Strategic planning of transportation infrastructure networks with case studies

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Research Article

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Posted Date: October 29th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1030158/v1

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Abstract

This paper discusses necessary qualitative and quantitative improvements in transport infrastructure networks and analyzes travel behavior and origin-destination situations. This paper studies idea about the re-planning of transportation infrastructures theoretically and implements a case study strategy that applies the gravity model and graph technique. Additionally, it has a mathematical model that assists in designing traffic flow in new streets, sidewalks, plazas, and spaces, while suggesting new urban land-use policies and transportation infrastructure-locating techniques. This work considers the planning of ground, railroad, maritime, and air transportation to build a comprehensive system in the urban master planning process. It prioritizes public transportation and suggests necessary geometrical adjustments to upgrade the situation of the infrastructure and prepare Chabahar city for its strategic and oceanic role. The outcome in geometric corrections in sight distance and transverse and longitudinal curves in streets, sidewalks, and squares will assist cities in the Silk Road project environmentally and make the region attractive to tourists and investors' eyes.

Keywords: Transportation infrastructure network, Planning and design, Master planning, Origin-Destination, graph technique, geometric correction

1. Introduction

Chabahar is a port city that has been a center of world trade since ancient times [1], and the importance of its communication corridors has been discussed.

Scholars have done some studies on the Chabahar urban transportation network and its connections with the world [2], [3], and [4].

Nevertheless, none of them has entered the planning and design of the urban transportation network and its surroundings.

It is necessary to respond to this shortcoming. Two phenomena are in the time of the new development of transportation infrastructure networks in Chabahar.

One is the inclusion of Chabahar in the China Silk Road project, known as one belt one road. The project has generated broad interest in 70 countries recently.

The plan is a global strategic transportation infrastructure development. Chinese government adopted it in 2013 [5], [6], [7], [8] and [9].

The other phenomenon is the Coronavirus pandemic, which voices rethinking on transportation regulation and planning and design procedures [10] and [11].

The quality of transport systems is affecting economic development in every country and region. Iran also needs southeast to northwest transportation links [12] and [13].

This need is for the close connection between economic growth and the development of transportation infrastructure. Chabahar is nowadays rapidly moving toward an integrated network economy, particularly linking Afghanistan to the waters.

The corridor will show Iran as an interwoven multilayer and multifaceted network [14].

It is no surprise that politically independent countries such as Pakistan, Afghanistan, and Iran aim at building stronger economic links through the Silk Road [15], [16], and [17].

Transport policy of the Silk Road favored the movement of persons and commodities in the 70 countries [18].

Besides, post COVID-19 era requires a new transport policy and infrastructure design.

The removal of barriers caused by the Coronavirus is necessary for obtaining the highest possible dynamic effects from the transportation network economy.

In the reopening of cities and economic activities, well-planned and designed transport network infrastructure is vital to the functioning and balanced development of the economy and society as an integrated system.

The economy and the development of transportation infrastructure are of great mutual importance. Chabahar connects land and air transportation to maritime lines by decreasing travel times and increasing reliability [19].

Chabahar will dominate trade patterns through transportation services.

The harbor will become the primary provider of raw materials and importer of consumer goods.

The transport sector is a central component of our modern society. Changes in society and the transportation sector are interconnected.

This paper aims to re-plan and design for new transportation reflecting the new era's requirements in the Chabahar context.

Outcomes of this paper will assist internal and external regional transportation planning everywhere to reopen the COVID-19 pandemic-affected communications.
This paper has five parts with an introduction, research methods and data, planning and design concerns, discussions, and conclusions.

2. Methods and data

This research applies both bulks of theoretical and experimental learnings. We perform a case study strategy to present new procedures for transportation infrastructure design for the post-covid-19 reopening of transportation activities. We analyze travel behavior by a gravity model and a graph technique to make necessary geometric corrections. The Chabahar region has a geopolitical and strategic position in Iran due to its location on Chabahar Bay, the Sea of Oman, and its connection with the Indian Ocean. Figure 1 exhibits the place of Chabahar.

