literature, survey, interviews with practitioners, and review of plans from innovative geometric design projects. These guidelines are to aid in improving work zone safety through construction projects of innovative geometric designs.

CHAPTER 2. LITERATURE REVIEW

This section provides an overview of construction phasing and MOT practices currently used throughout state agencies and municipalities implementing innovative geometric design intersections.

2.1 Roundabout

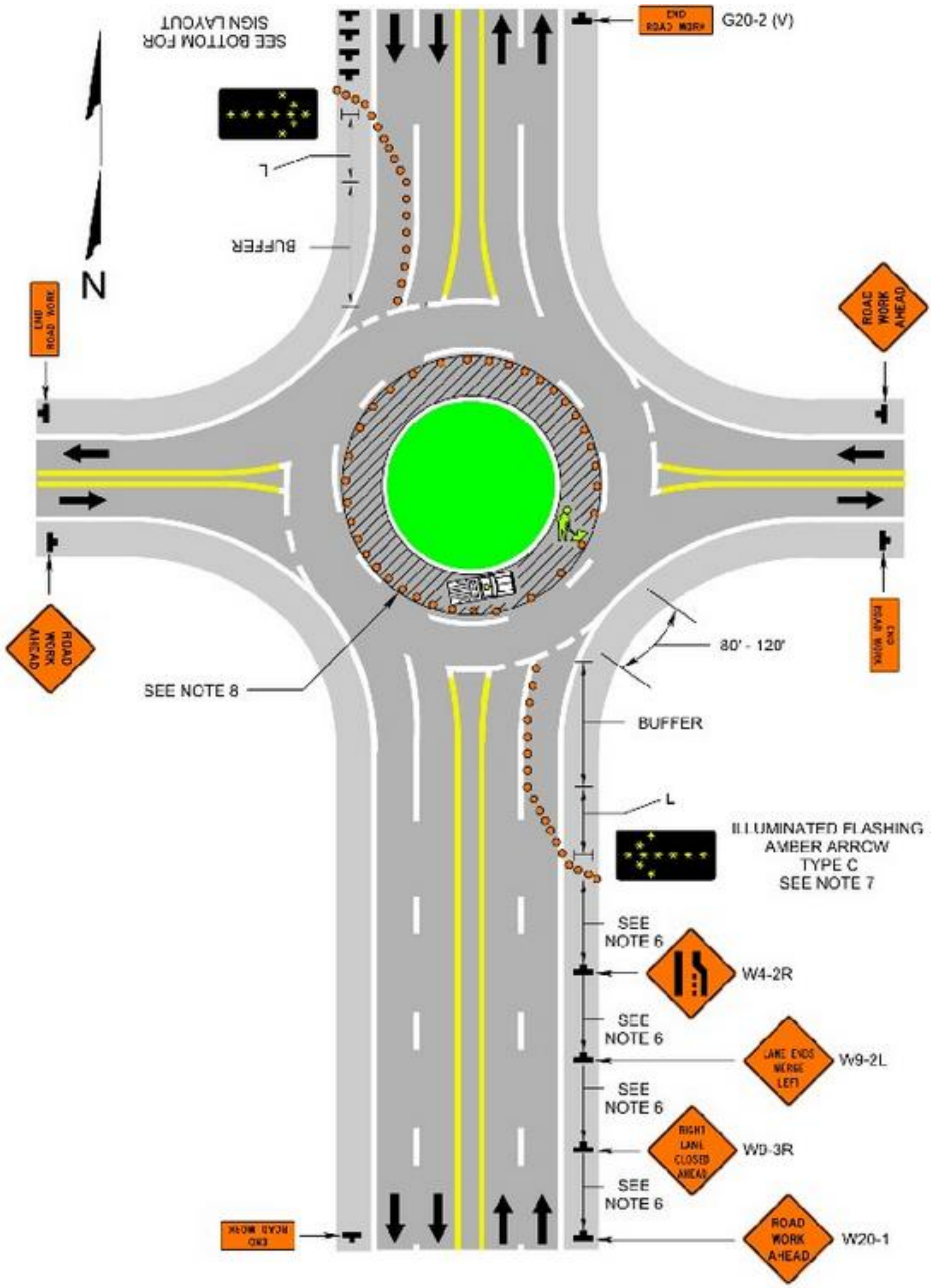
Roundabouts are generally categorized into two groups: single lane and multi-lane. This section presents existing literature relating to both groups of roundabouts. The Virginia DOT Work Area Protection Manual (VDOT 2011) includes operational guidelines for roundabout construction and maintenance projects. Flagging operations may be needed through work zones within single lane roundabouts due to the necessity to close the lane within the single lane roundabout. For this setup, a flagger is placed at each entrance to the roundabout and one entryway is allowed to travel through the roundabout at a time. Figure 2.1.1 shows a typical work zone setup for a single lane roundabout using flagger control. In this sample setup, traffic is directed to travel counter-clockwise, opposite of normal operations.



VDOT 2011

Figure 2.1.1 Standardized setup for single lane roundabout with flagger control

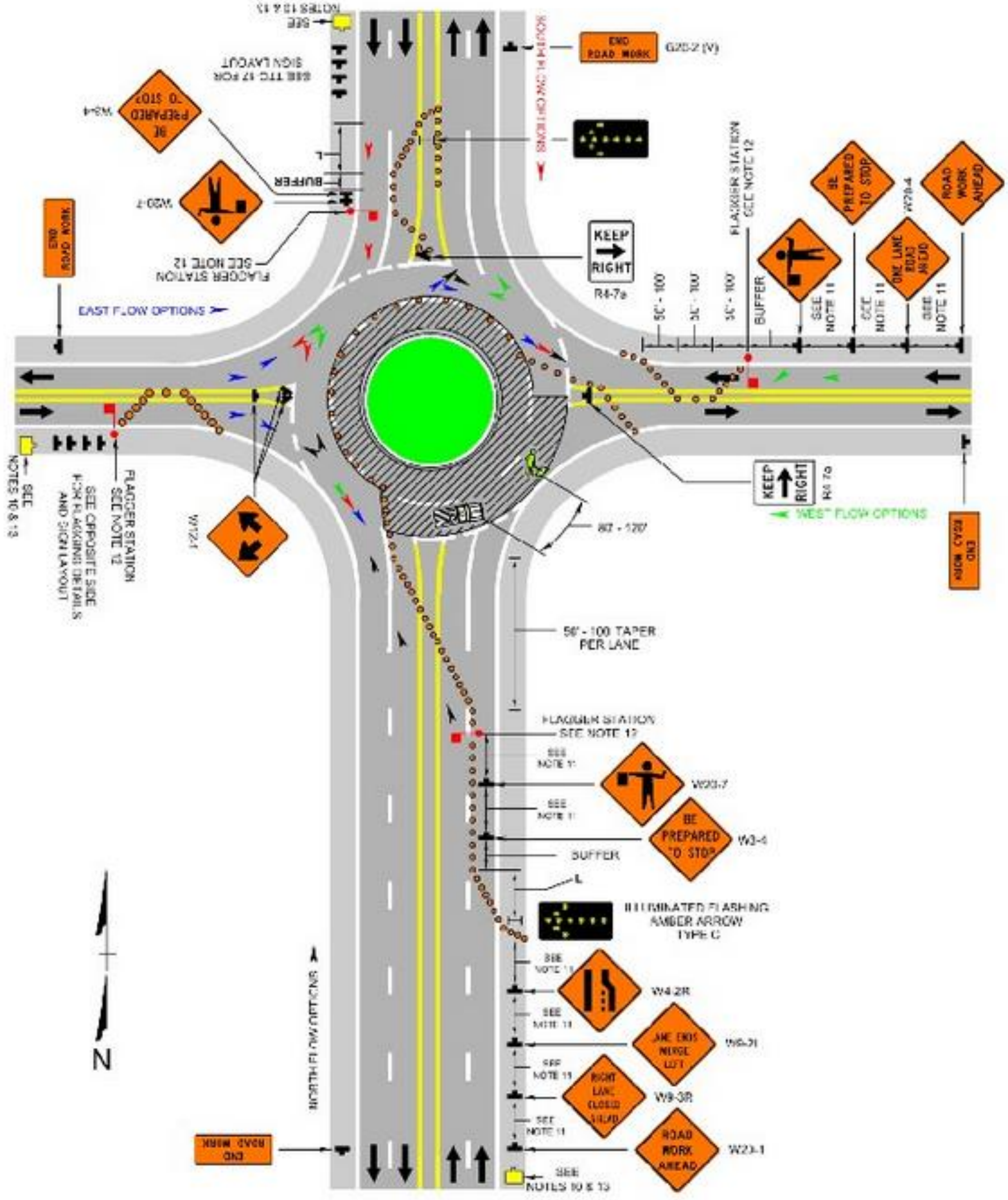
VDOT (2011) states that multi-lane roundabout work zones with a closure of the innermost lane are required to include proper signage and traffic control to ensure easy navigation through the roundabout during construction. Figure 2.1.2 shows a standard work zone organization of this scenario. In this setup, approaching roadways are reduced to one lane of travel in which roundabout operation is similar to a single lane roundabout.



VDOT 2011

Figure 2.1.2 Standardized setup for inner lane closure through multi-lane roundabout

Multi-lane roundabout work zones which result in the closure of the outer lane through quadrant closures call for careful work zone setup and traffic control to ensure travelers can easily traverse through the roundabout during construction as stated by VDOT (2011). Figure 2.1.3 shows a standardized setup of this scenario. This work zone setup requires a flagman operation in which flaggers are stationed at each leg of the roundabout to provide access through the roundabout on a turn basis.



VDOT 2011

Figure 2.1.3 Standardized setup for outer lane closure of multi-lane roundabout

FHWA (2013) recommends various considerations when leaving uncompleted work in a roundabout overnight. These considerations include construction of splitter islands, clearly marking uncompleted portions, adding temporary overhead lighting, and the use of flagging operations at the roundabout.

The Wisconsin Department of Transportation Roundabout Guide (WisDOT 2013) provides guidelines on roundabout MOT considerations. According to this guide, detouring traffic away from roundabout construction is ideal in order to increase safety and reduce congestion throughout the construction period. If detours are not available, then careful consideration must be placed on the construction staging of the roundabout. Typical roundabout construction staging is organized in 6 phases. In Phase I, proposed signing is installed and covered. Phase II involves removing pavement markings that do not conform to intended travel paths. Phase III encompasses construction of outside widening, if needed, while Phase IV involves reconstructing the approaches to the intersection, if applicable. Phase V involves construction of splitter islands and the delineation of the central island. Once these are complete, the installed signage should be uncovered and the intersection operated as a roundabout. In Phase VI, the construction on the central island is completed. If roundabout construction is not completed by nighttime, it is necessary to construct splitter islands before the central island in order to ensure travelers will follow the path of the roundabout. Any section of the roundabout left uncompleted during nighttime hours must be clearly marked, and temporary lighting may need to be deployed to ensure traveler safety.

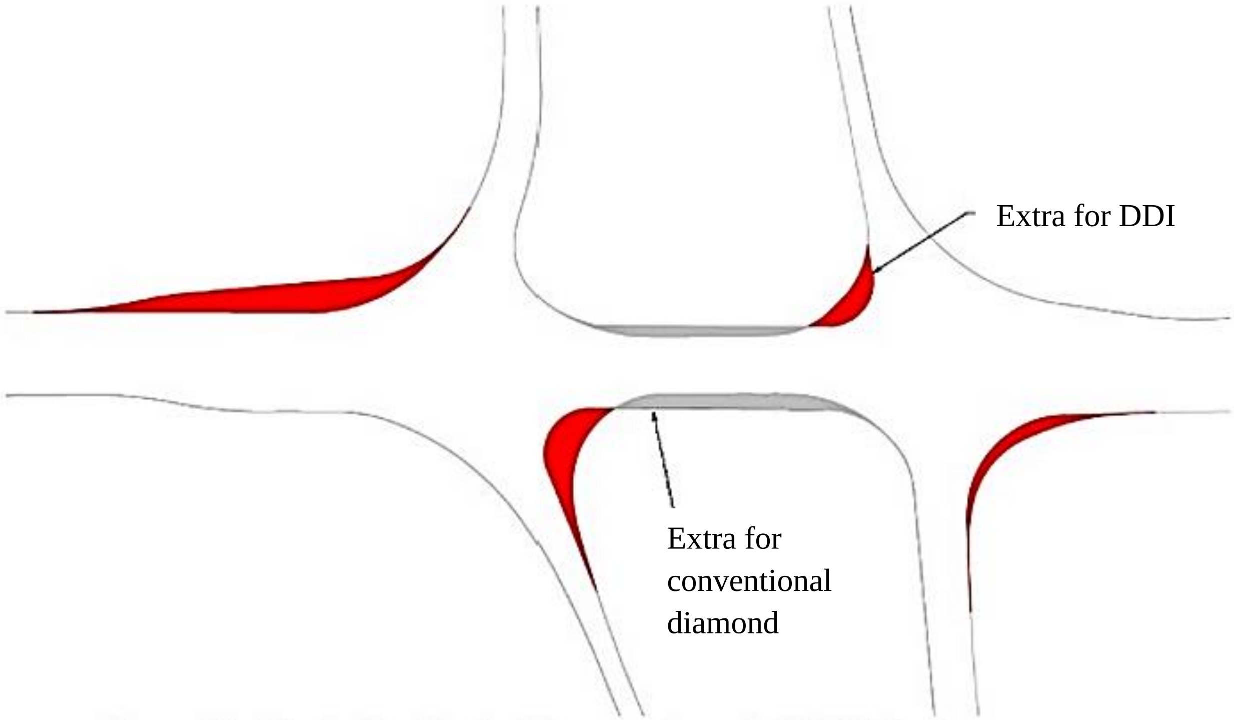
2.2 Single Point Urban Interchange

No existing studies were found pertaining to SPUI initial construction phasing or maintenance project traffic control. Information related to initial construction and maintenance project MOT was obtained through the survey and interview of practitioners.

2.3 Diverging Diamond Interchange

The FHWA Diverging Diamond Informational Guide (Schroeder et al. 2014) provides a thorough guide to aid transportation professionals in examining DDIs. This informational guidebook contains many aspects of the design process which includes but is not limited to policy and planning, safety, operational characteristics, construction and maintenance. The scope of this report focuses only on the construction and maintenance aspects of the DDI.

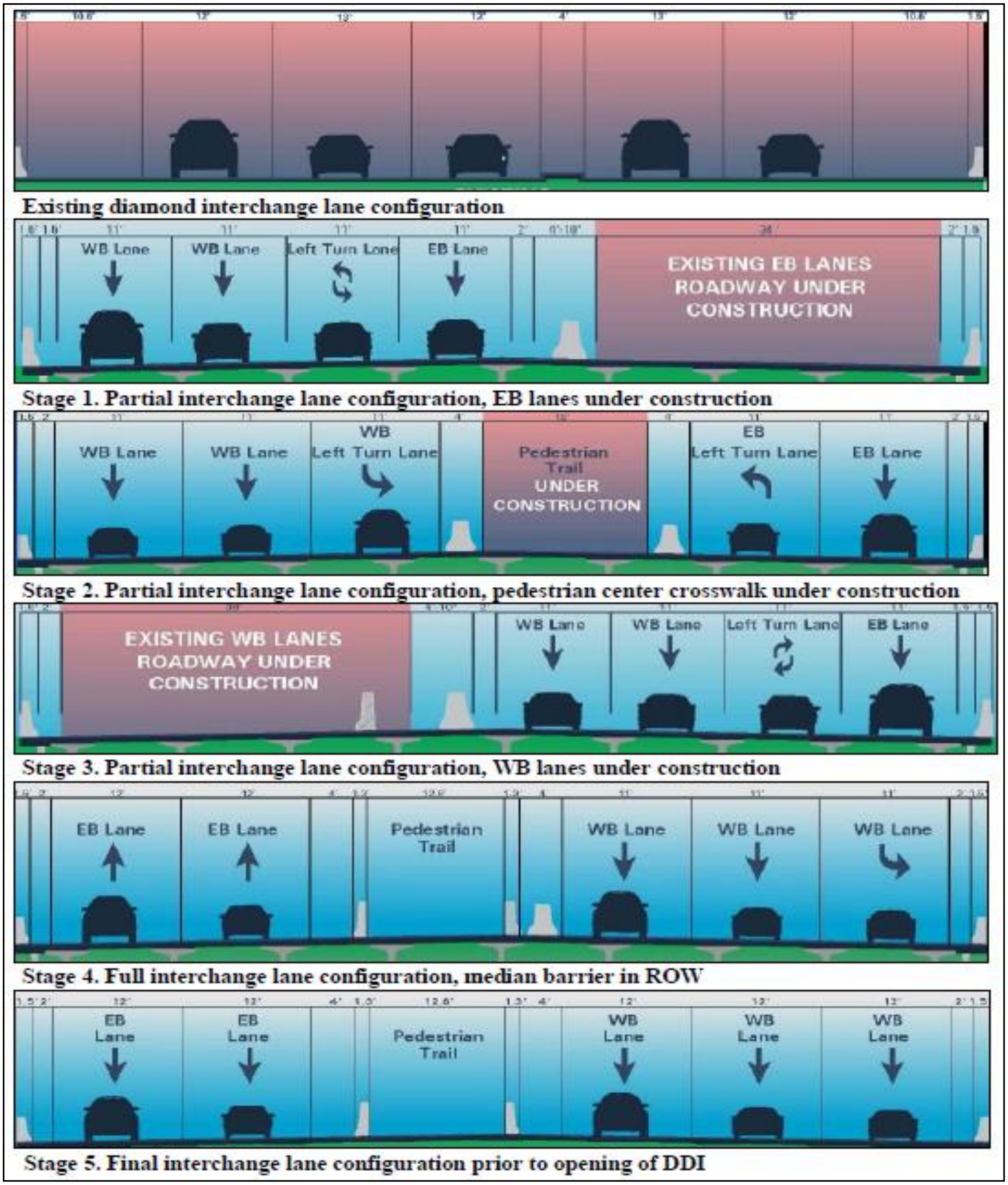
Schroeder et al. (2014) asks a series of questions to consider in determining construction phasing. These questions include whether or not a complete closure is possible, and if existing pavement is to be used through the DDI. The answers to these questions aid in determining whether or not construction phasing is necessary and the manner in which it should be orchestrated. One issue which leads to the need for more specific construction phasing is that the DDI requires a larger footprint at the crossovers than a standard diamond interchange design. Figure 2.3.1 displays a generalized change in footprint from transitioning into a DDI from a conventional interchange (Hughes et al. 2014).



Hughes et al. 2014

Figure 2.3.1 Footprint comparison between a DDI and conventional diamond interchange

This increased footprint leads to a need for construction on one or both sides of the roadway as well as through the turning movements in the process of a retrofitting. However, Hughes et al. (2014) did not provide information relating to construction phasing. Schroeder et al. (2014) provides an example of traffic phasing across a DDI bridge in which no additional cross-section right-of-way is required (Figure 2.3.2). In this example, Stage 1 involves shifting all traffic onto the north side of the roadway in which two westbound lanes, a left turn lane, and the eastbound lane share the allowable roadway. This allows for open construction on all of the eastbound lanes at once. In Stage 2, eastbound traffic is shifted back to the southern side of the roadway while leaving an area in the center for pedestrian path construction. Stage 3 involves shifting westbound lanes onto the newly constructed pavement on the southern portion of the cross-section which allows for the existing westbound lanes to be under construction. In Stage 4, traffic is shifted onto the final DDI configuration while leaving protection barriers at the pedestrian walkway. In Stage 5, the DDI construction phasing is complete and the intersection is fully opened. Schroeder et al. (2014) did not discuss information relating to the construction phasing of the DDI cross-overs.



Schroeder et al. 2014

Figure 2.3.2 Staging of DDI construction from an existing interchange

Schroeder et al. (2014) discussed another method of DDI construction which involves utilizing separate bridges for each direction of travel for the final DDI configuration. This method allows for the possibility for traffic to remain uninterrupted through the existing lanes until the new bridge and portions of the crossovers are complete. Once traffic is shifted, the remaining portions of the final configuration can be constructed (Figure 2.3.3). Through this construction strategy, the existing roadway is unaffected until only the intersection connections are ready to be made, which allows for more uninterrupted traffic movement.

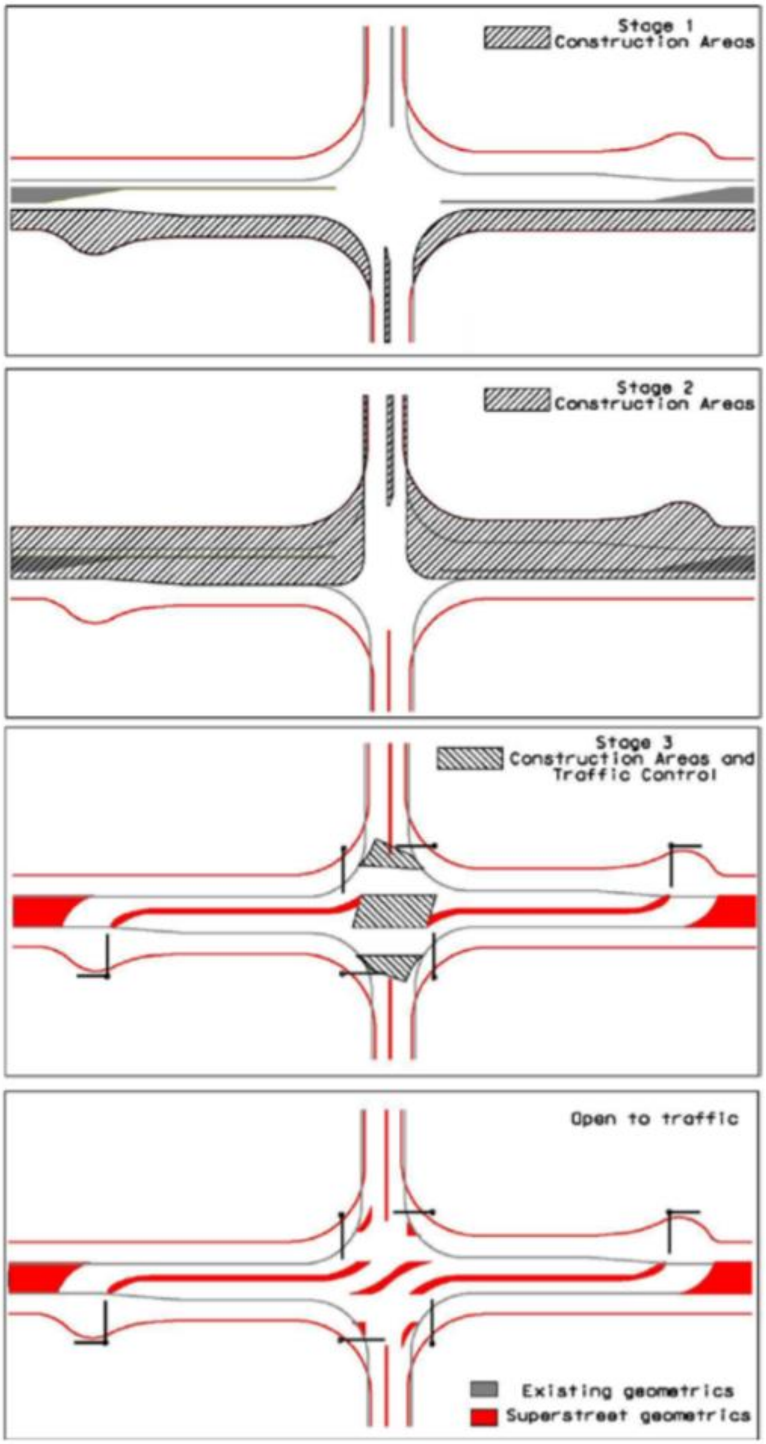
Schroeder et al. 2014

Figure 2.3.3 Construction staging using pre-cast construction methods

Schroeder et al. (2014) as well as other sources include little information on the specifics of MOT through maintenance projects. Schroeder states that DDI maintenance considerations are similar to that of standard interchange forms such as a single temporary lane closure.

2.4 Restricted Crossing U-Turn Intersection

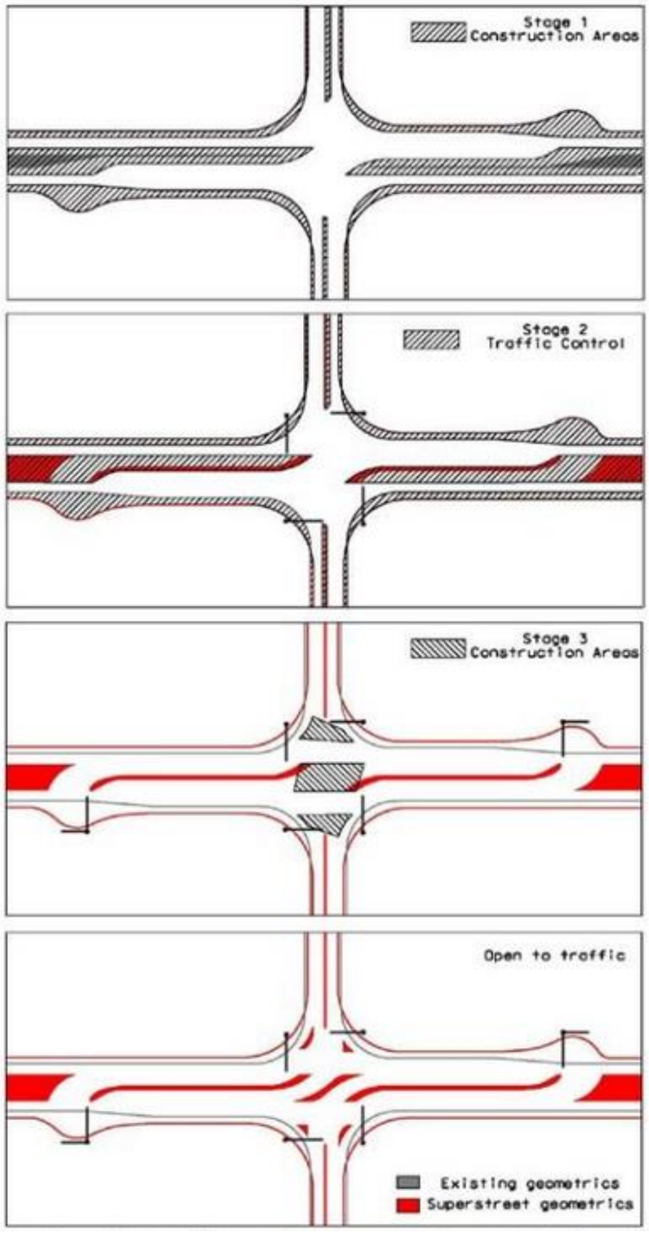
The Alternative Intersections/Interchanges: Informational Report (Hughes et al. 2010) states that construction phasing and MOT generally only becomes an issue in RCUT implementation whenever widening a two-lane road into a divided highway or retrofitting an existing intersection. Figure 2.4.1 shows an example construction phasing scheme for an instance in which RCUT construction involves widening a two-lane roadway. Stage 1 involves construction of lanes to carry one direction of traffic on the new roadway alignment. Stage 2 involves shifting the existing traffic onto the newly constructed lanes and beginning the construction of the opposite lanes as well as U-turns within the medians. In Stage 3, the center of the main intersection is closed in order to allow the construction of center of the intersection. Throughout Phase III, traffic utilizes median U-turn movements. Stage 4 involves shifting traffic onto the permanent RCUT configuration.



Hughes et al. 2010

Figure 2.4.1 Construction phasing for converting a two-lane roadway intersection into a multi-lane RCUT intersection

Hughes et al. (2010) provides an example for of construction phasing, shown in Figure 2.4.2, for the retrofit of an existing multi-lane intersection to a RCUT intersection. In Stage 1, U-turn crossovers and areas of left-turn crossovers that do not overlap with the minor roadway are constructed. Stage 2 involves completing construction of median U-turns and areas outside of the roadway intersection. In Stage 3, all minor street through traffic and main street left-turn traffic is shifted to the median U-turns and the main intersection center is closed. This allows for complete construction of the main intersection center. Stage 4 encompasses shifting all traffic to permanent RCUT configuration.



Hughes et al. 2010

Figure 2.4.2 Construction phasing for retrofitting an existing intersection with a RCUT intersection

2.5 Median U-Turn Intersection

According to Hughes et al. (2010), MOT only becomes an issue in MUT implementation whenever widening a two-lane road into a divided highway or retrofitting an existing intersection. MUT intersections are similar to a traditional intersection except for the median U-turns. An example construction phasing setup involving a roadway widening to form a multiple-lane divided highway, as provided by Hughes et al. (2010), contains three phases. Phase I involves the construction of new lanes to become one direction of travel. In Phase II, traffic is shifted onto newly constructed roadway segments, allowing construction to begin on the opposite direction and on median U-turns. Phase III involves completing the construction of median U-turns and the roadway. Once complete, all traffic is shifted to the final MUT intersection configuration.

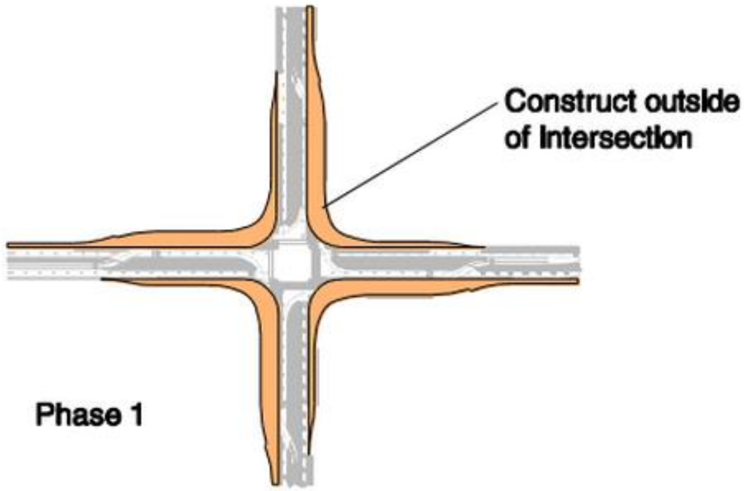
Hughes et al. (2010) provides a sample construction phasing scheme for retrofitting an existing single-lane or multi-lane intersection through three construction phases. Phase I of this example encompasses constructing median U-turns under normal traffic flow. In Phase II, all left-turn traffic is shifted onto median U-turns. Phase II involves completing the conversion from the traditional intersection configuration into the permanent MUT traffic layout. Once all construction is complete, traffic is shifted to the final MUT configuration in Phase III.

2.6 Displaced Left Turn Intersection

The FHWA Displaced Left Turn Informational Guide by Steyn et al. (2014) provides guidelines for both construction phasing and MOT through DLT intersections. Considerations and objectives through implementing a DLT intersection are similar to conventional intersections. Similar to other innovative geometric designs, DLTs can be implemented through retrofitting an existing intersection and often vary in construction and MOT strategies.

Steyn et al. (2014) describes three overall construction strategies for DLT intersections. These strategies include: complete closure, closure of one cross road at a time, and providing full access of all traffic movements throughout construction. Each construction strategy has implications for construction phasing and MOT. Consideration of each construction strategy is to be determined on a case-by-case basis through public meetings and outreach in order to best serve the surrounding area given the context of the surrounding environment. In cases in which either partial or full access should be kept open throughout construction, construction staging must be organized. The use of new pavement for temporary movements through construction is discouraged in order to avoid exposing travelers to new driving scenarios and setups multiple times through the extent of the project.

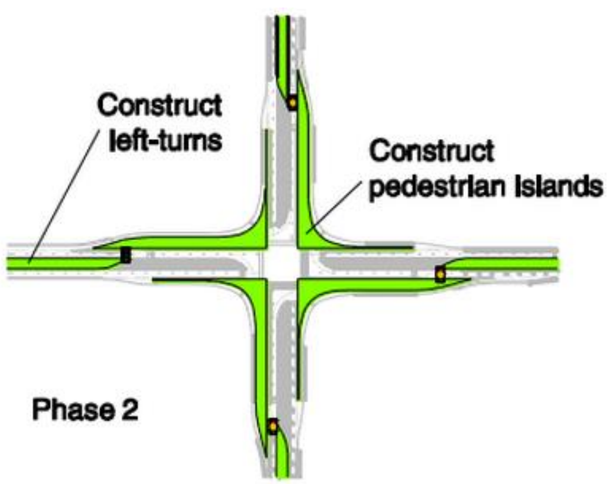
Steyn et al. (2014) includes a general three phase construction approach for the DLT intersection for retrofitting an existing conventional intersection. Figure 2.6.1 shows Phase I of this approach involving construction of outer portions of the DLT intersection. This construction involves constructing right-turn bypass lanes as well as installing a temporary traffic signal at the intersection for the purpose of Phase II operations. Traffic is maintained under existing signal operations at the main intersection throughout Phase I.



Steyn et al. 2014

Figure 2.6.1 Phase I of DLT retrofit construction

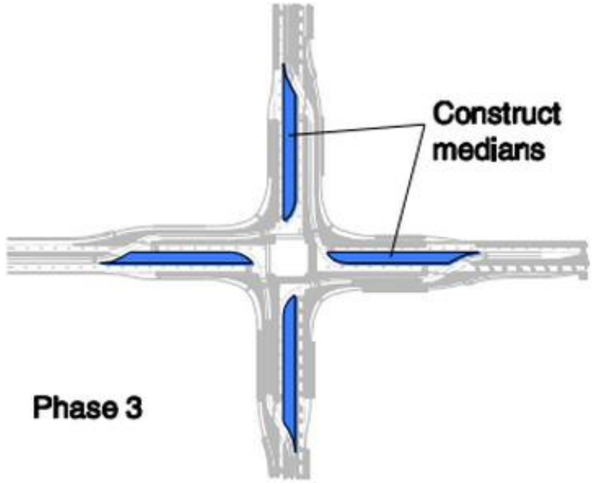
Phase II, as stated in Steyn et al. (2014), involves the construction of major pedestrian islands, new traffic signals at the main intersection, and major street left-turn lanes at the crossover intersections and traffic signals. Right turns should also be diverted onto the newly constructed right-turn bypass lanes while maintaining the other movements. Figure 2.6.2 shows affected areas in Phase II.



Steyn et al. 2014

Figure 2.6.2 Phase II of DLT retrofit construction

Steyn et al. (2014) sets Phase III to involve construction of medians along the minor streets and finalization of the street lighting installation, permanent signing, and pavement markings. Traffic is then to be directed to its final travel pattern. Figure 2.6.3 shows the affected areas in Phase III.



Steyn et al. 2014

Figure 2.6.3 Phase III of DLT retrofit construction

Pertaining to MOT, Steyn et al. (2014) suggests the use of more detailed work zone traffic control. The DLT Informational Guide suggests the use of guide signs prior to implementing the final DLT traffic layout to aid travelers through the new movements. Portable changeable message signs are suggested to aid in notifying travelers of the new intersection configuration.

According to Steyn et al. (2014), maintenance projects are similar to that of conventional intersections with the exception of additional raised median barriers. Maintenance pertaining to the raised median barriers typically requires the temporary closure of one adjacent lane.

CHAPTER 3. METHODOLOGY

This section explains methods used to create construction phasing and MOT Phasing Diagrams for each of the innovative geometric designs. Information obtained through an online survey of practitioners, in-person and telephone interviews of practitioners, and review of sample plans are discussed in this section. Each aspect serves as a source of information along with the literature review to determine best practices as well as factors to consider when developing MOT plans for innovative geometric designs.

3.1 Survey

An online survey of practitioners was conducted in order to assess current practices pertaining to temporary traffic control at innovative geometric design intersection work zones. The temporary traffic control practices for innovative geometric designs survey was created using an online survey creation website and distributed to practitioners throughout the United States including representatives from state departments of transportation, cities, counties, and private consultants. Contact information of practitioners originated from agencies such as MoDOT and FHWA. The survey was also sent to the listserv of the Transportation Research Board (TRB) Roundabout Committee to allow committee members and colleagues to participate. This survey consisted of 16 questions, including multiple-choice and fill-in answers. The multiple-choice questions involved asking the number of intersections for which the respondent's agency is responsible for through a scale of 0, 1 to 5, 6 to 10, and greater than 10. Respondents were asked about which methods have been utilized and were given choices of complete closure, phased construction with partial closure, construct temporary bypass, temporary traffic signal, and others. Respondents were also asked how frequently specific methods are utilized through a scale of rarely, sometimes, almost always, and always. Questions asking for a description provided further insight to practitioner experiences with each method and intersection type. This online survey was open for 5 weeks from January 5th to March 10th 2015.

The survey concluded by asking if the respondent would be willing to participate in a follow up interview and send project MOT plans for use as examples in constructing MOT Phasing Diagrams. The entire survey as it appeared on the website is included in Appendix C.

3.2 Interviews of Practitioners

Survey respondents were asked for the opportunity to further share experiences about developing MOTs via phone interviews. Survey respondents that wanted to take part in the interview process as well additional contacts collected from FHWA and other sources were asked to provide insight on MOT for innovative geometric designs. The contents of these phone interviews included lessons learned, factors considered, and recommendations for designing MOT Phasing Diagrams. Responses and recommendations from the interviews of practitioners facilitated the process of development of MOT Phasing Diagrams for each innovative design.

3.3 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 innovative design. 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 innovative design and what factors led to the chosen MOT and construction phasing method.

3.4 MOT Phasing Diagrams

MOT Phasing Diagrams were produced for each innovative design, utilizing information compiled from the literature review, survey of practitioners, interviews of practitioners, and review of sample plans provided. Interviews of practitioners comprised of more detailed discussions relating to MOT through innovative geometric designs. These interviews provided information on lessons learned, special considerations, and challenges faced through MOT. Interviews of practitioners also provide more knowledge to what factors should be considered and their effects on MOT. Recommendations and aspects applied to the MOT Phasing Diagrams are further discussed in the results section of this report. Collection of project plans to serve as examples for MOT through innovative geometric designs were vital in determining current MOT practices through these designs. Project plans received and methods used relating to MOT and construction phasing are further described in the results section of this report. Various factors and considerations to be considered through the MOT Phasing Diagrams are further explored through the results section. The MOT Phasing Diagrams show each stage of construction for the roundabout, SPUI, DDI, RCUT, MUT, and DLT innovative designs.

CHAPTER 4. RESULTS

This section presents the results obtained through the survey of practitioners, key findings from the interviews of practitioners, and sample project plans. Findings were applied to develop the MOT Phasing Diagrams sheets through initial construction of each innovative geometric design intersection which are presented at the end of this section.

4.1 Survey Results

The survey was completed by 48 practitioners across the United States from various state departments of transportation, cities, counties, consultants, and other agencies. Figure 4.1.1 shows the geographical distribution of participants throughout the country.

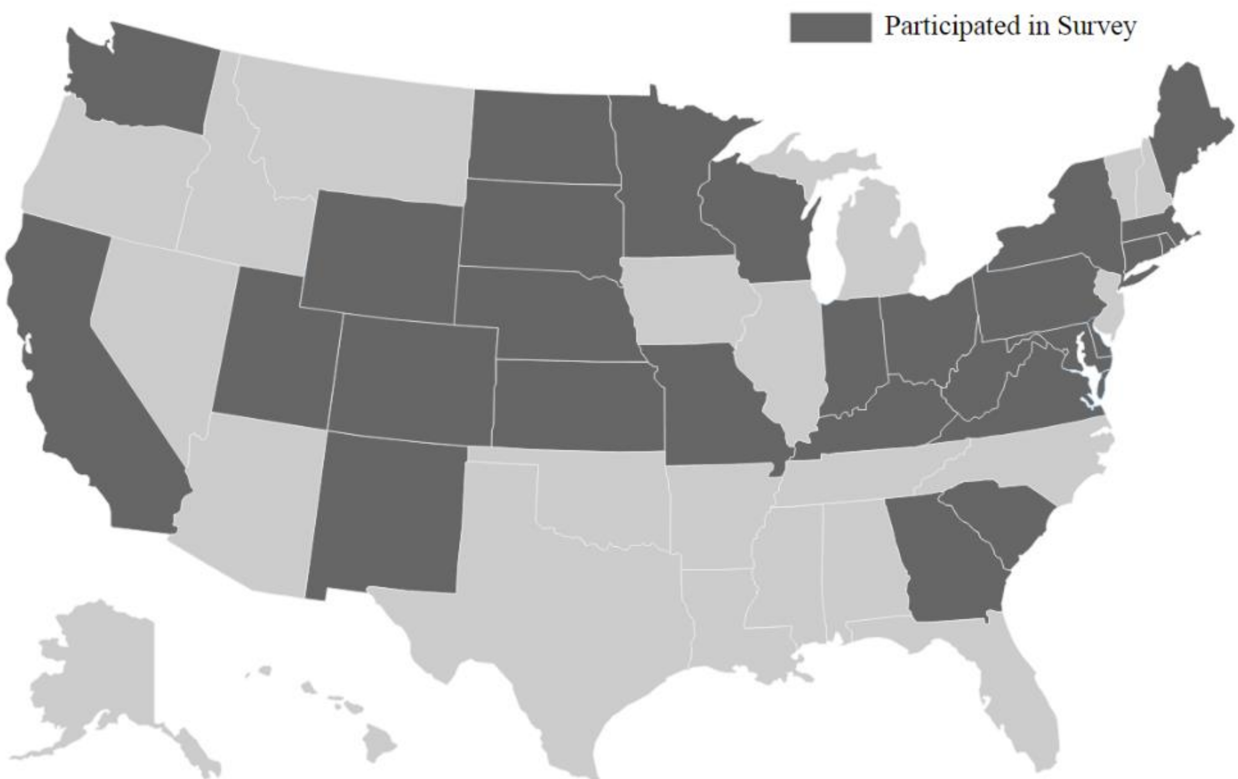


Figure 4.1.1 Distribution of survey participants by state

Table 4.1.1 shows the distribution between each agency type represented through survey respondents. A majority of the respondents represented various state DOTs at 65%. The smallest percentage of respondents was from within various cities at 4%. Consultants represented 19% of the respondents while various counties were represented by 6% of the respondents.

Table 4.1.1 Distribution of agencies represented by survey participants

What type of agency do you represent?		
Answer Options	**Response (percent)**	**Response Count**
State DOT	65%	31
City	4%	2
County	6%	3
Consultant	19%	9
Other	6%	3
answered question		48
skipped question		0

Each respondent was asked about initial construction and maintenance operations through each of the innovative geometric design intersections. These questions asked for the total number of each intersection type the respondent's agency is responsible for, what type of method is preferred through initial construction and maintenance projects, and how frequently the preferred method type is utilized for both initial construction and maintenance projects. Tables 4.1.2 through 4.1.4 show the results of all survey respondents' answers relating to initial construction.

Table 4.1.2 Survey respondent answers regarding experience with innovative designs

Approximately how many of the following designs does your agency operate in total?					
Answer Options	**0**	**1-5**	**6-10**	**>10**	**Response Count**
Roundabout	7	11	10	20	48
SPUI	20	12	8	3	43
DDI	30	12	2	1	45
RCUT	24	16	0	2	42
MUT	28	10	3	1	42
DLT	33	7	0	2	42
answered question					48
skipped question					0

Table 4.1.3 Survey respondent answers regarding predominant MOT methods used for initial construction

What is the predominant method used by your agency during initial construction for each intersection type?							
Answer Options	**Complete Closure**	**Phased Construction with Partial Closures**	**Construct Temporary Bypass**	**Temporary Traffic Signal**	**Other**	**N/A**	**Response Count**
Roundabout	8	38	1	2	1	4	46
SPUI	1	22	1	5	0	17	41
DDI	3	14	0	2	0	23	40
RCUT	1	16	0	1	0	23	39
MUT	1	13	0	1	0	25	39
DLT	2	8	0	1	0	30	40
If "Other" Please Describe							2
answered question							47
skipped question							1

Table 4.1.4 Survey respondent answers regarding frequency of MOT methods used for initial construction

How frequently does your agency use each method listed in Question 4 for initial construction?						
Answer Options	**Always**	**Almost Always**	**Sometimes**	**Rarely**	**N/A**	**Response Count**
Roundabout	8	28	6	1	5	47
SPUI	5	16	2	1	19	43
DDI	3	10	2	0	26	41
RCUT	1	15	0	1	24	41
MUT	1	13	0	0	27	41
DLT	2	7	0	0	32	41
answered question						47
skipped question						1

Survey participants were asked what methods are most widely used throughout the initial construction of each intersection. Phased construction with partial closures proved to be the most widely utilized method among every intersection type investigated. Each listed selection of initial construction methods was selected at least once from various agencies and one respondent selected the "other" option. This respondent stated that utilizing temporary truck detours was another method utilized through the initial construction of an innovative geometric design. When asked about the frequency at which the most prevalent initial construction method was used, 74% of responses, when excluding N/A, were observed to be “Almost Always” while only 17% were found to be in the “Always” category when excluding N/A responses. These results reinforce the idea that there is no one-size-fits-all approach to initial construction for innovative geometric designs and that a case by case approach should be used.

Roundabouts were found to be very common among survey respondents. A total of 20 respondent agencies were responsible for more than 10 roundabouts. Complete closures were found to be utilized more frequently for roundabouts than other innovative designs. This could be due to the frequent need for additional right-of-way when converting from a conventional intersection, the change in traffic movement pattern, the construction of the center island and inscribed circle, and the affected area of existing pavement through roundabout construction. MUT and DLT intersection types were found to be the least common among the intersections studied among the survey respondents. SPUIs were found to be the second most common innovative design represented. A temporary signal was utilized more frequently for SPUIs than other innovative designs. This could be due to a need to relocate the intersection through the construction process. Only one survey respondent agency was responsible for more than 10 MUTs and two survey respondent agencies were responsible for more than 10 DLT intersections. These results show a dispersed number for each intersection type without any intersection type being unrepresented.

Survey participants were also asked about the number of maintenance projects performed for each intersection type, most prevalent method used through maintenance projects, and how frequently the most prevalent method was utilized (Tables 4.1.5 through 4.1.7).

Table 4.1.5 Survey respondent answers regarding experience with maintenance projects for innovative designs

For how many designs listed in Question 2 has your agency performed maintenance projects (such as resurfacing, re-striping, etc.)?					
Answer Options	**0**	**1-5**	**6-10**	**>10**	**Response Count**
Roundabout	19	19	4	5	47
SPUI	29	9	3	1	42
DDI	36	3	1	0	40
RCUT	31	9	0	0	40
MUT	32	6	2	0	40
DLT	38	3	0	0	41
answered question					47
skipped question					1

Table 4.1.6 Survey respondent answers regarding predominant MOT methods used for maintenance projects

What is the predominant method used by your agency during maintenance projects for each intersection type?							
Answer Options	**Complete Closure**	**Phased Construction with Partial Closures**	**Construct Temporary Bypass**	**Temporary Traffic Signal**	**Other**	**N/A**	**Response Count**
Roundabout	2	25	0	0	4	15	44
SPUI	0	15	0	0	1	25	41
DDI	1	10	0	0	1	30	41
RCUT	0	13	0	0	1	26	40
MUT	0	8	0	0	3	29	40
DLT	0	6	0	0	0	33	39
If “Other” Please Describe							5
answered question							44
skipped question							4

Table 4.1.7 Survey respondent answers regarding frequency of MOT methods used for maintenance projects

How frequently does your agency use each method mentioned in Question 6 for maintenance projects?						
Answer Options	**Always**	**Almost Always**	**Sometimes**	**Rarely**	**N/A**	**Response Count**
Roundabout	5	25	2	0	14	45
SPUI	2	13	1	0	26	42
DDI	3	7	1	0	30	41
RCUT	1	9	2	1	28	41
MUT	2	8	1	0	30	41
DLT	1	4	1	0	34	40
answered question						45
skipped question						3

Maintenance projects were observed to be less prevalent than initial construction projects. The reason is because agencies have less experience with maintenance projects than initial construction projects, since these designs are relatively new. However, each intersection type was found to have multiple respondents with experience in maintenance projects for each innovative geometric design studied. There is less variation in the method used for maintenance projects than for initial construction. This could be due to the fact that maintenance projects have less of an impact on the network. Similar to initial construction, roundabouts were observed to be the most common innovative geometric design experiencing maintenance projects. DLT intersections were found to be the least common in only having three respondents having one to five DLT intersections each. Survey participants were also asked what method is utilized most for maintenance projects in innovative geometric designs. Phased construction with partial closures was the most common method for maintenance projects, having 89% of the responses when excluding N/A responses. Phased construction with partial closure was found to be the only method “most frequently” utilized in DLT intersections. Complete closures were found to be utilized “most frequently” for some survey respondents in DDIs and roundabouts. Complete closures represented 9% of the DDI respondents and 7% of the roundabout responses when excluding N/A responses. None of the other intersection types were found to have an agency utilize complete closures “most frequently”. The use of temporary bypasses and temporary traffic signals were found not to be the most predominant method used in any intersection type. Responses of “Other” accounted for 11% of the responses through all intersection types when N/A responses were excluded and were observed through each intersection type except for the DLT intersection. These responses were stated by the survey participants to be temporary truck detours, temporary lane closure by flagman control, and moving operations. When survey participants were asked on the frequency in which the predominant method was used through maintenance projects, 75% of the responses were “Almost Always” while 16% of the responses were “Always” when excluding N/A responses. This result supports the notion, similar to initial construction, that there is no one-size-fits-all method for maintenance operations through innovative geometric design intersections. This shows that MOT Phasing Diagrams should remain flexible for adjustments to fit a project scenario.

Survey participants were also asked how MOT plans were developed. Questions included what resources were used and what factors were considered when developing MOT plans. Table 4.1.8 shows the results of these two questions.

Table 4.1.8 Survey respondent answers pertaining to resources and factors utilized

What resources did you use to decide on the maintenance of traffic plans for your facilities?` Check all that apply.		
Answer Options	**Response Percent**	**Response Count**
MUTCD	91%	41
State Design Manual	73%	33
Experience/Knowledge	93%	42
Other (please specify)	9%	4
answered question		45
skipped question		3
What factors did you take into consideration when determining the maintenance of traffic plans for your facilities? Check all that apply.		
Traffic Counts	94%	43
Operating Speed	78%	36
% Trucks	67%	31
Availability of Alternate Routes	94%	43
Land Use Access	54%	25
Duration of Construction	89%	41
Rural/Urban	52%	24
Ped./Bike/ADA	57%	26
Other (please specify)	7%	3
answered question		46
skipped question		2

The MUTCD and previous experience were observed to be the most highly utilized resource in having over 90% response rate for each. State design manuals were also found to be widely used in developing MOT plans through these intersection types. The responses classified as “Other” were stated to be standard plans and design standards of other states. Respondents indicated that they considered a variety of factors when developing MOT plans for innovative geometric designs. Traffic counts and availability of alternate routes were found to be the most widely used factors at an over 90% selection rate. Land use access, rural versus urban, and pedestrian, bike, and Americans with Disabilities Act (ADA) were found to be the least influential factors in having a near 50% response rate. The “Other” selections accounted for 7% selection among survey participants and were stated to include pavement type and day versus night work. These results indicate that traffic counts and the availability of alternative routes were the factors that most agencies consider while other factors depend on characteristics of a project site. Other characteristics taken into consideration could include proximity to local police or fire departments, an area hospital, or even a major shopping center.

Survey participants were asked if experience showed whether a certain techniques for MOT performed less effectively than others. Respondents were given selection of complete closure, phased construction with partial closures, temporary bypass, temporary traffic signal, and other. Table 4.1.9 shows the results gathered from this question.

Table 4.1.9 Survey respondent answers regarding less effective techniques

Did you find that certain techniques for maintenance of traffic were less effective than others?		
Answer Options	**Response Percent**	**Response Count**
Complete Closure	19%	6
Phased Construction with Partial Closures	10%	3
Construct Temporary Bypass	48%	15
Temporary Traffic Signal	26%	8
Other	19%	6
Please describe		22
answered question		31
skipped question		17

The use of a temporary bypass generated the most concerns from respondents as it was selected as ineffective by 48% of respondents. This could be due to the requirement of additional right-of-way that a temporary bypass frequently requires and the resulting costs. Some agencies found the use of a temporary bypass to be cost effective when it could be utilized for future use, such as an additional roadway, as well as when considering ease of construction. Phased construction with partial closures had the lowest selection rate at 10% while the “Other” selection was used by 19% of the respondents. The methods contained in the “Other” selection were stated to include placing truck traffic on local streets and utilizing long detours. Key findings determined through the survey are as follows:

“Phased Construction with Partial Closures” was selected as an initial construction method by 90% of the respondents.

1. “Complete Closure” was selected as an initial construction method by 13% of the respondents.
2. No experience was selected for maintenance projects by 74% of respondents. This is because many of these types of facilities are new and have not required maintenance.
3. “Phased Construction with Partial Closures” was selected as the maintenance project method by 89% of respondents.
4. “Complete Closure” was selected as maintenance project method by 3% of respondents.
5. “Experience/Knowledge” and the “MUTCD” were the selected as used resources by over 90% of respondents. “State Design Manual” was selected as a resource used by 73% of respondents.

6. There are many important factors to consider when developing MOT plans. “Traffic Counts” and “Availability of Alternative Routes” were selected as factors considered by 94% of respondents. “Operating Speed” and “Duration of Construction” were selected by 78% and 89% of the respondents respectively. “% Trucks” was selected by 67% of respondents while “Land Use Access”, “Ped./Bike/ADA”, and “Rural/Urban” were selected by approximately 50% of respondents.
7. “Construct Temporary Bypass” was selected as a less effective technique by 48% of respondents and “Temporary Traffic Signal” was selected as less effective by 26% of respondents. “Complete Closure” was selected as less effective by 19% of respondents and “Phased Construction with Partial Closures” was selected as less effective by 10% of respondents.
8. Temporary bypasses are generally not suitable for MOT due to right-of-way and cost constraints
9. There is no one-size-fits-all method for constructing these types of facilities.

4.2 Interviews

Survey respondents as well as additional contacts generated from the survey process were asked to participate in an interview to share experiences pertaining to temporary traffic control through initial construction and maintenance projects for innovative geometric designs. Individuals from various DOTs, municipalities and consultant agencies participated in these interviews. Figure 4.2.1 shows the distribution of participants throughout the country.

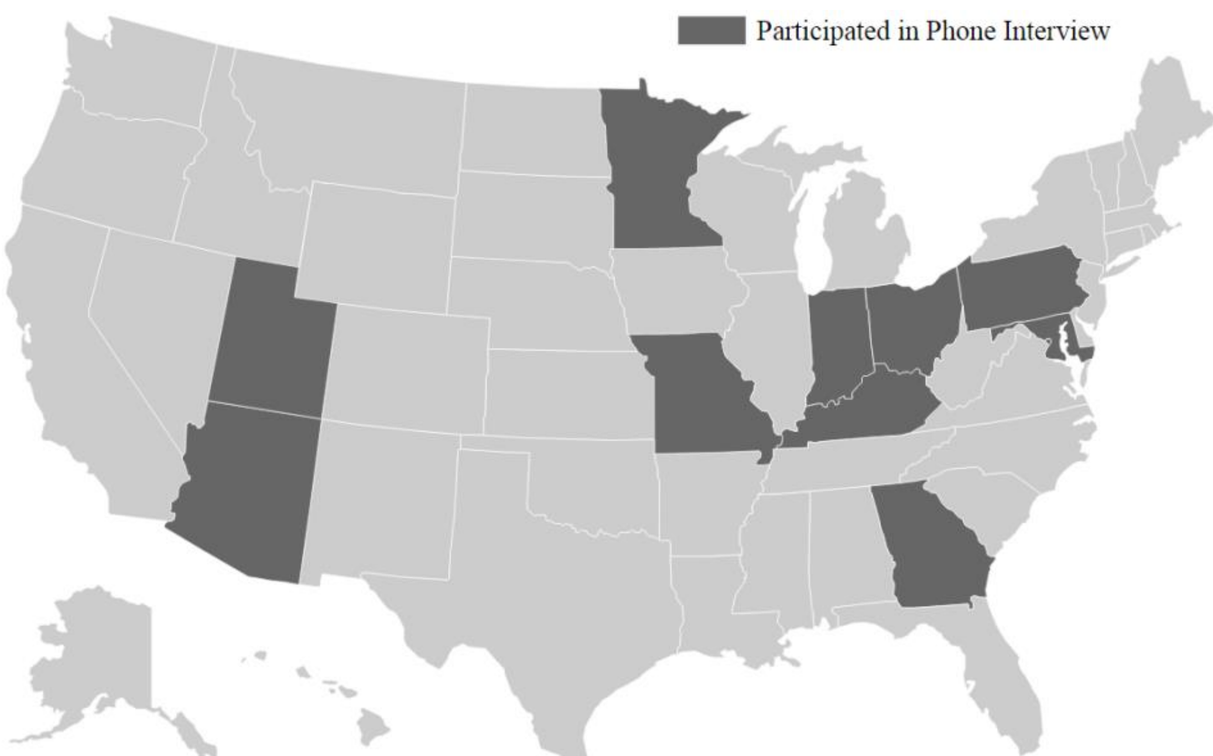


Figure 4.2.1 Distribution of interview participants by state

Table 4.2.1 shows the distribution between each agency type represented through interview participants. A majority of the respondents represented various state DOTs at 60%. The smallest percentage of participants was from cities and counties at 10% each. Consultants represented 20% of the phone interview participants.

Table 4.2.1 Distribution of agencies represented by phone interviews

Agency Type	Percentage	Interview Count
State DOT	60%	12
Consultant	20%	4
County	10%	2
City	10%	2
Total		**20**

Interview participants were asked to share experiences pertaining to construction and maintenance of innovative geometric designs. This included providing any recommendations that may benefit transportation practitioners to implement these designs. Key findings of practitioner 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 experienced with the final traffic configuration due to 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 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 and MUT to accommodate left turns during the construction of SPUIs in Utah 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, providing median crossover points near the roundabout could prove to be useful by significantly shortening the flagging zone and thus allowing for more efficient flagging operations. .
6. For any innovative geometric design, doubling the number of channelizers used through the extents of the work zone can prove valuable in preventing drivers from weaving.
7. Sequential lighting can provide valuable aid to drivers through the work zone setup for both daylight and nighttime periods.
8. Final conversion of some of these innovative designs, such as DDI, should be done under full closure which should occur when traffic counts are lower, such as weekend periods. The conversion could occur either through the middle or at the end of the project.

9. Use of innovative contracting techniques such as design build could be considered to allow contractors to determine methods used.

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.

4.3 Project Plan Examples

Project plan examples provide more information on the details included in maintenance of traffic plans for each innovative design such as construction phasing and work zone organization. Several practitioners sent project plans for projects involving innovative geometric designs. The example projects and analysis of these plans are detailed in this section. In total, thirteen agencies provided project plans or information as examples or standard guidelines relating to MOT and construction phasing. Table 4.3.1 shows the project plans and other information received from state DOTs, cities, and counties.

Table 4.3.1 List of provided project plans by innovative design type

Intersection Type	Received Plans	Project	Method Used
Roundabout	Columbia, MO	Clark Lane	Phased Construction with Temporary Bypass
		Clark Lane Phase II	Phased Construction with Temporary Bypass
		Mexico Gravel Rd.	Phased Construction with Partial Closure
		St. Charles Rd. and Lake of the Woods Rd.	Complete Closure
		Vandiver Dr.	Phased Construction
	KYTC	Mt. Zion Rd. (Florence)	Phased Construction with Temporary Bypass
		Johns Hill Rd. and University Dr.	Phased Construction with Partial Closures
	MnDOT	Highway 22 and Madison Ave. and Highway 22 and Adams St. (Mankato)	Full Closure
	MoDOT	MO 109 and MO 100, MO 109 and Pond Grover Loop Rd. (St. Louis County)	Phased Construction with Partial Closure
		MO 171 and MO 43 (Jasper County)	Phased Construction with Partial Closure
	MoDOT	Route 63 and Route M (Ashland)	Phased Construction with Temporary Closures
	ODOT	SR 235 and SR 41 (Clark County)	Phased Construction with Partial Closures
	Omni Means	Shasta View Dr. and Old Arturas Rd. (Redding, CA)	Phased Construction
		I-5 and Deschutes Rd. (Anderson, CA)	Phased Construction with Partial Closures
	Washington County MN	CR 18 and 4th St.	Phased Construction with Partial Closures
		C.S.A.H. 15 and T.H. 96	Phased Construction with Temporary Bypass
		C.S.A.H. 19 and C.S.A.H. 20/22	Phased Construction with Temporary Bypass
		Roundabout Staging Typical	Phased Construction with Partial Closures
	PennDOT	Temporary Traffic Control Guidelines	Phased Construction with Flagging Operation
SPUI	KYTC	KY 237 and KY 18 (Boone County)	Phased Construction with Temporary Bypass
	MnDOT	I-494 and Lyndale (Richfield)	Phased Construction with Partial Closures
	ODOT	I-75 and SR 63 (Monroe)	Phased Construction
	UDOT	SR-154 (Bangerter Hwy.) and 7800S (West Jordan)	Phased Construction with Temporary MUT
DDI	Crawford, Murphy, and Tilly	I-65 and Worthsville Rd. (Worthsville, IN)	Phased Construction with Partial Closures
	Crawford, Murphy, and Tilly	I-65 and Worthsville Rd. (Worthsville, IN)	Full Closure
	MoDOT	I-44 and Rangeline Rd. (Joplin)	Phased Construction with Partial Closures
		US 60/160 (James River Freeway) and MO 13 (Kansas Expressway) (Springfield)	Phased Construction with Partial Closures
		US 65 and Battlefield Rd. (Springfield)	Phased Construction with Partial Closures
	NMDOT	I-25 and NM 14 (Santa Fe)	Phased Construction with Partial Closures

Intersection Type	Received Plans	Project	Method Used
RCUT	MnDOT	US 52 and CR 66 (Vermillion)	Phased Construction with Partial Closures
	ODOT	Route 4B (Hamilton)	Phased Construction with Partial Closures
	MoDOT	US 63 and Route M (Atlanta)	Phased Construction with Partial Closures
	MoDOT	US 63 and RT B (Clark)	Phased Construction with Partial Closures
		US 63 and Calvert Hill Rd./Hinton Rd. (Columbia)	Phased Construction with Partial Closures
		MO 13 and 364 NE (St. Clair County)	Phased Construction with Partial Closures
MUT	Tucson, AZ	Grant Rd. and Oracle Rd.	Phased Construction with Partial Closures
MUT	PSOMAS	Grant Rd. and 1st Ave./Stone Ave. (Pima County, Arizona)	Phased Construction with Partial Closures
DLT	Engineering Design Source, Inc.	MO 30 and Summit Rd./Gravois Bluffs Blvd. (Fenton, MO)	Phased Construction with Partial Closures
	ODOT	Austin Blvd. and SR 741 (Miamisburg)	Phased Construction with Partial Closures

Project plans were received from the City of Columbia, Missouri; Kentucky Transportation Cabinet (KYTC); Minnesota DOT (MnDOT); Missouri DOT (MoDOT); Engineering Design Source, Inc.; Ohio DOT (ODOT); Omni Means; Washington County, Minnesota; Pennsylvania DOT (PennDOT); Utah DOT (UDOT); Crawford, Murphy and Tilly; New Mexico DOT (NMDOT); City of Tucson, Arizona; and Psomas. 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. For the roundabout, plans showing the use of a temporary bypass were obtained from Washington County, MN. Washington County, MN also provided a roundabout typical showing two stages of partial closures for striping operations. PennDOT provided typical drawings for roundabout phased construction with a flagging operation as part of their temporary traffic control guidelines. An expanded Table including descriptions of the phasing used for each project is provided in Appendix B. Case studies for some of the projects are described in Appendix C.

In total 19 plan sets were received relating to roundabout projects. The City of Columbia provided five project plan sets relating to roundabout intersections. These projects pertained to initial construction in which various methods were utilized including phased construction with partial closure, phased construction with temporary bypasses, and full closure. In one set of plans, the City of Columbia constructed a roundabout while maintaining access by allowing two-way traffic through the roundabout during construction phases. It was determined that the general public were familiar with roundabout intersections due to the number of roundabouts in the area, and no increase in illegal movements were observed after final traffic configuration was adopted. KYTC also provided example plans involving roundabout construction. The roundabout projects involved shifting traffic to newly constructed pavements as available. MoDOT provided plans relating to a roundabout construction project. This project involved the construction of two roundabouts replacing the ramp terminals of a conventional diamond interchange. The roundabout construction example involved temporary lane closures in which flaggers were utilized to ensure proper flow of traffic. Washington County, Minnesota, sent project plans pertaining to two roundabout construction projects and one maintenance project. For two of these roundabout construction projects, temporary bypasses were constructed to allow the complete construction of the roundabout and approaches. The maintenance project involved temporary closures with flagman operation in which through traffic of the main roadway was maintained. Washington Country, Minnesota, also provided typical application sheets that show work zone phasing and temporary traffic control setup for roundabout maintenance through a two lane roundabout. This setup involves temporary lane closures through each leg and completing one quadrant per phase to limit the impact on access. PennDOT provided traffic control guidelines which included temporary traffic control guidelines used through various single and multi-lane roundabout maintenance projects in various parts of the state. The methods include the organization of flagging operations through each scenario of roundabout construction. The scenarios include work zone setup when each lane of an approaching roundabout leg is closed and work zone setup for quadrant closures of a roundabout. Other agencies that provided roundabout sample plans include ODOT and Omni Means.

The Kentucky Transportation Cabinet provided a set of example plans involving SPUI construction. The project involved constructing a SPUI bridge adjacent to an existing at-grade intersection. Once construction of the SPUI was complete, phased construction was utilized to construct SPUI approaches and connections to existing roadways. The Ohio DOT provided project plans pertaining to SPUI construction. The SPUI project plans involved phased construction while maintaining full access. For this project, the existing bridge was first widened to the final width, and then the left-turn ramps were constructed. Once all left-turn facilities had been constructed, a temporary traffic signal was placed near the final location in the center of the bridge. During this stage, right-turn facilities were constructed while right-turn movements utilized the existing ramps. Traffic was then shifted to one side of the bridge to allow for roadway widening. Once this was completed, traffic was shifted to the opposite side of the bridge to allow for the completion of the roadway widening. Additional SPUI project plans were received from MnDOT and UDOT.

Crawford, Murphy, and Tilly provided projects plans for the construction of a DDI. The project was first designed utilizing phased construction under traffic but was later changed to a full closure due to changes in project conditions. The phased construction example involved building a separate bridge parallel to the original structure to serve as the eastbound lanes through the DDI final layout. This allowed for all traffic to be shifted to the newly constructed bridge while work was completed for the westbound bridge. Additional DDI plans were received from MoDOT and NMDOT.

ODOT provided project plans pertaining to RCUT construction. The RCUT example plan set utilized a multiphase construction scheme with temporary minor roadway closures. Median U-turns were constructed first along with roadway widening to the west of the existing roadway. Once the western portion of the roadway widening had been completed, traffic was shifted to the newly constructed roadway, allowing for construction to begin on the opposite side. Once complete, traffic was shifted to the final intersection configuration. Additional RCUT plans were received from MnDOT and MoDOT.

Tucson, Arizona, and Psomas provided project plans relating to MUT intersections on Grant Road in the Tucson area. These plans utilize phased construction with partial closures in which the existing roadway is reconstructed and converted into a MUT intersection.

Engineering Design Source, Inc., provided plans relating to DLT construction in Fenton, Missouri. The plans showed the DLT footprint, but the temporary traffic control setup was left to the contractor. ODOT also provided project plans pertaining to DLT construction. The DLT plans involved phased construction with temporary roadway closures. Left-turn facilities were constructed first, and as new intersection movements were constructed, traffic was then shifted and movements reopened as available.

4.4 Initial Construction MOT Phasing Diagrams

This section presents the MOT Phasing Diagrams and discusses construction phasing for initial construction for each intersection type studied. These sheets were constructed using survey responses, interview findings, and project plan examples. Aspects such as signage are not included in the Initial Construction MOT Phasing Diagrams and should follow guidelines stated in the MUTCD. Many of the interviewees indicated that they used signage and other components from the MUTCD once the sequence of phasing was determined. For practitioner convenience, these diagrams are also presented in Appendix D without the text descriptions.

4.4.1 Roundabout

Roundabout intersection projects proved to be particularly challenging due to the expanded geometry surrounding the initial conventional intersection footprint. The initial construction phasing methods developed apply to both single lane and multi-lane roundabouts. MOT Phasing Diagrams were developed for two types of roundabout construction phasing methodologies. These include phased construction with partial closures and phased construction with temporary bypass.

A MOT Phasing Diagram was developed for a case of retrofitting an existing conventional at-grade intersection into a single lane roundabout intersection through phased construction with partial closures. This method involves a four phase construction scheme. Figure 4.4.1.1 shows the initial conventional at-grade intersection.

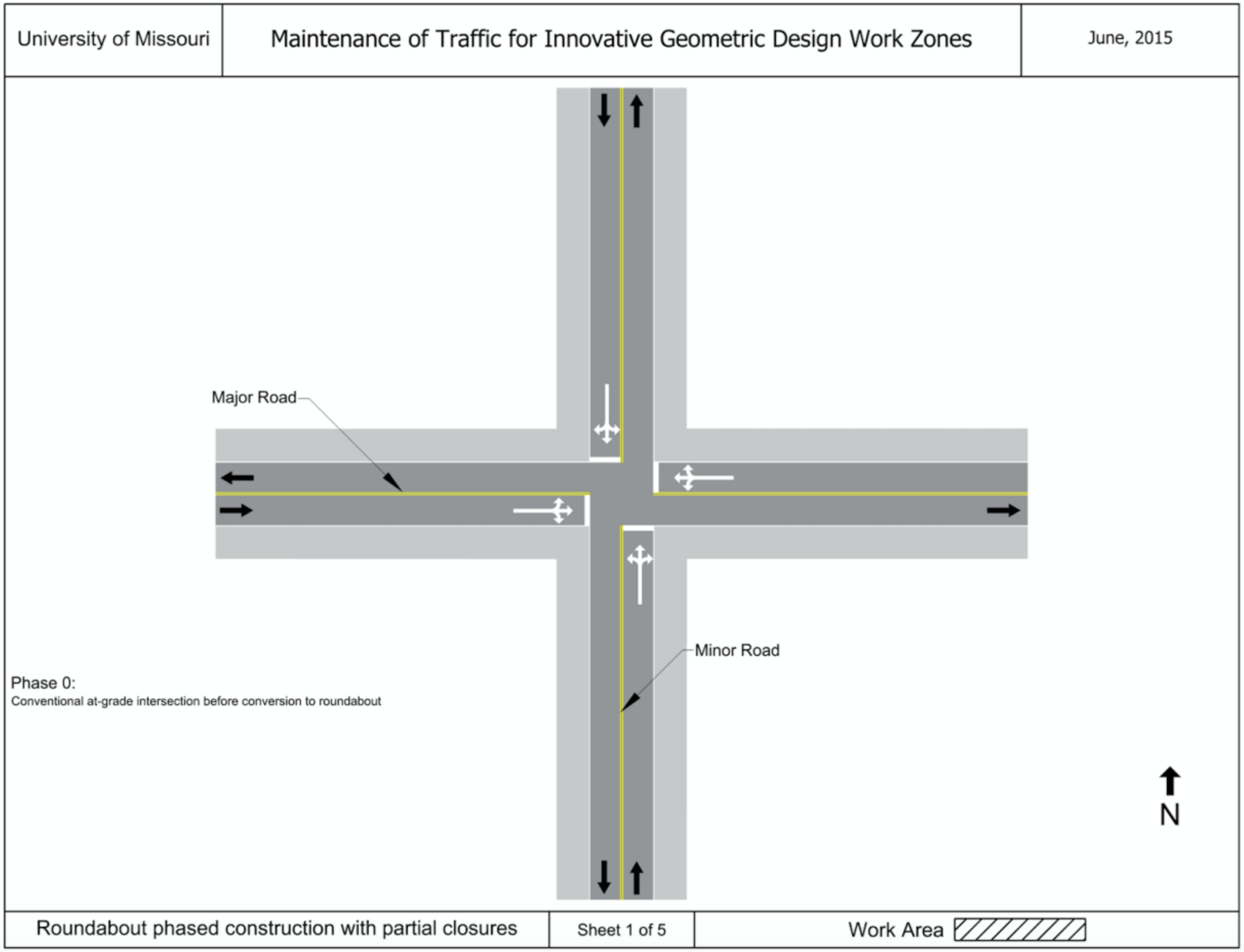


Figure 4.4.1.1 Roundabout phased construction with partial closures initial condition

Phase 1 of construction involves closing half of the intersection to allow construction of half of the roundabout as shown in Figure 4.4.1.2. The leg to be temporarily closed could be selected based on area constraints such as emergency access and traffic counts. A flagging operation or temporary traffic signal could be utilized to allow for two-way traffic on the two opposing legs that are not closed.

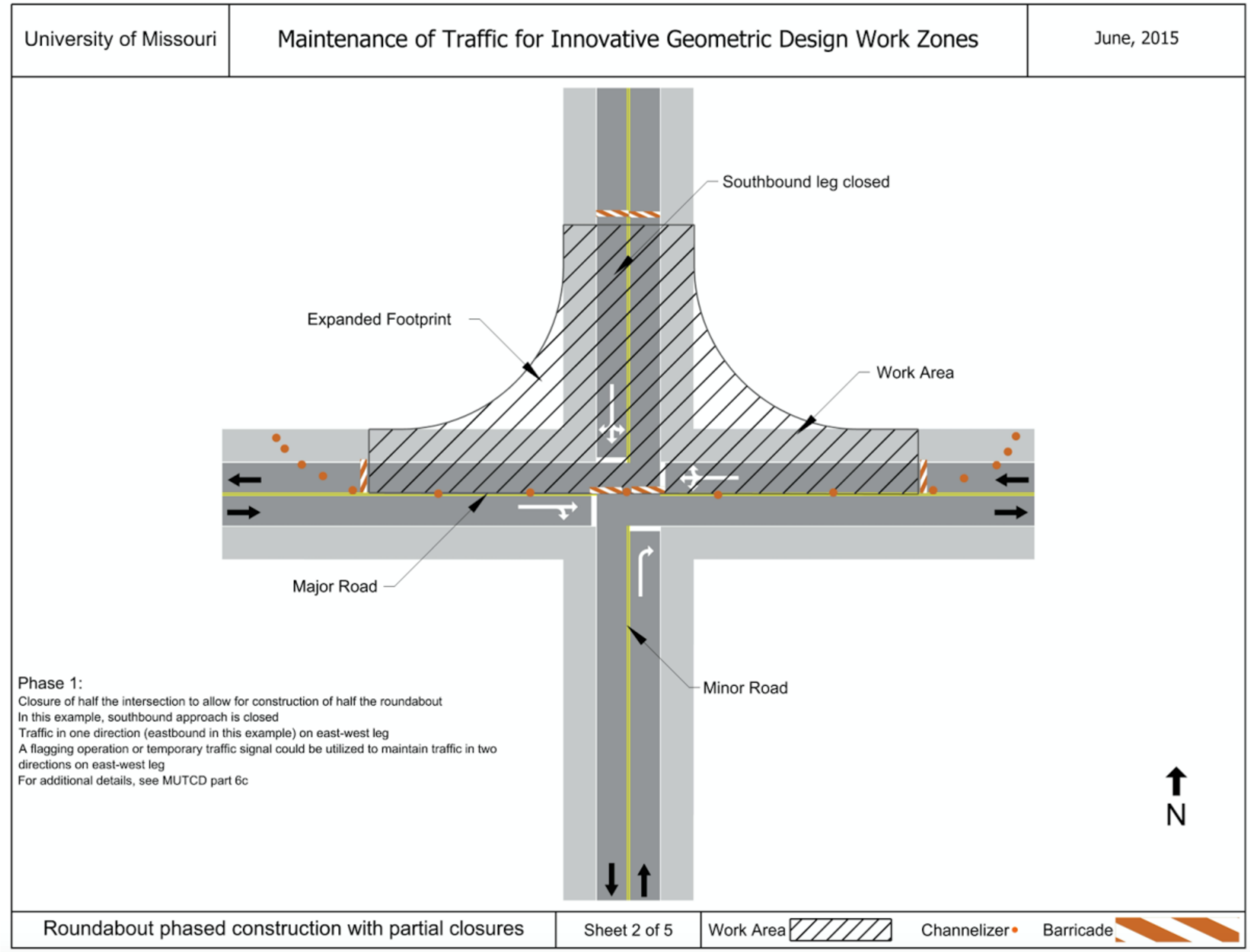


Figure 4.4.1.2 Roundabout phased construction with partial closures Phase 1 (closure of half the roundabout)

Phase 2 begins with opening the constructed half of the roundabout to traffic as appropriate. One-quarter of the remaining existing intersection is then closed for roundabout construction. Figure 4.4.1.3 shows the work area and MOT for this phase of construction. In this Figure, only northbound movements are allowed on the northbound approach. A flagging operation or temporary traffic signal may be utilized to allow two-way access through work zone in the north-south direction. On the eastbound and westbound approaches, one-way traffic is allowed, or a flagging operation could be utilized to allow for two-way traffic.

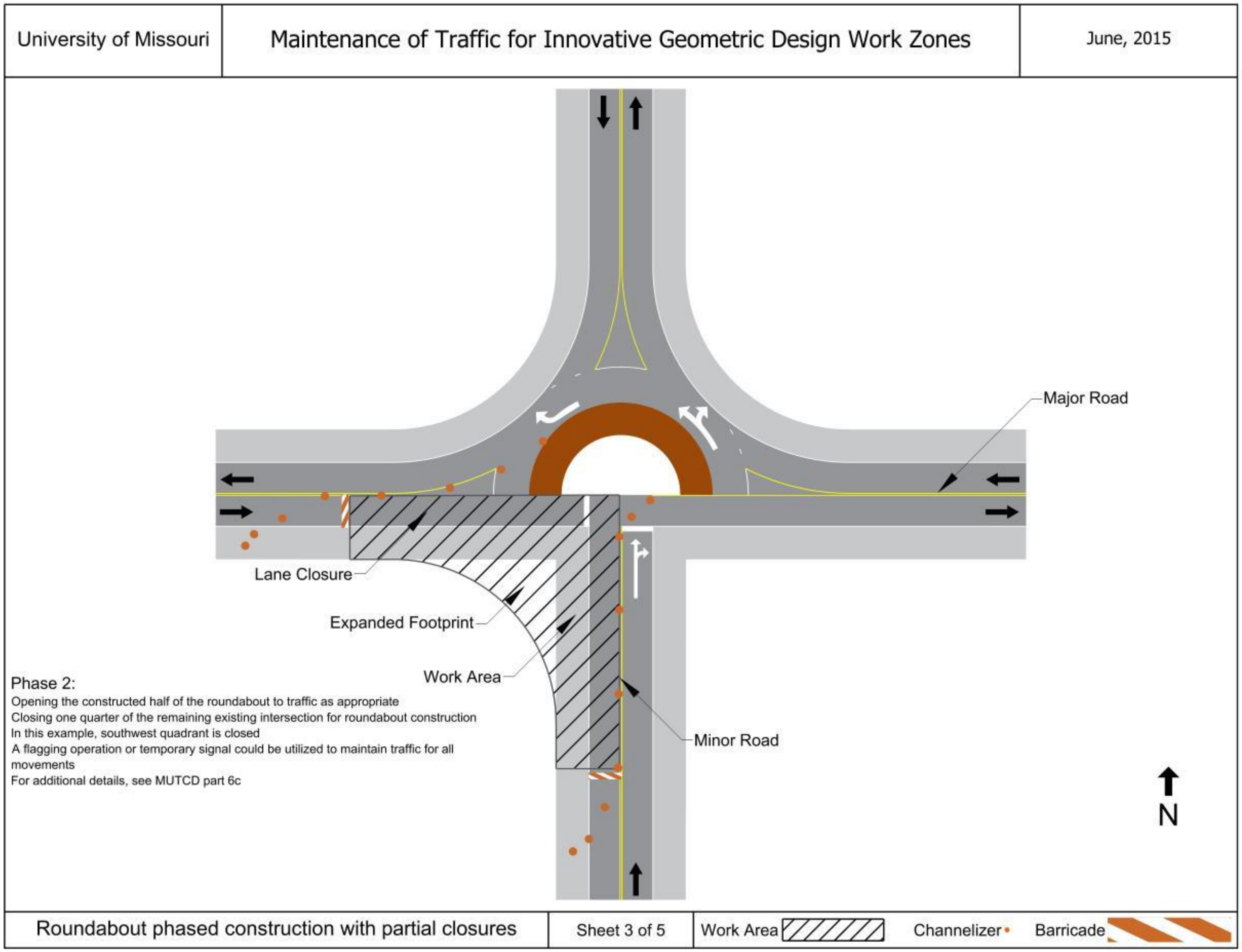


Figure 4.4.1.3 Roundabout phased construction with partial closures Phase 2 (closure of one quarter of intersection)

Phase 3 begins by opening the constructed quarter of roundabout from Phase 2 to traffic as shown in Figure 4.5.1.4. The remainder quadrant of the existing intersection to be converted into roundabout configuration is then closed to allow final construction. A flagging operation or temporary traffic signal may be utilized to allow full access through work zone.

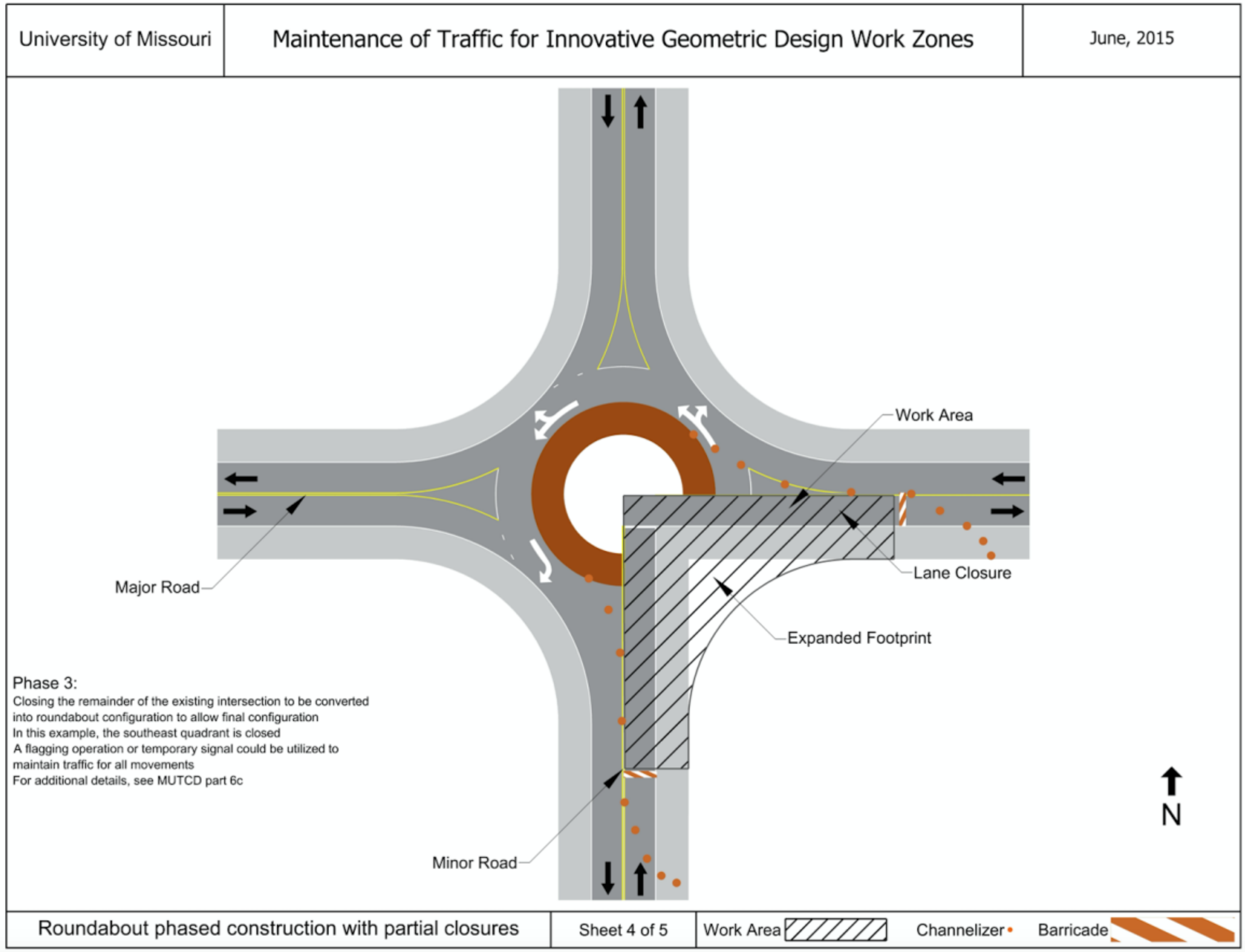


Figure 4.4.1.4 Roundabout phased construction with partial closures Phase 3 (construction of final quadrant)

Once Phase 3 is complete, the temporary traffic control devices can be removed and the roundabout is opened to the final traffic configuration. Figure 4.4.1.5 shows the final configuration of the roundabout.

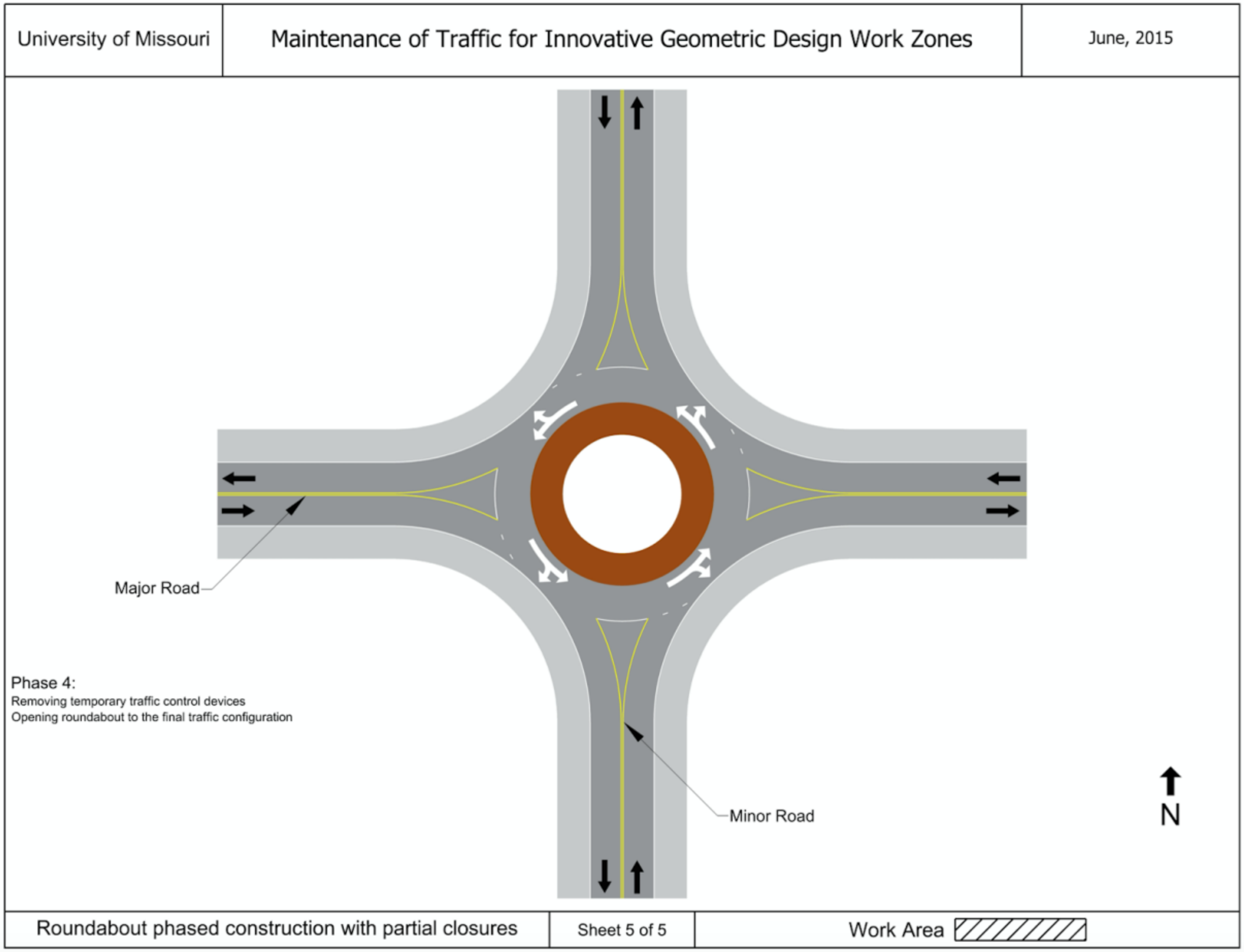


Figure 4.4.1.5 Roundabout phased construction with partial closures final configuration

After the initial closure of half of the intersection, this phasing organization mitigates closure to one roundabout leg for a single phase. The closure of certain legs may be considered based on traffic counts. Other phases may incorporate a flagging operation to allow full access among traffic movements (VDOT 2011). Attention to proper signage and public outreach is important to ensure travelers do not miss the final roundabout configuration and make illegal turning movements.

Another method that could be used to retrofit an existing conventional intersection into a roundabout intersection is through the use of a temporary bypass similar to the methods found in the Washington County, MN sample plans. The need of a bypass will depend on the ease of detouring without a bypass. Phased construction with the use of a temporary bypass involves three main phases. Figure 4.4.1.6 shows the initial conditions of the conventional intersection.

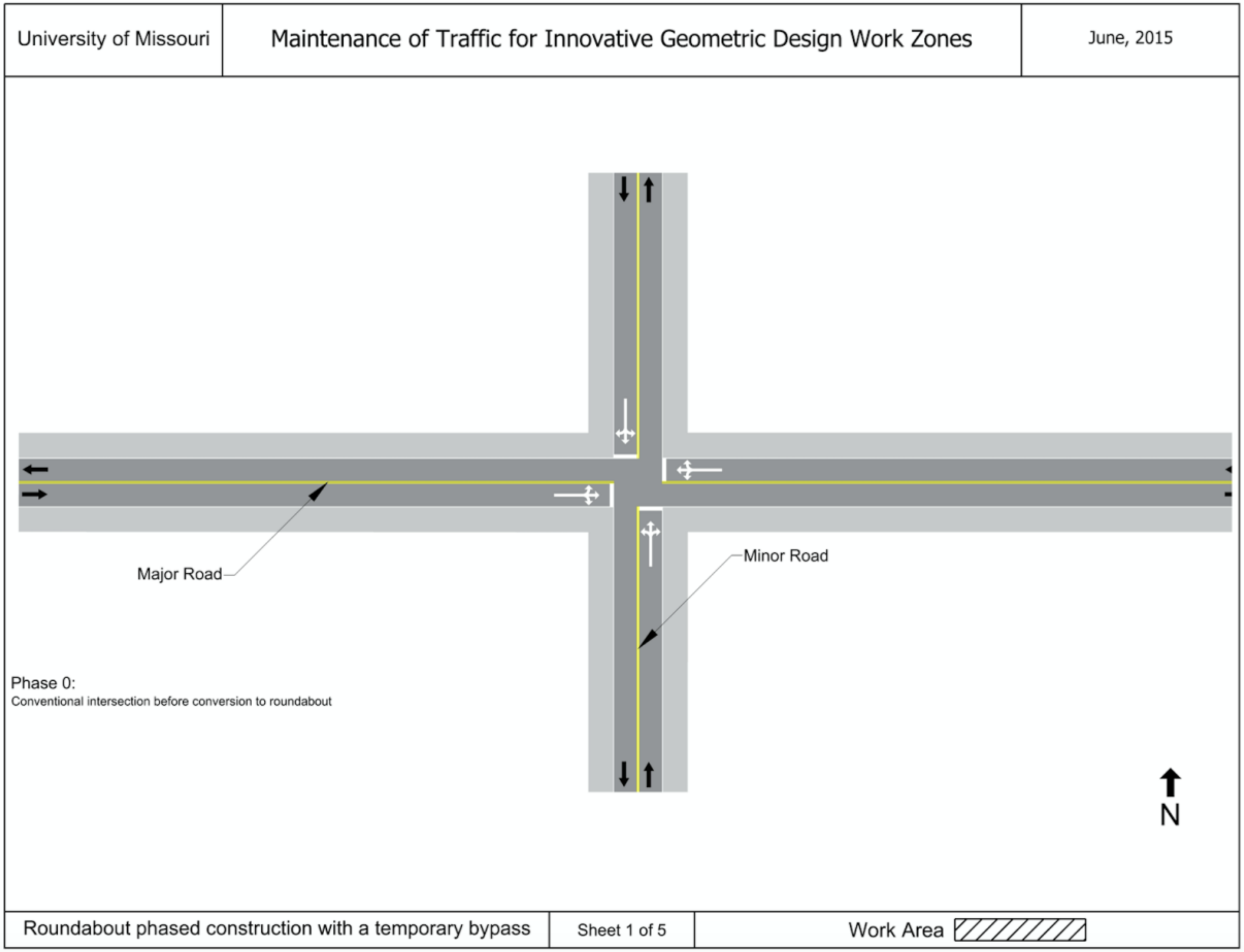


Figure 4.4.1.6 Roundabout phased construction with a temporary bypass initial condition

Phase 1 involves construction of the temporary bypass by considering movements needed to remain open through construction. This decision could be based on site considerations, such as emergency access or traffic counts. Figure 4.4.1.7 shows the work area and MOT during the construction of the temporary bypass in Phase 1. Phase 1 does not result in any significant impact to traffic movements.

