# Exploring the Effects of Directionality Interventions in Road Networks based on Topological Credentials: The Case of Sioux Falls

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## ABSTRACT

This study investigates the effects of systematic directionality interventions in road networks based on topological credentials. Recent advancements in network science have demonstrated how network connectivity or topology influences the functional behavior of network components such as nodes (i.e., intersections) and links (i.e., road segments) as well the agents (i.e., traffic) utilizing such networks. The transportation literature remains inconclusive regarding the effects of directionality interventions i.e., developing schemes or strategies by modifying the directionality (i.e., one way vs. both ways) of traffic operations in a link or a sequence of links for enhanced system performance. As such, this study conducted complex network analyses of the Sioux Falls network to assess the topological credentials i.e., the centrality of the available links in the network. Next, the study performed several simulation-based experiments to assess system performance for given directionality interventions. The same network is tested for normal operating conditions and disrupted conditions. Results show that network functionality reduces (72.09%) due to the disruption of the most central link. However, this can be recovered (up to 88.1%) by converting the three least central unidirectional links into bidirectional links, while the state of the central link remains disrupted. The proposed analytical framework of directionality interventions based on topological credentials such as centrality would help traffic managers to develop more efficient traffic operational schemes for an improved level of service at the system level.

## FIGURES

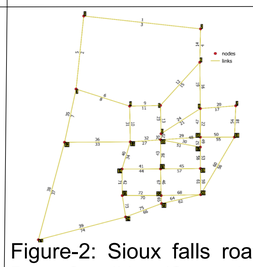



Figure-2: Sioux falls road network-Base Condition (Scenario-1)

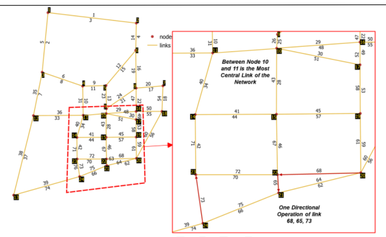



Figure-3: Scenario 1- the network is operating at the base condition

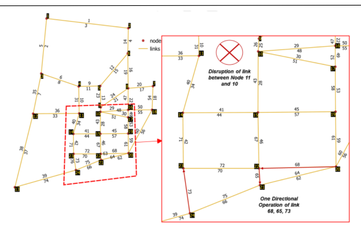



Figure-4: Scenario 2- the network is in disrupted condition

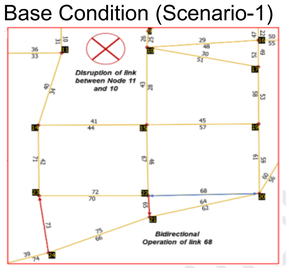



Figure-5: Scheme 1- link 68 is in bidirectional operation

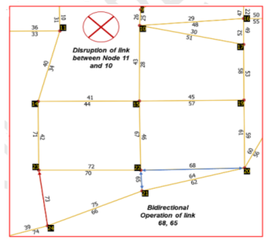



Figure-6: Scheme 2- link 65 and 65 are in bidirectional operation

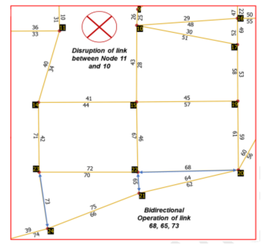



Figure-7: Scheme 3- link 73, 65, and 68 are in bidirectional operation

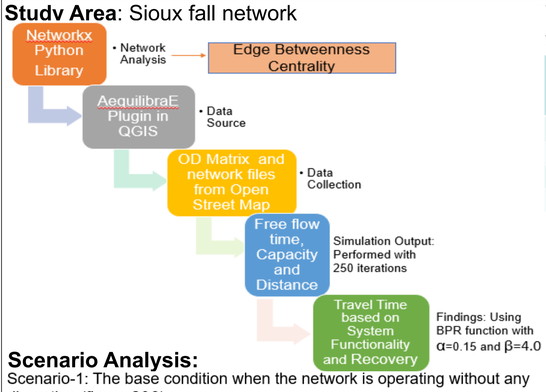
## BACKGROUND

With the advancement of network science, topological credentials are incorporated into the transportation network representing the intersections as nodes, road segments as edges, and traffic as agents. But not many studies have been done on the directionality of directed networks. Until now, it is unknown how directionality affects transportation network mobility and efficiency. During any natural disasters, traffic gridlocks occur at places, and create disruptions on different roads. These disrupted networks cause traffic congestion that is beyond traditional daily traffic patterns that increases travel time and flow exceeds capacity. As such, the system performance of the transportation system decreases and so does its resilience. Thus, it is necessary to identify those central links by analyzing the network matrices like degree centrality, betweenness centrality of links, etc.

The objective of this study is to investigate the network functionality for the change in directionality of certain edges, hence studying the network performance and resilience for the changed situation.