Figure 1 Place of Chabahar in the region. Source: [20]

The above map shows that Chabahar needs a comprehensive plan of all transportation modes when the city is an intersection of the road, rail, air, and maritime lines. The port city of Chabahar made this region prone to establish important activities and uses on a national and

transnational scale. This fact emphasizes the international role of Chabahar city and the extensive tasks of the city's transportation network system. Therefore, the efficiency of the Chabahar transportation network system becomes more than ever. Chabahar has approx. 350000 inhabitants [21]. We studied the travel behavior of the people in Chabahar with their origins and .destinations. Table 1 shows the result

Table 1 Travel production behavior in Chabahar city

Line	Type of trips	Number of travels
1	From the airport to the destination	8
2	From the airport to the offices	5
3	From the airport to the hotel	1
4	From the airport to the destination of friends' homes	1
5	From the airport to the universities	1
6	From the origin of the port to the destination of the house	2
7	From the origin of the port to the destination of the offices	4
8	From the port of departure to the hotel	0
9	From the origin of the port to the destination of friends' houses	1
10	From the origin of the port to the universities	0
11	From the terminal to the destination	10
12	From the terminal to the offices	1
13	From the terminal to the hotel	0
14	From the terminal to the destination of friends' homes	2
15	From the terminal to the destination of the universities	1
16	From the origin of the train station to the destination of the homes	0
17	From the origin of the train station to the offices	0
18	From the train station to the hotel	0
19	From the origin of the train station to the home of friends	0
20	From the origin of the train station to the universities	0
21	From home to airport	15
22	From the offices to the airport	6
23	From the hotel to the airport	1
24	From the friends' homes to the airport	3
25	From the origin of the universities to the airport	1
26	From home to port	4
27	From the origin of offices to the port	3
28	From the hotel to the port	1
29	From friends' homes to port	18
30	From the origin of universities to the port	1
31	From home to terminal	4
32	From the office to the terminal	1
33	From the hotel to the terminal	0
34	From the homes of friends to the destination of the terminal	2
35	From the origin of universities to the terminal	1
36	From home to train station	0
37	From the offices to the train station	0
38	From the hotel to the train station	0

39	From the origin of friends' homes to the train station	0
40	From home to work	25
41	From the origin of the place of work to the destination of the home	32
42	From home to school	16
43	From school to home	9
44	From home to the market	36
45	From the origin of the market to the destination of the home	22
46	From home to relatives	12
47	From the home of relatives to the destination of the home	8
48	From home to restaurant	1
49	From the origin of the restaurant to the destination of the home	0
50	From the home to the tourist centers	2
51	From the origin of sightseeing centers to the destination of the home	3
52	From home to friends	13
53	From friends' home to home destination	11
54	From the origin of the house to the mosque	2
55	From the origin of the mosque to the house	0
56	Personal travels	7

In the analysis of travel behavior in Chabahar, we find that most trips originate from homes. Table 2 shows the frequency of trips to major destinations.

Table 2 Number of trips from travel-making bases in Chabahar

Origins	Hotel	Offices	Homes	Train station	Terminal	Harbour	Airport
Number of travels	2	7	126	0	14	7	16

The bar chart below shows that the number of trips from home to various destinations is the highest.

