Assessing the impact of grenade explosion towards Phnom Penh’s road network reliability

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Abstract. Under normal circumstances, the motorist optimal route choice is based on the perception of shortest route between the successive destinations. However, during disaster, some links and nodes are not accessible and consequently motorists reroute their commutes based on limited road network performance information. Therefore, the entire road network reliability cannot be optimized. Therefore, an efficient traffic diversion plan is required to improve the road network reliability. We used the Technique for order of Preference by Similarity to Ideal Solution (TOPSIS) to rank all nodes in the study area based on their values of betweenness and closeness. The study aims to assess the impact of grenade explosion towards Phnom Penh’s road network reliability in Chamkar Mon district and a traffic diversion plan then was developed to keep the traffic movement unaffected. The results indicated that there are 4 nodes their TOPSIS rank index value (RIV) increased greater than 25%, while, on the other hand, there are 9 nodes with TOPSIS RIV value decreased greater than 25%. The results also showed that 6 nodes with TOPSIS RIV persists comparatively high before and after the incident. These information was used as the basis of the design of the traffic diversion plan.

1. Introduction
The impact of natural and manmade disasters on road network reliability has gained attention of researchers especially in recent years [1-2]. Road network reliability is concerned with the probability a road network provides a specific standard of performance [3]. It can be divided into three types: connectivity (or terminal), capacity and travel time reliability. Connectivity reliability refers to the probability that the road network nodes stay connected in the deteriorated road network [4], while the capacity reliability concerns the probability that the road network can accommodate a given level of traffic demand at a stated service level [5]. Travel time reliability is defined as the probability that travel time between two given nodes of a road network will not greater than a specified time period [6]. This indicates the higher the variability of travel time, the lower will be the travel time reliability. Under normal circumstances, the motorist optimal route choice is based on the perception of shortest route between the successive destinations. However, during disaster or emergency situations, some links and nodes are not accessible or unsustainably used, and consequently motorists reroute their commutes based on limited road network performance information. Therefore, the entire road network
performance cannot be optimized. In view of this, an efficient traffic diversion plan is required to improve the road network reliability.

Identifying influential nodes in complex networks has drawn significant attention in the field of network analysis [7-9]. Betweenness centrality and closeness centrality are two common topological measurements used to identify influential nodes. Betweenness centrality is a measure of number of shortest paths that pass through a particular node. Closeness centrality is a measure of the sum of geodesic distance of a node to all other reachable node in the network. Therefore, the more central a node is, the closer it is to all other nodes in the network. In road transportation, a high betweenness and closeness of a node implies more of the shortest road paths via the given node, indicating a larger selective probability of this node when effectively circulating traffic in the road network. However, the values of betweenness and closeness for a node may change significantly as a result of disasters or emergencies. Together, these sources of information will be used to design traffic diversion plan during disasters and emergencies. The fundamental concept for developing this plan is to divert the traffic from more congested nodes to those operating within or under capacity.

An apparent grenade explosion in Phnom Penh’s Chamkar Mon district, near the Tuol Sleng prison museum, on 6 September 2016 has caused injuries to at least four people and rattled the city. The Tuol Sleng prison museum is located within the city center of Phnom Penh, and therefore, this incident was greatly affect traffic in the area (See in Figure 1). The study area is surrounded by four main roads: the Preah Sihanouk, Samdech Monireth, Mao Tse Toung and Preah Monivong. We used the Technique for order of Preference by Similarity to Ideal Solution (TOPSIS) to rank all nodes based on their values of betweenness and closeness. This study aims to assess the impact of grenade explosion towards Phnom Penh’s road network reliability using TOPSIS technique and a traffic diversion plan then was developed.

![Figure 1. Study location](image)

2. Literature Review

Viewed from a more general perspective, reliability refers to the probability that a system, a device or component able to deliver expected service under the operating conditions for the intended time period [10]. A road network can be regarded as reliable when it can function in good condition and able to handle different levels of disruption for a specific time [11]. Reliability is widely used to assess a road network’s performance under disaster conditions [12]. The application of network reliability under disaster or emergency conditions is subjected to pre-disaster and post-disaster [13]. Disaster phases can be recognized based on the demand nature. These include: the evacuation phase at the inception and before the disaster, aid distribution after the disaster and post-disaster. During evacuation, a
reliable network is required to transport people to safe areas. In the aid distribution phase, a reliable network allows the timely delivery of humanitarian supplies to the disaster-affected areas. A reliable network is essential during the post-disaster recovery to allow individuals resume their daily activities. This study is related to evacuation reliability.

