



# Evaluation of the China Pakistan Economic Corridor Road Network: Shortest Route, Regional Distribution, and Robustness

Page 12

Received 02 July 2019  
Revised 09 Sep 2019  
Accepted 10 Oct 2019

Raja Awais Liaqat<sup>a</sup>

<sup>a</sup> Department of Mechanical Engineering, Capital University of Science & Technology, Islamabad, Pakistan; Email: awais.liaqat@cust.edu.pk

Mujtaba Hassan Agha<sup>b,1</sup>,

<sup>b</sup> NUST Business School (NBS), National University of Sciences and Technology, Islamabad, Pakistan; Email: mujtaba.gha@nbs.nust.edu.pk

Till Becker<sup>c</sup>

<sup>c</sup> Faculty of Business Studies University of Applied Sciences Emden/Leer Emden, Germany; Email: till.becker@hs-emden-leer.de

## Abstract

*Purpose* - The transport road network plays a significant role in the economic development of any country. An appropriate road network not only reduces transportation cost but it also serves as an infrastructural enabler for further economic development. The China-Pakistan Economic Corridor (CPEC) is part of the Chinese “Belt and Road Initiative”, seeking better connectivity between Asia, Europe, and Africa. The major part of the CPEC project is the development of a road network linking the port city of Gwadar (Pakistan) with Kashgar (China). This paper focuses on the quantitative evaluation of alternate routes within the CPEC road network inside Pakistan with regard to travel times, road development in provinces, a balanced distribution of road network among provinces, and robustness against road closures.

*Methodology* - The network is developed as an undirected graph with nodes as cities and edges as interlinking roads. Based on publicly available data, the paper identifies the shortest path from Gwadar to Khunjerab pass (Pakistan-China Border) and measures the distribution of the travelled distance among Pakistan’s provinces for each alternate route. Moreover, the robustness of road network is evaluated by a knock-out analysis.

*Results* - The results showed that an unconsidered route by the planners promises the shortest travel time and that some proposed routes have significantly unbalanced share amongst provinces. There is a variation in robustness between the alternate routes, but with any route selected, the road network is able to remain functional even after closure of multiple connections.

**NBR**

NUST Business Review  
NBR-19-0107  
Vol. 01, No. 01  
10, 2019  
pp. 12-43  
© NUST Business School

*Practical Implications* - This study provides a decision-making toolbox for analysis and policy-making related to economic corridors e.g. CPEC – which is at its inception phase, and still tied to limited availability of data.

*Originality* - The present study is novel because no prior study has covered the road network analysis of CPEC. Also, robustness and topographical analyses with respect to CPEC have not previously been undertaken.

**Key Points:**

- *Comparison of the three proposed routes of China Pakistan Economic Corridor (CPEC) road network based on travel time and distance.*
- *Evaluating the robustness of the CPEC road network via node and edge knock-out analysis.*
- *Shortest travel time is achieved using a combination of Eastern and Central routes.*
- *Eastern route gives the most equitable share of all provinces in the network.*

**Keywords:** China Pakistan Economic Corridor (CPEC), Knock-out Analysis, Network Failure, Robustness.

**Paper Type:** Research Paper

**1.0 Introduction**

The “Belt and Road Initiative” is an infrastructure development endeavour with the aim of building stronger economic links between Europe, Asia and Africa (Cheng, 2016). The Eurasian continent will be connected through the land based “Silk Road Economic Belt” while connectivity between Asia and Africa will be improved via the maritime Silk Road (Yang et al., 2017) as shown in Figure 1.

**Figure 1.**

*Routes of the Belt and Road Initiative  
(Adapted from Xinhua News Agency)*



Most of the countries covered by the Belt and Road Initiative are low-income economies and contribute only 30% to the world’s GDP (Huang, 2016). However, these countries have great potential for rapid economic growth if proper conditions are provided (Tian et al., 2016). This initiative will not only benefit the countries in the Belt and Road area through a Chinese outward direct investment (ODI), but also

upgrade industries in the underdeveloped north western region of China (Zheng & Liu, 2015).

The “China Pakistan Economic Corridor” (CPEC) is part of the “Belt and Road Initiative”. Considered as a gateway of economic prosperity and stabilization for Pakistan, (S Uddin et al. 2019). Acting as a framework of regional connectivity comprising of transport infrastructure development, energy projects, and special economic zones (Rafiq, 2017), this project aims to provide an easy access from north western provinces of China to the Arabian sea via Gwadar, which is the closest deep sea port for these regions (Cheng, 2016; Naseem, 2017). Moreover, CPEC has the potential to connect Middle East and Central Asian energy supplies to China (Shaikh et al., 2016; Sheu & Kundu, 2017).

While CPEC is a bilateral economic corridor between Pakistan and China, currently all the development projects under CPEC are being carried out only in Pakistan. China’s foreign direct investment (FDI) initiative is aimed at improving the underdeveloped infrastructure of Pakistan. The total estimated cost of CPEC is US\$62 billion (Garlick, 2018). CPEC is projected to reach completion by 2030. However, a 3000-kilometer road network mainly consisting of highways and motorways is scheduled to be completed by 2020. The road network encompasses 24 different projects of \$6.1 billion, of which some are enlisted in Table 1 (China-Pakistan Economic Corridor (CPEC), 2017).

The transport sector plays a significant role in the economic development of any country. Current plans define that the trade through CPEC will be accomplished via trucking. However, the transport sector in Pakistan is in poor condition, leading to an estimated annual loss of 8.5% to Pakistan’s GDP (Asian Development Bank, 2016)

**Table 1.**  
CPEC  
Infrastructure  
Projects

Project Name	Length (km)	Estimated Cost (US\$ M)
KKH Phase II (Thakot -Havelian Section)	118	1,315
Peshawar-Karachi Motorway (Multan-Sukkur Section)	392	2,889
Khuzdar-Basima Road N-30 (110 km)	110	80
Upgradation of D.I. Khan (Yarik) - Zhob, N-50 Phase-I (210 km)	210	195
KKH Thakot-Raikot N35 remaining portion (136 km)	136	719.8

*Source: cpec.gov.pk*

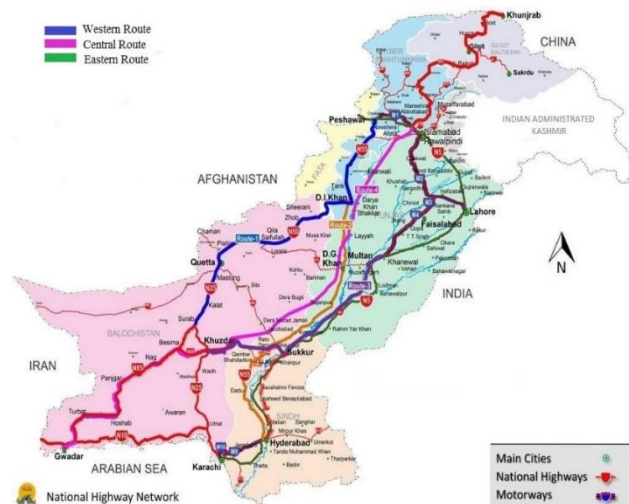
Investment in transport infrastructure is a tool for economic development, especially in developing countries (Nistor & Popa, 2016). Therefore, CPEC provides an opportunity for Pakistan to enhance its economic growth. Figure 2 shows the three planned routes for the CPEC road network as developed by the Planning Commission of Pakistan (Ministry of Planning, Development & Reform, 2017). These routes are the combination of existing roads in Pakistan

and the new ones being developed under the umbrella of CPEC infrastructure development projects. The routes are named: Eastern route, Central route and Western route according to their geographical alignment within Pakistan.

The substantial benefits that CPEC can bring to Pakistan depend on its actual implementation, which requires a number of decisions to be made by the policy makers. Jato et al. (2014) argued that major construction projects involve a variety of factors, which need to be considered, thus making decisions in such environments are difficult. Therefore, this study aims to provide a quantitative tool that can aid policy makers in Pakistan in their decision-making.

The major part of the CPEC project is the development of a road network linking the port city of Gwadar (Pakistan) with Kashgar (China). China's part of the CPEC road network (starting from Khunjerab Pass to Kashgar) is already constructed, therefore, this study will only evaluate the road network of CPEC in Pakistan, that is, from Gwadar to Khunjerab pass (Pak-China border). The study focuses on evaluating the robustness of a planned road network. Moreover, identification of important cities and evaluation of alternate routes with regards to travel time, travel distance and regional share (both geographical and population distribution) are also highlighted for the detailed evaluation of the CPEC road network in Pakistan.

Following this introduction, section 2 details the problem statement of this study. While, section 3 explains a further elaboration of the transport corridors and road network connectivity. The method for assessment and data collection is outlined in section 4. The key findings are highlighted and discussed in section 5. Finally, conclusions are presented in section 6.



**Figure 2.**  
*Routes of CPEC Road Network (Source: National Highway Authority (NHA) Government of Pakistan)*

## 2.0 Problem Statement

Nowadays, the major problem that CPEC project is facing is the strong criticism from some local ethnic groups and leaders of the smaller provinces of Pakistan (Bengali et al., 2015). The smaller provinces in Pakistan believe that the largest province (Punjab) will reap most of the expected benefits of CPEC and an undue importance is being given to the Eastern route (Peer, 2015). This political debate accrues serious concerns about the fulfilment and implementation of CPEC project for both China and Pakistan. The road network should not only provide fast linkage from the port city of Gwadar (Pakistan) to Kashgar (China) as travel time is directly related to transportation cost (Anderluh et al., 2019), but it should also provide equitable share for all regions within Pakistan. In this critical environment, there is a need to provide an unbiased approach that helps the policy makers analyse this multi criterion problem. So far, majority of the studies have approached CPEC from socio-economic and geo-political perspectives (Ali et al., 2018) but no quantitative study has been conducted that analyses the CPEC road network. Therefore, this study aims to address this gap by a quantitative assessment of alternate routes within the CPEC road network.