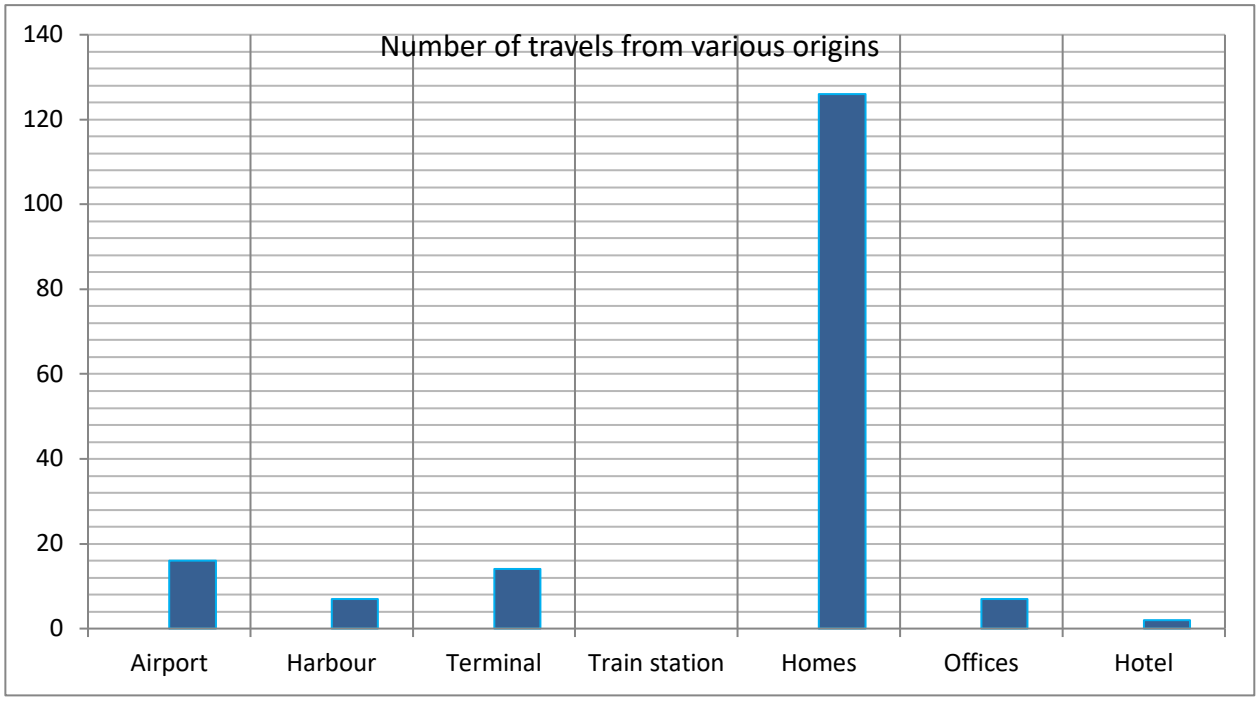

Figure 2 Frequency chart of travel from different origins in Chabahar city.

Table 3 shows the frequency of distribution of trips to travel destinations in the city of Chabahar'.

Table 3 Number of trips to travel destinations in Chabahar

Destinations	Work	Hotel	Offices	Home	Train station	erminal	Harbor	Airport
Number of travels	25	1	10	130	0	10	29	11

The bar chart below also shows the number of trips to different destinations in Chabahar.