Connectivity reliability is concerned with the probability that network nodes remains connected when links in the network break down. Konak and Smith pointed out that this reliability measure can be further divided into three groups on the basis of the number of nodes covered: two-terminal reliability (the probability of the present of a path between origin and destination nodes), all-terminal reliability (the probability that each node of the network is linked with all other nodes) and k-terminal probability (the probability that each two nodes in a subset k are linked). Iida and Wakabayashi defined connectivity as each link is represented with a binary state value of operating or failed; that is they are either in operation or not, or more broadly, offer an acceptable service or not. Due to its binary character, connectivity reliability does not consider changes in link capacity and, therefore it appears to be more suitable for acute events, such as earthquake. Moreover, Nicholson indicated that this reliability analysis is suitable is appropriate for sparse and uncongested road network, such as interstate highway system.

Capacity reliability is a measure to assess the performance of a deterioratable road network, when link capacity is depended on random variations as a result of user routing choices [5]. It can be defined as the probability that the network can successfully accommodate a certain traffic demand at an acceptable service level [1]. It is noted that the estimation of the relationships between the road network elements which are sensitive to stochastic variation and the targeted performance, especially studies included larger road networks [17]. The capacity reliability concept was employed to assess road network reliability as a result of disaster [18]. Previous studies indicated that the concept of capacity reliability and travel time reliability could be utilized as a valuable network tool to plan and evaluate traffic management program in urban areas [19].

A large volume of literature has been published on travel time reliability. Such reliability is concerned with the probability that a trip between a given origin destination (OD) pair can be accomplished less than a certain threshold time period given daily stochastic variation of travel demand [20]. This implies that an increase in time variance the lower would lead to a decrease in travel time reliability [21]. Carrion and Levinson indicated that road travel time can be separated into two components as free flow time and additional time. The first component is concerned with the time taken to complete a trip under free flow condition, while the second component regards an increase of travel time as a result of variations in the traffic conditions. They pointed out these variations can be categorized as predictable (e.g. peak-hour congestion) or unpredictable (e.g. traffic accidents). The predictable variations can be predicted by travellers and therefore necessary adjustments can be taken to offset the extra costs caused by congestion. The unpredictable variations are caused by the uncertainty of travel time. Wong and Sussman explained that this uncertainty can be divided into three types as follows: (1) variation between seasons and days of the week; (2) variation by changes in travel conditions due to weather and road incidents; and (3) variation regarded to motorist’s perception.

3. Methodology
In this section, we present the methodology used to design a traffic diversion plan during disasters or emergencies. We first present the network centrality measures (betweenness centrality and closeness centrality) used to identify influential nodes in the study road network, and then present the application of TOPSIS to evaluate the node importance. Data used to compute the network centrality measures were obtained from Google Map service.

3.1 Network Centrality Measures
Network centrality measures are indicators to measure a node’s importance in a network. Two commonly used network centrality measures are closeness centrality and betweenness centrality [24].
The betweenness centrality is a measure of the proportion of the shortest paths that pass through a particular node. It can be written as:

\[ BC(v) = \sum_{i \neq j \in v} \frac{\rho_{ij}(v)}{\rho_{ij}} \]  

(1)

where \( \rho_{ij} \) is the number of shortest paths between any two nodes \( i \) and \( j \), while \( \rho_{ij}(v) \) denotes the number of shortest paths between nodes \( i \) and \( j \) that pass through node \( v \). In regards to road traffic, a high betweenness centrality of a node indicating a large influence on the transfer of traffic through the road network, under the assumption that traffic primarily flows over the shortest paths between them. This measure can be normalized in the interval between zero and one by dividing it by \((n-1)(n-2)/2\), where \( n \) represents the number of nodes in the network.

Unlike betweenness centrality which measures the proportion of the shortest paths that pass through a node in a network, closeness centrality refers to the inverse of the average geodesic distance between a node and other nodes in the network [25]. The expression is as follows:

\[ C_c = \frac{n-1}{\sum_{i \neq j} d_{ij}} \]  

(2)

where \( d_{ij} \) is the minimal path length from node \( i \) to \( j \). In general, a node with a high degree of closeness centrality has shorter geodesic distance to other nodes in the network and thus it is more accessible. This centrality measure is a more comprehensive tool to rank important node as it considers the entire geographical structure of the network.