## 3.0 Literature Review

Road networks are considered as a means of socio-economic development because they link people and economies together (Javier Gutierrez & Paloma, 1996; Ivanova & Masarova, 2013). An improved road network not only increases accessibility and mobility but also reduces travel costs and time (Buurman & Rietveld, 1999; Deichmann et al., 2005). Socio-economic development linked with road network advancements includes better access to education (Bourdet, 1998), better health care delivery (Airey, 1992), greater employment opportunities (Windle & Cramb, 1997), increased household income (Jacoby, 2000), and reductions in poverty (Fan & Chan-kang, 2005). Road development can also enhance economic development in an area by providing basic infrastructure for investment and harnessing local and regional economic development potential (Lampe, 2016).

Lucas & Currie (2011) have investigated the relationship between transport opportunities and social outcomes. They claim that transport policy makers have to be more aware of the mobility and accessibility needs of low-income populations. Hof et al., (2011) point out that economic benefits can be generated from transport infrastructure, but the modelling and design of such infrastructure requires more variables than only the optimization of travel time. Furthermore, route choices and therefore the perception of routes by individuals are also dependent on various other variables (Prato et al., 2012; Vreeswijk et al., 2014).

Since CPEC's inauguration, several studies have been conducted that analyze the CPEC and its pros and cons for Pakistan. R. Ahmed & Mustafa, (2017), identified the relationship between strategic level policy decisions and the associated operational level impacts of CPEC for the agriculture sector of Pakistan. Qureshi (2015) discussed the legal and policy standpoint of CPEC arrangement between Pakistan and China. His study highlights the relevance of the application of both Pakistani law and international law to CPEC. Mahmood (2015) exhibited China's approach towards the construction of the road network and discussed the geostrategic implications of Chinese policies with relevance to CPEC policy framework. Latif et al., (2017), did quantitative analysis of an optical fibre project under CPEC and proposed a novel technique for carrying large capacity triple play services across CPEC. Munir et al., (2017), used mix integer linear programming technique for resource allocation of the cement industry along the CPEC proposed route. Ali et al., (2018), used multi criteria decision-making (MCDM) techniques for the assessment of energy projects under CPEC. He provided a framework for policy makers in selecting the best set of CPEC energy projects that should be completed in the first wave of development. Zhang et al., (2017), used the fuzzy comprehensive evaluation method (FCEM) to highlight the environmental and social risk factors involved in CPEC construction. They provided a framework for the analysis of environmental and social issues during the investment process of Chinese enterprises. As part of a World Bank report, Derudder et al., (2018), have already used centrality measures to identify important nodes in the CPEC network. However, their scope of CPEC only includes the Chinese side of the network, which results in almost only Chinese cities being considered as important due to their size and the dense road infrastructure in China. The available literature demonstrates that there have been many studies on CPEC but no quantitative study has been done that analyses the CPEC road network.

According to Dunn & Wilkinson (2015), graph theory is the most suitable tool for evaluating the characteristics of a network. In graph theory, the transportation network can be represented in form of an abstract graph composed of nodes and edges. This abstract graph can be used to determine network efficiency using metrics such as shortest path and centrality measurements (betweenness and closeness) as they demonstrate a node's involvement in the cohesiveness of the network (Latora & Marchiori, 2007). The shortest path not only refers to spatial distance, but also to travel time (Yao et al., 2014). Road networks often suffer connectivity issues due to unexpected failures and disruptions that result in closure of linking roads. While internal disruptions (accidents and technical failures) in the network

may have limited impact on it, external threats (earthquakes, floods, terror attacks, etc.) leave a greater impact on a road network (Bíl et al., 2015; Jenelius & Mattsson, 2015). The availability of alternate routes ensures the connectivity of the transportation system in cases of impediment (Balijepalli & Oppong, 2014; Jenelius, 2010).

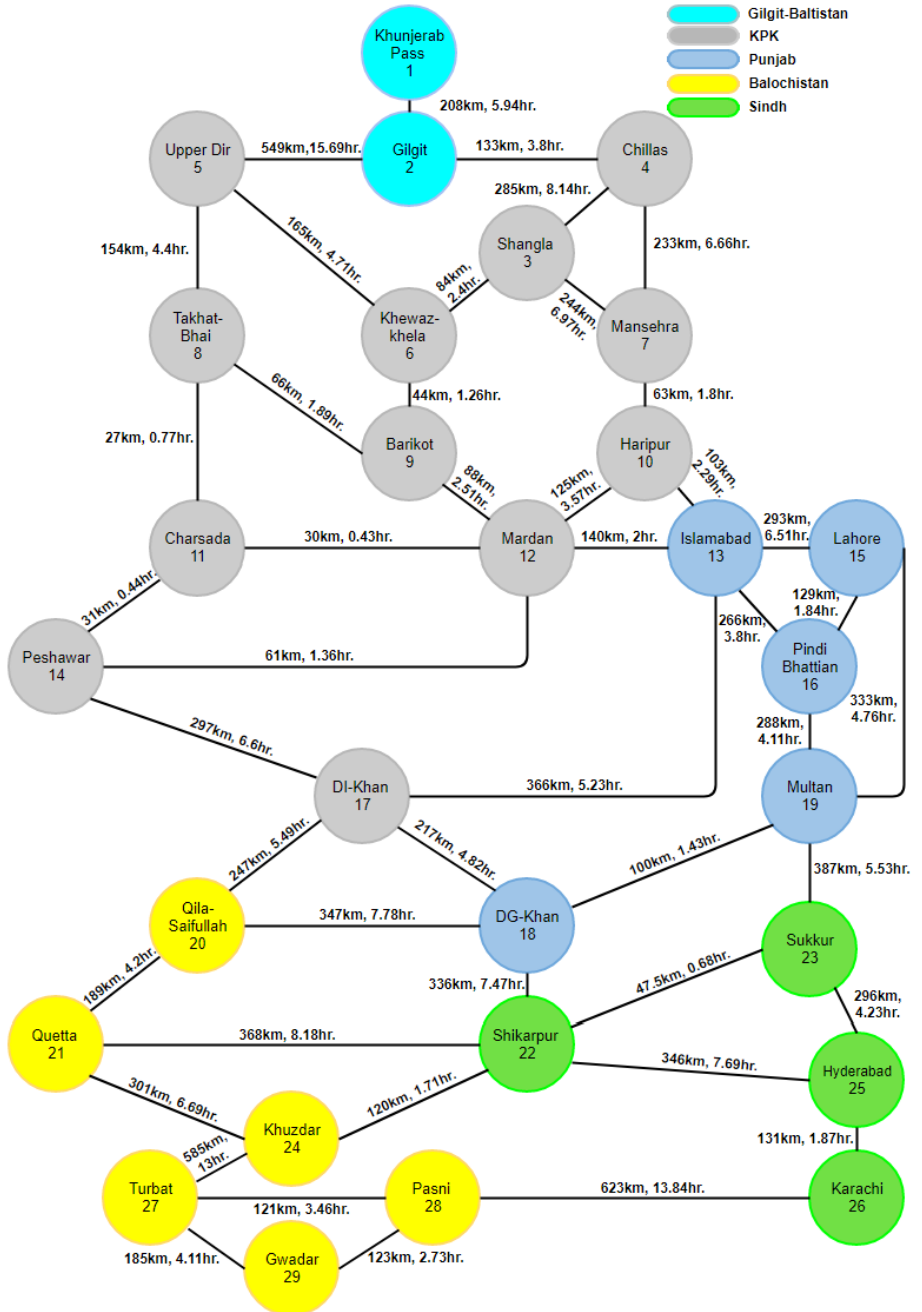
Road networks can be analysed using concepts such as vulnerability and robustness. Berdica (2002) did pioneer work to analyse the vulnerability of transportation networks and defined vulnerability as a susceptibility to incidents that can result in considerable reductions in road network performance and operational degradation. This notion has been adopted by Jenelius & Mattsson (2012) and Xu et al., (2017). The vulnerability of a transport network can be analysed either statically or dynamically. In this context, static network analysis investigates the consequences of disruptions by considering travel time as a static measure (Rodríguez-Núñez & García-Palomares, 2014). On the contrary, vulnerability is dynamically quantified by a large variety of metrics in terms of the coverage (Jenelius & Mattsson, 2012), accessibility (Berdica & Mattsson, 2007; Taylor et al., 2006; Taylor & Susilawati, 2012; Yu et al., 2012), reliability (Yao et al., 2014), and connectivity (Kurauchi et al., 2009) by considering travel time, travel distance, congestion, traffic flow patterns, and traffic flow density as decisive parameters.

Network robustness can be considered as reciprocal to vulnerability (Knoop et al., 2012; Rupi et al., 2015). Robustness can be defined as the stability against different varying conditions in the networks (Stricker & Lanza, 2014; Stricker et al., 2015). According to Sakakibara et al., (2004), robustness of road networks can be investigated either on the basis of network's topological structure using graph theory or traffic flow analyses for different types of disruptions. Like vulnerability, robustness of road networks has also been evaluated using either static analysis (Zhou et al., 2017) or dynamic indices by considering parameters like traffic flow, traffic density, traffic congestion and road structure (Sullivan et al., 2010; El-Rashidy & Grant-muller, 2014; Zhang et al., 2015; Cats, 2016).

#### 4.0 Methodology

Road network data were gathered from two different government organizations: National Highway Authority (National Highways Authority, 2017) and Geological Survey of Pakistan (Geological Survey of Pakistan, 2017). The road network model of CPEC represented in Figure 3 consists of 29 nodes (cities) connected by 46 edges (road links between cities). The network representation of the transport system is an undirected graph  $G = (V, E)$  that consists of a set of nodes  $V = \{v_1, \dots, v_{|V|}\}$  and a set of edges  $E = \{(v_i, v_j), \dots, (v_y, v_z)\}$  between a section of node pairs. The 29 cities selected represent

all the main cities that lie on the road network intersections and junctions. The cities that lie in between junction/intersection points were not considered in this study. An exception was made for Karachi, because it is the industrial centre of Pakistan, and therefore, we decided to display it on the map.