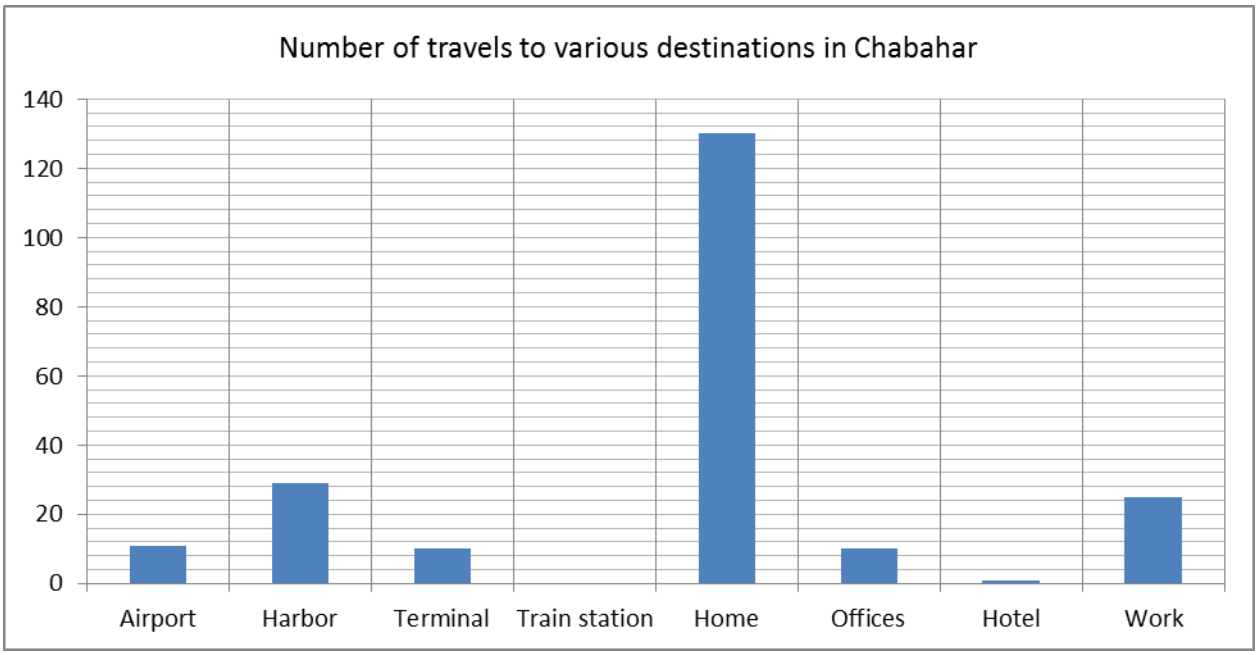

Figure 3 Frequency chart of travel to different destinations in Chabahar city

We questioned drivers when stopping at the station at 10 a.m. on the details of their trips. Table 3 reports the data**.** A professional look and a review of the development process of Chabahar city prove that the network of streets and passages of Chabahar city has undergone organic development. Chabahar is a city whose skeleton does not link to preplanning. It is spontaneously related to the pressure of the needs and desires of people.

Out of 2300 hectares of urban lands of Chabahar, only about 380 hectares are for transportation and warehouses, urban facilities and equipment, and waterways and roads. However, the land allocated to roads and streets is much less than 16.5% of the land in Chabahar.
Now, Chabahar city must establish a new model of physical and spatial structure. The model will include an urban transportation network according to its characteristics, economic, geopolitical, and international situation. For this purpose, the method shall allocate sufficient space for the network of streets and passages. According to the United Nations principle, a street network shall cover at least 30% of urban land to build a non-dormitory, efficient, and vibrant city. According to this principle, Chabahar city must have at least 18 km of streets and passages per square kilometer of urban land [22]. Chabahar moved toward an integrated network economy, in which network infrastructure will play a crucial role since the implementation of the Afghanistan-

Milak-Chabahar corridor [23] and [24]. The country-oriented policies are toward connected air, land, rail, and water lines transportation modes.

A strategic new infrastructure design is necessary. To identify new planning and design, we must understand this situation of the Chabahar transportation infrastructure network. Our field observation proves that Chabahar has not allocated enough land for the streets, sidewalks, terminals, and stops suitable for an international city. Streets have problems in sight distance, including stopping sight distance and passing sight distance. They need geometric correction in level and non-level crossings and pedestrian abutments at intersections. The slope of the city's both vertical and horizontal curves is incorrect. All streets, sidewalks, and cross-sections need earthworks in street flooring**.** Our observation suggests that the Chabahar transportation network system needs following remedies: New urban transportation system planning, geometric corrections of sidewalks, passages, streets, squares, and intersections, and connection of airport, harbor, train station, bus terminal, and taxi stations together. To improve traffic jams, we give priority to public transportation, as we in Figure 4 by bus and minibus lines.