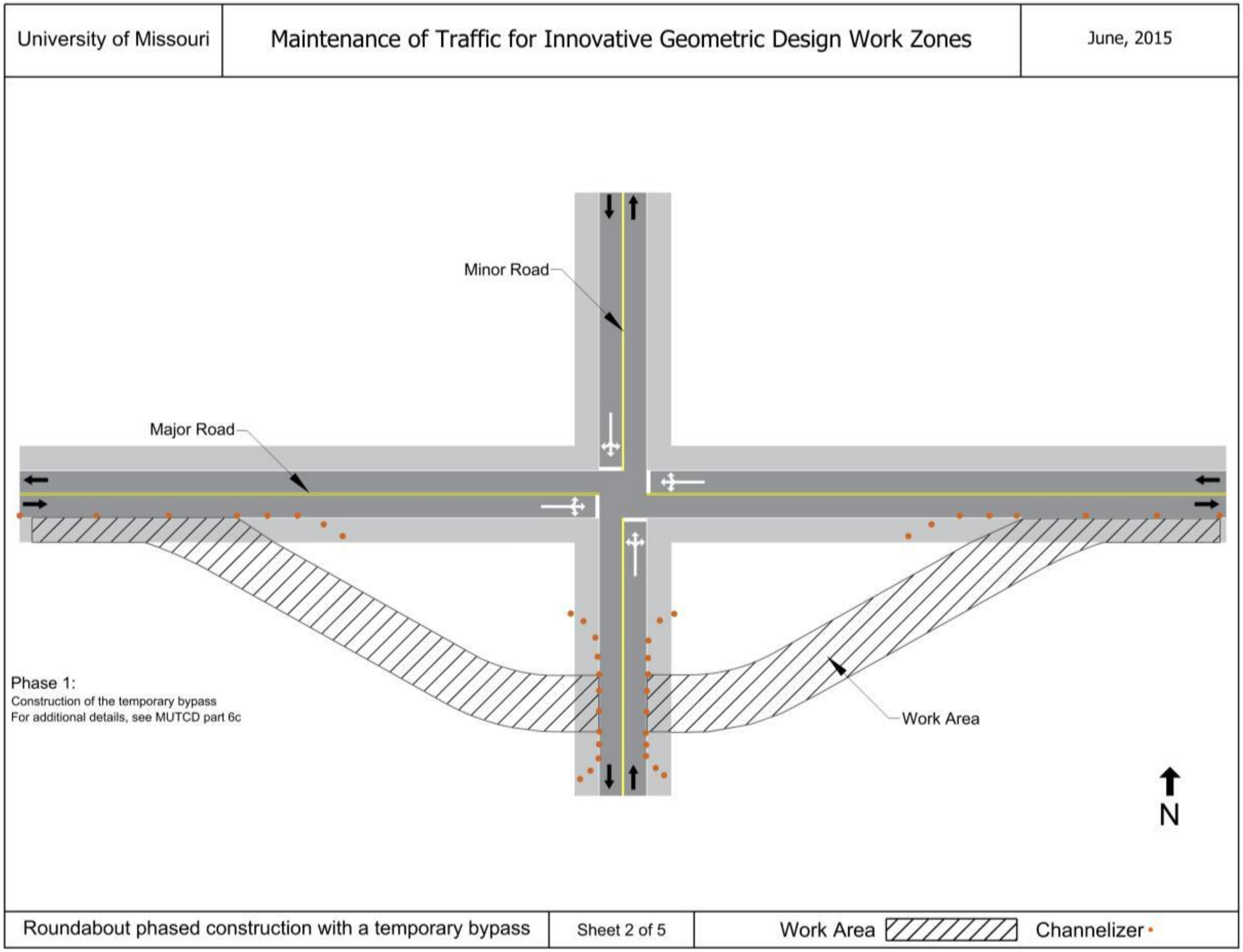


Figure 4.4.1.7 Roundabout phased construction with a temporary bypass Phase 1 (construction of temporary bypass)

Phase 2 involves diverting traffic to the temporary bypass, thus allowing the full closure of the intersection to be converted to a roundabout as shown in Figure 4.4.1.8. The use of one temporary bypass results in a temporary closure of one leg of the existing intersection. Additional bypasses may be constructed to allow further access.

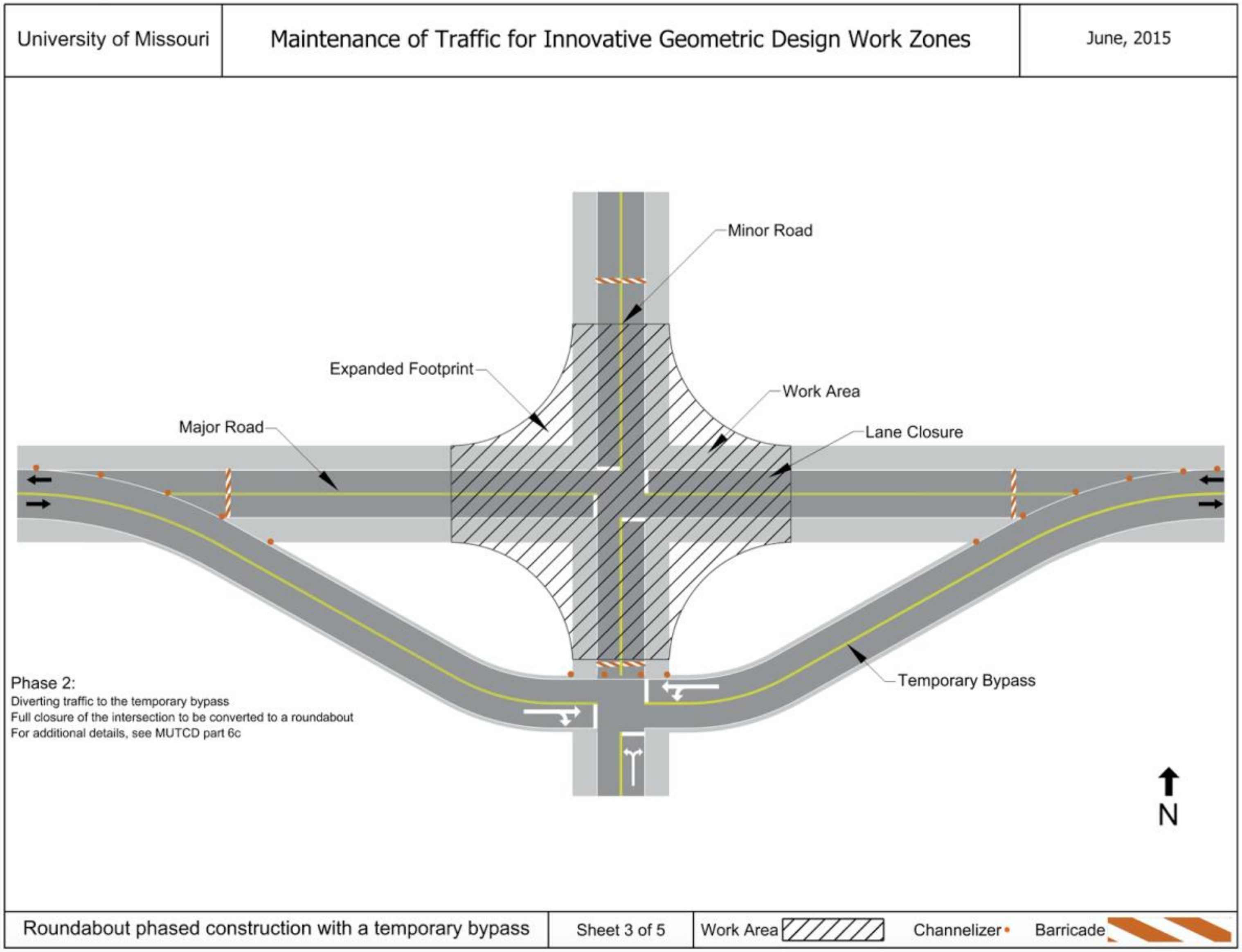


Figure 4.4.1.8 Roundabout phased construction with a temporary bypass Phase 2 (construction of roundabout)

Phase 3 begins once the roundabout construction is complete. Traffic is shifted onto the final roundabout configuration and deconstruction of the temporary bypass begins. Full access is allowed through Phase 3. Figure 4.4.1.9 shows the work area for the final construction and removal of the temporary bypass.

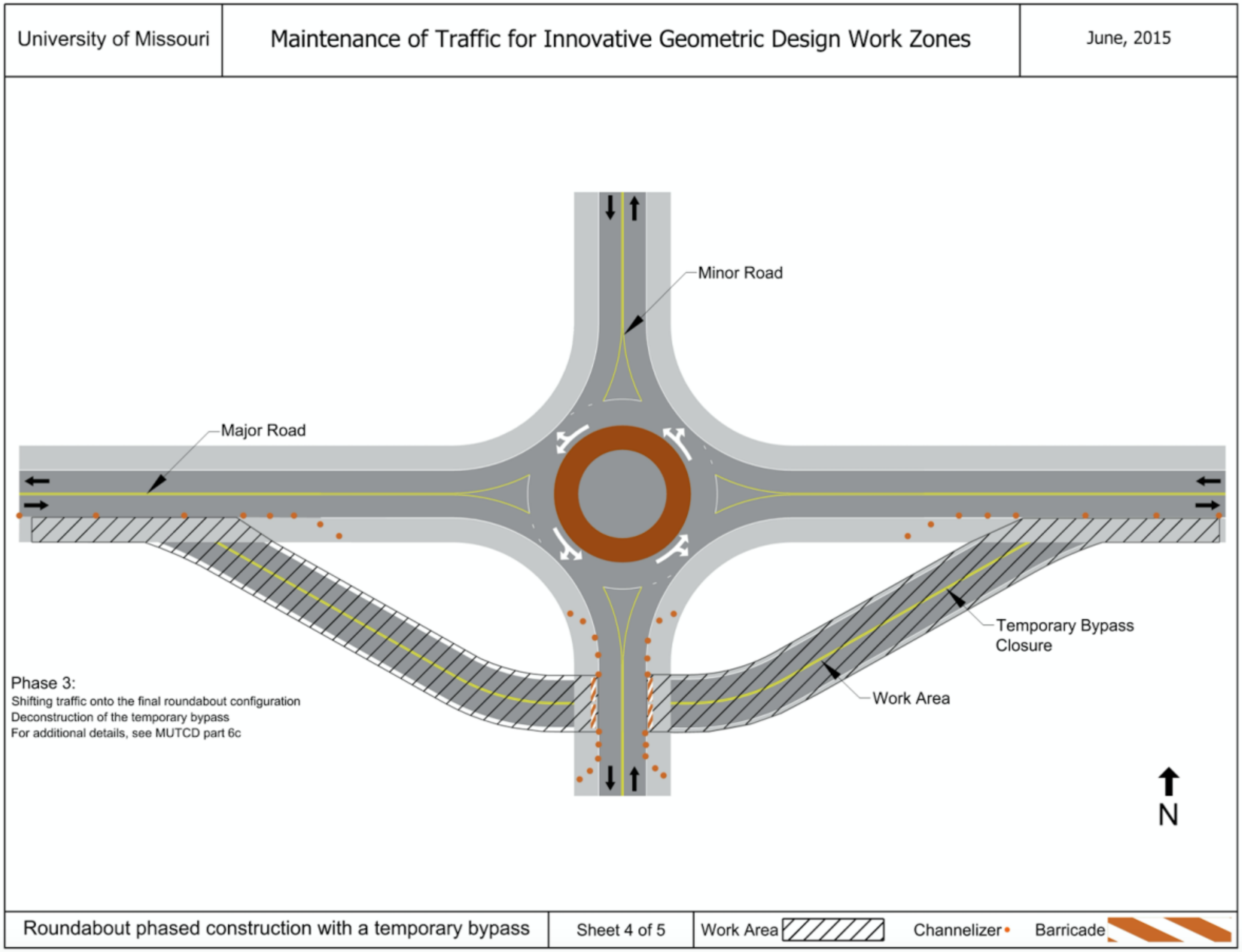


Figure 4.4.1.9 Roundabout phased construction with a temporary bypass Phase 3 (final construction and removal of temporary bypass)

The roundabout may be fully opened once the temporary bypass is deconstructed. Figure 4.4.1.10 shows the final configuration of the roundabout.

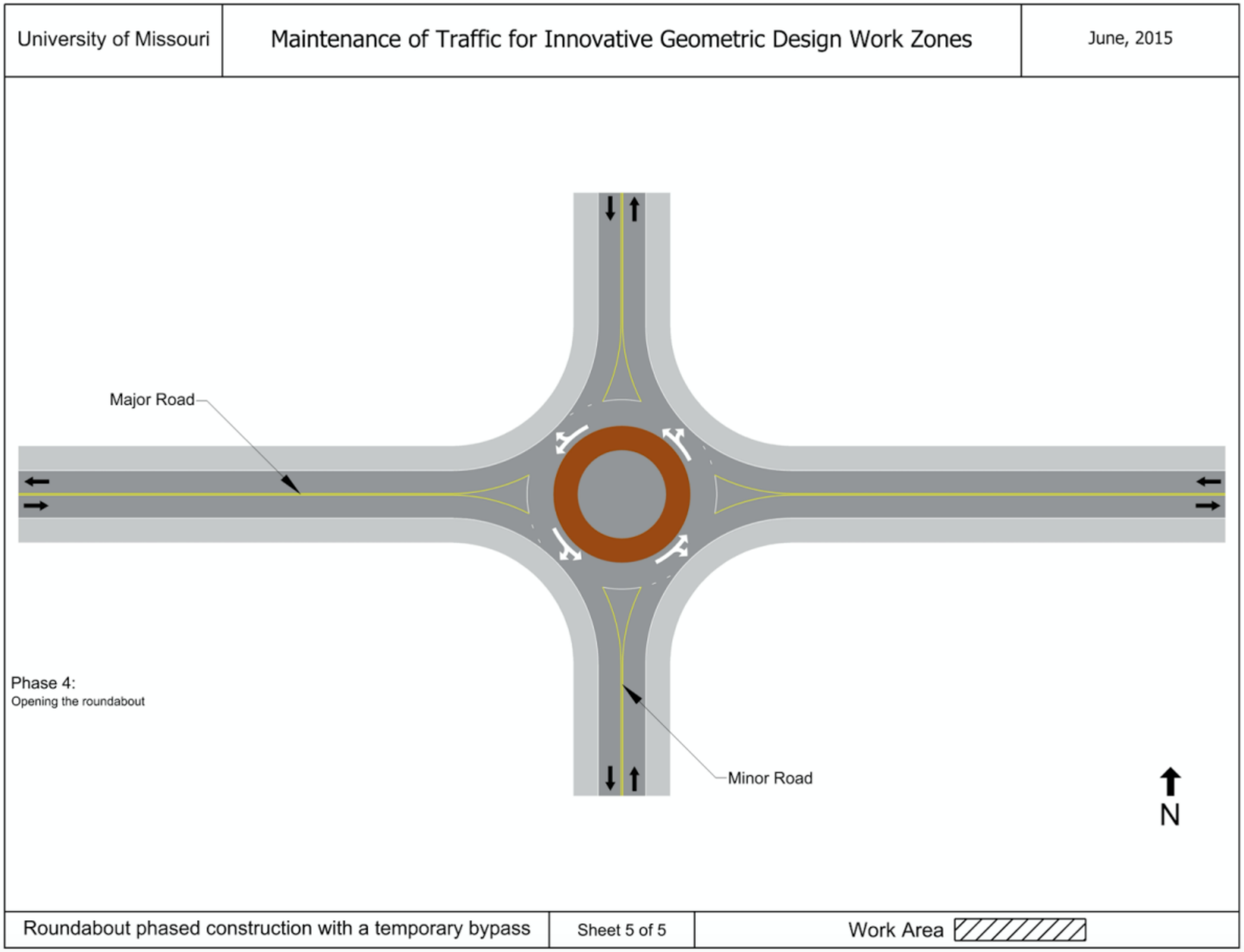


Figure 4.4.1.10 Roundabout phased construction with a temporary bypass final configuration

This construction phasing method allows for vital intersection movements to remain open while fully closing the existing intersection to expedite the construction process. The use of a temporary bypass provides a benefit of not requiring the usage of a flagging operation in order to maintain access. However, a bypass may prove to be not as cost effective due to the construction of a bypass.

4.4.2 SPUI

SPUIs can typically be constructed from a conventional diamond interchange while maintaining full access for all movements. A phased construction scheme of five phases was developed utilizing ODOT SPUI sample plans as well as other DOT and phone interview experiences. Figure 4.4.2.1 shows the initial conventional diamond interchange considered.

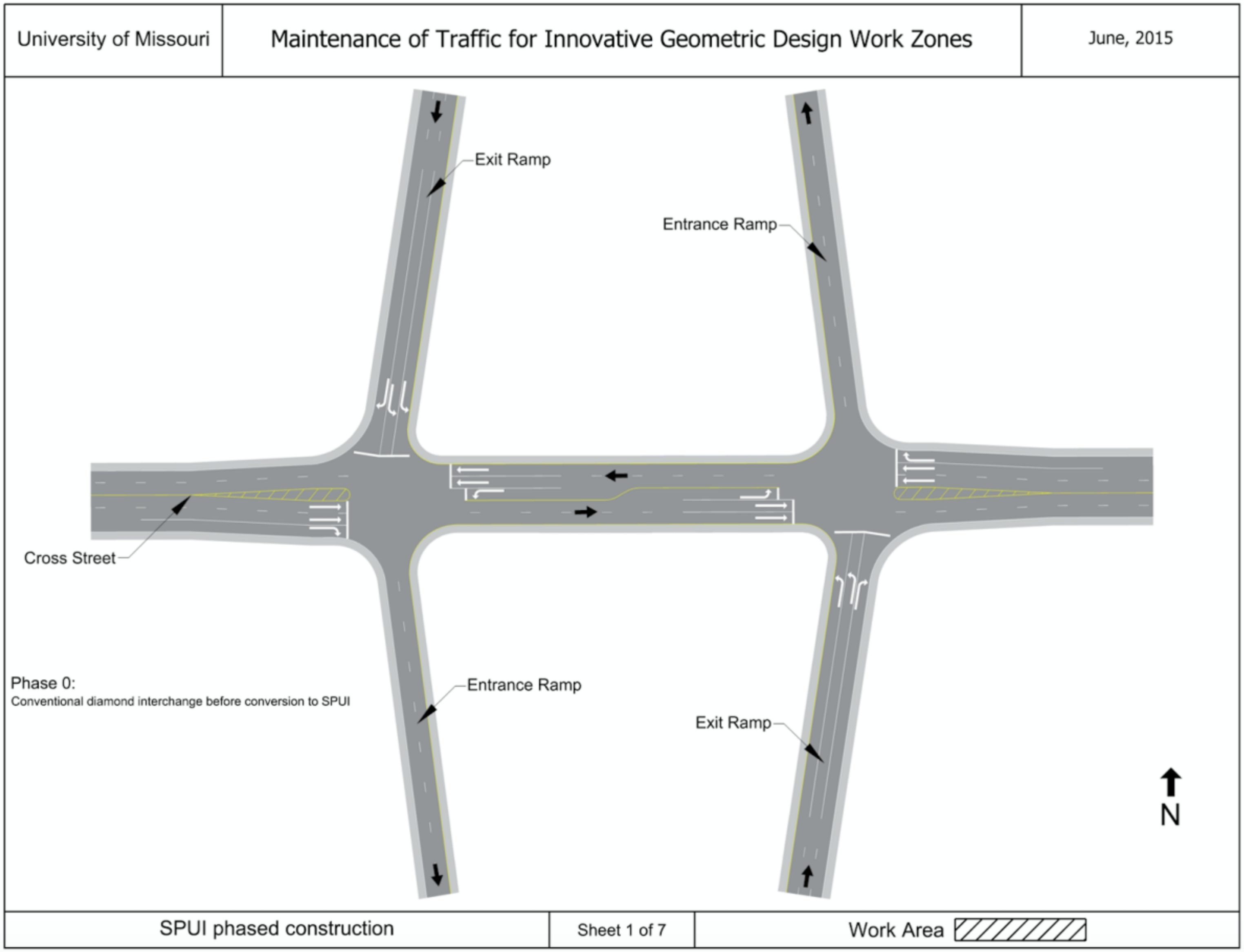


Figure 4.4.2.1 SPUI phased construction initial condition

Phase 1 involves the widening of the existing bridge to the final required width. This stage has little effect on bridge traffic due to barriers allowing travel to occur on adjacent lanes of bridge widening. Figure 4.4.2.2 shows the work area and MOT for the bridge widening.

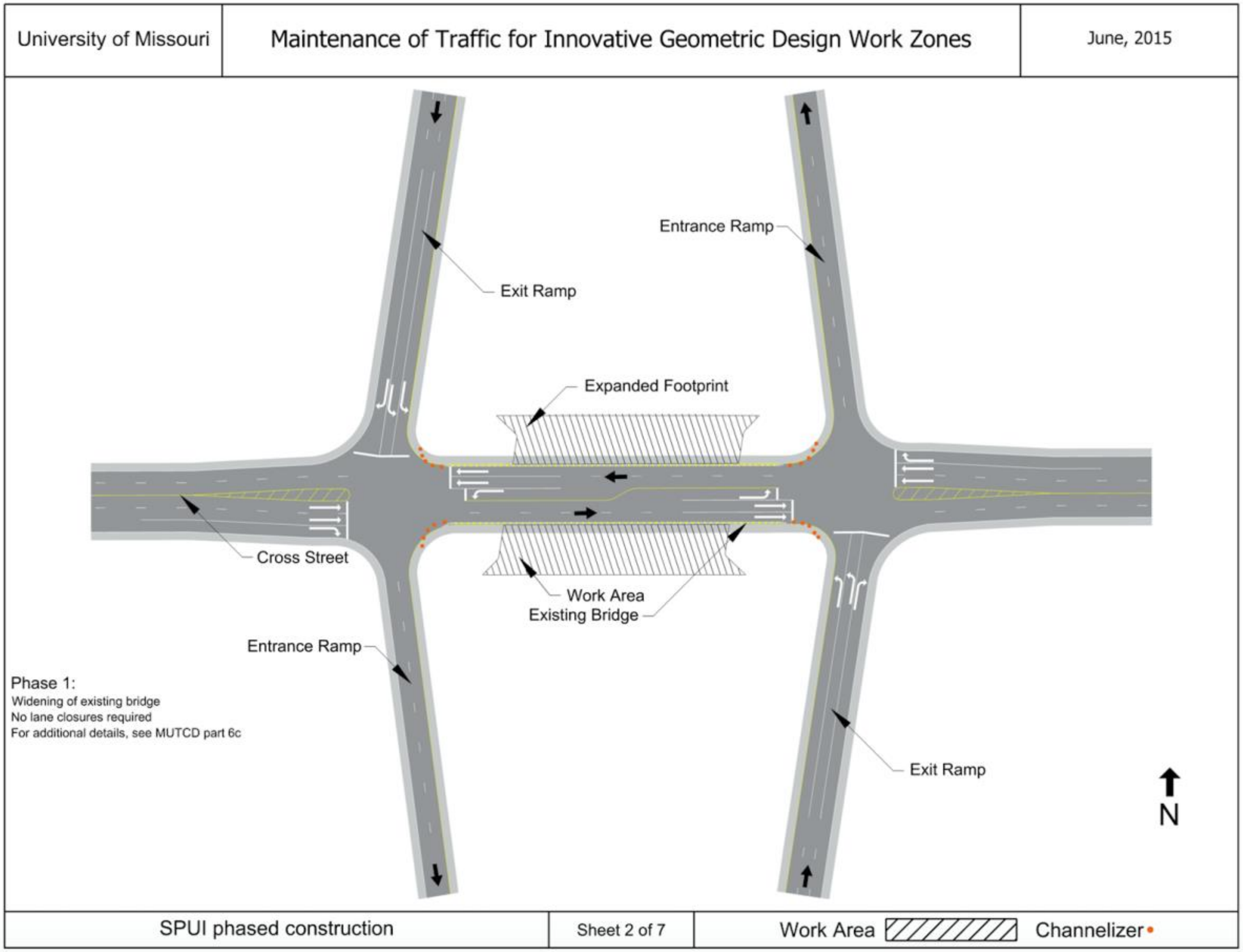


Figure 4.4.2.2 SPUI phased construction Phase 1 (widening of existing bridge)

Phase 2 involves beginning construction of the left-turn ramps once the bridge widening is complete as shown in Figure 4.4.2.3. This involves temporary closure of the innermost lane for both entrance and exit ramps.

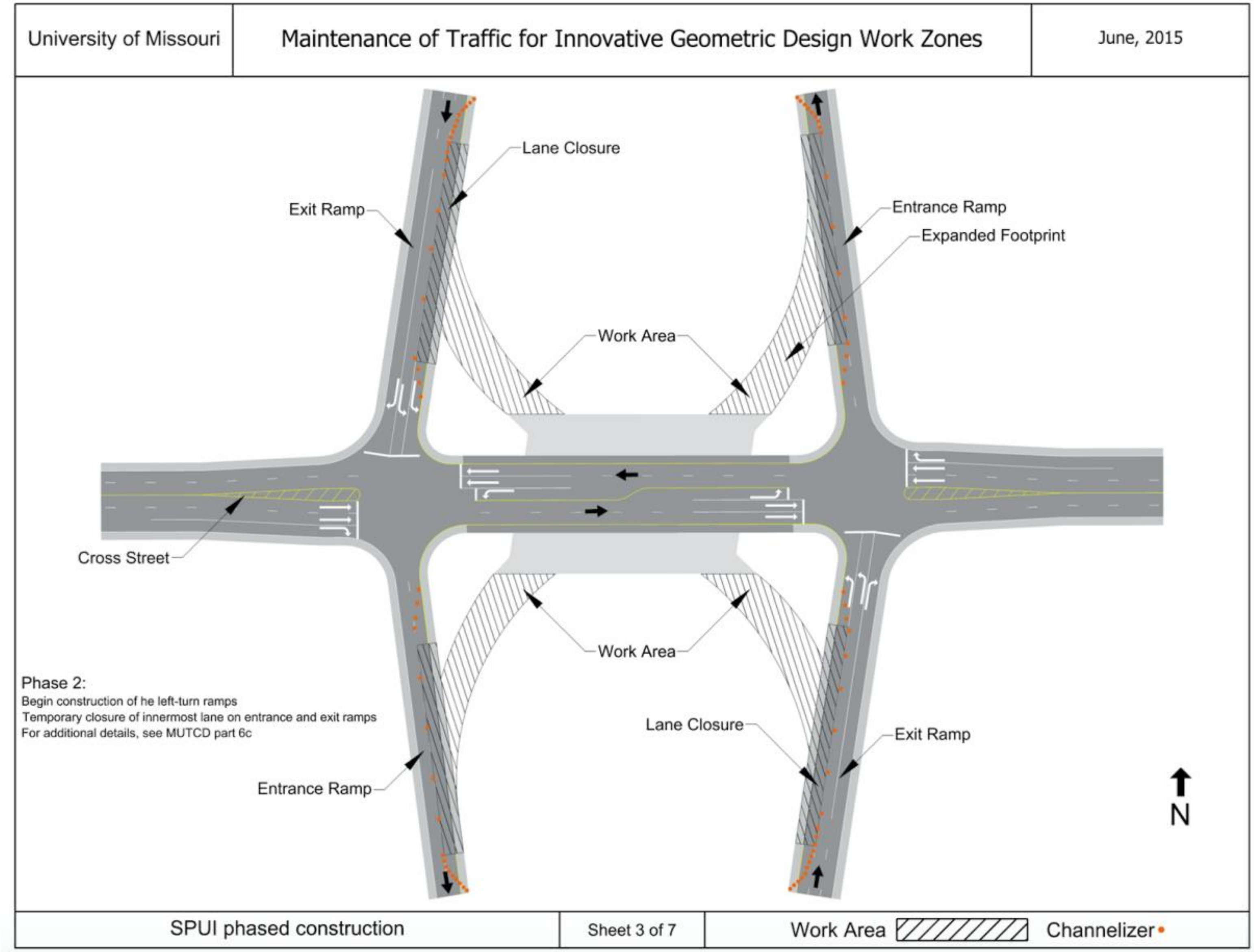


Figure 4.4.2.3 SPUI phased construction Phase 2 (construction of left turn ramps)

Phase 3 is divided into two sub-phases which involve construction of the connections to the newly constructed ramps and connections to the ramps constructed in the following phase. Phase 3a involves a temporary closure of one lane for the newly constructed ramps and existing ramps as shown in Figure 4.4.2.4. During this phase, traffic is shifted to one-side of the bridge to allow for one side of the roadway widening to be constructed. The connection is finalized between the newly constructed ramps and the existing roadway. The existing intersection signals are removed and a temporary traffic signal is placed at the center of the bridge for the left turn and through movements, while right turning movements at the initial condition intersections are converted to stop control.

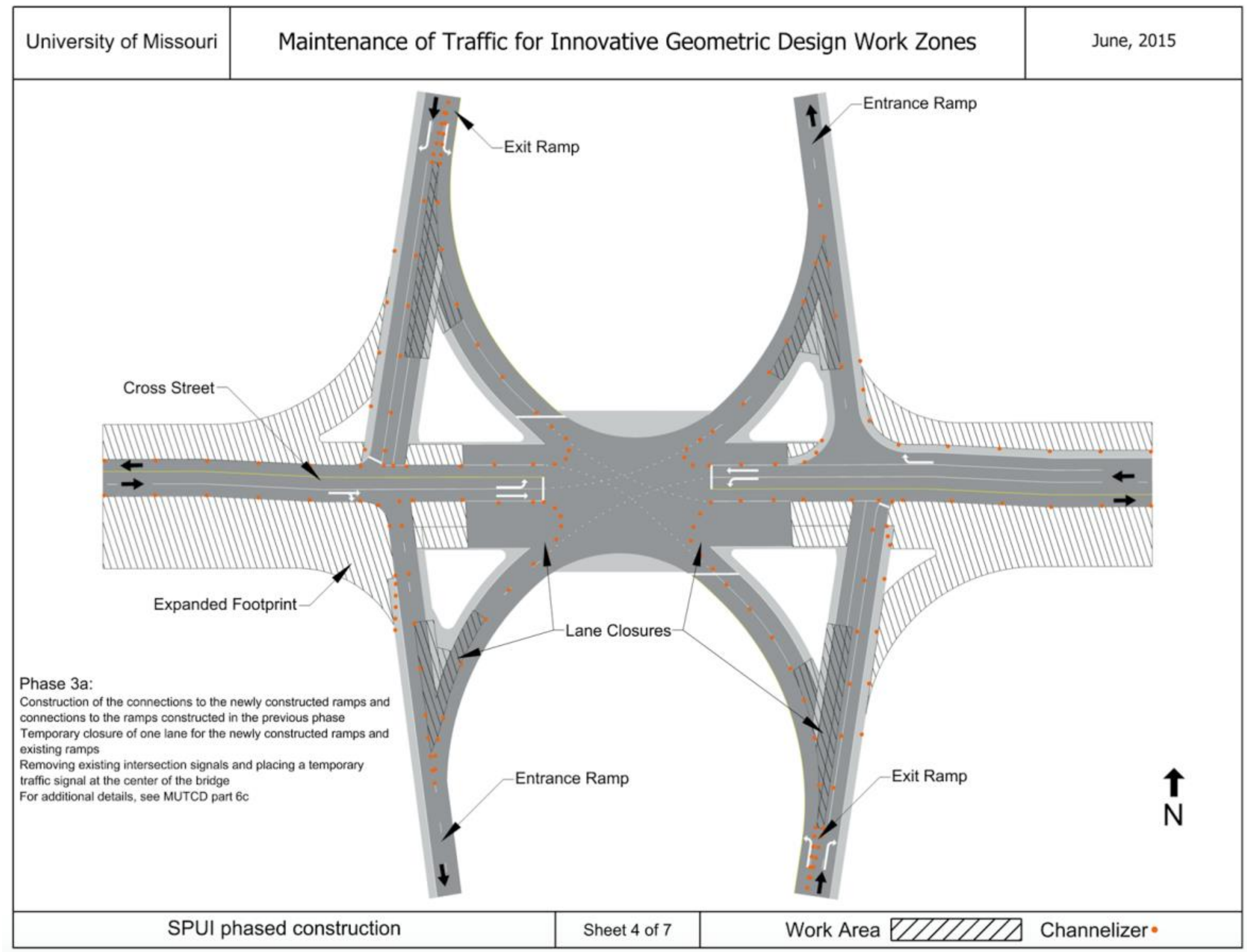


Figure 4.4.2.4 SPUI phased construction Phase 3a (construction of road widening)

Phase 3b begins once the connections between the left turn ramps and existing ramps have been constructed. Right turn traffic is shifted onto the innermost lane of the existing ramps and construction begins for the right turn facilities as shown in Figure 4.4.2.5. Throughout this phase construction is continued for the roadway widening available and the temporary traffic signal remains in the location previously placed.

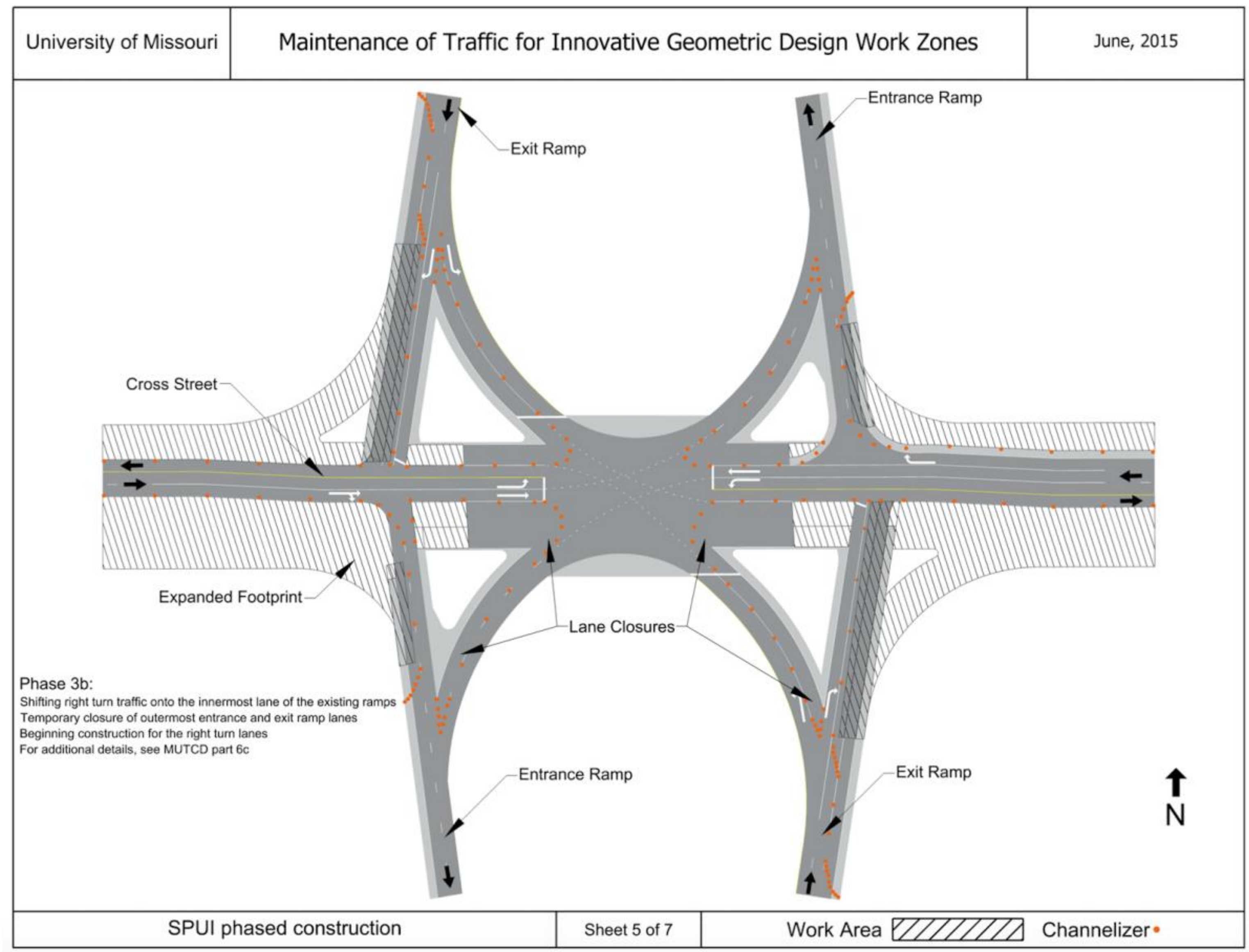


Figure 4.4.2.5 SPUI phased construction Phase 3b (construction of right turn facilities)

Phase 4 begins once the turning facilities are complete for the SPUI. Traffic is shifted onto the final ramp movements and the cross-traffic lanes are shifted onto the newly constructed roadway. This allows for the widening of the opposite side of the roadway to commence. The temporary traffic signal is moved with this shift and the conventional diamond approaches are deconstructed. Figure 4.4.2.6 shows the Phase 4 work area and MOT.

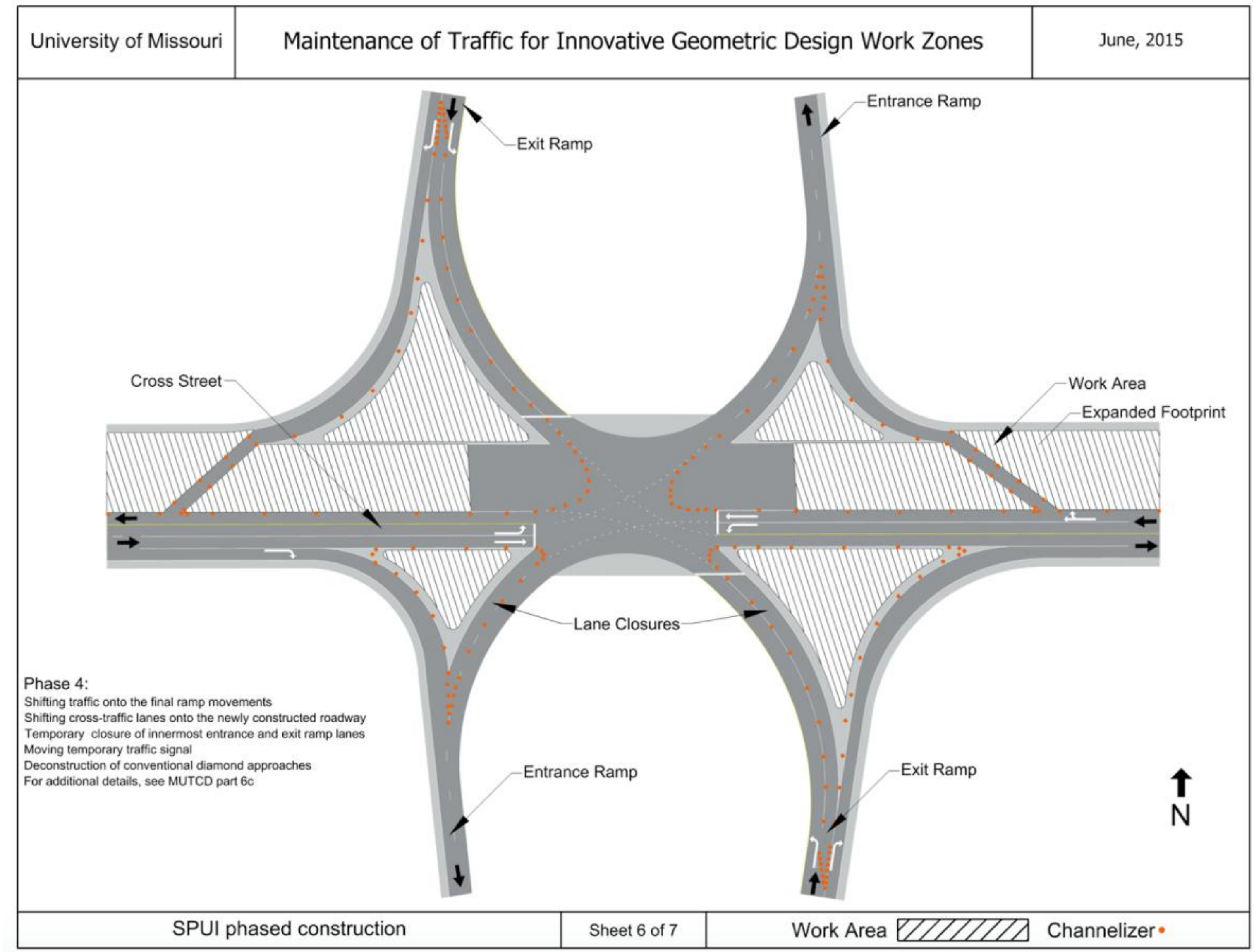


Figure 4.4.2.6 SPUI phased construction Phase 4 (widening of opposite side of roadway)

Once the roadway widening is complete, traffic is shifted onto the final SPUI configuration and the final signal control is installed. Figure 4.4.2.7 shows the final SPUI configuration.

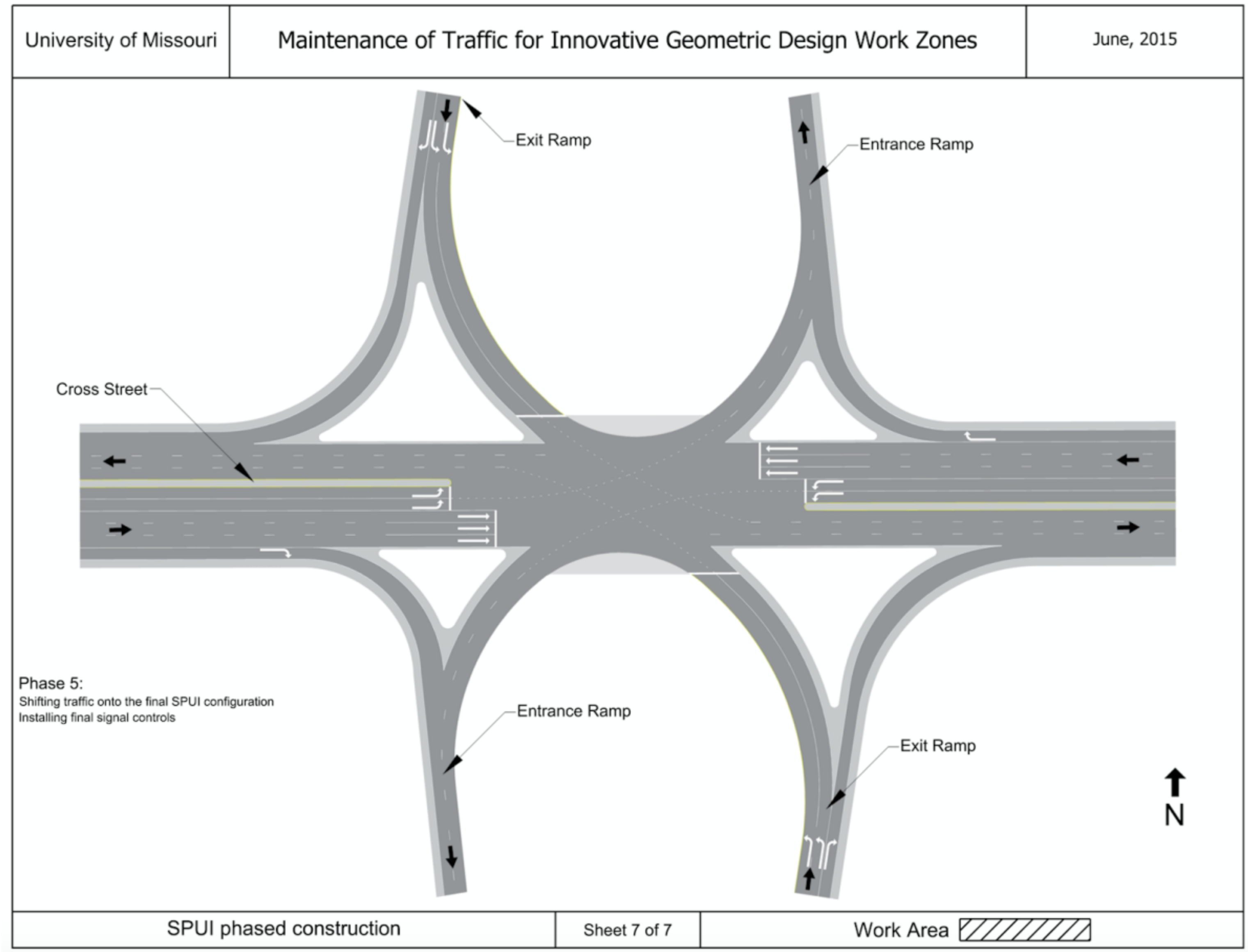


Figure 4.4.2.7 SPUI phased construction final configuration

This construction phasing method allows for a full retrofit from a conventional diamond interchange to a SPUI while maintaining full access. Shifting the traffic signals from the conventional diamond interchange setup to the SPUI location once the left-turn facilities are constructed allows for the full width of the bridge to be used for left-turn movements which provide space outside of the bridge for further construction.

4.4.3 DDI

DDIs can typically be constructed from a conventional diamond interchange while maintaining full access for all movements. A phased construction scheme for a DDI was developed utilizing six main phases. This scheme was developed based on experiences from MoDOT, Crawford, Murphy, and Tilly sample plans as well as practitioner phone interviews and Schroeder et al. (2014). Figure 4.4.3.1 shows the conventional diamond interchange considered.

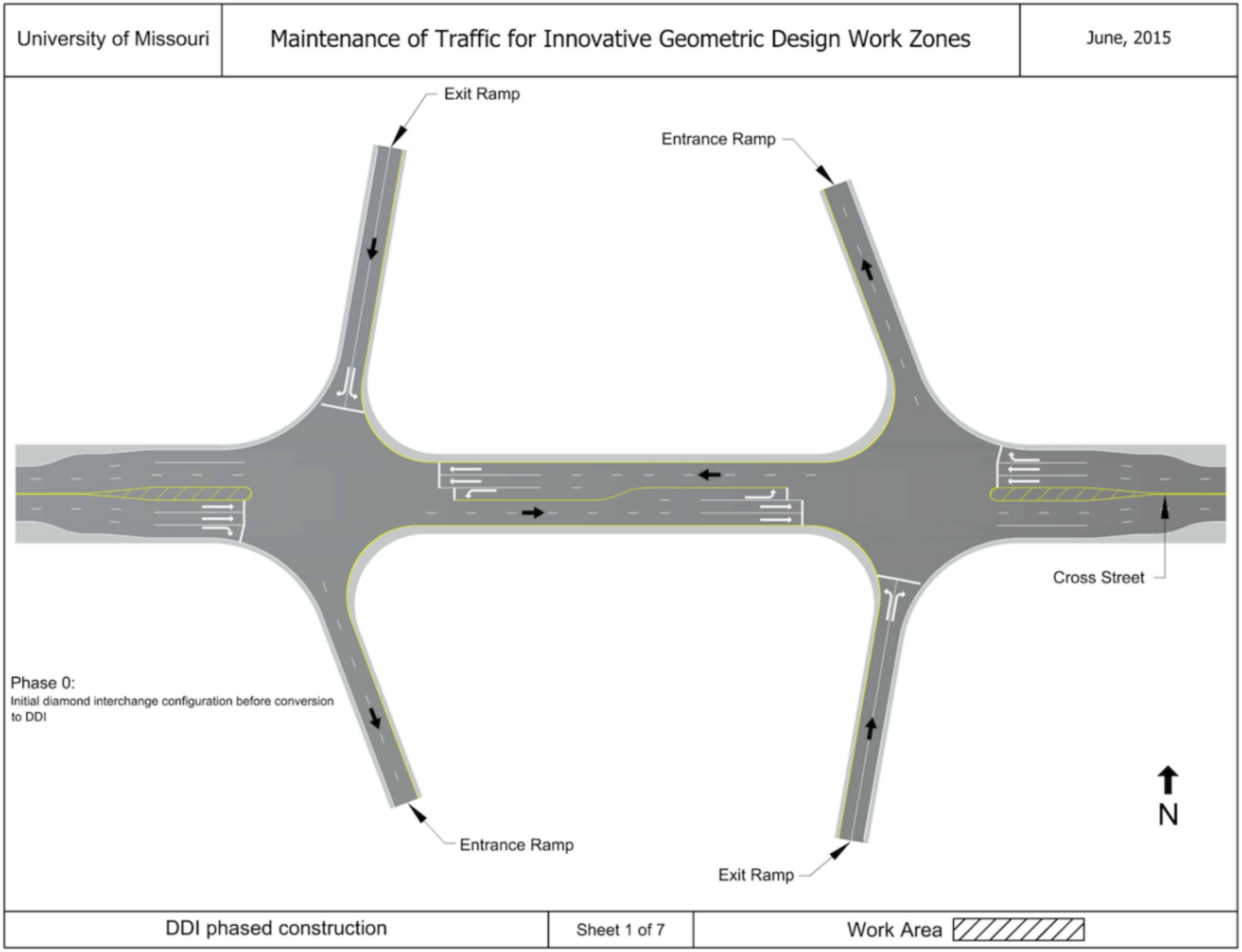


Figure 4.4.3.1 DDI phased construction initial condition

Phase 1 begins with construction of the bridge widening, if applicable, through the conventional diamond intersection. One benefit of a DDI interchange is that it does not require additional bridge cross-section when a pedestrian walkway is not constructed; however, the MOT Phasing Diagram here accounts for this construction of a pedestrian walkway. The staging methodology when a bridge widening is not required is similar to the MOT Phasing Diagram designed without the additional cross-section. The section of crossovers falling outside of the existing roadway is constructed through Phase 1 for both scenarios. Figure 4.4.3.2 shows the Phase 1 work area and MOT.

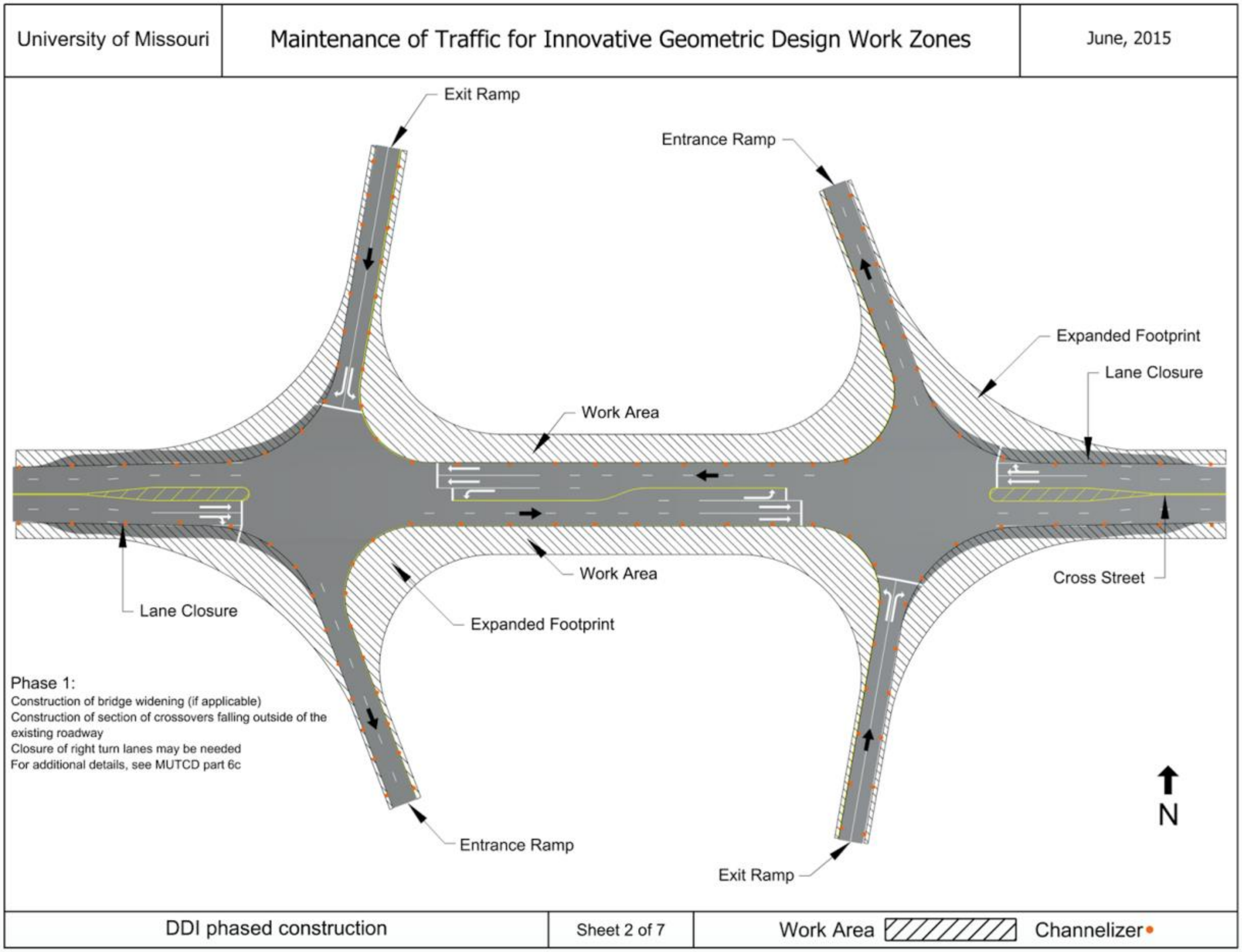


Figure 4.4.3.2 DDI phased construction Phase 1 (bridge widening and crossover construction)

Phase 2 begins with shifting the bridge deck traffic onto one side and beginning reconstruction of the bridge deck on the opposite side, if necessary. Construction of portions of crossovers outside of the existing roadway continues through Phase 2. Figure 4.4.3.3 shows the Phase 2 work area and MOT with construction on the south side of the bridge deck while traffic is maintained on the north side of the bridge deck.

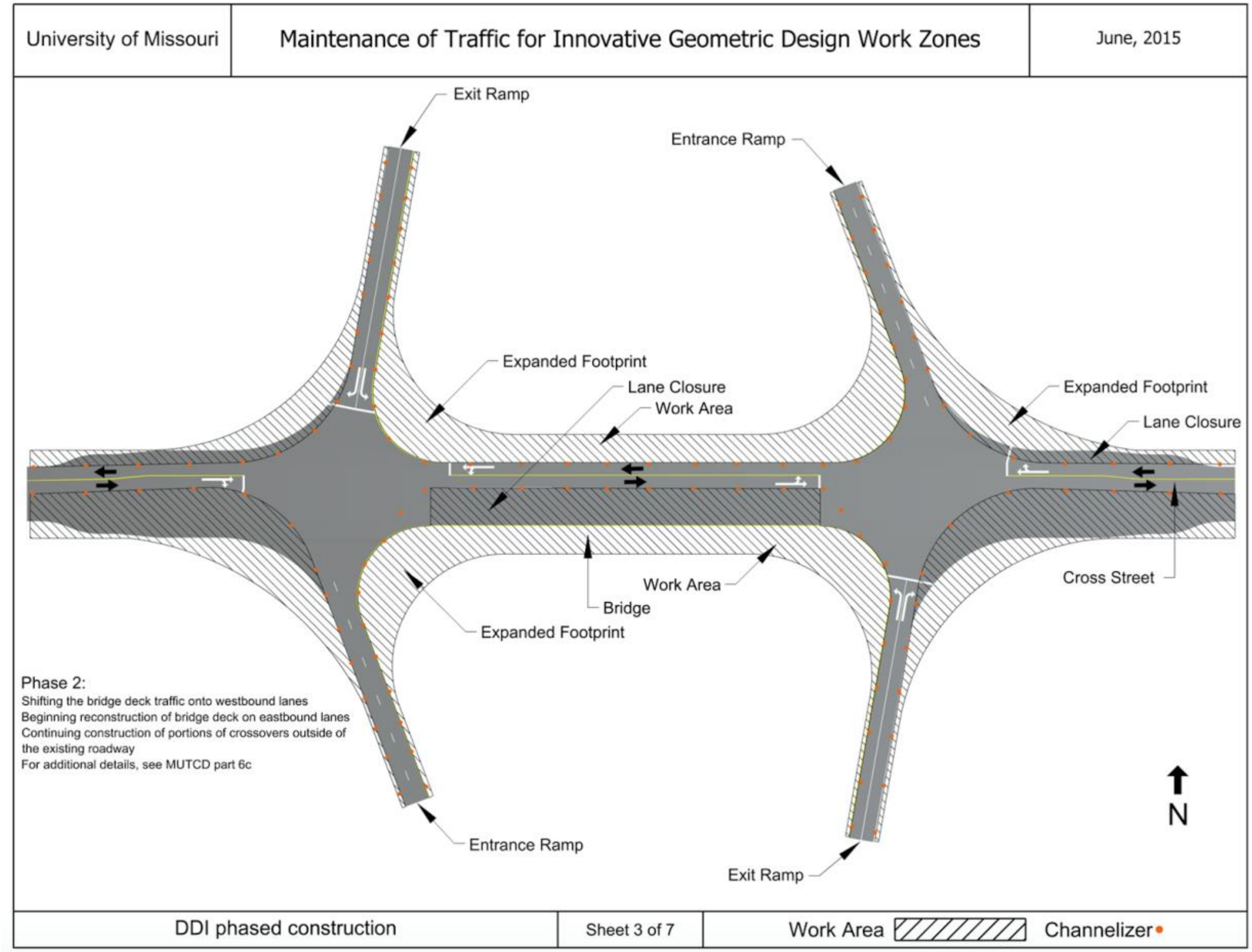


Figure 4.4.3.3 DDI phased construction Phase 2 (construction on south side of bridge deck)

In Phase 3, traffic is shifted to the newly constructed lanes from Phase 2. One lane of traffic is maintained in each direction. Construction is performed on the opposite side of the roadway and the median. Figure 4.4.3.4 shows the Phase 3 work area and MOT with construction taking place on the north side of the bridge deck while traffic is maintained on the south side of the bridge deck.

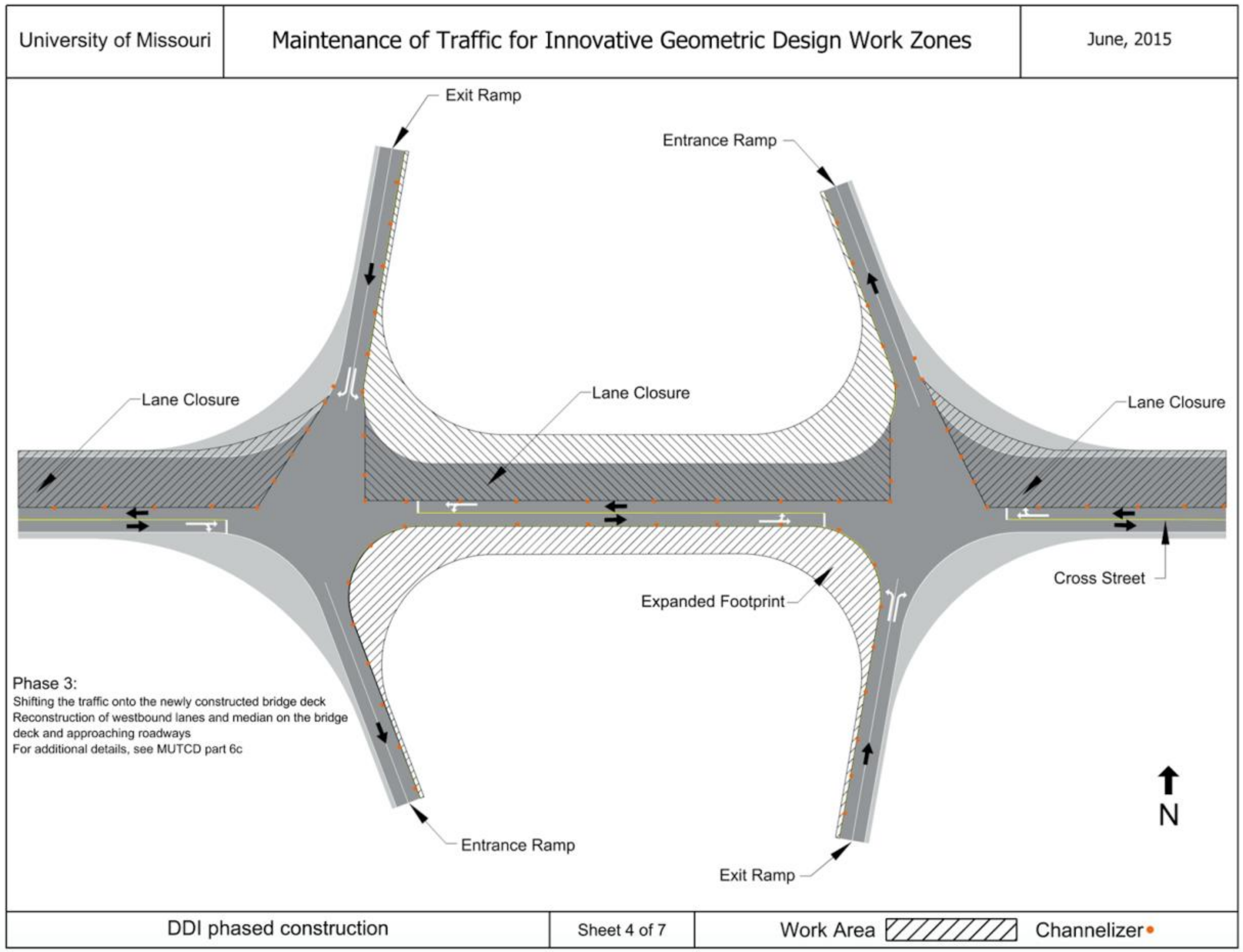


Figure 4.4.3.4 DDI phased construction Phase 3 (construction on north side of bridge deck and median)

Phase 4 involves maintaining two-way traffic on the areas constructed during Phases 2 and 3. Construction in the median takes place during this phase. Figure 4.4.3.5 shows the work area and MOT for Phase 4.

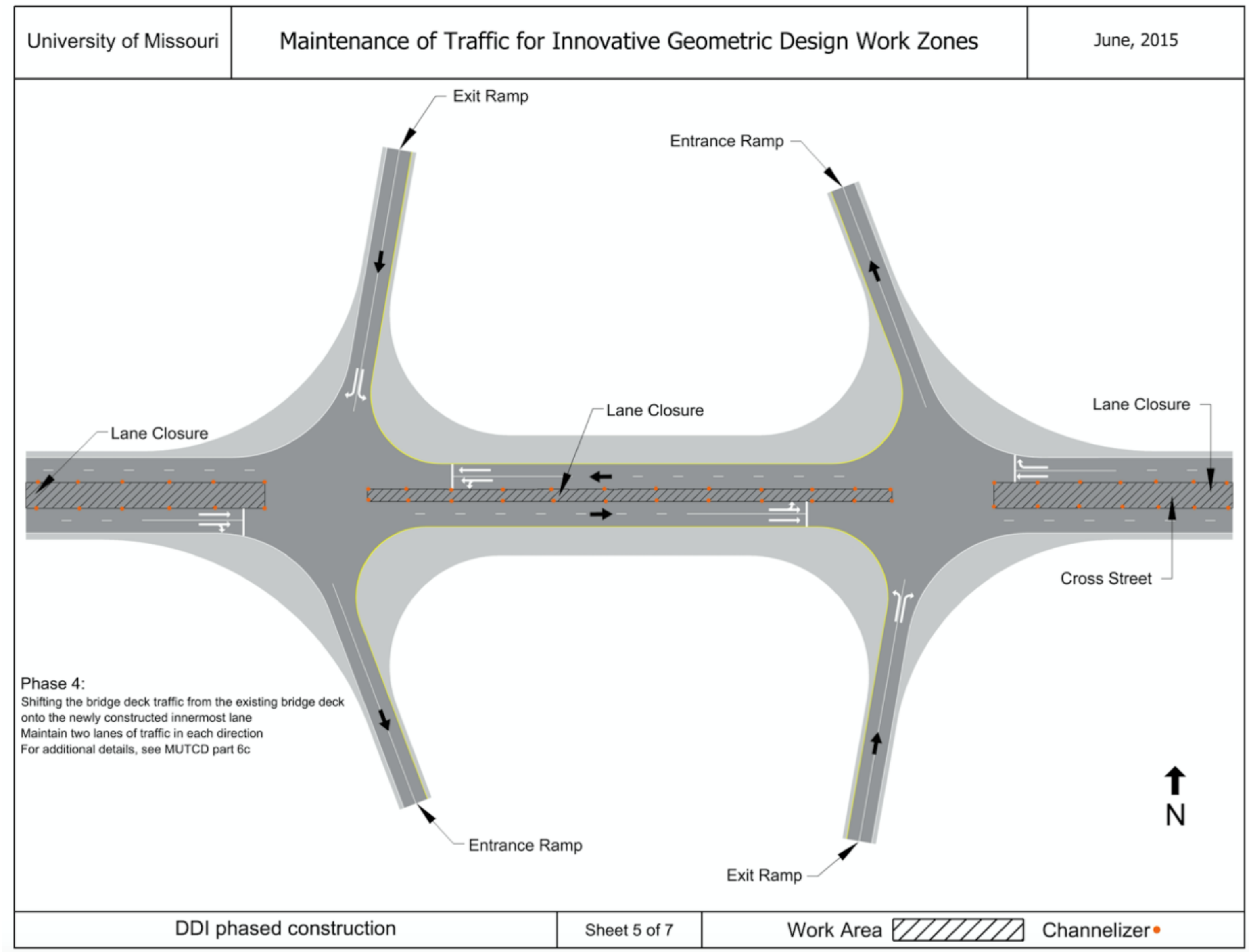


Figure 4.4.3.5 DDI phased construction Phase 4 (median construction)

Phase 5 begins once the bridge deck widening is complete. Utilizing temporary traffic control devices, traffic is shifted to final DDI configuration. This step requires a short complete closure of the interchange to set up the final DDI configuration with temporary traffic control devices. The final signal control is also constructed during this phase. This closure could occur overnight or during weekend periods to minimize effect on area traffic. Once traffic is shifted to the final DDI configuration, constructing the raised medians at each of the crossovers begins. Figure 4.4.3.6 shows the work area and MOT for the final conversion in Phase 5.

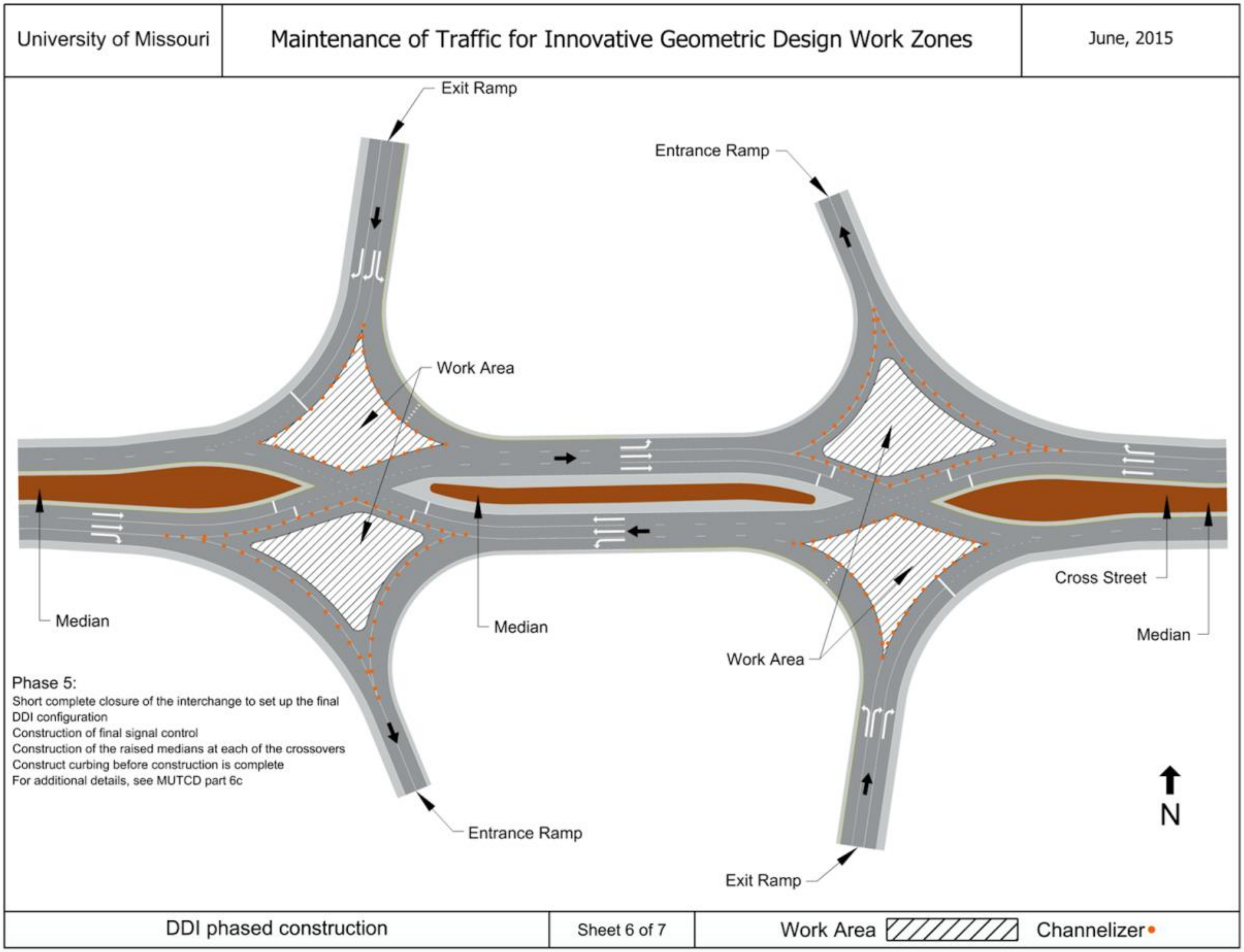


Figure 4.4.3.6 DDI phased construction Phase 5 (short complete closure and final conversion to DDI)

Once the raised medians are constructed, the DDI is fully opened to the final configuration. Figure 4.4.3.7 shows the final DDI configuration.

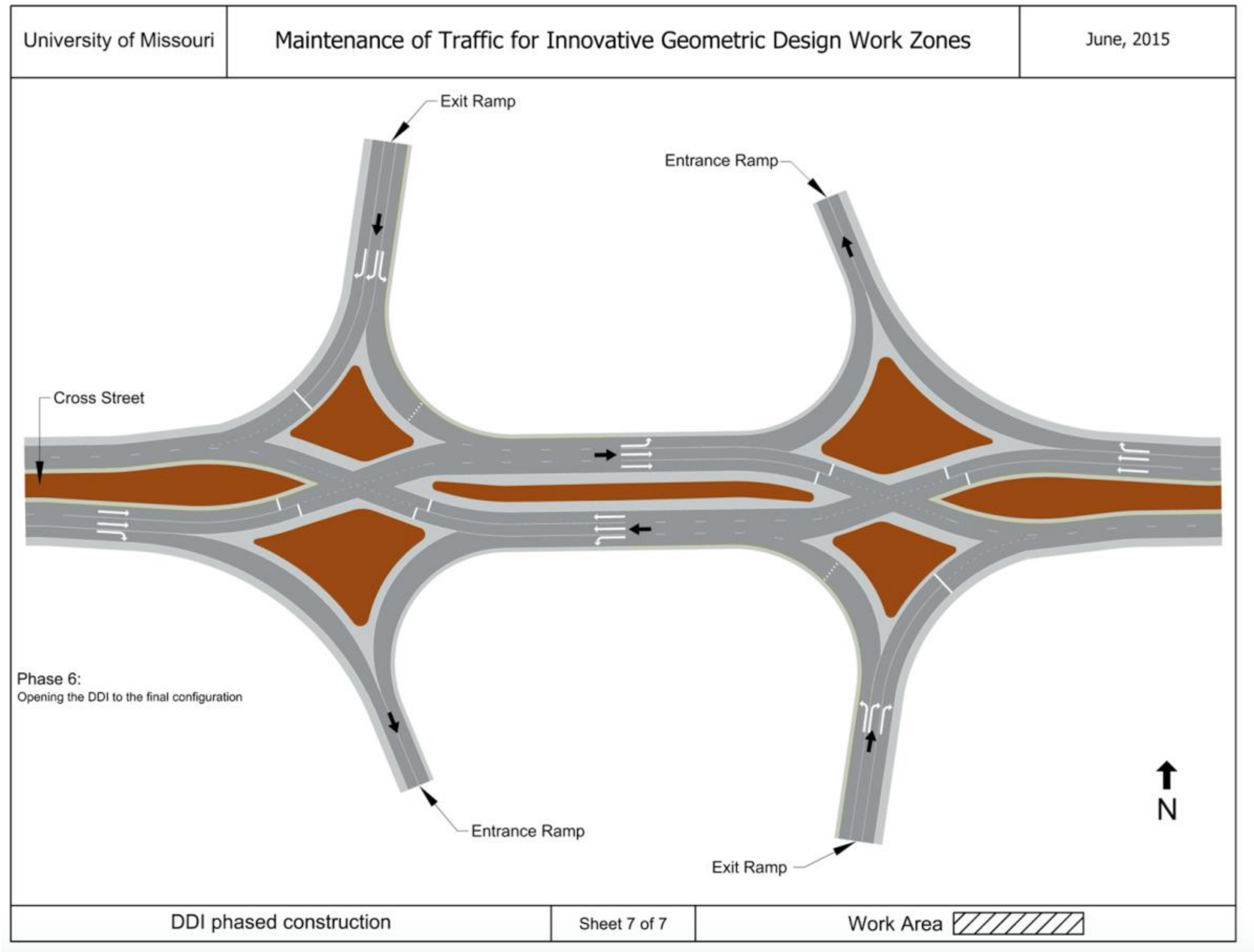


Figure 4.4.3.7 DDI phased construction final configuration

This six-phase approach allows for the retrofit construction of a DDI while maintaining full access with the exception of short closures to shift traffic to the DDI configuration. Deviations from this phasing scheme could occur due to differences in initial intersection configuration, condition of existing infrastructure, etc. High importance should be placed on public outreach with regards to MOT and final DDI configuration to mitigate the risk of wrong way movements through construction.

4.4.4 RCUT

RCUT intersection retrofit construction can typically be completed while maintaining full access throughout construction. A phased retrofit construction scheme of converting an RCUT from a conventional at-grade intersection was developed utilizing three main phases. This scheme was developed utilizing Hughes et al. (2010) as well as DOT sample plans and practitioner interviews. Figure 4.4.4.1 shows the initial intersection considered. The MOT Phasing Diagrams depict an urban RCUT intersection; however, this construction phasing scheme is also applicable to rural setting RCUTs.

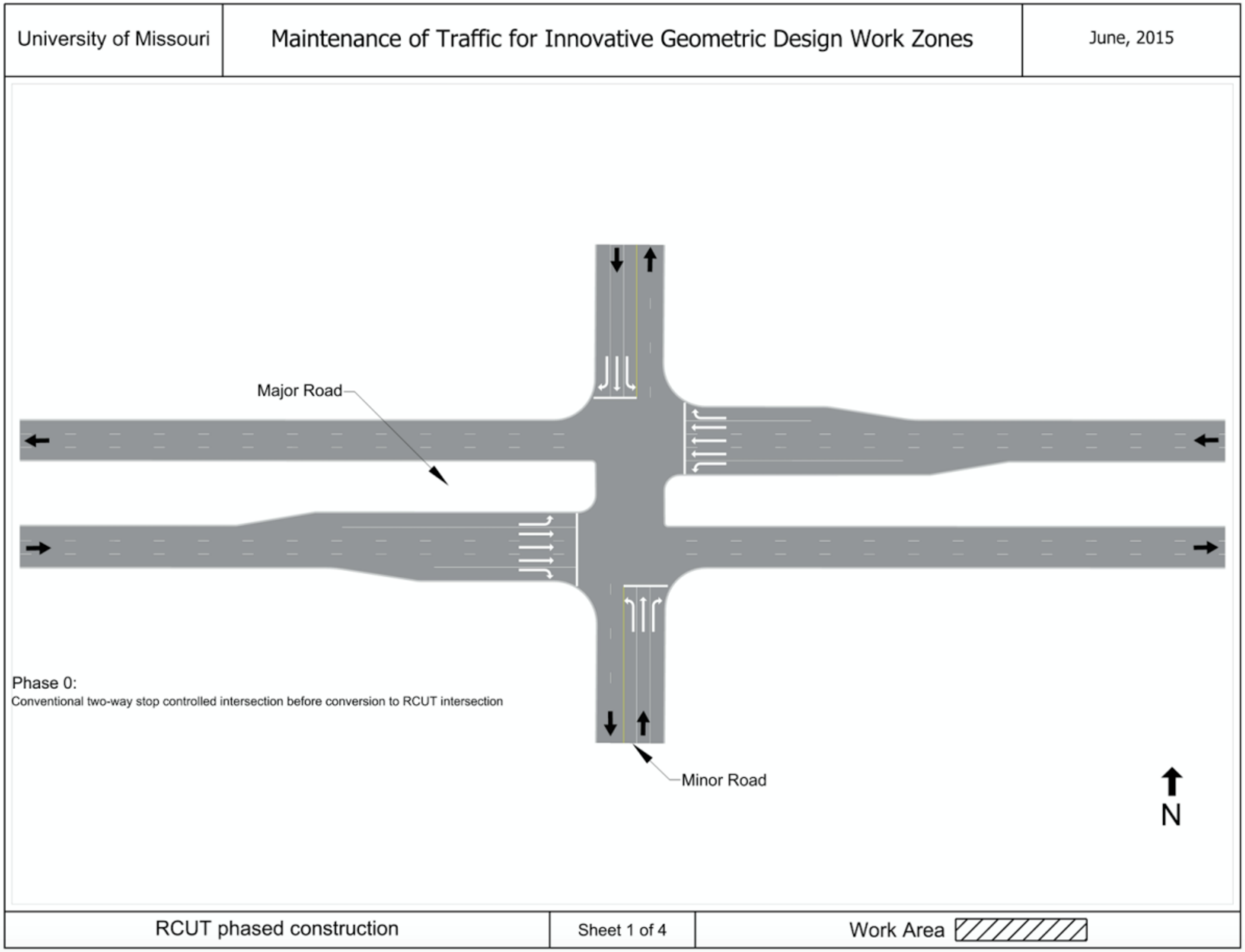


Figure 4.4.4.1 RCUT phased construction initial configuration

Phase 1 involves constructing the median U-turns on the main roadway. This phase is completed with little effect on traffic. Figure 4.4.4.2 shows the Phase 1work area and MOT.

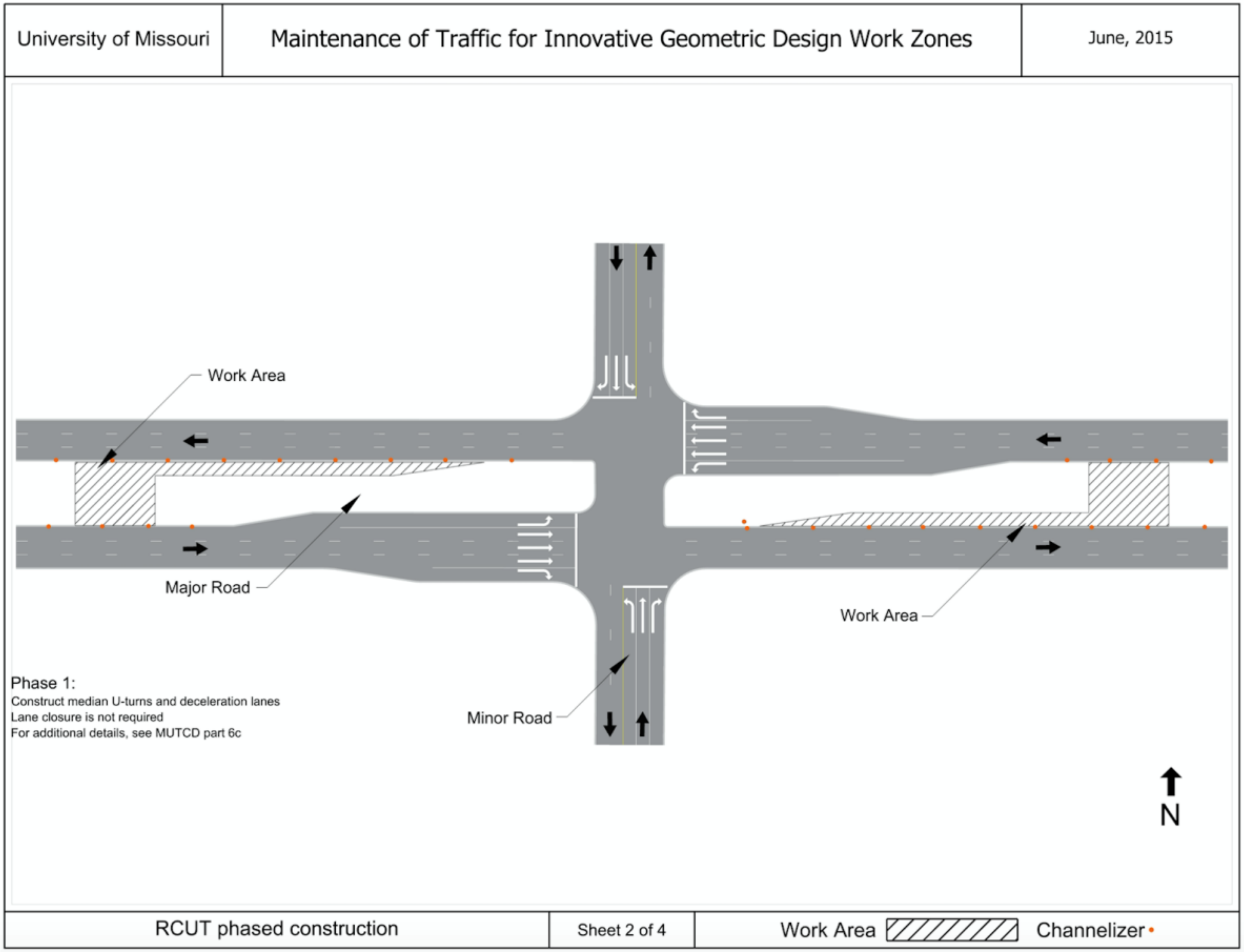


Figure 4.4.4.2 RCUT phased construction Phase 1 (construction of median U-turns)

Phase 2 begins once the median U-turns are constructed. Traffic is shifted from the main roadway left-turning movements and minor roadway through movements onto the newly constructed median U-turns. It is important that travelers are aware of the availability of the U-turn at this point. Removing traffic from the intersection center allows for construction to begin on the RCUT intersection center and minor road medians. Figure 4.4.4.3 shows work area and MOT for Phase 2.

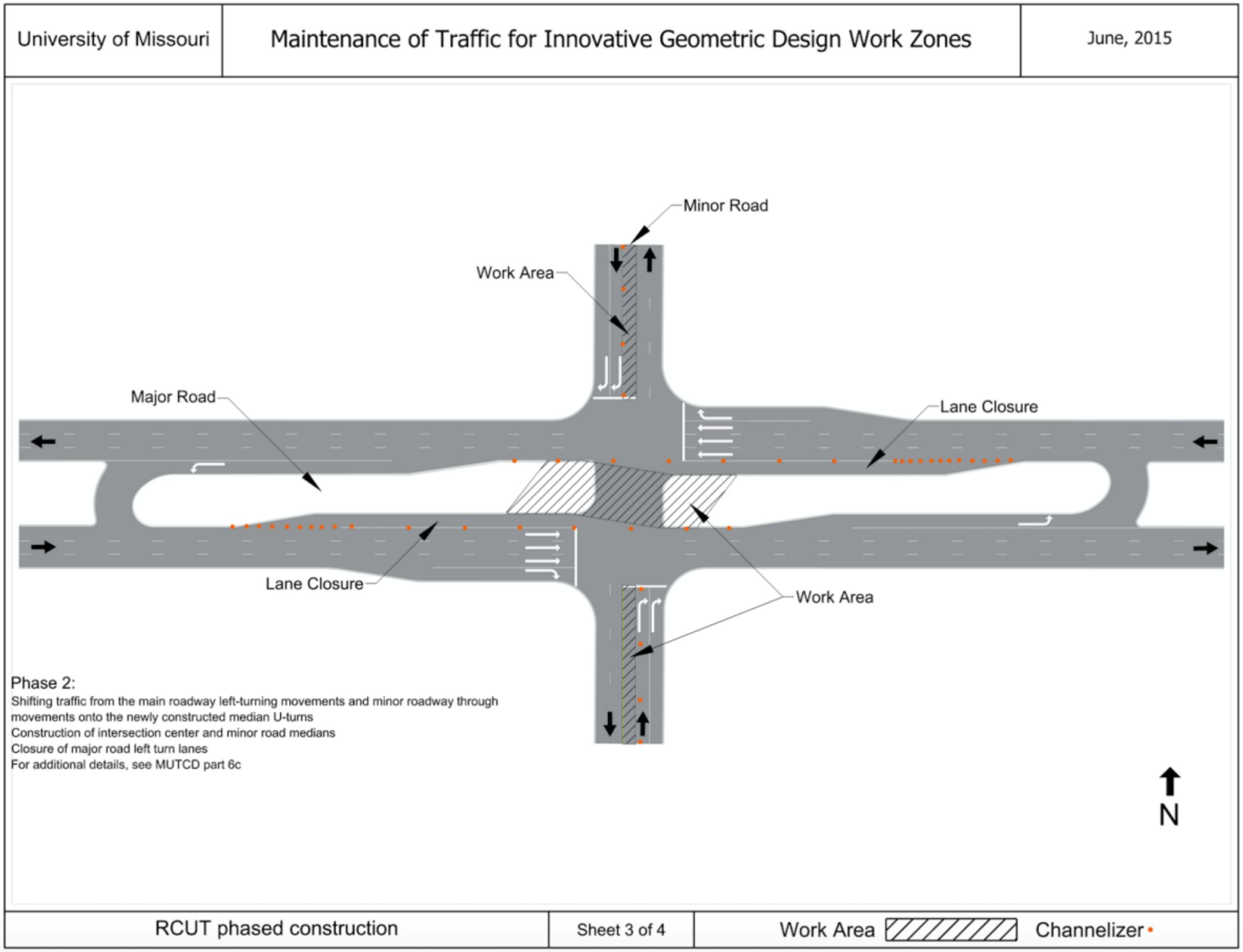


Figure 4.4.4.3 RCUT phased construction Phase 2 (construction of RCUT intersection center and minor road medians)

Once construction within the intersection center and minor roadway medians is complete, traffic is shifted onto the final RCUT configuration. Figure 4.4.4.4 shows the final RCUT intersection configuration. This three phase process allows for the construction of the RCUT intersection while maintaining full access for all movements. Deviations from these MOT Phasing Diagrams could be caused by differing initial configuration, alignments, and other special circumstances.

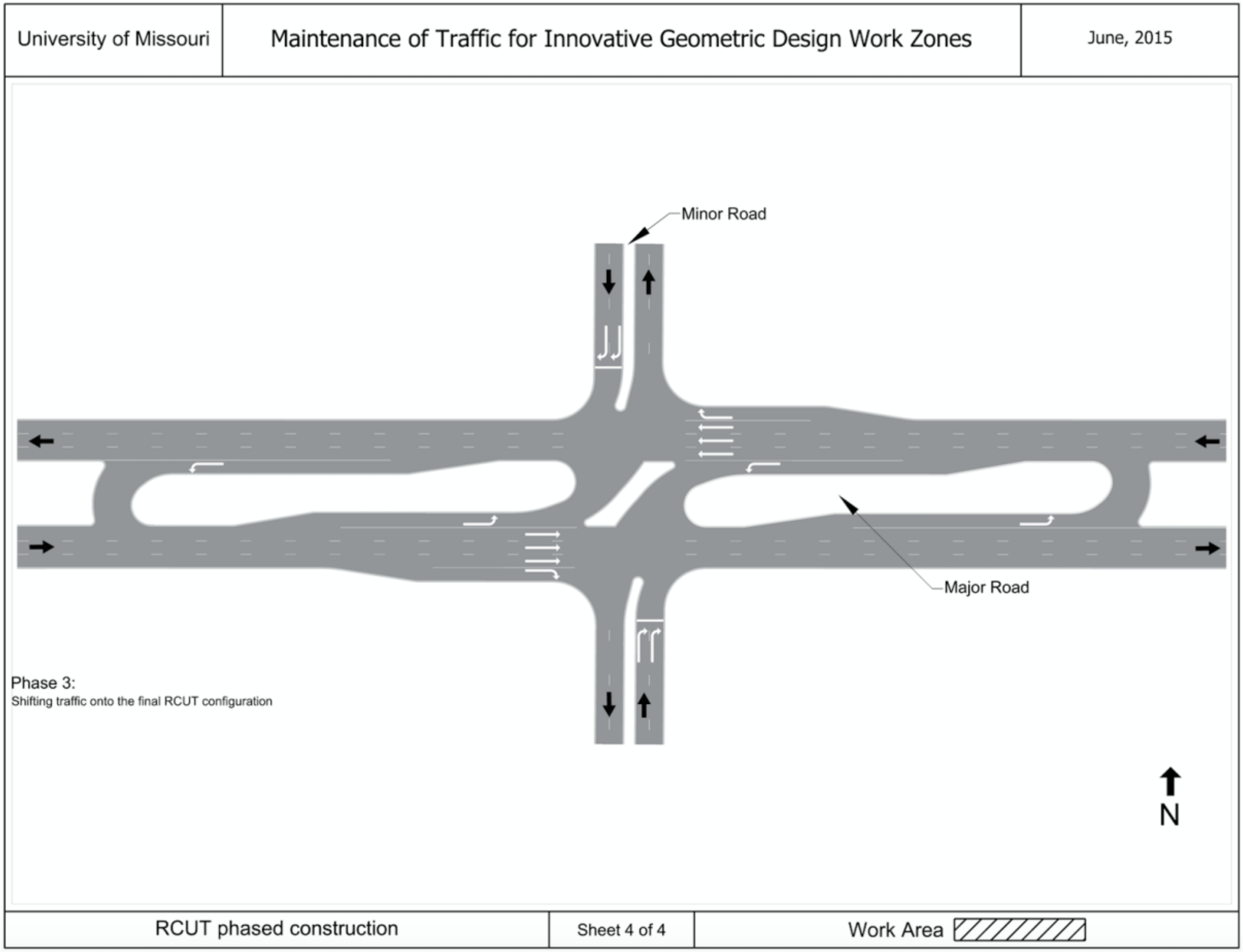


Figure 4.4.4.4 RCUT phased construction final configuration

4.4.5 MUT

A MUT intersection retrofit from a conventional at-grade intersection can be configured to maintain full access during construction. The MUT intersection retrofit construction from a conventional at-grade intersection type was developed utilizing three main phases. This scheme was developed utilizing Hughes et al. (2010) and practitioner interviews. Figure 4.4.5.1 shows the initial intersection considered.

