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Project Title

Proposing the Super DDI Design to Improve the Performance of Failing Service Interchanges in Mountain-Plains Region

University

University of Wyoming

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Research Needs

Investigating new alternative designs to improve the performance of old and failing service interchanges became a vital task since 1990s with growing traffic demand and tight budgets for funding new highways. Roundabout interchanges and the single-point interchange (SPI) were two of alternatives which became popular to respond the need of using new designs at this age. After some experiences of using roundabout interchanges, these interchanges could not be considered as a choice in high traffic cases anymore due to their low capacity. On the other hand, hundreds of SPIs were built in the U.S. during the 1990s and early 2000s. The SPI could perform good regarding capacity due to its single three-phase signal; however, its wide bridge made it a super expensive choice in many cases. The safety performance of SPIs was not observed satisfying enough because the design was complex for the users who were not familiar. Bared et al. (2005) made a comparison between the observed crashes of SPI and a tight diamond interchange and concluded no significant difference between these in terms of crash frequency.

As one of the best efforts done regarding finding new alternatives, the diverging diamond interchange (DDI) could convince the transportation profession and has become the most popular alternative interchange design in the US. Since the first established DDI in 2009, over 80 DDIs have been built till the end of 2017 and many more DDIs are in the planning stages (DDI Website 2017). Note that 12 of these DDIs are in operational level in Mountain-Plains Region (MPR) now. Utah with eight DDIs can be considered as one of the pioneers in utilizing DDI. The good performance of the DDI to transfer left turn traffic, the low number of conflict points, and the inexpensive construction cost are the primary advantages of the DDI based on the previous studies (Chlewicki 2003; Bared et al. 2005, and Edara et al. 2005; Yeom et al. 2015). However, the relatively bad performance of DDIs with high through traffic demand (which happens in many of the service interchanges), and the relatively difficult pedestrian crossing experience has made transportation agencies reluctant to use the DDI in some cases. For example, the DDI was not considered as an appropriate candidate for upgrading a conventional diamond interchange in a case study done in Alabama because no specific benefit was found for the reconstruction (Khan and Anderson 2016). Also, regarding the pedestrian performance, two different paths have been considered at a typical DDI: (1) a center crossing, and (2) an outside crossing. Both the paths include four free-flowing and four controlled crossings which present an unsafe condition (due to the free-flowing crossings) with the possibility of a long delay (due to the eight crossings) for pedestrians.

Based on the literature review provided in the previous paragraphs, alternative interchanges are obtaining the attention of transportation agencies and designers more than ever. The background of DDI is a clear example of searching for new designs to solve problems related to existing (conventional) interchanges. The number of existing interchanges in the U.S which are becoming out of service has been increasing daily due to the traffic growth. Note that the number of vehicles increased by about an average of 3.6 million each year since 1960 in the U.S (FHWA 2017). This fact is estimated to take many lives and cause billions dollar damages annually. Therefore, the need to replace our conventional interchanges with new ones might be one of the most important and compelling topics in highway design these days.

Based on the research done by Molan et al. (2018), the super DDI is predicted to show a high potential in improving the performance of the failing interchanges regarding all the measure of effectiveness (MOEs) involved in an interchange analysis (traffic operation, safety, and the pedestrians). Since super DDI is a new design, the following paragraphs has elaborated the design briefly to make a clear view for the readers. The first idea for the super DDI was made up during recent studies on alternative interchanges (Molan 2017; Molan and Hummer 2017; Molan and Hummer 2018a; Molan and Hummer 2018b). The previous works resulted that the synchronized interchange--which was inspired from by the superstreet intersection design--performs very good when there is a dominant through traffic condition. The pedestrian performance was also evaluated as a high-quality situation in the synchronized design. The super DDI combined these characteristics of the synchronized (superstreet) interchange to the DDI to boost its performance. Fig. 1 indicates the super DDI design. The direction of left turn traffic from EB (the arterial), and from NB (the freeway) have been illustrated by red and blue lines in Fig. 1, respectively.