As a pass-through node, its existence has no positive or negative impact on the subsequent analyses. The shortest path between source and sink node is evaluated using Dijkstra's algorithm (Oliveira & Pardalos, 2011) as it is considered to be the preeminent algorithm for evaluating shortest paths in the network (Saha Ray, 2013). The importance of different components in the network was analysed using the centrality calculations. Robustness is defined as the capacity of a network to not only remain functional but also maintain a high level of operational performance in face of disturbances. Therefore, the robustness of the network was evaluated using a knock-out analysis (Reka Albert & Hawoong Jeong, 2004). In this type of analysis, the edges of a network are removed incrementally, either selected randomly or following a certain criterion. After each removal of an edge of a performance measure, such as the shortest path between two nodes, a general efficiency measure like the network diameter is checked and the intensity of performance loss is analysed. Alternatively, the number of edge removals required to render the network dysfunctional (e.g. disconnected) is measured, which is often described as the property of robustness. This understanding of robustness from a network perspective has been applied in the research of biological systems (see, e.g., Min et al. (2011); Kitano, (2004)), but the concept is applicable to transportation networks in a uniform manner. In this study, the network robustness is computed by analysing how much deviation occurs in the shortest path (both in terms of distance and travel time) when an edge is removed from the network.

#### 4.1 Assumptions

For travel time computations, the following assumptions are used:

- *The network is undirected meaning that all edges can be travelled in both directions at the same speed.*
- *The edges have been categorized into three types: Motorways, Highways and Hilly Road. A hilly road is defined in this study as a road that passes through a mountainous terrain. This categorization is based on the authors' geographical knowledge and is in accordance with data from the National Highway Authority (National Highways Authority, 2017).*
- *The assumed speed of a truck on Motorways is set as 70 km/hour; Highways is 45 km/hour, and on Hilly roads it is 35 km/hour. Since there is no published data for truck speed in Pakistan, speed values of trucks from India have been used as the country has similar geospatial topology and similar types of trucks are in use. The average speed on National Highway in India was reported to be 45.88 km/hour (Balakrishnan & Sivanandan, 2015) and, maximum speed was 69 km/hour (Bains et al., 2013). The cogency of these values was corroborated by National Logistics Cell officials (National Logistics Cell, 2017).*

## 4.2 Research Limitations

The road network of CPEC is currently under construction and details about traffic flow, traffic density, etc. are not available. Hence, in this study, emphasis is on the geographical network rather than on traffic flows. Thus, the analysis carried out in this study is based on static edge travel time and distance. The details regarding nodes, edges, respective distances, road type, and time calculations are presented in Appendix (Table A.1 and A.2).

## 4.3 Modelling Software

All network modelling, path calculations, centrality assessment, knock-out analyses, robustness, and vulnerability calculations have been carried out using self-developed code in Python with the support of the NetworkX library.

## 5.0 Results and Analysis

### 5.1 Shortest Path Calculation

Figure 4a: Shortest Distance Route

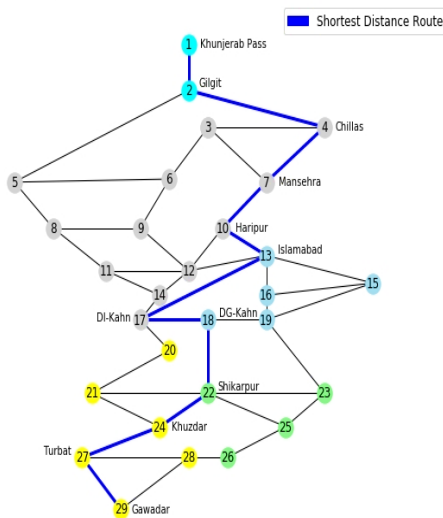
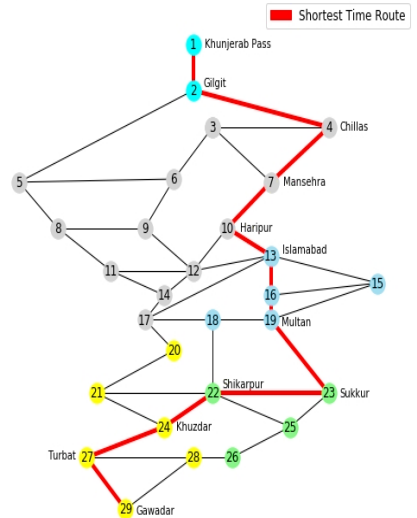


Figure 4b: Shortest Time Route



NBR  
1,1

**Figure 4.**  
*Shortest Path Calculation in terms of both Distance and Time. (The distances between the nodes in this figure and the following are not to scale. Nodes in densely populated areas had to be exploded for reasons of readability.)*

The shortest path between the entrance into Pakistan at Khunjerab Pass (Node 1, the source node) and the final destination of the goods, the port city of Gwadar (Node 29, the sink node), is evaluated both in terms of distance and travel time.

### 5.1.1. Shortest Distance Route

For the calculation of the shortest distance route, the weight of each edge is set to the road distance between its nodes in kilometers. For example, the road distance between Khunjerab pass (Node 1) and Gilgit (Node 2) is 208 km. The shortest path between source and sink in terms of distance is 2,549 kilometers (Figure 4 (a)).

### 5.1.2. Shortest Time Route

For shortest time route calculations, the weight of each edge is set to the time needed to travel between its two nodes. The travel time is calculated based on road conditions, i.e., whether the truck is traveling on Motorway, Highway or Hilly Roads. As discussed in Section 4, the speed of a truck is assumed 70 km/hr for Motorway, 45 km/hr for Highway and 35 km/hr for Hilly Roads. The shortest path from source to sink in terms of travel time is 53.43 hours (Figure 5 (b)). The overall travel distance for this route is 2,618.5 kilometres.

### 5.1.3. Comparison with Proposed Routes

In logistics networks, shortest travel time is directly related to total cost (Anderluh et al., 2019).

Several studies have been done on various logistics networks in order to estimate the shortest travel time amongst different routes in context of analysing total cost (see for example (Chen et al., 2015; Jeevan et al., 2015; Qin et al., 2014; Rahman & Shurong, 2017; Shaikh et al., 2016). In accordance with this, Hellinga and Fu (Hellinga & Fu, 1999) argued that drivers are more sensitive about expected travel time and likely to have a lower tolerance for experiencing travel times that exceed their expectations.

The network representation of the three different routes of CPEC planned by the government of Pakistan is shown in Figure 5. It can be seen from the network representation that there is an identical sub-route from Khunjerab Pass (Node 1) to Haripur (Node 10). However, after Haripur, the routes diverge along Eastern, Central, and Western alignments. The Western and Central routes combine again at Quetta (Node 21) and follow the same path thereafter up to Gwadar (Node 29).

It is evident from Figures 4 and 5 that neither the shortest distance nor the shortest time route matches completely with any of the three planned routes. However, the shortest path in terms of distance and travel time is similar. The routes are identical from Khunjerab Pass to Islamabad (1-2-4-7-10-13) and then from Shikarpur to Gwadar (22-24-27-29). The only difference is that the shortest distance route diverges from Islamabad-DI Khan-DG Khan-

Shikarpur (13-17-18-22) while the shortest time route diverges from Islamabad-Pindi Bhattian-Multan-Sukkur-Shikarpur (13-16-19-23-22).

NBR  
1,1

**Figure 5. CPEC planned routes.**

The Western route is composed of nodes 1-2-4-7-10-12-11-14-17-20-21-24-27-29, the Central route of 1-2-4-7-10-13-17-18-22-21-24-27-29, and the Eastern route of 1-2-4-7-10-13-16-19-23-25-2

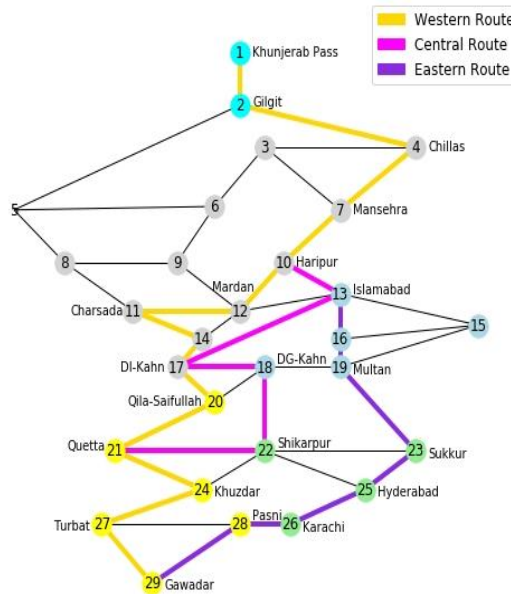


Table 2 shows a comparative analysis of the distance and travel time calculations for Western, Central, and Eastern routes along with the shortest distance route and shortest time route. The results show that amongst the planned three routes the best is the Eastern route. However, travel time for the Eastern route is 6% (i.e., an increment of 3.17 hours) more than the best alternate route given by the shortest time route, which might result in truck drivers selecting the route that provides the shortest travel time.

**Table 2.**  
*Difference between Routes in terms of distance and time*

Routes	Shortest Distance Route	Shortest Time Route	Western Route	Central Route	Eastern Route
Distance (Km)	2,549	2,618.5 (+69.5)	2,727 (+178)	3,098 (+549)	2,854 (+305)
Time (Hr)	56.83 (+3.4)	53.43	65.02 (+11.59)	69.54 (+16.11)	56.6 (+3.17)

Transport infrastructure is a key factor for the economic development of any region. Hence, for promoting equitable regional development, it is desirable that all the regions should get their proper share in the CPEC road network. Therefore, it is important to provide a concrete examination for the policy makers that which of the CPEC routes will benefit which region of Pakistan the most.