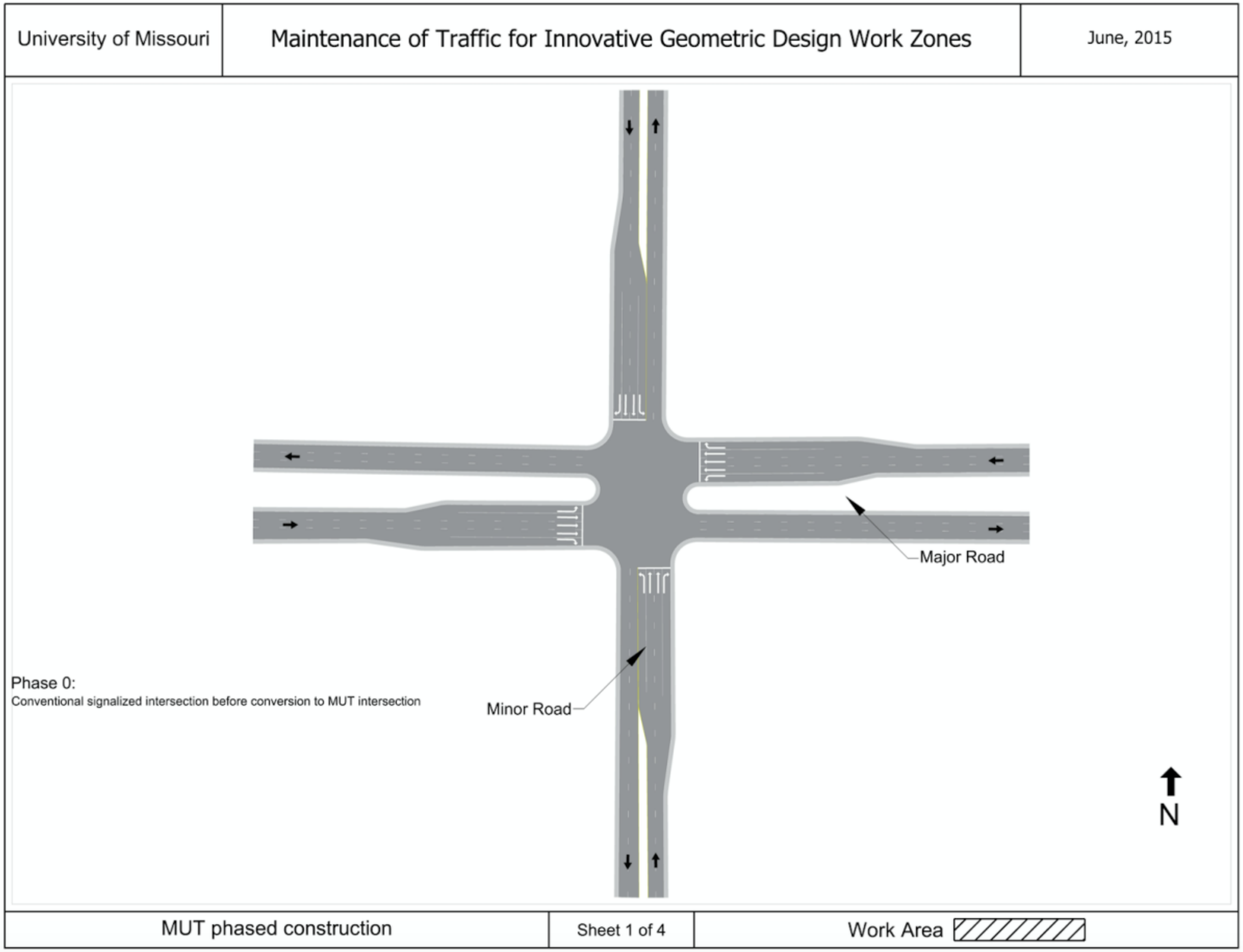


Figure 4.4.5.1 MUT phased construction initial configuration

Phase 1 involves constructing the median U-turns on the appropriate roadways as shown in Figure 4.4.5.2. This construction has little effect on traffic and does not require a lane closure.

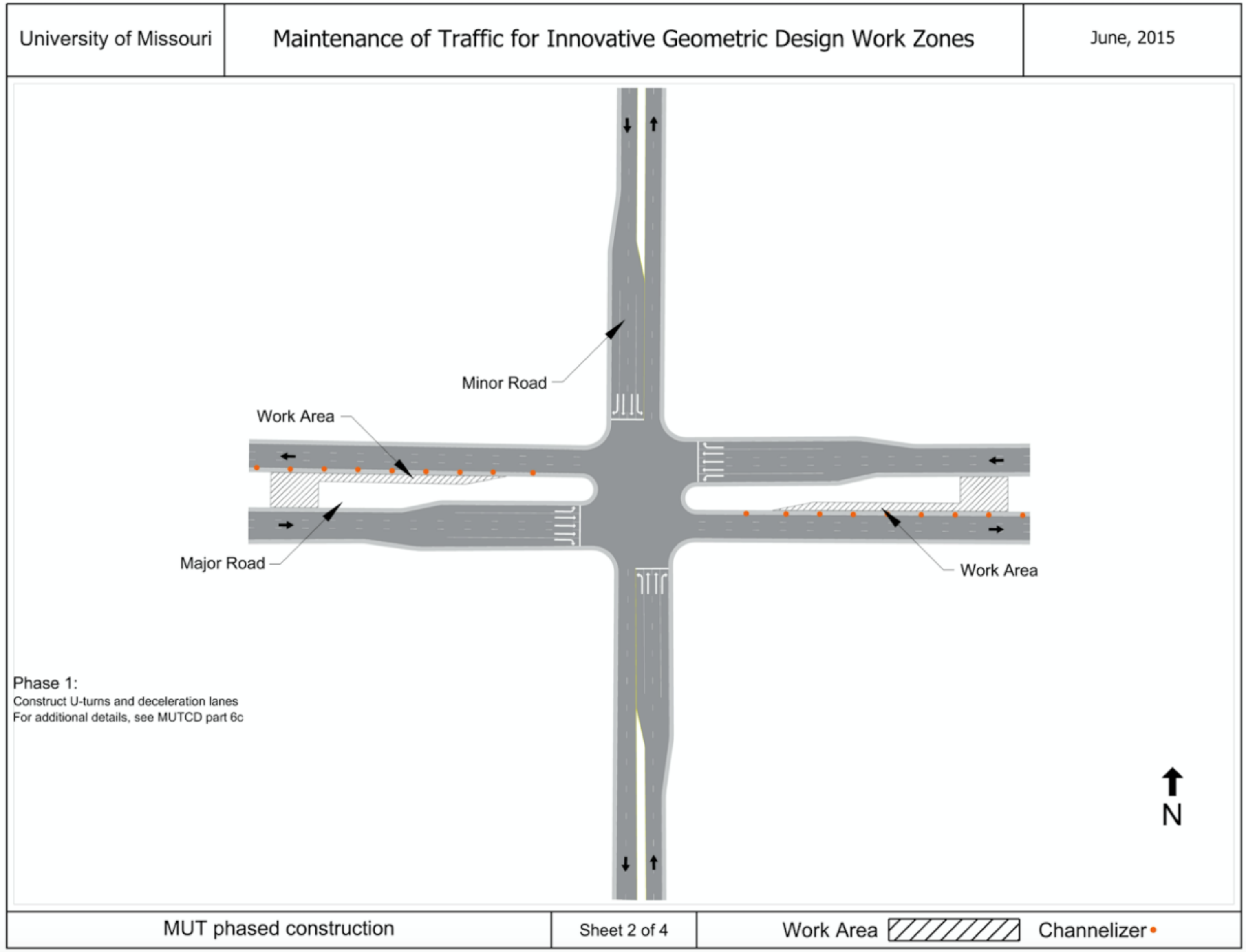


Figure 4.4.5.2 MUT phased construction Phase 1 (construction of median U-turns)

Phase 2 begins once the median U-turns are complete. All left turning movement traffic is shifted onto the median U-turns and the removal of the intersection center and original left-turn bays begins. The change in intersection configuration may require a short full closure of the intersection to setup the temporary traffic control and ensure travelers acknowledge the change in configuration. Figure 4.4.5.3 shows the work area and MOT for the Phase 2 removal of the intersection center and original left-turn bays.

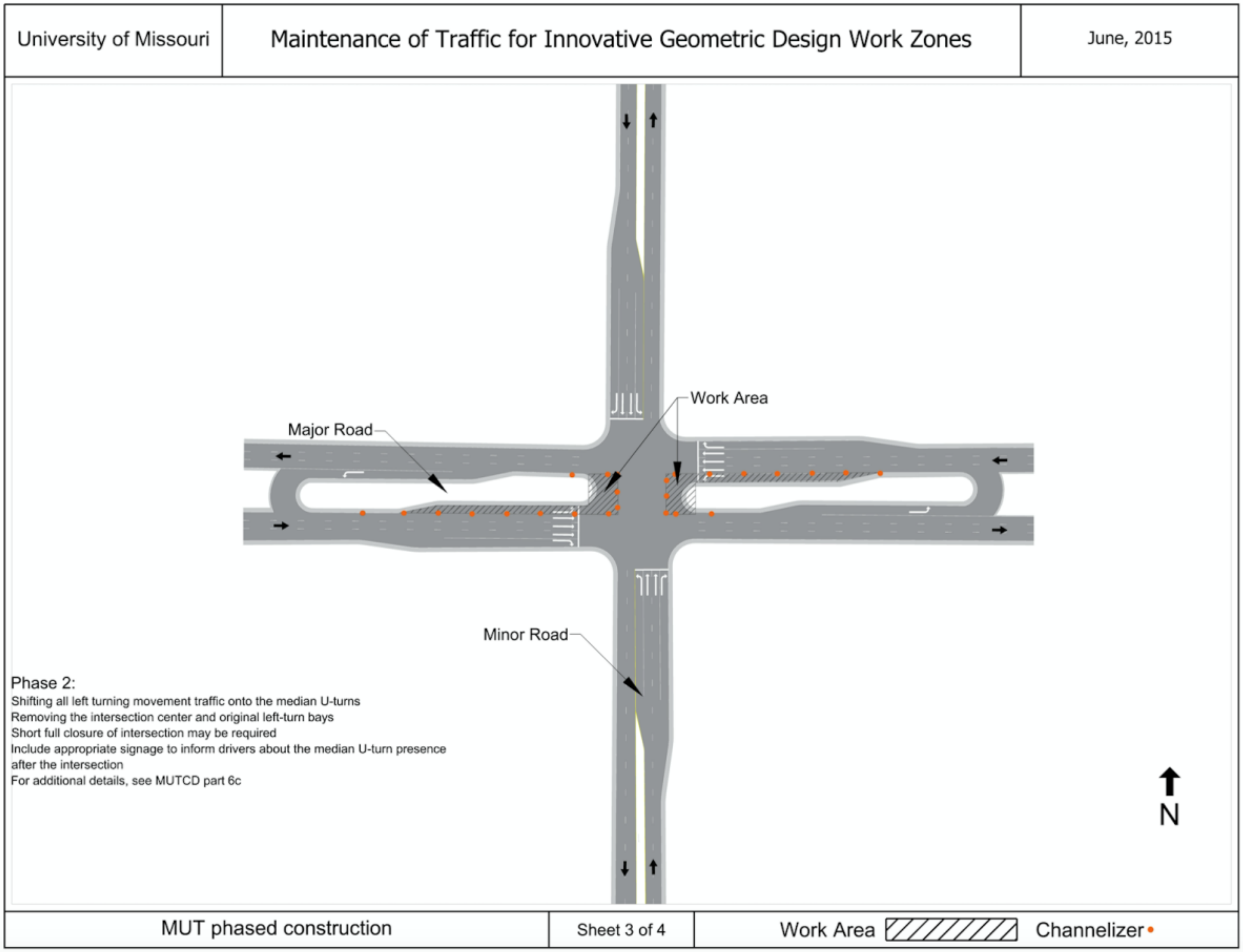


Figure 4.4.5.3 MUT phased construction Phase 2 (removal of intersection center and original left turn bays)

Once removal of the pavement is complete, the temporary traffic control is removed, and the intersection is fully opened to the MUT configuration. Figure 4.4.5.4 shows the final MUT intersection configuration.

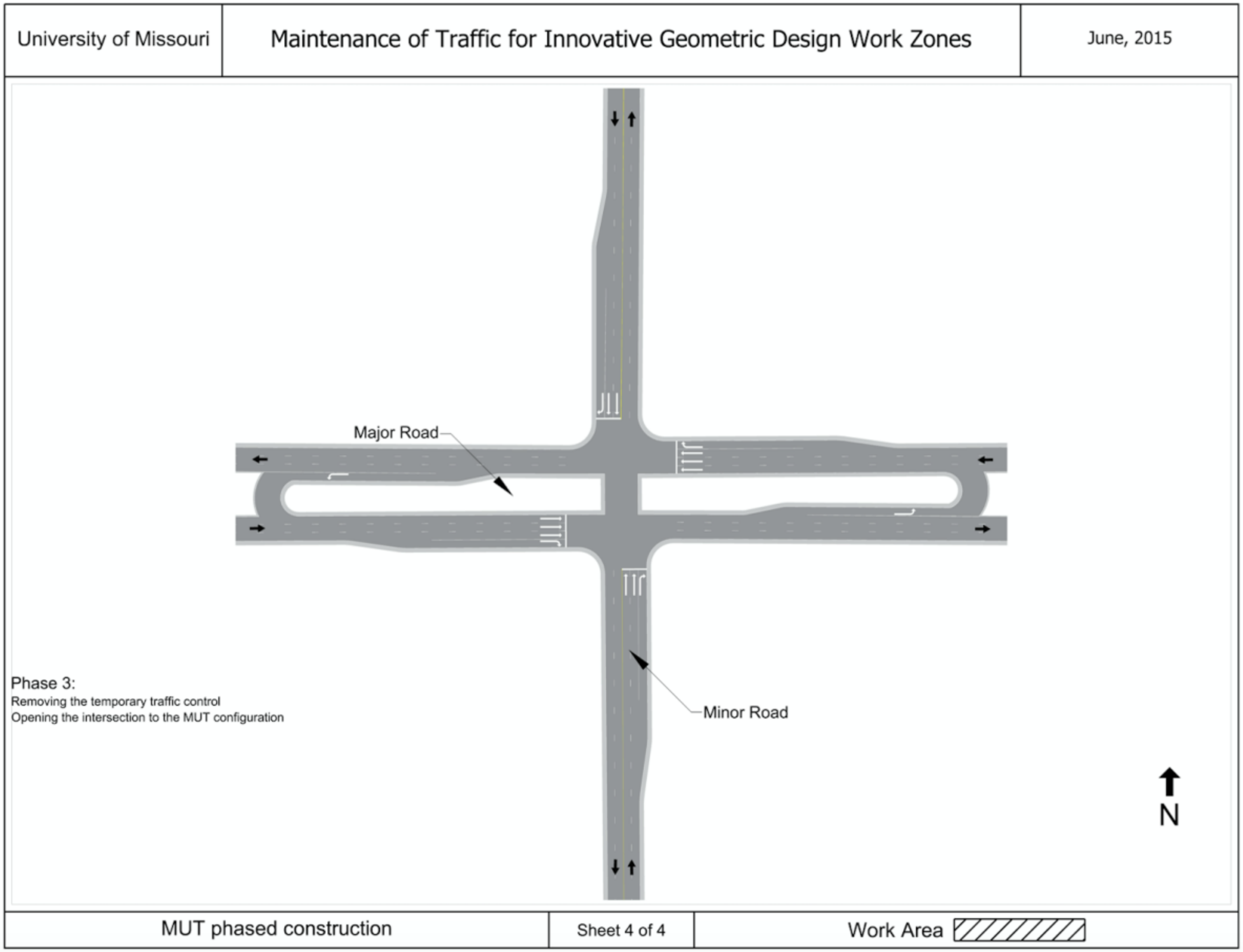


Figure 4.4.5.4 MUT phased construction final configuration

This three phase process allows for the intersection to be constructed while maintaining full access. For the MUT intersection, it is important to make sure drivers know of the median U-turn past the original left-turn point once median U-turns are utilized. This is accomplished through signage in advance of the intersection as well as through public outreach. Deviations from these MOT Phasing Diagrams could be caused by differing initial configuration, alignments, and other special circumstances.

4.4.6 DLT

DLT retrofit construction can be achieved while maintaining complete access through construction. The DLT intersection retrofit construction from a conventional at-grade intersection was developed utilizing four main phases by utilizing Steyn et al. (2014) as well as agency sample plans and practitioner interviews. Figure 4.4.6.1 shows the initial intersection configuration considered.

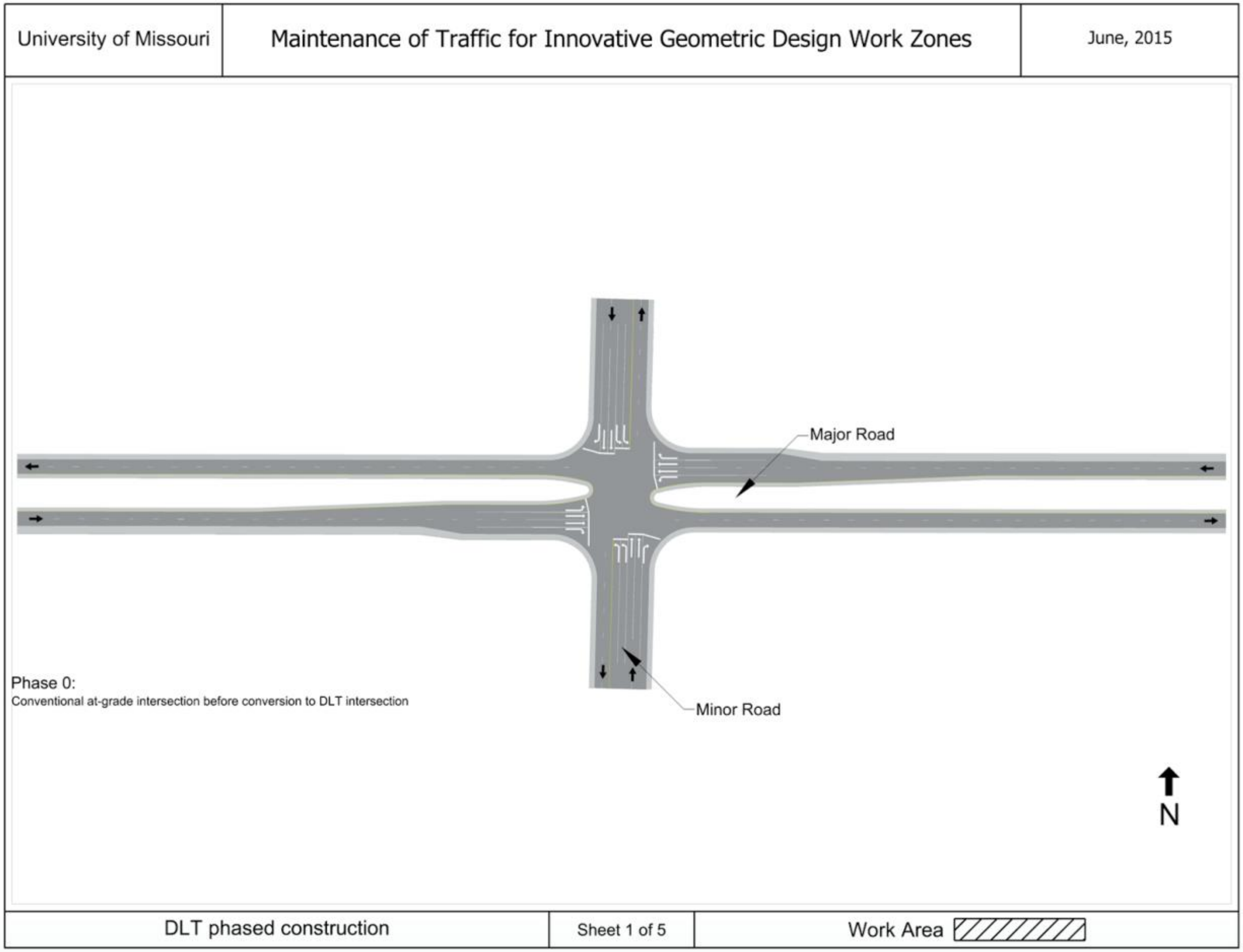


Figure 4.4.6.1 DLT phased construction initial configuration

Phase 1 involves construction of the minor roadway right-turn movements outside of the future left-turn bays as well as construction of the major roadway right-turn movements if applicable. This phase causes little effect to roadway traffic and does not require any lane drops. Figure 4.4.6.2 shows the Phase 1 work area and MOT.

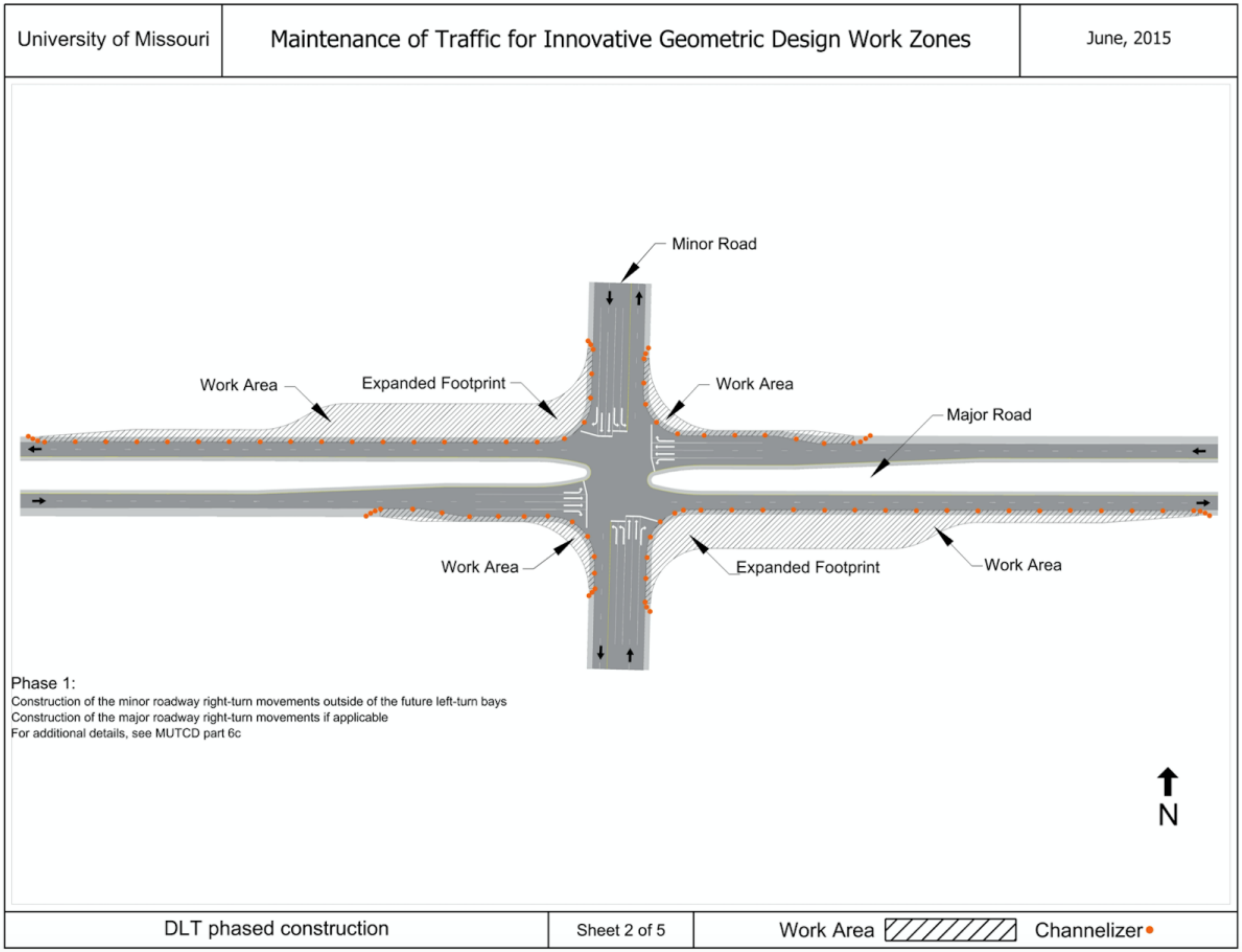


Figure 4.4.6.2 DLT phased construction Phase 1 (construction of right turn movements on major and minor roadways)

Phase 2 involves opening the newly constructed right-turn movements to traffic and beginning construction of the displaced left-turn bays and cross-overs for the main roadway as shown in Figure 4.4.6.3.

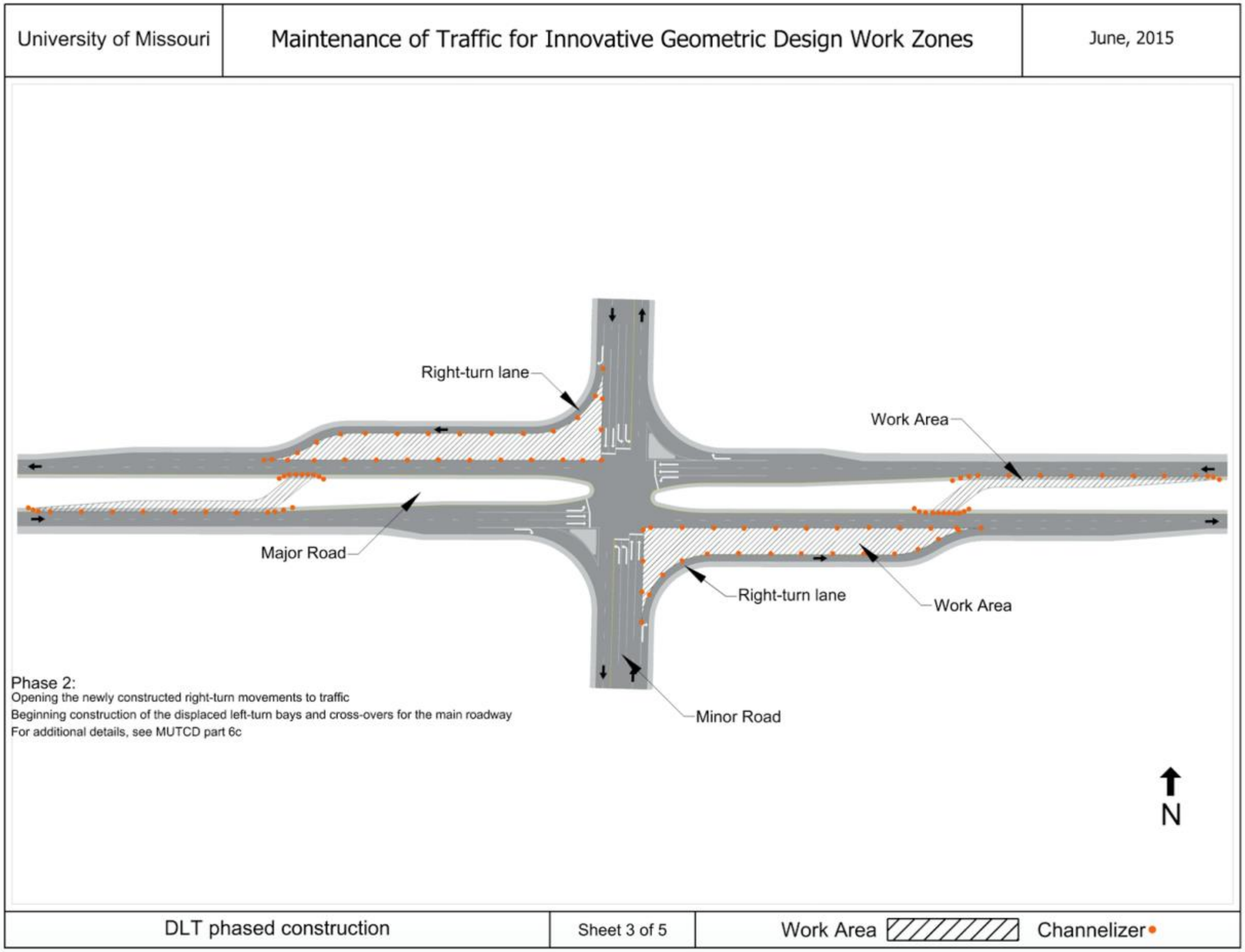


Figure 4.4.6.3 DLT phased construction Phase 2 (construction of displaced left turn lane bays and crossovers for major roadway)

Phase 3 begins once construction of left turn facilities is complete. Traffic is shifted to displaced left-turn bays and the original left-turn bays are closed at the original intersection. Pavement removal of the original left-turn movements is performed through this phase. Figure 4.4.6.4 shows the Phase 3 work area and MOT.

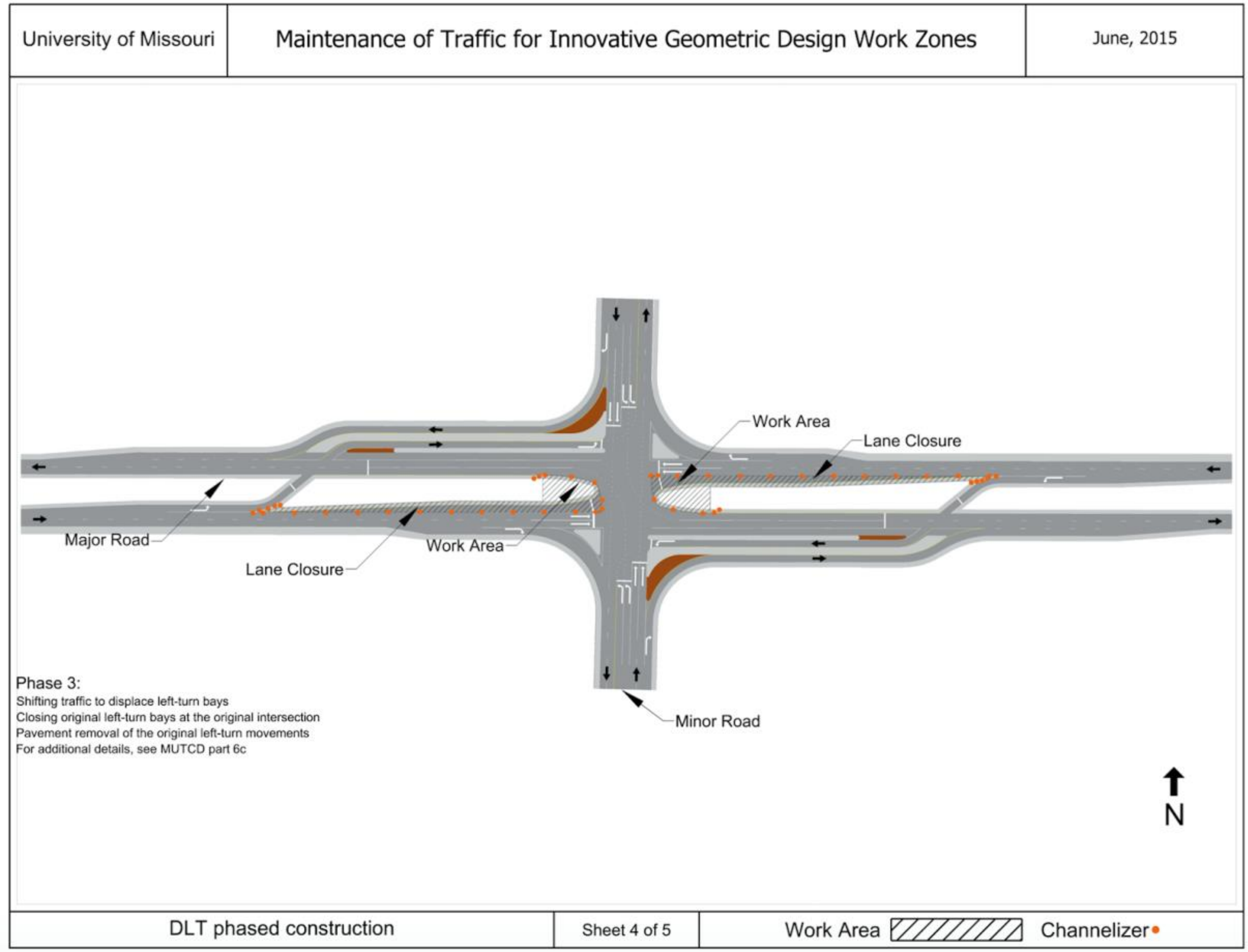


Figure 4.4.6.4 DLT phased construction Phase 3 (pavement removal of original left turn lanes)

Once the pavement removal and new configuration striping is complete, the DLT intersection is fully opened to the final traffic configuration. Figure 4.4.6.5 shows the final DLT configuration. This four phase construction scheme allows for the retrofit of an existing at-grade intersection into a DLT intersection while maintaining full access throughout construction. Deviations from these MOT Phasing Diagrams could be caused by differing initial configuration, alignments, and other special circumstances.

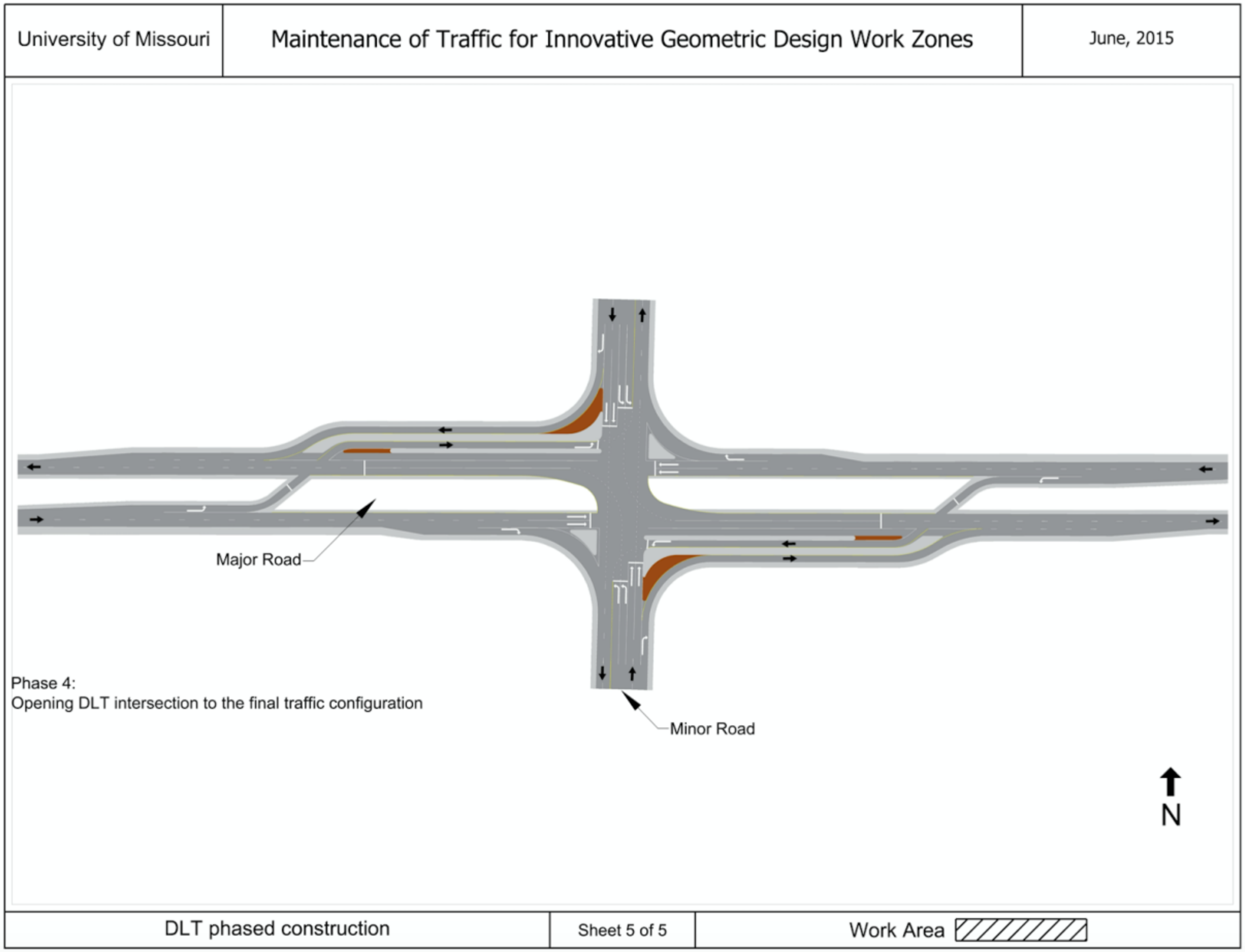


Figure 4.4.6.5 DLT phased construction final configuration

4.5 Maintenance Project MOT Diagrams

Maintenance project MOT diagrams were developed for each intersection type utilizing the design configurations constructed through the MOT Phasing Diagrams. The maintenance project MOT diagrams depict the MOT for various locations of maintenance work through each innovative design. Aspects such as signage are not included in the maintenance MOT diagrams since guidelines are available in the MUTCD. For practitioner convenience, these diagrams are also presented in Appendix D without the text descriptions.

4.5.1 Roundabout

Maintenance requiring a temporary closure of part of the circulatory roadway results in a need for a temporary detour for some of the movements. The use of signage is recommended to indicate that a right turn only is permitted for eastbound traffic and a right turn or through movement only is permitted for southbound traffic. Appropriate buffer spaces should be provided. Detour procedures and signage should follow guidelines stated in the MUTCD. The MOT diagram for the temporary closure the southern part of circulatory roadway is shown in Figure 4.5.1.1.

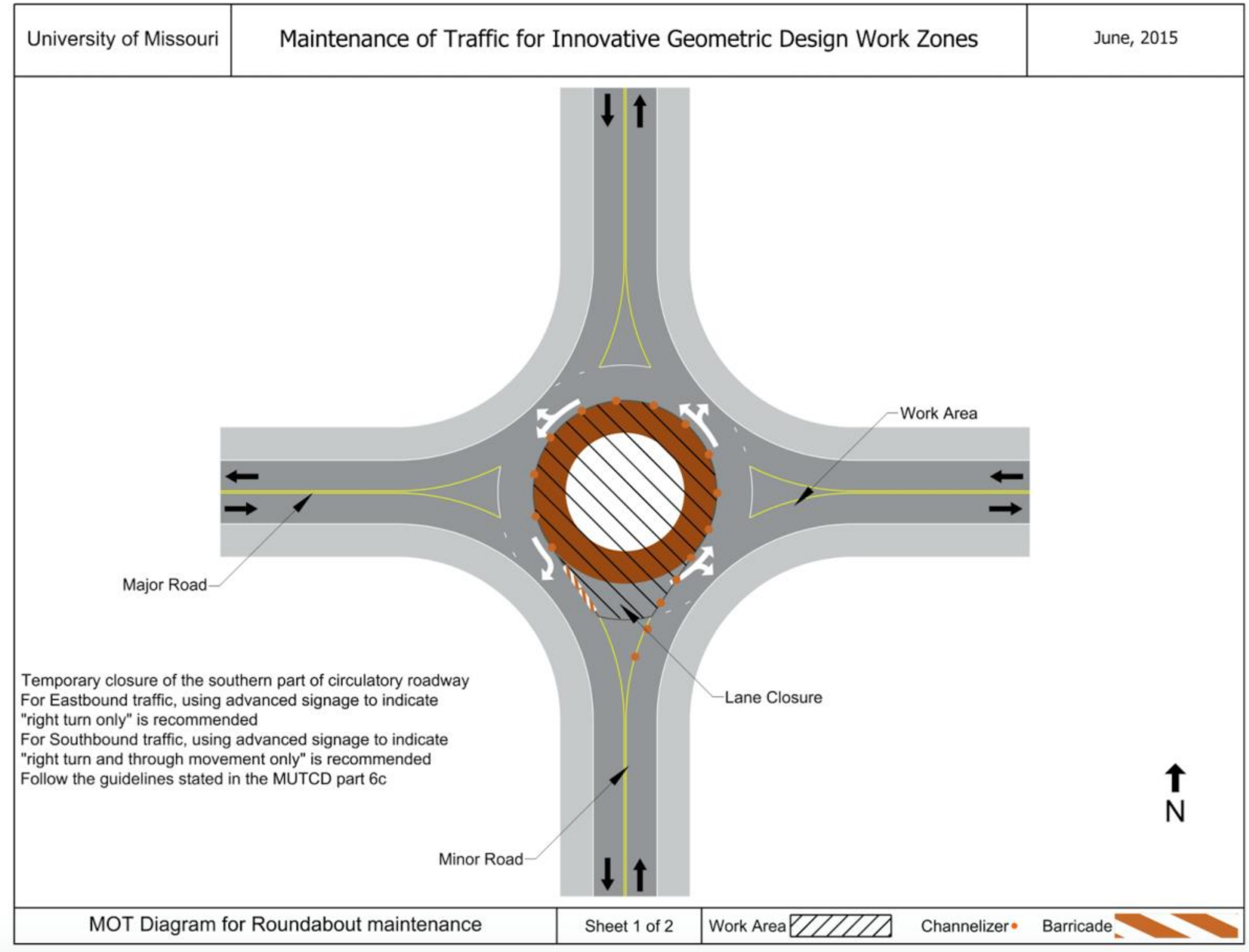


Figure 4.5.1.1 MOT diagram for roundabout maintenance of the southern part of circulatory roadway

Maintenance requiring the temporary closure of half of the intersection results in temporary closure of two intersection legs for the extent of roundabout. A 3-way flagging operation or 3-leg temporary traffic signal could be utilized to maintain traffic on all of the legs except the northbound leg. Speed in this area will be relatively low during the maintenance. Lane drop procedures, signage and flagging should follow guidelines stated in the MUTCD. Figure 4.5.1.2 shows the MOT diagram for the temporary closure of the southern half of the roundabout.

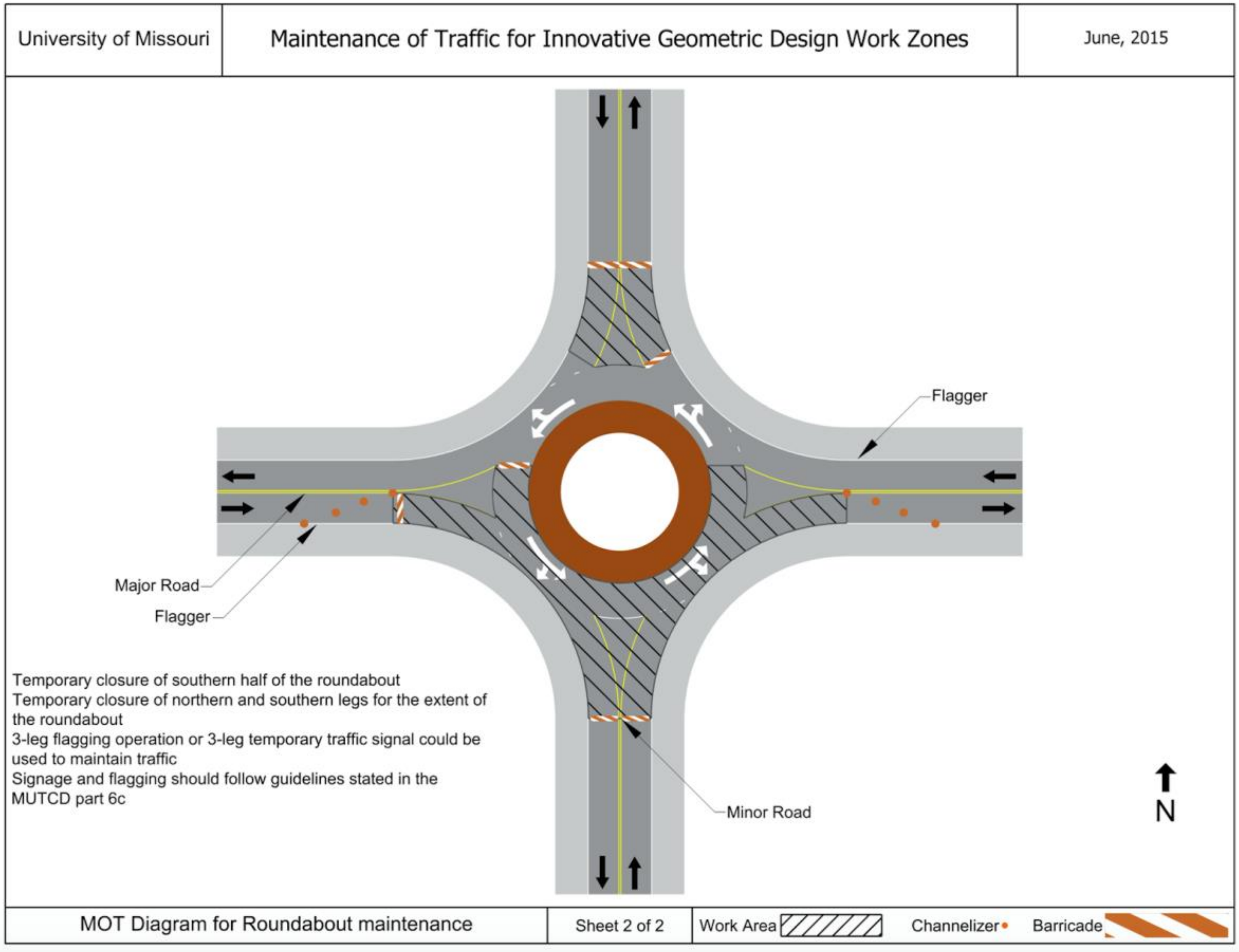


Figure 4.5.1.2 MOT diagram for roundabout maintenance of southern half of the intersection

4.5.2 SPUI

When maintenance requires the closure of the outside left turn lane of a SPUI entrance ramp, the innermost left turn lane should be temporarily closed. This results in the provision for only one left turn lane exiting the SPUI which allows for the maintenance work to commence. Temporary striping should be utilized to guide travelers to the correct lane when performing the left turn movement. Figure 4.5.2.1 shows the MOT diagram for the closure of the outside eastbound left turn lane at a SPUI.

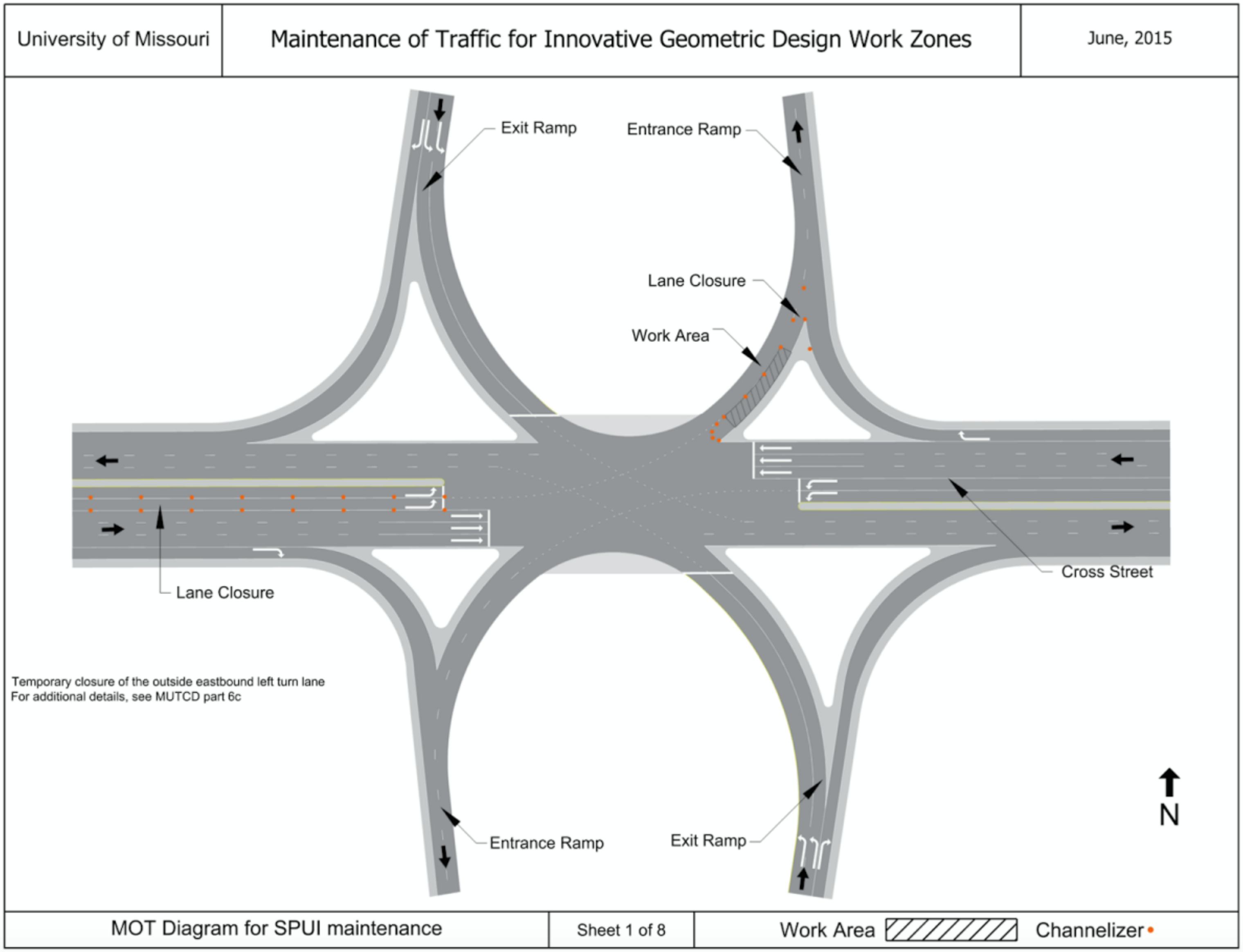


Figure 4.5.2.1 MOT diagram for SPUI maintenance of outside eastbound left turn lane

Maintenance requiring the temporary closure of the inside left turn lane of the entrance ramp results in a temporary closure of the innermost left turn lane on the SPUI. This allows for only one lane of left turn traffic exiting the SPUI to accommodate the maintenance work. Figure 4.5.2.2 shows the MOT diagram for the closure of the inside eastbound left turn lane.

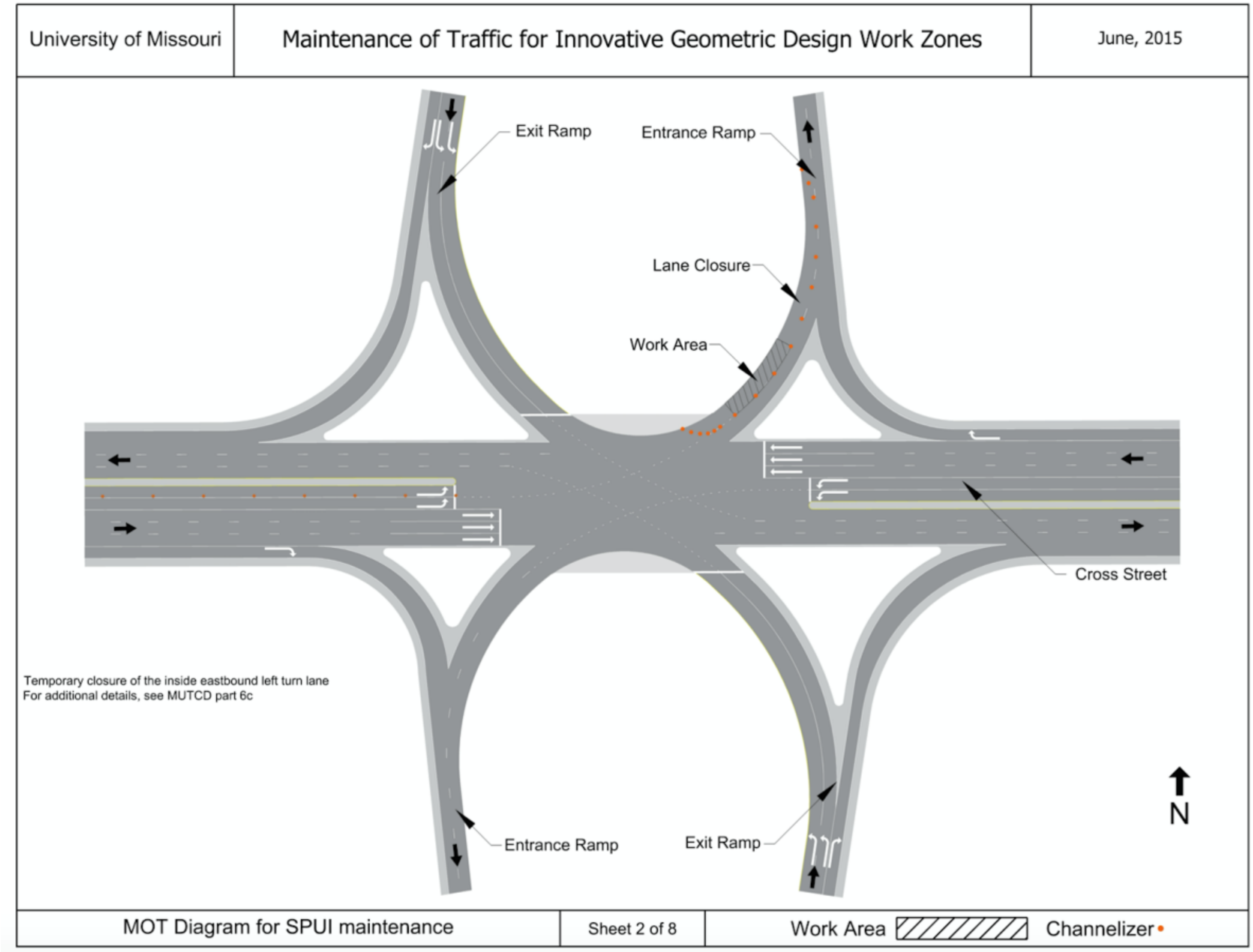


Figure 4.5.2.2 MOT diagram for SPUI maintenance of inside eastbound left turn lane

Maintenance requiring the temporary closure of the right turn entrance ramp results in the need of a temporary detour if right turn exit ramp is a single lane. For developing a detour, “Road Closure with Off-Site Detour” typical applications within the MUTCD should be applied to mitigate traffic effects. Figure 4.5.2.3 shows the MOT diagram for the maintenance of the westbound right turn entrance ramp.

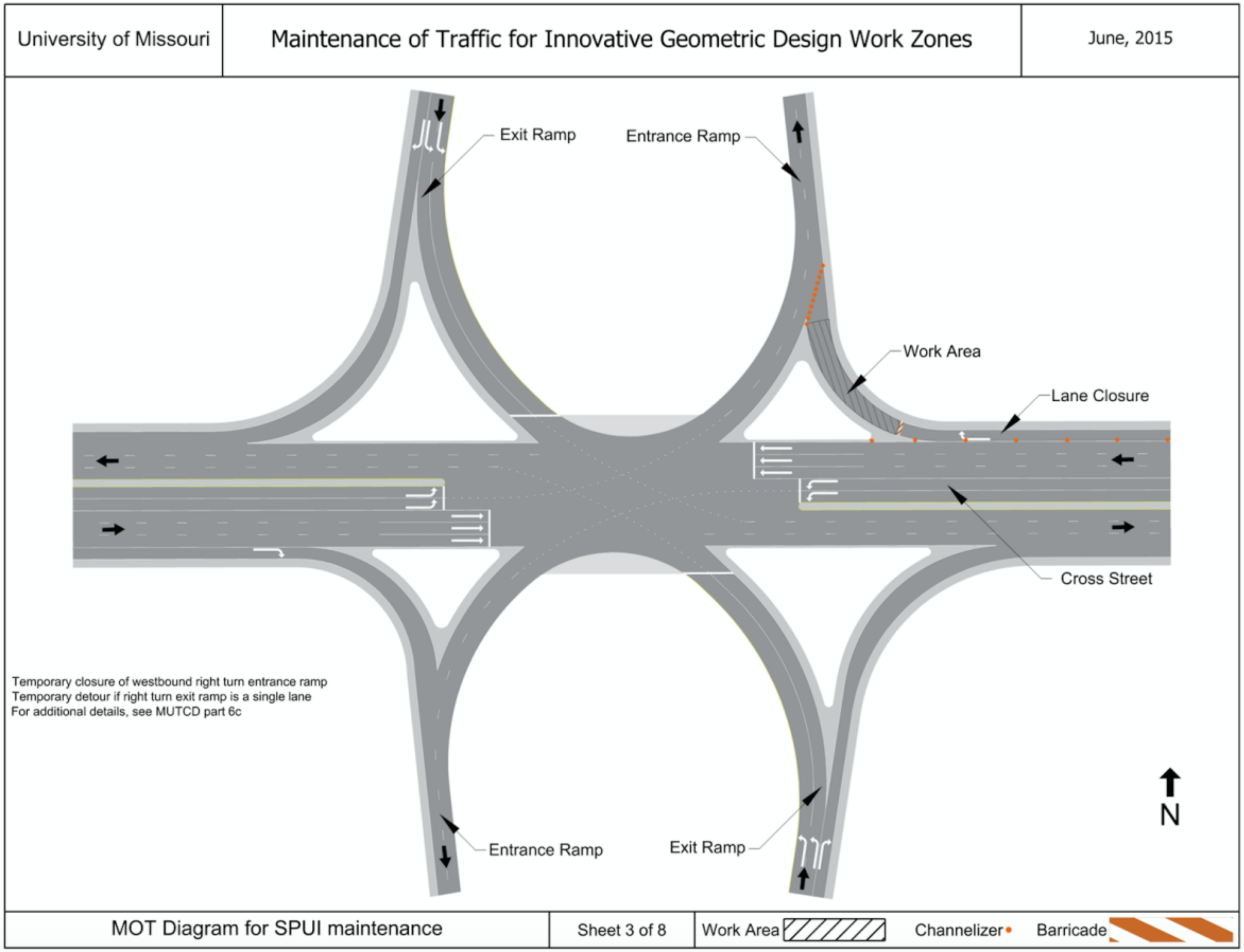


Figure 4.5.2.3 MOT diagram for SPUI maintenance of westbound right turn entrance ramp

Maintenance work involving a temporary closure of the outermost lane through a SPUI results in a temporary closure of the outermost lane throughout the extent of the SPUI. Full access may be maintained for all movements through this temporary closure. Figure 4.5.2.4 shows the MOT diagram for the temporary closure of the westbound outermost lane at a SPUI.

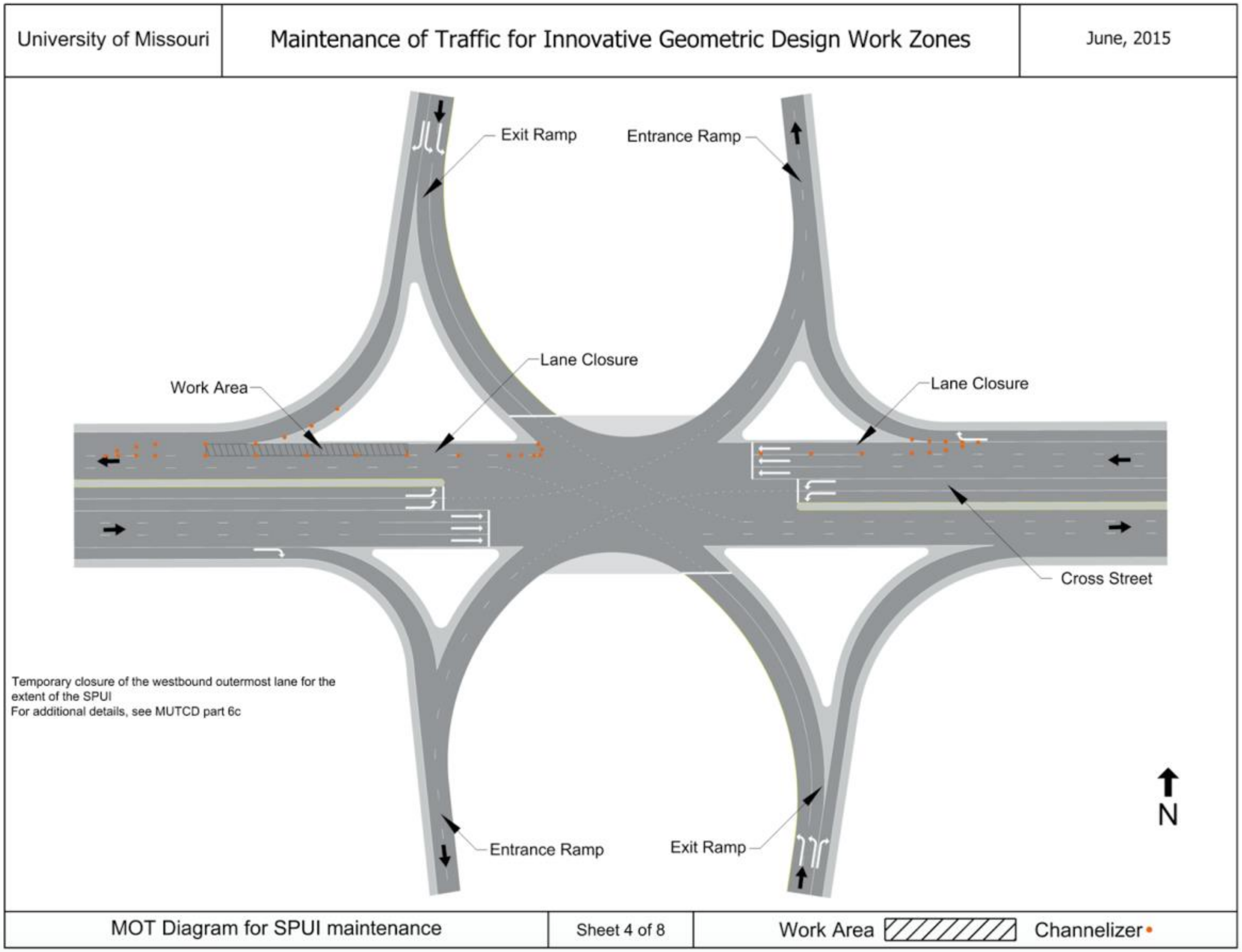


Figure 4.5.2.4 MOT diagram for SPUI maintenance of westbound outermost lane

Maintenance requiring a temporary closure of the center lane through the SPUI results in a temporary closure of the two outer lanes through the SPUI. This closure extends through the entire SPUI to ensure that drivers follow the MOT configuration and results in only a single lane of through traffic. Typical lane drop procedures and signage should follow MUTCD standards. Figure 4.5.2.5 shows the MOT diagram for the maintenance of the center lane.

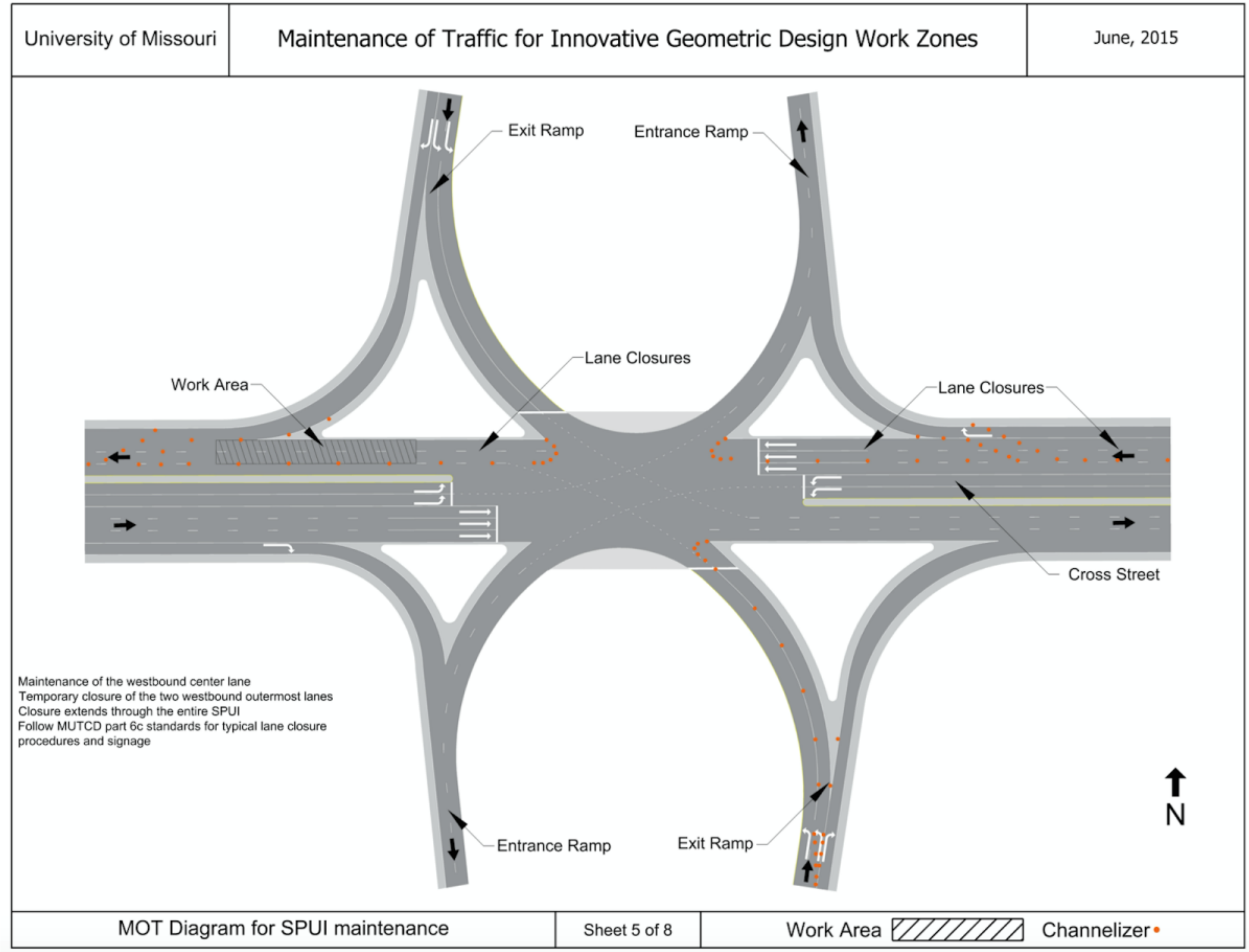


Figure 4.5.2.5 MOT diagram for SPUI maintenance of the westbound center lane

Maintenance requiring a temporary closure of the innermost lane results in a temporary closure of most of the innermost through lane for the extent of the SPUI. Lane drop procedures and signage should be followed as stated in the MUTCD. Figure 4.5.2.6 shows the MOT diagram for the maintenance of the westbound innermost lane.

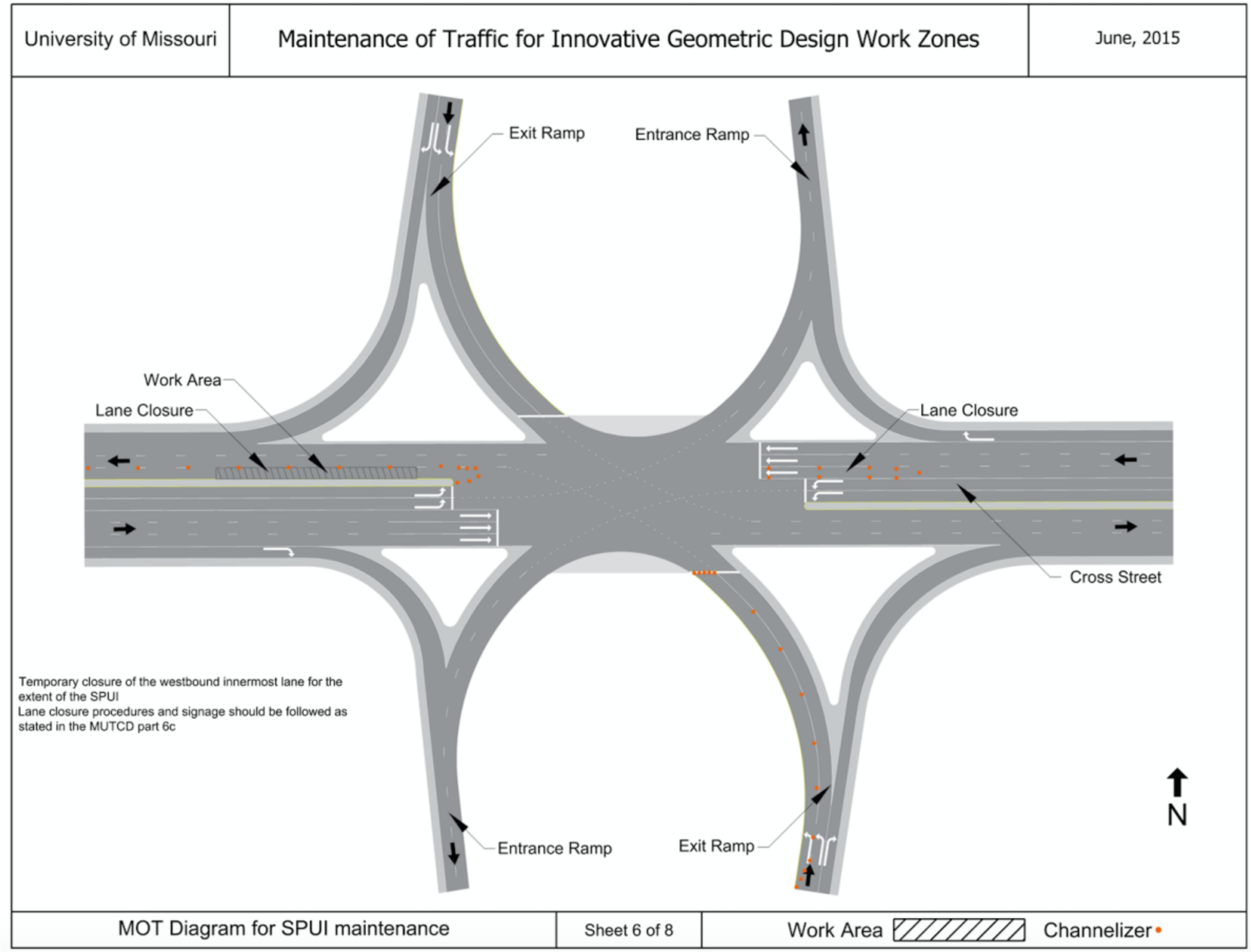


Figure 4.5.2.6 MOT diagram for SPUI maintenance of the innermost westbound lane

Maintenance requiring a temporary closure of the right turn exit ramp requires the use of a temporary detour if the ramp is single lane. Detour procedures and signage as stated in the MUTCD should be followed. The MOT diagram for the temporary closure of the northbound exit ramp right turn lane is shown in Figure 4.5.2.7.

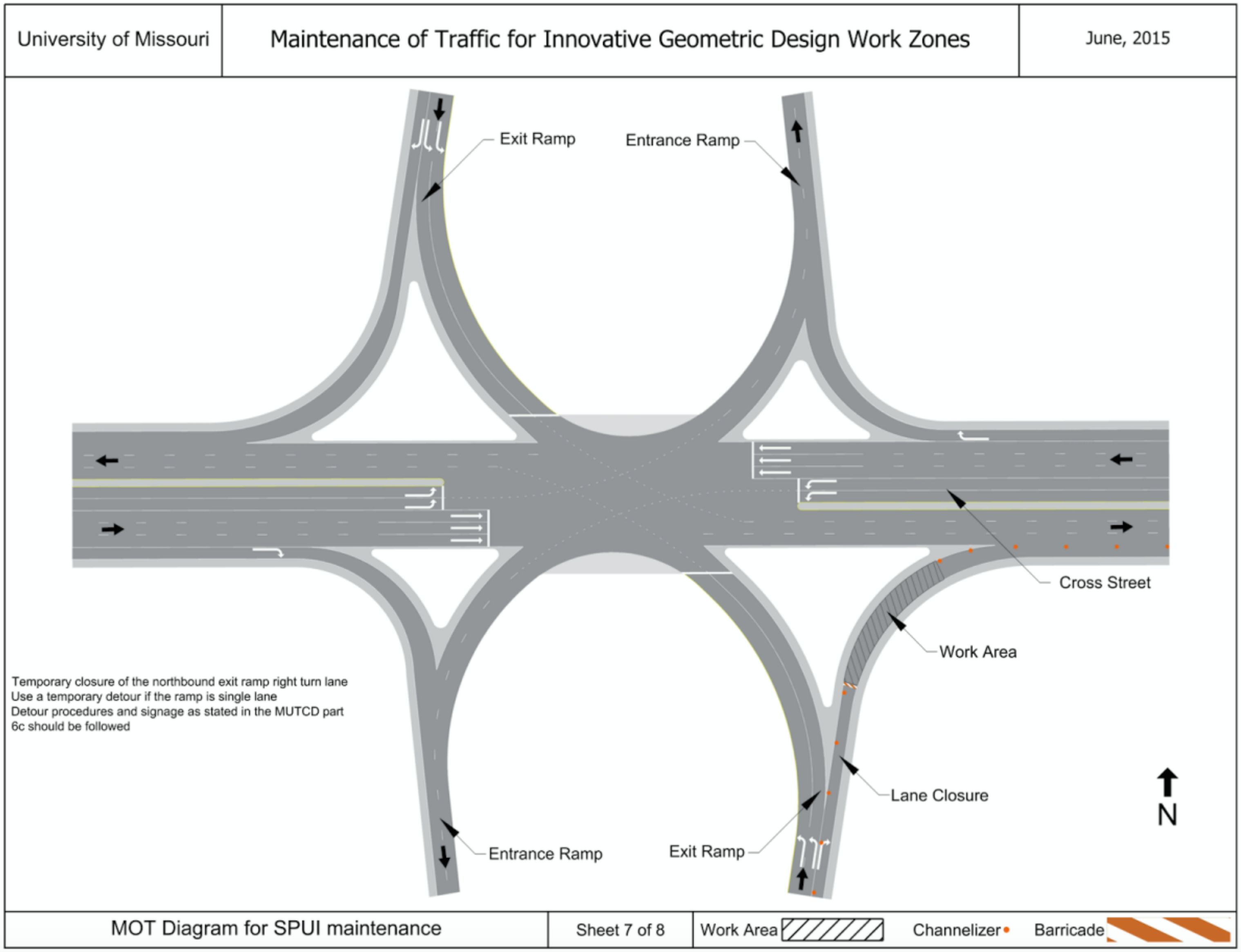


Figure 4.5.2.7 MOT diagram for SPUI maintenance of the northbound exit ramp right turn lane

Maintenance requiring a temporary closure of center of the intersection in a SPUI results in a temporary closure of all left turn lanes on the exit ramps. On the crossroad, the outer left turn lanes and innermost through lanes in both directions need to be temporarily closed. Lane closure, lane drop procedures and signage should be followed as stated in the MUTCD. Figure 4.5.2.8 shows the MOT diagram for the maintenance of the center of the SPUI.

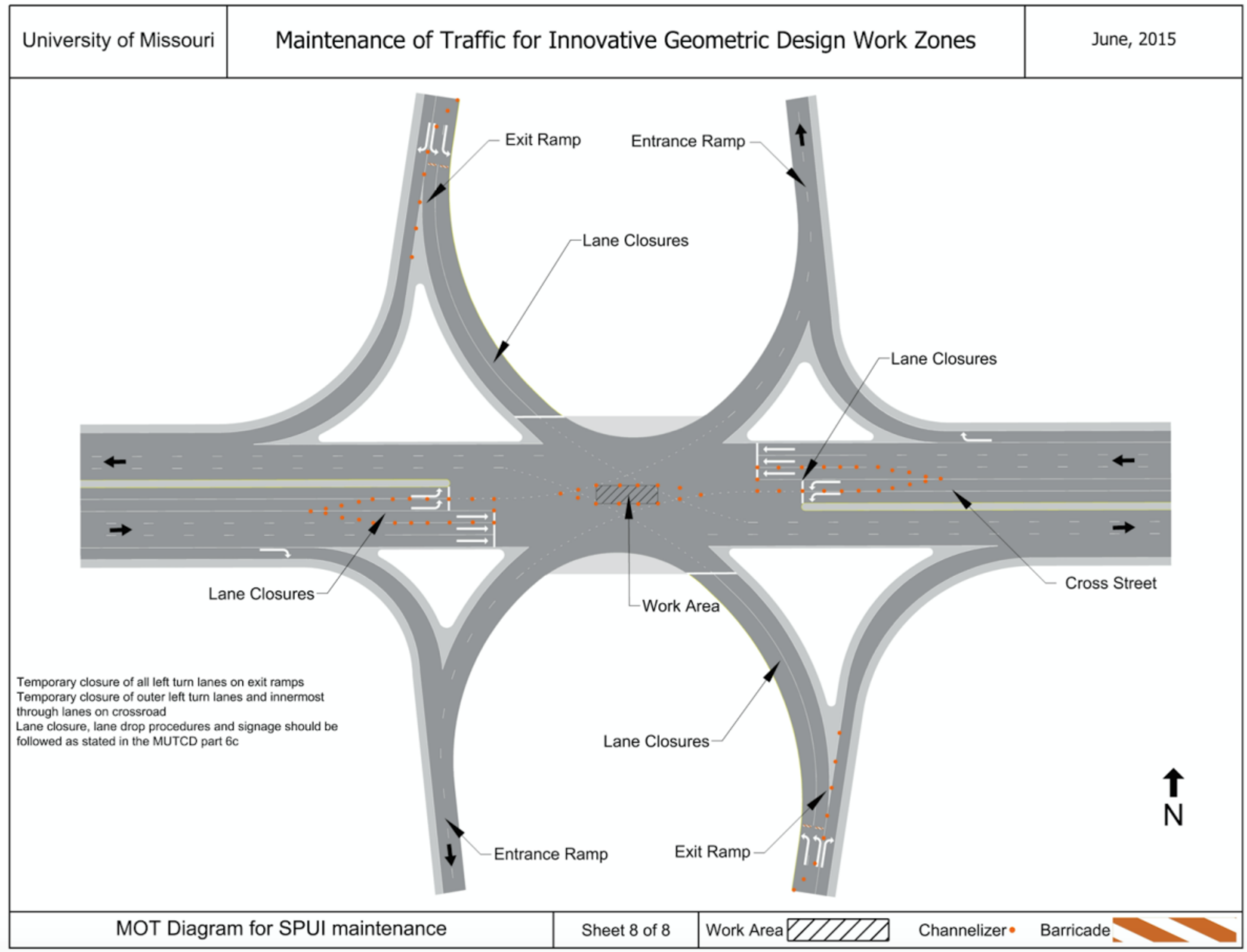


Figure 4.5.2.8 MOT diagram for SPUI maintenance of the intersection center

4.5.3 DDI

Maintenance requiring a temporary closure of the left turn entrance ramp lane results in a need for a temporary detour for the left turn movement. Detour procedures and signage should follow the MUTCD guidelines. Figure 4.5.3.1 shows the MOT diagram for the temporary closure of the left turn lane for the southbound entrance ramp.

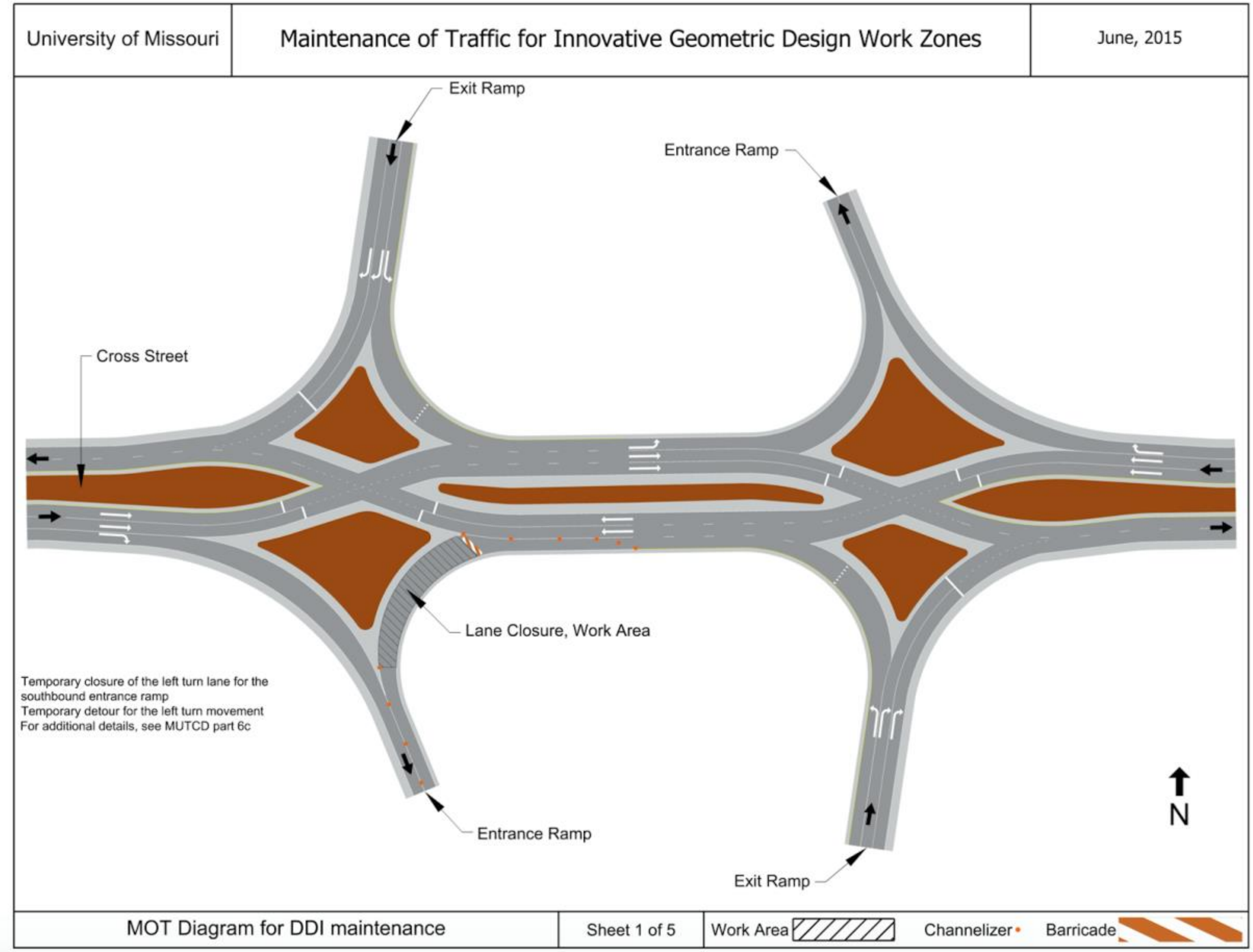


Figure 4.5.3.1 MOT diagram for DDI maintenance within the left turn lane for the southbound entrance ramp

Maintenance requiring a temporary closure of the left turn exit ramp results in a need for a temporary detour. Detour procedures and signage should follow guidelines stated in the MUTCD. The MOT diagram for the temporary closure of the southbound left turn exit ramp is shown in Figure 4.5.3.2.

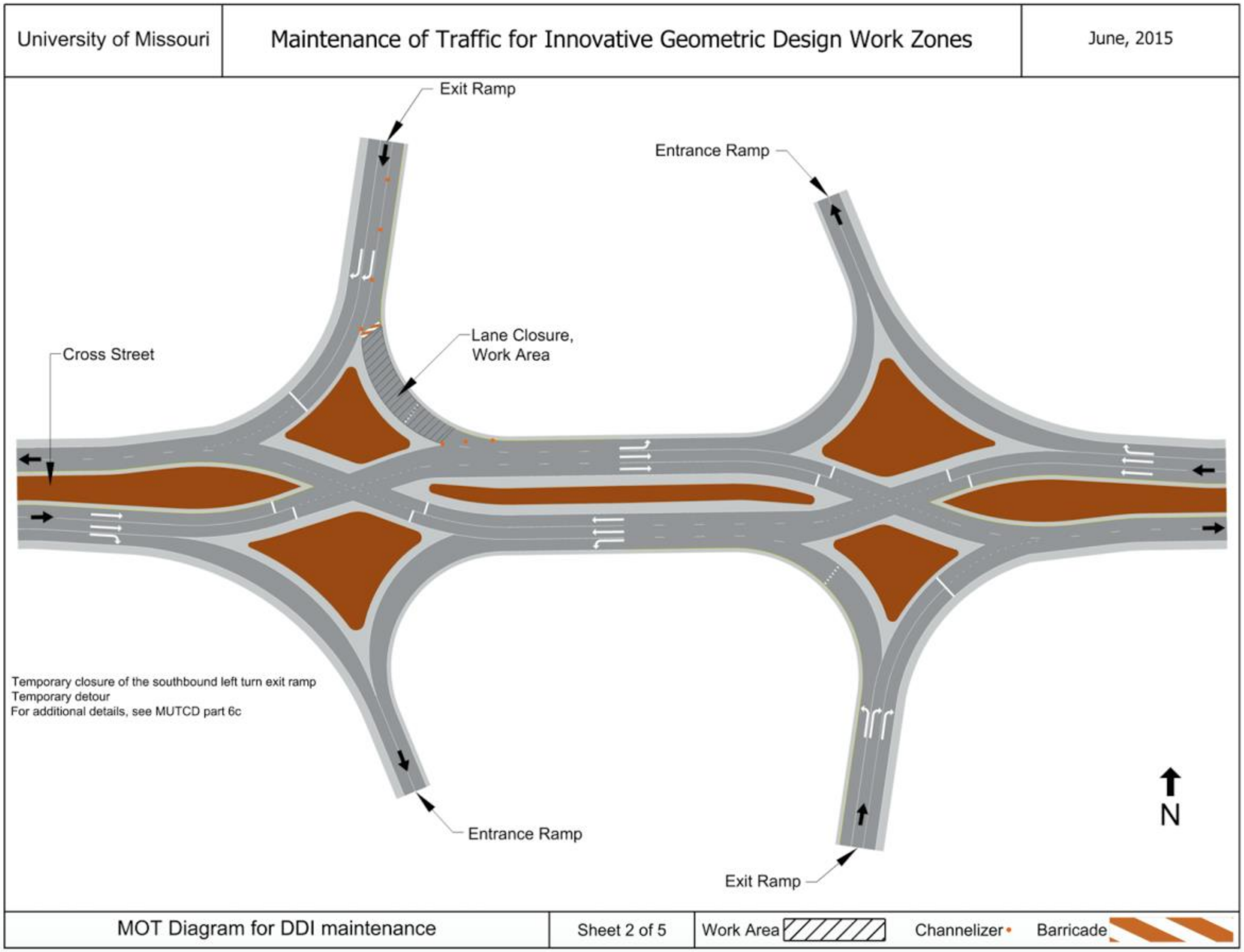


Figure 4.5.3.2 MOT diagram for DDI maintenance within the southbound left turn exit ramp lane

Maintenance requiring a temporary closure of the outermost DDI lane results in no restrictions to movement access, but does result in the loss of the weaving section. Left and right turn traffic is shifted onto the through lanes. Figure 4.5.3.3 shows the MOT diagram for the temporary closure of the westbound outermost DDI lane.

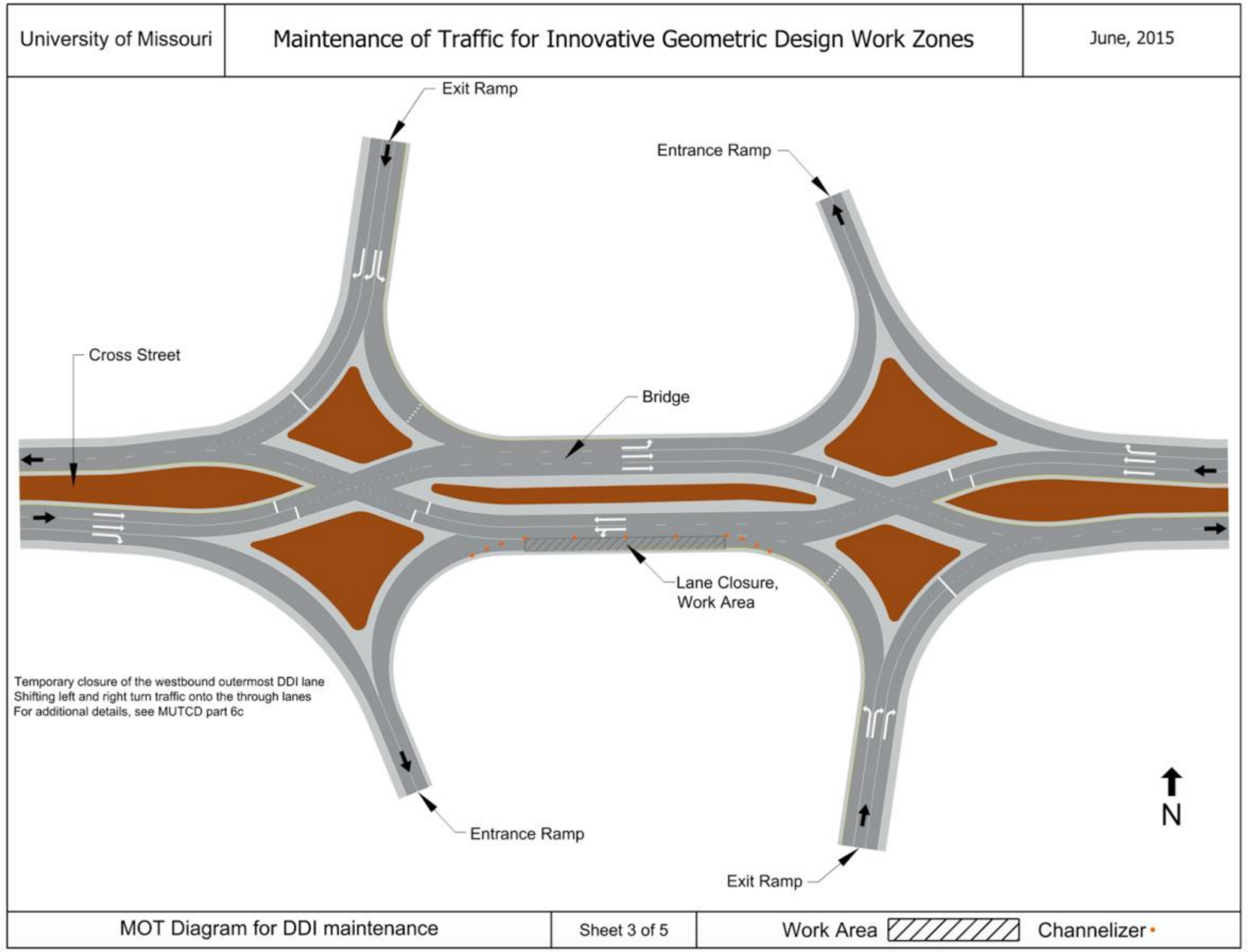


Figure 4.5.3.3 MOT diagram for DDI maintenance within the westbound outermost lane of DDI

Maintenance requiring a temporary closure of the outside through lane of the DDI results in a temporary closure of both the outside DDI through lane and turning lane. The outside through lane drop should extend through the extent of the DDI to ensure travelers follow the MOT. Lane drop procedures past the extent of the DDI should follow the guidelines set in the MUTCD. Figure 4.5.3.4 shows the MOT diagram for the maintenance of the eastbound outside through lane of the DDI.