3.2 Techniques for Order Preference by Similarity to Identical Solution

Betweenness and closeness centrality measures are widely used to evaluate node importance in a network but with limitations. One of the limitations of closeness centrality indicated by Wei et al. is that it cannot be used for disconnected networks. This is because two nodes in different components of the same network do not have a finite distance between them. Although the betweenness centrality can be applied to disconnected networks, it does not assign any value to nodes do not lie on the shortest path between any two other nodes [27]. This implies that if only one centrality measure is employed, then the rankings of influential nodes may be different by employing different centrality measure. In view of this the present study used both closeness and betweenness centrality to evaluate node importance. This was achieved by using the technique for order preference by similarity to identical solution (TOPSIS) developed by Hwang and Yoon.

The TOPSIS aims to provide guide to the decision-maker in the process of making the selection between alternatives. It fully uses the information of attribute, offers a cardinal ranking of alternatives, and attribute preferences need not be independent [29]. According to this technique, the rankings of alternatives is on the basis of the shortest Euclidean distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) (also known as anti-ideal solution). The PIS refers to a solution that maximizes the benefit criteria/attributes and also minimize the cost criteria/attributes, whereas the NIS is the one which minimizes benefit criteria/attributes and maximizes the cost criteria/attributes [30]. The final ranking is obtained by considering simultaneously the distances to both the PIS and the NIS, and a preference order is ranked according to their relative closeness [31].

The TOPSIS procedure is described in the following steps. The first step is to determine the decision matrix of \( n \) criteria/attributes and \( m \) alternatives. The second step is to normalize the decision matrix, while the third step is to weight the normalized decision matrix. We suppose that closeness and betweenness centrality have the same importance under evaluation. This implies that the weights for the two centralities are equal to 0.5. In step four, we determine the positive ideal and negative ideal solutions using the decision matrix. Next, we calculate the Euclidean distances from the positive ideal and negative ideal solutions, respectively. In the final step, the relative closeness of each alternative to the ideal solution is determined. Rank the alternatives in regard to the relative closeness to the ideal
solution in descending order. The alternative with higher value is regarded to be more important as they are closer to the positive ideal solution.

4. Results and Discussions
In the next section, we discuss results on the change in the centrality measures, while the design of traffic diversion plan is discussed in Section 4.2.

4.1 The Centrality Analysis Results
The closeness and betweenness centralities were computed for 175 nodes in the study road network, and then the TOPSIS rank index were computed based on both closeness and betweenness centralities. As shown in Table 1, there are 4 nodes their TOPSIS rank index value (RIV) increased by more than 25%. Therefore, it is expected a significant increase in traffic via these nodes after the grenade explosion. However, it is important to note that even though there is a significant increase in TOPSIS RIV for Nodes 75519 and 75520, their TOPSIS RIV after the incident is relatively small. This indicated that the incident’s impact on these two nodes’ performance was marginal. Conversely, there are 9 nodes their TOPSIS RIV decreased by more than 25% (Table 2) and thus it is anticipated a drastic decrease in traffic via these nodes after the incident. However, it is interesting to note that there are 6 nodes their TOPSIS RIV remained relatively high before and after the incident (Table 3).

| Table 1. Nodes’ TOPSIS RIV increased by more than 25% |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Node | Betweenness | Closeness | TOPSIS | Betweenness | Closeness | TOPSIS | % |
| 75464 | 0.128 | 0.096 | 0.589 | 0.199 | 0.097 | 0.829 | 41% |
| 75474 | 0.094 | 0.093 | 0.447 | 0.199 | 0.094 | 0.568 | 27% |
| 75519 | 0.017 | 0.077 | 0.141 | 0.039 | 0.077 | 0.195 | 39% |
| 75520 | 0.017 | 0.076 | 0.138 | 0.041 | 0.076 | 0.194 | 41% |