## 5.2 Regional Share of different routes

### 5.2.1 Geographical distribution across different routes

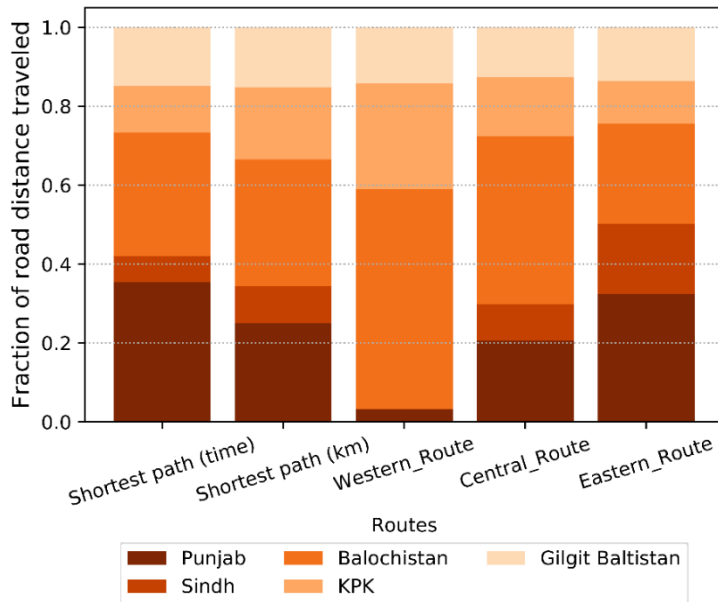
Figure 6 shows the geographical distribution, in terms of kilometres, for alternate routes within the CPEC road network in Pakistan. The three planned routes, the shortest distance, and the shortest travel time route will pass through several regions of Pakistan.

The result shows that the shortest travel time route will have a regional share distribution of 37% Punjab, 5% Sindh, 34% Balochistan, 9% KPK, and 15% of Gilgit-Baltistan in the CPEC network. Similarly, the shortest distance route comprises of all regions with an added share of KPK. In contrast, the

NBR  
1,1

Page 24

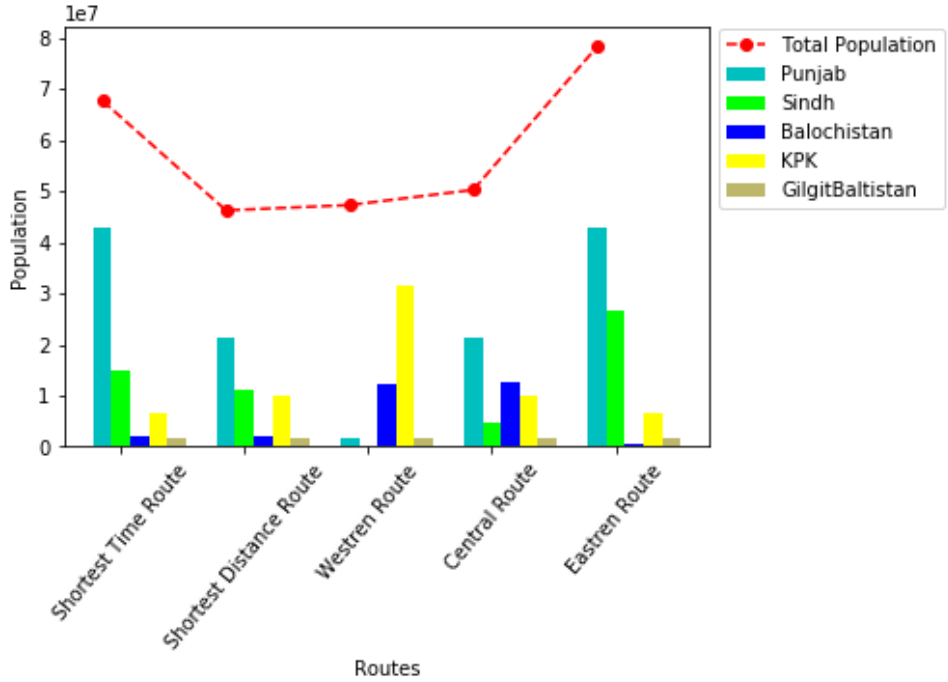
**Figure 6.**  
*Regional share  
of different  
routes of CPEC*



Western route only consists of three regions, i.e., Balochistan, KPK and Gilgit-Baltistan. However, the Eastern route exhibits the highest degree of equality in regional distribution, and it is furthermore the second most appropriate option with respect to travel time. It includes 34% Punjab, 17% Sindh, 24% Balochistan, 13% KPK and 12% of Gilgit- Baltistan.

### 5.2.2 Population Distribution across different routes

As discussed earlier, the transport sector plays a significant role in socio-economic development. Therefore, it is important to take in to account the population that benefits from the development of transport infrastructure. Figure 7 shows the population distribution for all the alternate routes within the CPEC road network. The population is not uniformly distributed along with the CPEC road network as shown in Table 3. The population data for the analysis is based on the census report issued by the Pakistan Bureau of



**Figure 7.**  
*Population  
Distribution for  
CPEC Road  
Network*

Statistics (Pakistan Bureau of Statistics, 2018). The population has been considered on the basis of small units (i.e., Tehsil) that are found within the radius of 30 km of specific edge passing through it.

**Table 3.**  
*Total and  
Regional  
Population  
Distribution  
along routes*

Route	Punjab	Sindh	Balochistan	KPK	Gilgit Baltistan	Total Population
Shortest Time	42,777,634	14,767,733	2,027,656	6,451,894	1,647,362	67,672,279
Shortest Distance	21,205,209	11,234,778	2,027,656	10,098,043	1,647,362	46,213,048
Western	1,883,556	0	12,121,166	31,607,740	1,647,362	47,259,824
Central	21,205,209	4,558,428	12,715,020	10,098,043	1,647,362	50,224,062
Eastern	42,777,634	26,727,583	581,232	6,451,894	1,647,362	78,185,705

The result shows that the Eastern route will cover the highest number (i.e., 78.1 Million) of the population across the route and Shortest Time Route is furthermore the second most appropriate option with respect to the population as it contains a population of 67.6 Million. However, the shortest distance route will only cover 46.2 Million people out of 20.01 Million population of Pakistan. Moreover, Western Route completely negates Sindh.

In contrast, out of all the five regions, Balochistan has the smallest population share among the available routes. Gilgit-Baltistan will have the

same number (i.e., 1.64 Million) as all the routes passing through this region, as discussed in 5.1.3. Although the total population of Central route is 5.02 Million, but it exhibits the highest degree of equality in population distribution.

### 5.3. Identification of Important Cities in the Network

Other than transport infrastructure, CPEC comprises of several economic zones to be established by 2030 at regions for the CPEC road network (China Pakistan Economic Corridor (CPEC), 2018). Therefore, it is important to identify key cities (nodes) in the road network that can act as transport hubs and ideal locations for special economic zones.

One of the most frequently used measures for the importance of a node is betweenness centrality which indicates whether a node provides a bridging role in the network. Betweenness centrality is calculated as the fraction of shortest paths between node pairs that pass through the node of interest and can be considered as a good measure to distinguish the most influential node in the network (Newman, 2005).

Closeness centrality focuses on how close a node is to all the other nodes in a network. It is calculated as the reciprocal value of the sum of the shortest paths from the observed node to all other nodes. Like betweenness centrality, it also describes the extent of the importance of a node in the network.

Figure 8 shows the normalised betweenness and closeness centrality values based on distances between nodes of the CPEC road network. The results indicate that the highest betweenness and closeness centrality values are for Islamabad (Node 13) and DI Khan (Node 17). From the centrality measures, it is clear that both Islamabad (Node 13) and DI Khan (Node 17) hold important positions in the CPEC road network of Pakistan. Not only do they provide the highest number of shortest paths to pass through them, but they also occupy central locations in the network. Hence, these two nodes will be frequented more during the transportation of goods and act as main transport hubs. The centrality calculations are limited to the CPEC road network. The importance of different cities would alter if cross-border trade with neighbouring countries (i.e., India, Iran, and Afghanistan) were taken into consideration.

### 5.4. Network Robustness

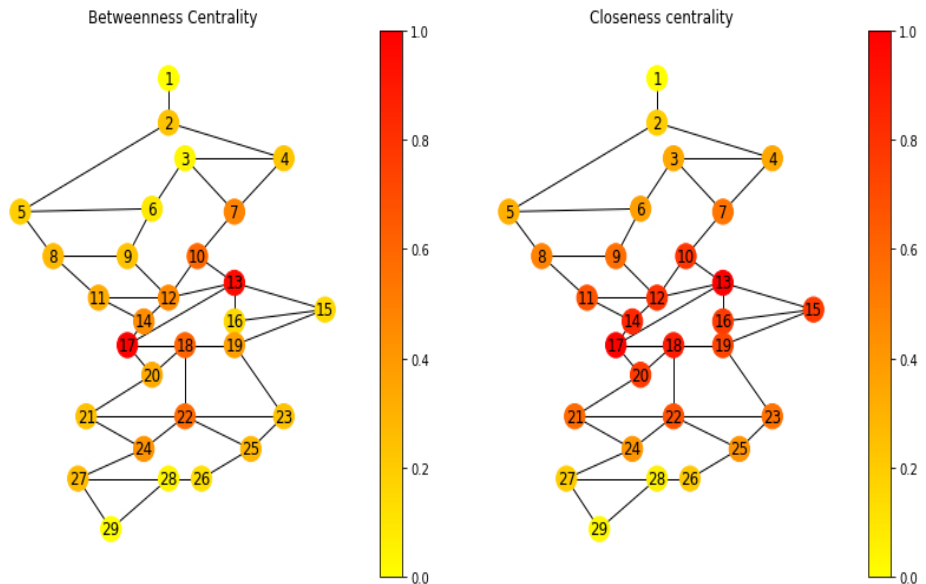
Stricker and Lanza (Stricker & Lanza, 2014), defined robustness as the ability of a system under impediment to remain in a predefined robustness zone. Regarding networks, Jenelius (Jenelius, 2009) claims that the importance of an edge can be estimated by the effect of any edge(s) removal on the performance of the system. Thus, combining the above two notions,

the network robustness is computed in this study by a knock-out analysis, i.e., quantifying the impact on the shortest path (both in terms of distance and travel time) when a single edge is or multiple edges are removed from the network, as described in Section 4.

#### 5.4.1. Path Robustness against Single Road Closure: Edge Knock-out Analysis

To assess the impact of the closure of a single road on the different CPEC routes, each edge on a route is removed and the shortest possible detour is calculated. It is assumed that travel time and distance remain unchanged for all other undisrupted edges when an edge is removed from the network.

To judge the robustness of the network, five distinct routes were considered:



**Figure 8.** Normalized centrality values as a proxy for importance of the nodes in the road network model. A higher value (red colour) denotes a higher centrality in the network. The node labels correspond to the numbering of the cities as in Figure 3.