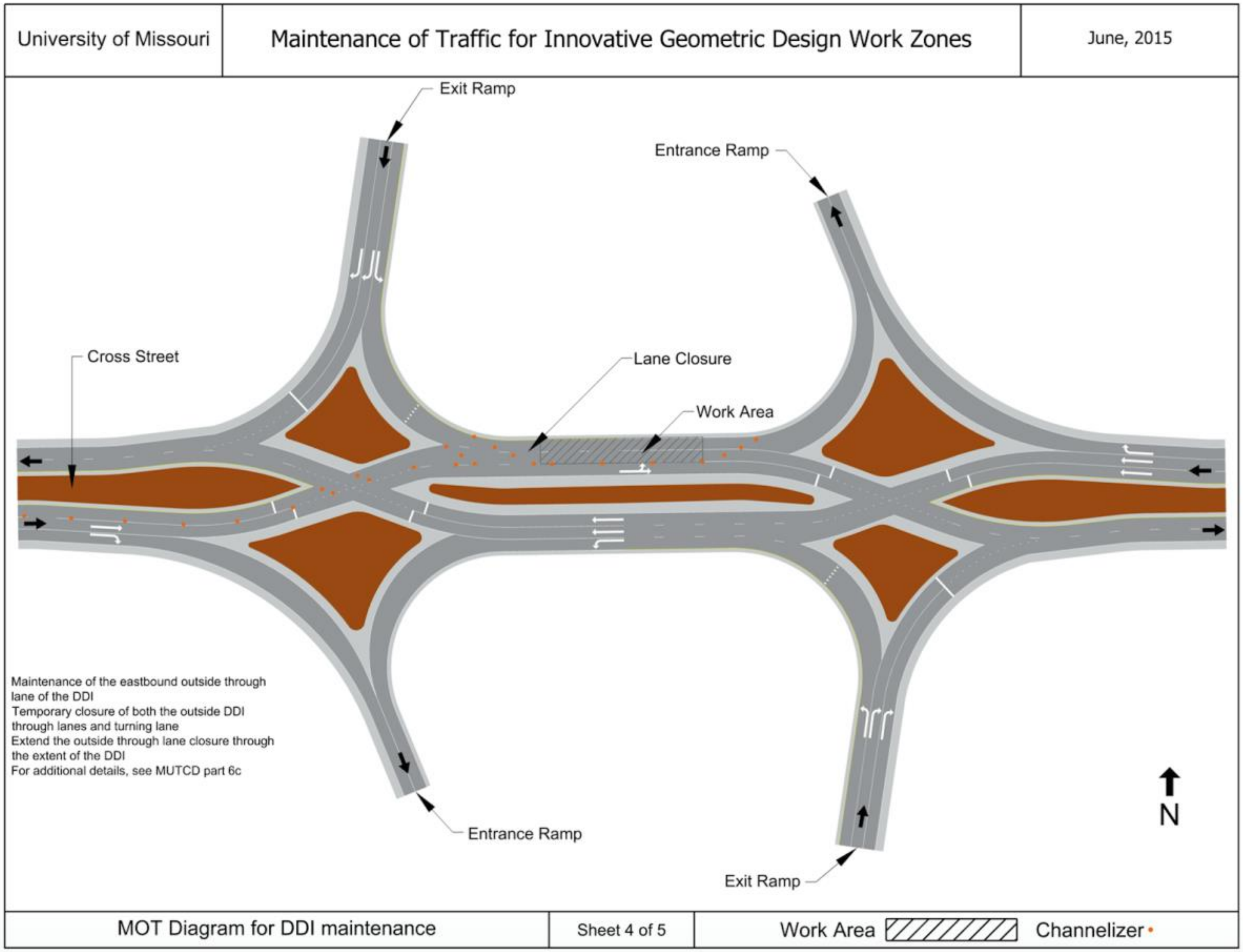


Figure 4.5.3.4 MOT diagram for maintenance within the eastbound outside DDI through lane

Maintenance requiring a temporary closure of the innermost DDI through lane results in a temporary closure of the innermost through lane through the extent of the DDI. This ensures that drivers follow the MOT. Lane drop procedures should follow guidance as stated in the MUTCD. The MOT diagram for the temporary closure of the eastbound innermost through lane is shown in Figure 4.5.3.5.

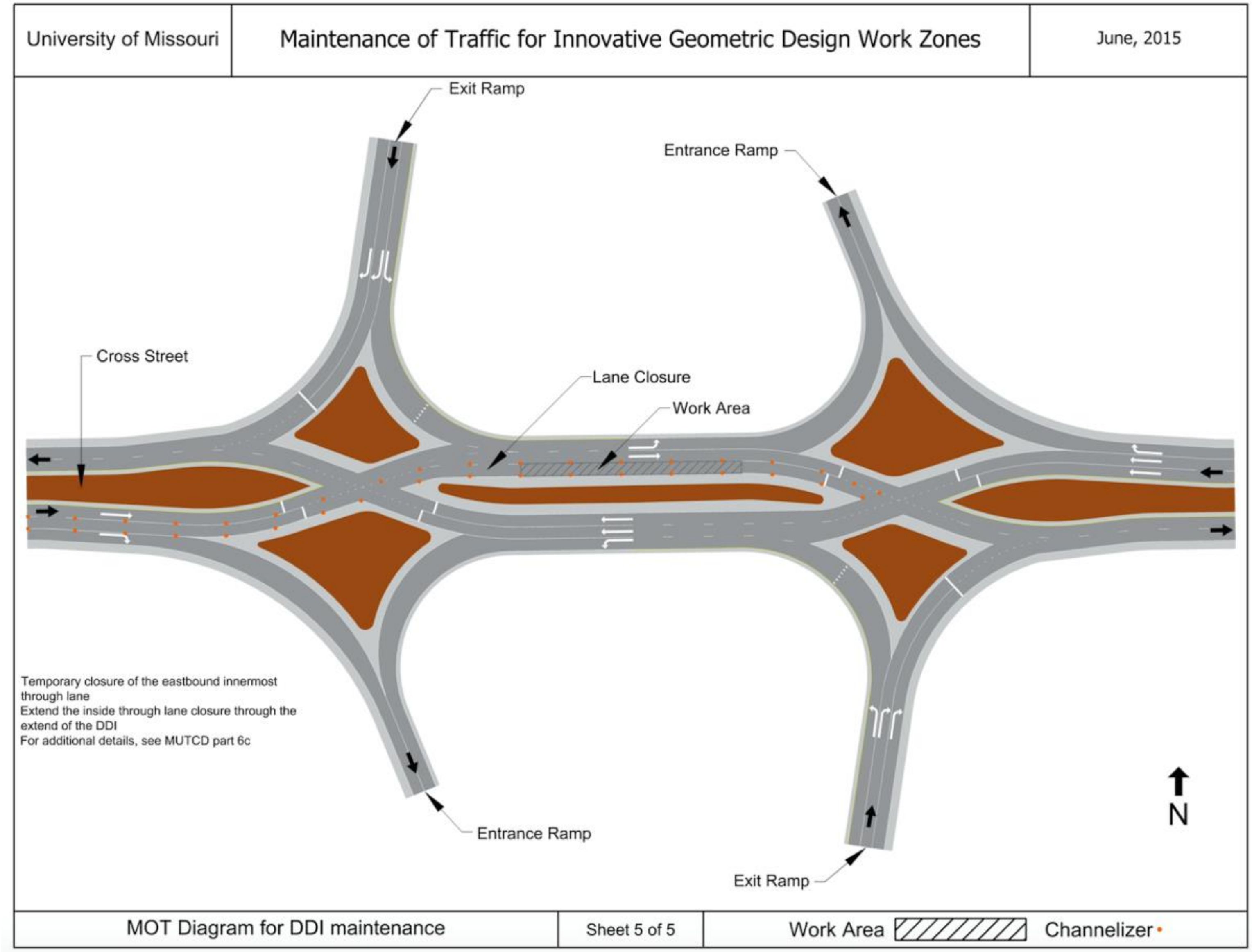


Figure 4.5.3.5 MOT diagram for maintenance within the eastbound innermost DDI through lane

4.5.4 RCUT

Maintenance of a RCUT intersection requiring a temporary closure of the center area results in no effect on movement access. Once the center portion of the RCUT is closed, traffic utilizes the median U-turns to maintain movement access. Appropriate MUTCD detour signage is required to advise drivers on how to make left turns since left turns can no longer be made directly. Figure 4.5.4.1 shows the MOT diagram for the temporary closure of the center of the intersection.

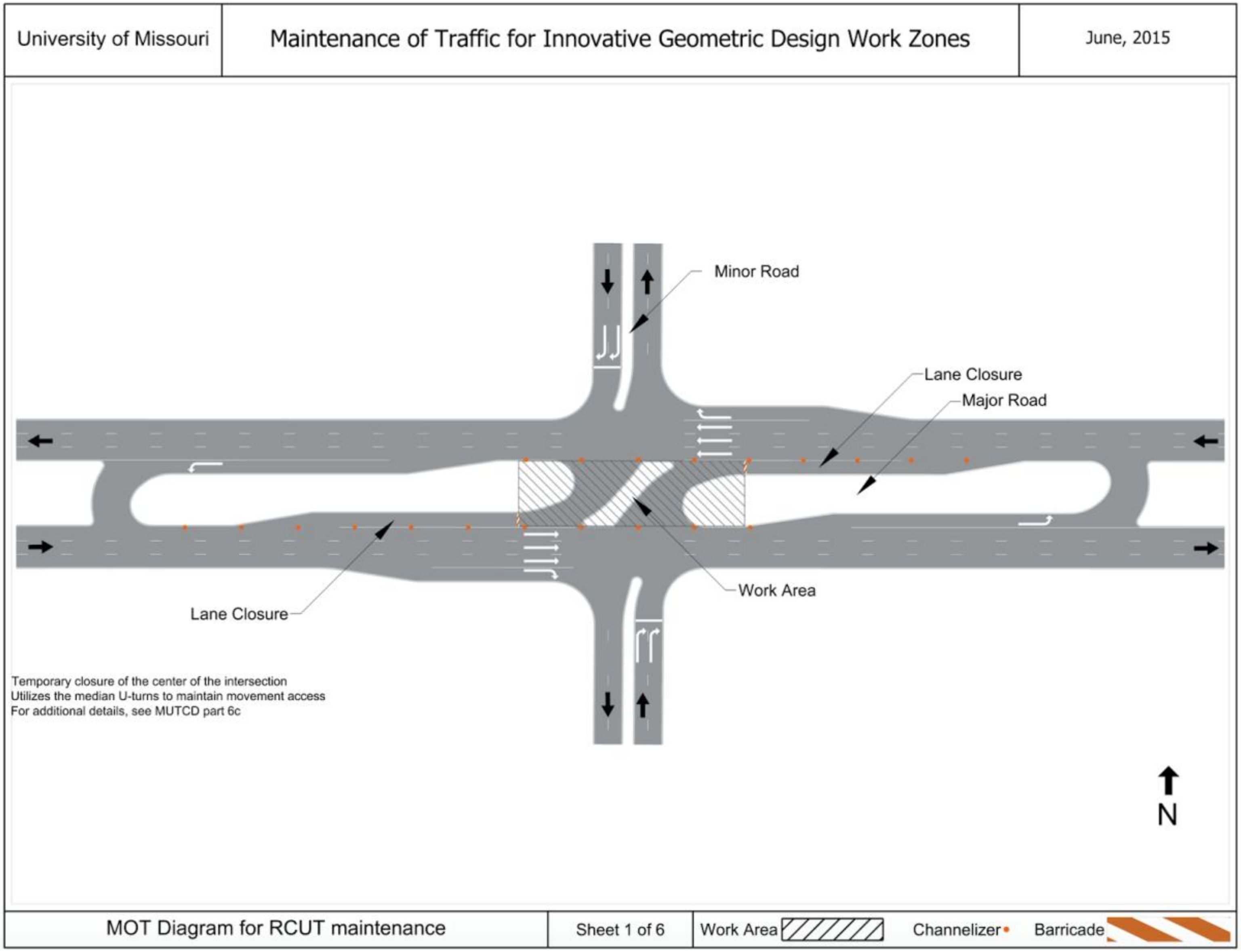


Figure 4.5.4.1 MOT diagram for maintenance within the RCUT center

Maintenance requiring a temporary closure of the median U-turn without a temporary U-turn results in a need for a temporary detour. The detour procedure and signage should follow guidelines stated in the MUTCD. The MOT diagram for the temporary closure of the median U-turn without provisions for a temporary U-turn is shown in Figure 4.5.4.2.

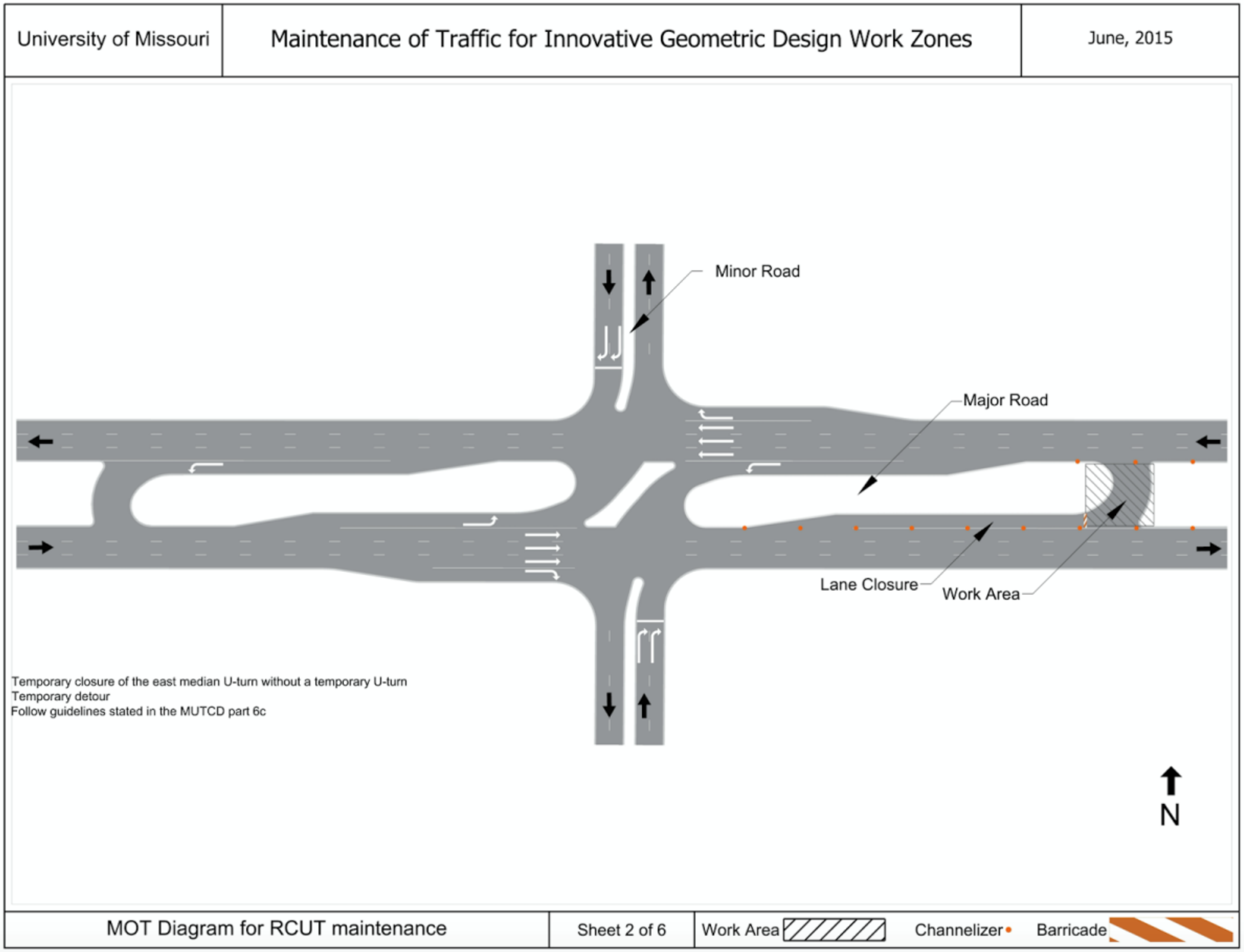


Figure 4.5.4.2 MOT diagram for maintenance within the RCUT median U-turn and no temporary U-turn

If U-turn movements need to be maintained, a temporary U-turn can provide movement access through the extent of the project. Figure 4.5.4.3 shows the MOT diagram for the closure of the east median U-turn with provision of a temporary U-turn. Allowing a temporary U-turn at the intersection is not desirable since this is not the normal traffic configuration for the RCUT.

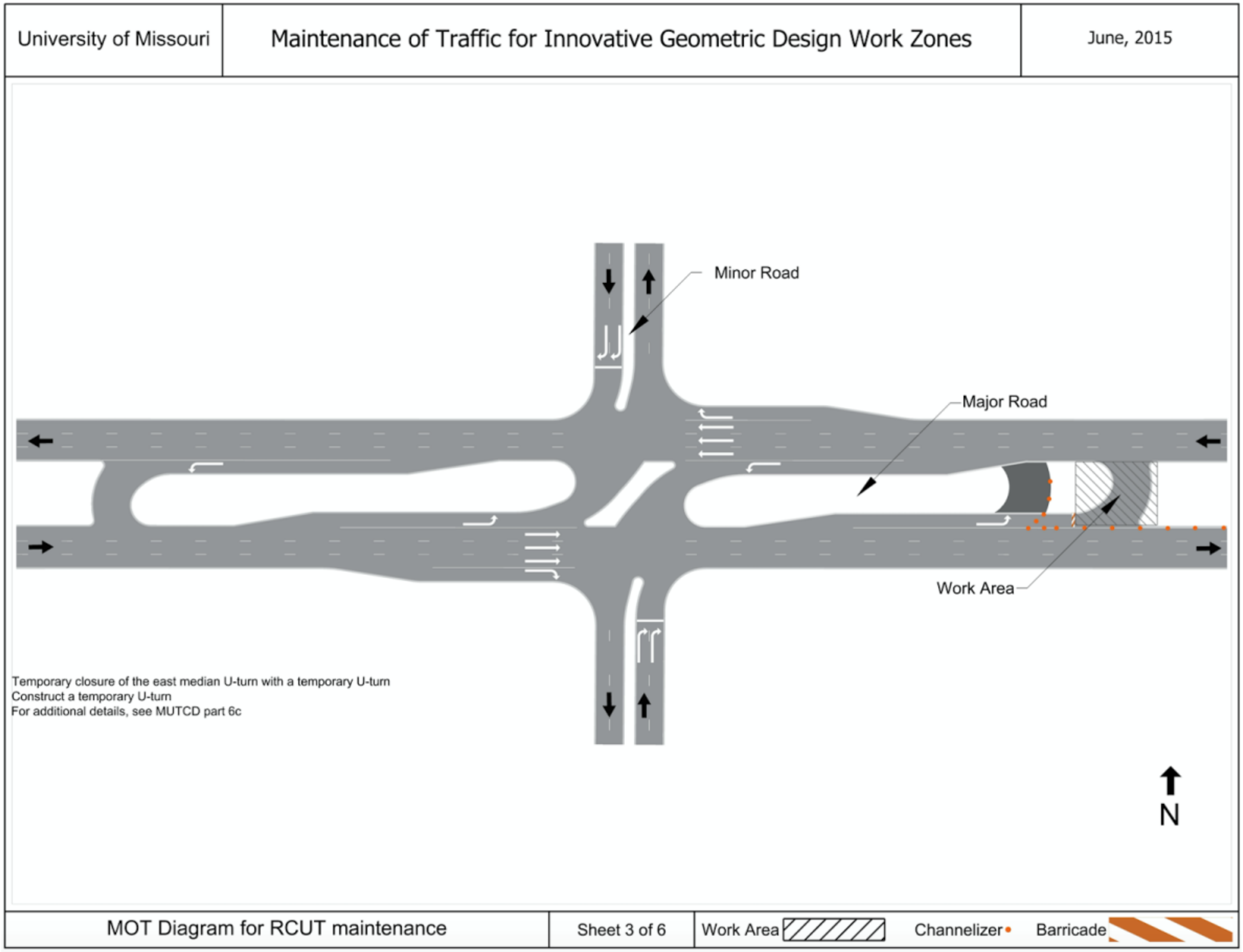


Figure 4.5.4.3 MOT diagram for maintenance within RCUT east median U-turn while providing temporary U-turn

Maintenance requiring a temporary closure of the outermost RCUT through lane results in no effect on movement access. The lane drop for this scenario should be extended through the extent of the RCUT intersection to ensure drivers acknowledge the MOT configuration. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.4.4 shows the MOT diagram for the closure of the outermost eastbound RCUT through lane.

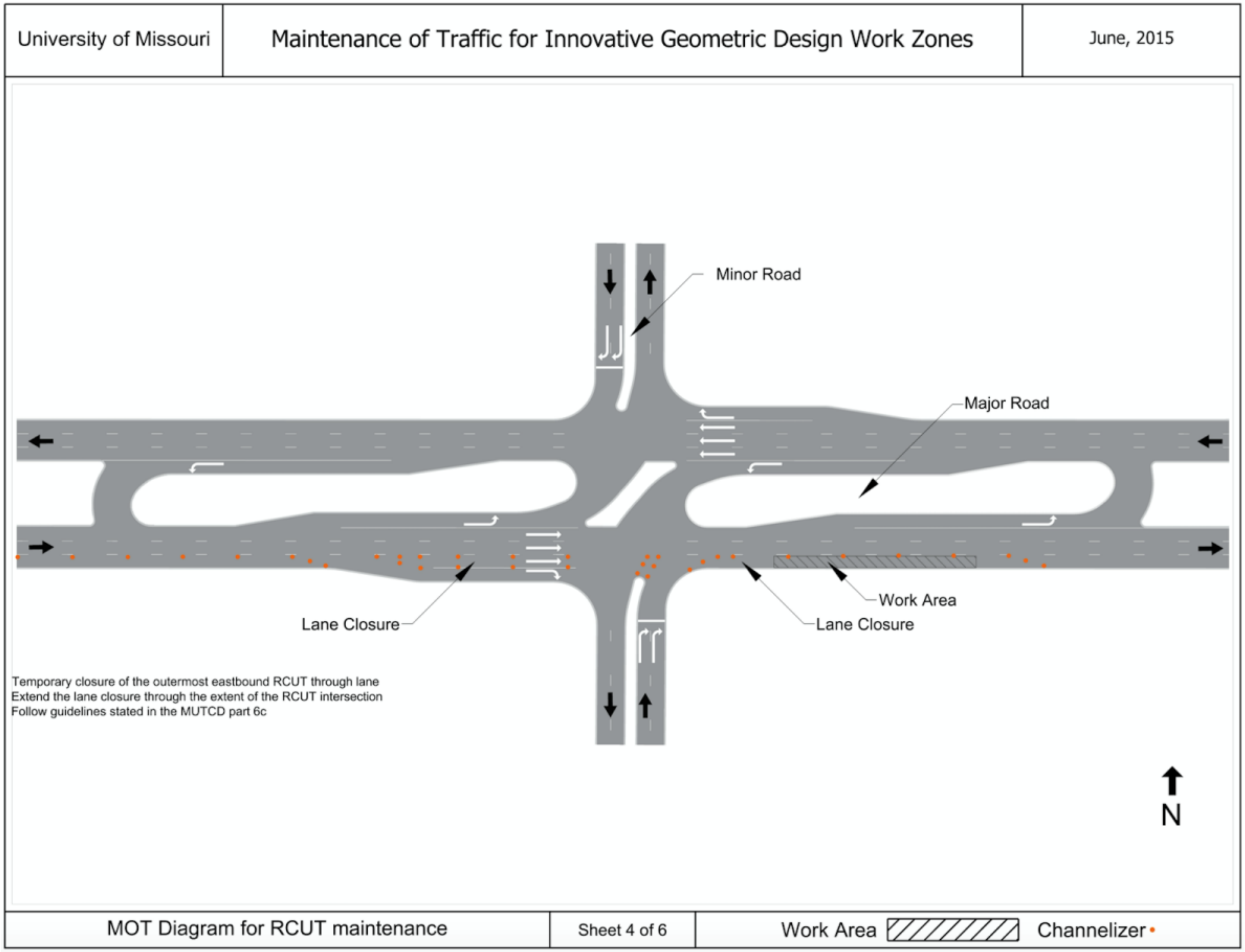


Figure 4.5.4.4 MOT diagram for maintenance within the eastbound outermost RCUT through lane

Maintenance requiring a temporary closure of the center RCUT through lane results in a temporary closure of the center and outside RCUT through lanes. The lane drop of the two lanes should extend through the extent of the RCUT intersection to ensure that drivers follow the MOT. Lane drop procedures and signage should follow guidelines stated in the MUTCD. The MOT diagram for the closure of the eastbound center RCUT through lane is shown in Figure 4.5.4.5.

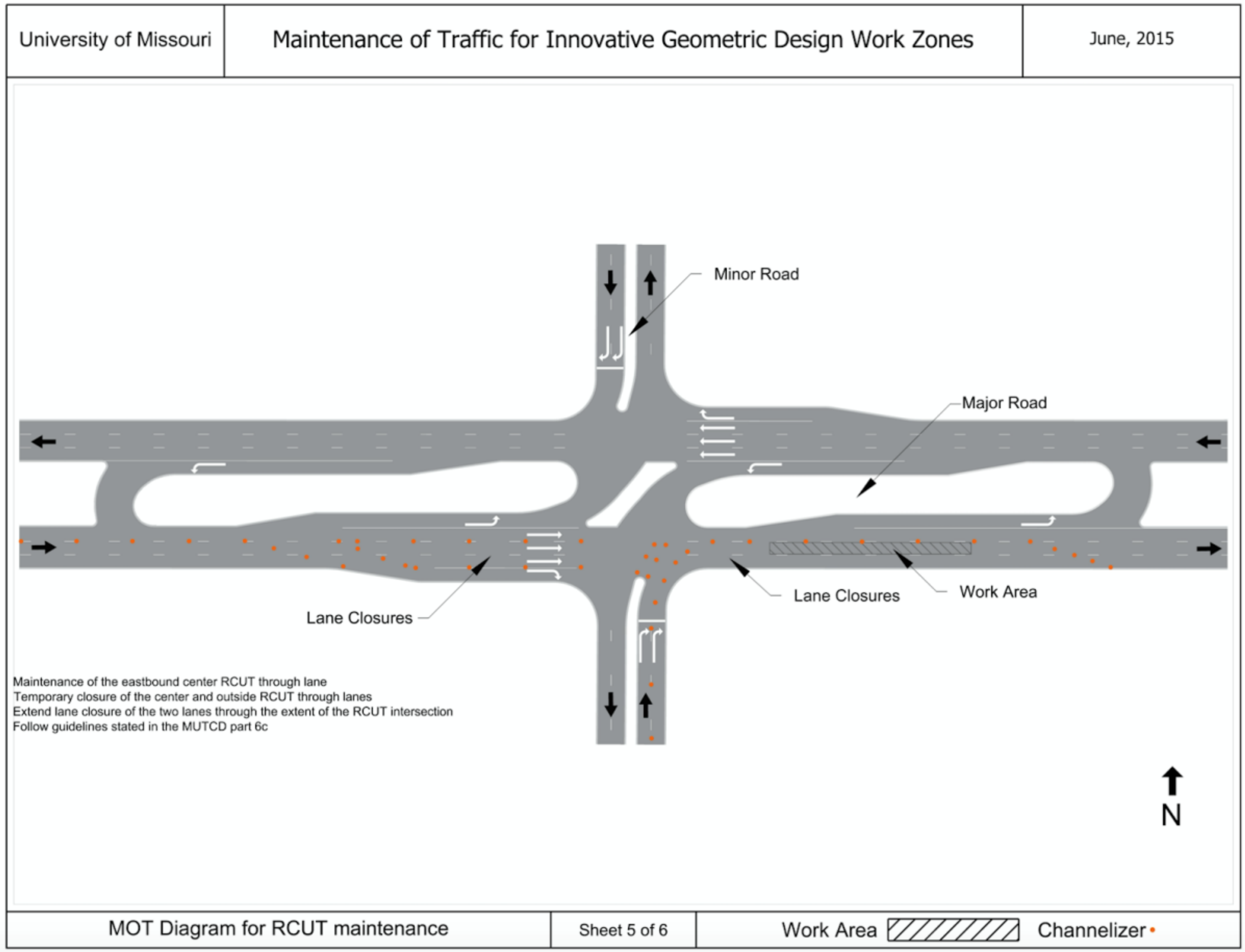


Figure 4.5.4.5 MOT diagram for maintenance within the eastbound RCUT center through lane

Maintenance requiring a temporary closure of the innermost RCUT through lane results in only a temporary closure of the innermost through lane. An opening is provided at the beginning of the U-turn deceleration lane to allow access to the median U-turn. The lane drop should extend through the entire RCUT intersection to ensure drivers understand the MOT. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.4.6 shows the MOT diagram for the temporary closure of the eastbound innermost RCUT through lane.

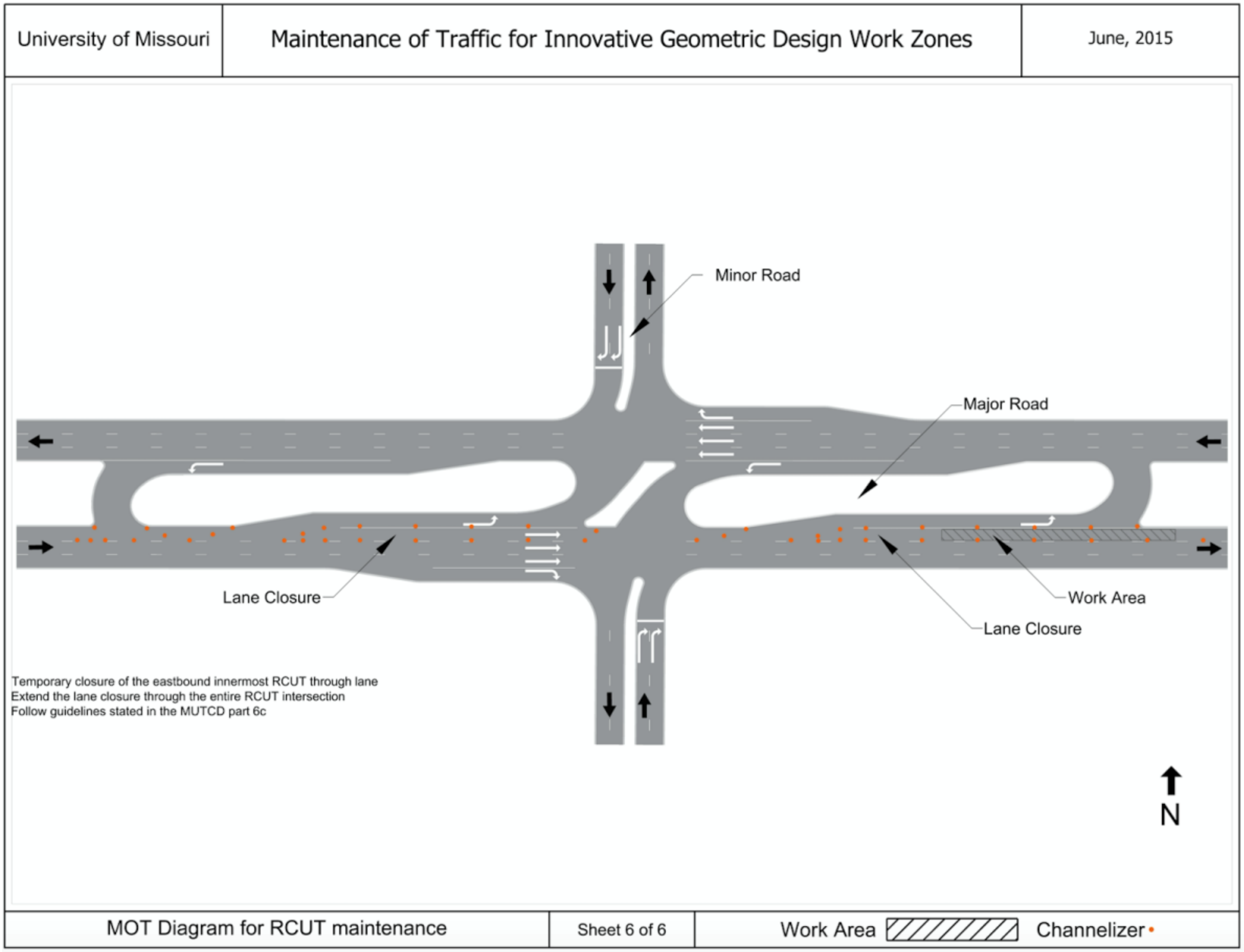


Figure 4.5.4.6 MOT diagram for maintenance within the RCUT eastbound innermost through lane

4.5.5 MUT

MUT maintenance MOT organization is similar to the RCUT MOT organization. Maintenance requiring a temporary closure of a median U-turn results in a need for a temporary detour if an additional median U-turn is not provided. Detour procedures and signage should follow the guidelines stated in the MUTCD. Figure 4.5.5.1 shows the MOT diagram for the temporary closure of the east median U-turn.

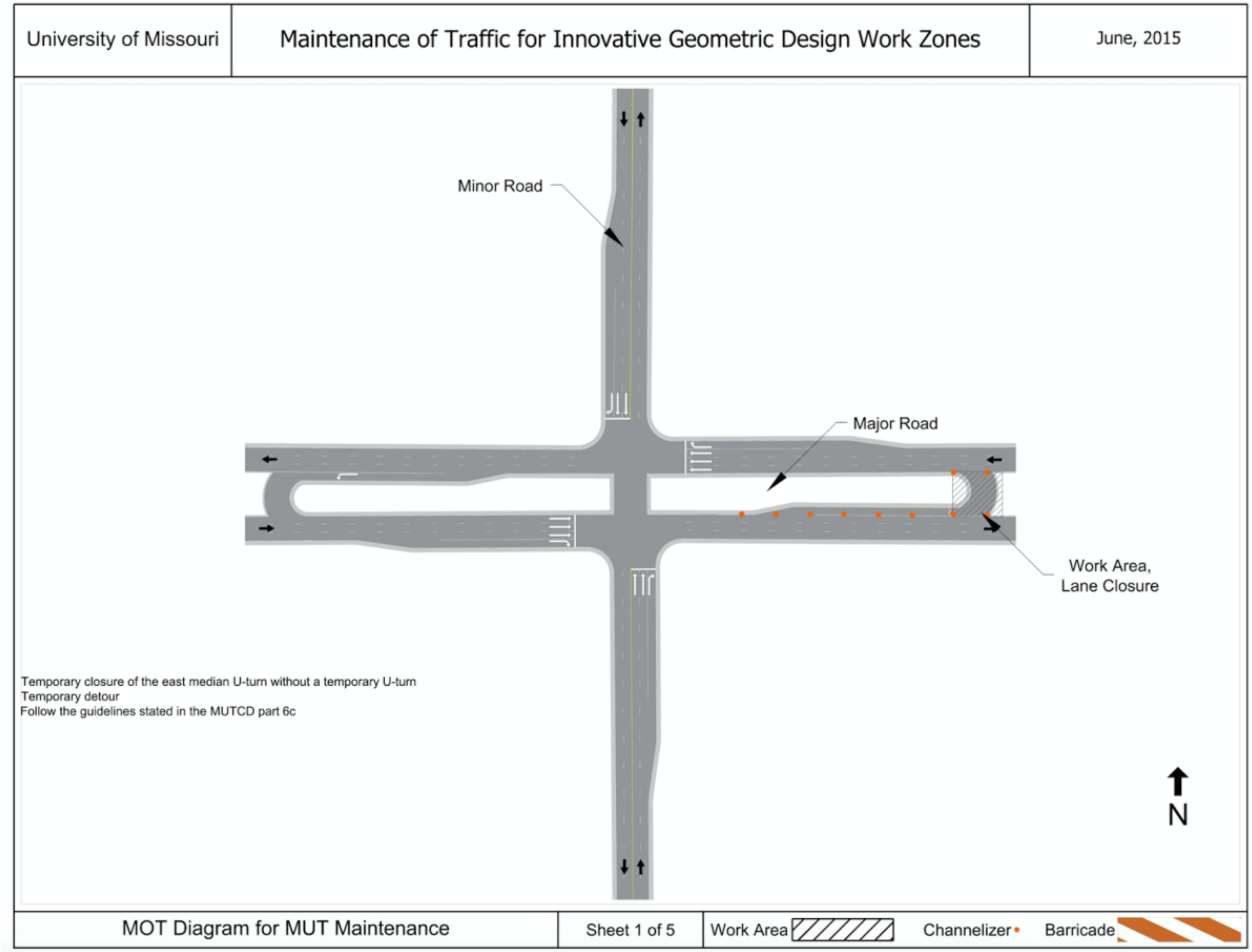


Figure 4.5.5.1 MOT diagram for maintenance within the MUT east median U-turn

If U-turn access should be maintained throughout the maintenance project, a temporary median U-turn may be constructed ahead of the permanent median U-turn. Figure 4.5.5.2 shows the MOT diagram for this scenario of maintenance for the east median U-turn.

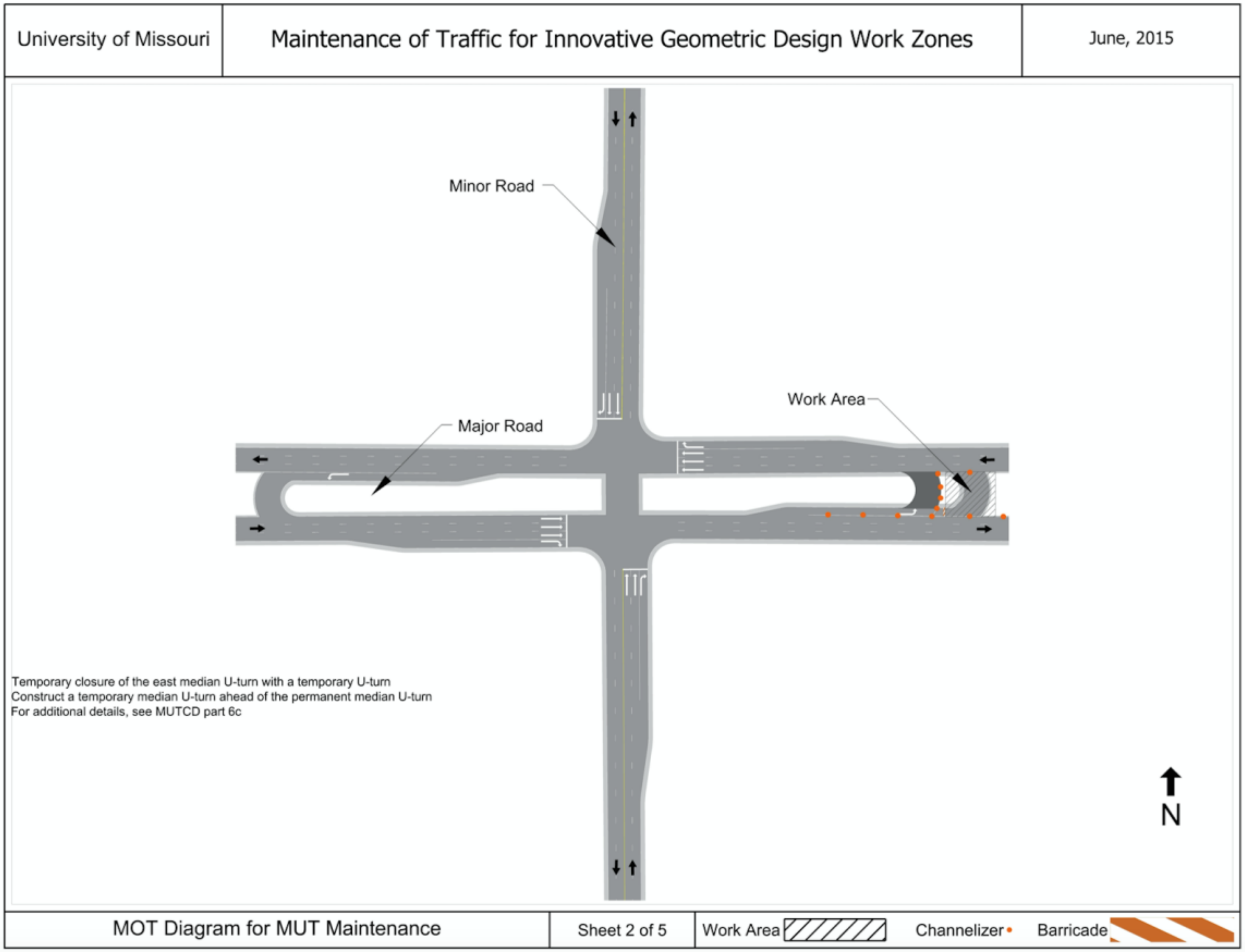


Figure 4.5.5.2 MOT diagram for maintenance within the MUT median east U-turn while providing temporary median U-turn for access

Maintenance requiring a temporary closure of the outermost MUT through lane results in a lane drop of the lane through the extent of the MUT intersection. This ensures that drivers acknowledge the MOT configuration. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.5.3 shows the MOT diagram for this scenario of maintenance for the eastbound outermost through lane.

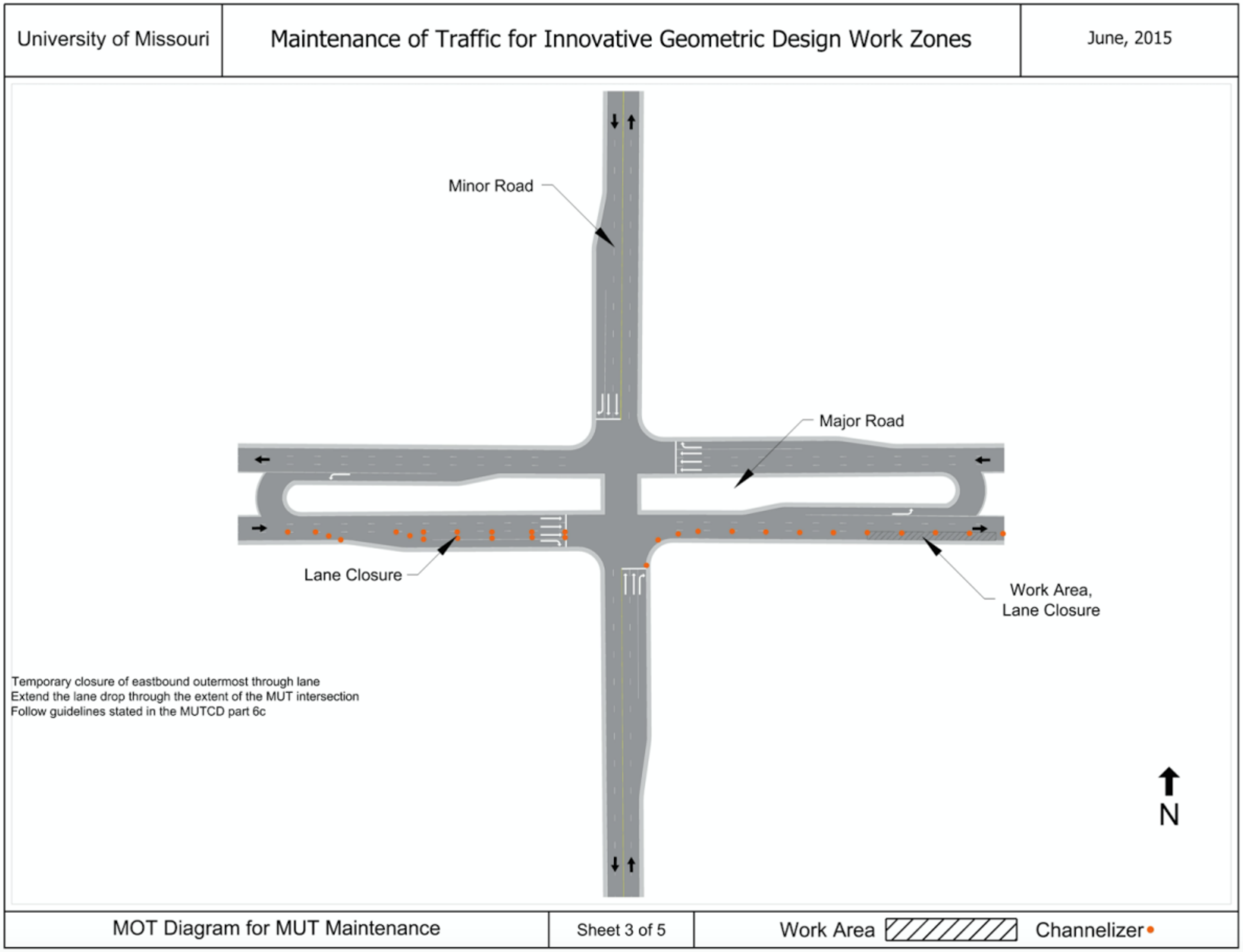


Figure 4.5.5.3 MOT diagram for maintenance within the eastbound outermost MUT through lane

Maintenance requiring a temporary closure of the center MUT through lane results in lane drops for both the center and outermost MUT through lanes. The lane drops should extend through the extent of the MUT intersection to ensure drivers follow the MOT. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.5.4 shows the MOT diagram for this scenario of maintenance for the eastbound center and outermost lanes.

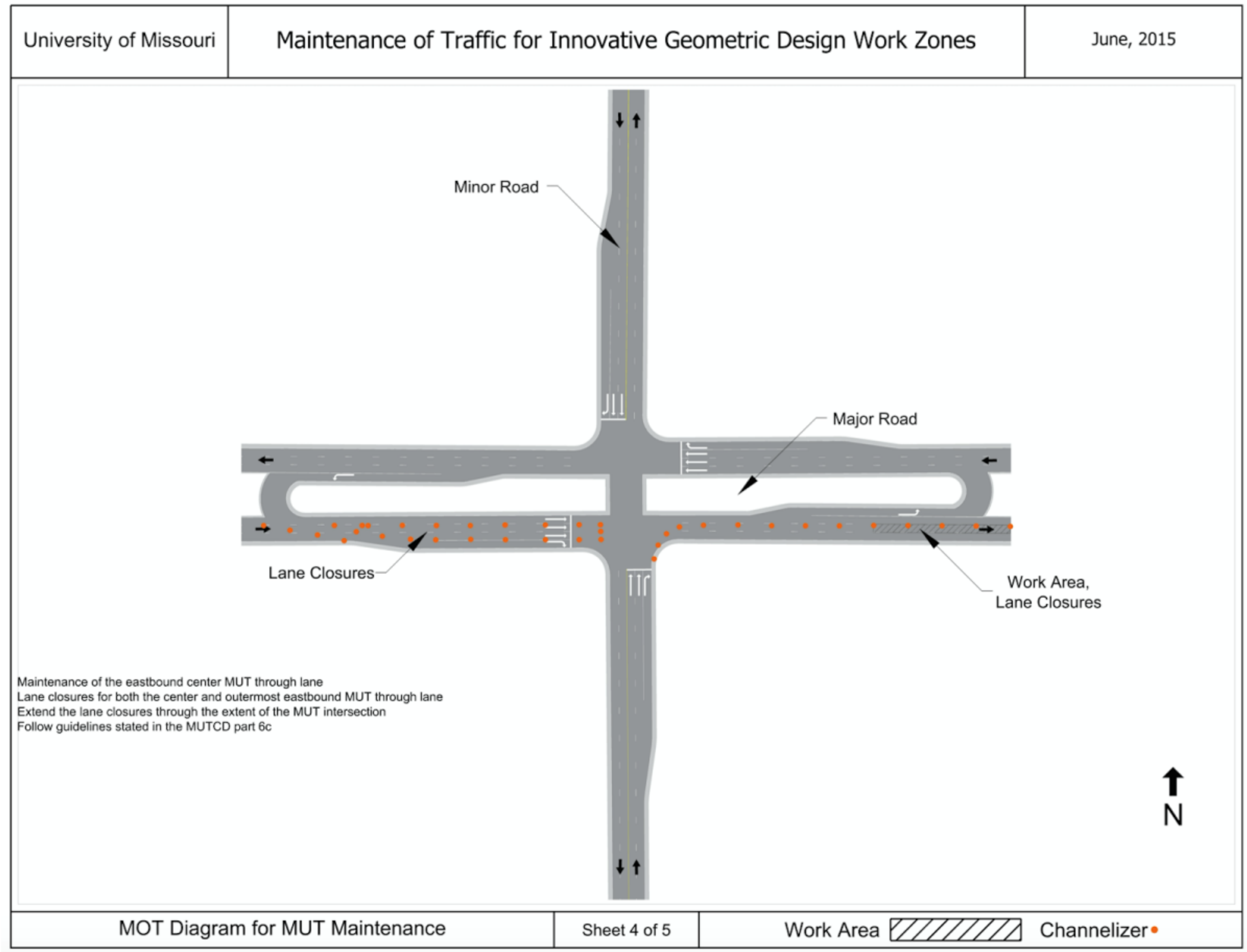


Figure 4.5.5.4 MOT diagram for maintenance within the eastbound MUT center through lane

Maintenance requiring a temporary closure of the MUT innermost through lane results in a lane drop of the innermost through lane for the extent of the MUT intersection. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.5.5 shows the MOT diagram for the closure of the inside eastbound lane.

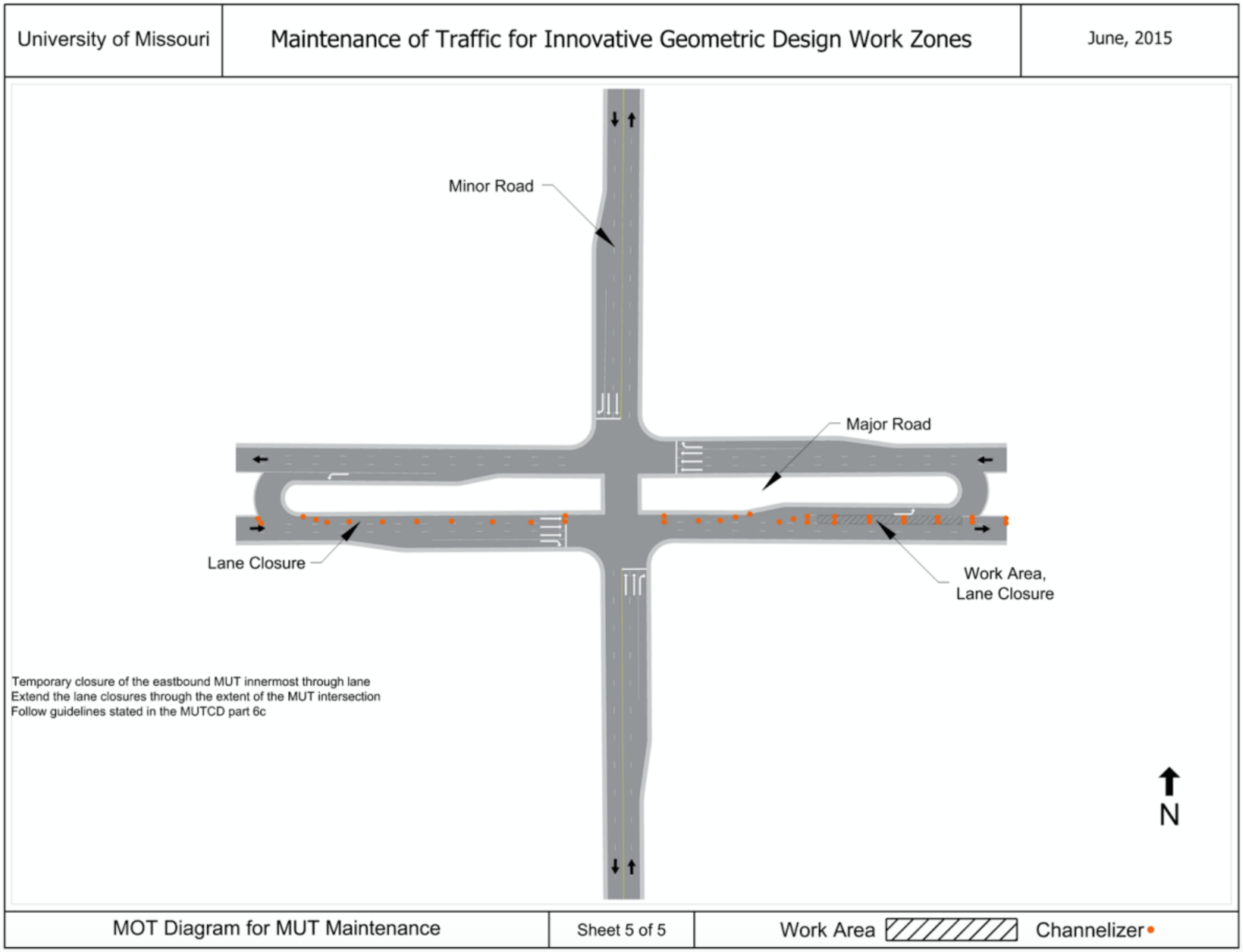


Figure 4.5.5.5 MOT diagram for maintenance within the innermost MUT eastbound through lane

4.5.6 DLT

Maintenance through a DLT intersection right turn requiring a temporary closure of the right turn results in a need for a temporary detour. Detour procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.6.1 shows the MOT diagram for this maintenance scenario for the eastbound DLT right turn lane.

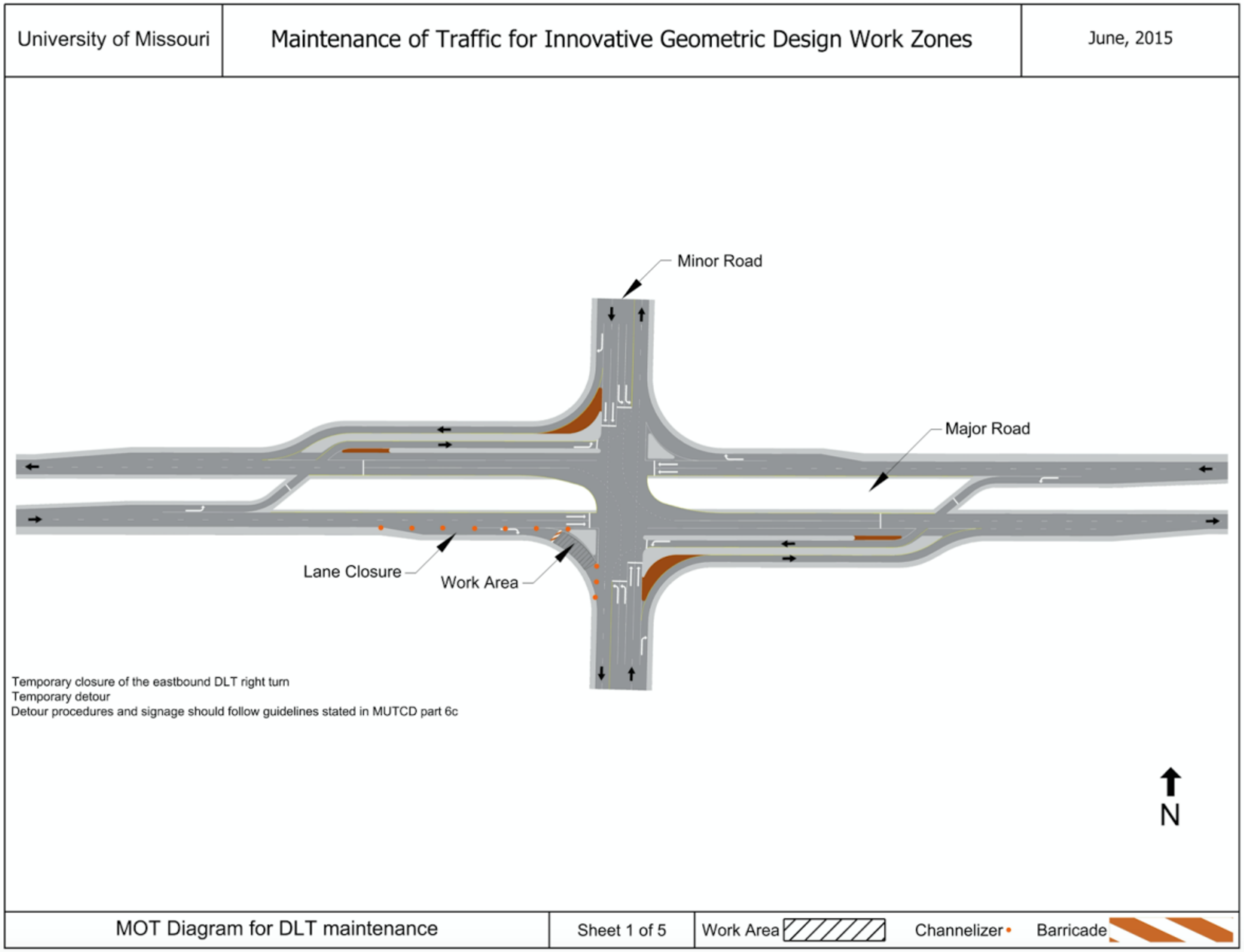


Figure 4.5.6.1 MOT diagram for maintenance within the eastbound DLT right turn lane

Maintenance requiring a temporary closure of the DLT left turn lane results in the need for a detour if a temporary left turn movement is not provided. Detour procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.6.2 shows the MOT diagram for this scenario of maintenance for the eastbound DLT left turn lane.

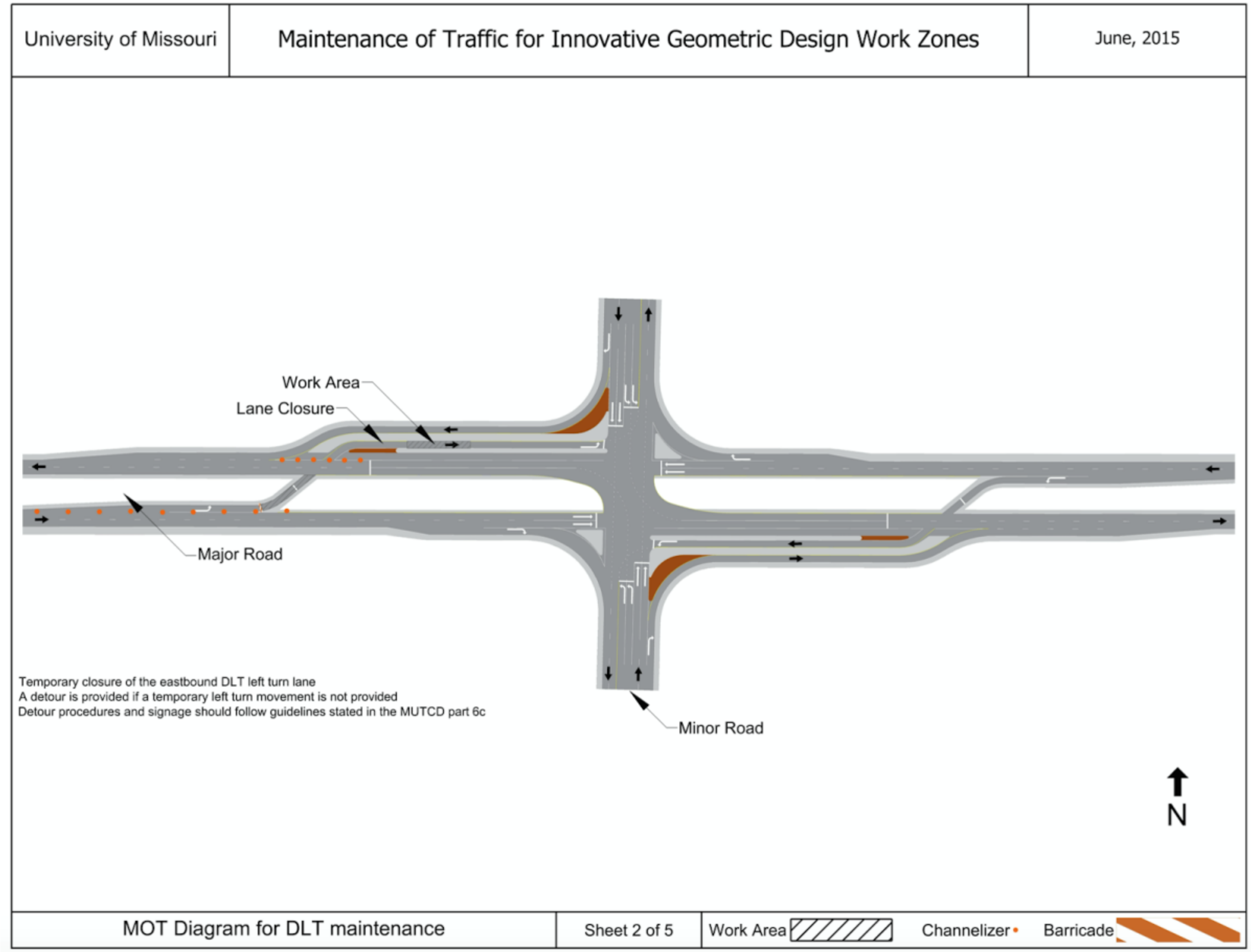


Figure 4.5.6.2 MOT diagram for maintenance within the eastbound DLT left turn lane

Another option for the temporary closure of the DLT left turn lane is to provide a conventional temporary left-turn bay at the intersection to accommodate the left turn movements that normally utilize the left turn bay as shown in Figure 4.5.6.3 for the eastbound DLT left turn lane. This option could be used in cases where left-turn movement access needs to be maintained during the maintenance project.

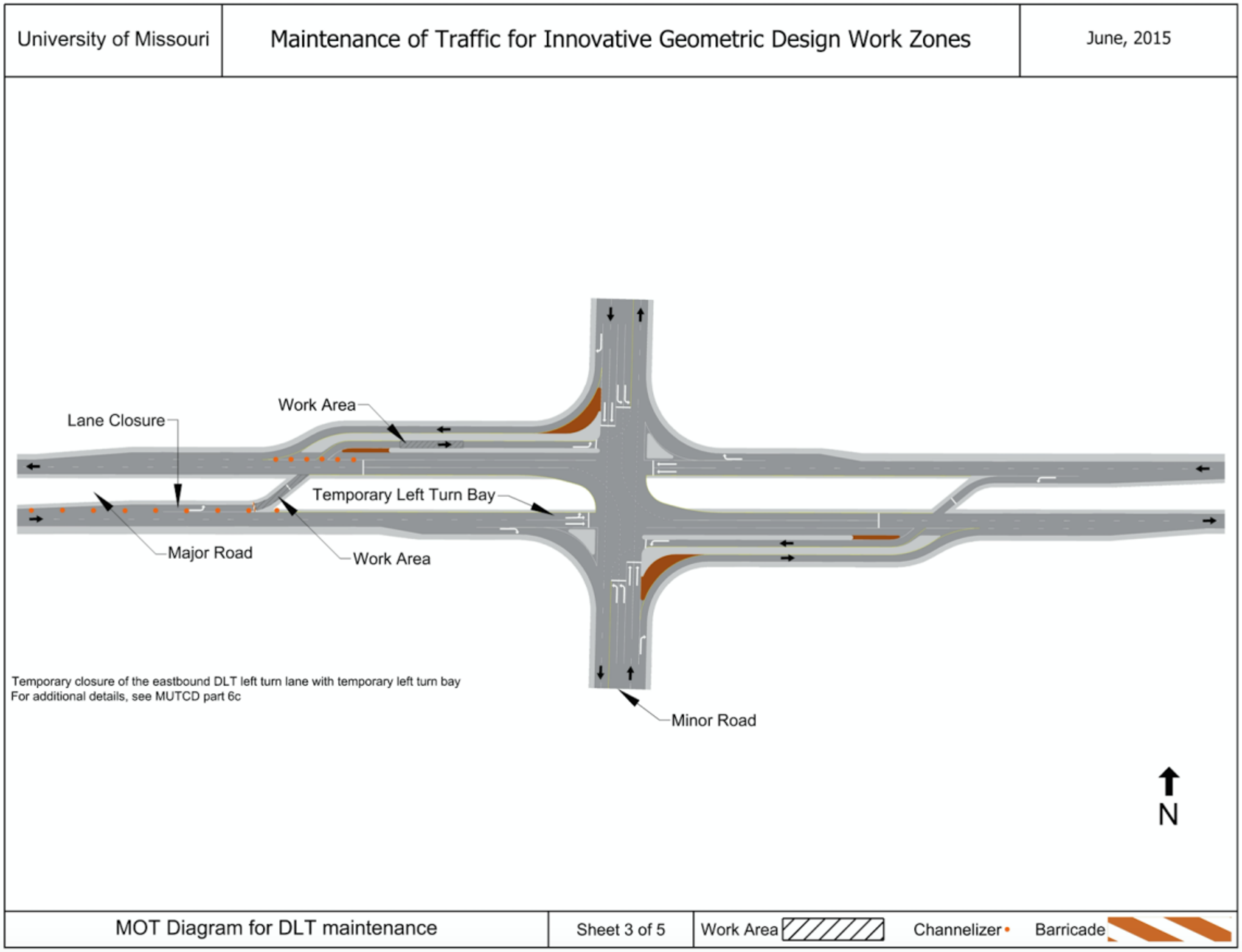


Figure 4.5.6.3 MOT diagram for maintenance of DLT left turn while providing temporary left turn bay at the cross street

Figure 4.5.6.4 shows a maintenance scenario with closure of the eastbound outside through lane on a DLT approach. If maintenance requires the temporary closure of the outside through lane on an approach with a DLT, the lane drop of the outside DLT through lane should extend through the extents of the DLT intersection to avoid possible driver confusion. If the cross street has dual left turn lanes, a closure of the inside left turn lane is required since there is only one receiving lane for the left turn. Lane drop procedures and signage should follow guidelines stated in the MUTCD.

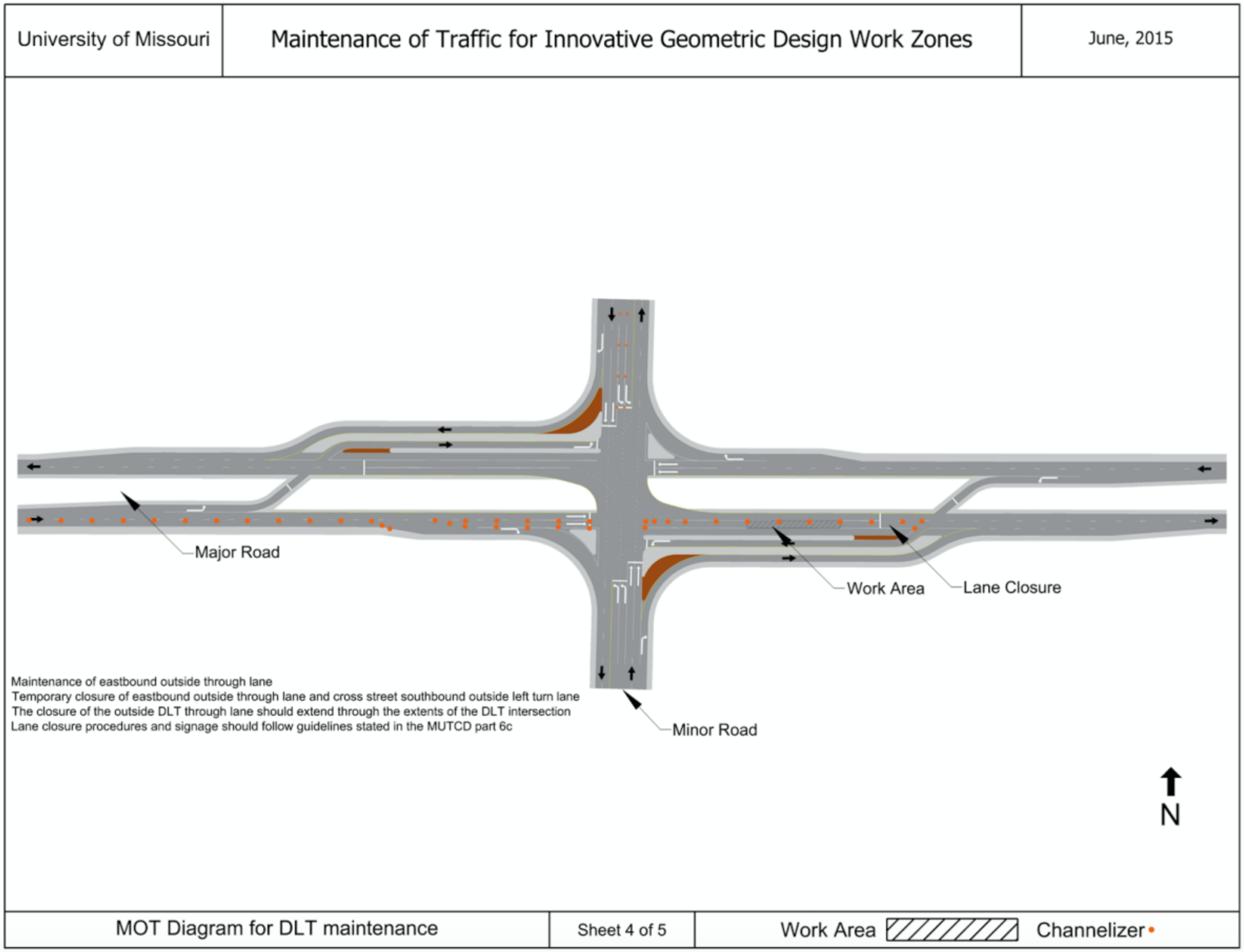


Figure 4.5.6.4 MOT diagram for maintenance within the DLT eastbound outside through lane

Maintenance requiring a temporary closure of the DLT innermost through lane results in a temporary closure of both the innermost through lane and cross street inside left turn lane. The lane drop of the through lane should extend through the extents of the DLT intersection. Lane drop procedures and signage should follow guidelines stated in the MUTCD. Figure 4.5.6.5 shows the MOT diagram for this scenario of maintenance for the eastbound DLT inside through lane.

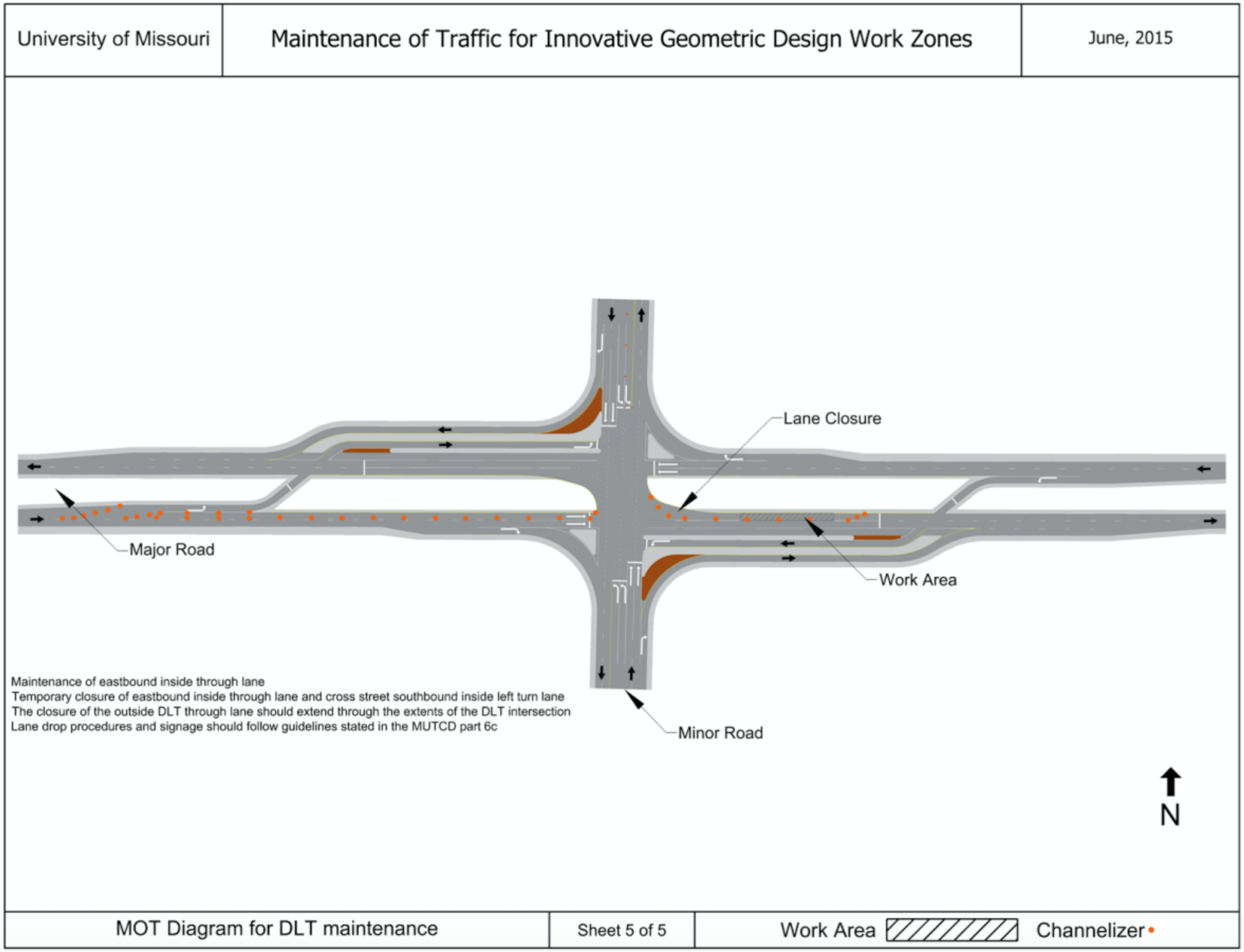


Figure 4.5.6.5 MOT diagram for maintenance within eastbound DLT inside through lane

CHAPTER 5. CONCLUSIONS

The use of innovative geometric designs continues to grow due to the efficiency and safety benefits that can be achieved using these designs. These designs handle traffic more efficiently and are often much more cost effective than the conventional solution. The intersections of interest in this research include roundabouts, SPUIs, DDIs, RCUTs, MUTs, and DLTs. There is currently no guidance in the MUTCD on MOT for initial construction of these designs. This is a particularly pressing issue because the need to implement these designs typically means that access is a necessity throughout construction, and therefore transportation practitioners looking to implement these designs could benefit from MOT Phasing Diagrams on initial construction and maintenance projects. MOT Phasing Diagrams were developed for roundabout, SPUI, DDI, RCUT, MUT, and DLT intersections. These MOT Phasing Diagrams could 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. Current practices throughout the United States were gathered through literature review, surveys and interviews of practitioners, and by examining project plans. The MOT Phasing Diagrams were designed to serve as a starting point for transportation practitioners, but other factors should be considered when developing MOT plans for these types of designs. These factors include the level of experience that the drivers in the surrounding area may have with these types of designs, availability of detours, traffic counts, buffer spaces, and anticipated impacts of a possible closure. Each of these factors aid in determining proper construction phasing and MOT methods. The results of the study indicate that each design examined in this project is capable of organized phased construction with little to no effect on movement access throughout construction. In general, the maintenance of traffic seems to be more straightforward for innovative designs in which traffic movements are separated (such as the RCUT or MUT) than for innovative designs in which traffic movements are grouped together (such as the DDI, SPUI, or roundabout). Some key recommendations of this report include:

1. Avoid using temporary movements through construction which would be considered an illegal movement for the final traffic movement configuration. If drivers are experienced with the final traffic configuration due to 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 channelizing islands before construction is complete to ensure drivers travel the intersection correctly.
3. For MUT, use appropriate signage to inform drivers about the median U-turn presence 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, providing median crossover points near the roundabout could prove to be useful by significantly shortening the flagging zone and thus allowing for more efficient flagging operations.

6. For any innovative geometric design, doubling the number of channelizers used through the extents of the work zone can prove valuable in preventing drivers from weaving.
7. Sequential lighting can provide valuable aid to drivers through the work zone for both daylight and nighttime periods.
8. Final conversion of some of these innovative designs, such as DDI, should be done under full closure which should occur when traffic volumes are low, such as weekend periods. The conversion could occur either through the middle or at the end of the project. A short full closure period also ensures that drivers acknowledge the change in intersection configuration.

Additional findings through the interview process from interviewee opinions and recommendations include:

1. Use of innovative contracting techniques such as design build could be considered to allow contractors to determine methods used for MOT of these designs.
2. Other factors such as drainage, necessity of movements, and other situations can affect phasing.
3. Depending on the specific location, it could be important to make special accommodations for pedestrians, bicycles, and the disabled.
4. With low speeds through the work zone, sharp angles in temporary traffic control are acceptable.
5. MOT plans should be continually reevaluated throughout the duration of the project.
6. Avoid the use of unwarranted temporary signals, because public pressure might make them permanent.

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APPENDIX A. SURVEY

SWZDI
Smart Work Zone Deployment Initiative

Temporary Traffic Control Practices for Innovative Geometric Designs

This is a short 16-question survey that will take approximately 5 minutes.

Development of maintenance of traffic plans for innovative geometric designs can be challenging, especially when retrofitting existing intersections. This Federal Highway Administration (FHWA) Smart Work Zone Deployment Initiative (SWZDI) project will develop guidelines for the preparation of maintenance of traffic plans for projects with innovative geometric designs in both rural and urban implementations.

Your input based on your experience in implementing these designs will help to develop MOT Phasing Diagrams. If it would be more appropriate for someone else at your organization to take this survey, please send their name and email address to Henry Brown (brownhen@missouri.edu).

Examples of some of the innovative geometric designs are shown below.


Single Point Urban Interchange (SPUI)


Diverging Diamond Interchange (DDI)


Displaced Left Turn (DLT)


Restricted Crossing U-Turn (RCUT - Urban)


Median U-Turn (MUT)


Roundabout


Restricted Crossing U-Turn (RCUT - Rural)

1. What type of agency do you represent?

- State DOT
- City
- County
- Consultant
- Other

2. Approximately how many of the following designs does your agency operate in total?

	0	1-5	6-10	>10
Roundabout				
SPUI				
DDI				
RCUT				
MUT				
DLT				

3. For how many designs listed in question 2 has your agency performed maintenance projects (such as resurfacing, re-striping, etc.)?

	0	1-5	6-10	>10
Roundabout				
SPUI				
DDI				
RCUT				
MUT				
DLT				

Questions 4-7 aim to differentiate methods used during initial construction versus maintenance projects for each intersection type.

4. What is the predominant method used by your agency during initial construction for each intersection type?

	Complete Closure	Phased Construction with Partial Closures	Construct Temporary Runaround	Temporary Traffic Signal	Other	N/A
Roundabout	☐	☐	☐	☐	☐	☐
SPUI	☐	☐	☐	☐	☐	☐
DDI	☐	☐	☐	☐	☐	☐
RCUT	☐	☐	☐	☐	☐	☐
MUT	☐	☐	☐	☐	☐	☐
DLT	☐	☐	☐	☐	☐	☐

If "Other" Please Describe

5. How frequently does your agency use each method listed in question 4 for initial construction?

	Always	Almost Always	Sometimes	Rarely	N/A
Roundabout	☐	☐	☐	☐	☐
SPUI	☐	☐	☐	☐	☐
DDI	☐	☐	☐	☐	☐
RCUT	☐	☐	☐	☐	☐
MUT	☐	☐	☐	☐	☐
DLT	☐	☐	☐	☐	☐

6. What is the predominant <u>method</u> used by your agency during <u>maintenance projects</u> for each intersection type?

	Complete Closure	Phased Construction with Partial Closures	Construct Temporary Runaround	Temporary Traffic Signal	Other	N/A
Roundabout	☐	☐	☐	☐	☐	☐
SPUI	☐	☐	☐	☐	☐	☐
DDI	☐	☐	☐	☐	☐	☐
RCUT	☐	☐	☐	☐	☐	☐
MUT	☐	☐	☐	☐	☐	☐
DLT	☐	☐	☐	☐	☐	☐

If "Other" Please Describe

7. How frequently does your agency use each method mentioned in question 6 for <u>maintenance projects</u>?

	Always	Almost Always	Sometimes	Rarely	N/A
Roundabout	☐	☐	☐	☐	☐
SPUI	☐	☐	☐	☐	☐
DDI	☐	☐	☐	☐	☐
RCUT	☐	☐	☐	☐	☐
MUT	☐	☐	☐	☐	☐
DLT	☐	☐	☐	☐	☐

8. What resources did you use to decide on the maintenance of traffic plans for your facilities? Check all that apply.

- ☐ MUTCD
- ☐ State Design Manual
- ☐ Experience/Knowledge
- ☐ Other (please specify)

9. What factors did you take into consideration when determining the maintenance of traffic plans for your facilities? Check all that apply.

- ☐ Traffic Counts
- ☐ Operating Speed
- ☐ % Trucks
- ☐ Availability of Alternate Routes
- ☐ Land Use Access
- ☐ Duration of Construction
- ☐ Rural/Urban
- ☐ Ped./Bike/ADA
- ☐ Other (please specify)

10. Did you find that certain techniques for maintenance of traffic work particularly well over others?

- ◉ Yes
- ○ No

Please describe

11. Did you find that certain techniques for maintenance of traffic were less effective than others?

- [ ] Complete Closure
- [ ] Phased Construction with Partial Closures
- [ ] Construct Temporary Runaround
- [ ] Temporary Traffic Signal
- [ ] Other

Please describe

12. Do you have any additional recommendations for developing maintenance of traffic plans for projects with innovative geometric designs? If so, please describe them here.

13. Would you be willing to provide additional information about your experiences through a follow-up phone call?
If yes, please leave your name and telephone number below.

Name

Telephone

14. Would you be willing to send project typical application sheets for use as examples for maintenance of traffic?

- ( ) Yes
- ( ) No

If yes, please provide your email address for follow-up

15. Would you like to receive a copy via email of the final project report that will include maintenance of traffic typical application sheets for different alternative geometric designs when it is completed?

○ Yes

○ No

If yes, please provide your email address

if you did not already provide it in Question # 14.

16. Do you have any additional comments on maintenance of traffic plans for alternative geometric designs?

Thank you for participating in this survey. Your input will greatly aid us in determining best temporary traffic control practices pertaining to innovative geometric designs.

Done

APPENDIX B. TABLE OF PLANS WITH DESCRIPTIONS

Table B.1 List of provided project plans by innovative design type with descriptions

Intersection Type	Received Plans	Project	Method Used	Notes
Roundabout	Columbia, MO	Clark Lane	Phased Construction with Temporary Bypass	Multiphase. Construct temporary by-pass prior to beginning modifications to existing roadway. Continue shifting traffic to newly improved roadway until project is completed.
		Clark Lane Phase II	Phased Construction with Temporary Bypass	Multiphase. Construct temporary by-pass prior to beginning modifications to existing roadway. Continue shifting traffic to newly improved roadway until project is completed.
		Mexico Gravel Rd.	Phased Construction with Partial Closure	Multiphase. Utilized temporary closures to construct roundabout and approaches one leg at a time, allow traffic as available. Place portable changeable message sign two weeks before construction to inform the public of closures.
		St. Charles Rd. and Lake of the Woods Rd.	Complete Closure	Place portable changeable message signs two weeks before construction to inform the public of closure.
		Vandiver Dr.	Phased Construction	Multiphase with allowing for original movements throughout construction. Project involved construction of new roadway connecting Mexican Gravel Rd. and Vandiver Dr.
	KYTC	Mt. Zion Rd. (Florence)	Phased Construction with Temporary Bypass	Multiphase. Construct new roundabout construction aside existing. Utilized temporary frontage roads to allow access as roundabout approaches and connections were constructed.
		Johns Hill Rd. and University Dr.	Phased Construction with Partial Closures	Multiphase. Construct new pavement prior to modifying existing road and shift traffic onto newly improved roadway as available.
	MnDOT	Highway 22 and Madison Ave. and Highway 22 and Adams St. (Mankato)	Full Closure	Two roundabouts at adjacent intersections were built in three phases using detour routes. In Phase 1, temporary access was constructed. In Phase 2, Highway 22 was closed between Bassett Dr. and Highway 14. Then construction of the roundabouts was started. In Phase 3, construction of roundabouts was completed, and temporary access was removed.

Intersection Type	Received Plans	Project	Method Used	Notes
Roundabout	MoDOT	MO 109 and MO 100, MO 109 and Pond Grover Loop Rd. (St. Louis County)	Phased Construction with Partial Closure	Two roundabouts were constructed, including one roundabout which replaced a signalized ramp terminal at a full diamond interchange (MO 100). In Phase 1, temporary pavement and permanent widening on MO 109 were constructed. In Phases 2 and 3, a temporary signal and temporary pavement were used to construct the roundabouts in stages. In Phase 3, the WB MO 100 on ramp and Pond Grover Loop Road were closed. Phase 4 included the construction of the truck aprons, center islands, center splitter islands, and median.
		MO 171 and MO 43 (Jasper County)	Phased Construction with Partial Closure	Multilane roundabout that was converted from a signalized intersection. Phases 1 and 2 included full depth widening. A temporary signal was utilized. In Phase 3, the center island, curb, and truck apron were constructed. In Phase 4, the channelizing islands were constructed. Lane nearest the island under construction was closed at night.
		Route 63 and Route M (Ashland)	Phased Construction with Temporary Closures	Roundabout interchange. Multiphase. Closed and constructed segments of the roundabout per phase. Flagging operation allowed for access to be maintained. Used nearby RCUTs to help maintain traffic.
	ODOT	SR 235 and SR 41 (Clark County)	Phased Construction with Partial Closures	Multiphase. Two legs closed throughout most of construction, detour used. Temporary pavement used for through movements.
	Omni Means	Shasta View Dr. and Old Arturas Rd. (Redding, CA)	Phased Construction	Multiphase. Temporary driveways had to be installed and 1 inch asphalt overlay placed at end of construction.
		I-5 and Deschutes Rd. (Anderson, CA)	Phased Construction with Partial Closures	Multiphase. Closed and constructed segments per phase. Existing/nearby roads used for detours.
	Washington County MN	CR 18 and 4th St.	Phased Construction with Partial Closures	Striping maintenance utilizing flagging operation.
		C.S.A.H. 15 and T.H. 96	Phased Construction with Temporary Bypass	Phased construction with partial roadway closure. Temporary bypass was constructed to allow for main road access and complete construction of roundabout.

Intersection Type	Received Plans	Project	Method Used	Notes
Roundabout	Washington County MN	C.S.A.H. 19 and C.S.A.H. 20/22	Phased Construction with Temporary Bypass	Phased construction with partial roadway closure. Temporary bypass was constructed to allow for main road access and complete construction of roundabout.
		Roundabout Staging Typical	Phased Construction with Partial Closures	Temporary traffic control typical applications sheet for in-roundabout segment closures.
	PennDOT	Temporary Traffic Control Guidelines	Phased Construction with Flagging Operation	Temporary traffic control typical applications sheet for in-roundabout segment closures.
SPUI	KYTC	KY 237 and KY 18 (Boone County)	Phased Construction with Temporary Bypass	Multiphase. Constructed temporary diversion prior to modification of existing roadway. SPUI is constructed adjacent to existing intersection and phasing is utilized to connect SPUI to existing roadways.
	MnDOT	I-494 and Lyndale (Richfield)	Phased Construction with Partial Closures	Multiphase. Bridge closed, alternate routes used. Through traffic allowed. Bypass ramp used in later phases. Traffic directed to ramps after construction, then back onto newly constructed main road.
	ODOT	I-75 and SR 63 (Monroe)	Phased Construction	Multiphase. Maintained complete access throughout construction, converting a conventional diamond interchange into a SPUI. Began with widening bridge deck, followed by construction of left-turn ramps. Approaching roadways were widened and traffic was shifted to allow construction of opposite side, utilizing temporary a temporary traffic signal. Once complete, traffic was shifted to final configuration.
	UDOT	SR-154 (Bangerter Hwy.) and 7800S (West Jordan)	Phased Construction with Temporary MUT	Multiphase. Temporary MUT used to maintain complete access throughout construction, converting a signalized at grade intersection into a SPUI. Begins with ramp construction, number of lanes decreased in all directions. Traffic diverted to ramps for construction. Once completed, traffic was shifted to final configuration.
DDI	Crawford, Murphy, and Tilly	I-65 and Worthsville Rd. (Worthsville, IN)	Phased Construction with Partial Closures	Originally designed as multiphase. Constructed second bridge adjacent to existing to serve as eastbound lanes in final layout. Constructed approaches to new bridge and once complete, all traffic is shifted to newly constructed bridge and reconstruction of existing bridge began. Once complete, traffic was shifted to final configuration.

Intersection Type	Received Plans	Project	Method Used	Notes
DDI	Crawford, Murphy, and Tilly	I-65 and Worthsville Rd. (Worthsville, IN)	Full Closure	Switched to full closure because of changes in project conditions. Utilized detours to divert traffic during DDI construction.
	MoDOT	I-44 and Rangeline Rd. (Joplin)	Phased Construction with Partial Closures	A full clover converted to DDI. In Phase 1 full depth outside shoulders on I-44 were constructed, and temporary outer ramp connections were built. In Phase 2, the center portion of the new I-44 bridge was constructed, temporary signals were activated, and outer ramp traffic was shifted to temporary connections. In Phase 3, the westbound portion of the new bridge and center islands were constructed, and permanent traffic signals were installed. In Phase 4, the eastbound portion of new bridge was constructed, the new ramps were connected, the permanent traffic signals were activated, and the remaining center islands were constructed. Phase 5 included the construction of permanent barriers, ramp islands, and sidewalks.
		US 60/160 (James River Freeway) and MO 13 (Kansas Expressway) (Springfield)	Phased Construction with Partial Closures	In Phase 1, all median strips and islands were removed and, full depth pavement was constructed under the median strips and islands. In Phase 2, the southbound lanes on Kansas Expressway were constructed. In Phase 3, pavement and bridge repairs on the northbound lanes of Kansas Expressway were performed. In Phase 4, the medians were constructed. In Phase 5, the interchange was temporarily closed (right turns on and off ramps were allowed), islands were constructed, and traffic was switched to the DDI configuration.
		US 65 and Battlefield Rd. (Springfield)	Phased Construction with Partial Closures	Project is under construction in 2015. A temporary DDI configuration is being utilized.

Intersection Type	Received Plans	Project	Method Used	Notes
DDI	NM DOT	I-25 and NM 14 (Santa Fe)	Phased Construction with Partial Closures	A partial clover converted to DDI. This project under construction in 2015. Phase 1 includes some ramp closures with temporary detours and temporary signals. Traffic on NM 14 reduces to one lane in each direction with crossovers. Widening for the DDI on NM 14 is constructed under traffic with NM 14 traffic shifts. Phase 2 utilizes detours on NM 14 to allow for the demolition of an existing off ramp bridge structure. The I-25 off ramps are constructed, and the DDI construction is completed under one-lane NM 14 traffic shifts. In Phase 3, final paving, signing, and striping are completed, and the DDI opens to traffic.
RCUT	MnDOT	US 52 and CR 66 (Vermillion)	Phased Construction with Partial Closures	The intersection was constructed in 2 phases. Traffic on CR 66 utilized a local road detour, and traffic on US 52 was reduced to one lane in each direction. In Phase 1, conflicting pavement markings were covered, and the CR 66 approaches were constructed. In Phase 2, the median construction was performed, and two U-Turns were constructed on US 52 on both sides of the CR 66 intersection. Then the left turn lanes and intersection islands were constructed.
	ODOT	Route 4B (Hamilton)	Phased Construction with Partial Closures	Multiphase with temporary side-roadway closures. Median U-turns and available west side of the future roadway were constructed first. Once the west side construction was complete, traffic was shifted onto the newly constructed roadway and work began on the east side. Once complete, all traffic was shifted to final configuration.
	MoDOT	US 63 and Route M (Atlanta)	Phased Construction with Partial Closures	The downstream U-turns were first constructed. Then, after completing construction of the U-turns and accommodating all movements, the median was closed. The median cross overs were fully closed for about 3 weeks to allow for the construction of improvements to the NB/SB left turns and the removal of the Route M through movement.