| Table 2. Nodes’ TOPSIS RIV decreased by more than 25% |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Node | Betweenness | Closeness | TOPSIS | Betweenness | Closeness | TOPSIS | % |
| 75473 | 0.144 | 0.089 | 0.651 | 0.076 | 0.085 | 0.337 | -48% |
| 75475 | 0.077 | 0.086 | 0.369 | 0.043 | 0.083 | 0.218 | -41% |
| 75476 | 0.138 | 0.085 | 0.623 | 0.109 | 0.082 | 0.462 | -26% |
| 75592 | 0.052 | 0.061 | 0.231 | 0.041 | 0.061 | 0.169 | -26% |
| 75611 | 0.016 | 0.067 | 0.106 | 0.009 | 0.065 | 0.078 | -26% |
| 75612 | 0.025 | 0.069 | 0.141 | 0.036 | 0.068 | 0.104 | -26% |
| 75622 | 0.043 | 0.058 | 0.191 | 0.031 | 0.058 | 0.132 | -31% |
| 75626 | 0.043 | 0.056 | 0.187 | 0.031 | 0.056 | 0.128 | -31% |
| 75627 | 0.033 | 0.053 | 0.143 | 0.021 | 0.054 | 0.088 | -39% |

| Table 3. Nodes’ TOPSIS RIV remains relatively high before and after the incident |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Node | Betweenness | Closeness | TOPSIS | Before grenade explosion | After grenade explosion |
| 75469 | 0.182 | 0.098 | 0.819 | 0.201 | 0.098 | 0.836 |
| 75470 | 0.222 | 0.099 | 1 | 0.241 | 0.101 | 1 |
| 75471 | 0.198 | 0.095 | 0.891 | 0.189 | 0.096 | 0.789 |
| 75477 | 0.151 | 0.091 | 0.685 | 0.157 | 0.092 | 0.659 |
| 75489 | 0.181 | 0.098 | 0.817 | 0.185 | 0.098 | 0.776 |
| 75528 | 0.166 | 0.089 | 0.747 | 0.172 | 0.091 | 0.717 |
4.2 Design of Traffic Diversion Plan

Figure 2 shows the distribution of more influential nodes in the study area after the incident. The green cross indicates nodes’ TOPSIS RIV decreased by more than 25%, while the red cross represents nodes’ TOPSIS RIV increased by more than 25% after the grenade explosion. The purple triangle sign represents nodes’ TOPSIS RIV remained relatively high before and after the incident.

The incident location, which is represented by the black circle in Figure 2, was not accessible to traffic after the incident. Therefore, the traffic originally planned to pass through this node must reroute to the next shortest route. According to the traffic diversion concept, traffic moving within the study road network should be diverted to the nodes with significant decrease in TOPSIS RIV, but not to the nodes with significant increase in TOPSIS RIV as well as nodes with relatively high TOPSIS RIV before and after the incident. This would improve traffic circulation during the incident. Figure 3 illustrates the recommended diversion routes designated in the study road network. The blue line shows the diversion route from the North to the South and vice versa. The green line indicates the diversion route to the West, towards the Tuol Sleng Prison museum, while the blue line indicates the diversion route to the East, towards the Samdech Monireth road.
5. Conclusion and Recommendations

This study assessed the impact of grenade explosion towards Phnom Penh’s road network reliability and a traffic diversion plan was then designed based on the assessment results. Results indicated that there were 4 nodes their TOPSIS RIV increased greater than 25%, while, on the other hand, there were 9 nodes with TOPSIS RIV value decreased greater than 25% after the incident. The results also showed that 6 nodes with TOPSIS RIV persistently high before and after the incident. These information was used as the basis of the design of the traffic diversion plan to keep the traffic movement unaffected after the incident.

A limitation of this study is that the TOPSIS model omitted distance between the node and other traffic attraction places, such as shopping areas, schools and tourist attraction places (such as The Tuol Sleng genocide museum). It is anticipated that more traffic will be attracted to nodes closer to these traffic attraction places even the nodes are not placed on the shortest path. Besides, node and link capacity should also be included in the TOPSIS model for two reasons. Second, an increase in node or link capacity would increase the traffic flow. Consequently, this would attract more traffic to higher capacity nodes and links. Third, an increase in TOPSIS RIV may have different impact on the performance of node/link with different capacity. This may have implication on the design of traffic diversion plan. Therefore, further research should be conducted to investigate into the effect of the above mentioned factors on identifying influential nodes and hence improving the design of traffic diversion plan.

Road network are vulnerable to manmade and natural disasters that can cause a massive destruction to the infrastructure. Consequently, this poses a threat to vehicle travel on a degraded road network and prevent access for the emergency services, aids workers and relief supplies. Therefore, it is crucial to understand road network reliability, know the most influential nodes and the consequences to network disruption in order to improve road network design and develop traffic diversion plans during the disaster. This is necessary to achieve a sustainable road network.

6. References

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