Note that the left turns from the arterial cross each other. All the through and right-turning traffic follow a conventional route, as opposed to a DDI in which the two arterial through movements cross and re-cross each other. Fig. 2 also shows the traffic signal phasing of the super DDI. This phasing system has an important role in making the design advantageous in comparison to conventional DDIs. In fact, with many demand patterns the progression system of the DDI is not strong enough to make the network invulnerable against the threat of spillback and long delays; however, the super DDI prepares a perfect progression system using half signals that affect only one direction of the arterial instead of full signals that affect both directions of the arterial. For comparison, note that a conventional parclo B interchange with loops serving the left turns from the freeway to the arterial only uses half signals and is consequently a very efficient design while the traffic signals in most conventional designs such as diamond interchanges are full signals that provide poor two-way progression.

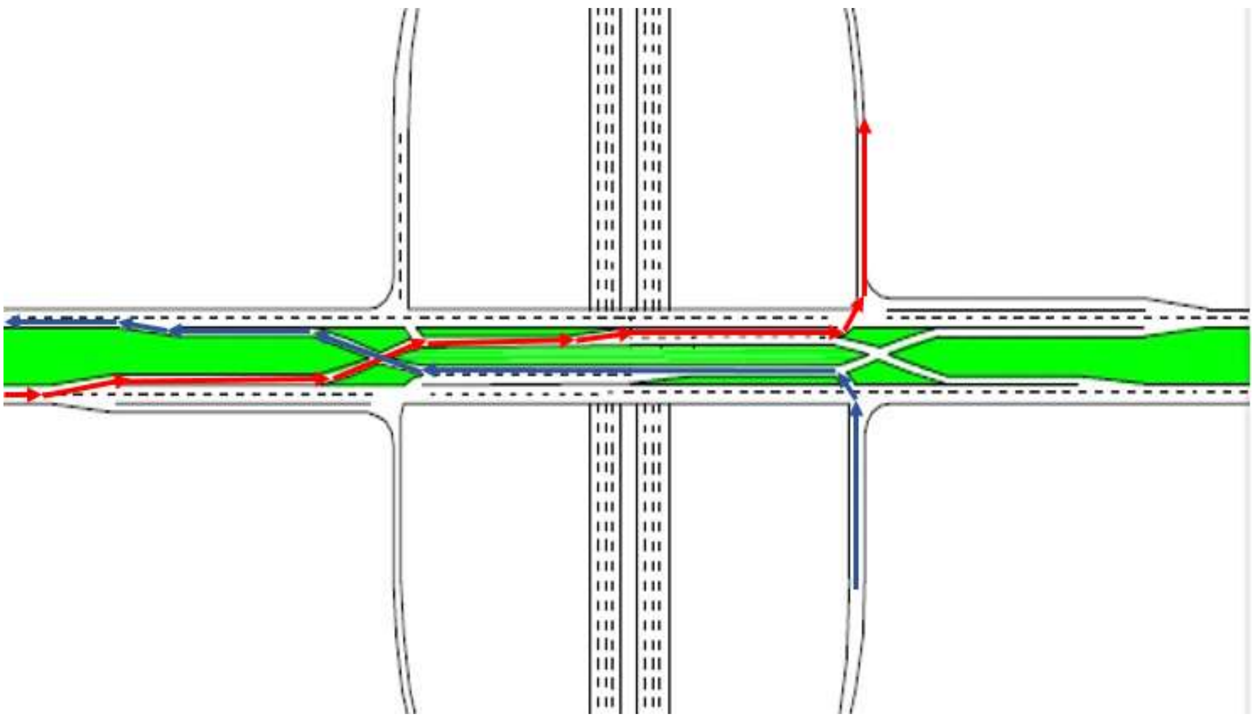


Fig 1. Super DDI geometry (the red and blue lines show the direction of left-turn traffic from EB and from NB ramp-not to scale)