Figure 4 Map of the proposed routes for Chabahar public transportation development

Source: Author's work

3. Modeling transportation networks

Our planning for the transportation network in Chabahar in the post-Covid-19 era shall find answers to the following questions:

- Number of travelers from and to Chabahar
- Number of cars getting in the city and leaving it
- Probability of choosing a travel mode in the city
- Determine the best route between an origin and a destination
- How much does a travel of passengers or transport of cargo cost depending on mode and route?

We find answers to the questions by building a mathematical model, which clarifies freights and passengers' travels. Using the gravity model, the normalization technique, adjusting factor, and graph laws, we calculate the number of trips or weight of cargos similar to work [25]. We begin our model with the following equation.

$$T'_j = T_j \frac{\sum_{i=1}^{I} T_i}{\sum_{j=1}^{J} T_j} \geq T_j \times \frac{37500}{36850} = T_j \times 1.0204 \qquad (1)$$

In equation (1), T_{ij} is the number of travels from and to Chabahar, T_i is the number of travels from Chabahar origin, and T_j the number of travels to Chabahar

Choosing a destination or distributing trips is the second stage of modeling for the transportation system of Chabahar city. With gravity, we can calculate the number of trips to every destination. We supply data from the Chabahar travel behavior chart. We interviewed travelers from home destinations to other destinations in Chabahar and gathered data as well. Here, we write equation (2).

$$T_{ij} = T_i \times \frac{T_j \times f(C_{ij}) \times K_{ij}}{\sum_{j=1}^{n} T_j \times f(C_{ij}) \times K_{ij}} \qquad (2)$$

In equation (2), $f(C_{ij})$ represents travel costs and K_{ij} is the degree function.

Setting the data gathered in equation (2) and normalization of the number of trips to destinations, we calculated a total of 36,750 travels. See the detail of travels in table 4.

Table 4 Details of trips in Chabahar city

Name	Household numbers	Origins	Destinations
Chabahar	15000	22500	20750
Chabahar suburb	10000	15000	16000
Total	25000	37500	36750

A step of the modeling for the Chabahar transportation network system is to predict travel behavior. By setting the origin-destination matrix, we analyze the routes that the passenger or cargo choose. Analyzes are concerning our studies of travel behavior data, the cost and time the traveler is willing to pay, as well as socio-psychological indicators. In the analysis of travel behavior, we find that more trips are to homes. Chabahar residents have travel two modes to choose from now. One is the public sector by bus, minibus, and taxi. The other is personal car. In both cases, the travelers have to use the existing network of passages and streets. Considering the economic situation of more people, we calculate the probability of choosing travel mode in Chabahar city with the help of the following generic and classical relationship:

$$L = \prod_{n=1}^{N} f(Y_n | X_n, \theta) \qquad (3).$$

In equation (3), L is the maximum probability of a mode, X_n is the sample population that we have considered in this calculation for 5 passengers $\{1, 1, 1, 0, 1\}$ and θ are our parameters. In the curve, our assumption is that for the five members of the sample community in the generic function of (3), the values 0 to 1 are assigned to each mode selection.