- Shortest time route (edges: 2-4, 4-7, 7-10, 10-13, 13-16, 16-19, 19-23, 23-22, 22-24, 24-27, 27-29)
- Shortest distance route (edges: 2-4, 4-7, 7-10, 10-13, 13-17, 17-18, 18-22, 22-24, 24-27, 27-29)
- Western route (edges:2-4, 4-7, 7-10, 10-12, 12-11, 11-14, 14-17, 17-20, 20-21, 21-24, 24-27, 27-29)
- Central route (edges: 2-4, 4-7, 7-10, 10-13, 13-17, 17-18, 18-22, 22-21, 21-24, 24-27, 27-29) and
- Eastern route (edges: 2-4, 4-7, 7-10, 10-13, 13-16, 16-19, 19-23, 23-25, 25-26, 26-28, 28-29)

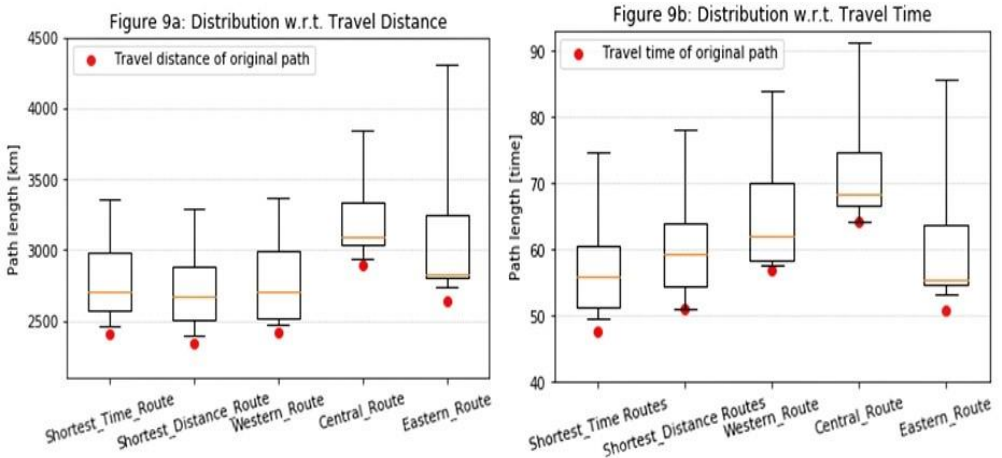
It is important to note that the edge between Khunjerab Pass (Node1) and Gilgit (Node 2) is not considered in the edge knock out analysis, as its



removal will leave the network dysfunctional. This is due to the peculiar nature of the CPEC road network in Pakistan, as there is no alternate path between Khunjerab Pass (Node1) and Gilgit (Node 2). Thus, edge knock-out analysis is carried out on all the edges between Gilgit (Node 2) to Gwadar (Node 29).

The removal of a single edge from a specific route means that the original route remains in operation, but only the two cities being connected by the removed edge need to be re-connected by finding the shortest available path between them. The resulting route distance is by definition larger (or at least equal) than the original route distance. The impact, both in terms of distance travelled and travel time, was evaluated and the edge knock-out distribution analysis is presented in Figure 9.

Figure 9 (a) shows the distribution of the resulting distances of various routes of the observed road network with respect to travel distance. The red dot represents the original travel distance of the indicated routes. For the shortest travel distance route as shown in Figure 9 (a), the original travel distance is 2341 km excluding the edge travel distance between Khunjerab Pass (Node 1) and Gilgit (Node 2). The median for the shortest distance route after removing the edges is 2725 km, indicated by the orange line in the middle of the box plot. The overall distribution of travel distance including detours for any a removed edge lies within 2410-3300 km, as indicated by the lower and upper whiskers. The box in the middle of each box plot spans from the lower to the upper quartile values. While comparing all the routes in Figure 9 (a), it seems that the median of the shortest travel distance route is nearby the Western route, shortest travel time route, and Eastern route.



**Figure 9.**  
*Edge Knock-out  
distribution  
analysis of  
different routes  
of CPEC*

Similarly, Figure 9 (b) illustrates the change in travel time of different routes. The red dot, in this case, represents the original travel time of each route. Figure 9 (b) shows that for shortest travel time route, the original travel time is 47.49 hours excluding the edge travel time between Khunjerab Pass (Node 1) and Gilgit (Node 2). In case of shortest travel time, the lower and upper whiskers lie between 50 and 75 hours. Although the median of shortest travel time and Eastern route is approximately equal, the broader variation in the Eastern route represents the existence of critical links within the route that results in an increase in travel time. It also supports the argument that other than the shortest travel time route the Eastern route is the most viable option in all the three proposed routes as shown in Table 1.

The results indicate that the knock-out analysis as applied here can be used to distinguish different routes in a transportation network regarding the impact of edge removals (as a proxy for a breakdown of a transportation connection) on the performance. The advantage of this type of study is that it can be applied to other transportation networks as well and that the effort to implement it is manageable. The observed performance criterion to quantify robustness can be adapted to the given case and is not limited to travel time or distance. However, the effects of edge removals across different networks can only be compared to a limited extent due to the impact of individual network properties such as network size or connectivity on selected performance measures.

#### 5.4.2 Network Robustness against Collective Road Closures: Multiple Edge Knockout Analysis

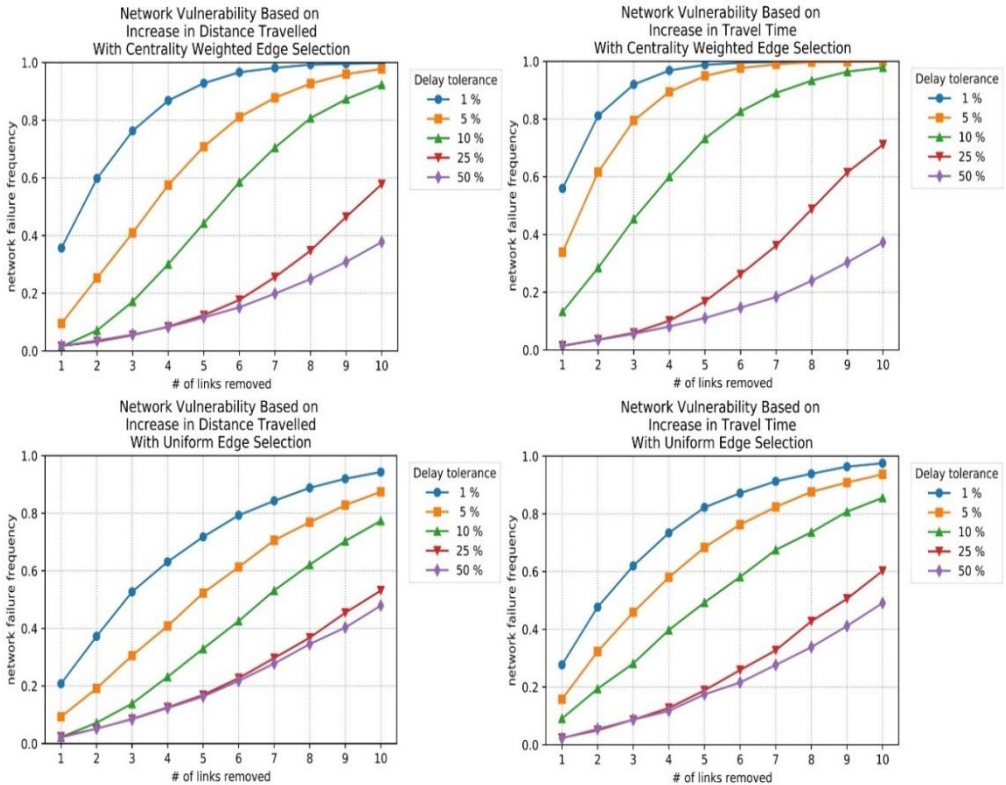
The previous section investigated the impact of a single edge removal as part of a knock-out analysis. However, under certain circumstances, more severe events can threaten the functioning of a network. In terms of our graph model, such an event would cause the failure of multiple items in the network. These events could be nationwide natural disasters, such as earthquakes, floods, or coordinated attacks. Therefore, a second type of edge knock-out analysis was conducted, which investigated the impact of multiple edge removal in the network as shown in Figure 10.

On the basis of definition of robustness, this study tends to evaluate by considering the edge removals from the network. The functionality of the system, i.e., the observed road network, can be expressed as keeping up the ability to deliver goods in time. Therefore, we define robustness in this case as a maximally accepted increase in travel time or distance after a certain number of edges have been removed. For example, in case of accepting a 10% increase, the network will be robust as long as the edge removals do not result in the travel time increasing over 52.23 hours (which is the minimum

travel time of 47.49 hours plus a 10% increase). Thus, during the knock-out analysis, a network failure probability is observed. It indicates how likely it is that the minimum travel time or distance from source to sink does not increase above the selected threshold after the removal of a certain number of edges.

Due to the large number of possible permutations when selecting the order of edges to be removed, it was necessary to find an evaluation method that allows an average over numerous different combinations of removed edges. Consequently, this type of knock-out analysis removes a bunch of

NBR  
1,1



**Figure 10.**  
Network  
Robustness  
Measurements

edges in a random fashion from the network and checks after the removal if the robustness condition as described above is still met. This process is repeated 10,000 times and the network failure probability of the network is determined from the empirically observed results. Again, only the network from Gilgit (Node 2) to Gwadar (Node 29) was used. Regarding the procedure of the random selection of edges, two variants were applied. First, each edge in the network had a uniform probability to be chosen for removal. In the second variant, the probability of an edge to be removed was proportional to its edge betweenness centrality in order to simulate targeted attacks on important connections in the network. The procedure was

repeated for five different robustness thresholds, i.e., 1%, 5%, 10%, 25%, and 50%, in combination with the simultaneous removal of one to ten edges.

The resulting probability distribution functions are displayed in Figure 9. It can be observed that for low threshold values, there is a steep increase in failure frequency when removing more edges. In turn, extremely high tolerance regarding travel time or distance increase barely has an impact on robustness. It is noteworthy that targeted attacks, simulated by weighted edge selection, have a clearly stronger impact on robustness (as expected), but also travel time turns out to be more sensitive than distance. In general, this type of analysis can be used as a risk assessment of the complete network and as a comparative tool for possible variations of the same network.