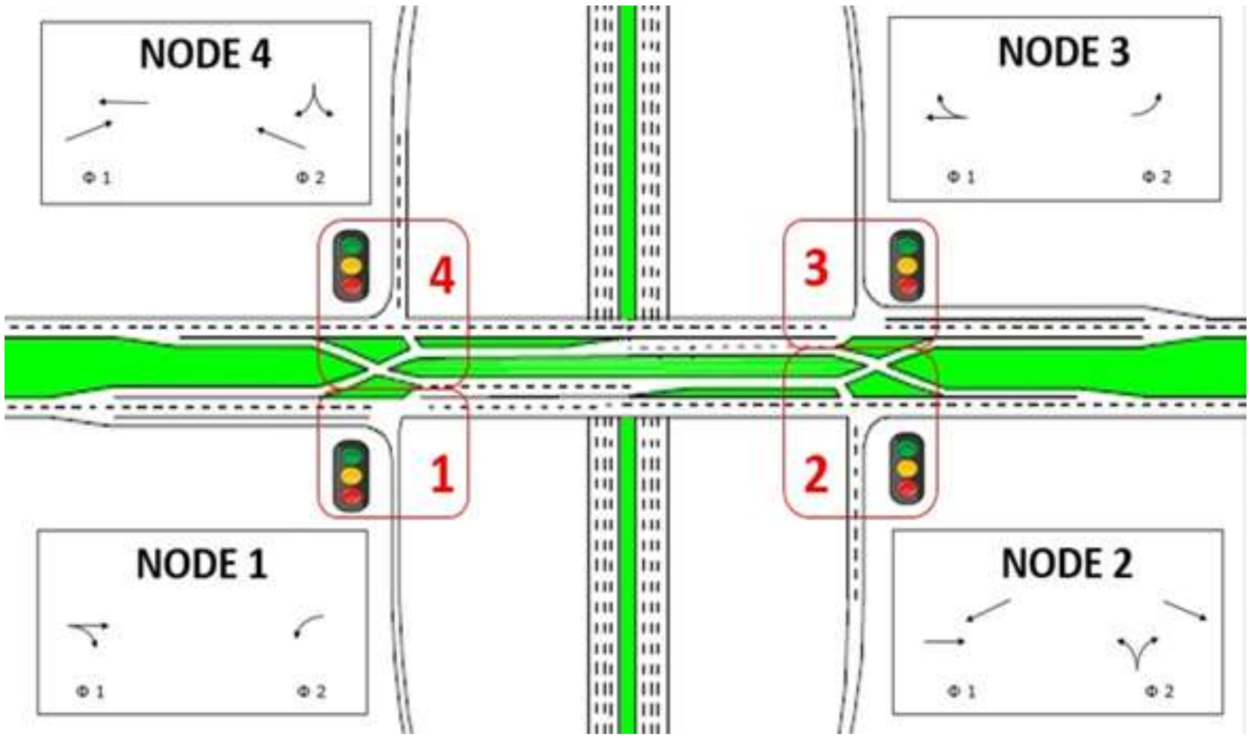


Fig 2. Super DDI phasing diagram

Research Objectives

1. The most failing and hazardous interchanges will be investigated in MPR. The study concludes a ranking (based on the current traffic operation and safety statistics) for future interchange improvements
2. The study evaluates and compares the performance of super DDI design as possible substitute in comparison to conventional service interchanges in MPR
3. The performance of the super DDI will be compared with the existing DDIs and SPIs to analyze the advantages of the super DDI in comparison to the other alternatives
4. Proposed geometric and signal diagrams will be prepared for each site studied to provide the detail regarding geometric features and the traffic signal data of the super DDI design

In summary, the study seeks to provide a comprehensive information of benefits of using the new Super DDI in MPR.

Research Methods

The method of this research will include the following steps:

At first, a literature review will be collected focusing mostly on the previous efforts regarding the interchange improvements in MPR.

Then, the most hazardous interchanges will be investigated in MPR using the traditional “Rate Quality Control (RQC),” and the “Crash Severity (CS)” techniques. Equations 1, and 2 illustrate the formulas required for the RQC, and CS methods, respectively.

$$Rc = Ra + K (Ra / M) 0.5 + (1 / 2M) \quad \text{Equation. 1}$$

Rc = Critical rate for a segment
Ra = Average accident rate for all segments
M = Average exposure (100 million vehicles miles of travel on a segment)
K = A probability factor determined for the desired level of significance (usually = 1.645)

$$EPDO = 541.74 (F) + 29.18 (A) + 2.5 (B) + 6.06 (C) + PDO \quad \text{Equation. 2}$$

EPDO = Number of equivalent PDO (property damage only) collisions
F, A, B, C = Fatal, Type A, B, and C crash injuries

RQC method introduces a critical rate (Rc) based on Equation. 1 to investigate the sites with a higher crash rate than Rc as hazardous sites. The CS method also converts all the different levels of crash injuries to an equivalent PDO rate for comparing the crash-severity of sites. Note that Equation 2 is consistent with the cost estimations presented in Table 1.