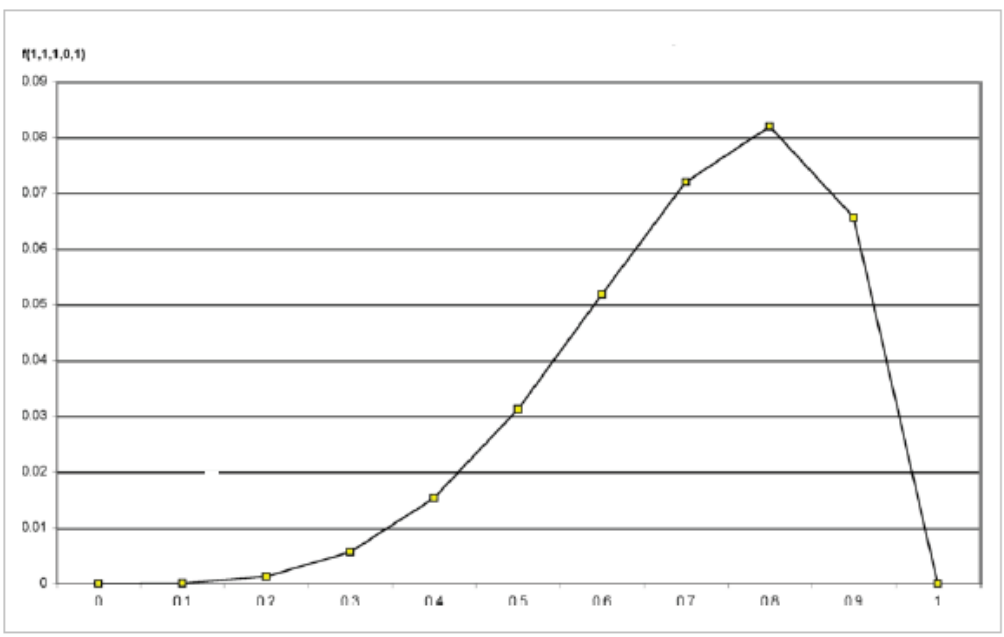

Figure 5 Probability curve for selecting public or personal transport mode derived from the probability function.

The next stage of planning the transportation network is routing. To determine the best route between an origin and a destination, considering price, time, and traffic capacity factors, it is necessary to know the number of passengers on each line, route, or street. On a line (street) that connects two nodes, we consider the number of trips as traffic flow. It is equal to the number of cars entering and leaving the route. When the number of incoming trips is greater than the number of the out-of-route line will be made. Therefore, there will be a traffic delay. For example, when 2100 cars enter Imam Khomeini Boulevard, but only 2000 cars leave, there will still be 100 cars on the street, which will cause a queue. The goal of systematic transportation planning in Chabahar is to minimize the total time a passenger spends entering and exiting a street. Here we apply the statistics that we gathered in a graph. We use the laws of graph classic theory [26], [27], and [28]. Consider the network of streets and boulevards that connect Tis, Quds Boulevard, Komb, and Ramin to the center of Chabahar.

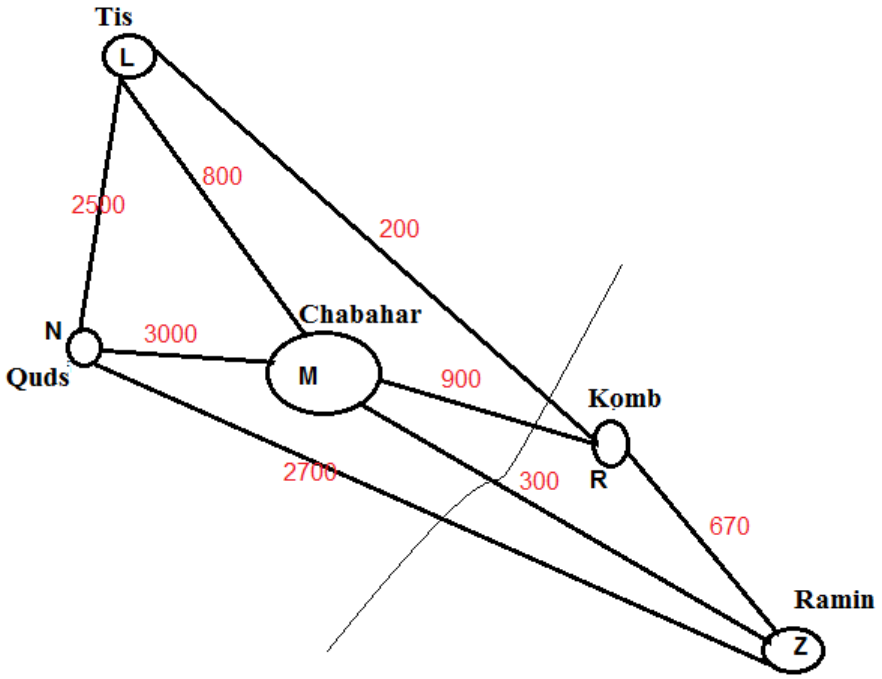

Figure 6 Graph of a part of the street network of Chabahar city

We now assume that passenger traffic is flowing from one station to another. For example, the flow of travel to Chabahar and vice versa is smooth. We have also determined the capacity of