## METHODOLOGY

**Study Area**: Sioux fall network




**Scenario Analysis:**
Scenario-1: The base condition when the network is operating without any disruption (figure-2&3)
Scenario-2: Disrupted condition when the most central (based on BC value) link between nodes 10 and 11 failed (figure-4). Divided into three schemes:
i. Scheme-1: link 68 is considered operating bidirectional (figure-5)
ii. Scheme-2:Links 68 and 65 are considered bidirectional (figure-6)
iii. Scheme-3: Links 68, 65, and 73 are considered bidirectional (figure-7)

Table 1: Attributes of selected links in the Sioux Falls network

| Link ID | From-node | To-node | BC Value | Free Flow Time (minutes) | Distance (miles) |
|---|---|---|---|---|---|
| 27,32 | 10 | 11 | 0.077 | 5 | 5 |
| 68 | 20 | 22 | 0.017 | 2 | 2 |
| 65 | 22 | 21 | 0.020 | 2 | 2 |
| 73 | 24 | 23 | 0.024 | 3 | 3 |

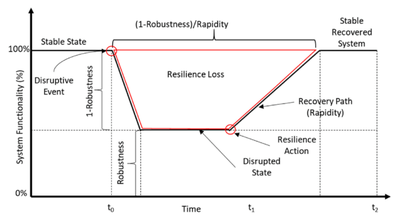



Figure-1: System Functionality and Concept of Resilience Measure

## RESULT

Table 2: Summary of system performance under different scenarios and schemes

| Scenario/ Scheme | Operating Conditions | System's Travel Time (min) | Resiliency Indicator (System Performance in %) |
|---|---|---|---|
| Scenario-1 | Base Condition | 738.71 | 100.00 |
| Scenario-2 | Disrupted Condition | 944.89 | 72.09 |
| Scheme-1 | Link 68 is bidirectional | 915.39 | 76.08 |
| Scheme-2 | Links 68 and 65 are bidirectional | 858.9 | 83.73 |
| Scheme-3 | Links 68, 65, 73 are directional | 826.81 | 88.07 |

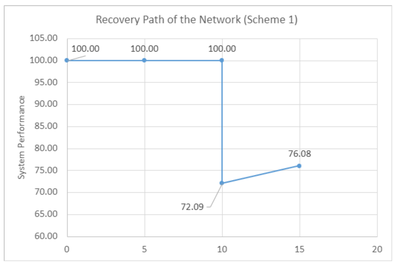



Figure-8: System Performance and Recovery Path under Scheme 1

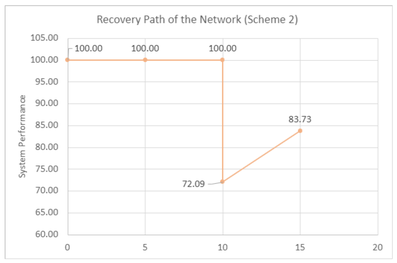



Figure-9: System Performance and Recovery Path under Scheme 2

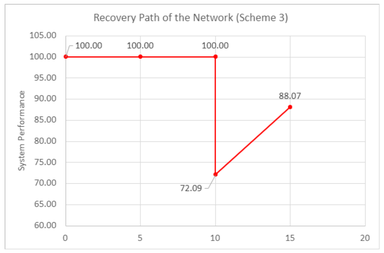



Figure-10: System Performance and Recovery Path under Scheme 3

## Result

- The simulation result shows that, after the disruption, the travel time increases from 738.71 to 944.89 mins (28 increases) and this delay is expected.
- The link between 11 and 10 is the most central link in the network and the failure of its operation will affect the network significantly.
- The performance loss based on the travel time is found as 27.91%, yet the system has an efficiency of up to 72.09%.
- In scheme 1, link 68 is reconfigured to bidirectional, and the BC value changed from 0.017 to 0.030 - the topologic importance of the link increased.
- The consequence it increases from 72.09% to 76.08%.
- Hypothetically 5 days are considered for the system to make schemes 1, 2, 3 fully operational.
- Scheme 2 increases the performance to 83.73% of the system, better than scheme 1 (figure-9).
- Both links 68 and 65 are operating bidirectional and due to change in network topology, their BC value changes from 0.017 to 0.027 and 0.020 to 0.030 respectively
- In Scheme 3, more improvement is observed, the system performance seems to increase by 88.07% when all three links 68, 65, and 73 operate bi-directionally (figure-10).
- The topology of the network changes again and the new BC values of the links are 0.022, 0.026, and 0.030 for links 68, 65, and 73 respectively.

## DISCUSSION

- The directionality intervention in the road network is used to investigate the effect of topological credentials on the network's performance.
- The results show that the network can recover up to 88.07% functionality from 72.09% (in disrupted condition) when the most central link is still non-operational.
- Three links (68, 65, and 73 links), ordered in the least centrality values, are tested with the changed behavior of directionality.

## CONCLUSION

- Directionality is the most prominent contributing factor to this phenomenon.
- Transportation Planners and emergency officials can use directionality interventions as an emergency response strategy during emergency situations.
- During evacuation process, directionality interventions can be used to minimize traffic gridlocks and lessen travel time.

**Future Scope of Work:** How the link reversal and capacity will be influenced by directionality? What is the sequence of directionality implemented to links that maximize the networks' functionality?

## ACKNOWLEDGMENT

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