Table 1. Comprehensive Costs of crashes (FHWA 2009)

Injury Severity of Crash	Average Economic Cost
Death	$4,008,900
Incapacitating Injury (A)	$216,000
Non-incapacitating Injury (B)	$79,000
Possible Injury (C)	$44,900
No Injury (PDO)	$7,400

Afterward, the study will present a risk ranking for the sites based on RQC and CS analyses.

The next step focuses on the traffic operation of the existing service interchanges. For this reason, the ratio of traffic volume over capacity (V/C) will be calculated using Critical Lane Volume (CLV) method to gain an evaluation of the traffic operation at the interchanges. CLV method is an old, quick, software-independent measure of intersection or interchange performances. CLV considers the conflicting movements at nodes, including arterial through movements, crossover movements, merging movements from off-ramp to arterial, and merging movements at the beginning of the on-ramp (Maji et al. 2013). Therefore, the service interchanges will be ranked based on the V/C values to recognize the locations with a poor traffic operation. Combining this step with the results extracted from the previous step (finding hazardous locations), the final prioritized ranking of interchanges ‘condition will be presented (the first objective of the study).

Now, the interchanges (at least one from each state in MPR) with a high-priority of improvements will be selected for the comparison with the proposed super DDI design. The study will also communicate the DOTs in MPR to get information regarding their future interchange improvement projects. In that way, these interchanges will be also modeled and compared to the super DDI. It should be mentioned that the super DDI will be a very cheap alternative when there is a minimum bridge width of 120 ft or when there are two bridges (with a minimum width of 50 width for each) at the location. Almost all the existing SPIs and a portion of the DDIs have this feature. Then, the super DDI can be applied to them by considering only low-cost countermeasures such as pavement marking changes. Therefore, the study team try to recognize and analyze at least five of the interchanges which have the opportunity of getting upgraded by super DDI design in a low-cost budget. This task will release very important results since the super DDI will probably be the most beneficial choice for these cases due to earning much benefits by paying very low. As a future work, it is suggested that one of these interchanges will be selected for establishing the first super DDI due to the low costs of construction. Then, by receiving good feedback after the first experience, the super DDI can be known promising enough for the agencies to consider it in their big projects with no risk of a fail.

After listing the interchanges involved in the analysis, the required data including the traffic flow (volumes, speeds, and types of vehicles), traffic signal data (timings, phases, and progression system), pedestrian (volume, and speed), geometric features (grades, and radii) will be collected. The study team hopes to gain all the information based on the available databases; however, the data will be collected conducting field studies when needed.

In the analysis part of the study, the interchanges will be evaluated considering traffic operation, safety, and the pedestrian performance as the primary MOEs of the study. PTV VISSIM, which is an able microscopic simulation software for modeling different traffic patterns with detailed geometric configurations and drivers' behavioral characteristics, plays the key role in the traffic operation analysis. The majority part of the pedestrian analysis will be also conducted by VISSIM. For the safety analysis, SSAM (Surrogate Safety Assessment Model) was selected to reveal a comprehensive view of vehicle conflicts in each interchange. SSAM, which was introduced in 2008 in a study supported by Federal Highway Administration (FHWA) (Gettman and Head 2008), uses the trajectory files of traffic simulation packages to recognize the type and number of near misses between vehicles during the simulation period.

For validating the simulation outcomes, vehicle travel times will be obtained installing video cameras on all different sides of an existing interchange to observe and record the travel times for a two-hour period. Then, the same interchange will be modeled to compare the simulation outcomes and the real travel time values. As a possible alternative, in the case of availability and access to probe data, the validation can be done using the vehicle travel times extracted from Bluetooth and GPS (Global Positioning System).

As the last step of this research, an assessment of improvement costs and benefits of using proposed super DDI design in comparison to the existing interchanges will be estimated.