Intersection Type	Received Plans	Project	Method Used	Notes
RCUT	MoDOT	US 63 and RT B (Clark)	Phased Construction with Partial Closures	The downstream U-turns were first constructed. Then, after completing construction of the U-turns and accommodating all movements, the median was closed. The median cross overs were fully closed for approximately three weeks to allow for the construction of improvements to the NB/SB left turns and the removal of the Route B through movement.
		US 63 and Calvert Hill Rd./Hinton Rd. (Columbia)	Phased Construction with Partial Closures	In phase 1, right turn lane improvements and shoulder improvements were constructed. In phase 2, the right turn acceleration lanes were constructed. In Phase 3, the northerly and southerly J-turns were constructed. In phase 4, the median crossover was closed and offset lefts and median deceleration lanes were constructed. One lane in each direction on US 63 was closed with channelizers during construction
		MO 13 and 364 NE (St. Clair County)	Phased Construction with Partial Closures	In Phase 1, loons and side road entrances were constructed. Side road entrances were built one side at a time so that half of them remained open to traffic. In Phase 2, the median crossovers and turn lanes for the loons were constructed. Finally in phase 3, the median turn lanes and islands for intersection were constructed. The loons were not opened until new signs were installed.
MUT	Tucson, AZ	Grant Rd. and Oracle Rd.	Phased Construction with Partial Closures	In Phase 1, the center medians were removed, and temporary paving was placed in the median. In Phase 2, reconstruction of the eastbound lanes of Grant Rd. was performed. Phase 3 included the reconstruction of the westbound lanes of Grant Rd. In Phase 4, the north and south legs of Oracle Rd. were constructed. In phase 5, the median was constructed, signals were installed and activated at Oracle Rd. and the indirect left-turn intersections, and the final pavement lifts were placed.
	PSOMAS	Grant Rd. and 1st Ave./Stone Ave. (Pima County, Arizona)	Phased Construction with Partial Closures	This project is currently being designed in 2015. The first two phases consist of partial construction in each direction. In Phase 3, the median areas are constructed. Phase 4 includes minor paving and construction of curb and sidewalk areas. All paving within the traveled way must be completed on nights or weekends to minimize traffic impacts.

Intersection Type	Received Plans	Project	Method Used	Notes
DLT	Engineering Design Source, Inc.	MO 30 and Summit Rd./Gravois Bluffs Blvd. (Fenton, MO)	Phased Construction with Partial Closures	Plans show DLT setup and footprint. Temporary traffic control was left to the contractor.
	ODOT	Austin Blvd. and SR 741 (Miamisburg)	Phased Construction with Partial Closures	Multiphase with temporary roadway closures. Left turns were constructed first and traffic was shifted to final configuration as available.

APPENDIX C. CASE STUDIES

This section describes case studies for each innovative design that show different construction phasing schemes and methodologies used by various agencies.

C.1 Roundabout

C.1.1 C.S.A.H. 19 and C.S.A.H. 20/C.S.A.H. 22 (Washington County, Minnesota)

This project included the construction of a roundabout at C.S.A.H. 19 and C.S.A.H. 20/C.S.A.H. 22 in Washington County, Minnesota. The roundabout replaced an existing three-leg intersection which is shown in Figure C.1.1.1. C.S.A.H. 22 was extended east of C.S.A.H. 19 and connected with C.S.A.H. 20. The construction of the new roundabout occurred directly on top of the existing intersection. Factors that were considered during initial construction were the available right of way, traffic volumes, and detour availability.

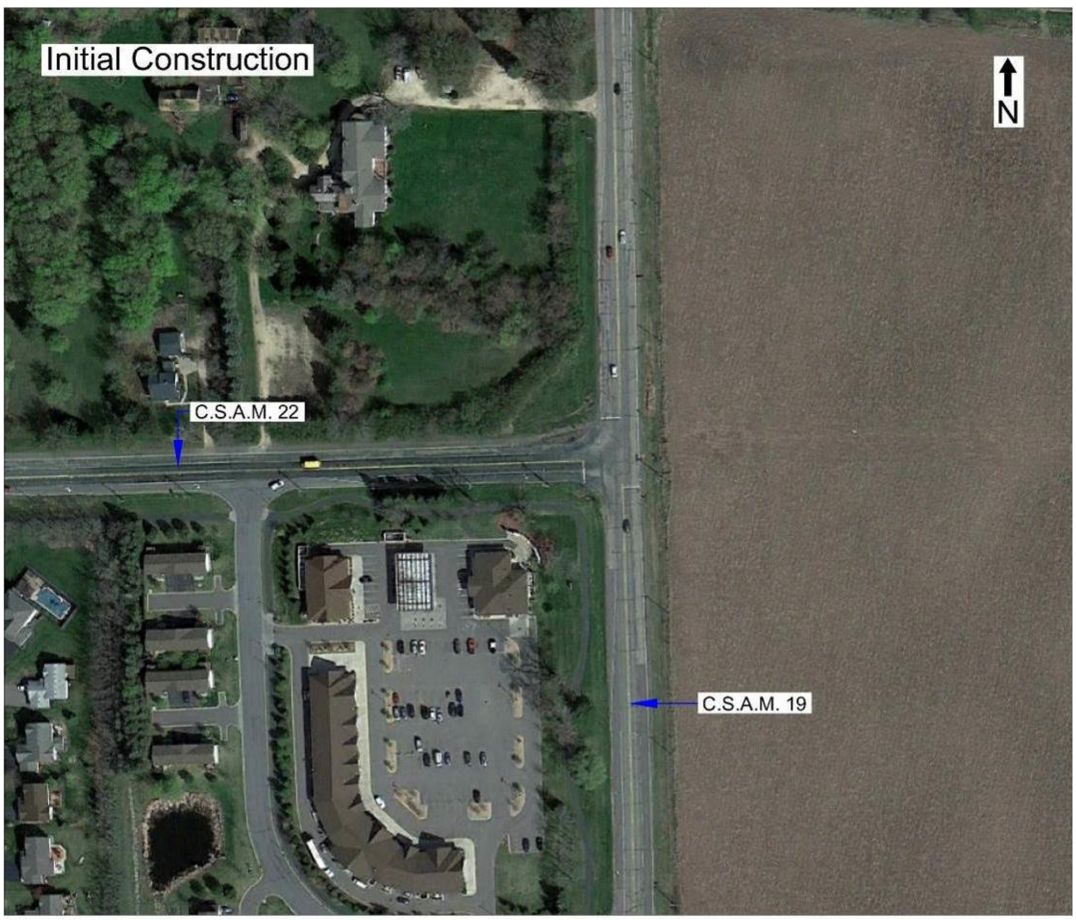


Image ©Google Earth 2015

Figure C.1.1.1 Initial condition of roundabout at C.S.A.H. 19 and C.S.A.H. 20/C.S.A.H. 22

The roundabout construction, as shown in Figure C.1.1.2, was accomplished by utilizing a temporary bypass to maintain two way traffic on C.S.A.H. 19. Temporary bypasses were favored because keeping the most legs of the intersection open was well-received by the public. The C.S.A.H. 22 approach was closed during construction.

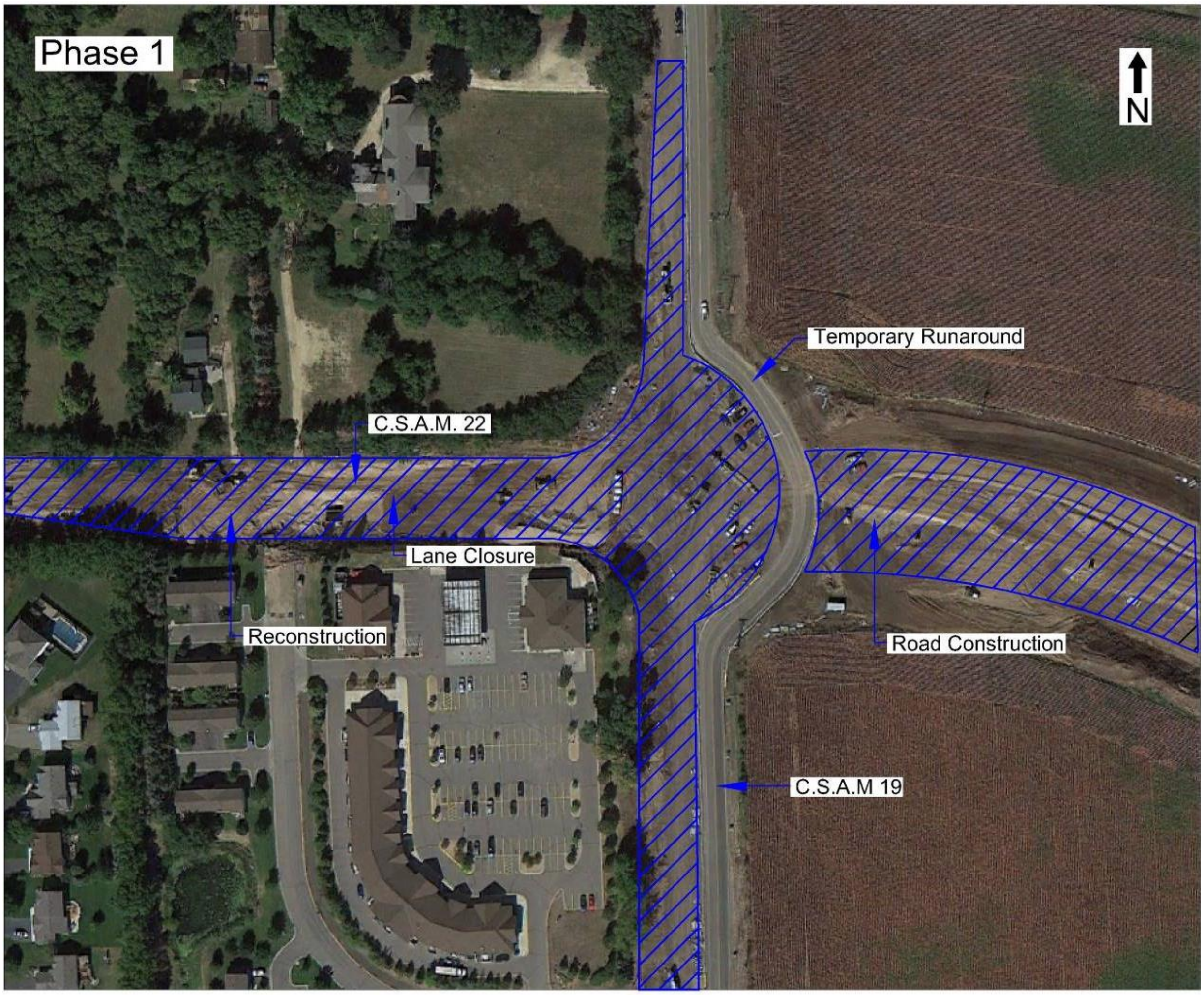


Image ©Google Earth 2015

Figure C.1.1.2 Construction of roundabout at C.S.A.H. 19 and C.S.A.H. 20/C.S.A.H. 22

After finishing construction of the roundabout traffic was shifted onto the final roundabout configuration and the temporary bypass was deconstructed. Figure C.1.1.3 shows the final configuration of the intersection.

Image ©Google Earth 2015

Figure C.1.1.3 Final configuration of roundabout at C.S.A.H. 19 and C.S.A.H. 20/C.S.A.H. 22

C.1.2 MO 171 and MO 43 (Jasper County, Missouri)

This project included the construction of a new multi-lane roundabout at an existing signalized intersection. Figure C.1.2.1 shows the former configuration of the intersection, which is a conventional at-grade intersection. The MOT for the project used phased construction and partial closures with four phases. In order to facilitate the movement of traffic, at least one lane of traffic was kept open in each direction at all times during project.

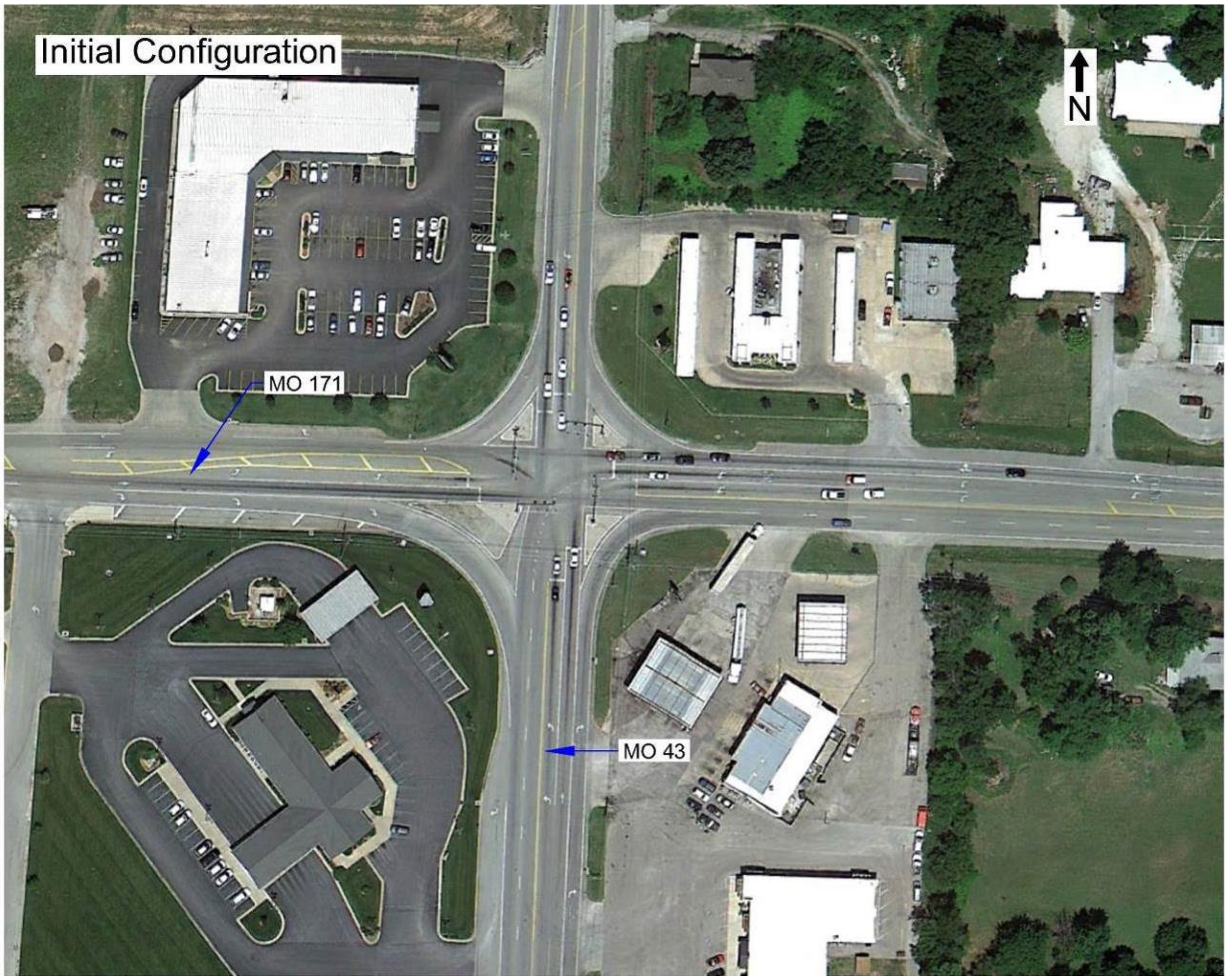


Image ©Google Earth 2015

Figure C.1.2.1 Conventional signalized intersection at MO 171 and MO 43

In Phase 1, the outside westbound lanes on MO 171 and outside northbound and southbound lanes on MO 43 were narrowed to construct full depth widening and shoulders on the north side of MO 171 and the north approach of MO 43. The existing traffic signals were used to maintain the existing traffic flow. Figure C.1.2.2 show the work area during Phase 1.

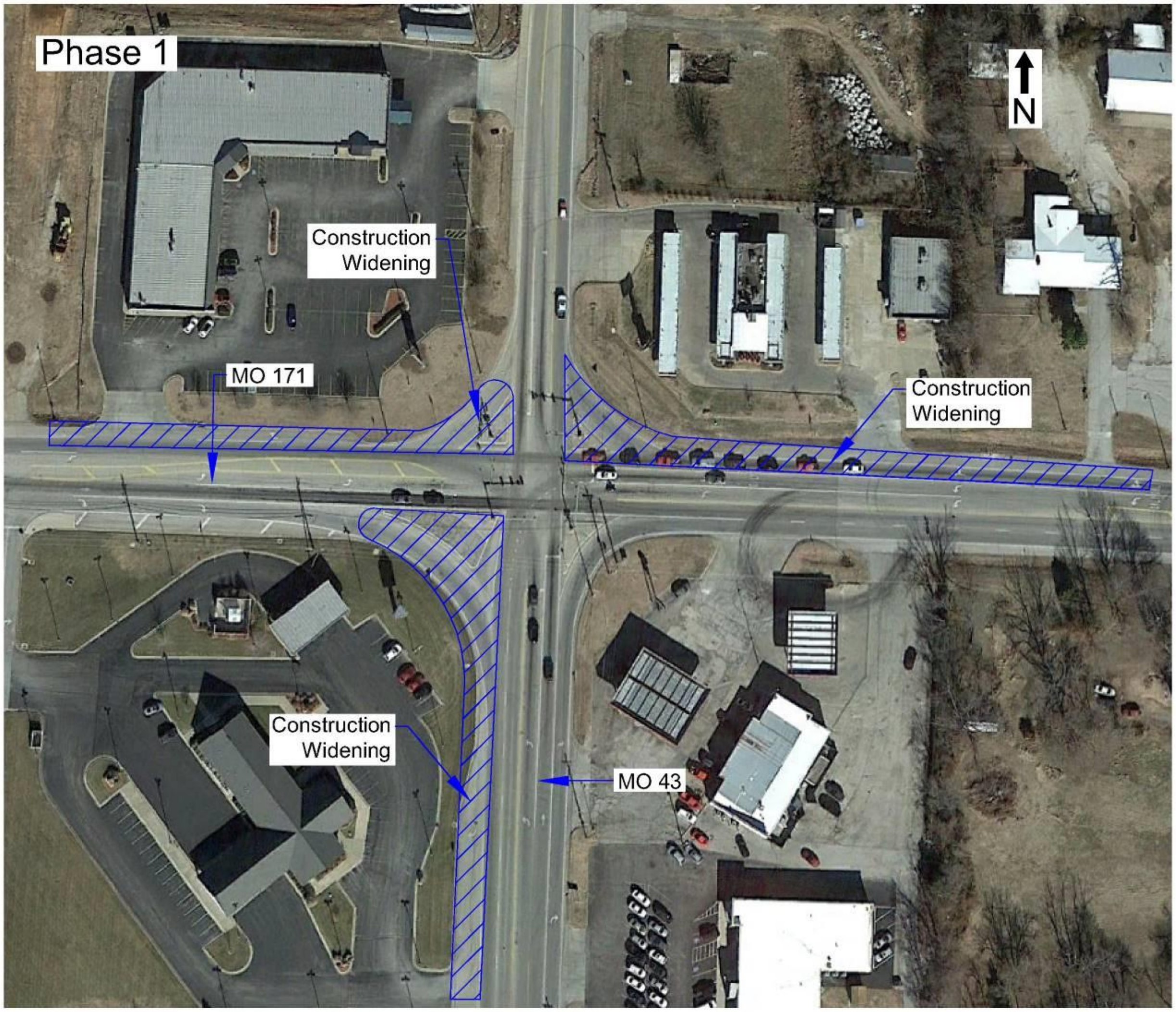


Image ©Google Earth 2015

Figure C.1.2.2 Phase 1 construction of roundabout at MO 171 and MO 43

In Phase 2, as shown in Figure C.1.2.3, the outside eastbound lane of MO 171 was also narrowed, and full depth widening and shoulders were constructed on the south side of MO 171 and the south approach of MO 43. A temporary signal was also installed, and the existing signal controller was removed.

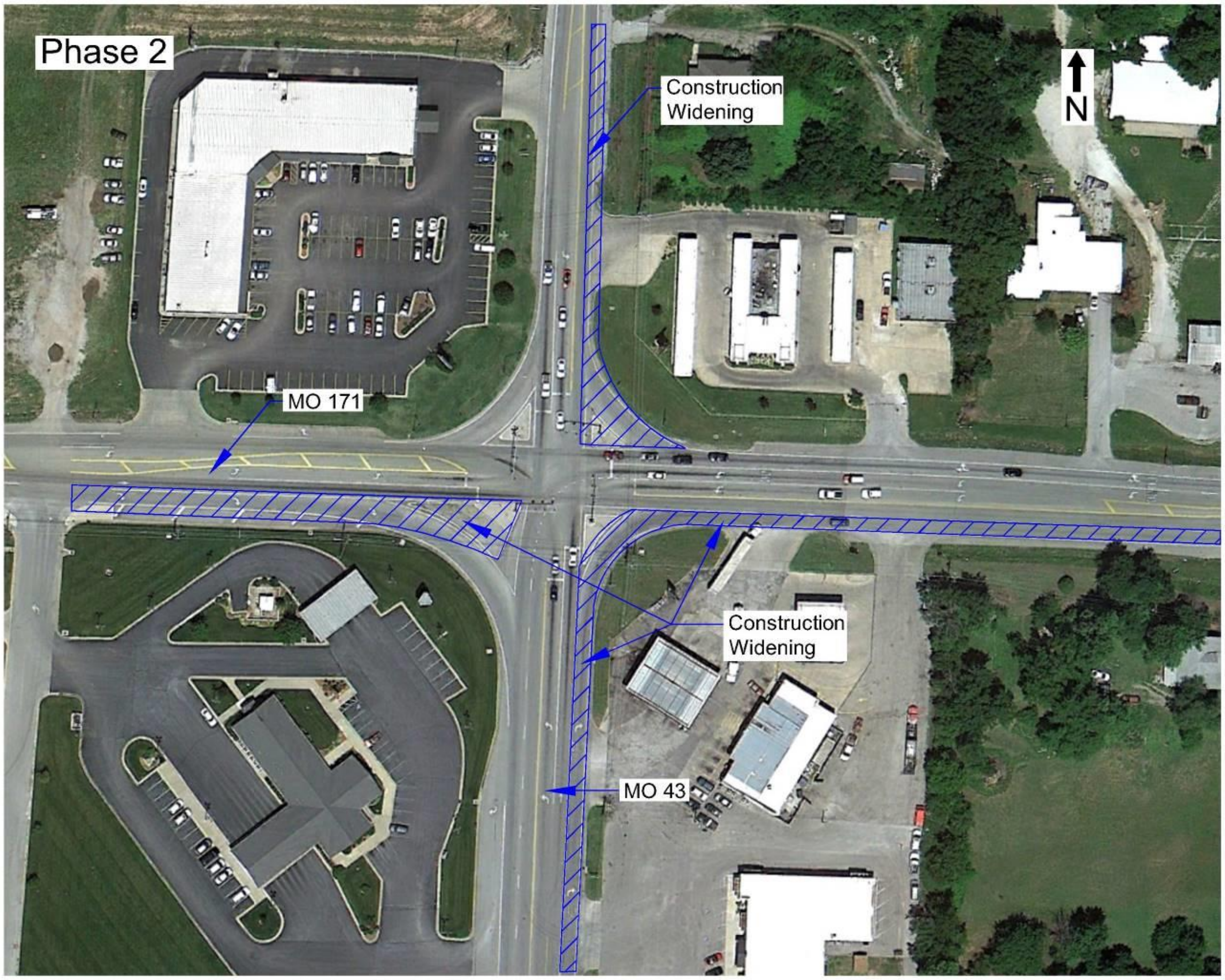


Image ©Google Earth 2015

Figure C.1.2.3 Phase 2 construction of Roundabout at MO 171 and MO 43

Phase 3 began with deactivating the existing signals. Then, channelization was provided to operate the intersection as a modified single lane roundabout with a right turn only lane at each approach. The center island, curb, and truck apron were constructed, and the existing islands and signals were removed. Figure C.1.2.4 shows the work area and channelization for this phase of construction.

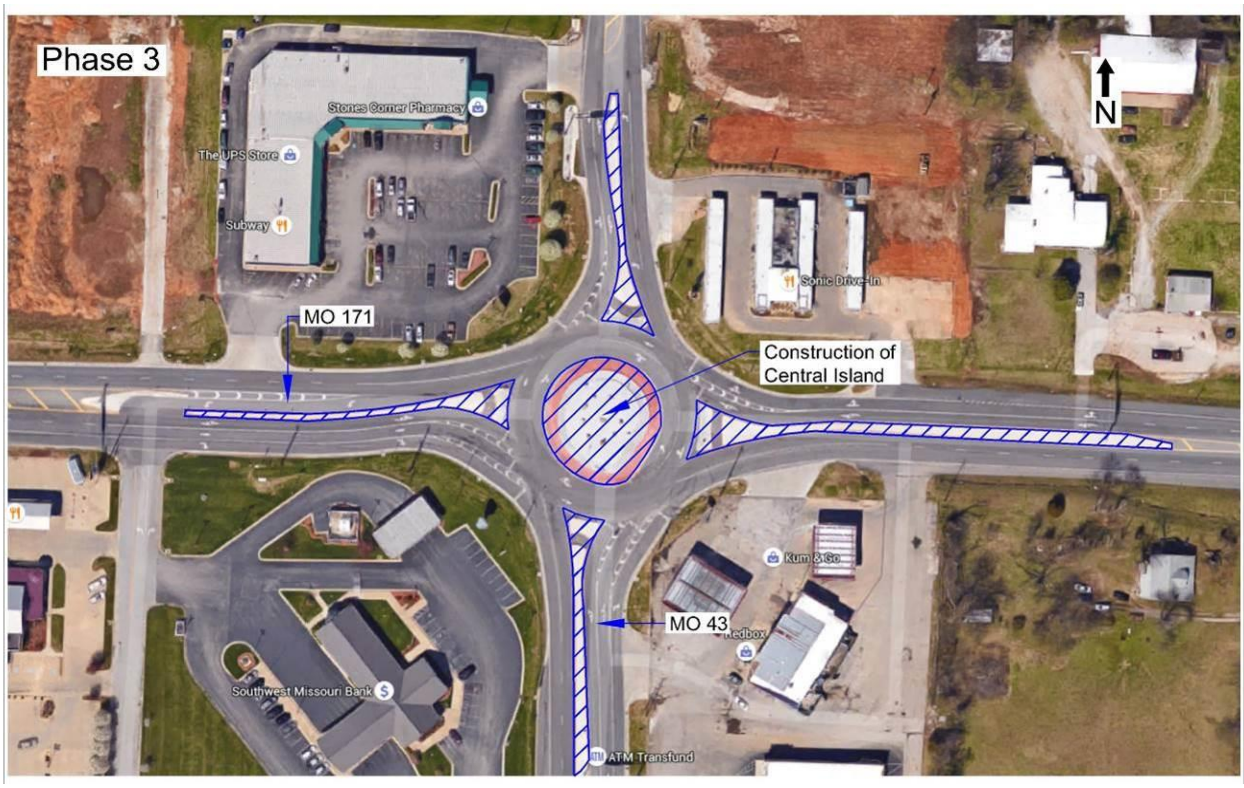


Image ©Google Earth 2015

Figure C.1.2.4 Phase 3 construction of roundabout at MO 171 and MO 43

In Phase 4, as shown in Figure C.1.2.5, the channelizing islands were constructed, and the permanent pavement markings and signing were completed. Traffic flow was maintained as a two-lane roundabout during daylight hours. During nighttime operation, the lane nearest the island under construction was closed for construction.

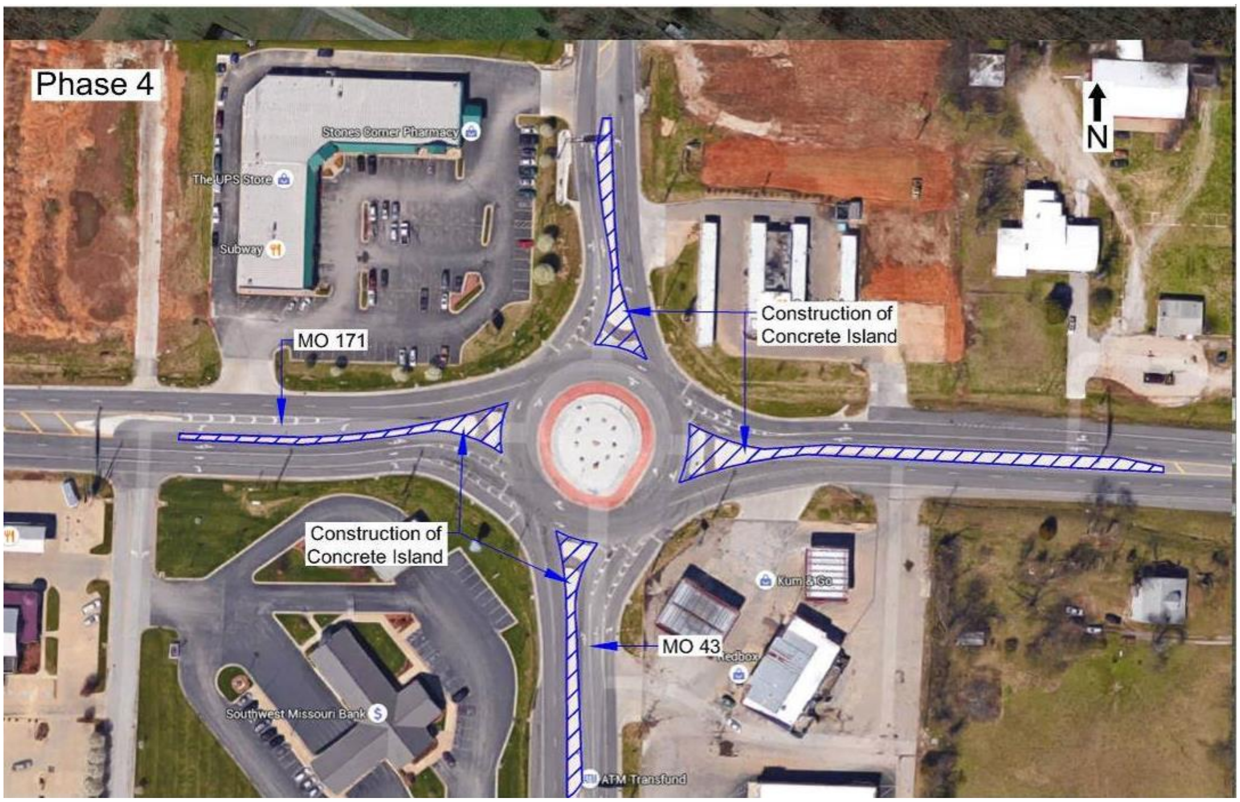


Image ©Google Earth 2015

Figure C.1.2.5 Phase 4 construction of roundabout at MO 171 and MO 43

After constructing the channelizing islands, the temporary traffic control devices were removed, and the roundabout was opened to the final traffic configuration. Figure C.1.2.6 shows the final configuration of the roundabout.

Image ©Google Earth 2015

Figure C.1.2.6 Final configuration of roundabout at MO 171 and MO 43

C.2 SPUI

C.2.1 SR-154 (Bangerter Highway) and 7800 South (West Jordan, Utah)

SR-154 (Bangerter Highway) and 7800 South in West Jordan, Utah, was originally a signalized at-grade intersection as shown in Figure C.2.1.1. The intersection was converted to a SPUI in 2011 by the Utah Department of Transportation (UDOT). The area is growing rapidly, and Bangerter Highway provides access to many local businesses. UDOT promised to maintain access to all these business at all times during the construction. The intersection is also close in proximity to a residential area, mall, and school and is extremely limited by its existing space; the new intersection is located at the same place as the previous intersection.

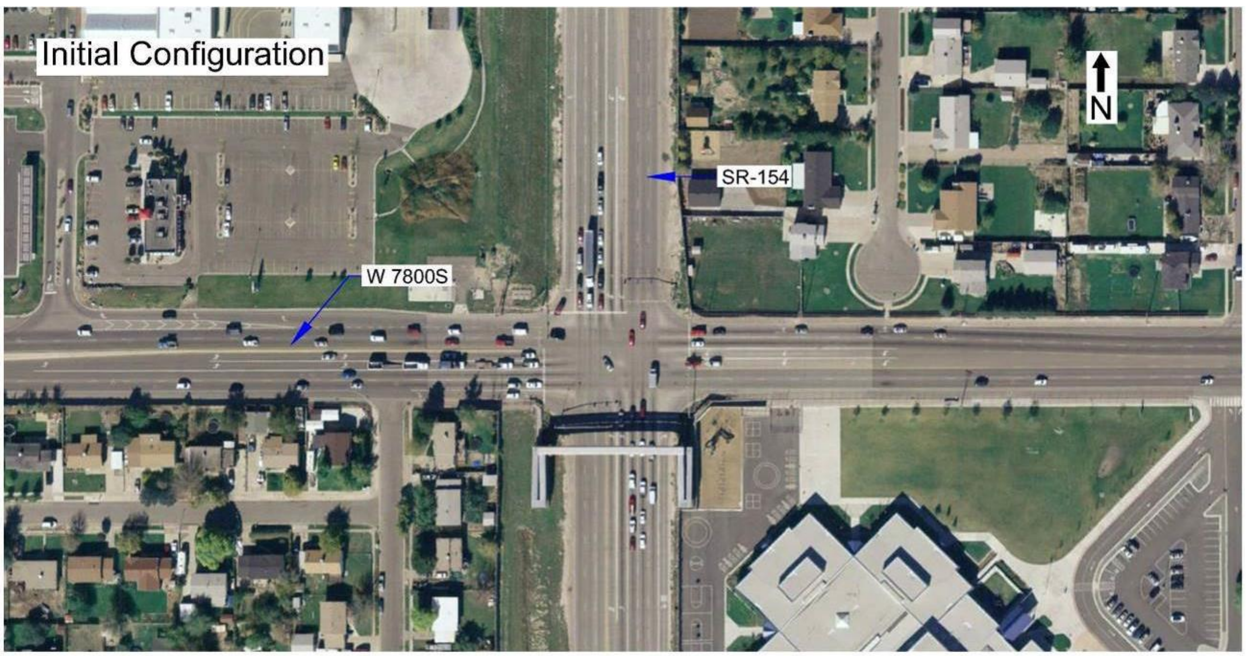


Image ©Google Earth 2015

Figure C.2.1.1 Signalized at-grade intersection at Bangerter Highway and 7800 South

The SPUI was constructed using phased construction and a temporary closure. To accommodate the left turns during construction and help accelerate construction, median U-turns were constructed. The traffic movements for Phase 1 are shown in Figure C.2.1.2. The on and off ramps were constructed during this phase. All existing movements were allowed as the only construction areas were located on the outer lanes of Bangerter Highway.

UDOT 2012a

Figure C.2.1.2 Traffic movements for Phase 1 construction of SPUI at Bangerter Highway and 7800 South

In Phase 2, traffic was diverted to the ramps to allow for the construction of the center of the SPUI. Figure C.2.1.3 shows the construction area and traffic movements for Phase 2. Temporary signals were installed, and a temporary MUT was added at each end of the project on Bangerter Highway to accommodate left turns. This configuration allowed the design/build contractor to meet UDOT's MOT lane restrictions by maintaining all through lanes. With the left turns moved away from the intersection, the contractor was able to build the bridge in one phase.

UDOT 2012a

Figure C.2.1.3 Construction area and traffic movements for Phase 2 construction of SPUI at Bangerter Highway and 7800 South

The Bangerter Highway/7800 South conversion from an at-grade intersection to a SPUI differed from the typical SPUI conversion with its innovative use of the MUT to accommodate left turns. With high traffic and close proximity to a mall, school, and residential area, there was little room for expansion from the original intersection. The contractor was required to bid for days used over the allowed number. Each of these days cost $10,000 per day per direction. The overall method of construction and the MUT worked very well as it accelerated construction and accommodated high volumes of traffic during the construction process. Figure C.2.1.4 shows the final configuration of the SPUI interchange.

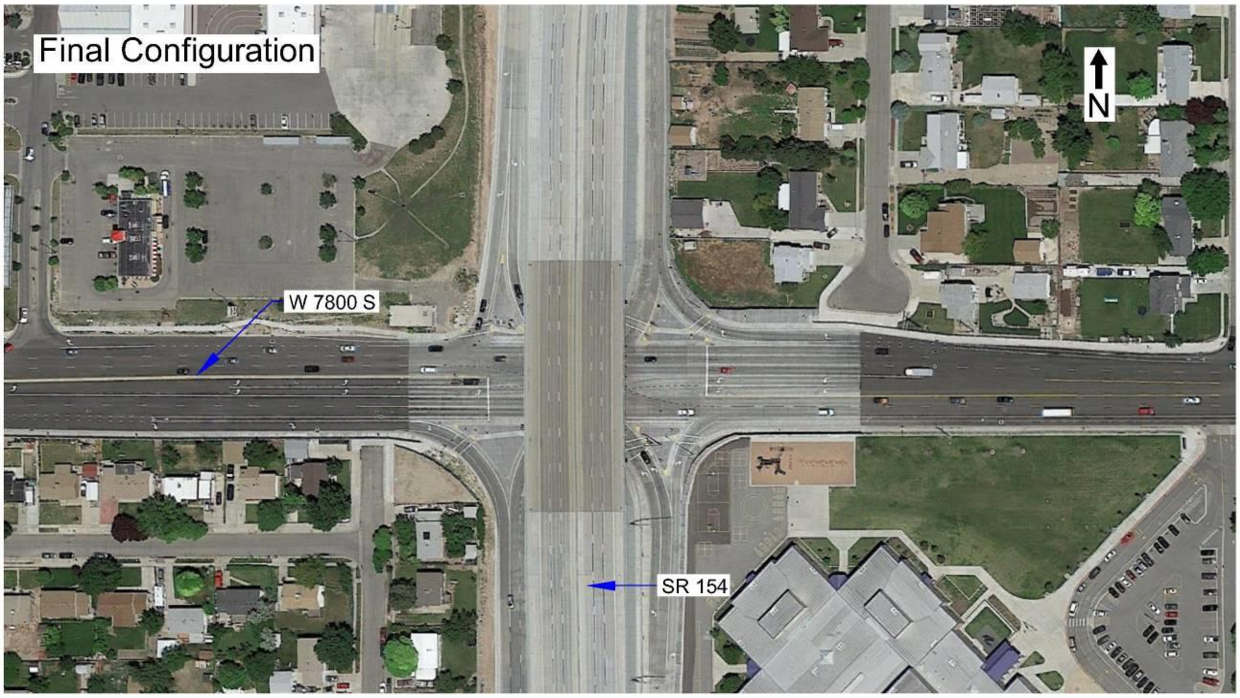


Image ©Google Earth 2015

Figure C.2.1.4 Final configuration of SPUI at Bangerter Highway and 7800 South

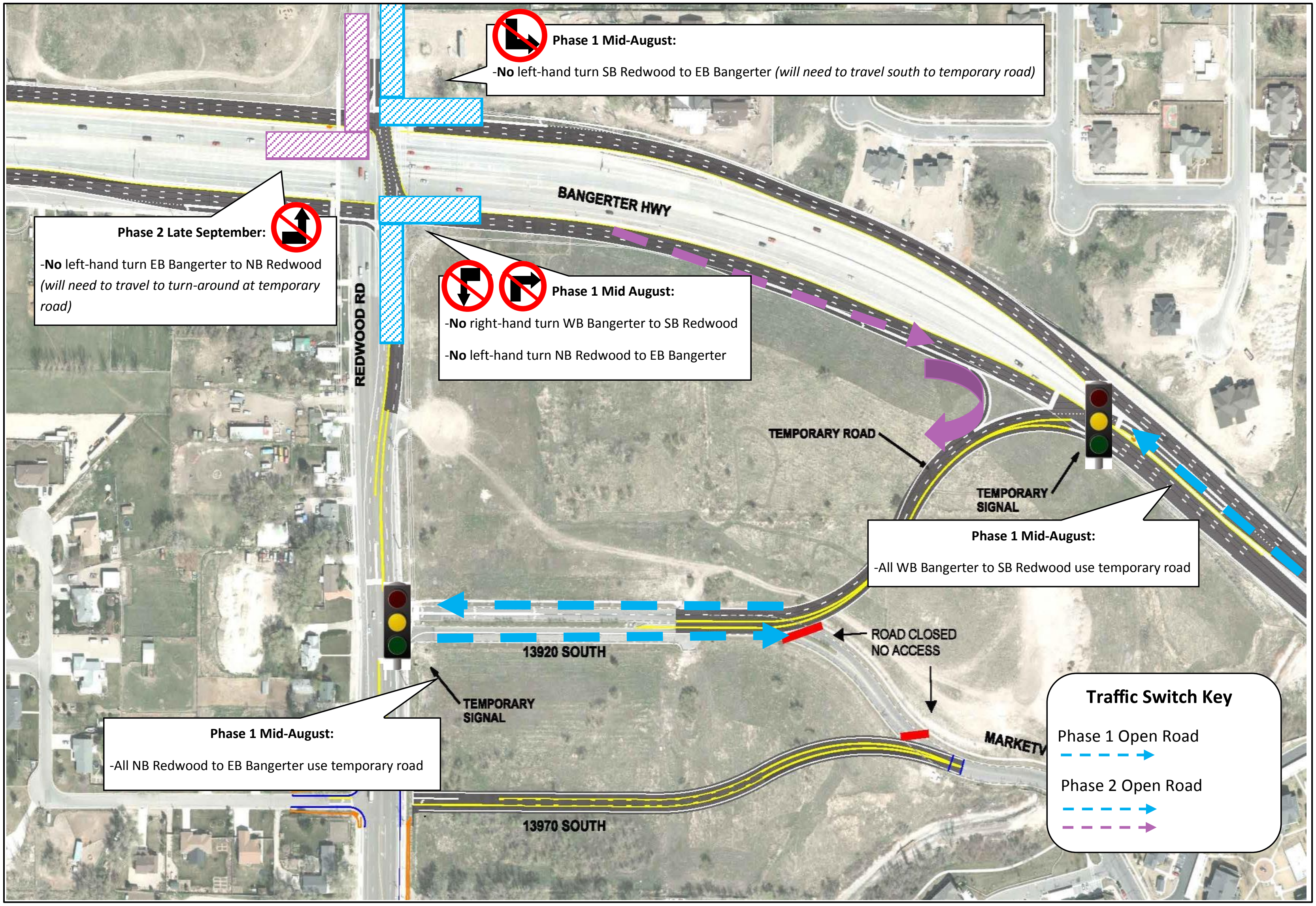
C.2.2 SR-154 (Bangerter Highway) and SR-68 (Redwood Road) (Bluffdale, Utah)

The intersection between SR-68 (Redwood Road) and SR-154 (Bangerter Highway) in Bluffdale, Utah, was converted to a SPUI by UDOT. Construction began in 2014, and the anticipated completion date is July 2015 (UDOT 2012b). As shown in Figure C.2.2.1, the previous configuration of the intersection was a conventional signalized at-grade intersection. Bangerter Highway is a major corridor in the area, and the community surrounding Bangerter Highway and Redwood Road is projected to grow at an accelerated pace. This upgrade helps to accommodate more traffic and increase safety.

Image ©Google Earth 2015

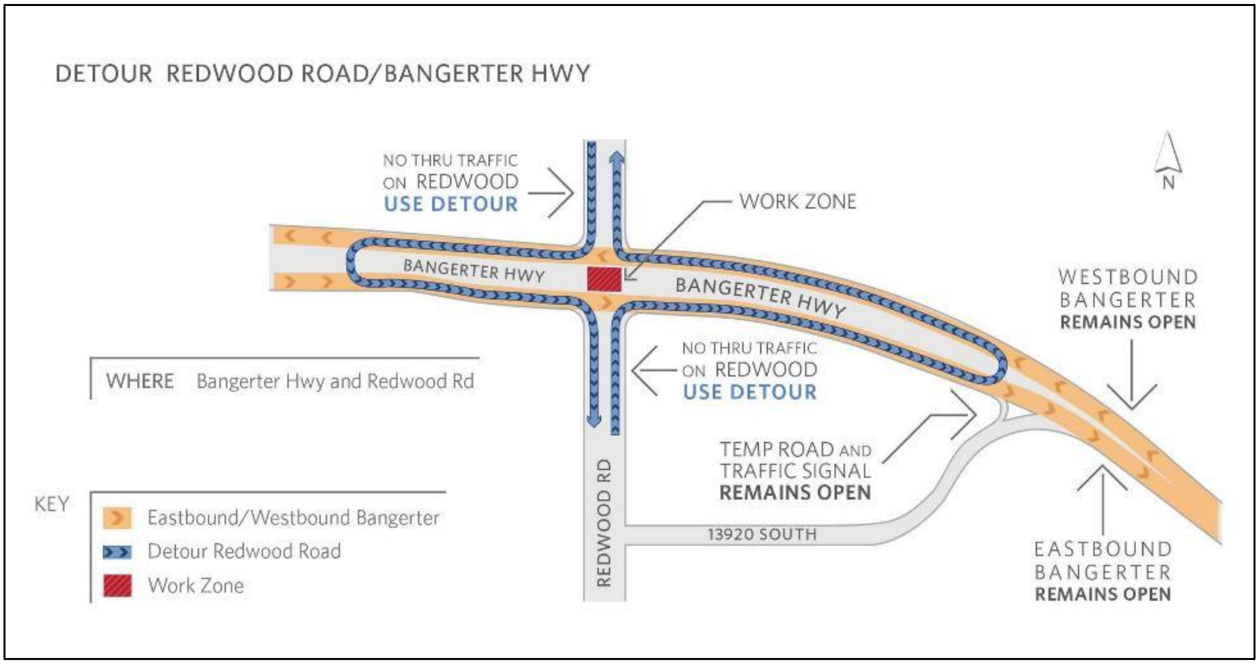
Figure C.2.2.1 Conventional signalized at-grade intersection at Bangerter Highway and SR-68 (Redwood Road)

This SPUI was constructed using phased construction and temporary closures. Figure C.2.2.2 shows the traffic switch timeline for each phase. After the new interchange ramps were constructed, through traffic was directed onto them. A Quadrant/DLT was created by branching off SR-68 using part of an existing road (13920 South) to accommodate left-turning traffic and help accelerate construction. This configuration moved left turns approximately 1000 feet from the intersection. Temporary signals were installed at the Redwood Road/13920 South intersection and at the 13920 South extension/Bangerter Highway intersection. Through traffic on Redwood Road followed a detour as shown in Figure C.2.2.3.



UDOT 2012b

Figure C.2.2.2 UDOT traffic switch timeline for SR-154 and SR-68



UDOT 2012b

Figure C.2.2.3 Redwood Road detour for construction of SPUI at Bangerter Highway and Redwood Road

The use of the Quadrant/DLT creates a unique case in comparison with the typical SPUI construction. To create the Quadrant/DLT, a local landowner/ land developer gave the right-of-way. This process reduced the construction schedule by 4 to 5 months. In order to complete the construction as quickly as possible, UDOT provided a daily incentive of $40,000 up to $200,000 maximum to the design/build contractor.

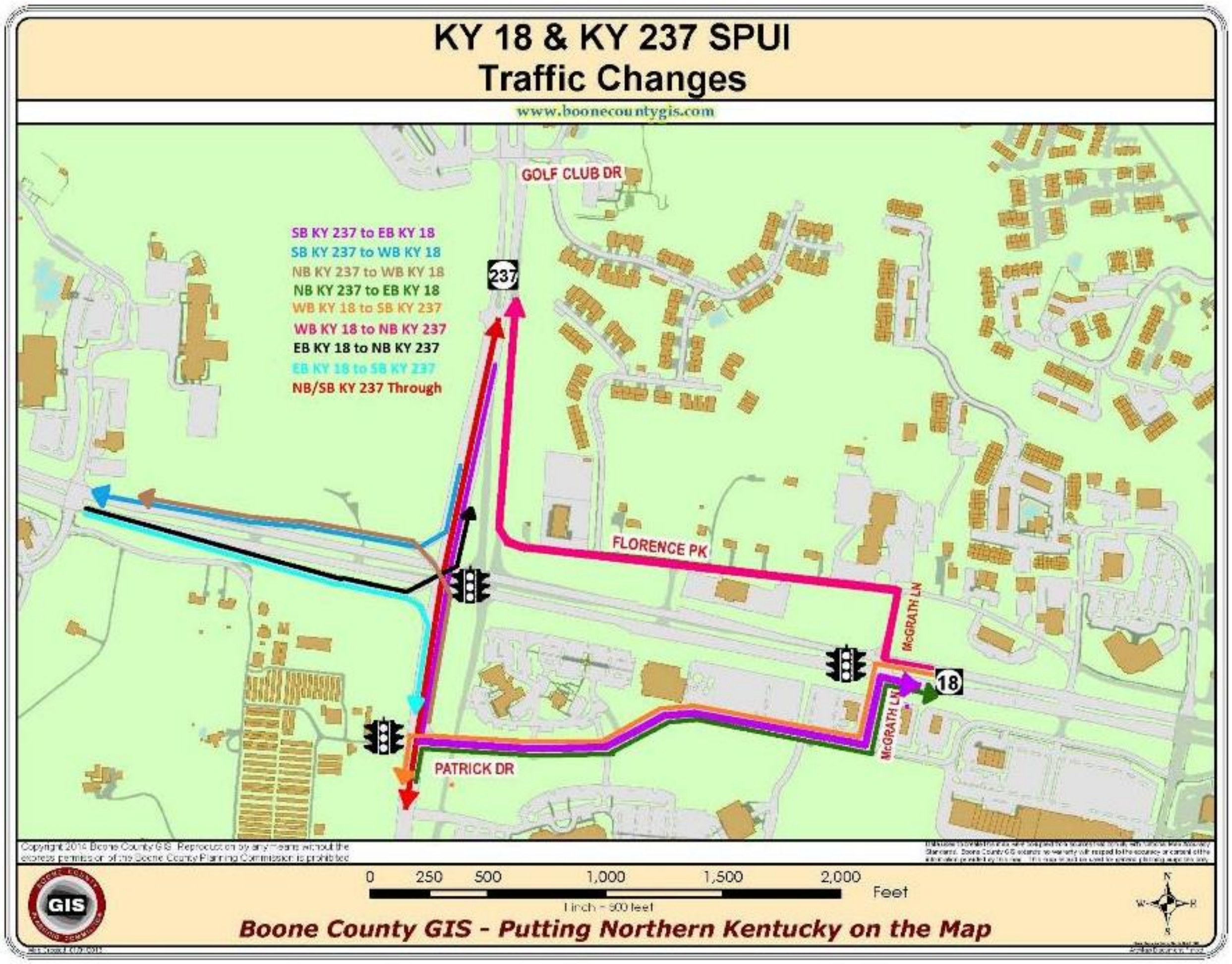
C.2.3 KY 237 and KY 18 (Boone County, Kentucky)

The at-grade KY 237 (also referred to as Camp Ernst Road and N. Bend Road) and KY 18 intersection in Boone County, Kentucky, near Limaburg was converted into a SPUI in 2013 and 2014. As it is shown in Figure C.2.3.1 the former configuration of the intersection was a conventional signalized at-grade intersection. The new SPUI interchange is located slightly west of the previous existing intersection. High traffic volumes created a need for the new intersection. A local middle school, church, and several businesses are located near the project. Extra right-of-way allowed for the new intersection to be displaced from the original intersection.

Image ©Google Earth 2015

Figure C.2.3.1 Conventional at-grade intersection at KY 237 and KY 18

The SPUI was constructed using phased construction with partial closures. Figure C.2.3.2 shows the traffic configuration during construction.



Copyright 2014 Boone County GIS

Figure C.2.3.2 Traffic configuration for SPUI at KY 18 and KY 237

In Phase 1, the west portion of the new KY 237 lanes was constructed while one lane of traffic in each direction was maintained on KY 237. Portions of the northeast, northwest, and southwest ramps were also constructed. A temporary north-south connector in the southeast quadrant of the existing intersection was constructed for use in Phase 2, and temporary pavement was installed for SB KY 237 left turns. The existing signal was maintained, and temporary sheet piling was installed around the signal cabinet to allow for embankment construction. On KY 18, the bridge piers and abutments were constructed while two lanes of traffic were maintained in each direction. The construction area in this phase is shown in Figure C.2.3.3.

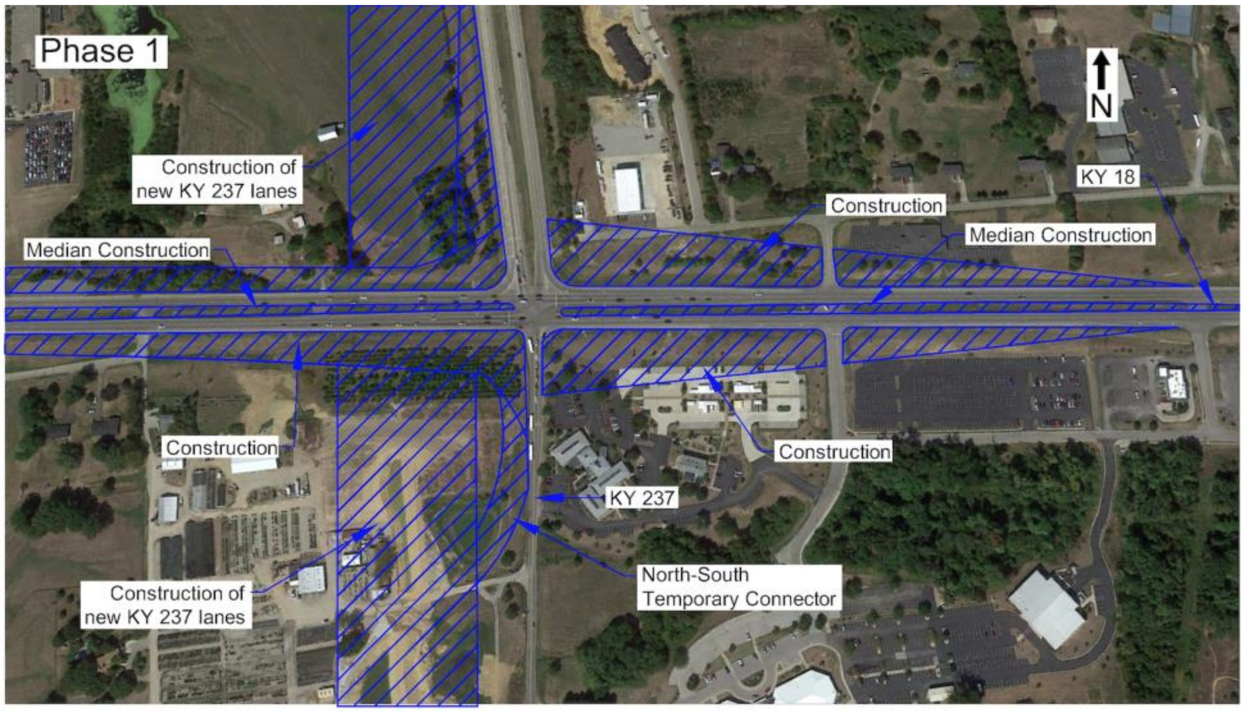


Image ©Google Earth 2015

Figure C.2.3.3 Phase 1 construction of SPUI at KY 18 and KY 237

The Phase 2 construction of the interchange is shown in Figure C.2.3.4. At the beginning of Phase 2, a full weekend closure of the intersection was utilized to allow for the construction of the north-south connector in the southeast quadrant to be completed. McGrath Lane and Patrick Drive were constructed in order to allow the west half of the interchange to open to traffic in Phase 3. In Phase 2, the bridge was constructed, and temporary signals were installed. Pedestrian signals were installed near the bridge deck. One lane of traffic was maintained in each direction on KY 237. On KY 18, construction took place in the median while two lanes of traffic were maintained in each direction. At the conclusion of Phase 2, a temporary west/north connector was constructed in the northeast quadrant of the intersection to provide access from Florence Pike to KY 237.

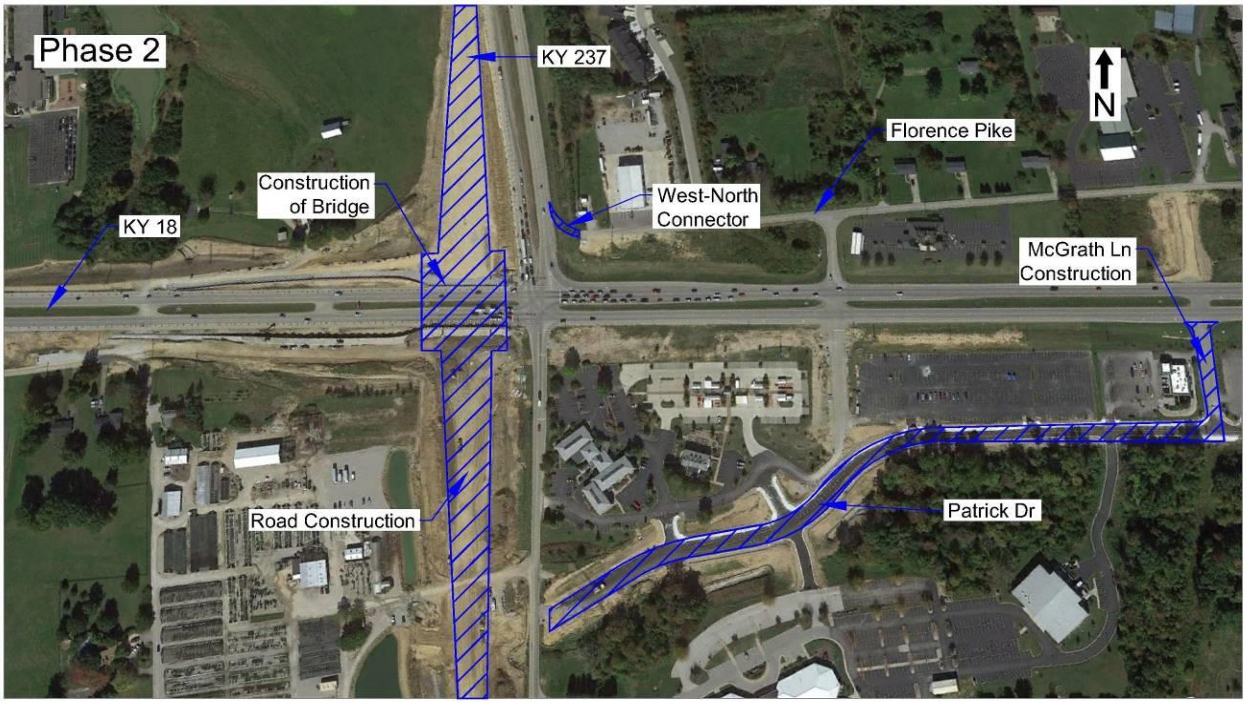


Image ©Google Earth 2015

Figure C.2.3.4 Phase 2 construction of SPUI at KY 18 and KY 237

The Phase 3 construction is shown in Figure C.2.3.5. In Phase 3, the west half of the SPUI was opened to traffic. The northeast and southeast ramps were constructed one at a time, beginning with the northeast ramp. The northeast ramp was put into use immediately after completion. The east side of the KY 237 pavement was also constructed. Some traffic movements were detoured using Patrick Drive, Florence Pike, and the temporary west/north connector. One lane of traffic in each direction was maintained on KY 237.

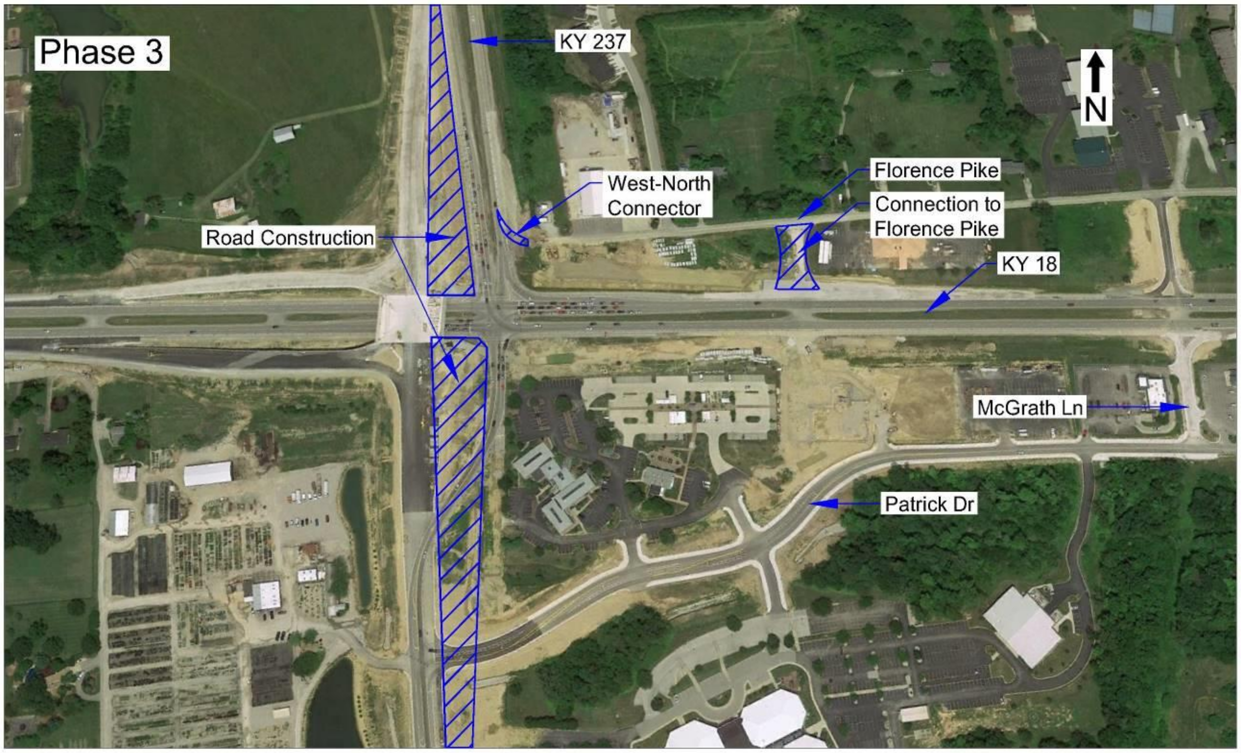


Image ©Google Earth 2015

Figure C.2.3.5 Phase 3 construction of SPUI at KY 18 and KY 237

Figure C.2.3.6 shows Phase 4 of construction. In Phase 4, construction of the embankment on the east side of KY 237 was completed while two lanes of traffic in each direction were maintained on KY 237. The contractor was permitted to close on lane of traffic in each direction on KY237 at nighttime to facilitate the completion of construction. The temporary traffic signals were removed. The final conversion to a SPUI took place as the signal heads were adjusted to their final position and the remaining signal equipment was installed.

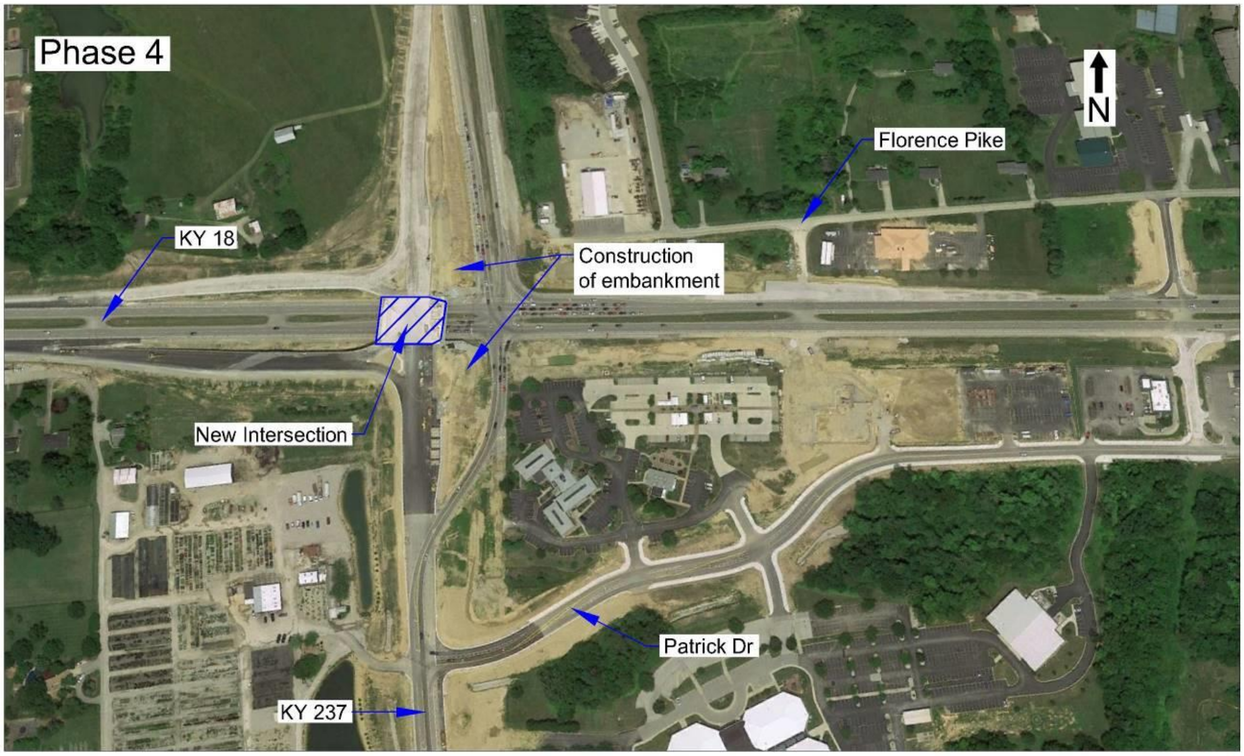


Image ©Google Earth 2015

Figure C.2.3.6 Phase 4 construction of SPUI at KY 18 and KY 237

C.3 DDI

C.3.1 US 60/160 (James River Freeway) and MO 13 (Kansas Expressway) (Springfield, Missouri)

The interchange at James River Freeway and Kansas Expressway in Springfield, Missouri was converted to a Diverging diamond interchange in 2010. The former configuration of the interchange was a conventional full diamond as shown in Figure C.3.1.1.

Image ©Google Earth 2015

Figure C.3.1.1 Conventional diamond interchange at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

The DDI interchange was constructed using a phased construction with partial closures in 6 phases. In Phase 1, as shown in Figure C.3.1.2, all median strips and islands were removed, and full depth pavement was constructed under the median strips and islands. Full depth widening was placed on the west side along MO 13 and the ramps. Temporary traffic signals were installed, and the existing traffic signals were removed. Two lanes of traffic on MO 13 in each direction and the ramp turning movements were maintained.

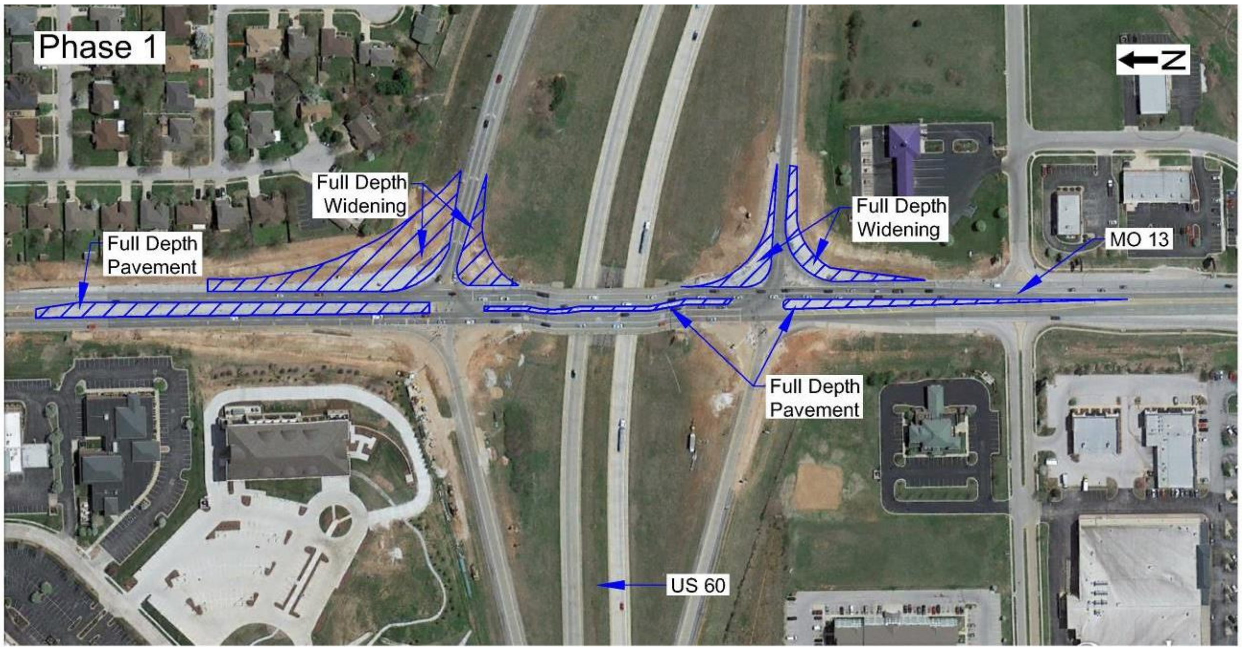


Image ©Google Earth 2015

Figure C.3.1.2 Phase 1 construction of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

In Phase 2, full depth widening was accomplished along the east side of MO 13 and the ramps, and full depth pavement was constructed on the southbound lanes. Installation was started on the permanent traffic signals away from traffic. Figure C.3.1.3 shows the work area for this phase of project.

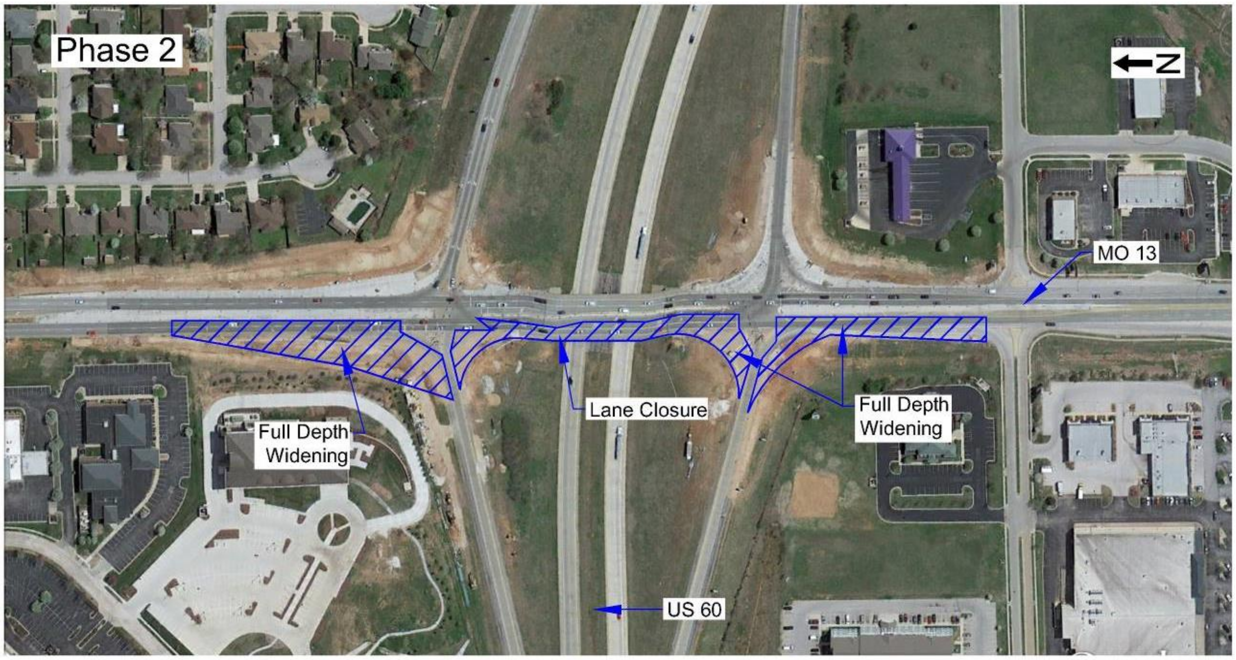


Image ©Google Earth 2015

Figure C.3.1.3 Phase 2 construction of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

In Phase 3, pavement and bridge repairs on the northbound lanes were performed. Two southbound lanes and one northbound lane of traffic on MO 13 and the ramp turning movements were maintained during Phases 2 and 3. Figure C.3.1.4 shows the work area for this phase.

Image ©Google Earth 2015

Figure C.3.1.4 Phase 3 construction of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

In Phase 4, as shown in Figure C.3.1.5, the pavement was resurfaced, and the median strip and barrier walls were constructed. Two lanes of traffic on MO 13 in each direction were maintained. Ramp turning movements were maintained except as needed during the overlay work.

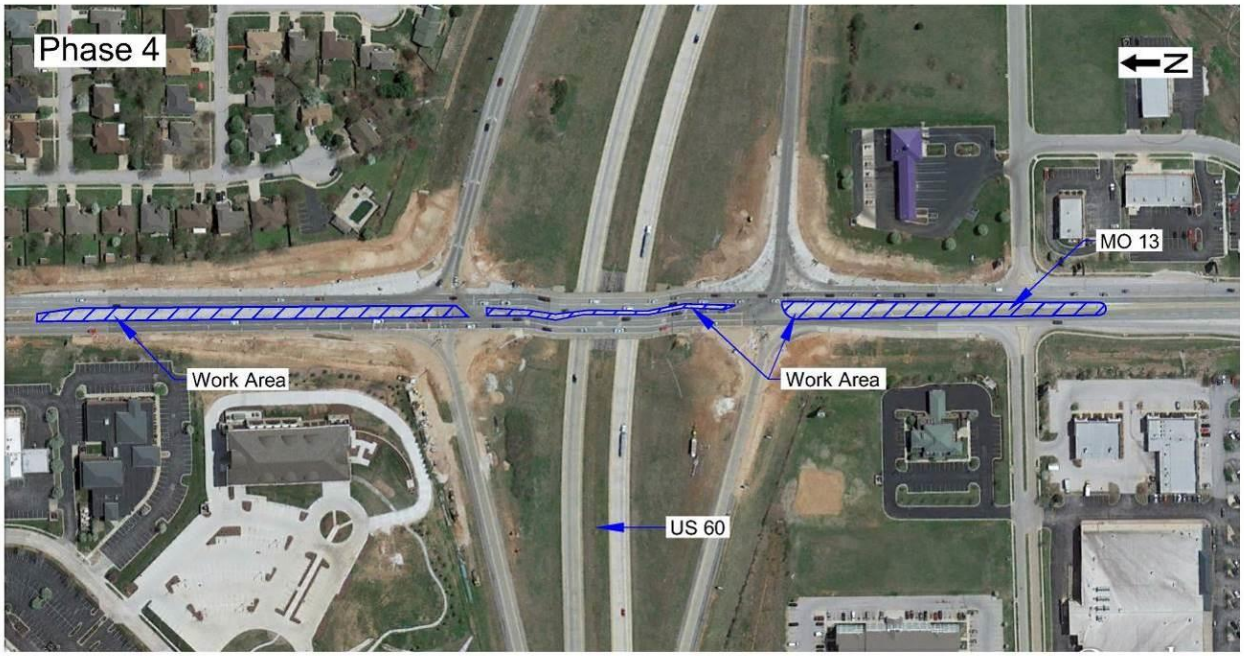


Image ©Google Earth 2015

Figure C.3.1.5 Phase 4 Construction of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

In Phase 5, the interchange was temporarily closed with the exception that right turns on and off the ramps were allowed. Channelizers were utilized for delineating islands and median strips. Permanent pavement markings were also applied in this phase. After finishing the installation and testing of the new permanent signals, the temporary signals were removed. Figure C.3.1.6 shows the construction area for Phase 5.

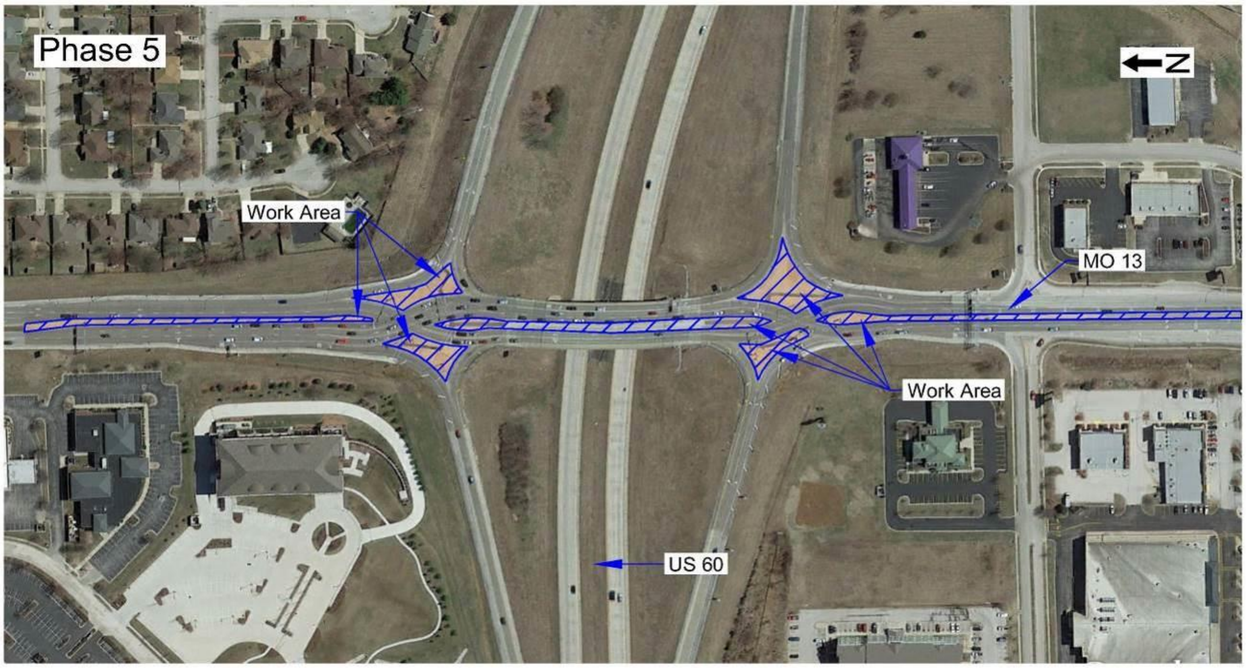


Image ©Google Earth 2015

Figure C.3.1.6 Phase 5 construction of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

Finally, traffic was switched to DDI in Phase 6. In order to delineate the islands and median strips, channelizers were used. As the last part of the project, the islands and median strips were completed. Figure C.3.1.7 shows the final configuration of the diverging diamond interchange.

Image ©Google Earth 2015

Figure C.3.1.7 Final configuration of DDI at US 60/160 (James River Freeway) and MO 13 (Kansas Expressway)

C.4 RCUT

C.4.1 MO 13 and Route 364 NE (St. Clair County, Missouri)

The intersection between MO 13 and Route 364 NE in St. Clair County, Missouri was converted to a RCUT intersection in 2013. The intersection was previously a conventional stop controlled intersection as shown in Figure C.4.1.1. Due to several crashes at this intersection, MoDOT converted it to a RCUT intersection.

Image ©Google Earth 2015

Figure C.4.1.1 Conventional at-grade intersection at MO 13 and Route 364 NE

For the construction of this RCUT intersection, phased construction with partial closures was utilized, and the project was built in 3 phases. In Phase 1, the loons (bulb-outs) and side road entrances were constructed. One lane of traffic in each direction on the MO 13 median lanes was maintained using channelizers. The side road entrances were built one side at a time so that half of them remained open to traffic. Figure C.4.1.2 shows the work area for this phase of the project.

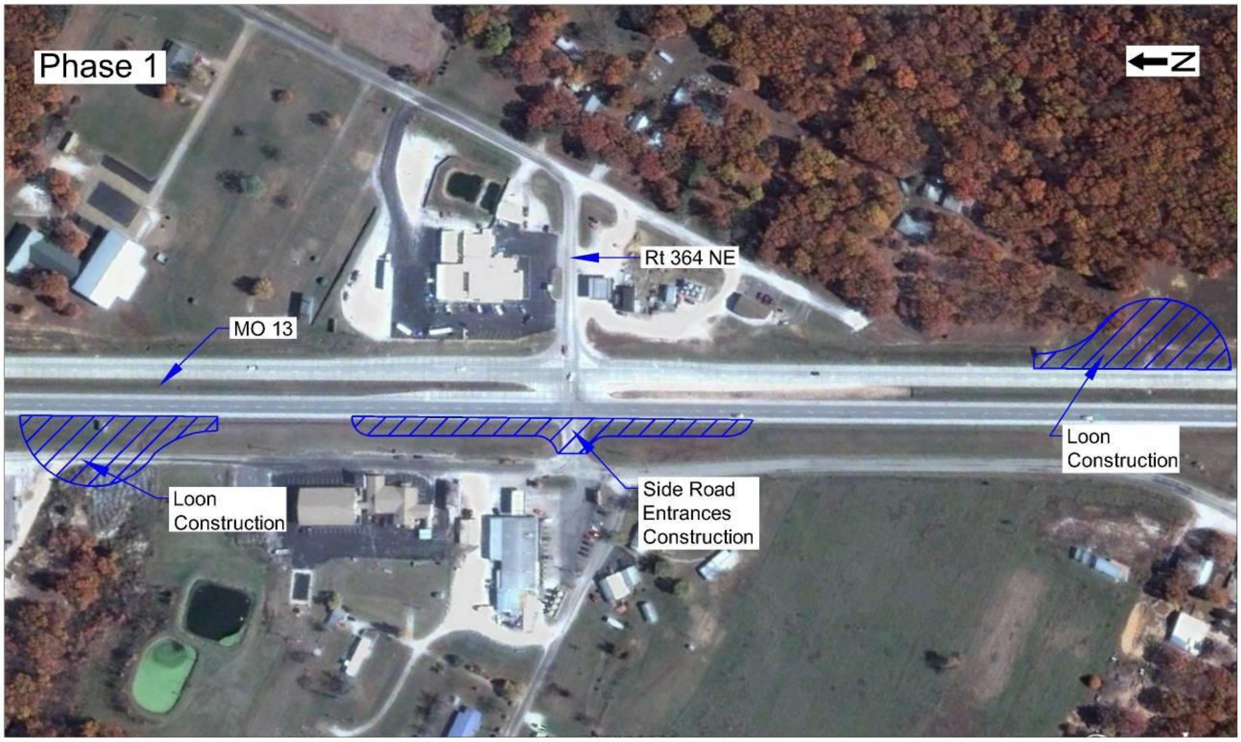


Image ©Google Earth 2015

Figure C.4.1.2 Phase 1 construction of RCUT at MO 13 and Route 364 NE

In Phase 2, as shown in Figure C.4.1.3, the median crossovers and deceleration lanes for the median crossovers were constructed while one lane of traffic in each direction on the MO 13 outside lanes was maintained.

Image ©Google Earth 2015

Figure C.4.1.3 Phase 2 construction of RCUT at MO 13 and Route 364 NE

Finally in Phase 3, the median turn lanes and islands for intersection were constructed under partial MO 13 lane closures as shown in Figure C.4.1.4. New signs were installed, and the final RCUT configuration was opened to traffic. The final configuration of the RCUT intersection is shown in Figure C.4.1.5.

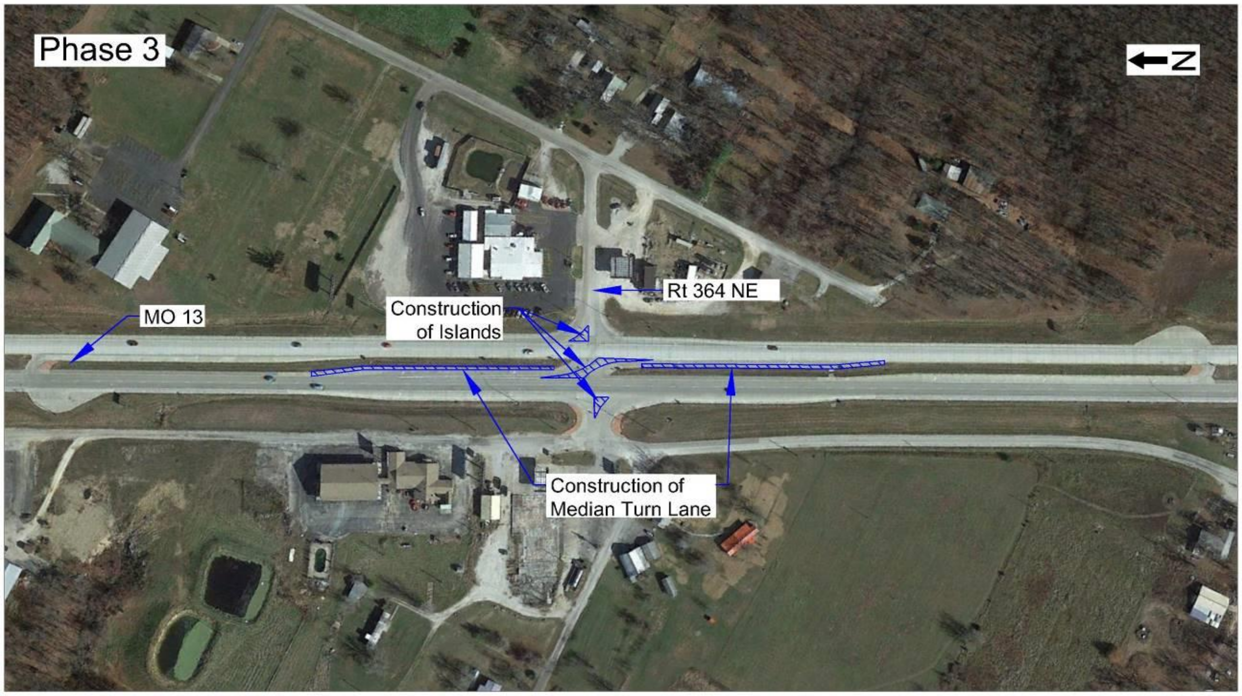


Image ©Google Earth 2015

Figure C.4.1.4 Phase 3 construction of RCUT at MO 13 and Route 364 NE

Image ©Google Earth 2015

Figure C.4.1.5 Final configuration of RCUT at MO 13 and Route 364 NE

C.5 MUT

C.5.1 Grant Road and Oracle Road (Tucson, Arizona)

The intersection between Grant Road and Oracle Road in Tucson, Arizona, was converted to a MUT intersection in 2013. The previous configuration of this MUT intersection was a conventional signalized intersection as shown in Figure C.5.1.1. Since this intersection is located in a busy area of the city, it was important to reduce delays on the main road via a conversion to a MUT intersection, thus reducing delays from left-turns.

Image ©Google Earth 2015

Figure C.5.1.1 Conventional at-grade intersection at Grant Road and Oracle Road

In order to construct the MUT intersection, phased construction with partial closure method was utilized. The project included 5 phases. Considering the high volume of traffic at this intersection, it was necessary to maintain traffic in all directions during construction. Hence, two lanes of traffic in each direction and the left turn lane were kept open to traffic during construction. In Phase 1, as shown in Figure C.5.1.2, the center medians were removed, and temporary paving was placed in the median. A temporary span wire signal was installed at Oracle Road.

Image ©Google Earth 2015

Figure C.5.1.2 Phase 1 Construction of MUT at Grant Road and Oracle Road

In Phase 2, reconstruction of the eastbound lanes of Grant Road was performed while two lanes of traffic were maintained in each direction on the westbound lanes of Grant Road. Traffic signal foundations and conduits were also installed. Figure C.5.1.3 shows the work area in the second phase of construction.

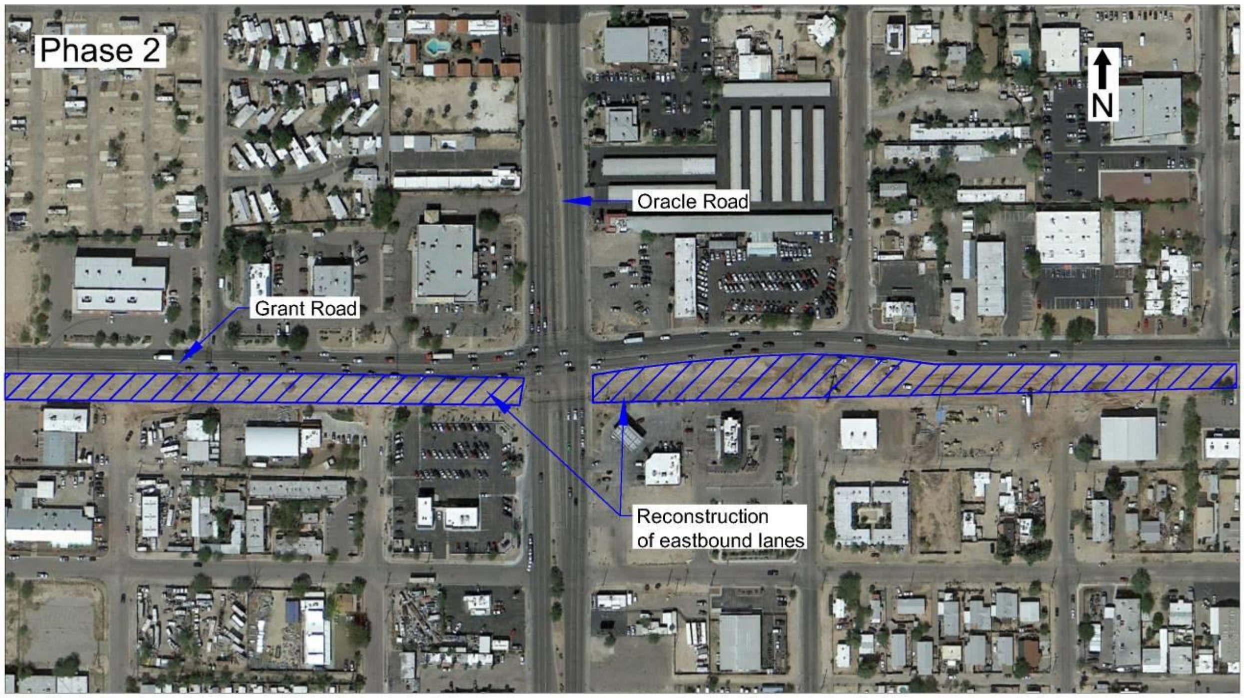


Image ©Google Earth 2015

Figure C.5.1.3 Phase 2 construction of MUT at Grant Road and Oracle Road

Phase 3, as shown in Figure C.5.1.4, included the reconstruction of the westbound lanes of Grant Road while two lanes of traffic in each direction were maintained on the eastbound lanes of Grant Road. Traffic signal foundations were also installed.

Image ©Google Earth 2015

Figure C.5.1.4 Phase 3 construction of MUT at Grant Road and Oracle Road

In Phase 4, the north and south legs of Oracle Road were constructed in stages. Figure C.5.1.5 show the parts of the intersection that were reconstructed during this phase.

Image ©Google Earth 2015

Figure C.5.1.5 Phase 4 construction of MUT at Grant Road and Oracle Road

In Phase 5, the median was constructed as shown in Figure C.5.1.6. Signals were installed and activated at Oracle Road and at the two indirect left turn intersections on Grand Road where left-turning vehicles make U-turns. Special traffic control measures such as signs were installed at the indirect left turn intersections, and the final pavement lifts were placed.