Hence, even networks of different sizes and structures can be compared. On the downside, the interpretation of the resulting curves needs more attention and the observed results cannot be expressed in a single figure as, e.g., in the previously studied single-edge knock-out analysis when considering the average travel time or distance. Furthermore, the necessity of a-priori selection of the threshold for a network failure influences the outcome, so that ideally multiple thresholds must be tested.

## 6. Conclusion

The China Pakistan Economic Corridor (CPEC) is a framework of regional connectivity. The novelty of this research is the quantification of the properties of the CPEC road network, an area that has not been explored by other researchers up to now. In this study, the performance and robustness of the CPEC road network were investigated and questions regarding the shortest route, the share of different regions in the network, and the robustness of the network were answered using a model based on graph theory and tools from the domain of network analysis.

The government of Pakistan has planned three routes as possible options for the development of CPEC: The Eastern, Central, and Western routes. However, the results in this study indicated the presence of another route that is shortest in terms of travel time. This “shortest travel time route” is the combination of Central and Eastern routes. The regional distribution of each route within the network was analysed and the results suggested that the shortest travel time route does not contain the desirable share of regions due to the underrepresentation of Sindh, which is the second largest province, and the overrepresentation of Punjab. On the other hand, the Eastern route exhibited the most equitable share either with respect to infrastructure (i.e., 34% Punjab, 17% Sindh, 24% Balochistan, 13% KPK, and 12% of Gilgit-Baltistan) or by population distribution (i.e., 78.1 Million) for all the provinces in the network.

Moreover, the significance of various cities in the CPEC road network was evaluated and it was found that both Islamabad and DI Khan can act as transport hubs because of their high centrality values. According to Pakistan's Ministry of Planning, Development and Reform, an important aspect of CPEC is the development of Special Economic Zones (SEZ). Hence, owing to their high centrality values, both Islamabad and DI-Khan have the potential to become logistics centres for warehousing activities in Pakistan. Moreover, Islamabad's central location in the network is further strengthened by its presence on the shortest travel time route. The results also indicate that apart from the source Khunjerab Pass and the sink Gwadar, the most important node that causes the network to become dysfunctional is Gilgit.

Furthermore, the robustness of the network was determined using a knock-out analysis for single as well as multiple edges (link roads between cities). The single edge removal analysis also supports the argument that other than the shortest travel time route the Eastern route is the most viable option in all the three proposed routes. Moreover, to estimate the overall performance of the CPEC road network, multiple edge knock-out analysis was performed. This was done to analyse the sustainability of the network under severe conditions (for instance, natural disasters) where multiple links (roads) can be broken. It was established that the CPEC road network is robust and can maintain good operational performance.

The strength of the study is that it provides a tool for analysis of economic corridors (like CPEC) which are at the inception phase with limited availability of data. While the research presented in this paper focused on providing a decision-making toolbox for the policy makers of Pakistan (in context of CPEC road network in Pakistan), this research can be used as a template for similar analysis in other regions of the world using publically available data such as government reports, google maps, etc. Furthermore, additional aspects regarding road flow capacity, demographic changes, and multi-modal transport can also be integrated with our calculations for more far reaching insight into benefits and risks of economic corridor-based road networks.

#### **Author Contributions:**

*R. A. Liaqat: Literature Search and Review, Data Collection, Network Modelling and Manuscript Writing.*

*M. H. Agha: Content Planning, Literature Search and Review, Data Collection, Manuscript Writing and Editing.*

*T. Becker: Network and Robustness Analysis, Manuscript Writing and Editing.*

## References

- Ahmed, R., & Mustafa, U. (2014). Impact of CPEC projects on agriculture sector of Pakistan: Infrastructure and agricultural output linkages. Pakistan Institute of Development Economics (PIDE): Islamabad, Pakistan. 511–528.
- uddin Ahmed, S., Ali, A., Kumar, D., Malik, M. Z., & Memon, A. H. (2019). China Pakistan Economic Corridor and Pakistan's energy security: A meta-analytic review. *Energy policy*, 127, 147-154. <https://doi.org/10.1016/j.enpol.2018.12.003>
- Airey, T. (1992). The impact of road construction on the spatial characteristics of hospital utilization in the Meru district of Kenya. *Social Science and Medicine*, 34(10), 1135–1146. [https://doi.org/10.1016/0277-9536\(92\)90287-Z](https://doi.org/10.1016/0277-9536(92)90287-Z)
- Ali, Y., Rasheed, Z., Muhammad, N., & Yousaf, S. (2018). Energy optimization in the wake of China Pakistan Economic Corridor (CPEC). *Journal of Control and Decision*, 5(2), 129–147. <https://doi.org/10.1080/23307706.2017.1353929>
- Anderluh, A., Larsen, R., Hemmelmayr, V. C., & Nolz, P. C. (2019). Impact of travel time uncertainties on the solution cost of a two-echelon vehicle routing problem with synchronization. *Flexible Services and Manufacturing Journal*, 1-23. <https://doi.org/10.1007/s10696-019-09351-w>
- Asian Development Bank. (2016). Pakistan Enabling Economic Corridors through Sustainable Transport Sector.
- Bains, M. S., Bhardwaj, A., Arkatkar, S., & Velmurugan, S. (2013). Effect of Speed Limit Compliance on Roadway Capacity of Indian Expressways. *Procedia - Social and Behavioural Sciences*, 104, 458–467. <https://doi.org/10.1016/j.sbspro.2013.11.139>
- Balakrishnan, S., & Sivanandan, R. (2015). Influence of lane and vehicle subclass on free-flow speeds for urban roads in heterogeneous traffic. *Transportation Research Procedia*, 10, 166-175. <https://doi.org/10.1016/j.trpro.2015.09.066>
- Balijepalli, C., & Oppong, O. (2014). Measuring vulnerability of road network considering the extent of serviceability of critical road links in urban areas. *Journal of Transport Geography*, 39, 145–155. <https://doi.org/10.1016/j.jtrangeo.2014.06.025>
- Bengali, K., Baloch, I., Khan, B., Tareen, M., Hafeez, M., & Yousaf, S. (2015), "China Pakistan Economic Corridor? The Route Controversy.", available at: <http://www.cmpru.gov.pk/reports/CPEC.pdf> (accessed 18 October 2018)

- Berdica, K. (2002). An introduction to road vulnerability: What has been done, is done and should be done. *Transport Policy*, 9(2), 117–127. [https://doi.org/10.1016/S0967-070X\(02\)00011-2](https://doi.org/10.1016/S0967-070X(02)00011-2)
- Berdica, K., & Mattsson, L. (2007). Vulnerability: A Model-Based Case Study of the Road Network in Stockholm. *Critical Infrastructure*, 81–106. [https://doi.org/https://doi.org/10.1007/978-3-540-68056-7\\_5](https://doi.org/https://doi.org/10.1007/978-3-540-68056-7_5)
- Bíl, M., Vodák, R., Kubeček, J., Bílová, M., & Sedoník, J. (2015). Evaluating road network damage caused by natural disasters in the Czech Republic between 1997 and 2010. *Transportation Research Part A: Policy and Practice*, 80, 90–103. <https://doi.org/10.1016/j.tra.2015.07.006>
- Bourdet, Y. (1998). The Dynamics of Regional Disparities in Laos: The Poor and the Rich. *Asian Survey*, 38(7), 629–652. <https://doi.org/10.2307/2645753>
- Buurman, J., & Rietveld, P. (1999). Transport Infrastructure and Industrial Location: The Case of Thailand. *Review of Urban and Regional Development Studies*, 11(1), 45–62. <https://doi.org/10.1111/1467-940X.00004>
- Cats, O. (2016). The robustness value of public transport development plans. *Journal of Transport Geography*, 51, 236–246. <https://doi.org/10.1016/j.jtrangeo.2016.01.011>
- Chen, X. Z., Lu, Q. C., Peng, Z. R., & Ash, J. E. (2015). Analysis of transportation network vulnerability under flooding disasters. *Transportation Research Record*, 2532, 37–44. <https://doi.org/10.3141/2532-05>
- Cheng, L. K. (2016). Three questions on China's "Belt and Road Initiative". *China Economic Review*, 40, 309–313. <https://doi.org/10.1016/j.chieco.2016.07.008>
- China Pakistan Economic Corridor (CPEC). (2017). CPEC Infrastructure Projects. Retrieved from <http://cpec.gov.pk/infrastructure>
- China Pakistan Economic Corridor (CPEC) (2018). CPEC Special Economic Zones (SEZs). Retrieved from <http://cpec.gov.pk/special-economic-zones-projects>
- Deichmann, U., Kaiser, K., Lall, S. V., & Shalizi, Z. (2005). Agglomeration, transport, and regional development in Indonesia. The World Bank.
- Derudder, B., & Kunaka, C. (2018). Connectivity Along Overland Corridors of the Belt and Road Initiative, Tech. rep., The World Bank.
- Dunn, S., & Wilkinson, S. M. (2015). Increasing the resilience of air traffic networks using a network graph theory approach. *Transportation*

*Research Part E: Logistics and Transportation Review*, 90, 39–50.

<https://doi.org/10.1016/j.tre.2015.09.011>

El-Rashidy, R. A., & Grant-muller, S. M. (2014). An assessment method for highway network vulnerability. *Journal of Transport Geography*, 34, 34–43. <https://doi.org/10.1016/j.jtrangeo.2013.10.017>

Fan, S., & Chan-kang, C. (2005). Road Development, Economic Growth, and Poverty Reduction in China.

Geological Survey of Pakistan. (2017). <http://www.gsp.gov.pk/> (accessed 9 December 2017)

Hellinga, B., & Fu, L. (1999). Route selection considering travel time variability. In 6th World Congress on Intelligent Transport Systems, Toronto, Ontario.

Hof, B., Heyma, A., & van der Hoorn, T. (2012). Comparing the performance of models for wider economic benefits of transport infrastructure: results of a Dutch case study. *Transportation*, 39(6), 1241–1258. <https://doi.org/10.1007/s11116-011-9383-4>

Huang, Y. (2016). Understanding China's Belt & Road Initiative: Motivation, framework and assessment. *China Economic Review*, 40, 314–321. <https://doi.org/10.1016/j.chieco.2016.07.007>

Ivanova, E., & Masarova, J. (2013). Importance of Road Infrastructure in the Economic Development and Competitiveness. *Economics and Management*, 18(2), 263–274.