Expected Outcomes

A recent work (Molan et al. 2018) evaluated the performance of the super DDI in comparison to four other designs including a conventional diamond, parclo B, DDI, and an existing interchange in Milwaukee, WI. According to Molan et al. (2018), the proposed super DDI could perform substantially better than all the other designs under the conditions tested. Overall, the super DDI showed an 18% lower travel time, a 49% higher rate of completed tests, 95% fewer simulated conflicts, and safer and faster conditions for pedestrians than a conventional DDI. The study team believes that the results show the strong potential of the super DDI in improving the existing interchanges in MPR and the current project can start a procedure to achieve significant benefits by improving the interchanges even in a short-term schedule.

Note that the pointed study (Molan et al. 2018) considered over 800 simulation tests in the study including 432 VISSIM tests for the traffic operation analysis, 216 VISSIM tests for the pedestrian performance, and 216 SSAM tests for the safety analysis. These tests were involved with different ratios of traffic volume, traffic turning volume (high-tuning, moderate-turning, and low-turning conditions), traffic distribution, and heavy vehicle volume.

Relevance to Strategic Goals

Interchanges are one of the important components of any transportation system and their poor performance can easily impact the whole network either in terms of safety or the traffic operation costs. The current project has considered both the safety and economic evaluation to make sure that the final conclusions meet the requirements for providing these targets. The detail provided regarding the methodology in the previous section elaborated the methods to reach each of these goals.

Educational Benefits

The students will be involved in the study from the very first phase. Since the study contains a considerable volume of data collection and data analysis, this fact cannot be possible except by providing an organized group of the students to do the project together as a teamwork activity. Fortunately, the department of Civil Engineering at University of Wyoming offers a course entitled "Traffic Simulation Modeling," then many of the students are also familiar with the usage of the important simulation packages of transportation engineering such as VISSIM. Therefore, as an example of being involved, the students will gain practical experiences conducting simulation models in a high-level project.

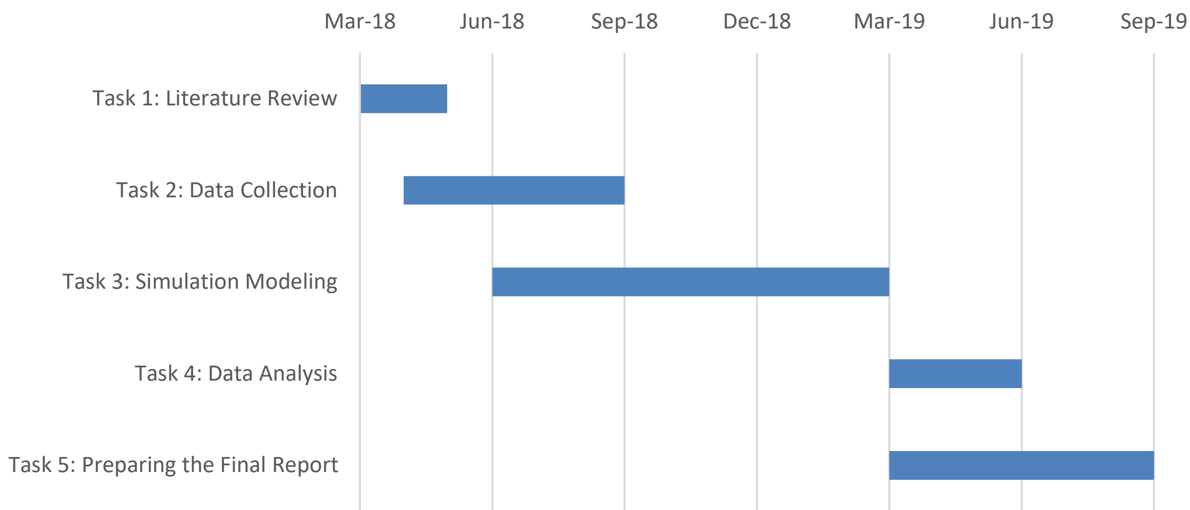
Technology Transfer

The study team will submit the findings for publications in various Journals and possibly at the Transportation Research Board (TRB).

Work Plan

1. Literature Review
2. Data Collection
3. Simulation Modeling
4. Data Analysis
5. Preparing the Final Report

An 18-month period is required to complete the tasks in this study. The following figure shows the recommended timeline based on a start on March 2018, and an end on September 2019.



Project Cost

Total Project Costs:	$118,156
MPC Funds Requested:	$ 59,795
Matching Funds:	$ 58,361
Source of Matching Funds:	University of Wyoming/Wyoming Technology Transfer Center

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