Image ©Google Earth 2015

Figure C.5.1.6 Phase 5 construction of MUT at Grant Road and Oracle Road

After finishing the construction of median pavements and removing the temporary traffic control devices, the U-turns were opened to traffic. The final configuration of the MUT intersection is shown in Figure C.5.1.7.

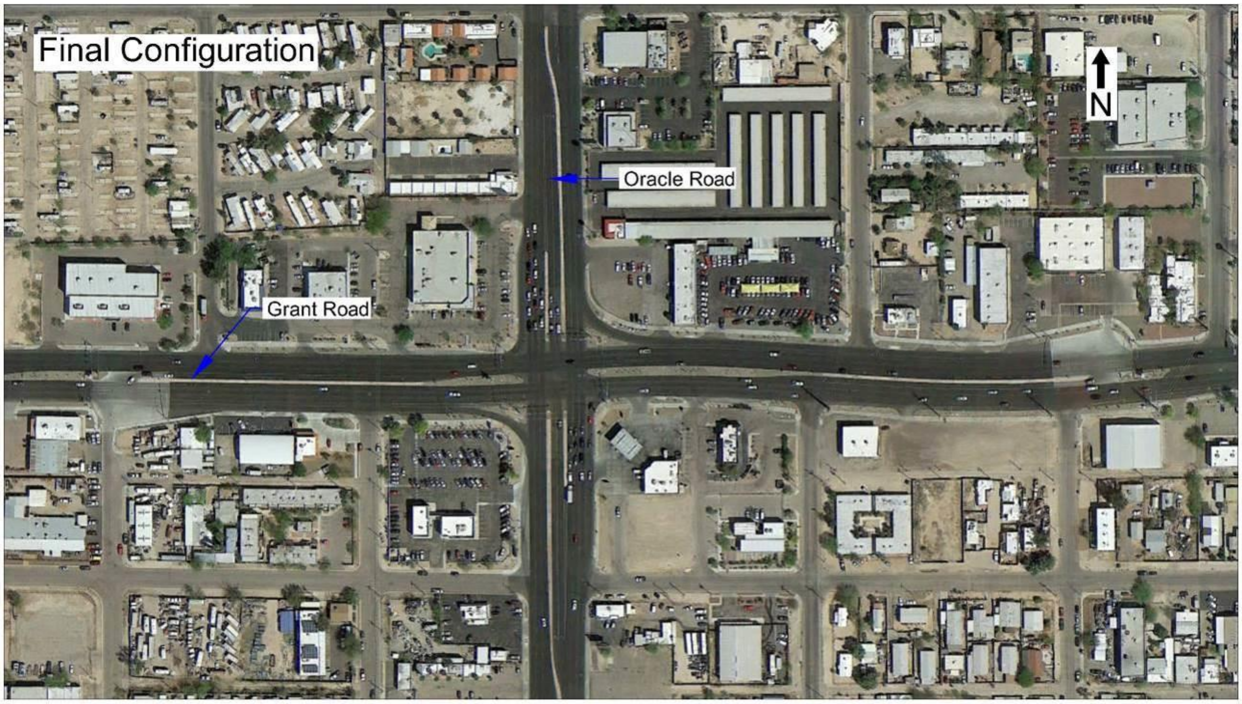


Image ©Google Earth 2015

Figure C.5.1.7 Final configuration of MUT intersection at Grant Road and Oracle Road

C.6 DLT

C.6.1 Austin Boulevard and SR 741 (Miamisburg, Ohio)

To help alleviate traffic congestion, an intersection in Miamisburg, Ohio at Austin Boulevard and SR 741, just east of Interstate 75, was converted to a DLT intersection by ODOT in 2009. The former configuration of the intersection was a conventional signalized at-grade intersection shown in Figure C.6.1.1. To the west of the DLT intersection, Austin Boulevard crosses I-75, and is then known as Miamisburg-Springboro Pike. The construction of the DLT intersection was part of a project to build a new diamond interchange at I-75 and Austin Boulevard/Miamisburg-Springboro Pike. During construction, Austin Landing, a shopping and entertainment area, was under construction adjacent to the intersection. The new DLT intersection was placed directly on top of the old intersection. There are DLTs on the Austin Boulevard legs of the intersection but not on the SR 741 legs of the intersection.

Image ©Google Earth 2015

Figure C.6.1.1 Conventional at-grade intersection at Austin Boulevard and SR 741

This DLT project consisted of two general phases. Phase 1 construction is shown in Figure C.6.1.2. In this phase, Austin Boulevard/ Miamisburg-Springsboro Pike was closed between SR 741 and Wood Road, and traffic was detoured. Portions of Austin Boulevard off the existing road were constructed near the intersection. Farther east of the intersection, temporary pavement on the north side of Austin Boulevard was used to carry traffic while work was performed on the existing Austin Boulevard. The existing traffic signal at Austin Boulevard and SR 741 was maintained. Two through lanes and one left turn lane were maintained in each direction on SR 741.

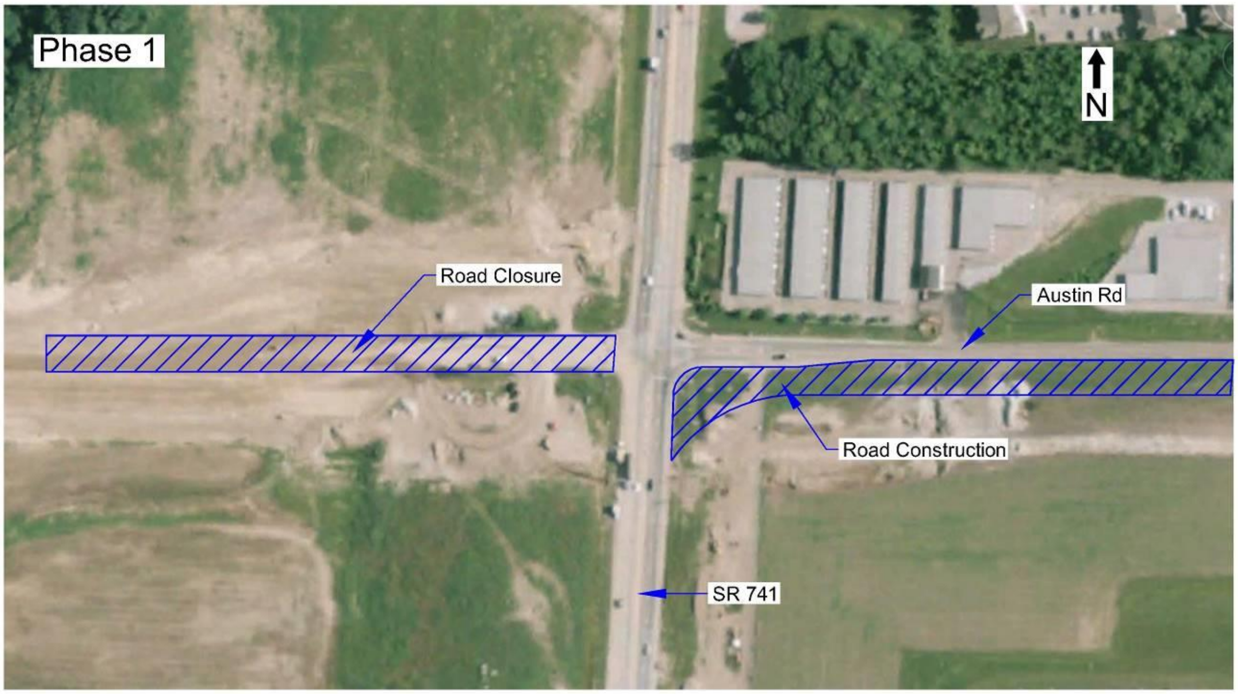


Image ©Google Earth 2015

Figure C.6.1.2 Phase 1 construction of DLT at Austin Boulevard and SR 741

The construction during Phase 2 consisted of two steps. During Step 1, the east leg of Austin Boulevard was closed while the remaining construction on the east leg of Austin Boulevard was performed, and the existing traffic signal was removed. Work was also performed on the east side of SR 741. Crossovers were used on SR 741 to maintain one lane of traffic in each direction. Lane closures and construction area are shown in Figure C.6.1.3

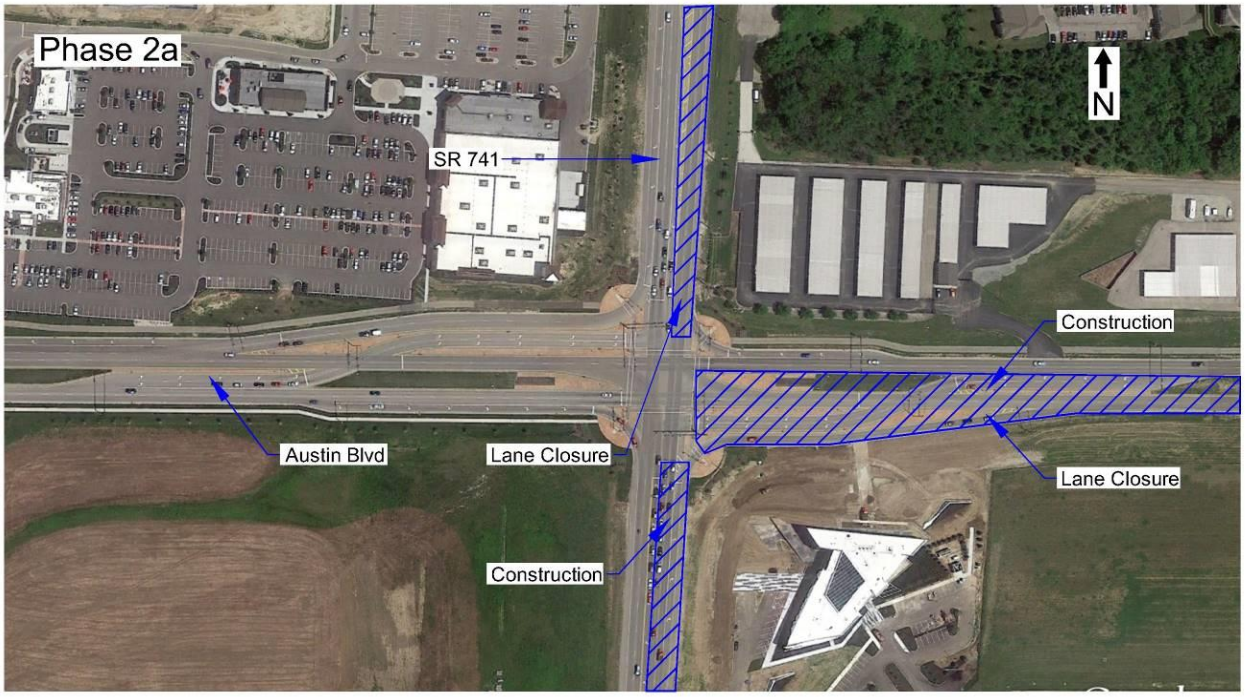


Image ©Google Earth 2015

Figure C.6.1.3 Phase 2 Step 1 construction of DLT at Austin Boulevard and SR 741

During Step 2, work was performed on the west side of SR 741 and the west leg of Austin Boulevard as shown in Figure C.6.1.4. The east leg of Austin Boulevard was reopened, and a temporary traffic signal was utilized. Crossovers were used on SR 741 to maintain one lane of traffic in each direction.

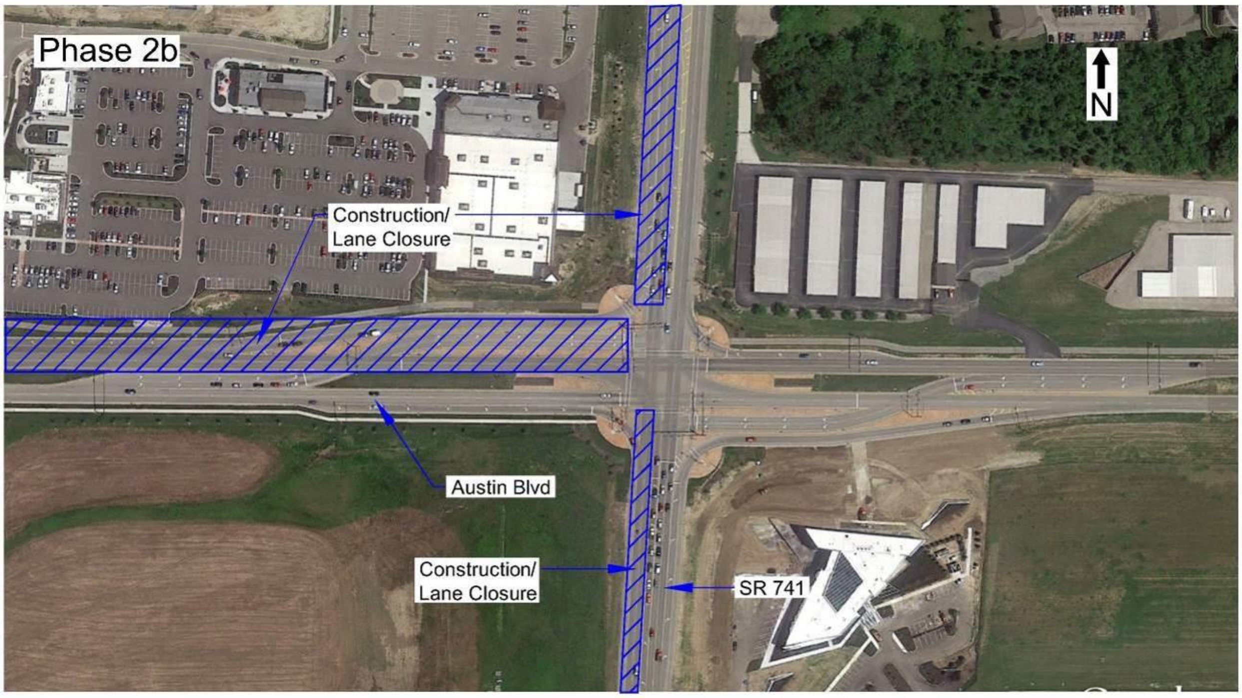


Image ©Google Earth 2015

Figure C.6.1.4 Phase 2 Step 2 construction of DLT at Austin Boulevard and SR 741

The construction of the median nose on Austin Boulevard was deferred until after Step 2 of Phase 2 was completed and traffic was shifted back to its permanent location. Figure C.6.1.5 shows the final configuration of the DLT intersection.

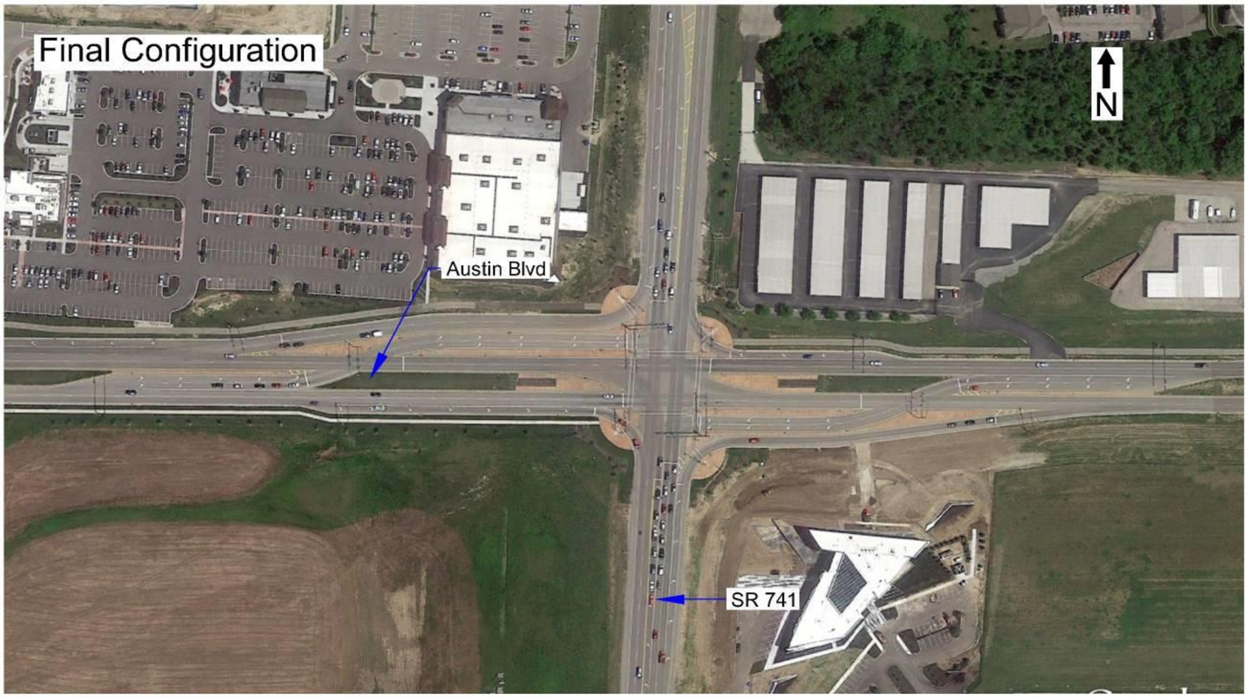


Image ©Google Earth 2015

Figure C.6.1.5 Final configuration of DLT at Austin Boulevard and SR 741

APPENDIX D. MAINTENANCE OF TRAFFIC DIAGRAMS

D.1 Initial Construction MOT Phasing Diagrams

D.1.1 Roundabout

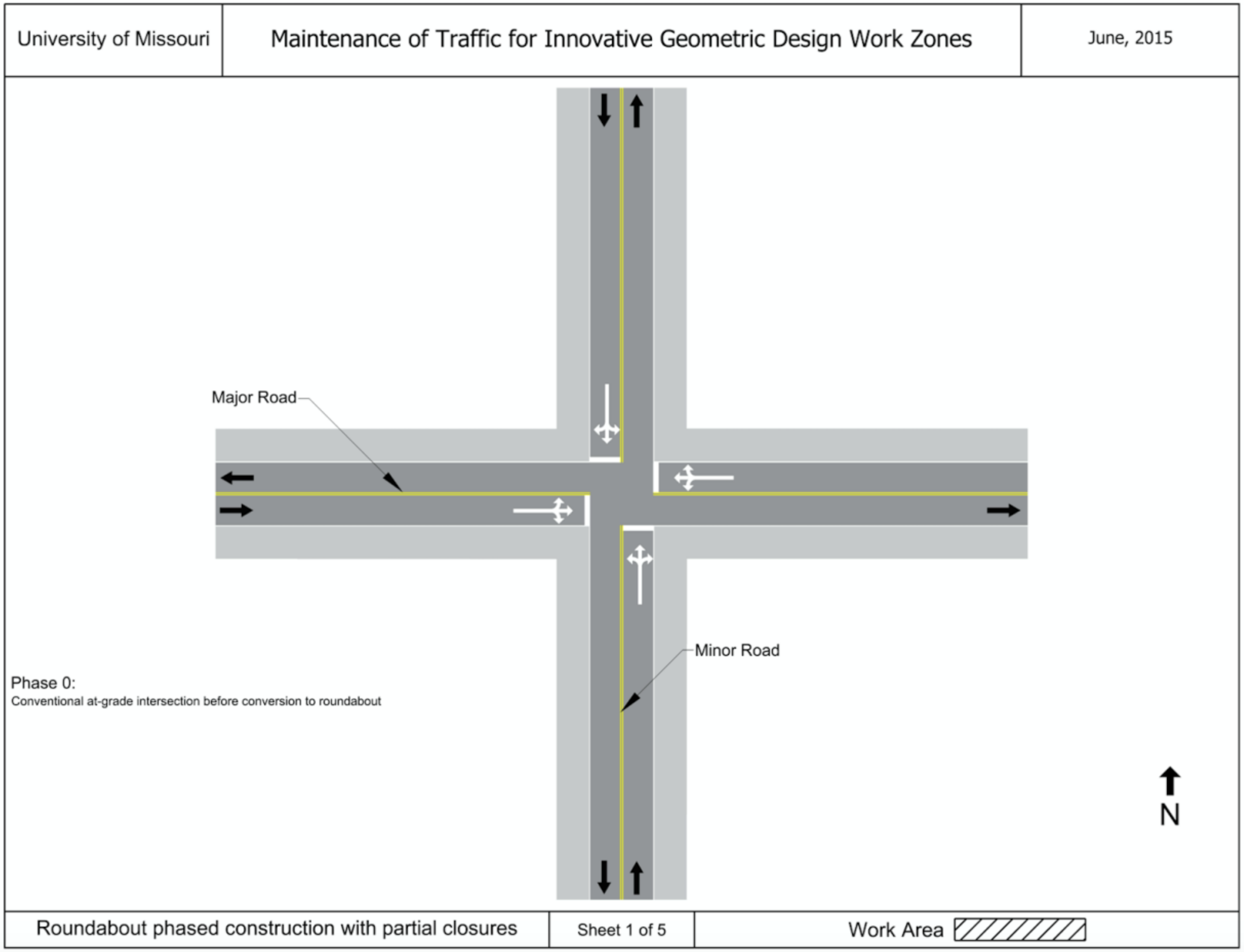


Figure D.1.1.1 Roundabout phased construction with partial closures initial condition

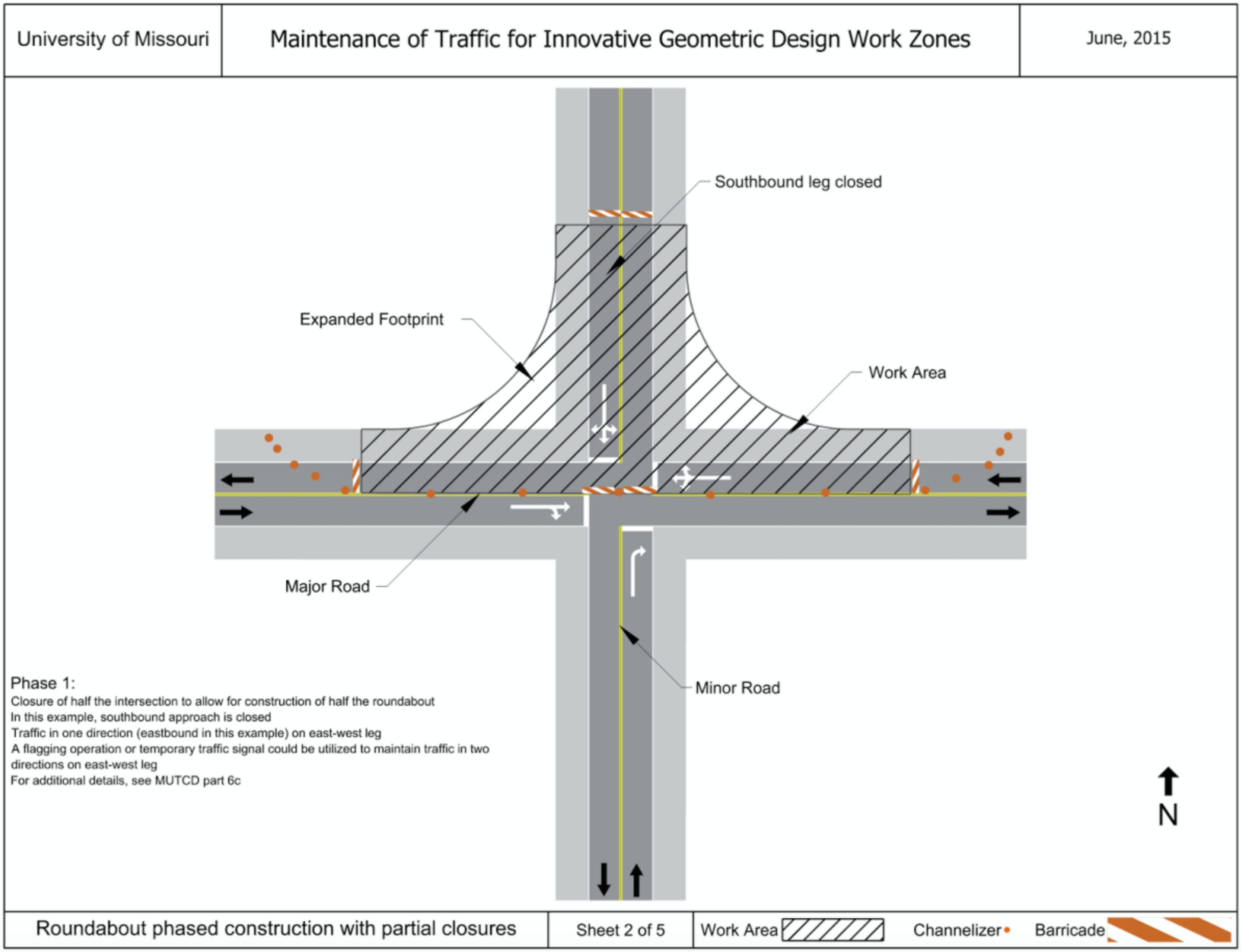


Figure D.1.1.2 Roundabout phased construction with partial closures Phase 1 (closure of half the roundabout)

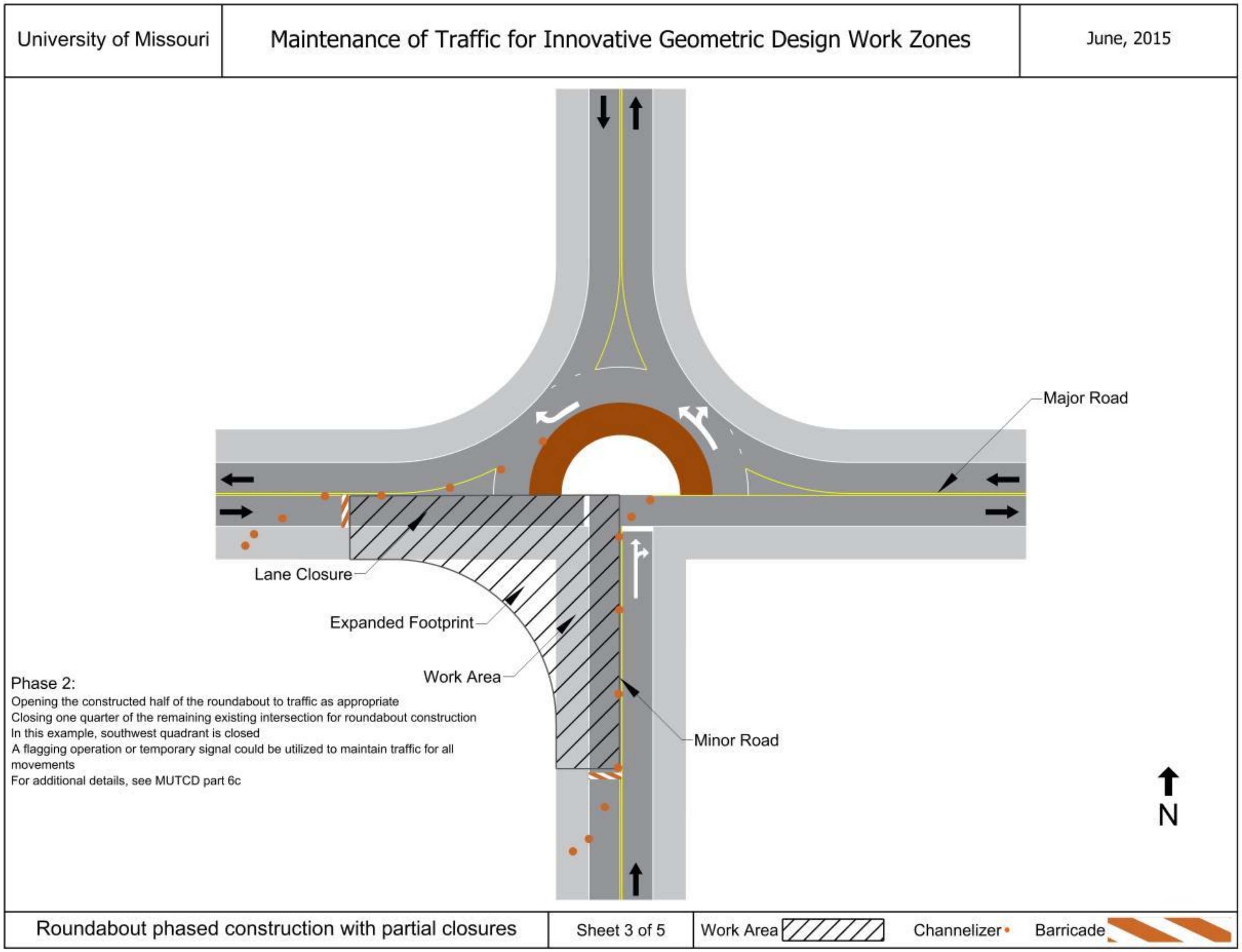


Figure D.1.1.3 Roundabout phased construction with partial closures Phase 2 (closure of one quarter of intersection)

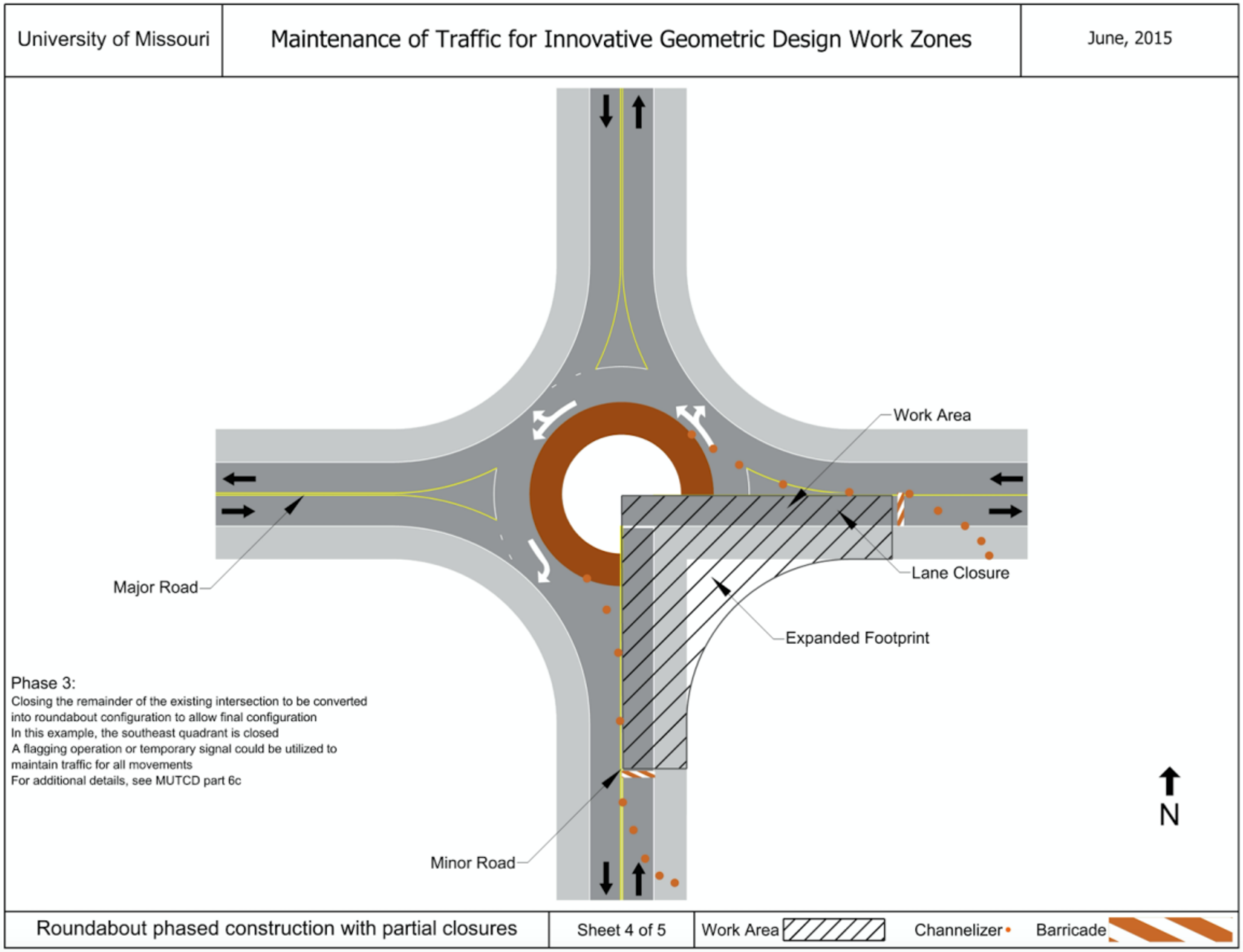


Figure D.1.1.4 Roundabout phased construction with partial closures Phase 3 (construction of final quadrant)

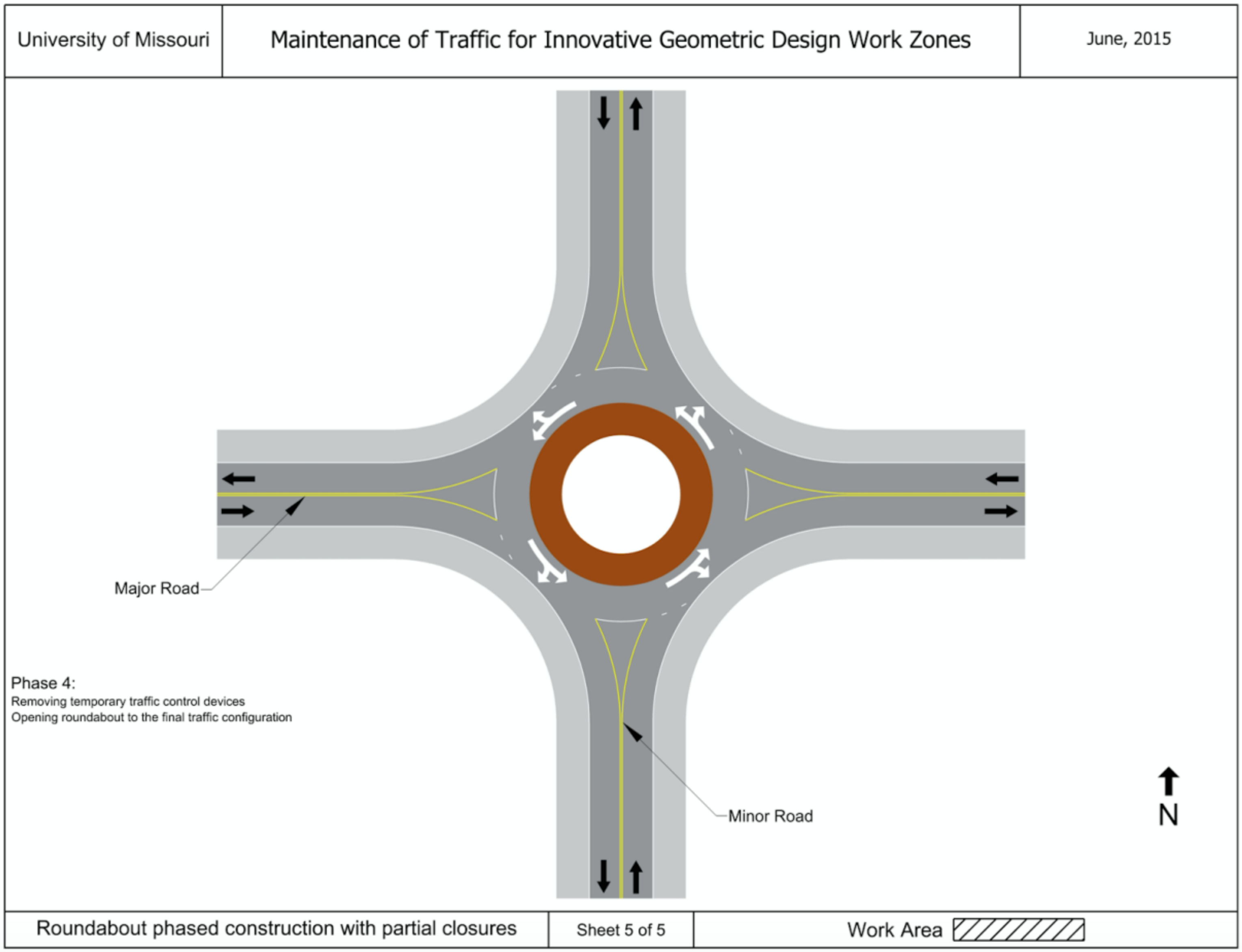


Figure D.1.1.5 Roundabout phased construction with partial closures final configuration

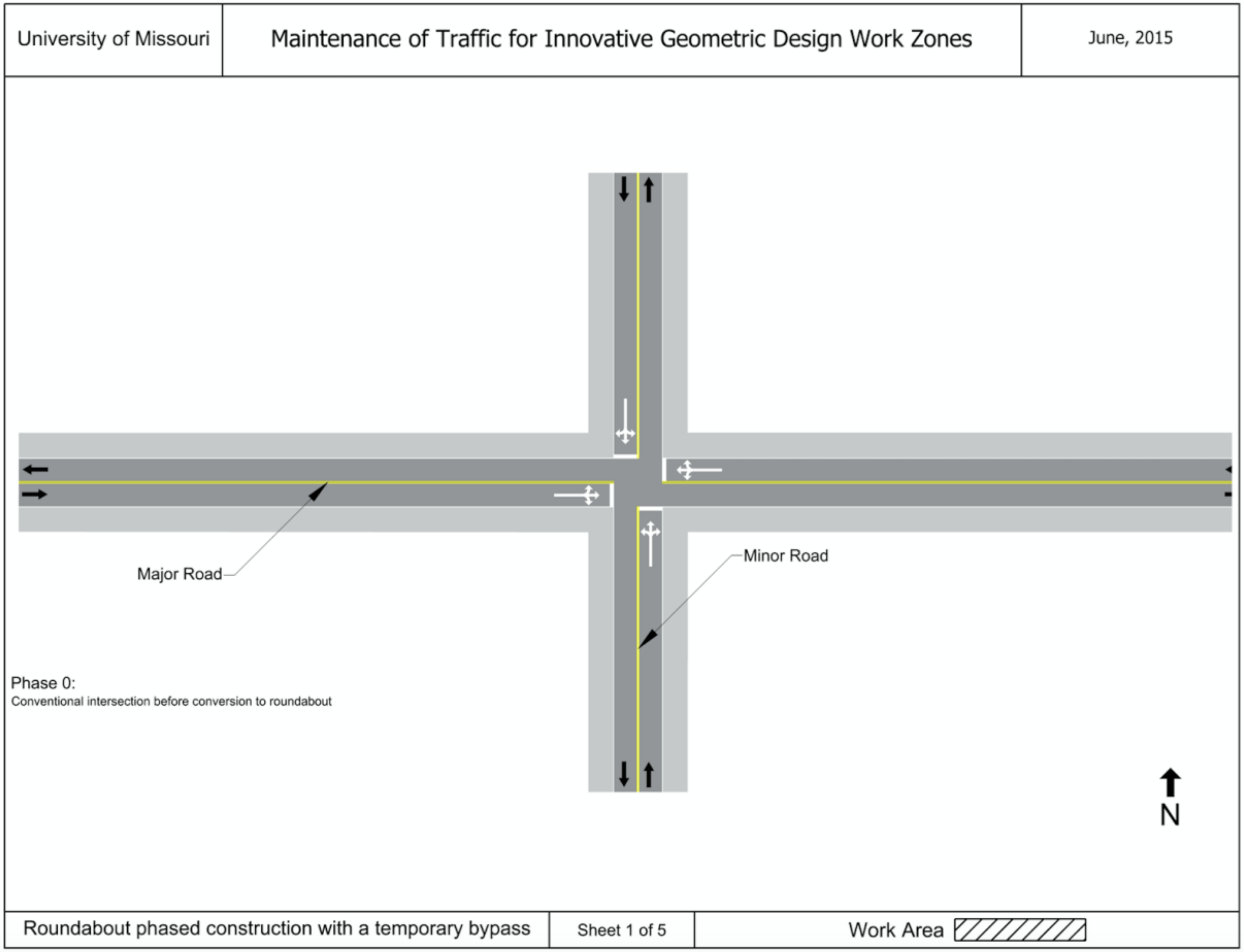


Figure D.1.1.6 Roundabout phased construction with a temporary bypass initial condition

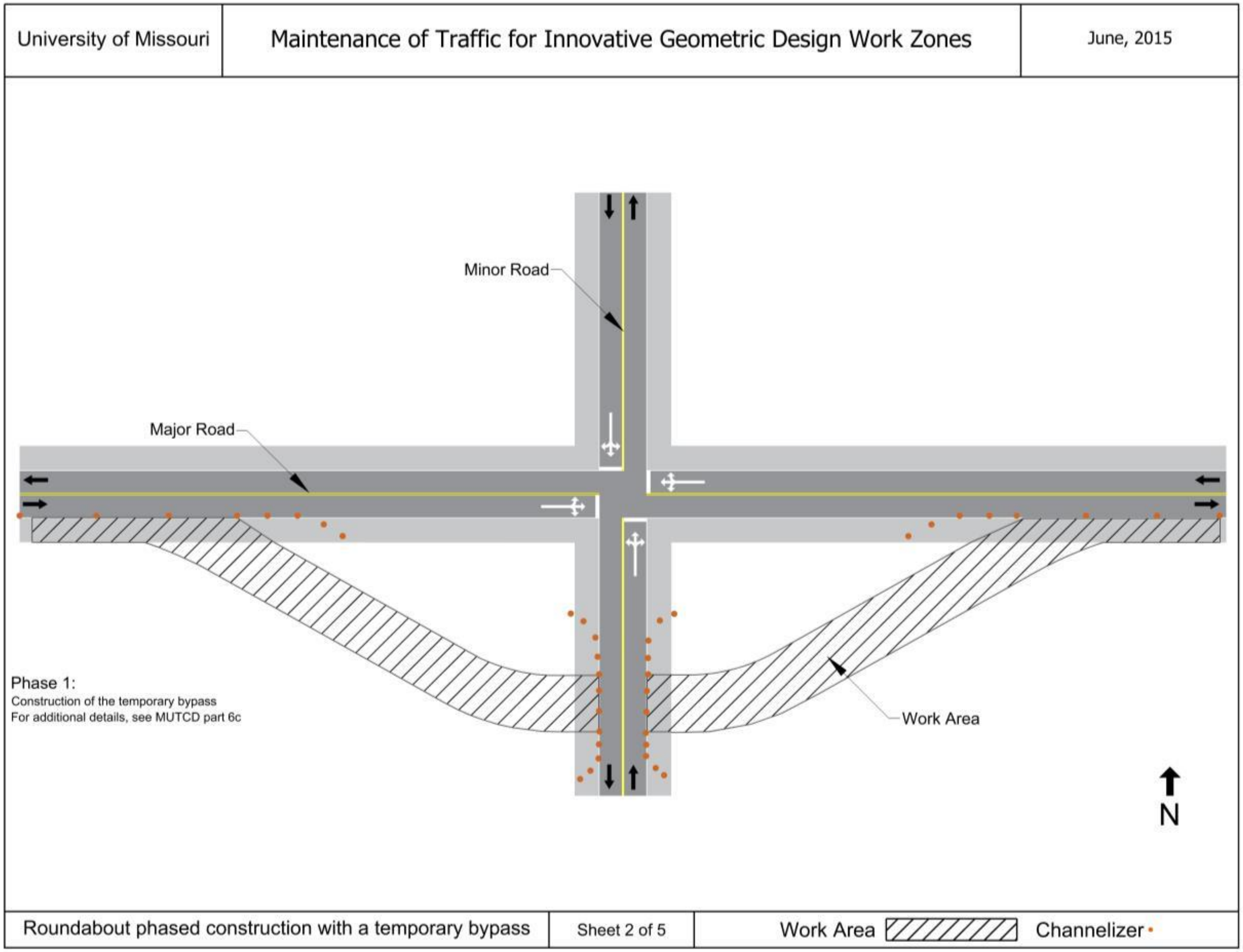


Figure D.1.1.7 Roundabout phased construction with a temporary bypass Phase 1 (construction of temporary bypass)

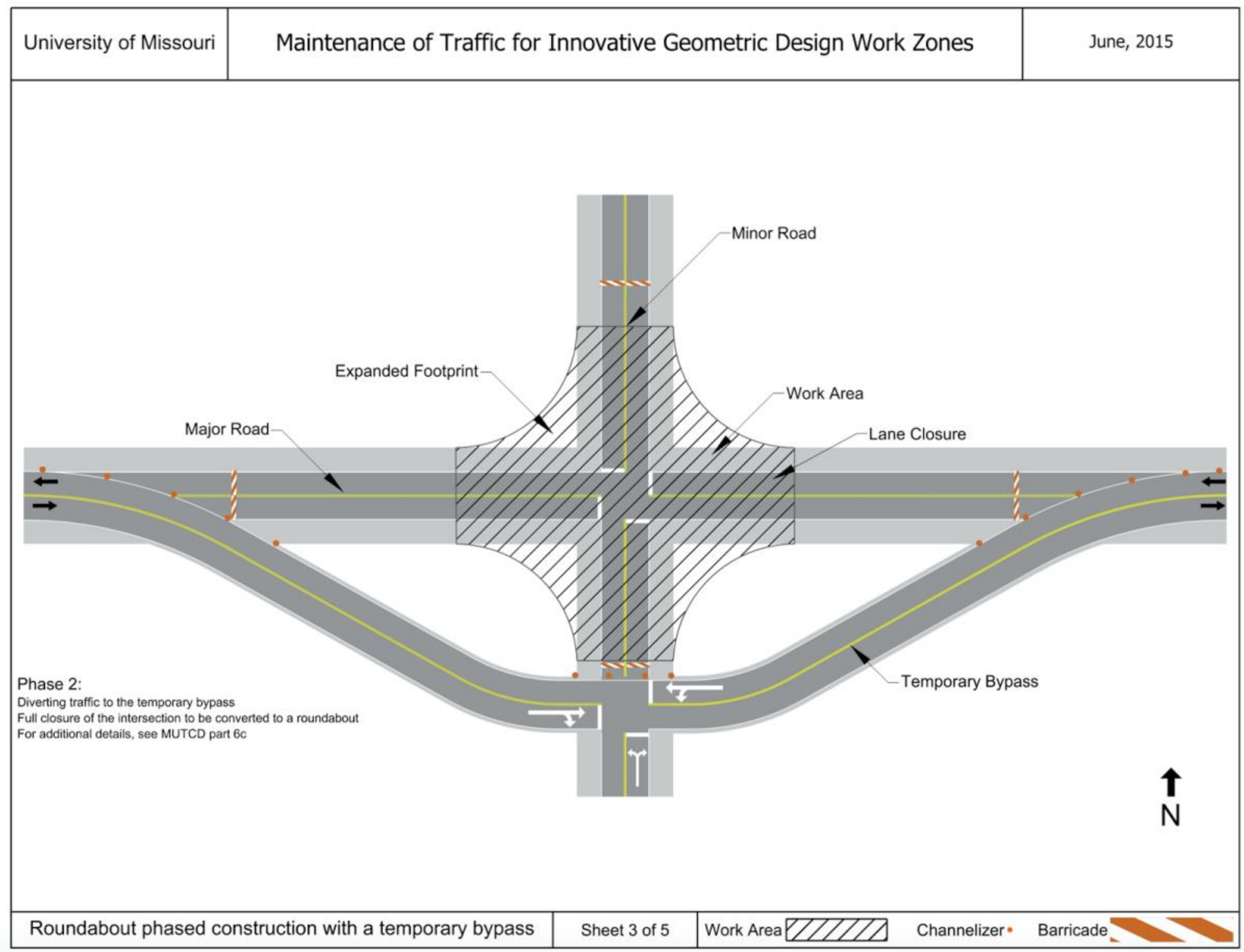


Figure D.1.1.8 Roundabout phased construction with a temporary bypass Phase 2 (construction of roundabout)

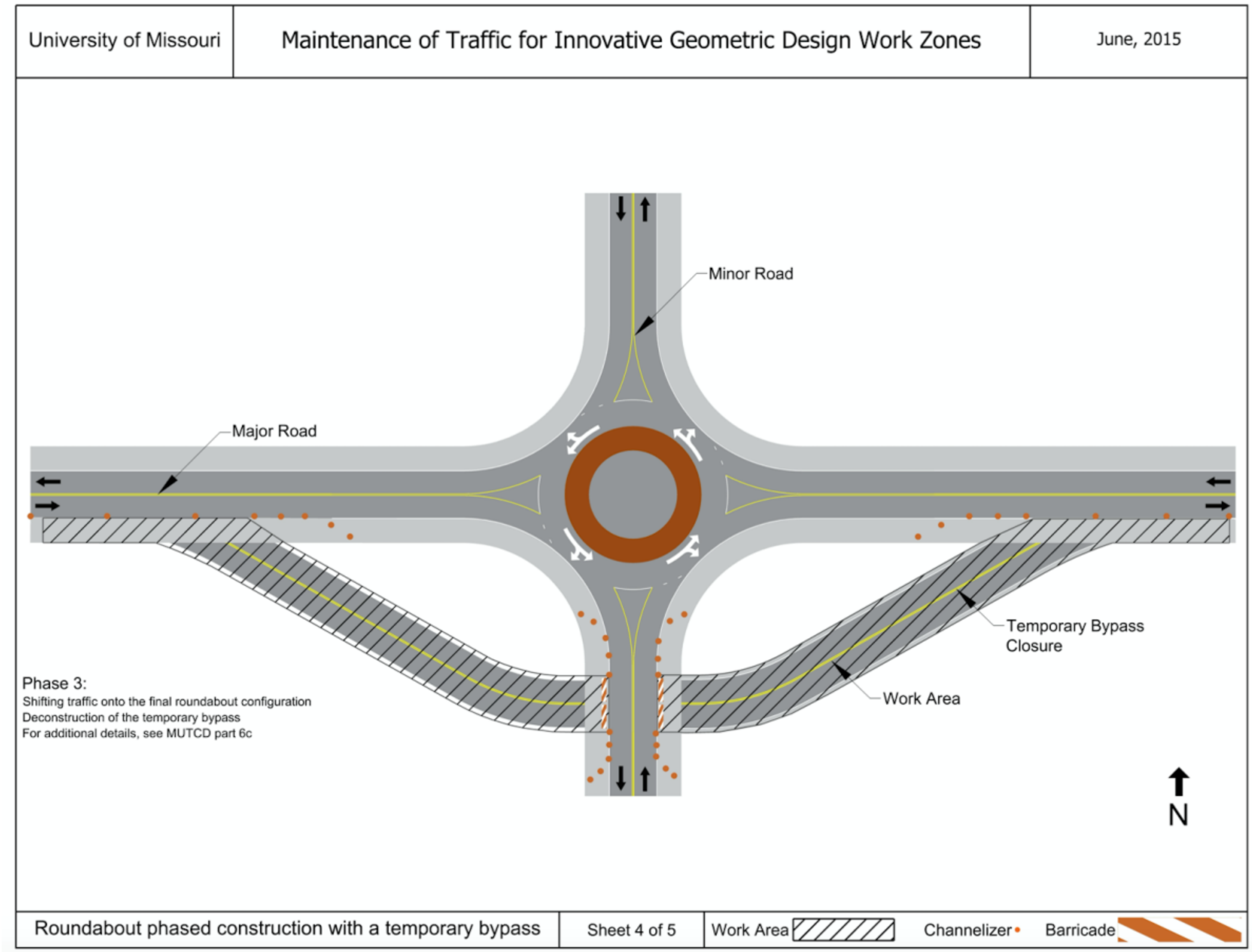


Figure D.1.1.9 Roundabout phased construction with a temporary bypass Phase 3 (final construction and removal of temporary bypass)

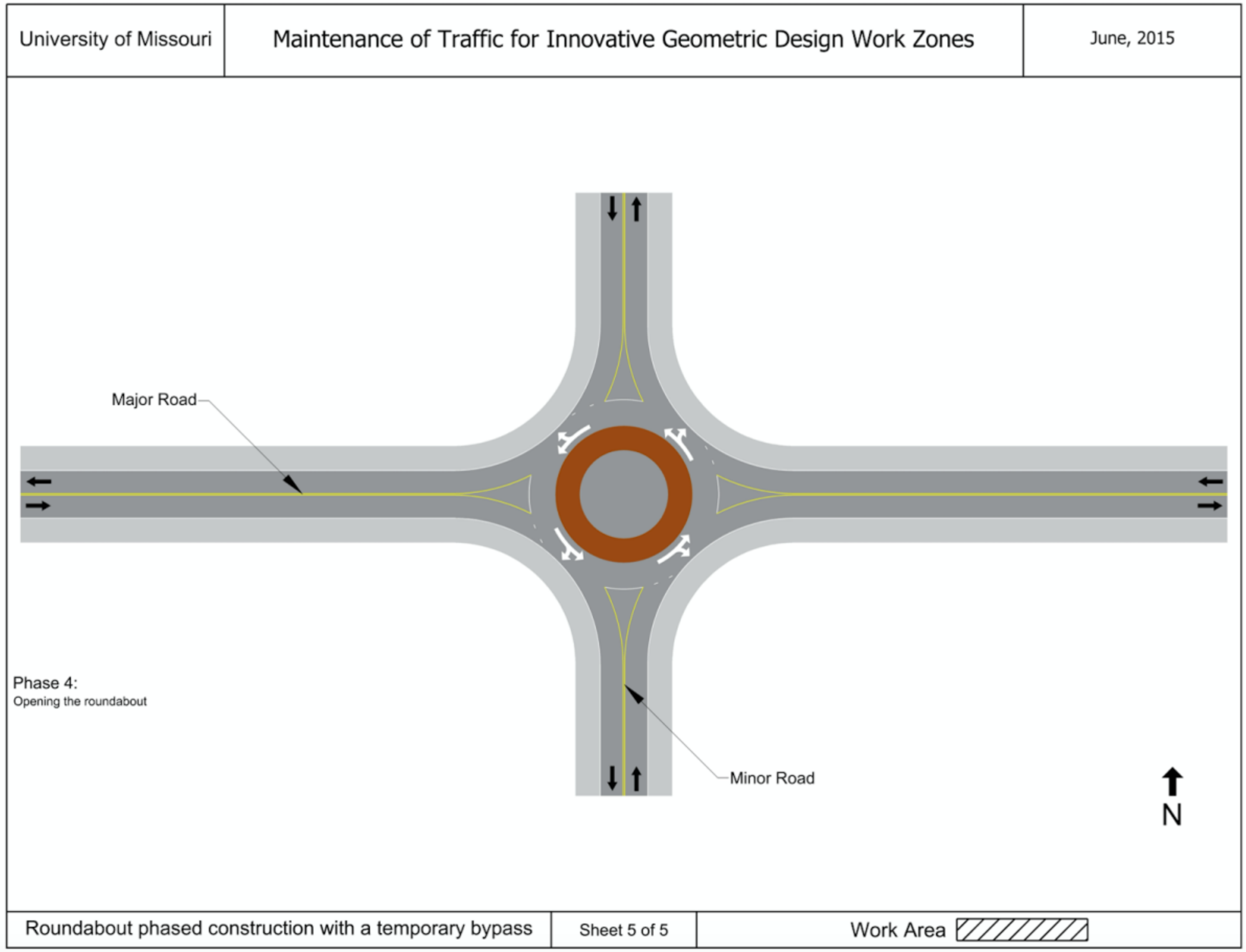


Figure D.1.1.10 Roundabout phased construction with a temporary bypass final configuration

D.1.2 SPUI

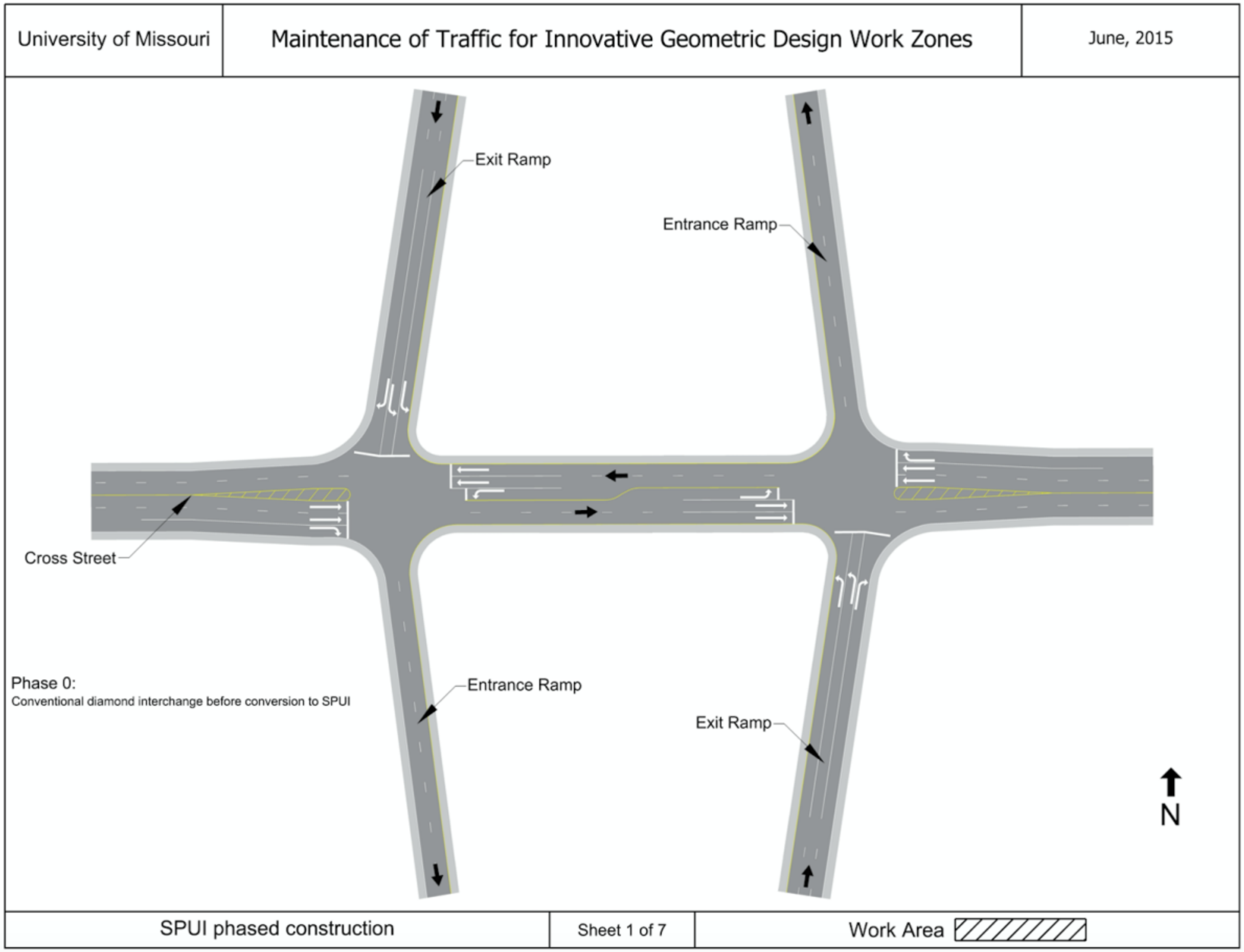


Figure D.1.2.1 SPUI phased construction initial condition

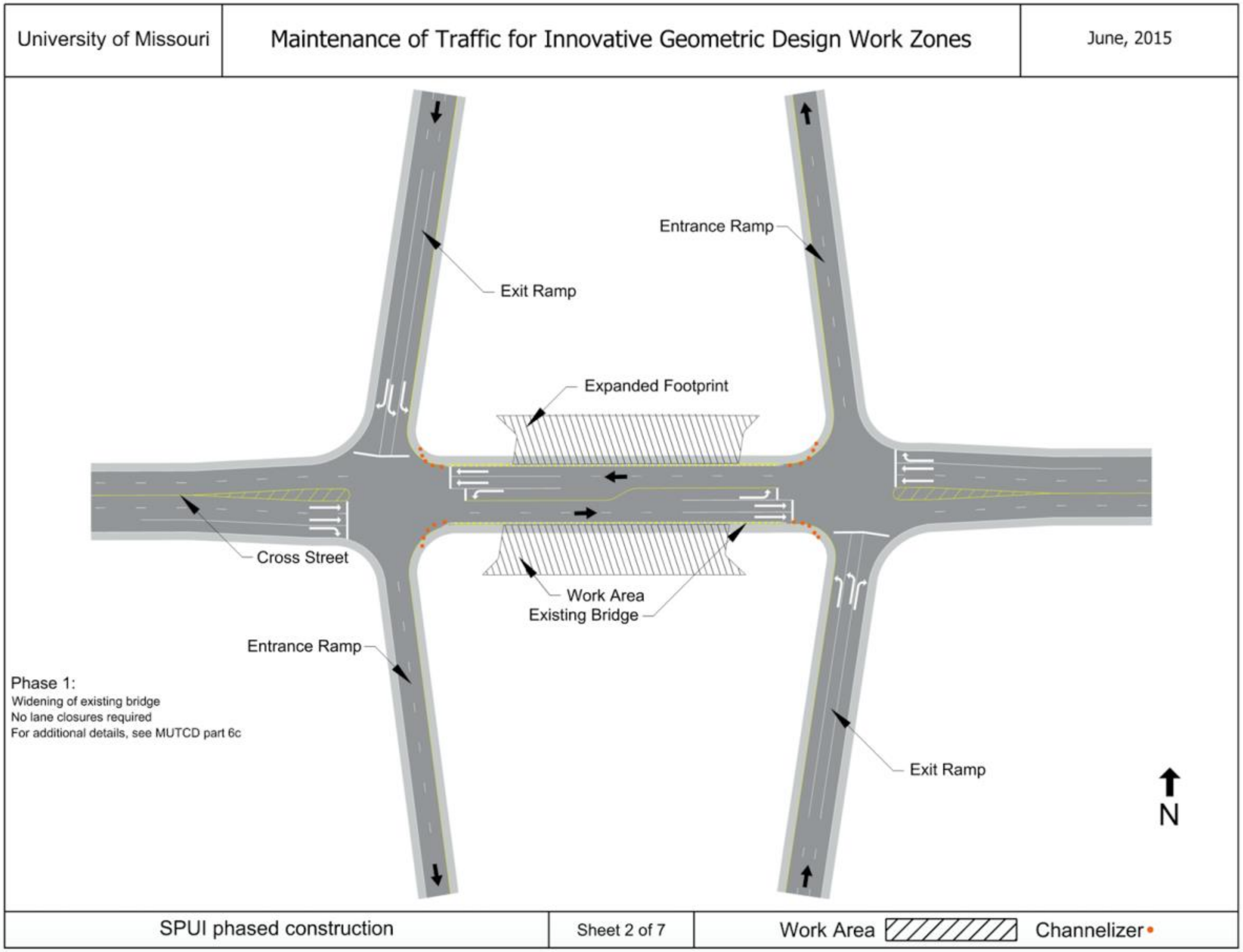


Figure D.1.2.2 SPUI phased construction Phase 1 (widening of existing bridge)

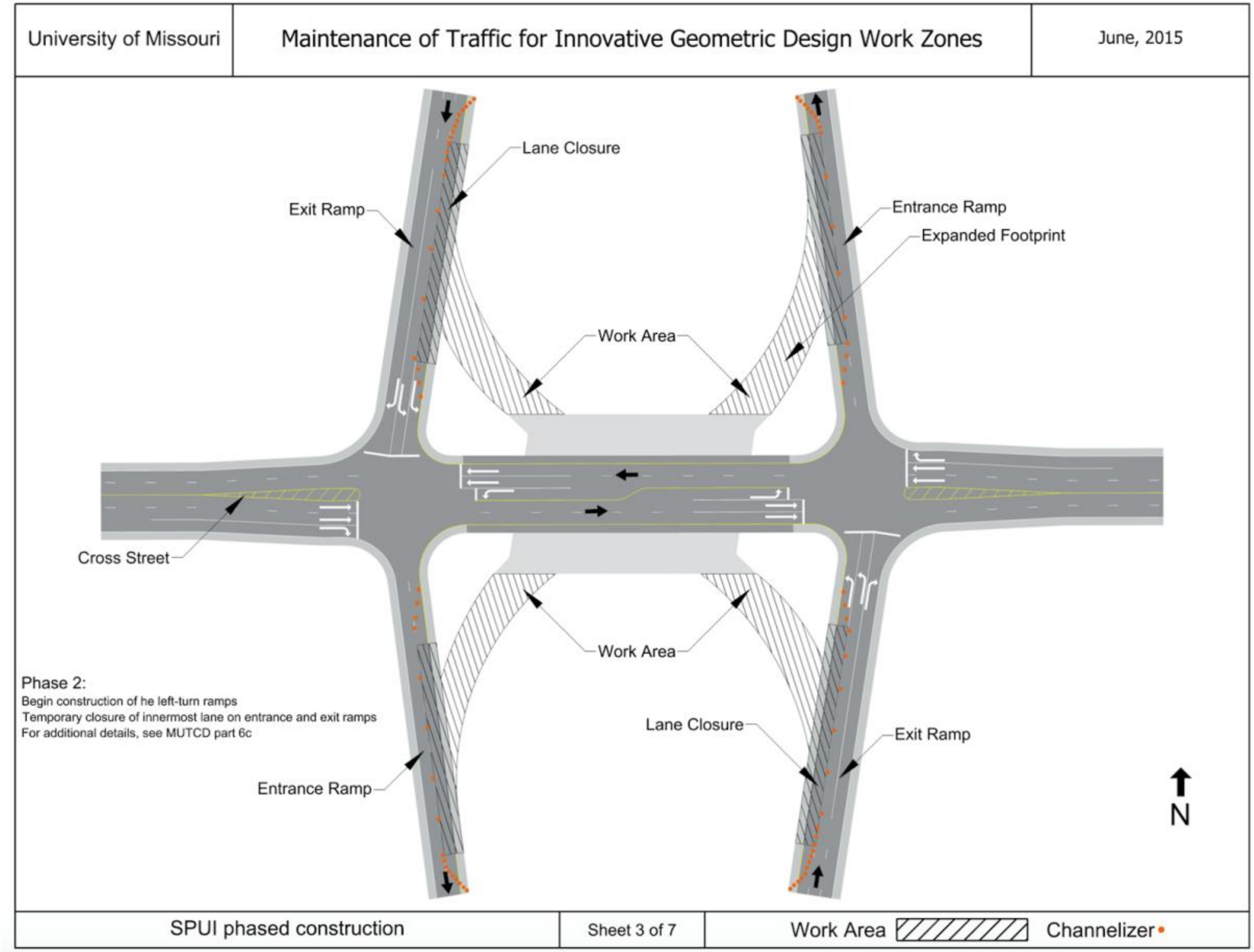


Figure D.1.2.3 SPUI phased construction Phase 2 (construction of left turn ramps)

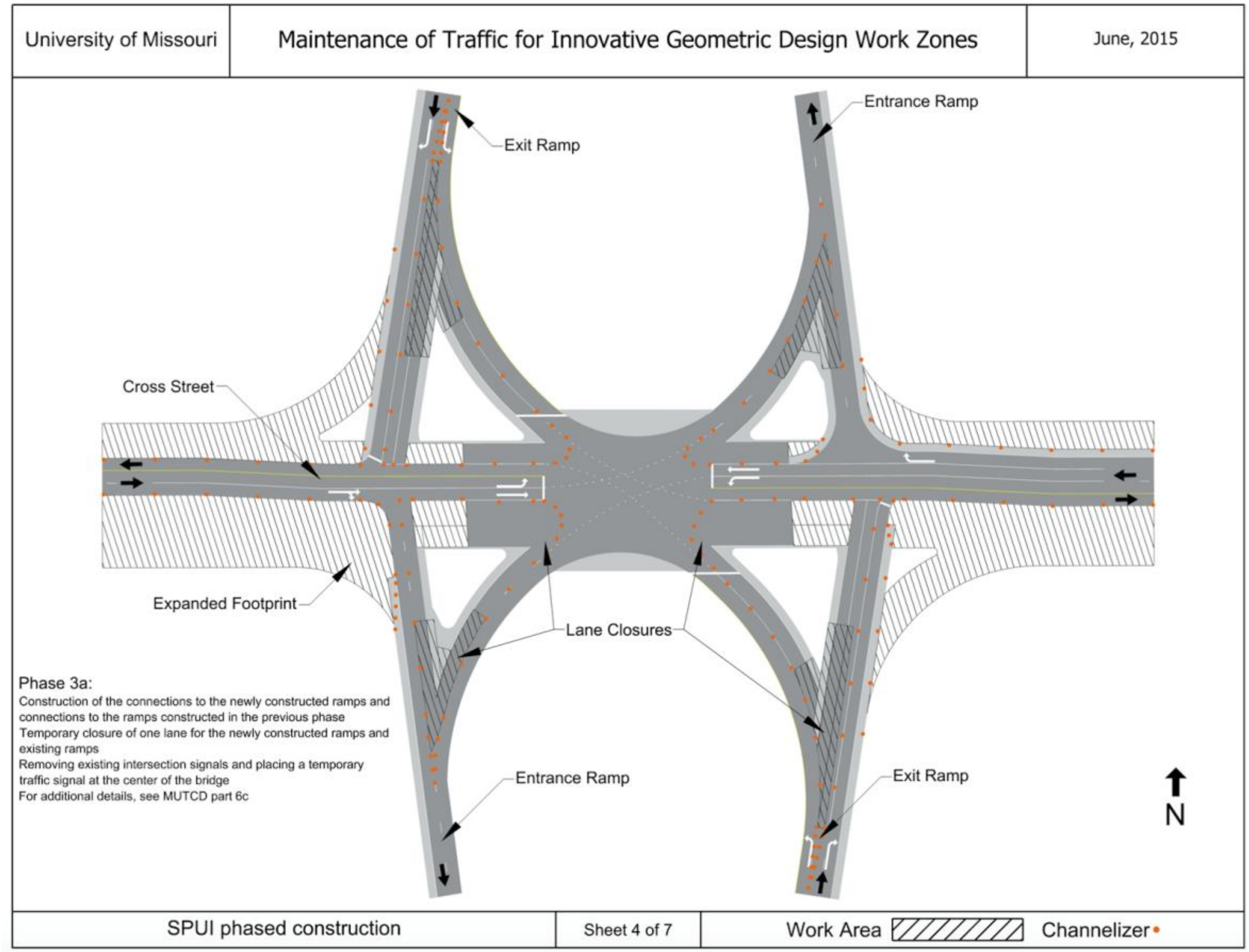


Figure D.1.2.4 SPUI phased construction Phase 3a (construction of road widening)

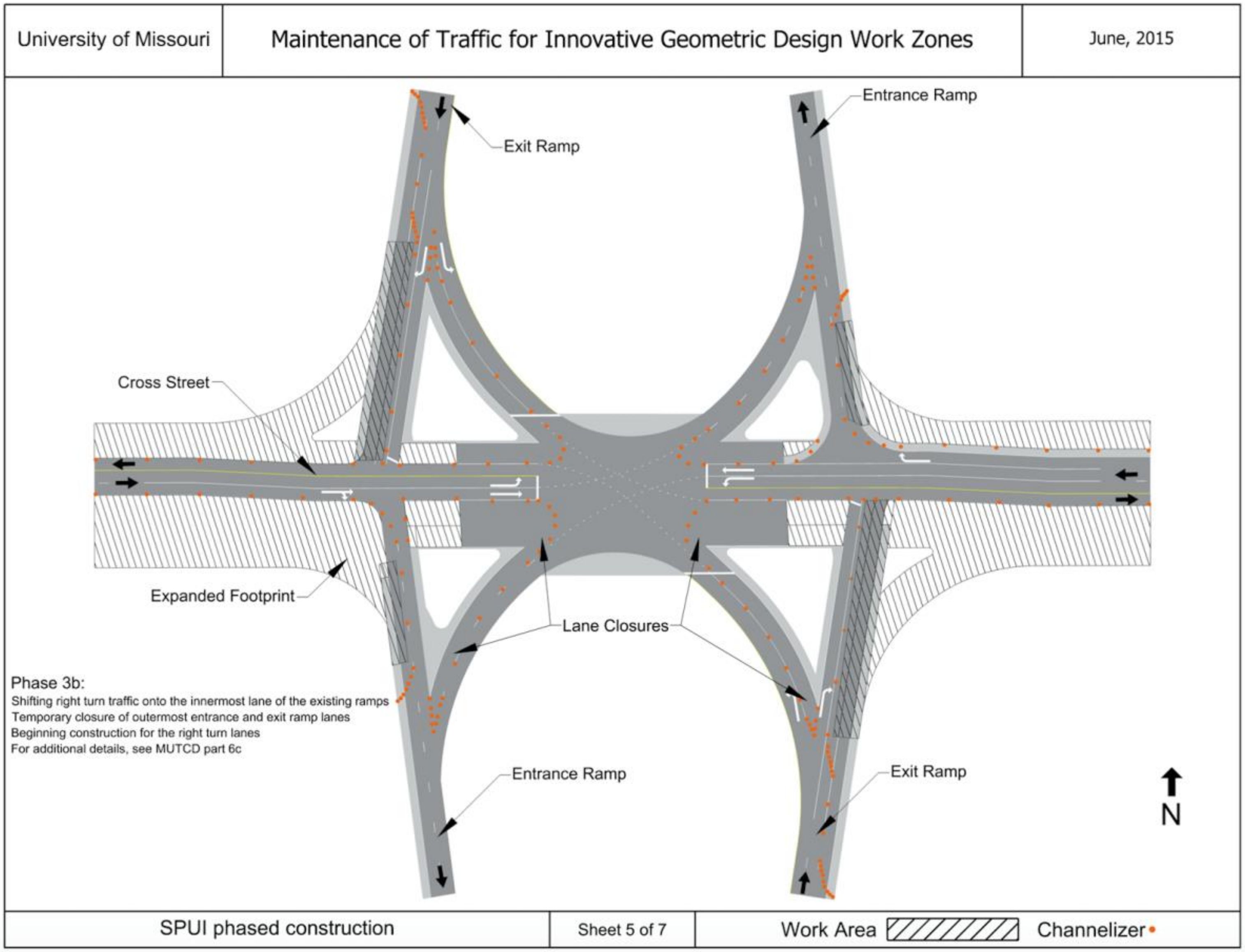


Figure D.1.2.5 SPUI phased construction Phase 3b (construction of right turn facilities)

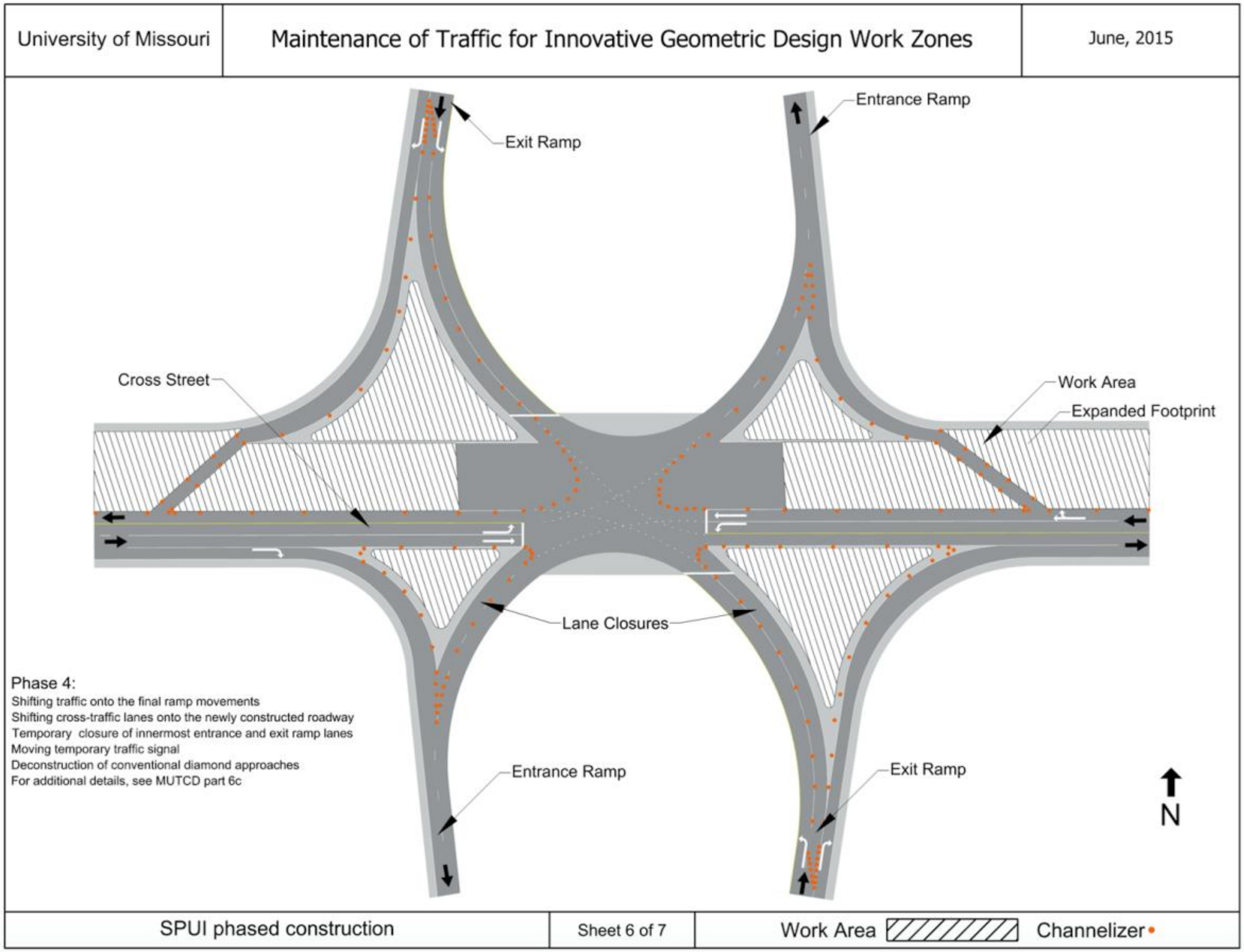


Figure D.1.2.6 SPUI phased construction Phase 4 (widening of opposite side of roadway)

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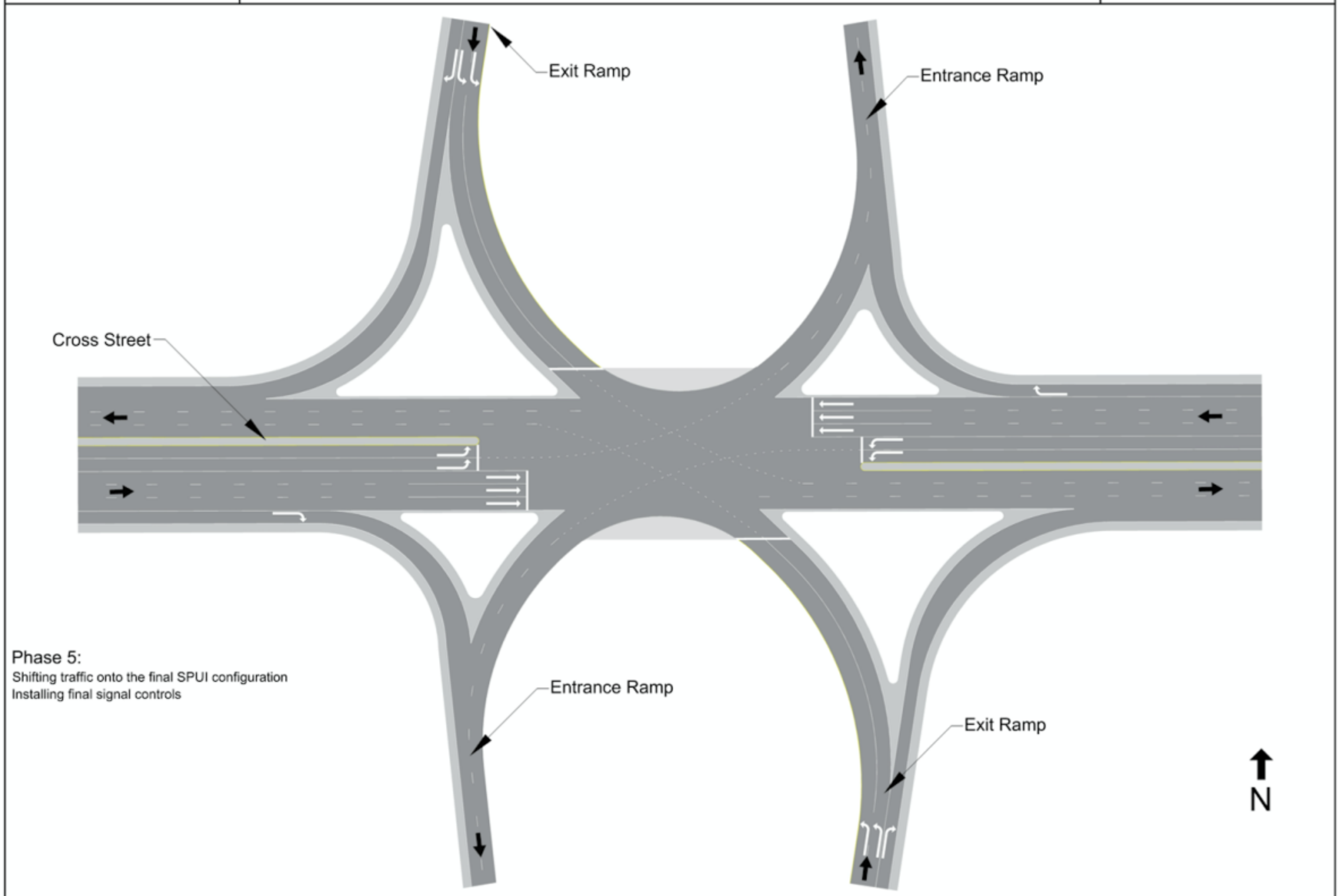

SPUI phased construction	Sheet 7 of 7	Work Area

Figure D.1.2.7 SPUI phased construction final configuration

D.1.3 DDI

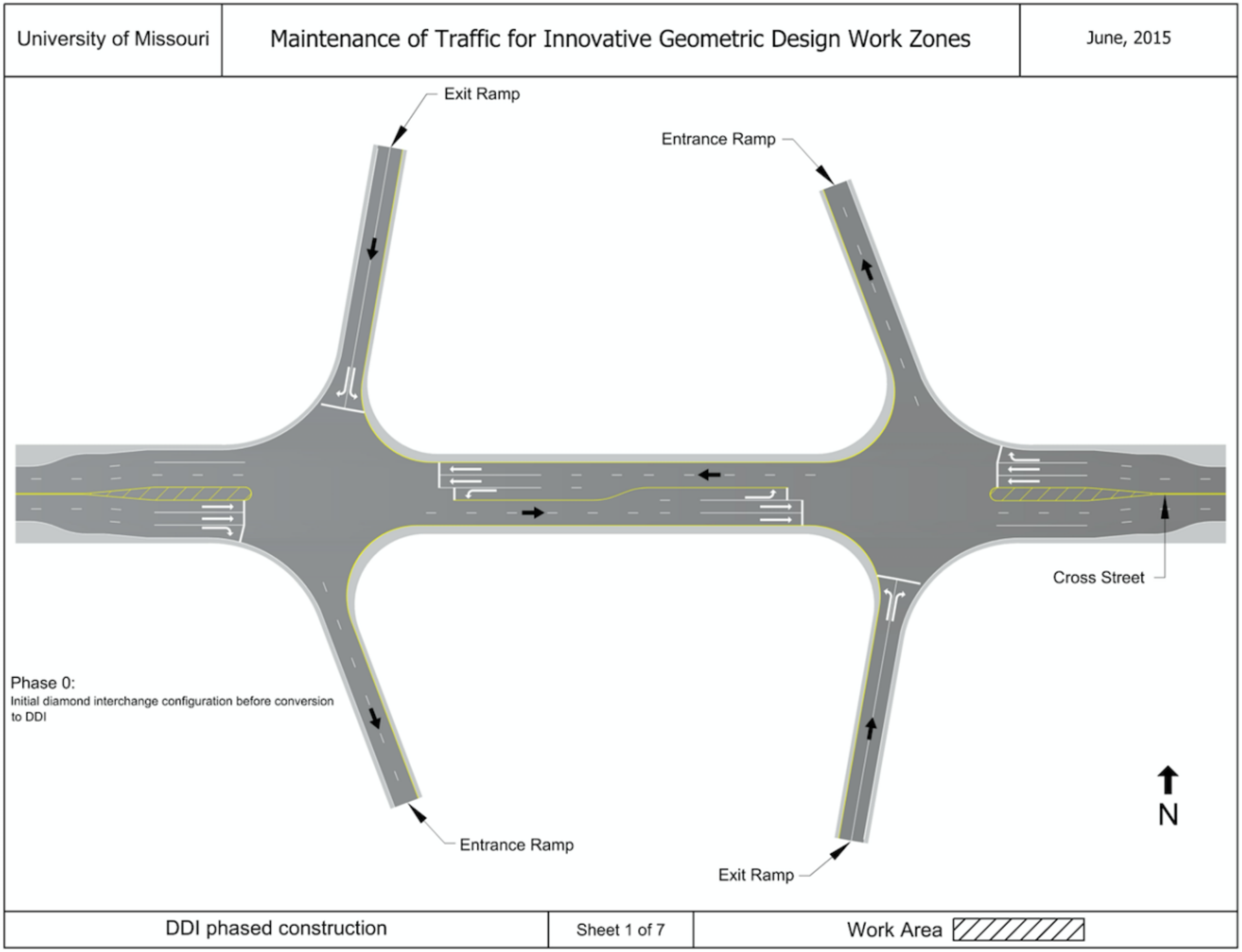

Figure D.1.3.1 DDI phased construction initial condition

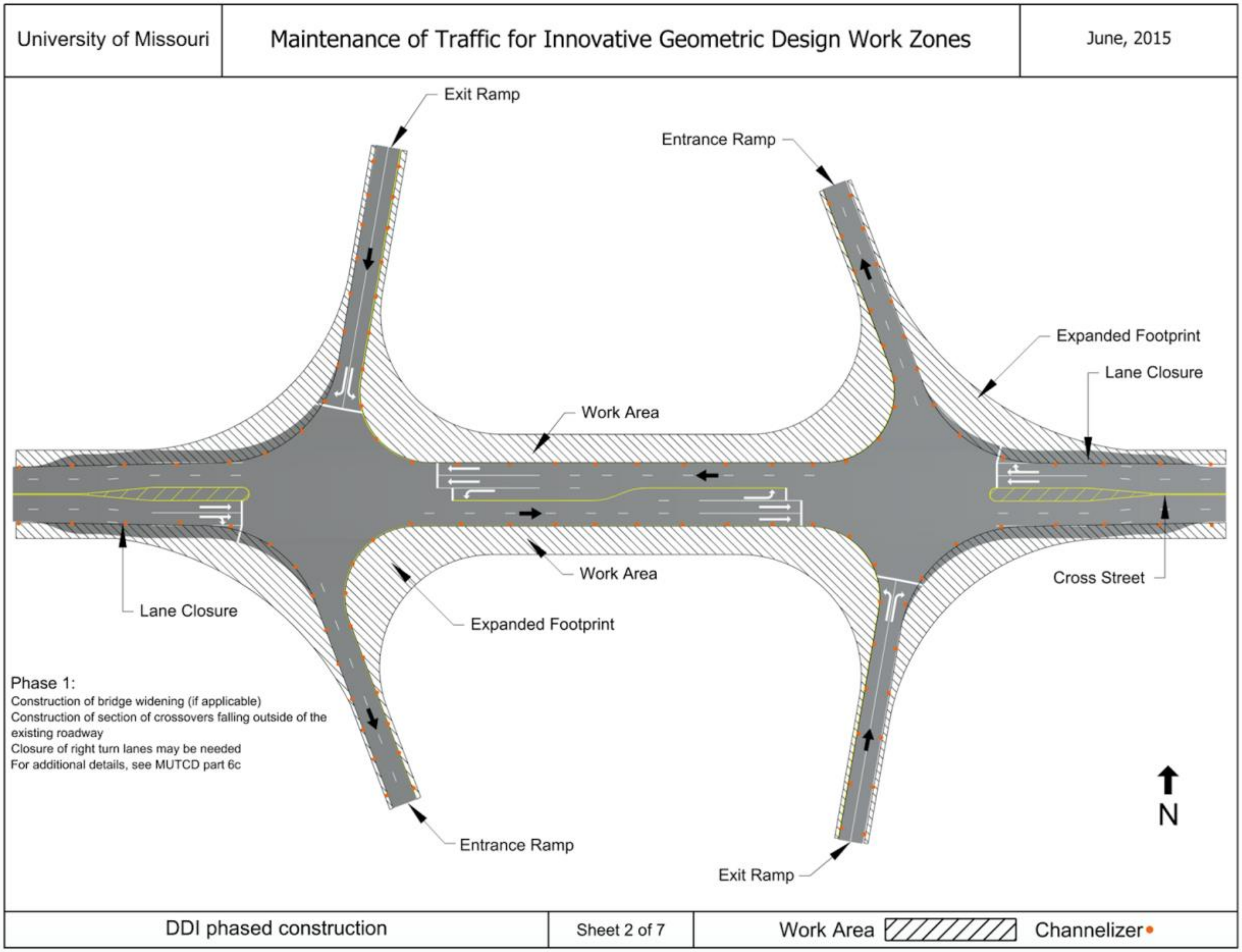

Figure D.1.3.2 DDI phased construction Phase 1 (bridge widening and crossover construction)

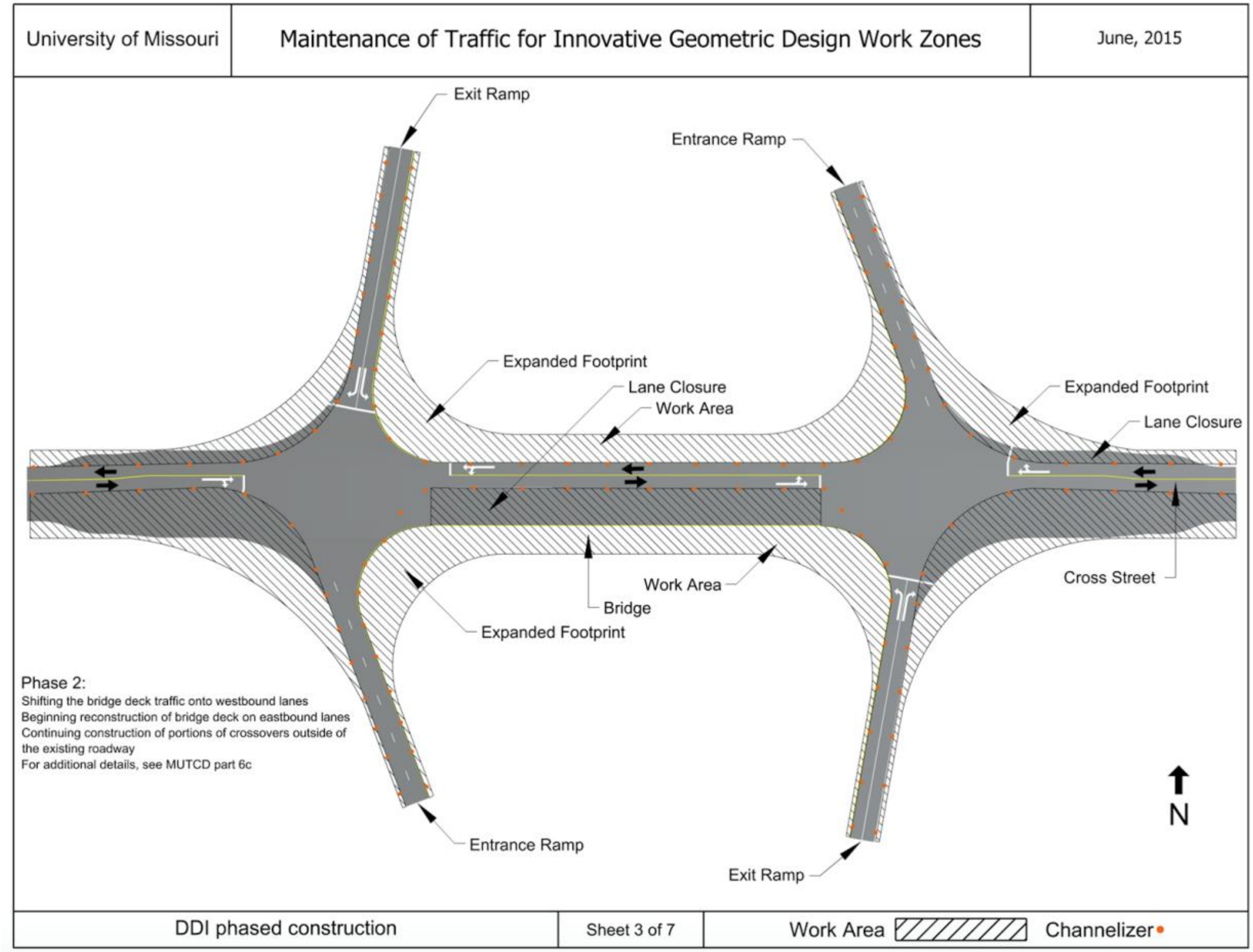

Figure D.1.3.3 DDI phased construction Phase 2 (construction on south side of bridge deck)