<https://doi.org/http://dx.doi.org/10.5755/j01.em.18.2.4253>

Jacoby, H. G. (2000). Access to markets and the benefits of rural roads. *Economic Journal*, 110(465), 713–737. <https://doi.org/10.1111/1468-0297.00562>

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., & Canteras-Jordana, J. C. (2014). A review of application of multi-criteria decision-making methods in construction. *Automation in Construction*, 45, 151–162. <https://doi.org/10.1016/j.autcon.2014.05.013>

Javier Gutierrez and Paloma. (1996). Accessibility in the European Union: The impact of the trans-European road network. *Journal of Transport Geography*, 4(1), 15–25. [https://doi.org/10.1016/0966-6923\(95\)00042-9](https://doi.org/10.1016/0966-6923(95)00042-9)

Jeevan, J., Chen, S. L., & Lee, E. S. (2015). The challenges of Malaysian dry ports development. *Asian Journal of Shipping and Logistics*, 31(1), 109–134. <https://doi.org/10.1016/j.ajsl.2015.03.005>

Jenelius, Erik; Mattsson, L. G. (2015). Road network vulnerability analysis: Conceptualization, implementation and application. *Computers*,



*Environment and Urban Systems*, 49, 136–147.

<https://doi.org/10.1016/j.compenvurbsys.2014.02.003>

Jenelius, E. (2009). Network structure and travel patterns: explaining the geographical disparities of road network vulnerability. *Journal of Transport Geography*, 17(3), 234–244.

<https://doi.org/10.1016/j.jtrangeo.2008.06.002>

Jenelius, E. (2010). Redundancy importance: Links as rerouting alternatives during road network disruptions. *Procedia Engineering*, 3, 129–137. <https://doi.org/10.1016/j.proeng.2010.07.013>

Jenelius, E., & Mattsson, L. G. (2012). Road network vulnerability analysis of area-covering disruptions: A grid-based approach with case study. *Transportation Research Part A: Policy and Practice*, 46(5), 746–760. <https://doi.org/10.1016/j.tra.2012.02.003>

Jeremy Garlick (2018) Deconstructing the China–Pakistan Economic Corridor:

Pipe Dreams Versus Geopolitical Realities, *Journal of Contemporary China*, 27:112, 519-533. <https://doi.org/10.1080/10670564.2018.1433483>

Kitano, H. (2004). Biological robustness. *Nature Reviews Genetics*. <https://doi.org/10.1038/nrg1471>

Knoop, V. L., Snelder, M., van Zuylen, H. J., & Hoogendoorn, S. P. (2012). Link-level vulnerability indicators for real-world networks. *Transportation Research Part A: Policy and Practice*, 46(5), 843–854. <https://doi.org/10.1016/j.tra.2012.02.004>

Kurauchi, F., Uno, N., Sumalee, A., & Seto, Y. (2009). Network Evaluation Based on Connectivity Vulnerability. *Transportation and Traffic Theory 2009: Golden Jubilee*, 637–649. [https://doi.org/10.1007/978-1-4419-0820-9\\_31](https://doi.org/10.1007/978-1-4419-0820-9_31)

Lampe, K. J. (2016). Rural Development in Mountainous Areas: Why Progress Is So Difficult. In *Mountain Research and Development, Workshop on the Stability and Instability of Mountain Ecosystems*. 3,14–19.

International Mountain Society. available at:

<http://www.jstor.org/stable/3672993>

Latif, Z., Jianqiu, Z., Ullah, R., Pathan, Z. H., & Latif, S. (2017). Application of Optical Frequency Comb in High-Capacity Long Distance Optical Communication for China-Pakistan Economic Corridor. *Journal of Optical Communications*, 38(3), 331–340.

<https://doi.org/10.1515/joc-2017-0014>

Latora, V., & Marchiori, M. (2007). A measure of centrality based on network efficiency. *New Journal of Physics*, 9, 188.

<https://doi.org/10.1088/1367-2630/9/6/188>

- Lucas, K., & Currie, G. (2011). Developing socially inclusive transportation policy: Transferring the United Kingdom policy approach to the State of Victoria? *Transportation*, 39(1), 151–173. <https://doi.org/10.1007/s11116-011-9324-2>
- Mahmood, M. (2015). *China – Pakistan Economic Corridor - The Geo Strategic Dimension and Challenges*.
- Min, Y., Jin, X., Chen, M., Pan, Z., Ge, Y., & Chang, J. (2011). Pathway knockout and redundancy in metabolic networks. *Journal of Theoretical Biology*, 270(1), 63–69. <https://doi.org/10.1016/j.jtbi.2010.11.012>
- Ministry of Planning, Development & Reform. (2017). Retrieved from <http://www.pc.gov.pk/>
- Munir, M., Khalid, R., & Latif, M. (2017). Route optimization for the cement industry under the CPEC initiative. *Business Review*, 12(2), 65–83. Available at: <http://e-space.mmu.ac.uk/621182/http://e-space.mmu.ac.uk>
- Naseem, N. (2017). Geopolitical Value of Gwader for the Region (Mainly for Pakistan, China and the Region). *South Asian Studies (1026-678X)*, 29(2), 519–530. Available at: <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=100306235>
- National Highways Authority. (2017), <http://nha.gov.pk/en/> (accessed 19 November 2017)
- National Logistics Cell. (2017), <http://www.nlc.com.pk/> (accessed 27 December 2017)
- Newman, M. E. J. (2005). A measure of betweenness centrality based on random walks. *Social Networks*, 27(1), 39–54. <https://doi.org/10.1016/j.socnet.2004.11.009>
- Nistor, F., & Popa, C. C. (2016). The Role of Transport in Economic Development. 534. *Naval Academy Press*. Available at: <https://mpira.ub.uni-muenchen.de/70586/>
- Oliveira, C. A. S., & Pardalos, P. M. (2011). *Mathematical Aspects of Network Routing Optimization (53)*. Springer New York. <https://doi.org/10.1007/978-1-4614-0311-1>
- Pakistan Bureau of Statistics. (2018). Retrieved from <http://www.pbs.gov.pk/>
- Peer M (2015) China-Pakistan Economic Corridor: Issue of western, eastern routes raised again. URL <https://tribune.com.pk/story/937045/china-pakistaneconomic-corridor-issue-of-western-eastern-routes-raised-again>

- Prato, C. G., & Bekhor, S. (2012). Latent variables and route choice behaviour. *Transportation*, 39(2), 299–319. <https://doi.org/10.1007/s11116-011-9344-y>
- Qin, J., He, Y., & Ni, L. (2014). Quantitative efficiency evaluation method for transportation networks. *Sustainability*, 6(12), 8364–8378. <https://doi.org/10.3390/su6128364>
- Qureshi, A. H. (2015). China/Pakistan Economic Corridor: A Critical National and International Law Policy Based Perspective. *Chinese Journal of International Law*, 14(4), 777–799. <https://doi.org/10.1093/chinesejil/jmv045>
- Rafiq, A. (2017). "China-Pakistan Economic Corridor (CPEC), Barriers and Impact." available at: <https://www.usip.org/sites/default/files/2017-10/pw135-the-china-pakistan-economic-corridor.pdf> (accessed 21 November 2018)
- Rahman, S. U., & Shurong, Z. (2017). Analysis of Chinese Economic and National Security Interests in China-Pakistan Economic Corridor (CPEC) under the Framework of One Belt One Road (OBOR) Initiative. *Arts and Social Sciences Journal*, 8(4), 1-7. <https://doi.org/10.4172/2151-6200.1000284>
- Reka Albert, Hawoong jeong, A.-L. B. (2004). Error and attack tolerance of complex networks. *Physica A: Statistical Mechanics and Its Applications*, 340(1–3), 388–394. <https://doi.org/10.1016/j.physa.2004.04.031>
- Rodríguez-Núñez, E., & García-Palomares, J. C. (2014). Measuring the vulnerability of public transport networks. *Journal of Transport Geography*, 35, 50–63. <https://doi.org/10.1016/j.jtrangeo.2014.01.008>
- Rupi, F., Angelini, S., Bernardi, S., Danesi, A., & Rossi, G. (2015). Ranking links in a road transport network: A practical method for the calculation of link importance. *Transportation Research Procedia*, 5, 221–232. <https://doi.org/10.1016/j.trpro.2015.01.003>
- Saha Ray, S. (2013). Algorithms on Graphs. In *Graph Theory with Algorithms and its Applications*, 49–93. Springer India. [https://doi.org/10.1007/978-81-322-0750-4\\_5](https://doi.org/10.1007/978-81-322-0750-4_5)
- Sakakibara, H., Kajitani, Y., & Okada, N. (2004). Road Network Robustness for Avoiding Functional Isolation in Disasters. *Journal of Transportation Engineering*, 130(5), 560–567. [https://doi.org/https://doi.org/10.1061/\(ASCE\)0733-947X\(2004\)130:5\(560\)](https://doi.org/https://doi.org/10.1061/(ASCE)0733-947X(2004)130:5(560))
- Shaikh, F., Ji, Q., & Fan, Y. (2016b). Prospects of Pakistan-China Energy and Economic Corridor. *Renewable and Sustainable Energy Reviews*, 59, 253–263. <https://doi.org/10.1016/j.rser.2015.12.361>