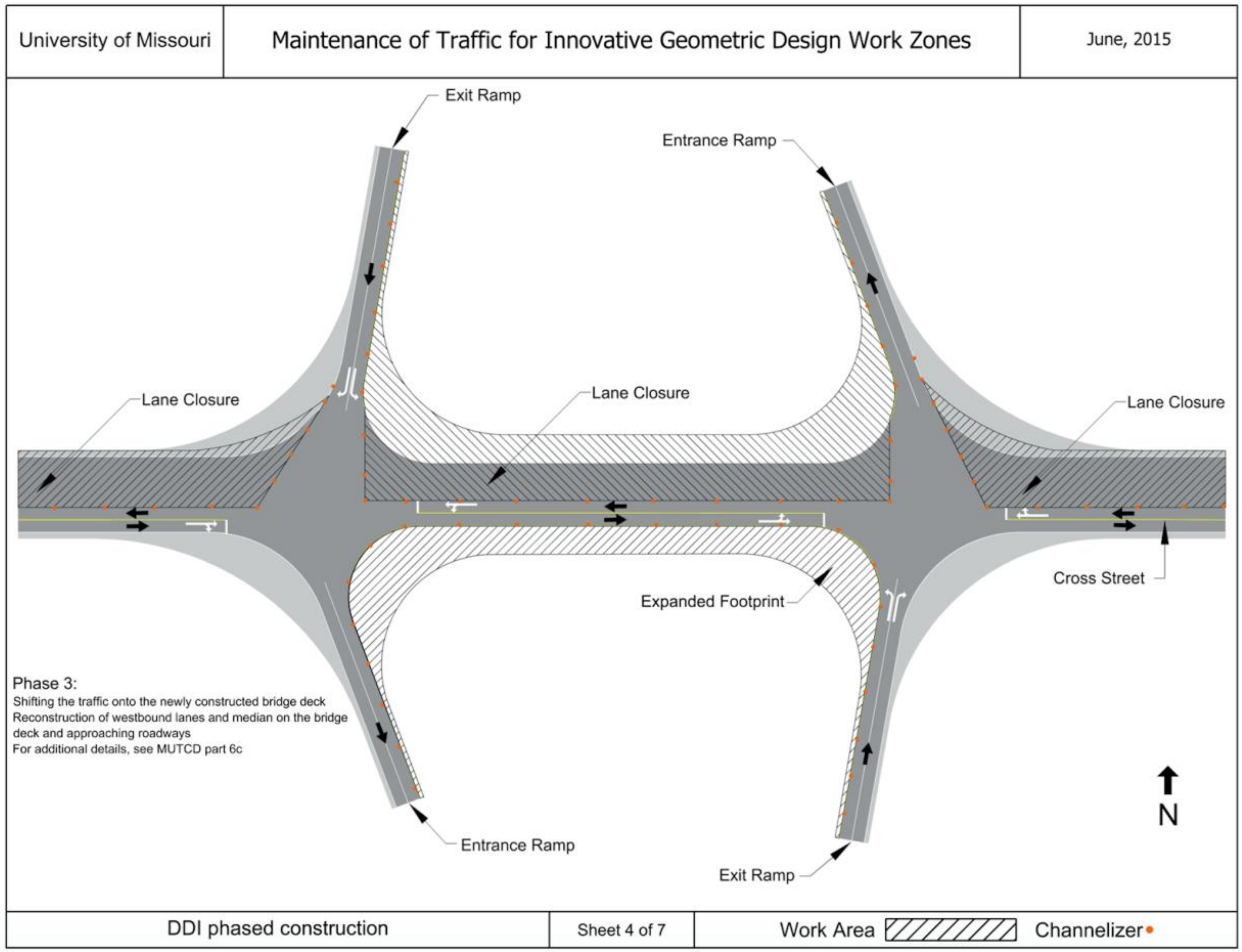

Figure D.1.3.4 DDI phased construction Phase 3 (construction on north side of bridge deck and median)

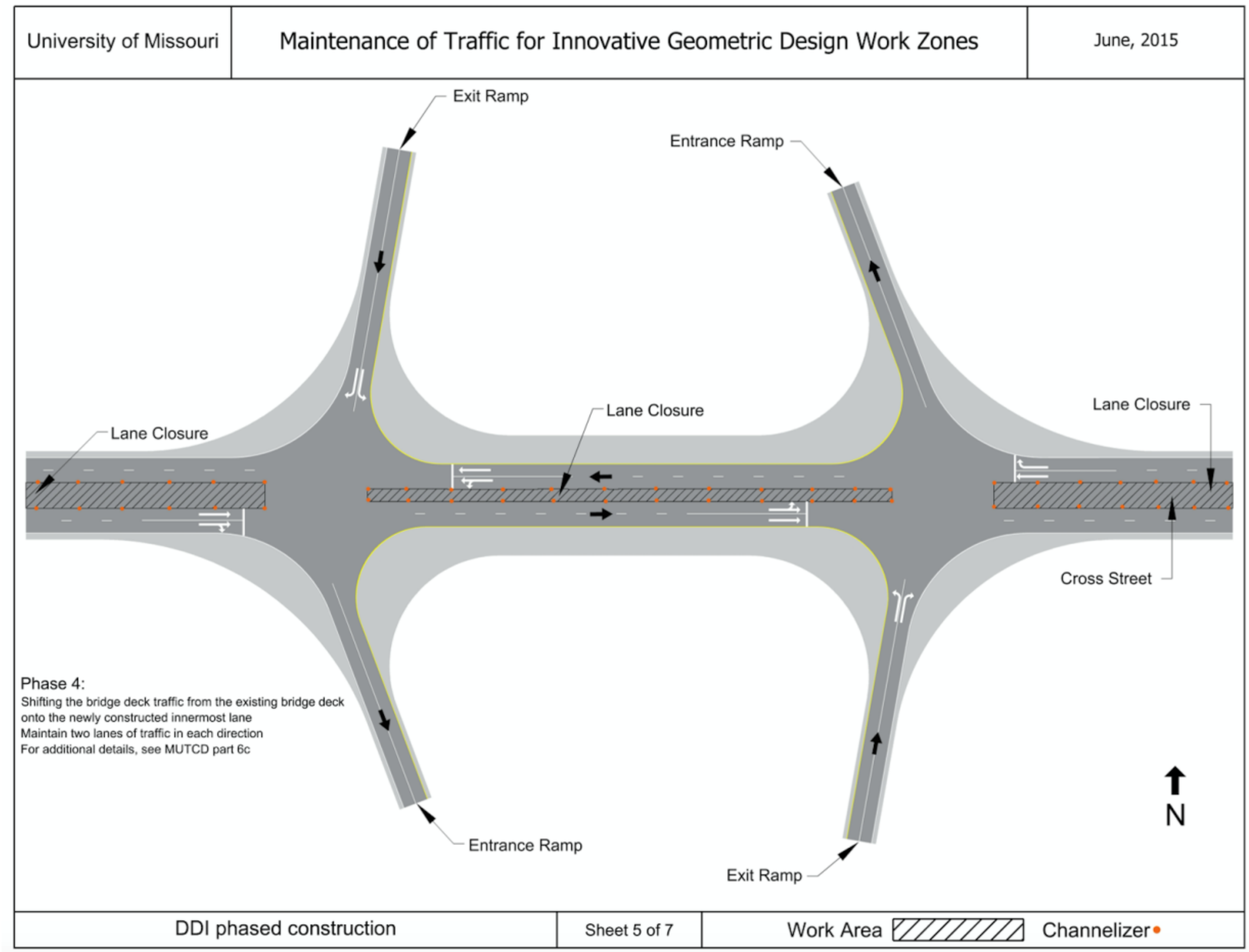

Figure D.1.3.5 DDI phased construction Phase 4 (median construction)

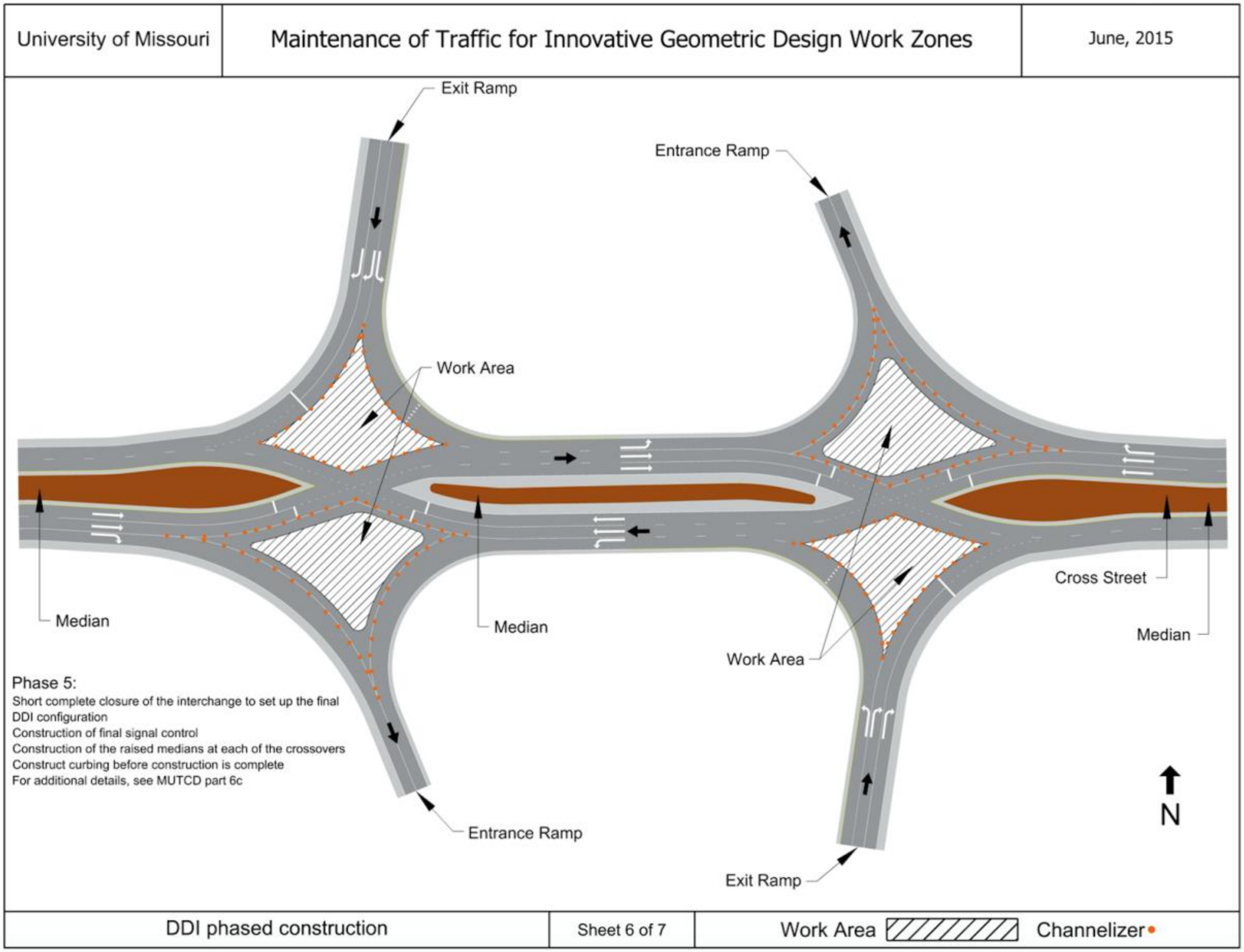

Figure D.1.3.6 DDI phased construction Phase 5 (short complete closure and final conversion to DDI)

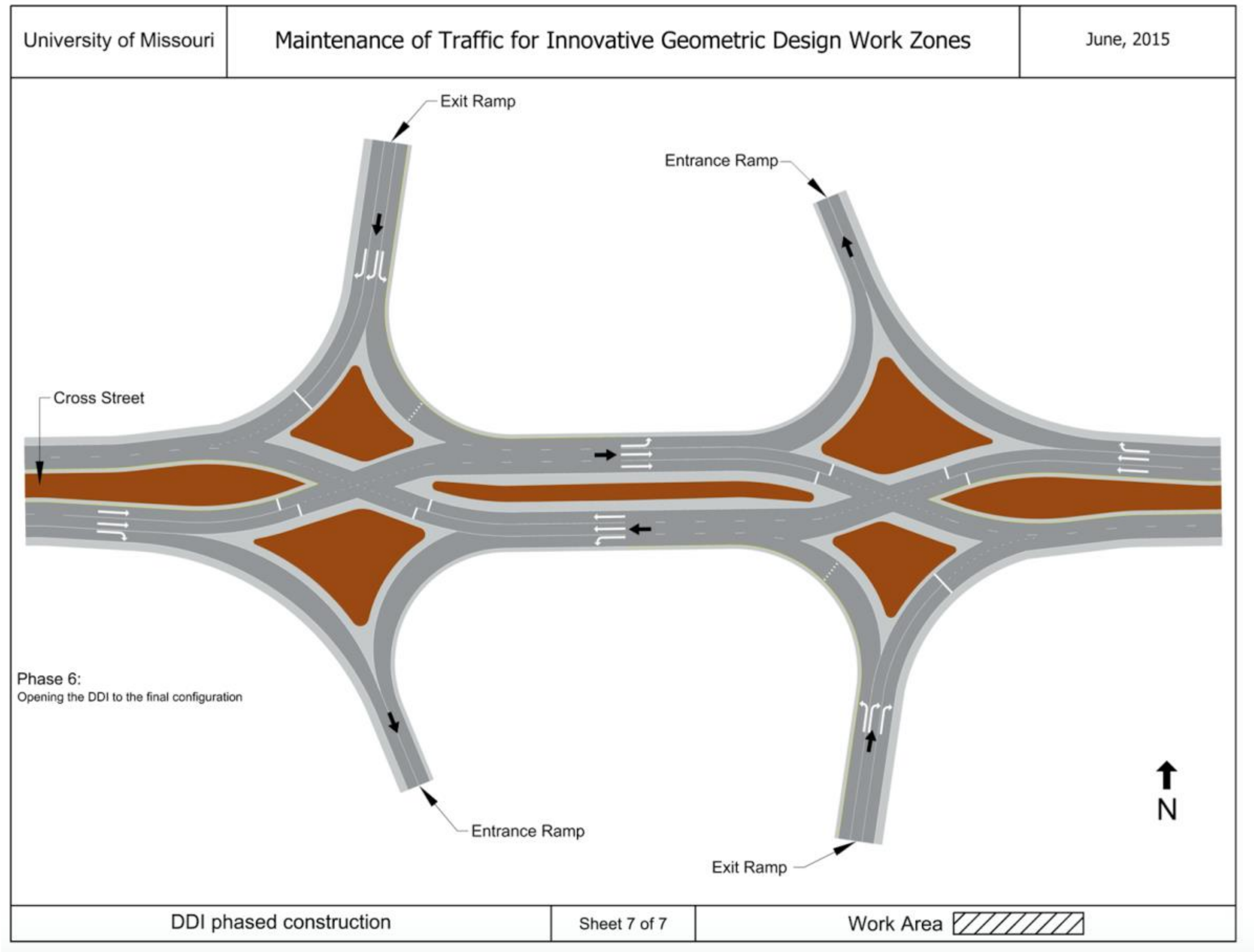

Figure D.1.3.7 DDI phased construction final configuration

D.1.4 RCUT

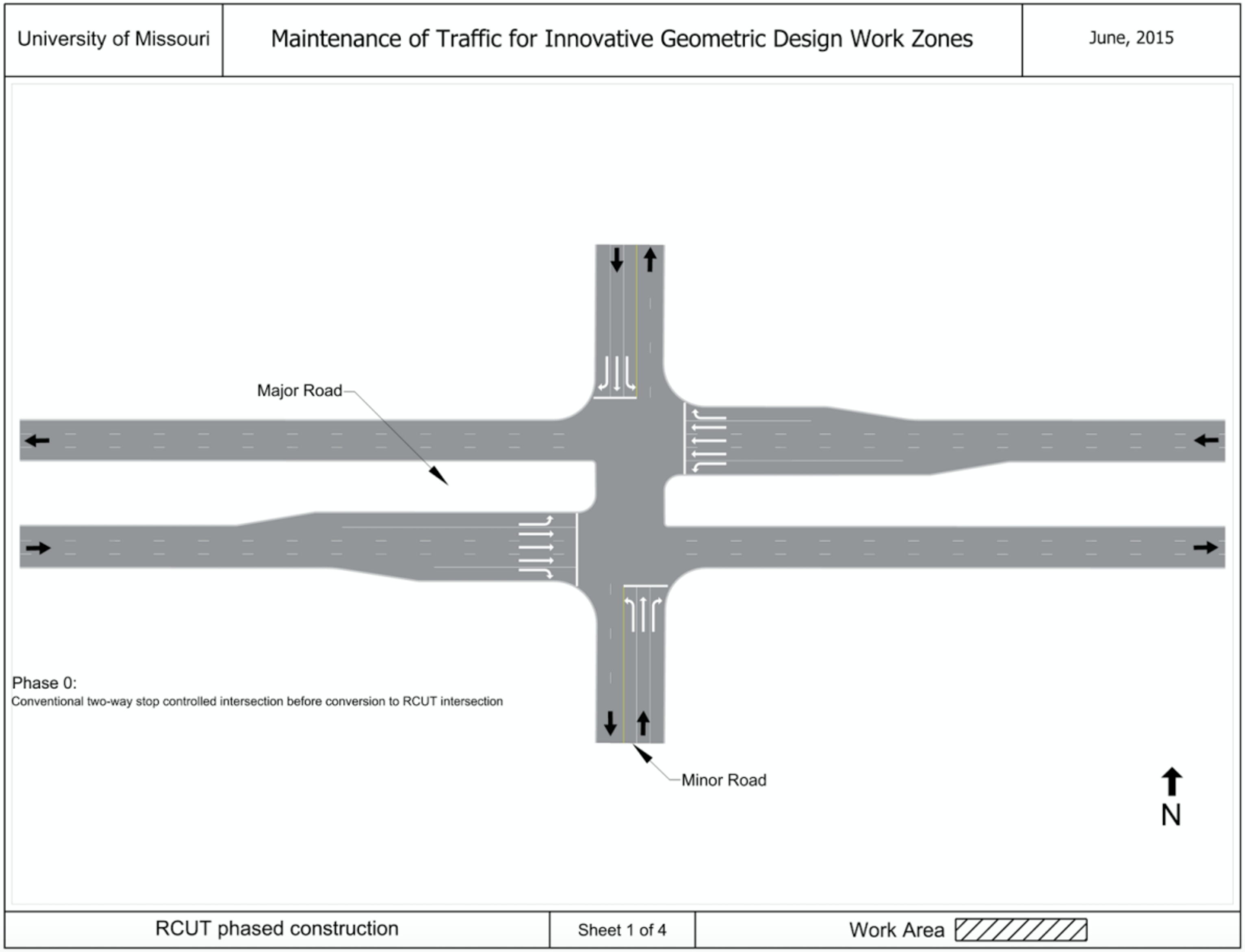

Figure D.1.4.1 RCUT phased construction initial configuration

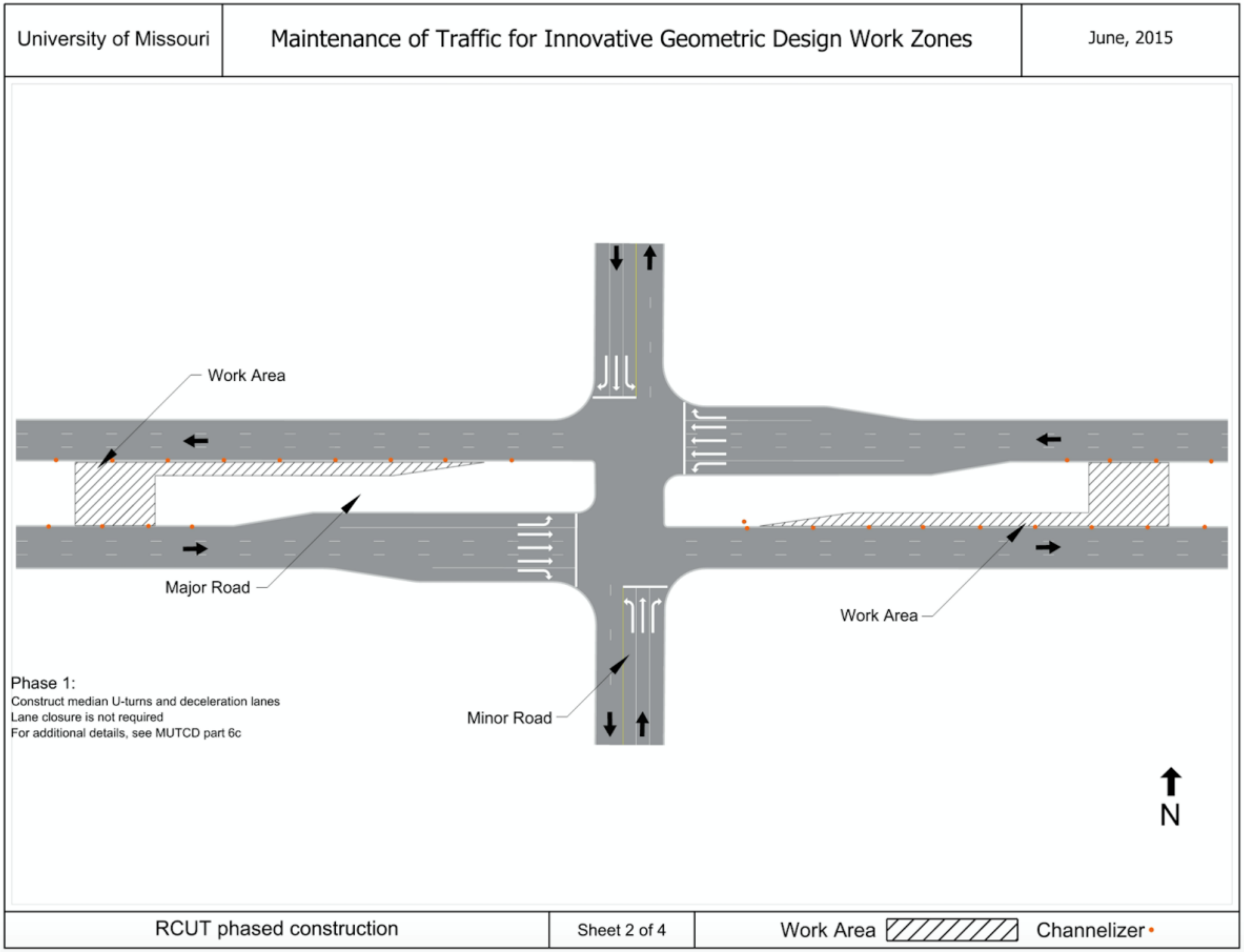

Figure D.1.4.2 RCUT phased construction Phase 1 (construction of median U-turns)

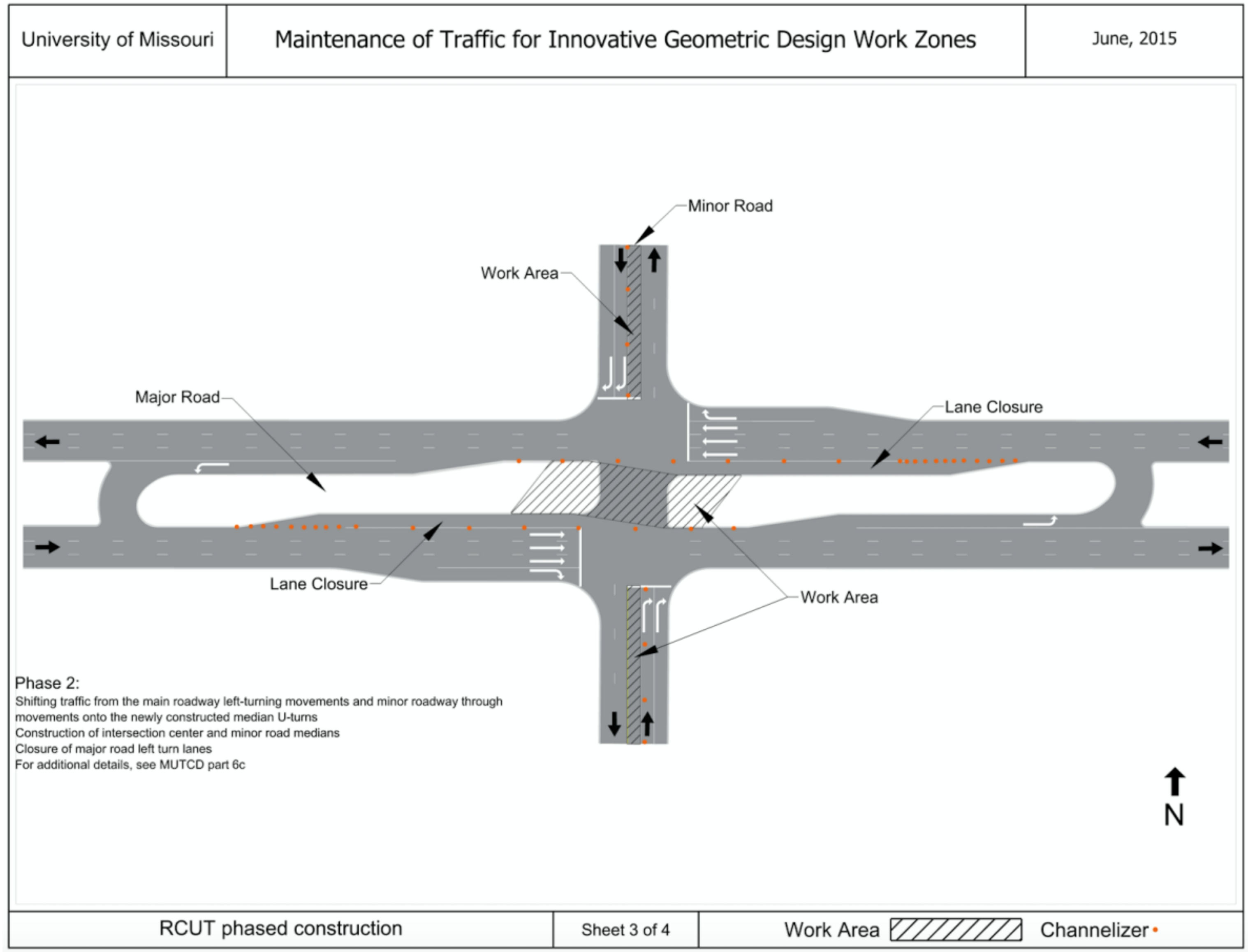

Figure D.1.4.3 RCUT phased construction Phase 2 (construction of RCUT intersection center and minor road medians)

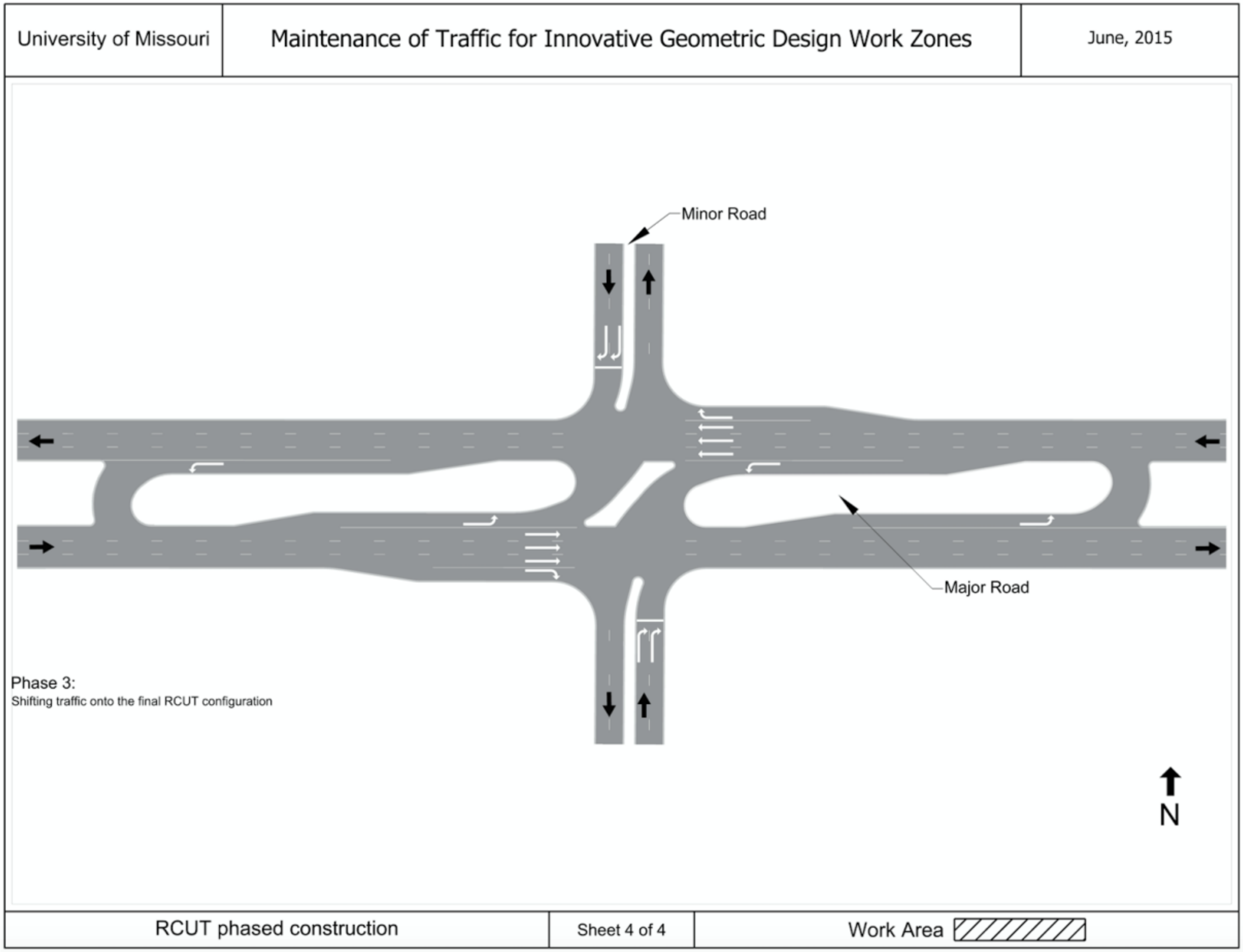

Figure D.1.4.4 RCUT phased construction final configuration

D.1.5 MUT

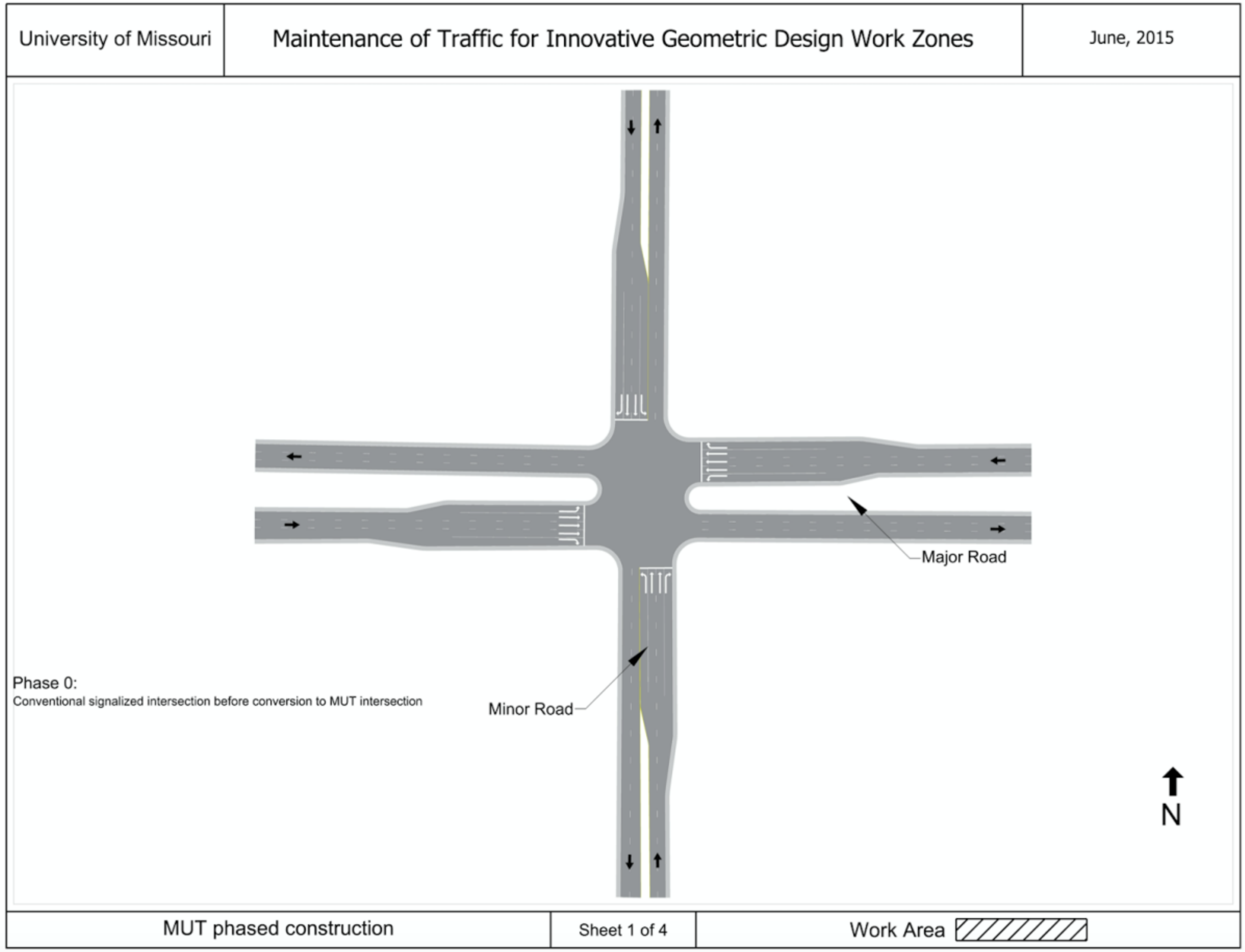

Figure D.1.5.1 MUT phased construction initial configuration

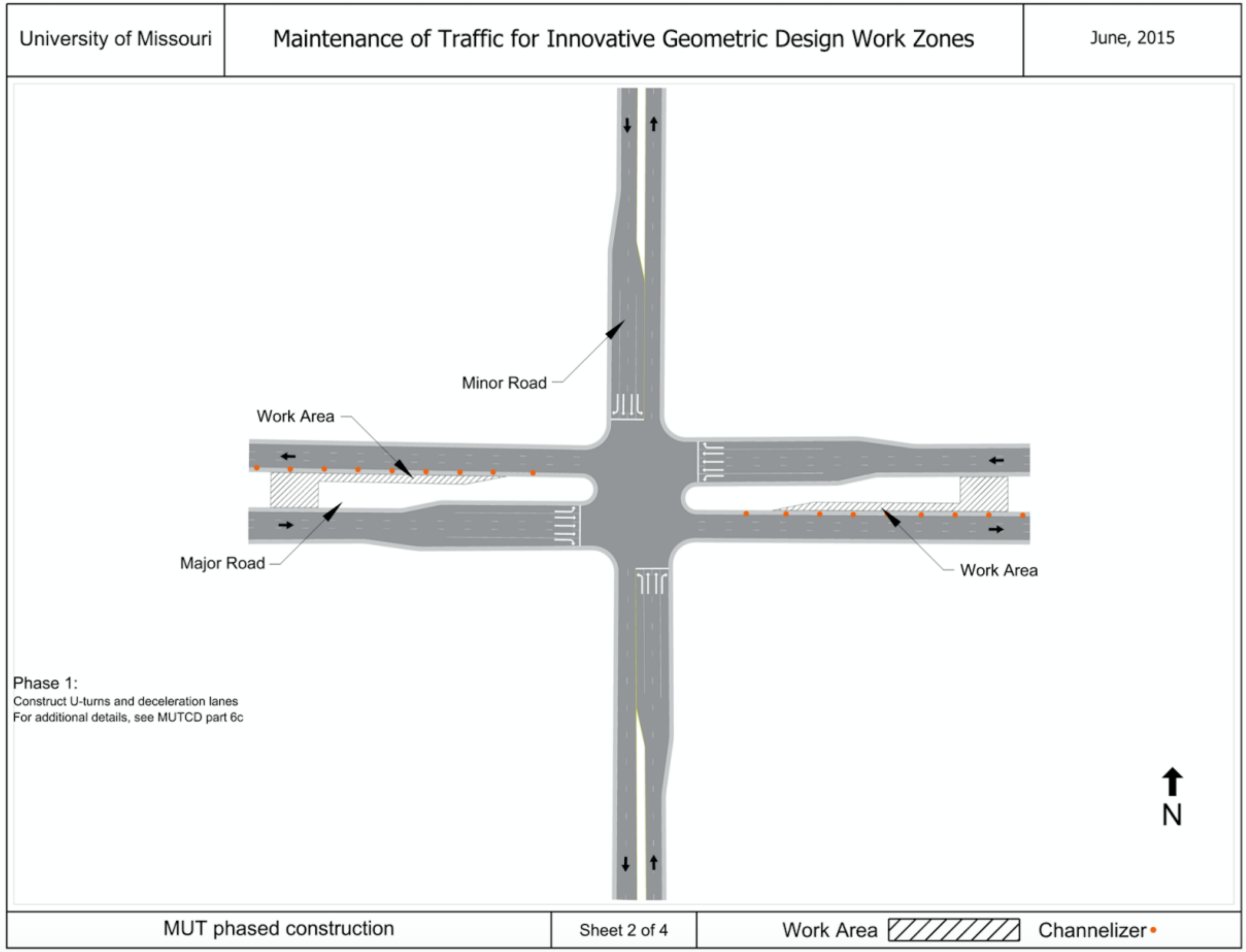

Figure D.1.5.2 MUT phased construction Phase 1 (construction of median U-turns)

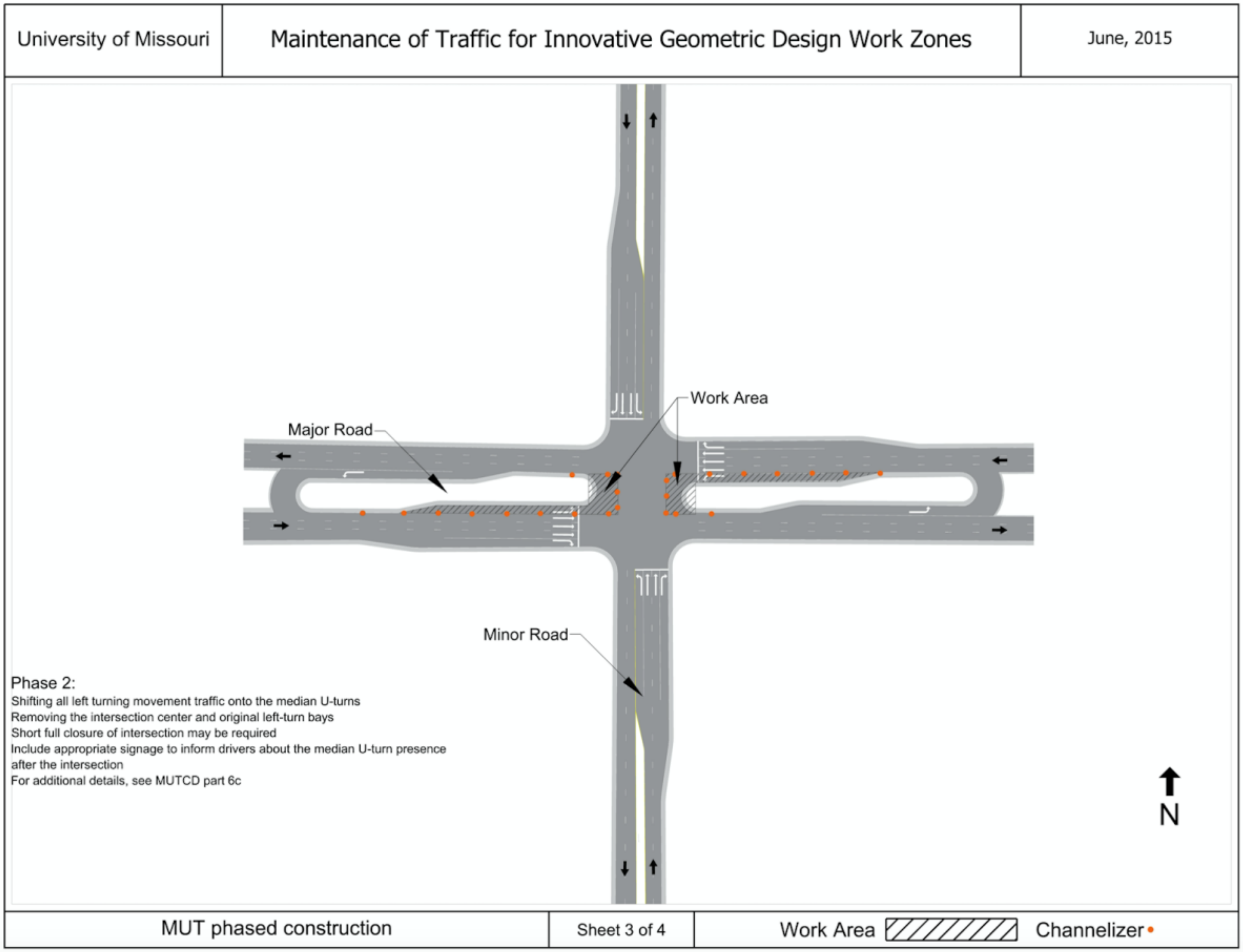

Figure D.1.5.3 MUT phased construction Phase 2 (removal of intersection center and original left turn bays)

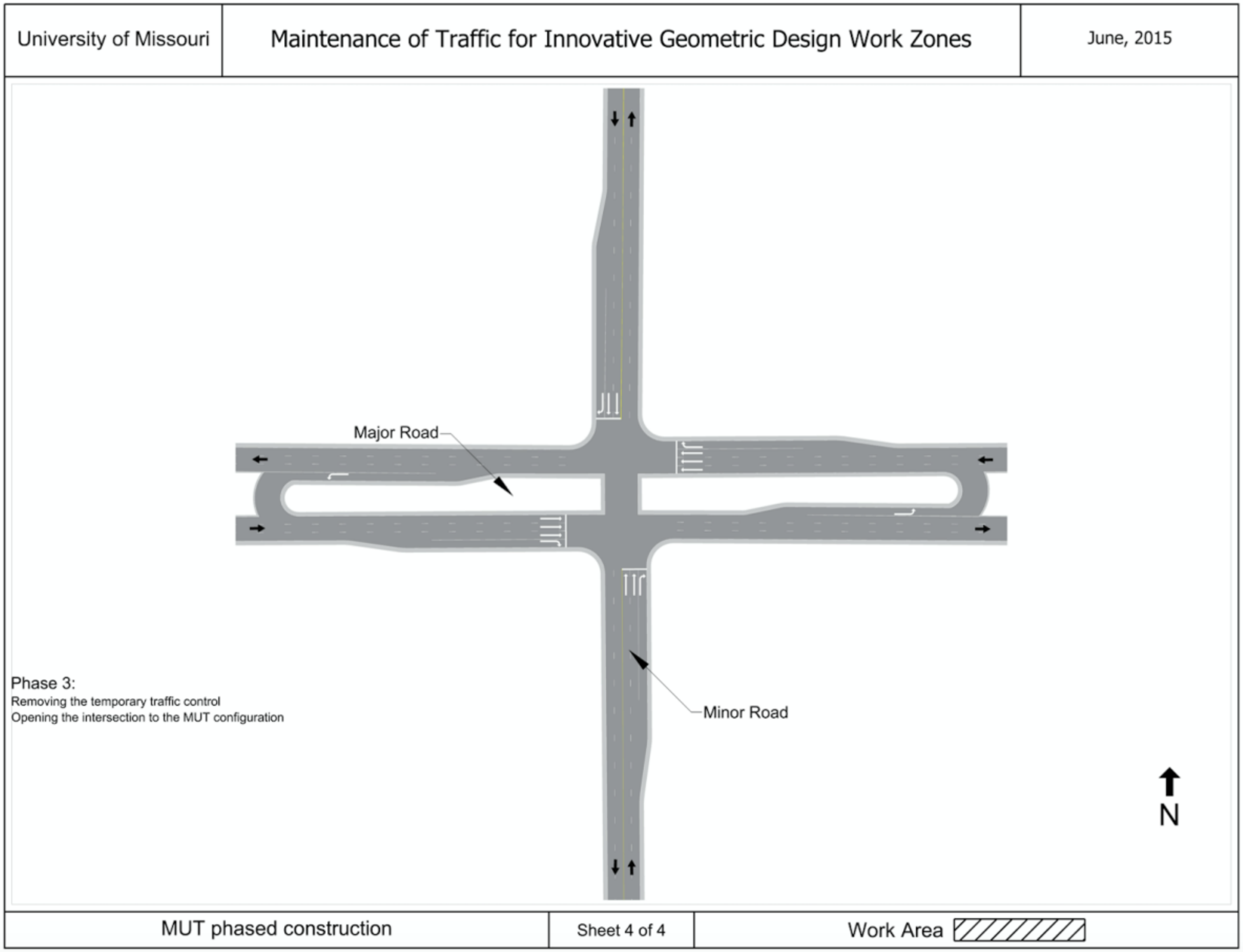

Figure D.1.5.4 MUT phased construction final configuration

D.1.6 DLT

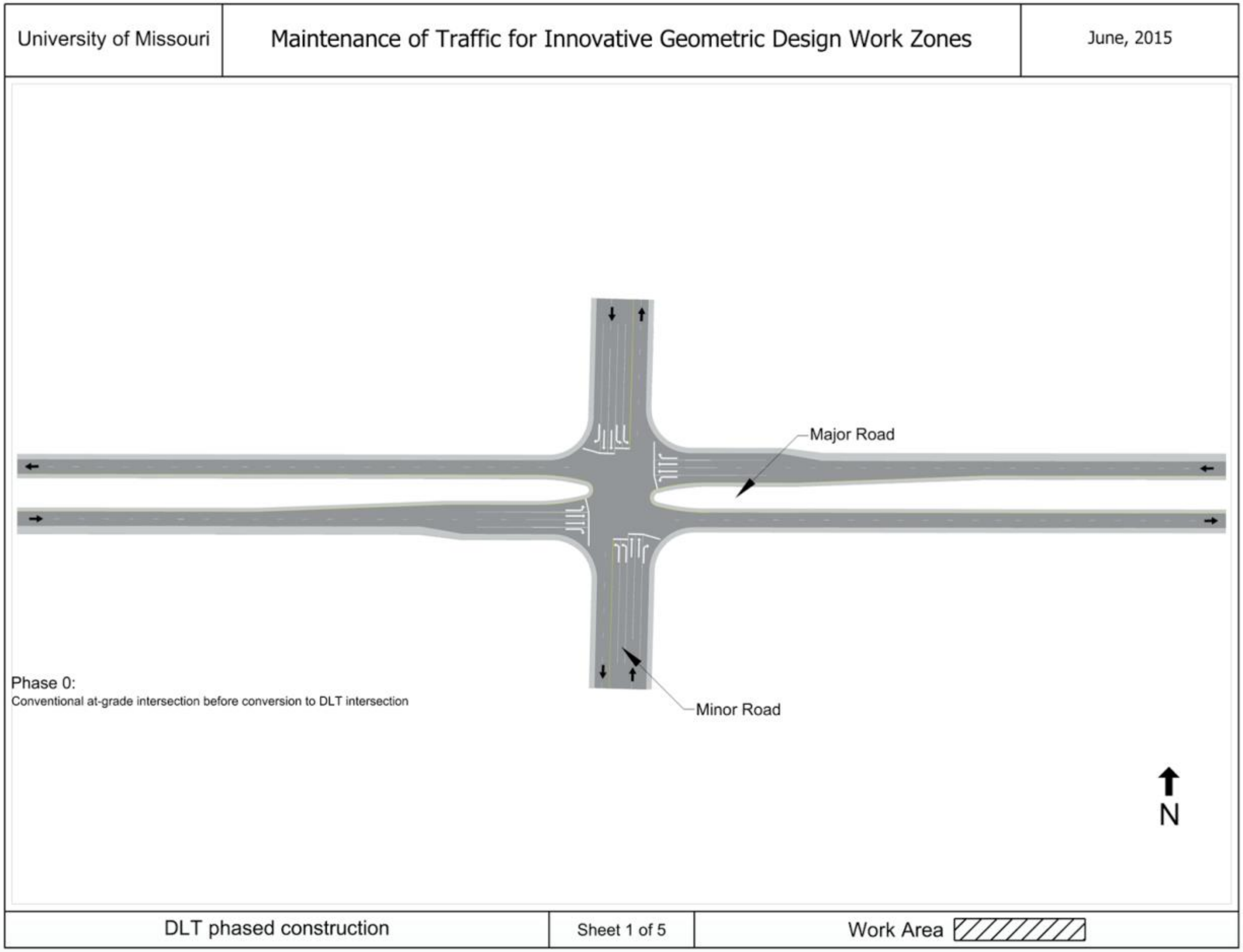

Figure D.1.6.1 DLT phased construction initial configuration

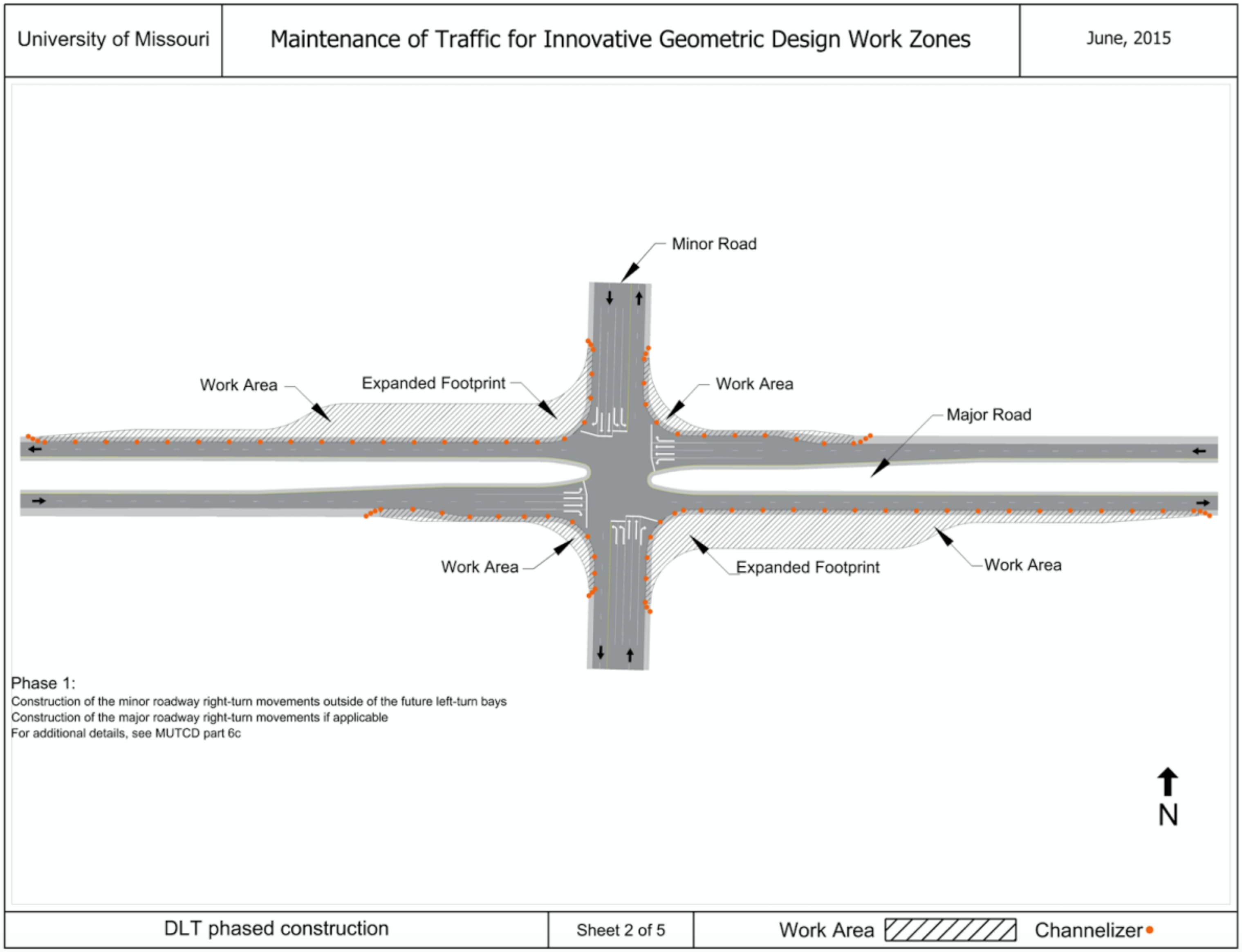

Figure D.1.6.2 DLT phased construction Phase 1 (construction of right turn movements on major and minor roadways)

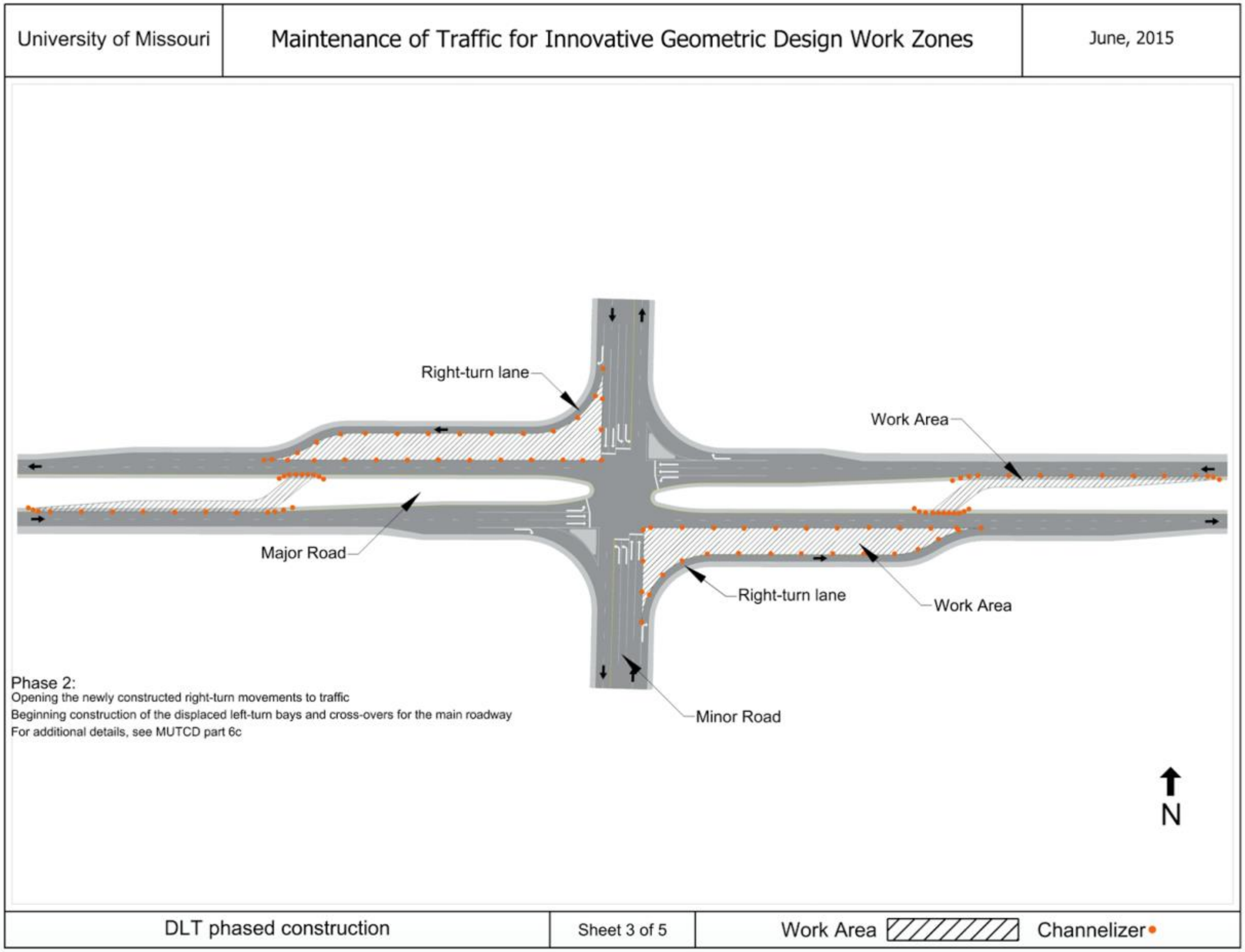

Figure D.1.6.3 DLT phased construction Phase 2 (construction of displaced left turn lane bays and crossovers for major roadway)

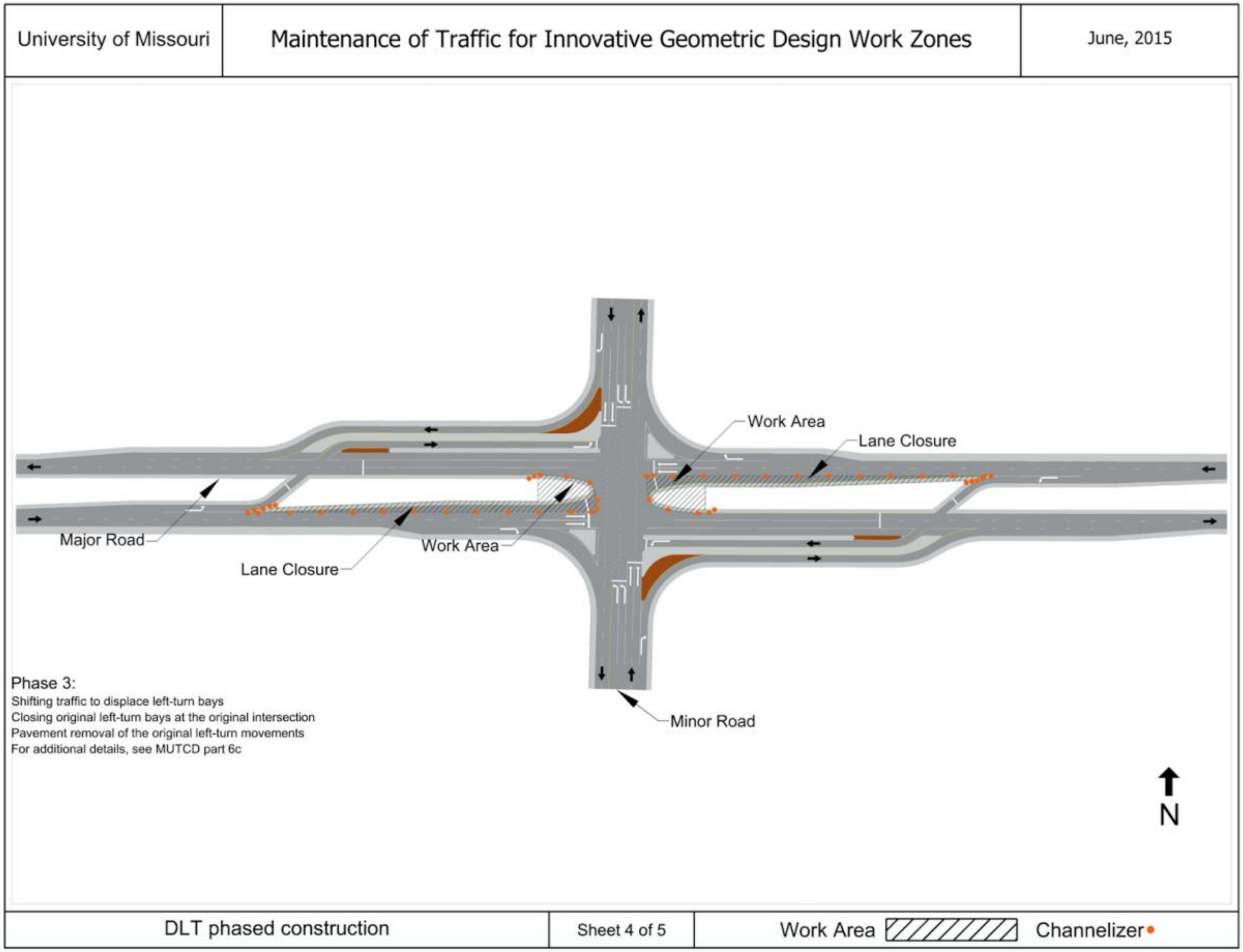

Figure D.1.6.4 DLT phased construction Phase 3 (pavement removal of original left turn lanes)

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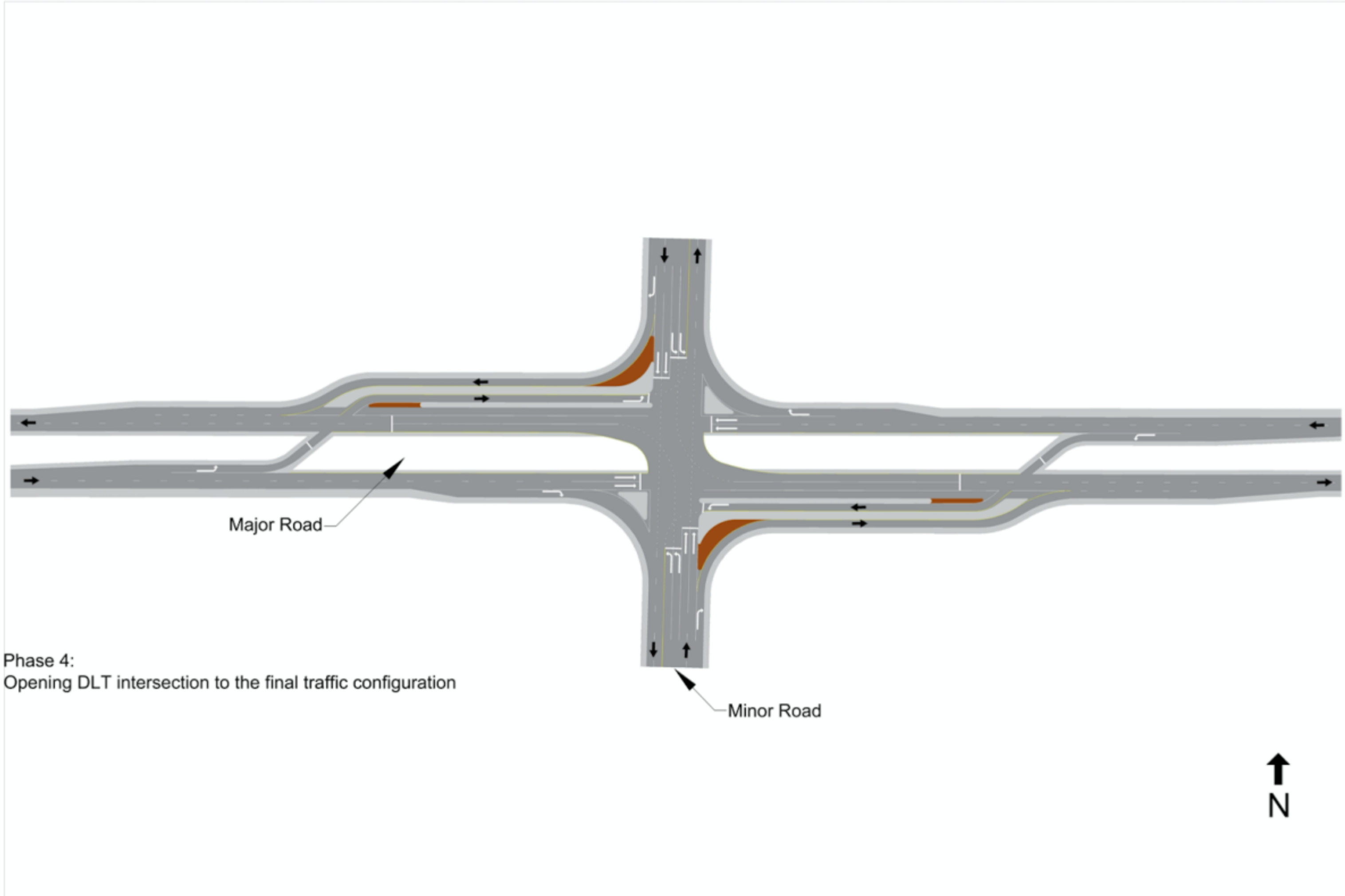

DLT phased construction	Sheet 5 of 5	Work Area

Figure D.1.6.5 DLT phased construction final configuration

D.2 Maintenance Project MOT Diagrams

D.2.1 Roundabout

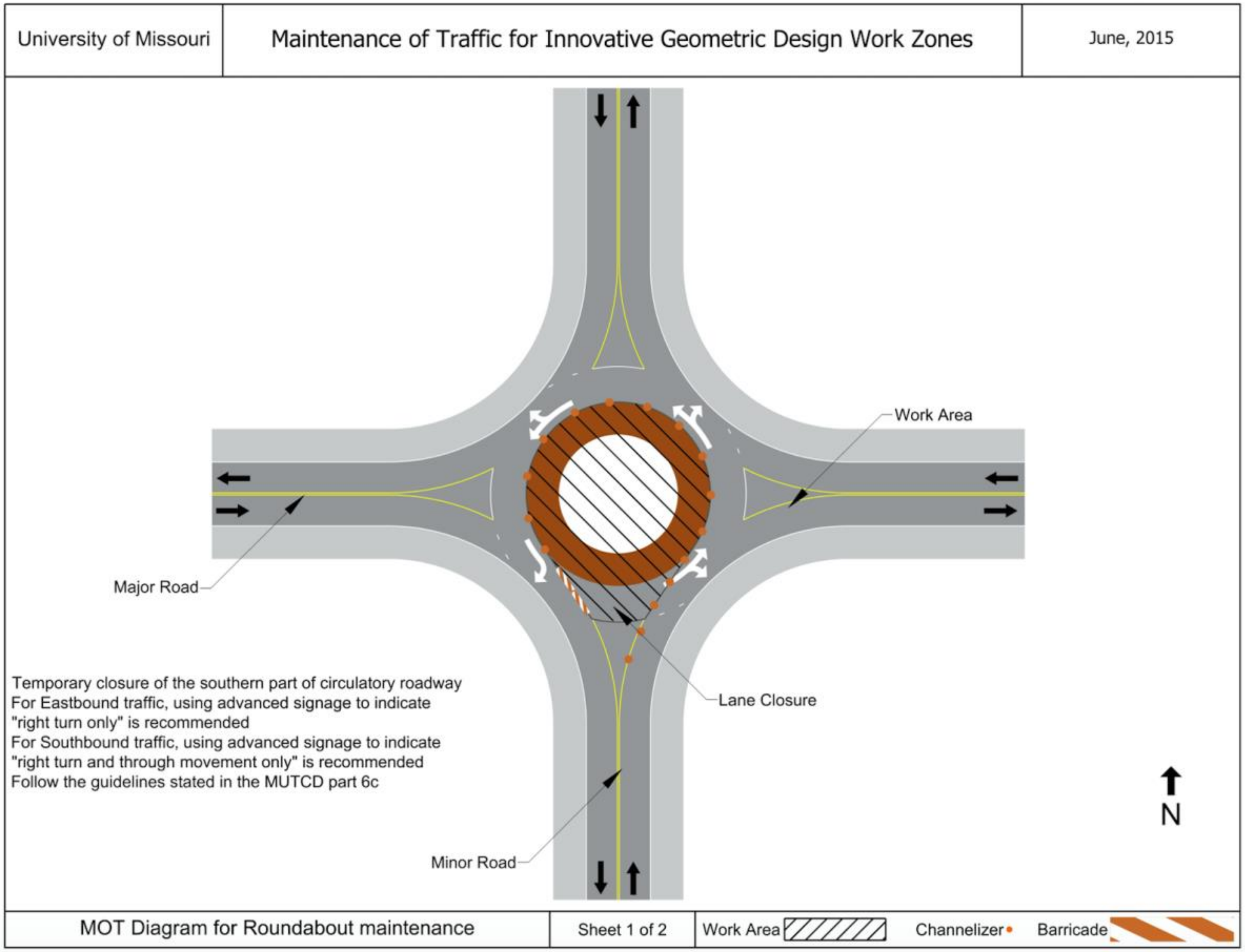

Figure D.2.1.1 MOT diagram for roundabout maintenance of the southern part of circulatory roadway

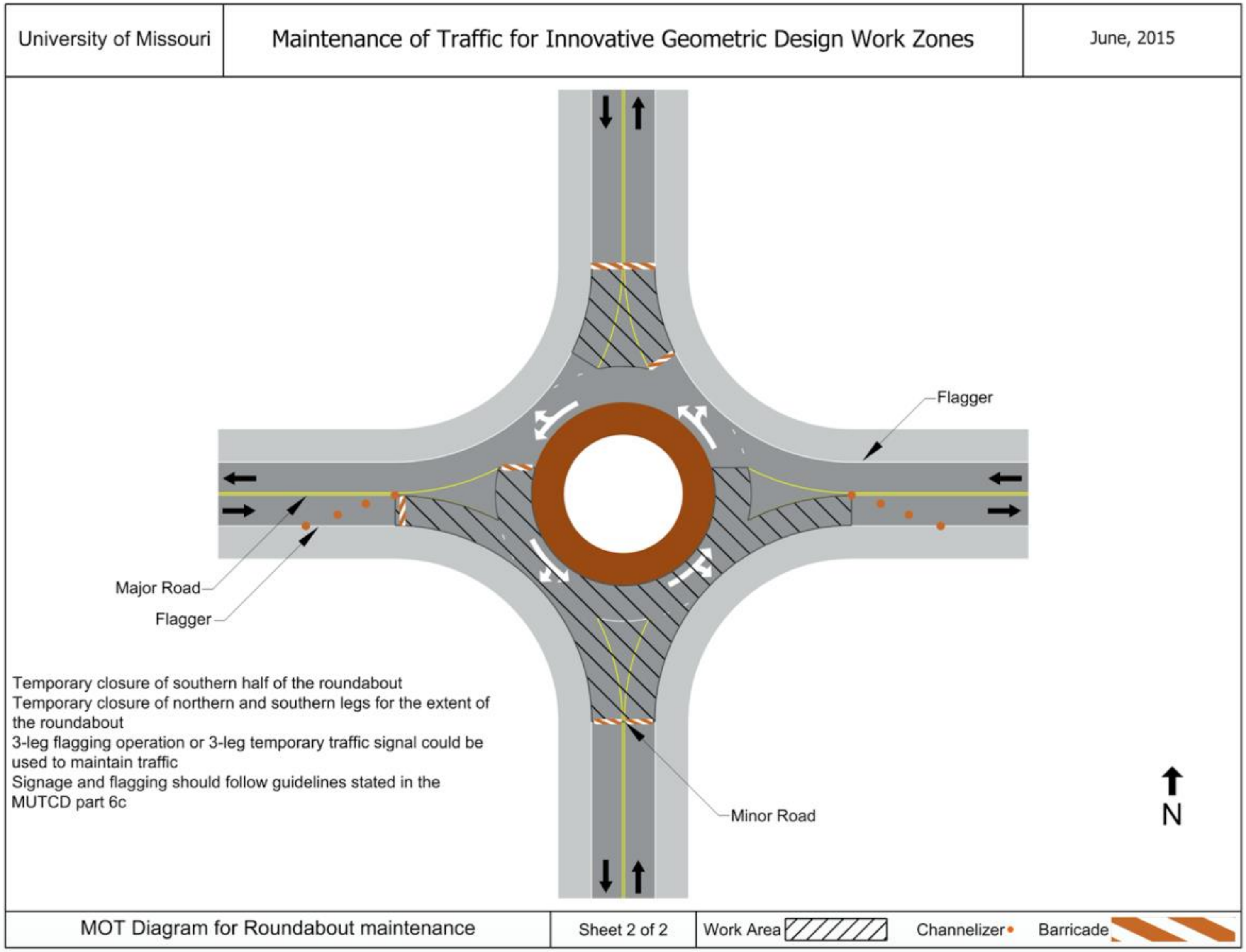

Figure D.2.1.2 MOT diagram for roundabout maintenance of southern half of the intersection

D.2.2 SPUI

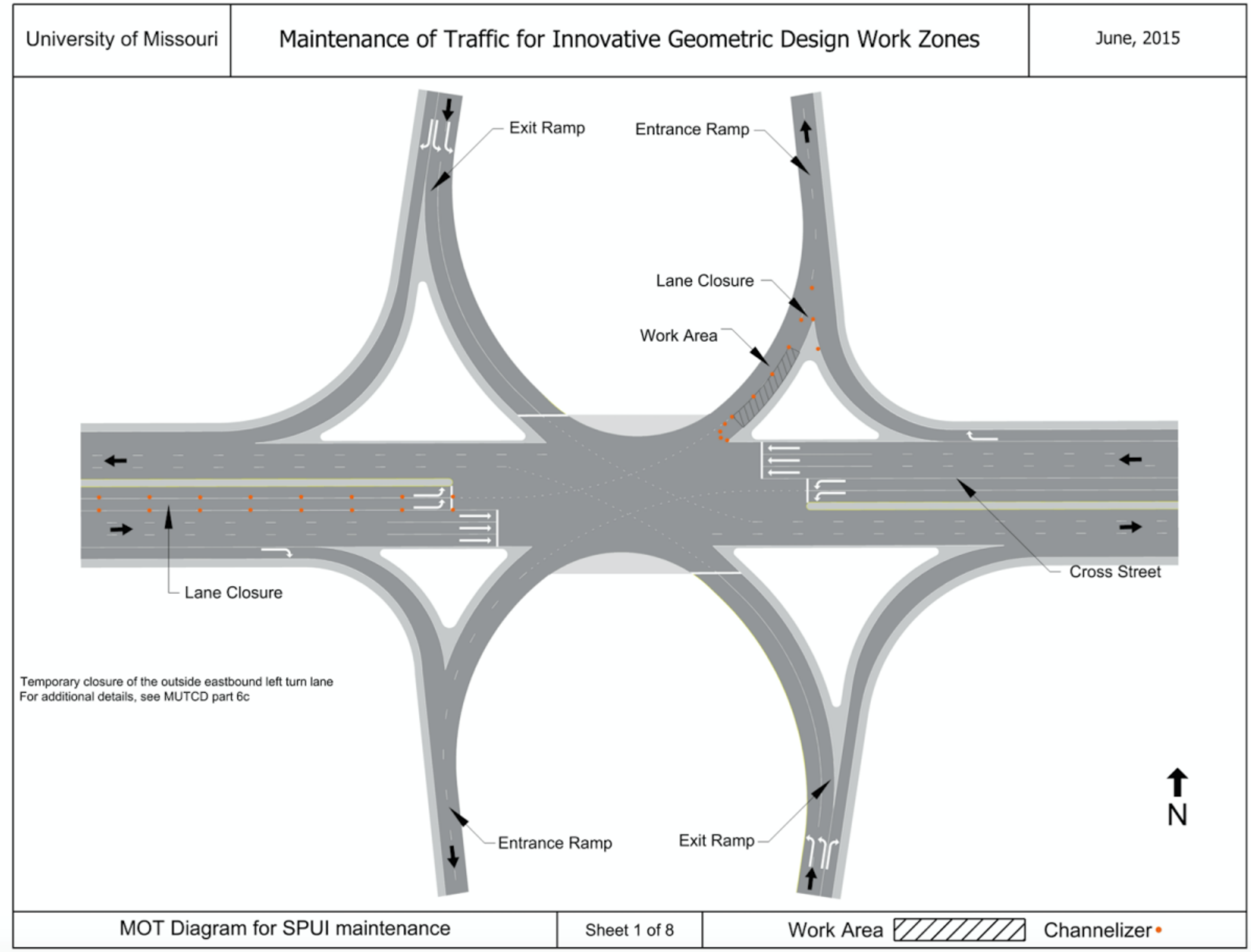

Figure D.2.2.1 MOT diagram for SPUI maintenance of outside eastbound left turn lane

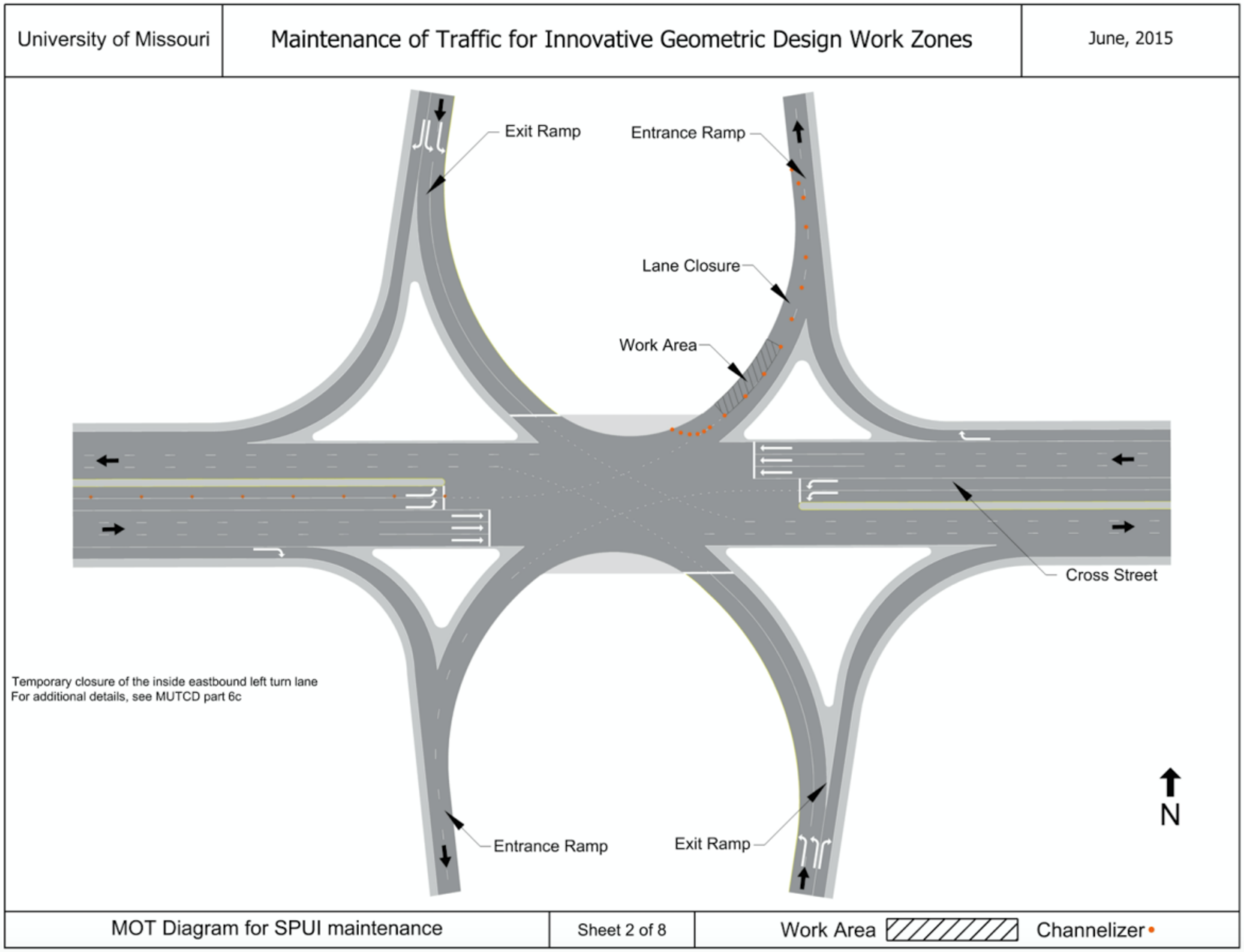

Figure D.2.2.2 MOT diagram for SPUI maintenance of inside eastbound left turn lane

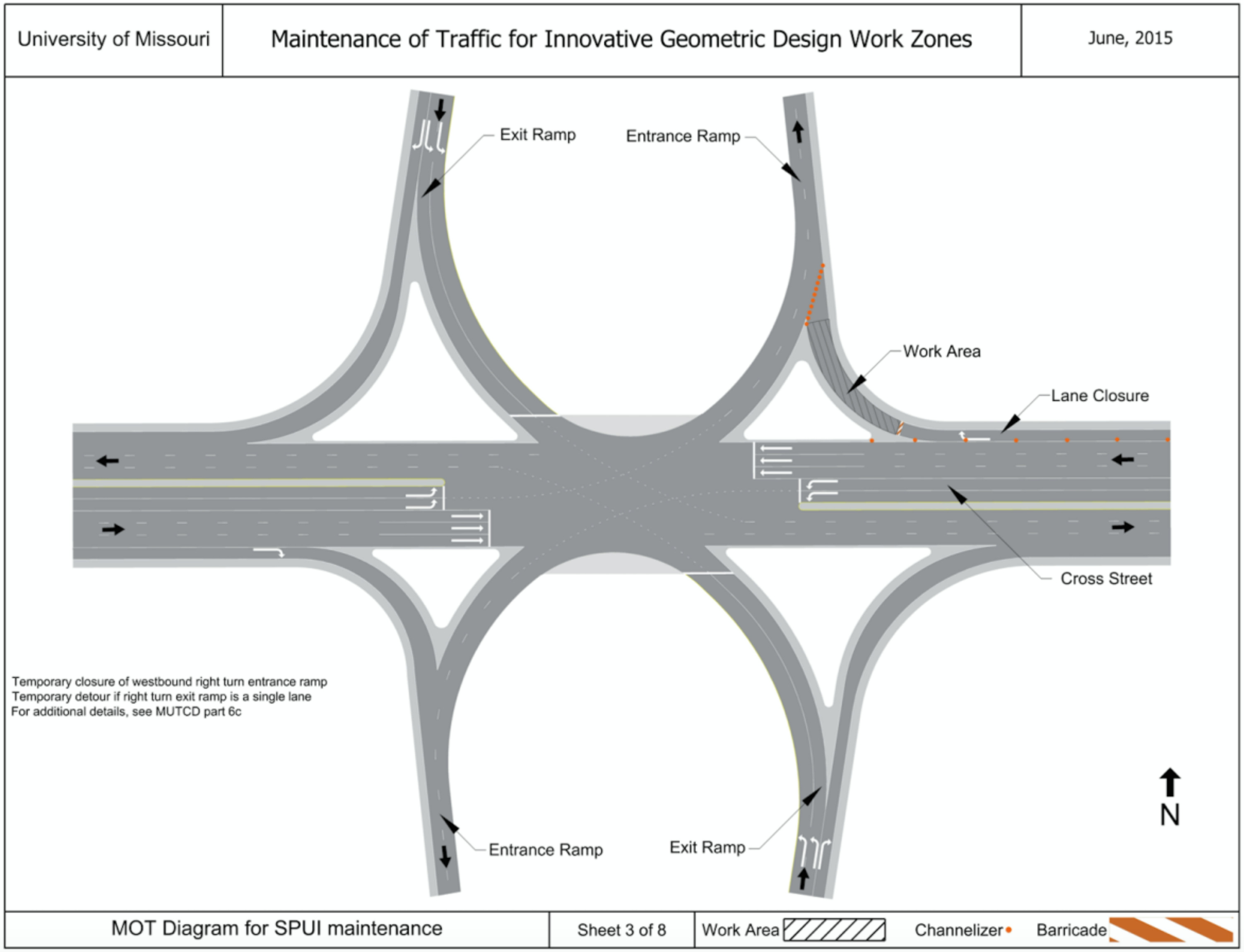

Figure D.2.2.3 MOT diagram for SPUI maintenance of westbound right turn entrance ramp

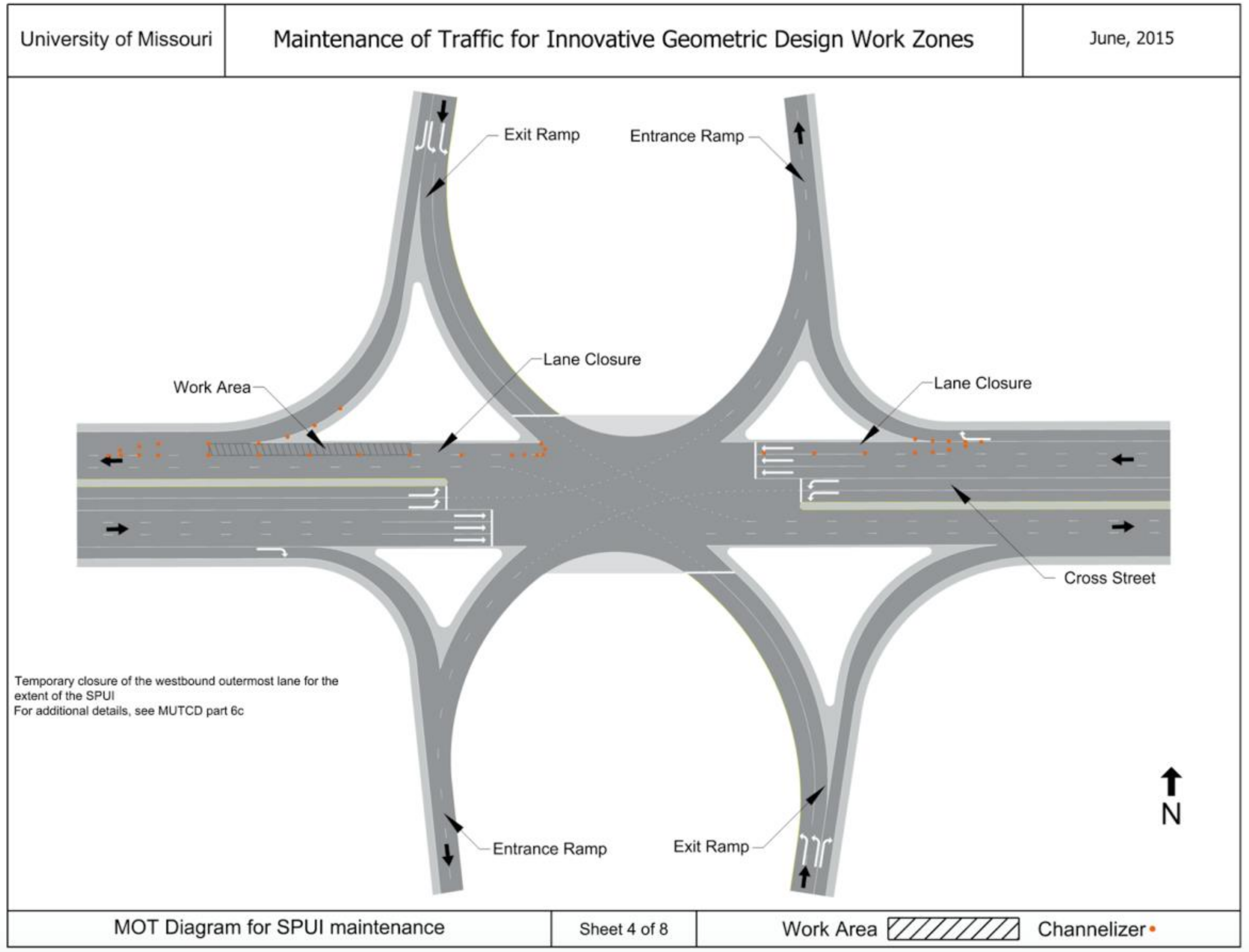

Figure D.2.2.4 MOT diagram for SPUI maintenance of westbound outermost lane

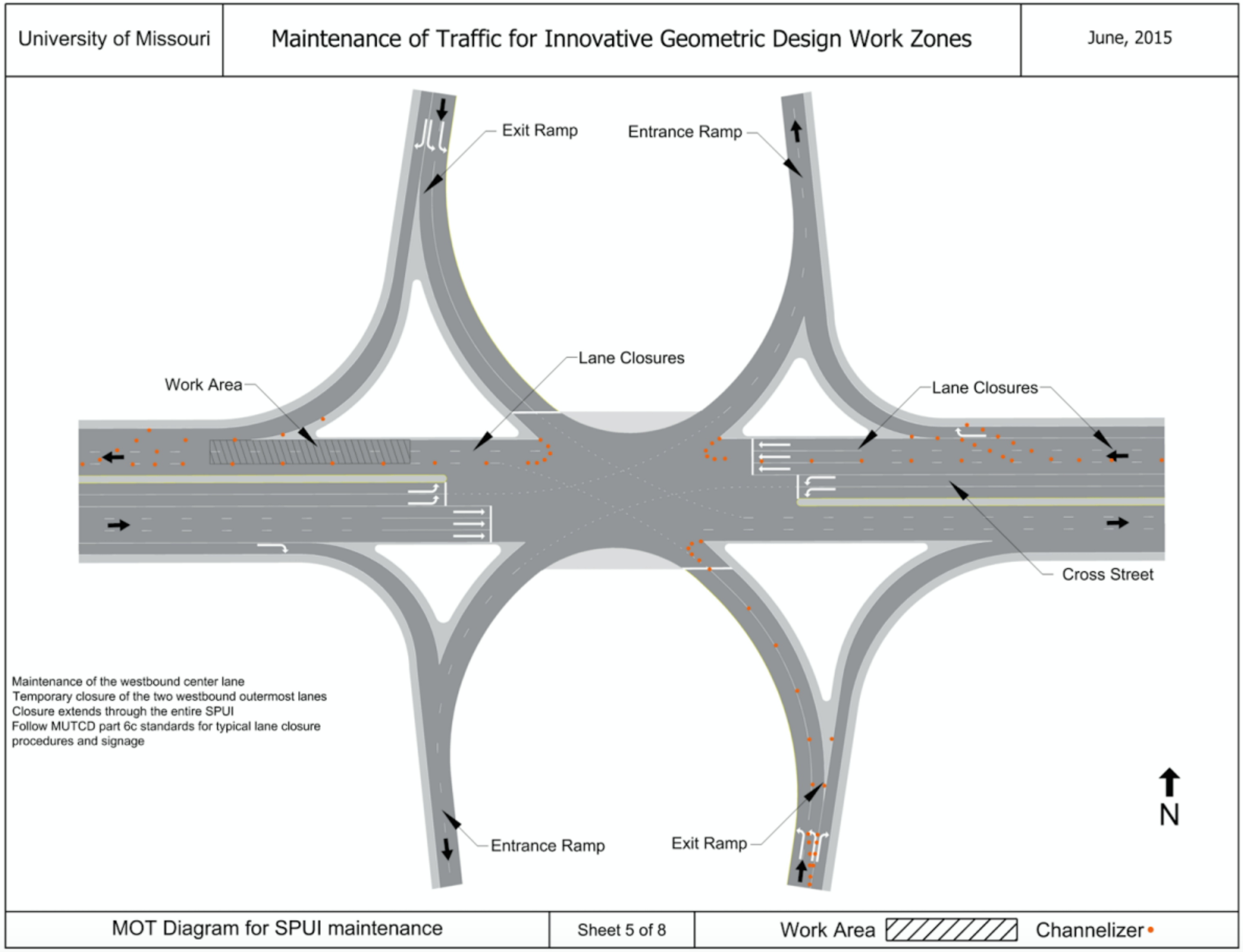

Figure D.2.2.5 MOT diagram for SPUI maintenance of the westbound center lane

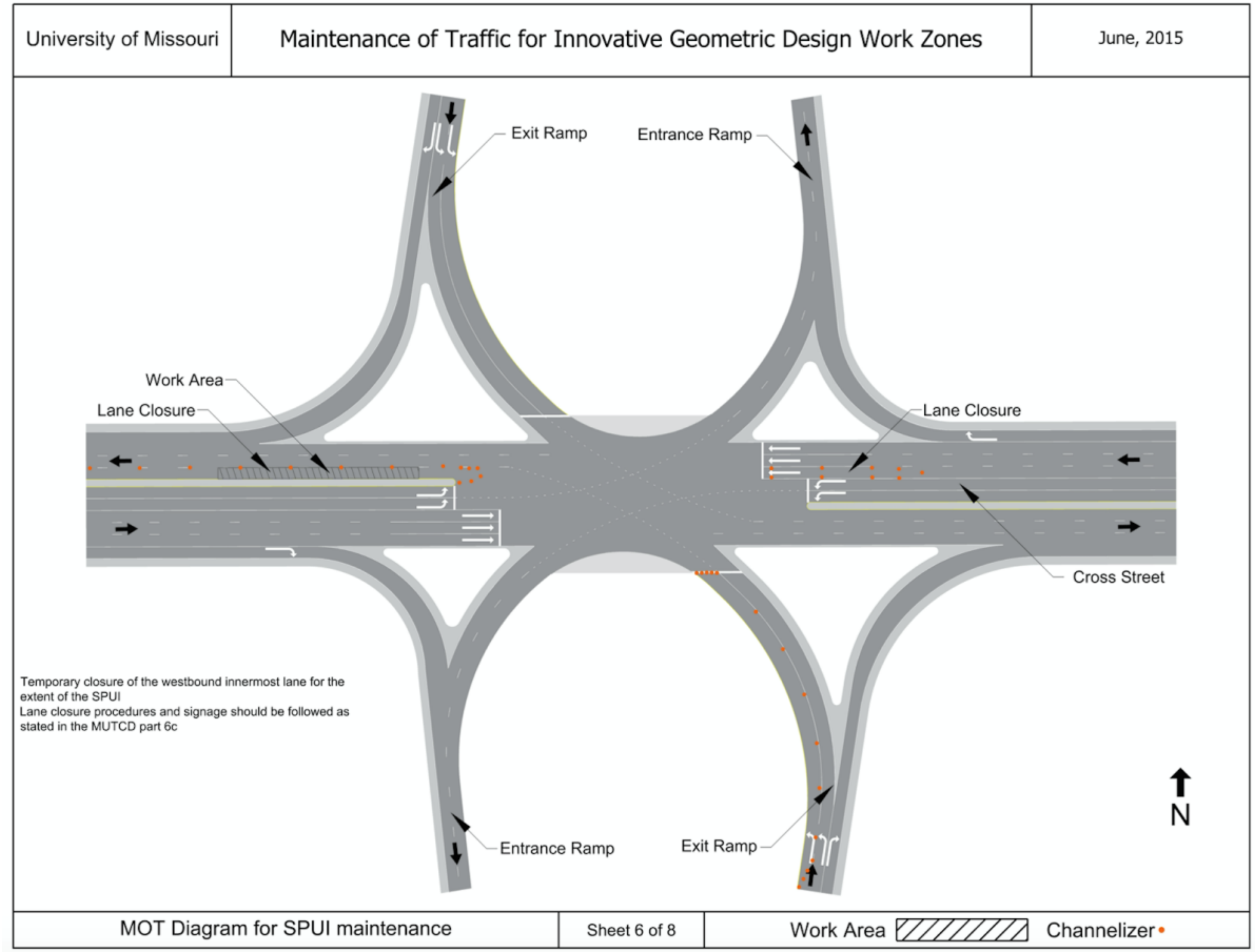

Figure D.2.2.6 MOT diagram for SPUI maintenance of the innermost westbound lane

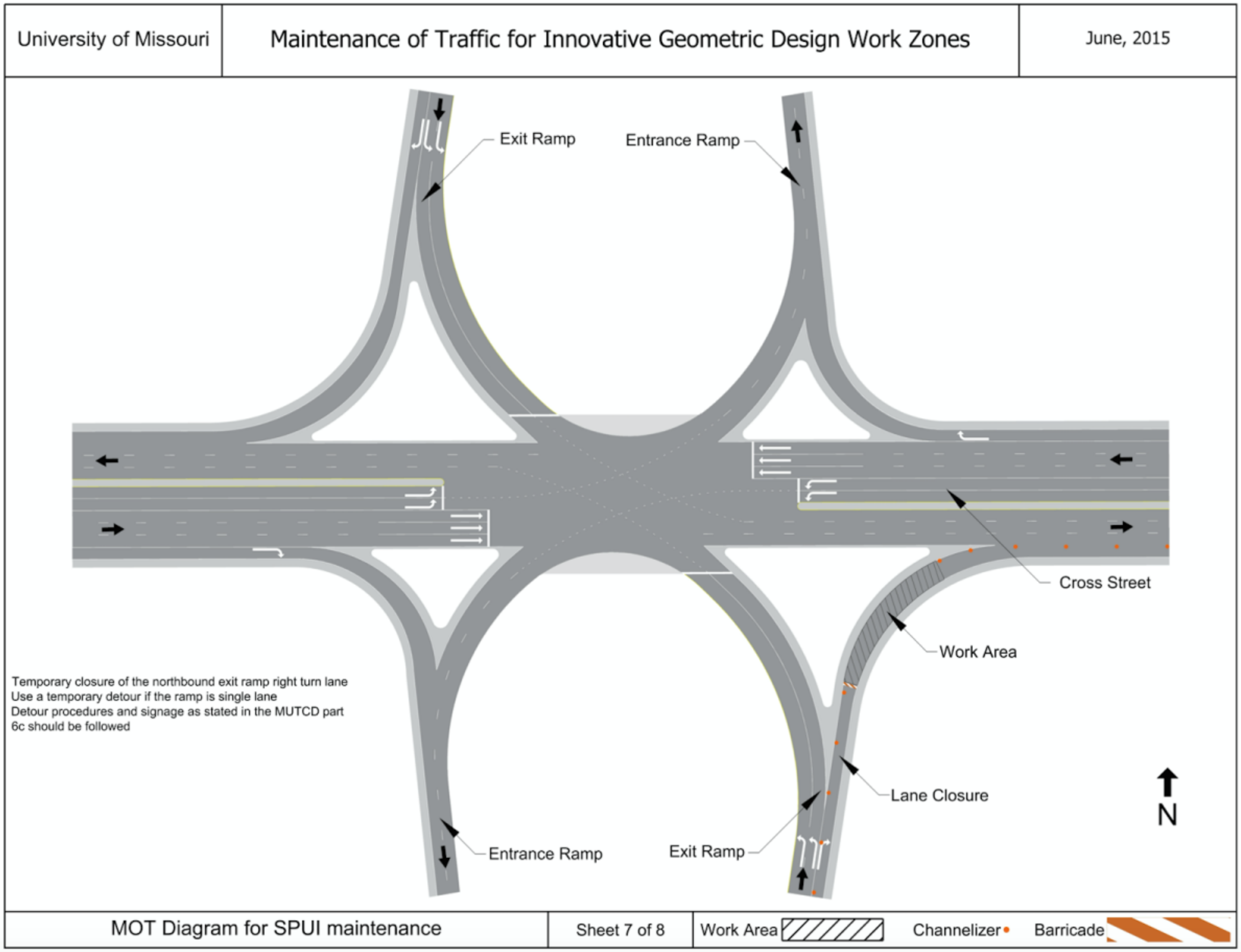

Figure D.2.2.7 MOT diagram for SPUI maintenance of the northbound exit ramp right turn lane

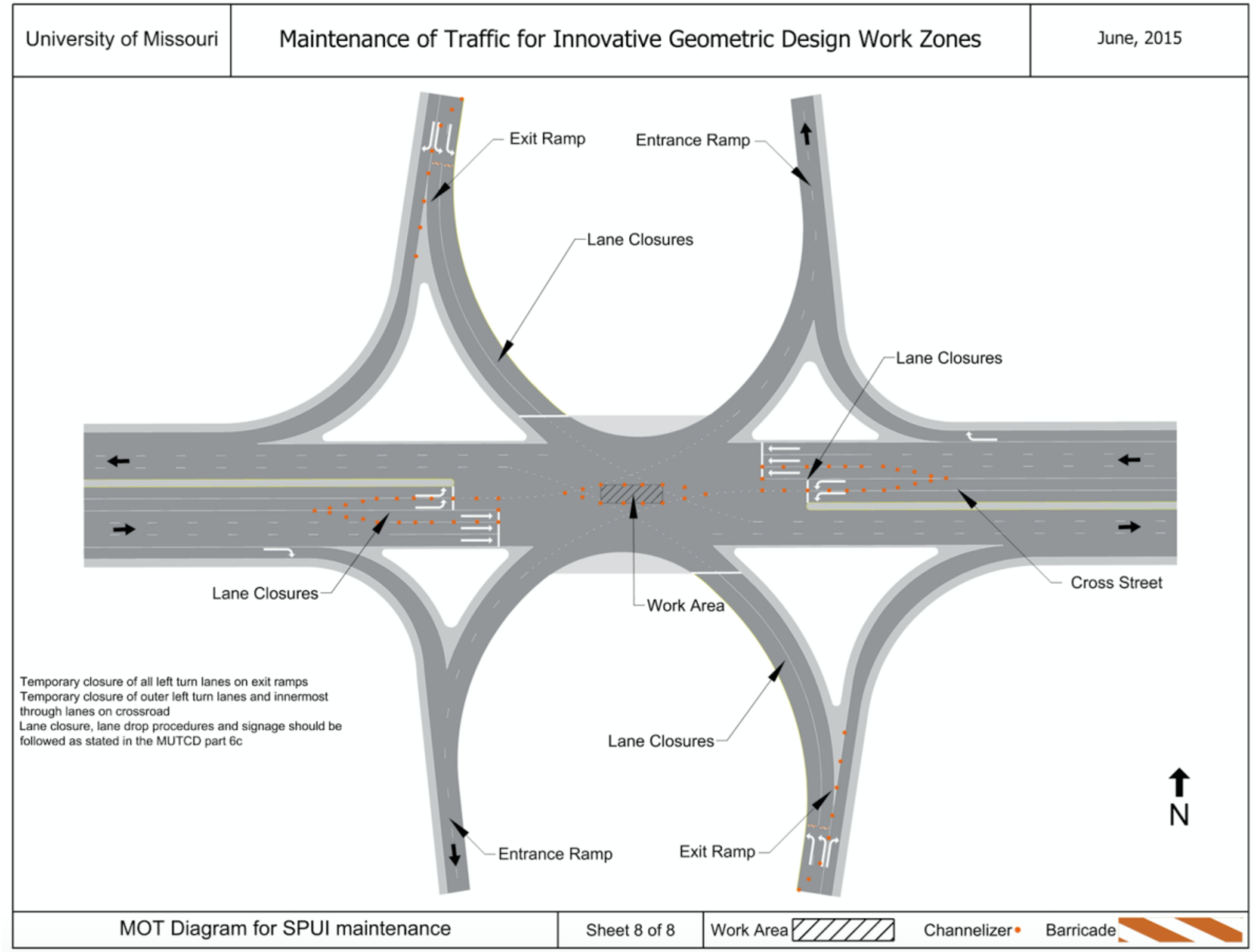

Figure D.2.2.8 MOT diagram for SPUI maintenance of the intersection center

D.2.3 DDI

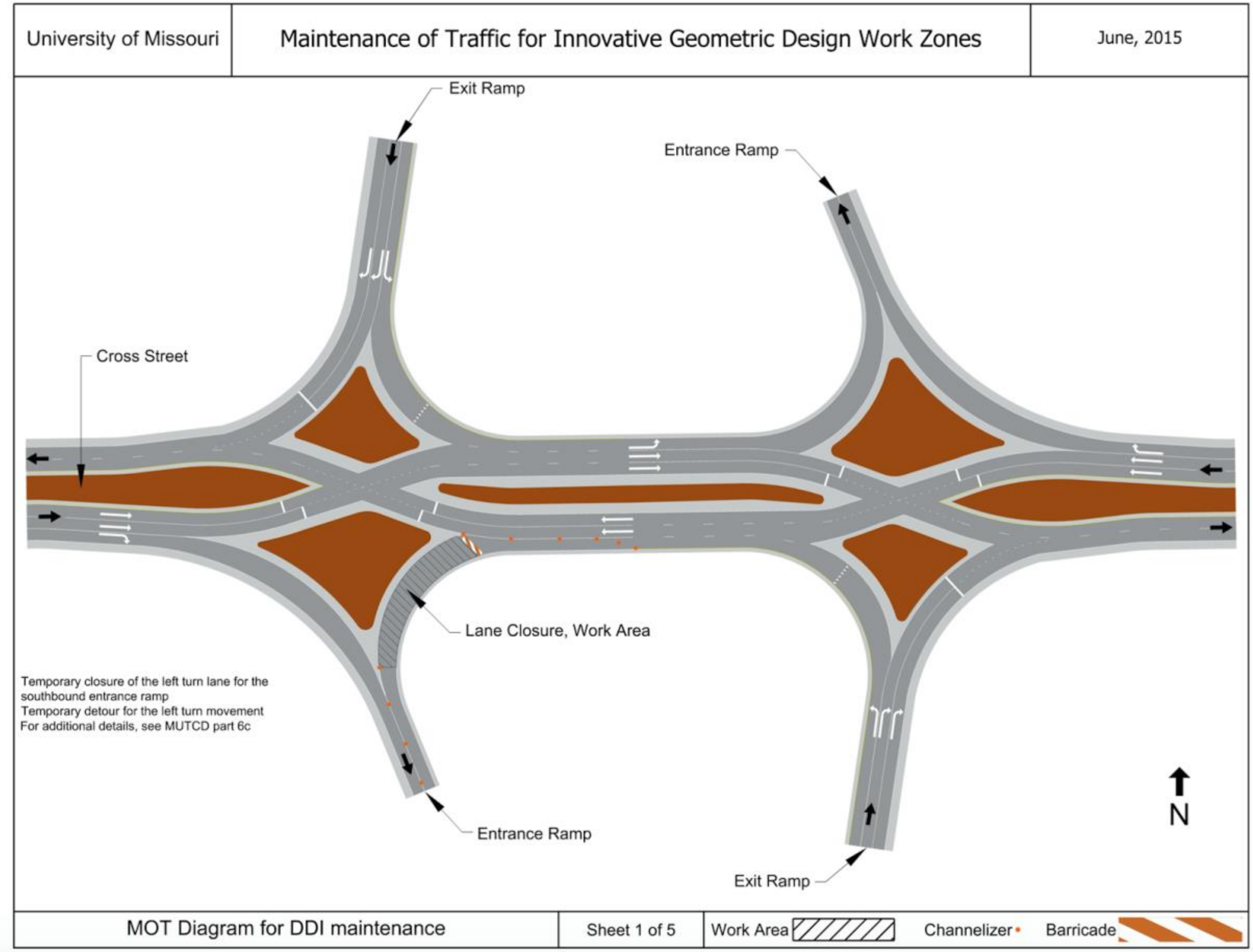

Figure D.2.3.1 MOT diagram for DDI maintenance within the left turn lane for the southbound entrance ramp

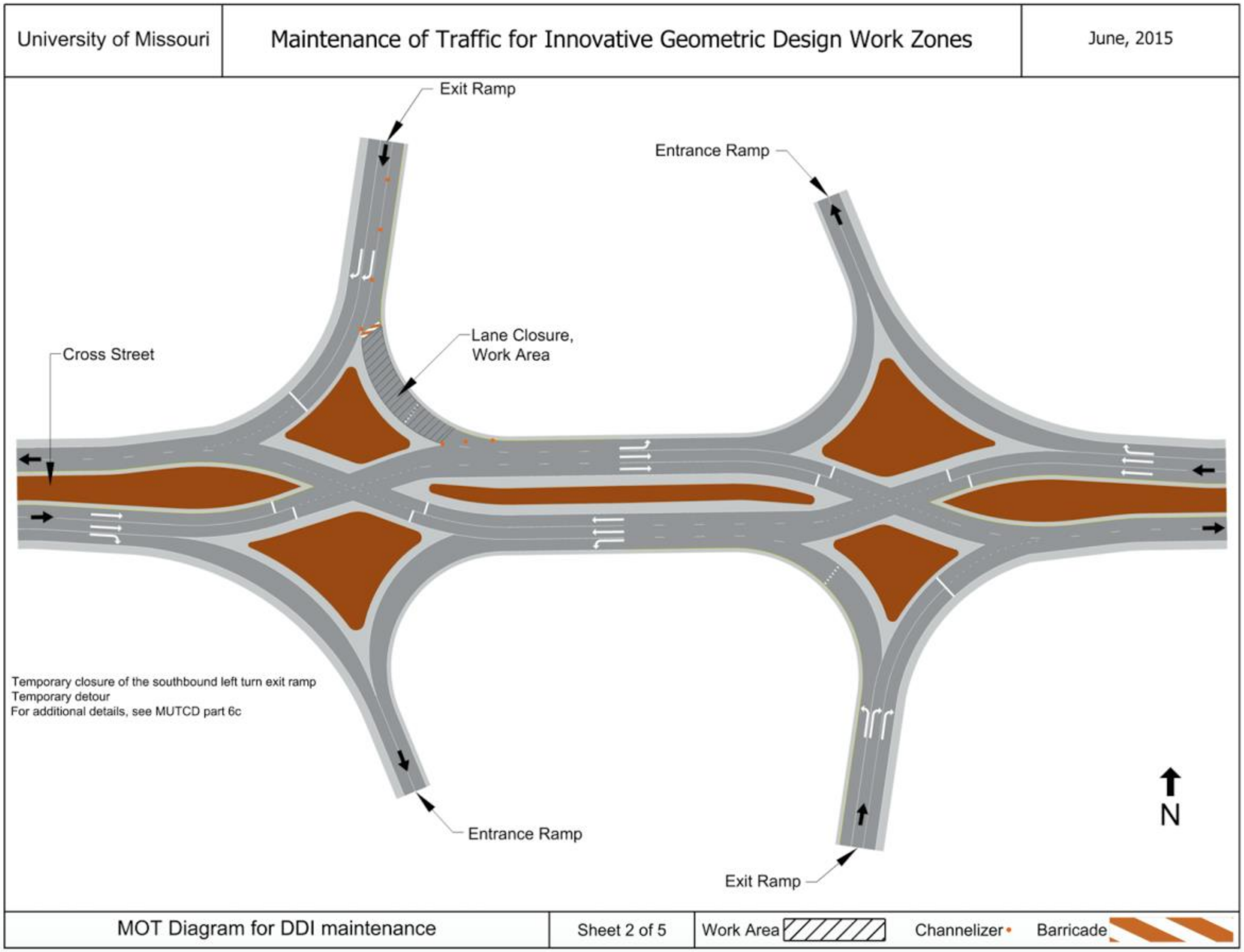

Figure D.2.3.2 MOT diagram for DDI maintenance within the southbound left turn exit ramp lane

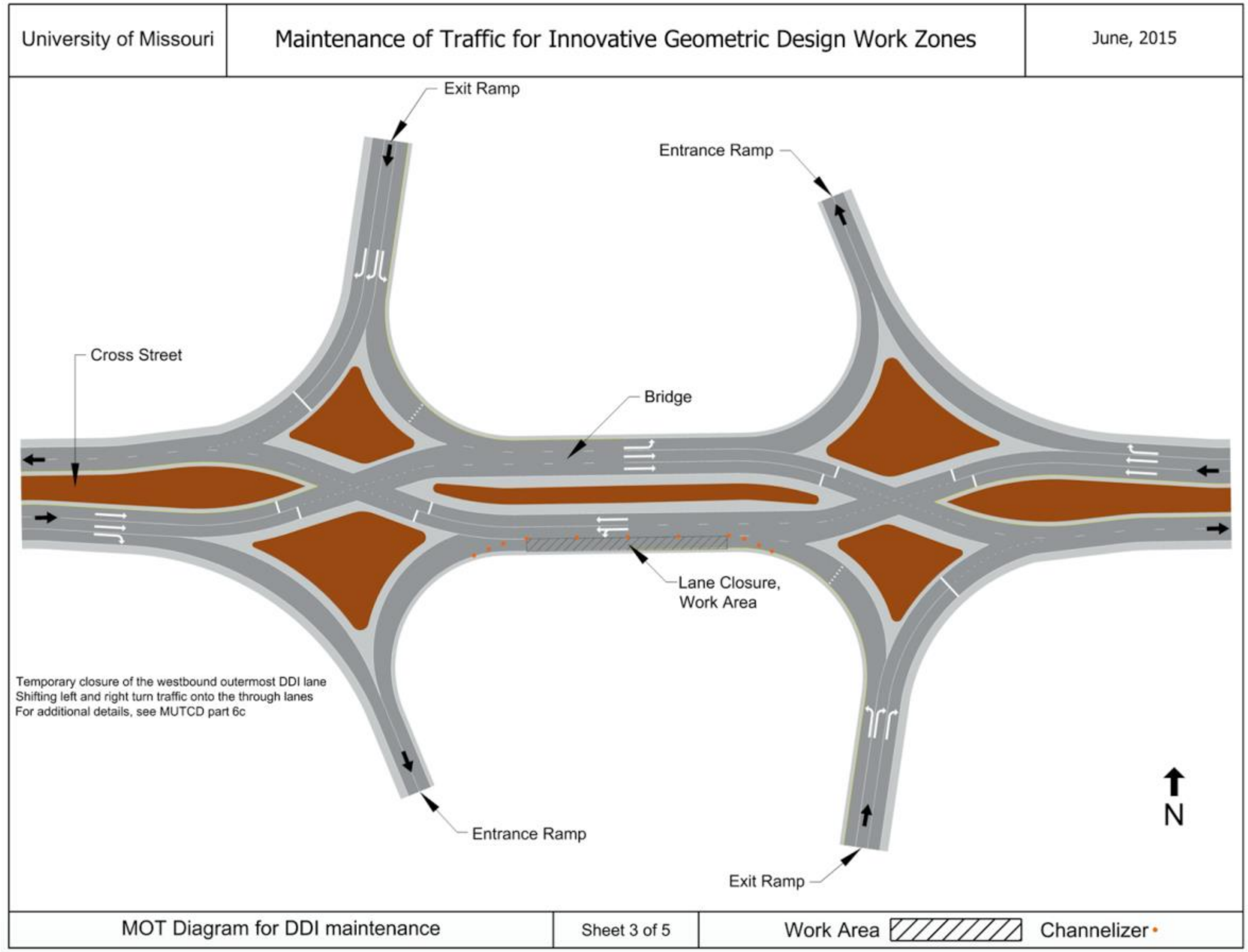

Figure D.2.3.3 MOT diagram for maintenance within the westbound outermost lane of DDI

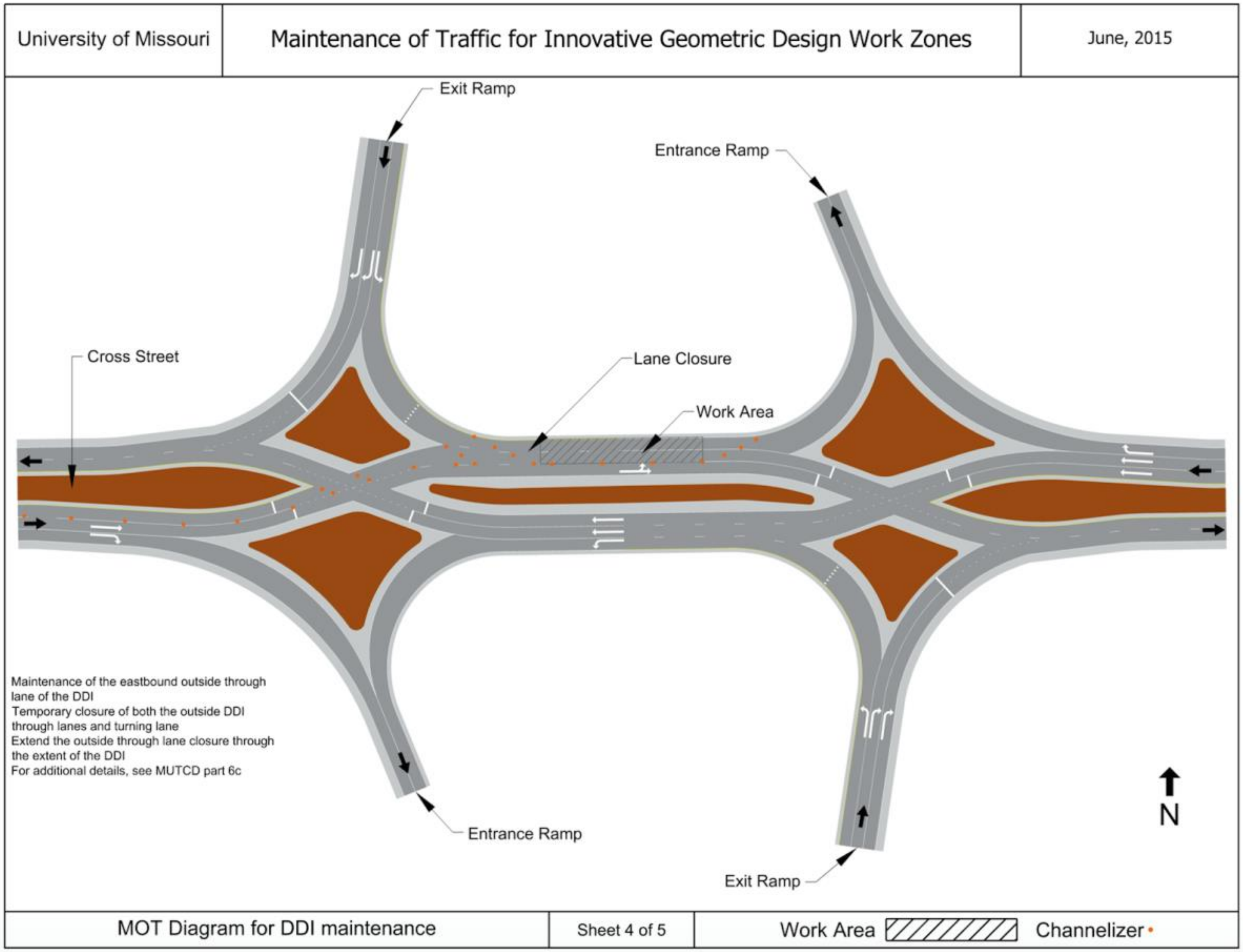

Figure D.2.3.4 MOT diagram for maintenance within the eastbound outside DDI through lane

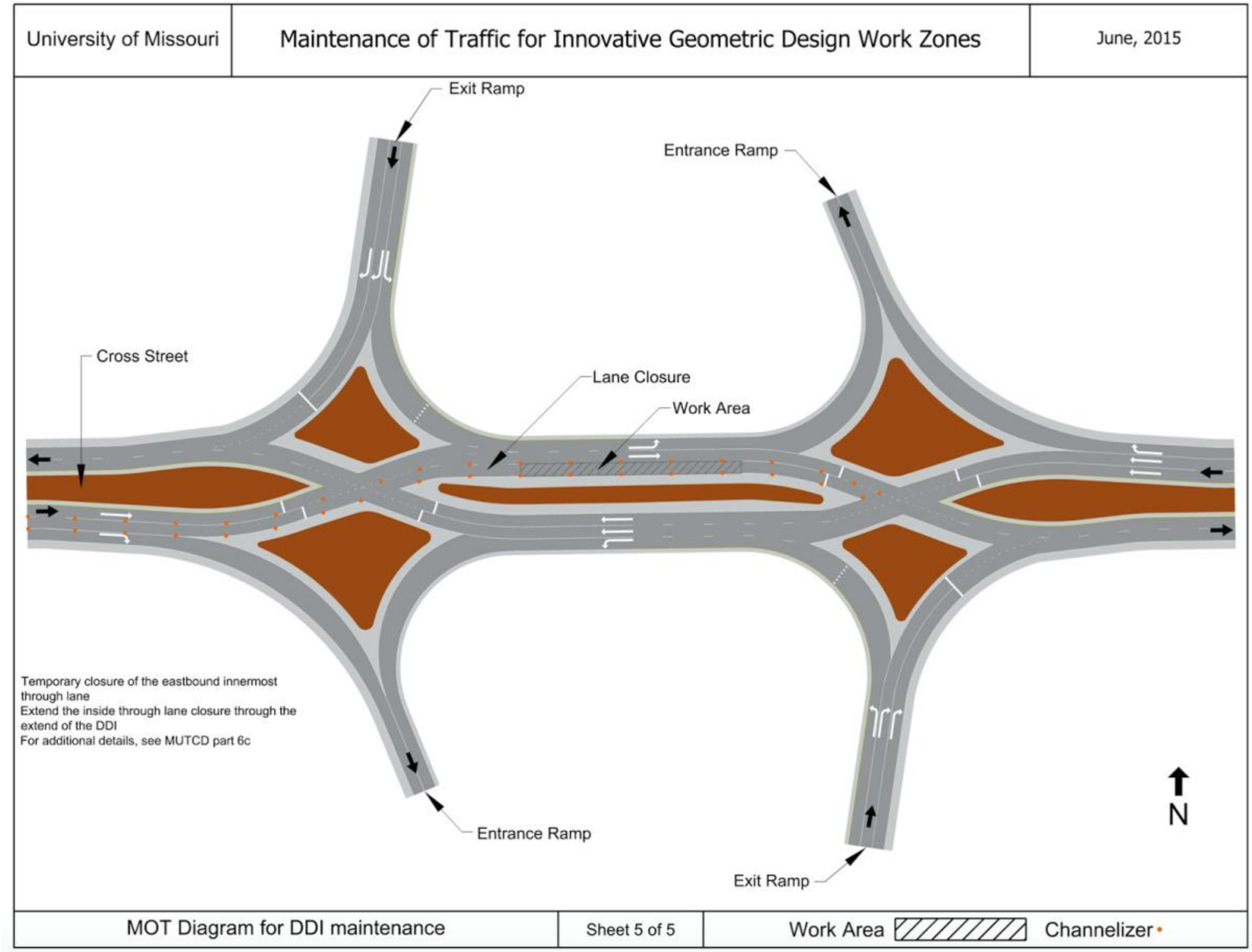

Figure D.2.3.5 MOT diagram for maintenance within the eastbound innermost DDI through lane

D.2.4 RCUT

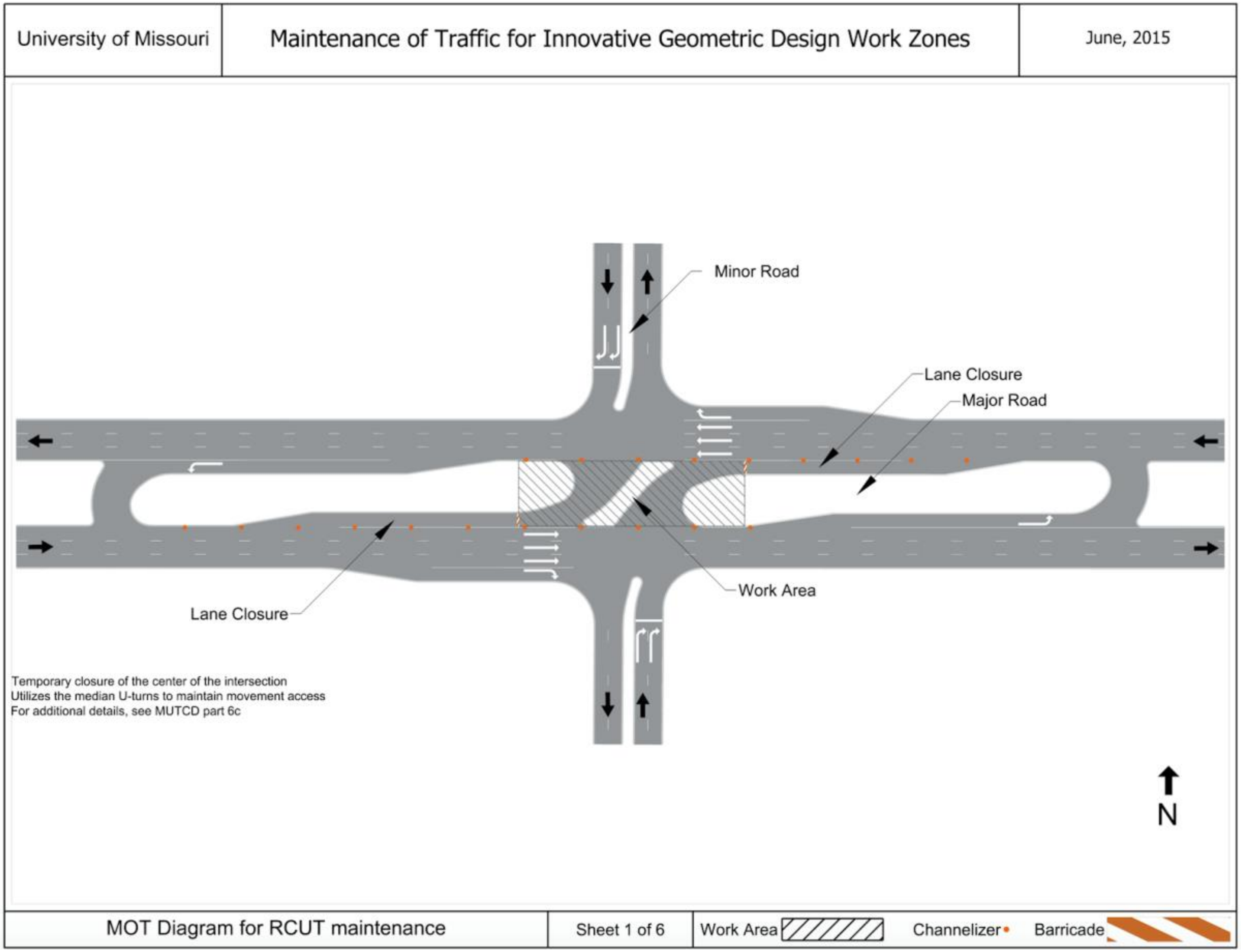

Figure D.2.4.1 MOT diagram for maintenance within the RCUT center

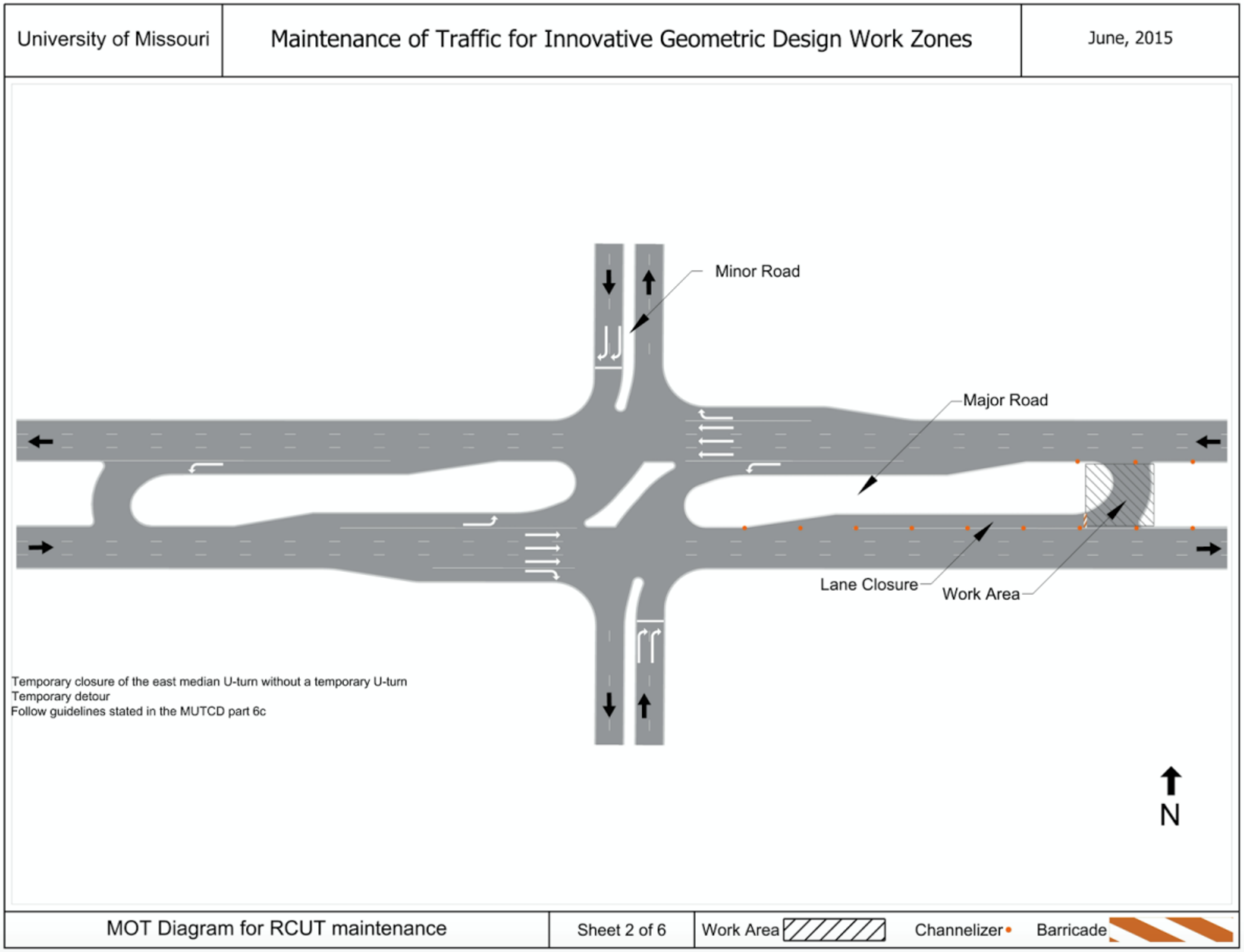

Figure D.2.4.2 MOT diagram for maintenance within the RCUT median U-turn and no temporary U-turn

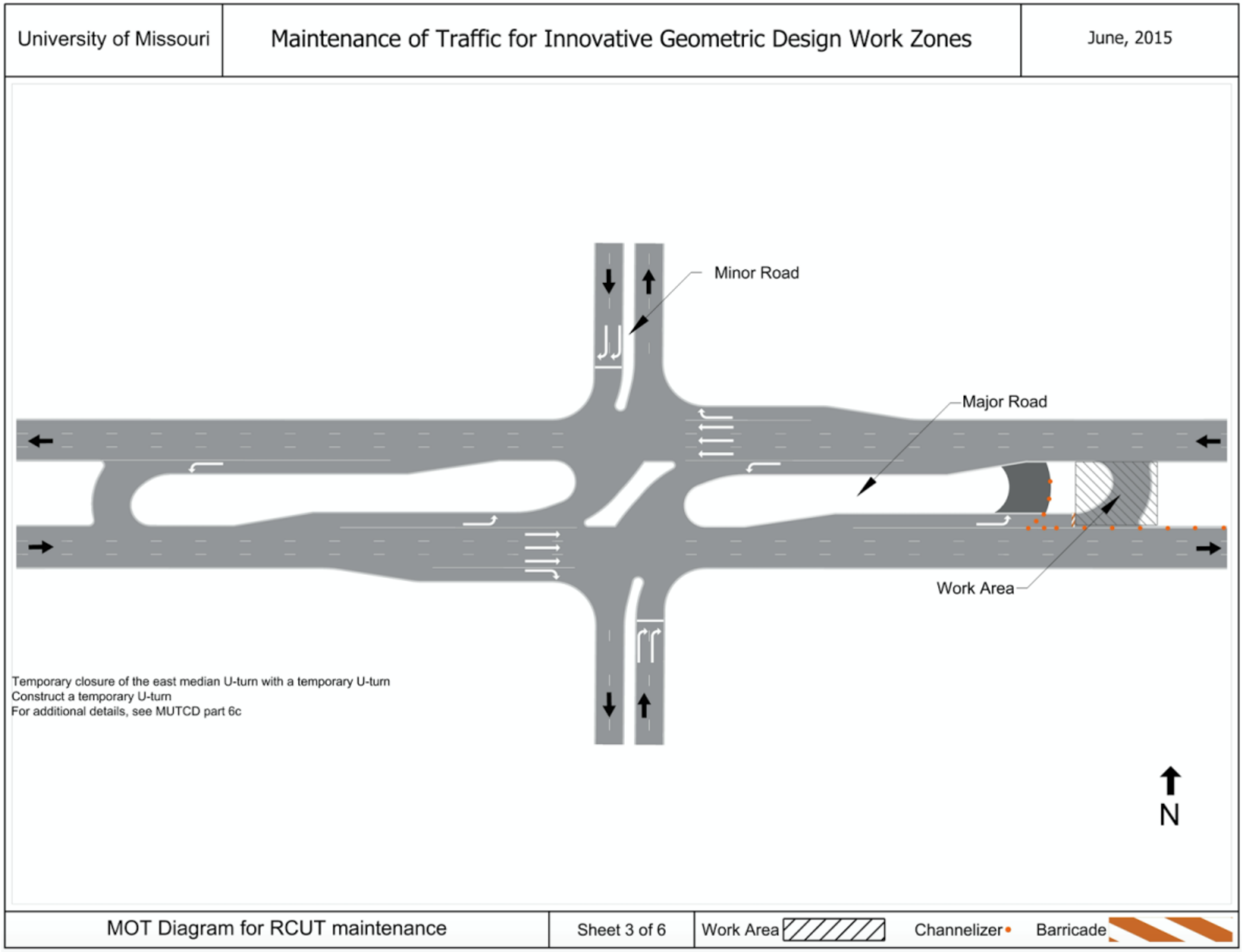

Figure D.2.4.3 MOT diagram for maintenance within RCUT east median U-turn while providing temporary U-turn

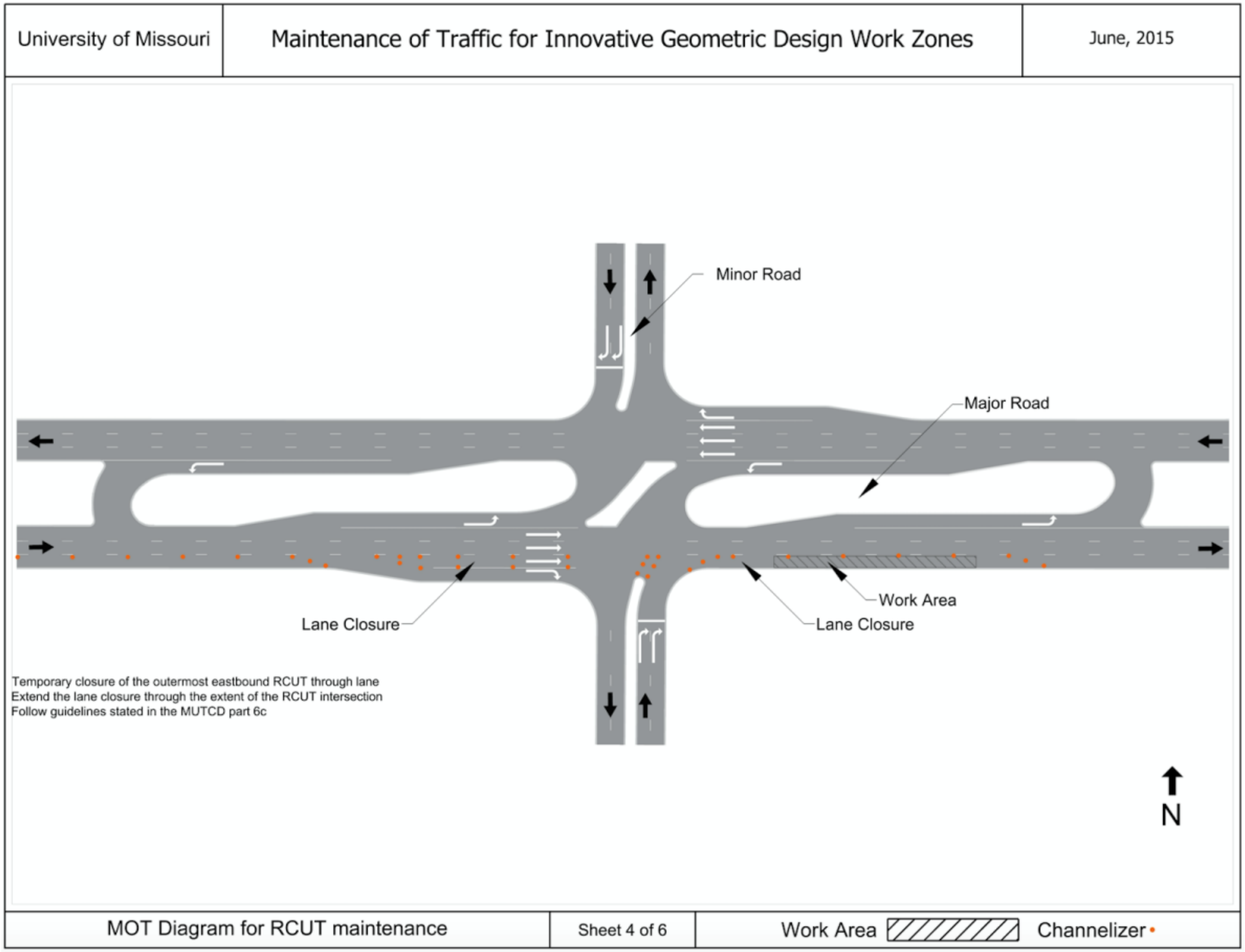

Figure D.2.4.4 MOT diagram for maintenance within the eastbound outermost RCUT through lane

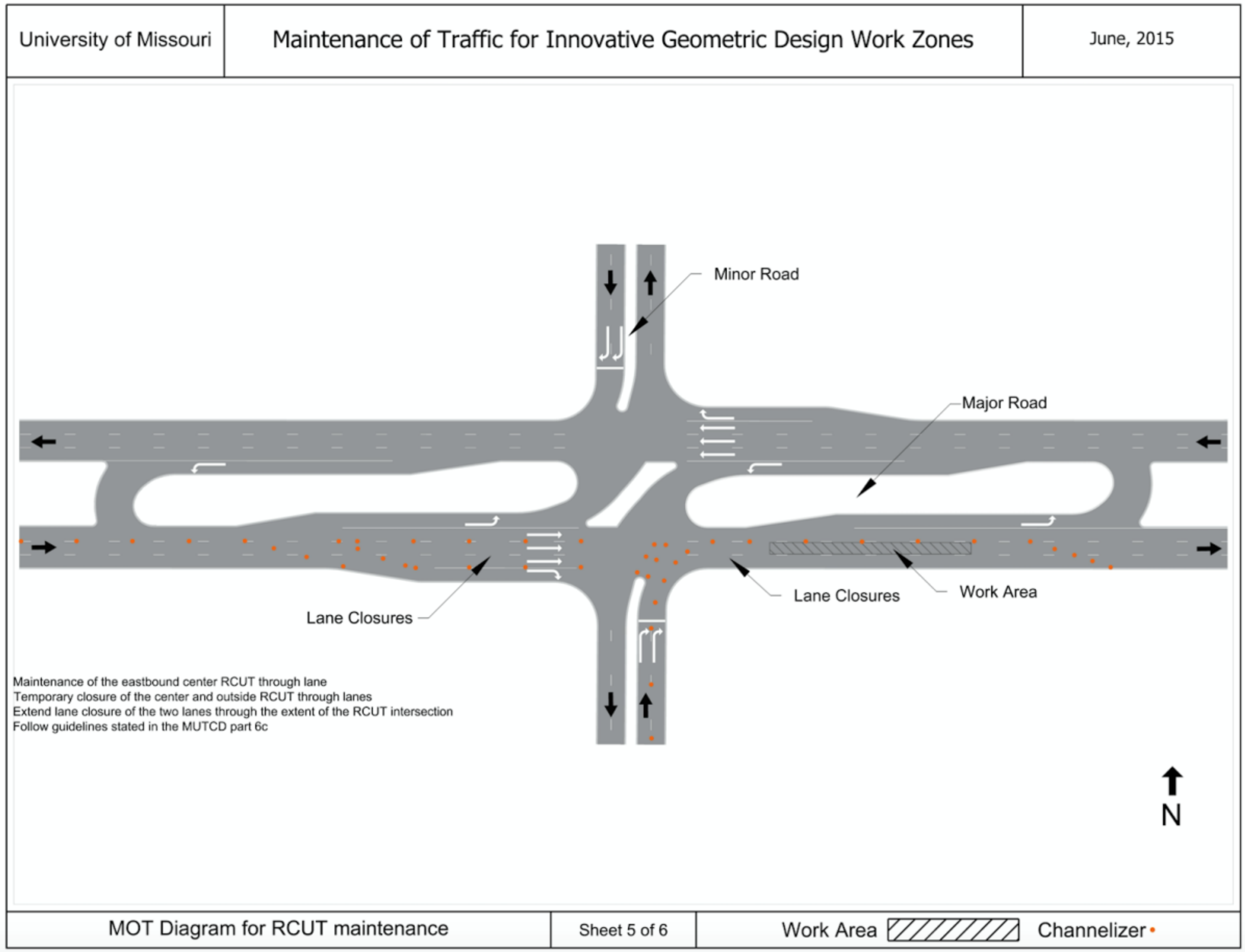

Figure D.2.4.5 MOT diagram for maintenance within the eastbound RCUT center through lane

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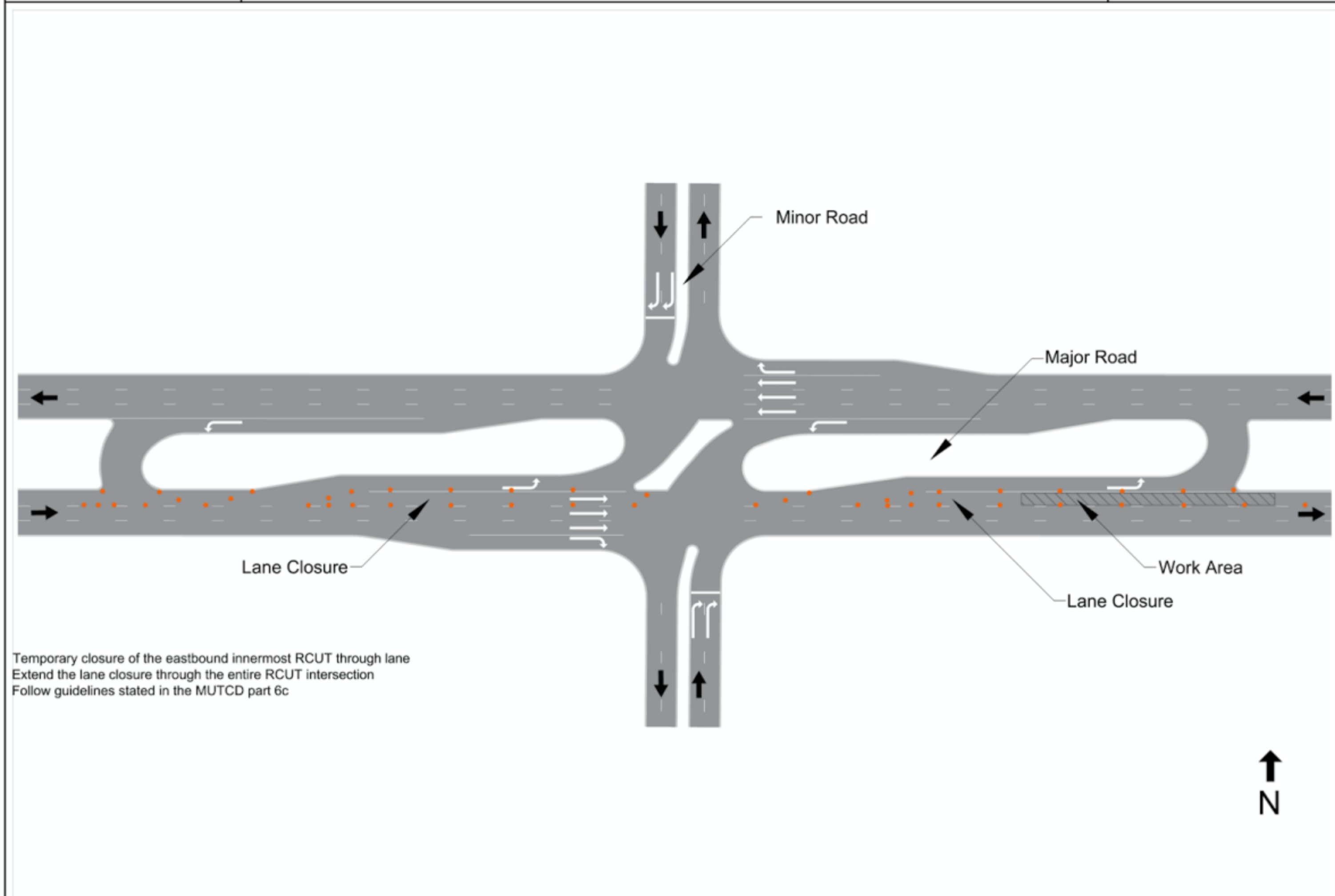

MOT Diagram for RCUT maintenance	Sheet 6 of 6	Work Area	Channelizer

Figure D.2.4.6 MOT diagram for maintenance within the RCUT eastbound innermost through lane

D.2.5 MUT

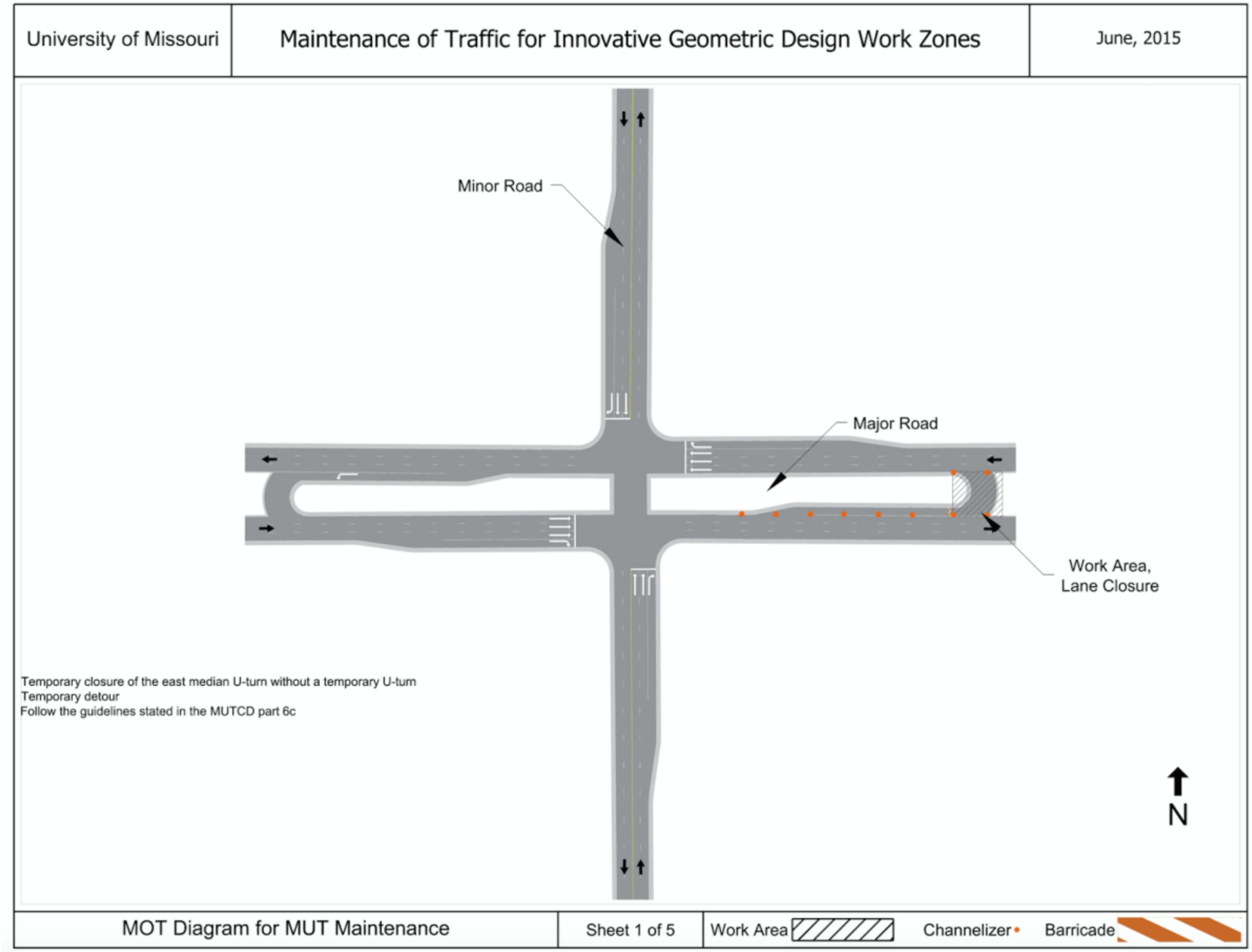

Figure D.2.5.1 MOT diagram for maintenance within the MUT east median U-turn

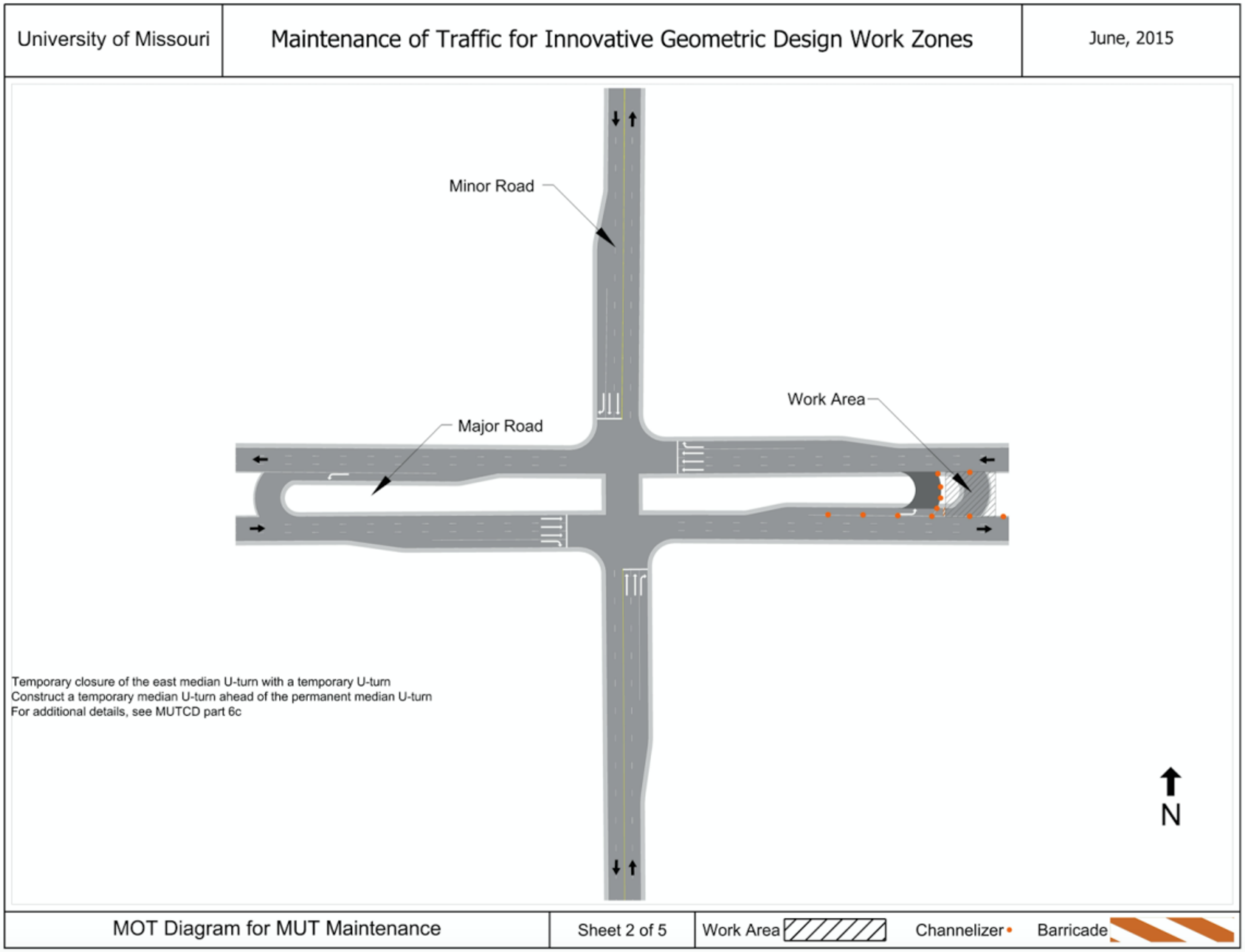

Figure D.2.5.2 MOT diagram for maintenance within the MUT median east U-turn while providing temporary median U-turn for access

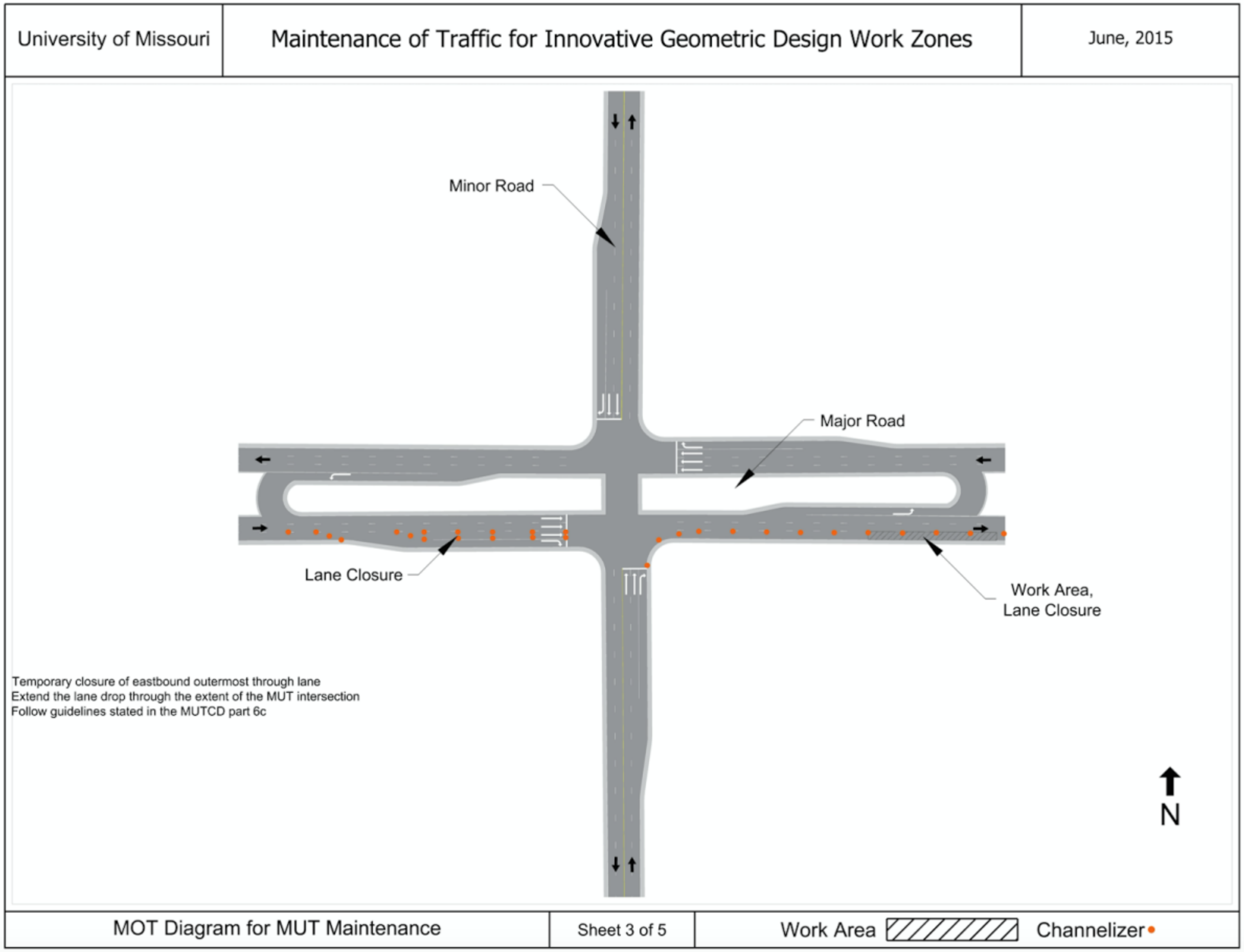

Figure D.2.5.3 MOT diagram for maintenance within the eastbound outermost MUT through lane

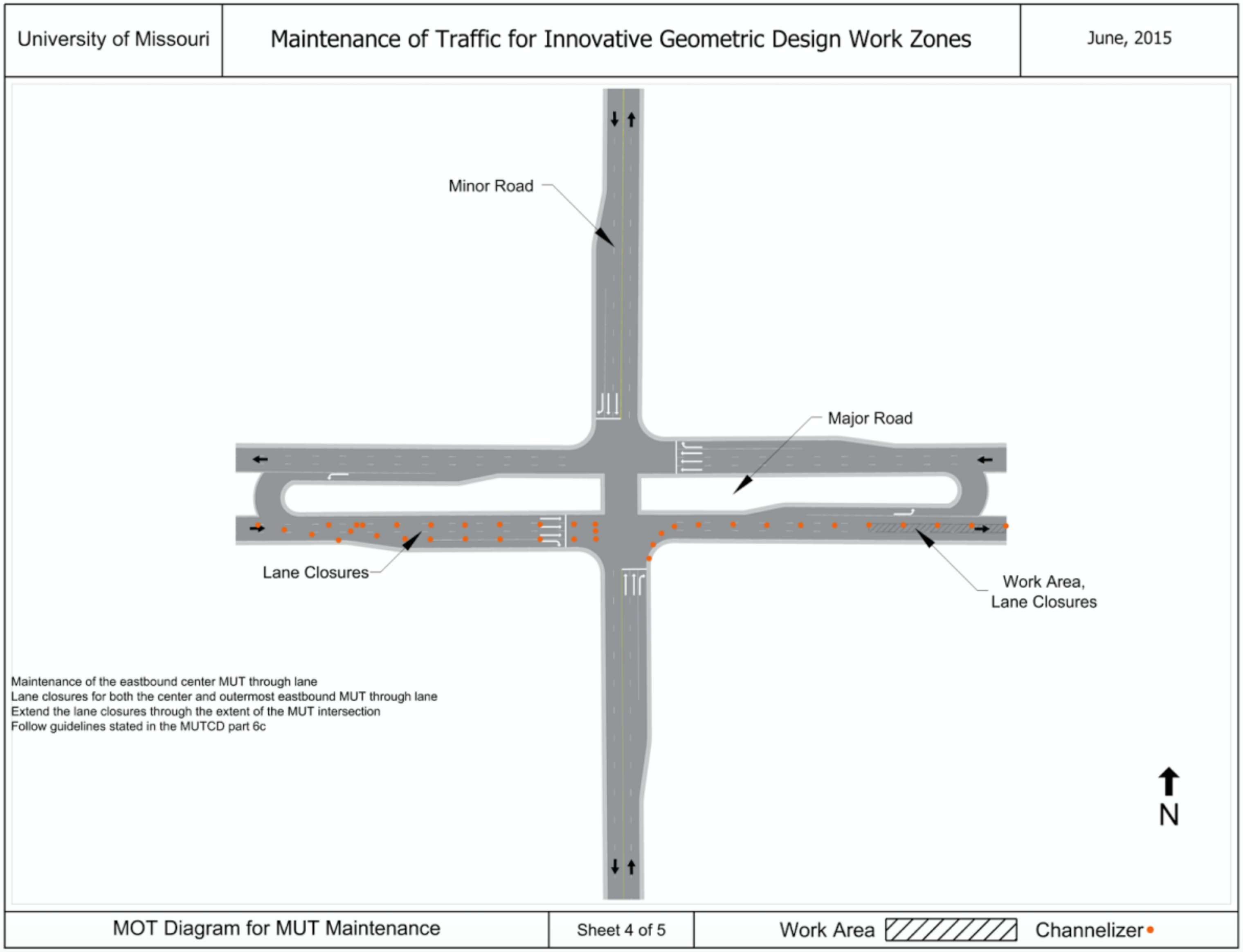

Figure D.2.5.4 MOT diagram for maintenance within the eastbound MUT center through lane

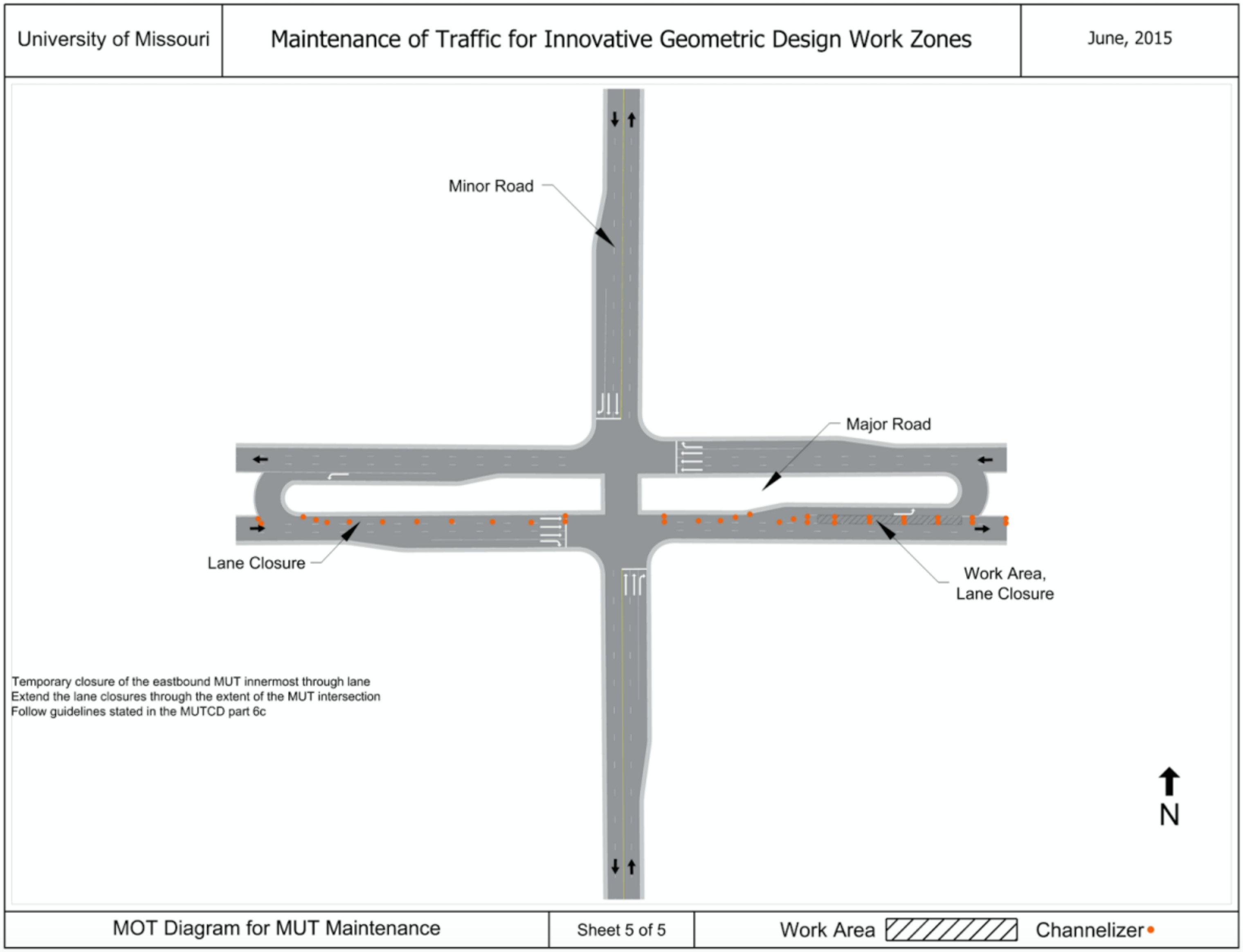

Figure D.2.5.5 MOT diagram for maintenance within the innermost MUT eastbound through lane

D.2.6 DLT

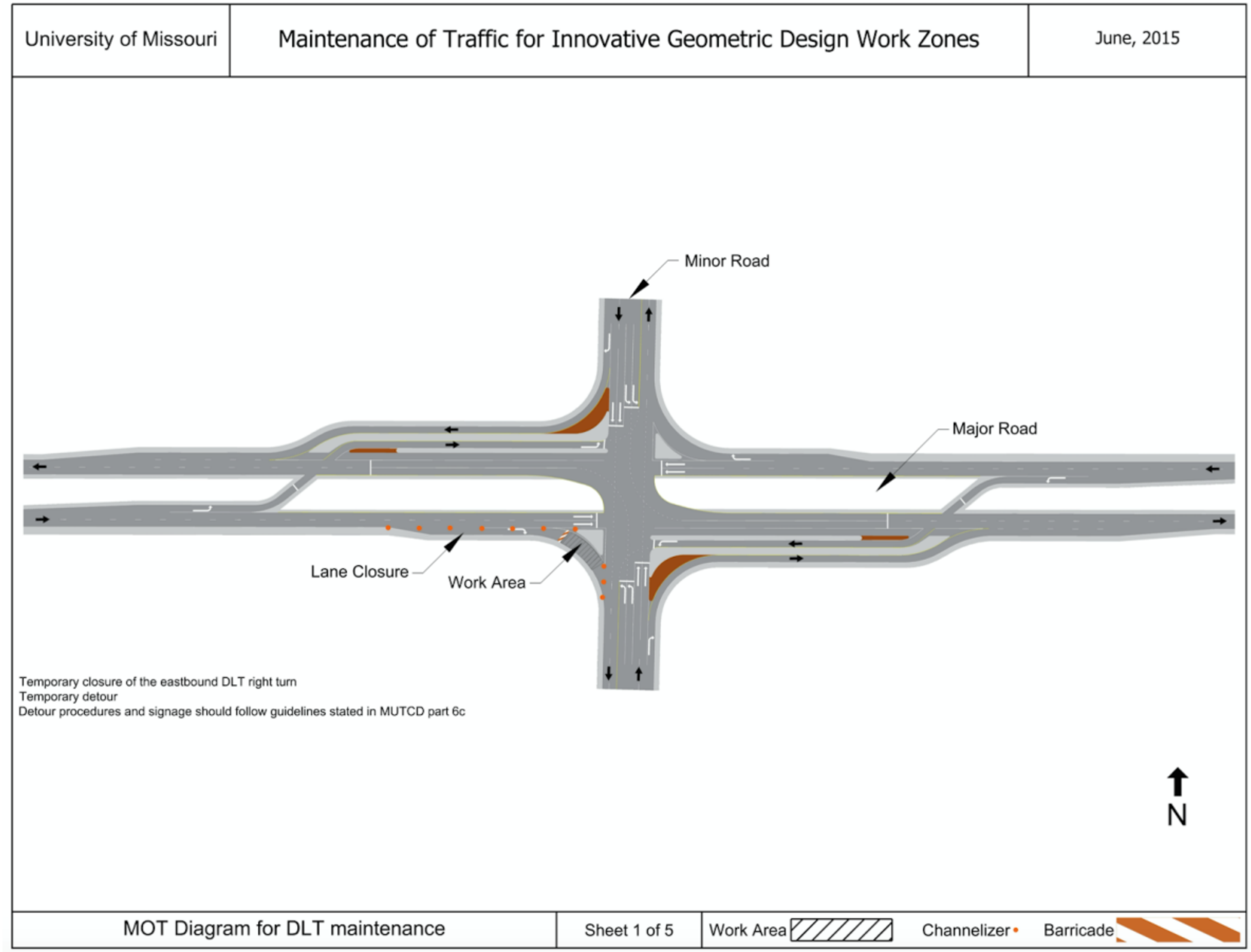

Figure D.2.6.1 MOT diagram for maintenance within the eastbound DLT right turn lane

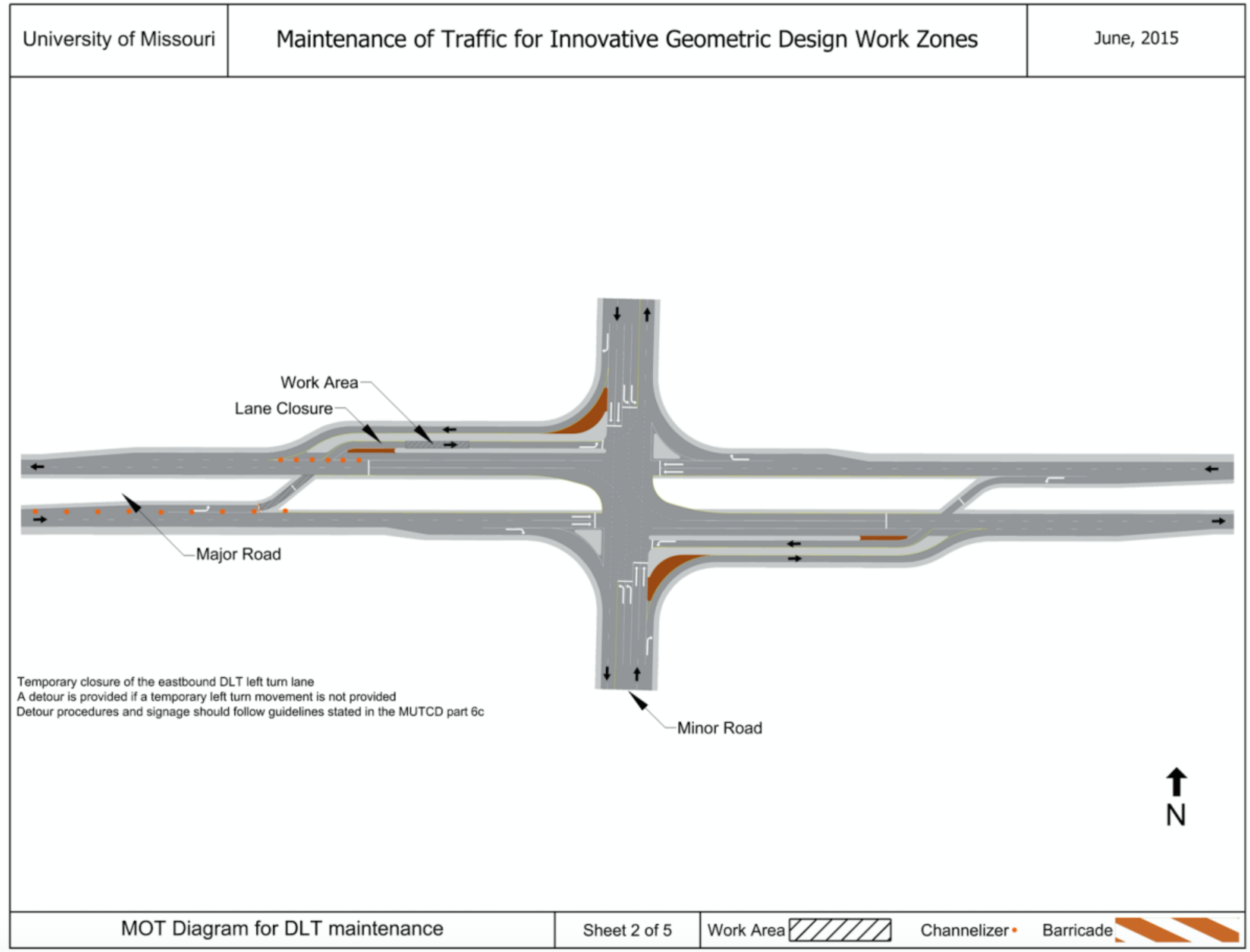

Figure D.2.6.2 MOT diagram for maintenance within the eastbound DLT left turn lane

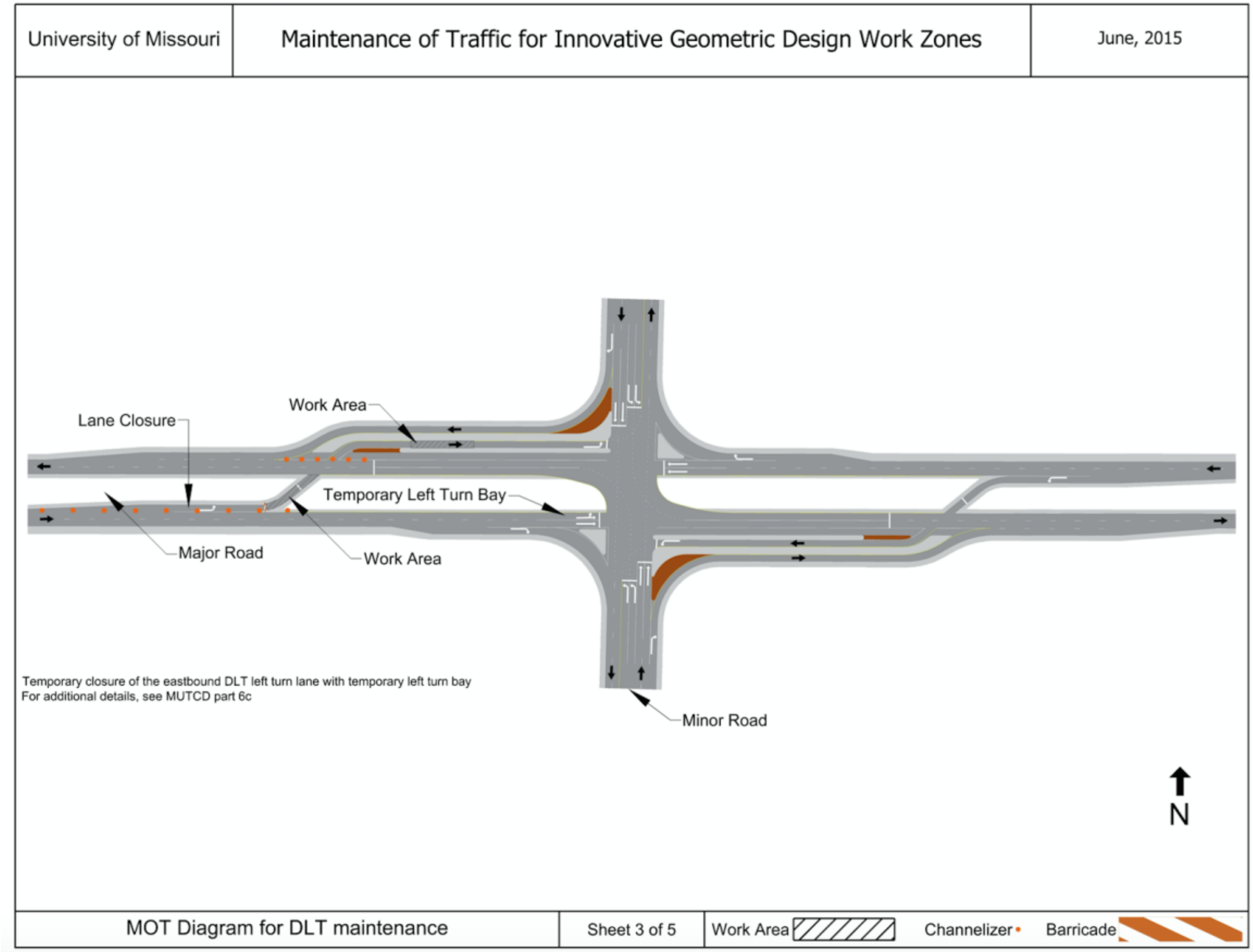

Figure D.2.6.3 MOT diagram for maintenance of DLT left turn while providing temporary left turn bay at the cross street

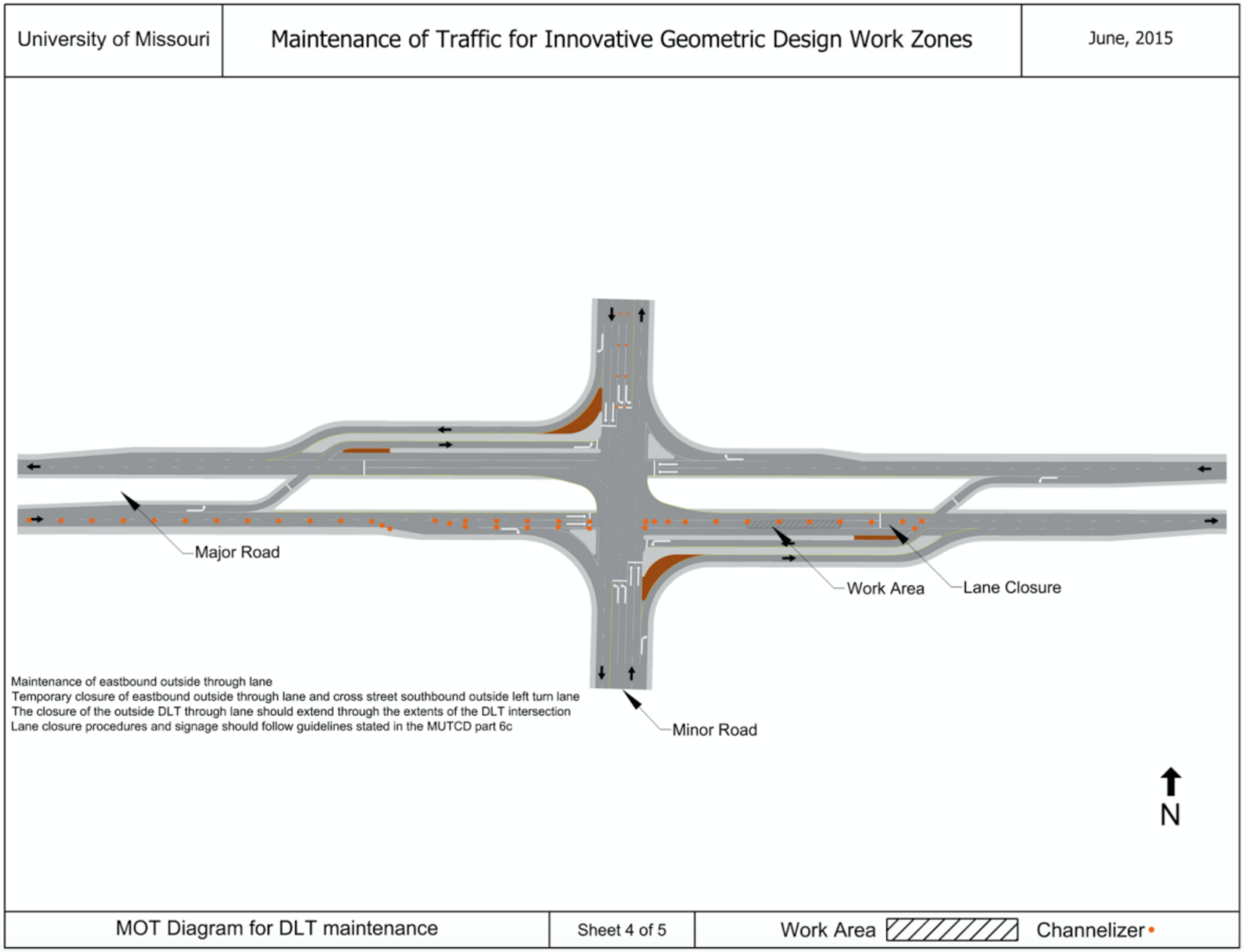

Figure D.2.6.4 MOT diagram for maintenance within the DLT eastbound outside through lane

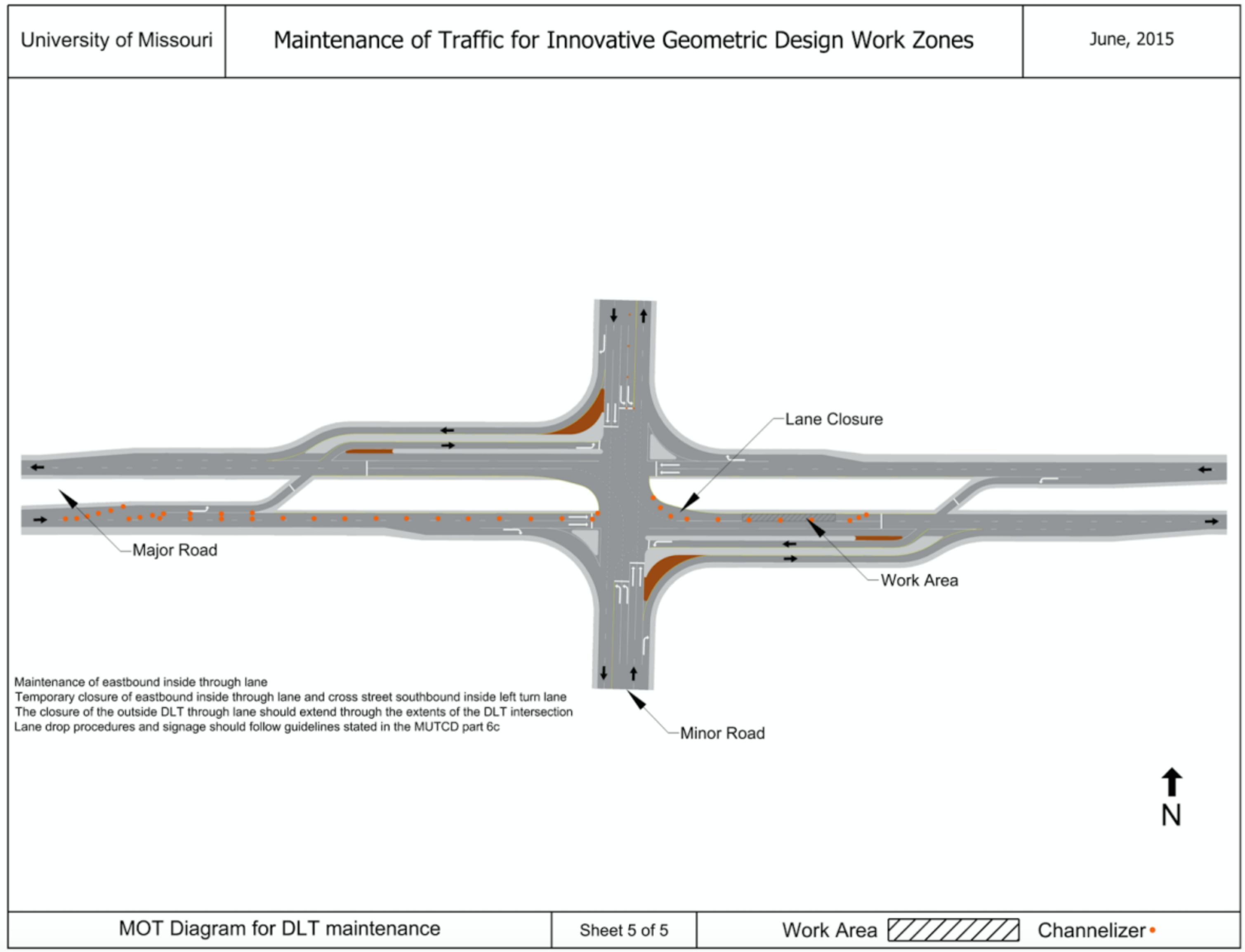

Figure D.2.6.5 MOT diagram for maintenance within eastbound DLT inside through lane