- Sheu, J. B., & Kundu, T. (2017). Forecasting time-varying logistics distribution flows in the One Belt-One Road strategic context. *Transportation Research Part E: Logistics and Transportation Review*, 117, 5–22. <https://doi.org/10.1016/j.tre.2017.03.003>
- Stricker, N., & Lanza, G. (2014). The concept of robustness in production systems and its correlation to disturbances. *Procedia CIRP*, 19(C), 87–92. <https://doi.org/10.1016/j.procir.2014.04.078>
- Stricker, Nicole, Pfeiffer, A., Moser, E., Kádár, B., Lanza, G., & Monostori, L. (2015). Supporting multi-level and robust production planning and execution. *CIRP Annals - Manufacturing Technology*, 64(1), 415–418. <https://doi.org/10.1016/j.cirp.2015.04.115>
- Sullivan, J. L., Novak, D. C., Aultman-Hall, L., & Scott, D. M. (2010). Identifying critical road segments and measuring system-wide robustness in transportation networks with isolating links: A link-based capacity-reduction approach. *Transportation Research Part A: Policy and Practice*, 44(5), 323–336. <https://doi.org/10.1016/j.tra.2010.02.003>
- Taylor, M. A., Sekhar, S. V., & D'Este, G. M. (2006). Application of accessibility-based methods for vulnerability analysis of strategic road networks. *Networks and Spatial Economics*, 6(3-4), 267-291. <https://doi.org/10.1007/s11067-006-9284-9>
- Taylor, M. A. (2012). Remoteness and accessibility in the vulnerability analysis of regional road networks. *Transportation research part A: policy and practice*, 46(5), 761-771. <https://doi.org/10.1016/j.tra.2012.02.008>
- Tian, W., Yu, M., & Zhang, F. (2016). The exceptional performance of Chinese outward direct investment firms. *China Economic Journal*, 9(2), 209-219. <https://doi.org/10.1080/17538963.2016.1172783>
- Vreeswijk, J., Thomas, T., Berkum, E. Van, & Arem, B. Van. (2014). Perception bias in route choice. *Transportation*, 41(6), 1305–1321. <https://doi.org/10.1007/s11116-014-9552-3>
- Windle, J., & Cramb, R. A. (1997). Remoteness and rural development: economic impacts of rural roads on upland farmers in, 38(1), 37–53.
- Xu, L. jun, Fan, X. chao, Wang, W. qing, Xu, L., Duan, Y. lian, & Shi, R. jing. (2017). Renewable and sustainable energy of Xinjiang and development strategy of node areas in the “Silk Road Economic Belt.” *Renewable and Sustainable Energy Reviews*, 79(March 2016), 274–285. <https://doi.org/10.1016/j.rser.2017.05.031>
- Yang, D., Pan, K., & Wang, S. (2017). On service network improvement for shipping lines under the one belt one road initiative of China. *Transportation Research Part E: Logistics and Transportation Review*. <https://doi.org/https://doi.org/10.1016/j.tre.2017.07.003>

Yao, B., Hu, P., Lu, X., Gao, J., & Zhang, M. (2014). Transit network design based on travel time reliability. *Transportation Research Part C: Emerging Technologies*, 43, 233–248.

<https://doi.org/10.1016/j.trc.2013.12.005>

Yu, B., Lam, W. H. K., Sumalee, A., Li, Q., & Li, Z. (2012). Vulnerability analysis for large-scale and congested road networks with demand uncertainty. *Transportation Research Part A*, 46(3), 501–516.

<https://doi.org/10.1016/j.tra.2011.11.018>

Zhang, R., Andam, F., & Shi, G. (2017). Environmental and social risk evaluation of overseas investment under the China-Pakistan Economic Corridor. *Environmental Monitoring and Assessment*, 189(6).

<https://doi.org/10.1007/s10661-017-5967-6>

Zhang, X., Miller-Hooks, E., & Denny, K. (2015). Assessing the role of network topology in transportation network resilience. *Journal of Transport Geography*, 46, 35–45.

<https://doi.org/10.1016/j.jtrangeo.2015.05.006>

Zheng, L., & Liu, Z. (2015). Spatial pattern of Chinese outward direct investment in the Belt and Road Initiative area. *Progress in Geography*, 34(5), 563–570. <https://doi.org/10.11820/dlkxjz.2015.05.004>

Zhou, Y., Sheu, J. B., & Wang, J. (2017). Robustness Assessment of Urban Road Network with Consideration of Multiple Hazard Events. *Risk Analysis*, (1). <https://doi.org/10.1111/risa.12802>

Sr. no.	Links	Distance	Punjab		Sindh		Balochistan		KPK		Gilgit Baltistan		Time
			%share	Road Type	% share	Road Type	% share	Road Type	% share	Road Type	% share	Road Type	
1	1 to 2	208	0%		0%		0%		0%		100%	Hilly Road	5.94
2	2 to 4	133	0%		0%		0%		0%		100%	Hilly Road	3.8
3	2 to 5	549	0%		0%		0%		61%	Hilly Road	39%	Hilly Road	15.69
4	3 to 6	84	0%		0%		0%		100%	Hilly Road	0%		2.4
5	3 to 7	244	0%		0%		0%		100%	Hilly Road	0%		6.97
6	4 to 3	285	0%		0%		0%		80%	Hilly Road	20%	Hilly Road	8.14
7	4 to 7	233	0%		0%		0%		79%	Hilly Road	21%	Hilly Road	6.66
8	5 to 6	165	0%		0%		0%		100%	Hilly Road	0%		4.71
9	5 to 8	154	0%		0%		0%		100%	Hilly Road	0%		4.4
10	6 to 9	44	0%		0%		0%		100%	Hilly Road	0%		1.26
11	7 to 10	63	0%		0%		0%		100%	Hilly Road	0%		1.8
12	8 to 9	66	0%		0%		0%		100%	Hilly Road	0%		1.89
13	8 to 11	27	0%		0%		0%		100%	Hilly Road	0%		0.77
14	9 to 12	88	0%		0%		0%		100%	Hilly Road	0%		2.51
15	10 to 12	125	0%		0%		0%		100%	Hilly Road	0%		3.57
16	10 to 13	103	40%	Highway	0%		0%		60%	Highway	0%		2.29
17	11 to 12	30	0%		0%		0%		100%	Motorway	0%		0.43
18	11 to 14	31	0%		0%		0%		100%	Motorway	0%		0.44
19	12 to 13	140	21.50%	Motorway	0%		0%		##	Motorway	0%		2
20	12 to 14	61	0%		0%		0%		100%	Highway	0%		1.36
21	13 to 15	293	100%	Highway	0%		0%		0%		0%		6.51
22	13 to 16	266	100%	Motorway	0%		0%		0%		0%		3.8
23	13 to 17	366	75.40%	Motorway	0%		0%		##	Motorway	0%		5.23
24	14 to 17	297	0%		0%		0%		100%	Highway	0%		6.6
25	15 to 16	129	100%	Motorway	0%		0%		0%		0%		1.84
26	15 to 19	333	100%	Motorway	0%		0%		0%		0%		4.76
27	16 to 19	288	100%	Motorway	0%		0%		0%		0%		4.11
28	17 to 18	217	70.50%	Highway	0%		0%		##	Highway	0%		4.82
29	18 to 20	347	25.90%	Highway	0%		74.10%	Highway	0%		0%		7.78
30	19 to 18	100	100%	Motorway	0%		0%		0%		0%		1.43
31	20 to 17	247	0%		0%		39%	Highway	61%	Highway	0%		5.49
32	21 to 20	189	0%		0%		100%	Highway	0%		0%		4.2
33	21 to 22	368	0%		33%	Highway	67%	Highway	0%		0%		8.18
34	21 to 24	301	0%		0%		100%	Highway	0%		0%		6.69
35	22 to 18	336	50%	Highway	50%	Highway	0%		0%		0%		7.47
36	23 to 19	387	85.80%	Motorway	14.20%	Motorway	0%		0%		0%		5.53
37	23 to 22	47.5	0%		100%	Motorway	0%		0%		0%		0.68
38	23 to 25	296	0%		100%	Motorway	0%		0%		0%		4.23
39	24 to 22	120	0%		60%	Motorway	40%	Motorway	0%		0%		1.71
40	25 to 22	346	0%		100%	Highway	0%		0%		0%		7.69
41	26 to 25	131	0%		100%	Motorway	0%		0%		0%		1.87
42	27 to 24	585	0%		0%		100%	Highway	0%		0%		13
43	27 to 28	121	0%		0%		100%	Hilly Road	0%		0%		3.46
44	28 to 26	623	0%		4%	Highway	96%	Highway	0%		0%		13.84
45	29 to 27	185	0%		0%		100%	Highway	0%		0%		4.11
46	29 to 28	123	0%		0%		100%	Highway	0%		0%		2.73

**Appendix**  
Table A.1:  
Details of all  
links between  
the nodes

**Table A.2:**  
*Nodes and their  
elevations*

Node no.	Cities	Elevation (Meters)
1	Khunjerab pass	4,693
2	Gilgit	1,500
3	Shangla	1,524
4	Chillas	1,146
5	Upper Dir	1,841
6	Khewazakhela	1,138
7	Mansehra	1,088
8	Takhat Bhai	402
9	Barikot	800
10	Haripur	520
11	Charsada	276
12	Mardan	286
13	Islamabad	620
14	Peshawar	359
15	Lahore	217
16	Pindi Bhattian	184
17	DI khan	165
18	DG khan	1,800
19	Multan	1,22
20	Qilla Saifullah	844
21	Quetta	1,680
22	Shikarpur	13
23	Sukkur	67
24	Khuzdar	1,237
25	Hyderabad	13
26	Karachi	8
27	Turbat	129
28	Pasni	10
29	Gwadar	8

## About Author

### Raja Awais Liaquat

*Mr. Raja Awais Liaquat is the MS student of Engineering Management at Capital University of Science and Technology, Islamabad. He has his Bachelors in Mechanical Engineering from Muhammad Ali Jinnah University, Islamabad campus. His research area focuses on supply chain optimization and logistics management of complex networks.*

### Mujtaba Hassan Agha

*Dr. Mujtaba Hassan Agha is Professor and Head of Department Operations and Supply Chain at NUST Business School. He did his PhD in Industrial Engineering from Institute National Polytechnique Toulouse (INPT), University of Toulouse (France). His teaching and research areas of interest are Production & Logistics Systems, Supply Chain Management and Energy Management.*

### Till Becker

*Dr. Till Becker is Professor of Information Systems at the University of Applied Sciences Emden/Leer in Germany. He obtained his PhD in International Logistics from Jacobs University in Bremen, Germany. His research focuses on complex networks in manufacturing and logistics and on the ongoing digitalization in industry.*

*The Corresponding Author Professor Mujtaba Hassan Agha can be contacted at:  
[mujtaba.agha@nbs.nust.edu.pk](mailto:mujtaba.agha@nbs.nust.edu.pk)*