this flow based on experimental statistics along each section of the lines (network streets). Our problem now is to determine the maximum capacity of the traffic flow on the route from Tis to Quds Boulevard. To solve the flow of traffic and routing in the Chabahar transportation network using the above graph, we should explain the idea of cutting. The street network of Chabahar city in the graph is called graph g. We show this graph as a set V.

$$V = \{N, L, M, R, Z\} \qquad (4)$$

Imagine that $\overline{P}$ and P are two subsets of V separated a curved line, cut, as we now have:

$$P \cup \overline{P} = V \qquad (5)$$

Chabahar city center is an origin in P and destination station is in $\overline{P}$. In this case, $(P, \overline{P})$ called a cut. This cut divides the graph of nodes in the network into two parts. In Chabahar urban network, to solve the problem of determining capacity and routing, we have considered 5 urban centers or nodes, in which case we have:

$$P = \{N, L, M\}, \text{ and } \overline{P} = \{Z, R\} \qquad (6)$$

For each side of the graph, we assume a positive real number that indicates the capacity of the traffic flow or the number of cars passing through it. $C\ (L,\ M)$ determines the capacity of the route from the origin of Quds, N, to the destination of Ramin, Z.

$$f(L,M) \leq C(L,M) \qquad (L,M) \in V \qquad (7)$$

$$\sum_{M \in In(L)} f(L,M) - \sum_{M \in Out(L)} f(L,M) = \begin{cases} V for L = N \\ 0\, for L \neq N \\ -V for L = N \end{cases} \qquad (8)$$

In (8), In is the number of cars coming into the city and Out is the number of leaving the city.

We writ for two parts of our cut $p = \{N, M, R\}$ and $\overline{p} = \{L, Z\}$

$$C(P, \overline{P}) = \sum C(L,M) \quad L \in P, \text{ and } M \in \overline{P} \qquad (9)$$

To show this relationship numerically, we have determined the cutting capacity of the Chabahar street network based on traffic capacity and the number of passing cars. Hence, the result of the calculation will be:

$$C(P,\overline{P}) = C(N,R) + C(M,R) + C(L,Z) = 3000 + 800 + 300 = 4100 \quad (10)$$

Similarly, we calculate the necessary capacity for cars to travel on any route (street) or any other part of the Chabahar street-based network with empirical statistics. This calculation makes it possible to plan and design correctly and under the current and future needs of the transportation network system of Chabahar city. The purpose of the mathematical planning model is to avoid queuing and to minimize the consumption of time and money and ensure the smooth flow of traffic.

4. Planning and design concerns

Both Chabahar and Gwadar, as shown in Figure 1, are candidates for the Silk Road project due to their oceanic location. Therefore, Chabahar needs an extensive network of urban and suburban transportation infrastructure with modern technologies and vehicles. The Coronavirus also showed the importance of redesigning per capita transportation space. The mathematical model, expressed in equations 1-10, stated the principles and purposes of travel behavior. It also predicted the number of trips with the traffic graph technique. The interpretation of the model in the previous section shows the need for re-planning and design with more land allocation. Town building engineers suggested up to 30% of the urban land for the network of streets [29], but this recommendation was before COVID- 19-experience. The COVID-19 epidemic showed the need for wide streets, stations, sidewalks, and service offices to avoid overcrowding. Therefore, the Chabahar transportation system should increase the per capita land allocated for the Chabahar transportation infrastructure network. In particular, Chabahar should build an international airport with a train station and passenger and cargo port.

Simultaneously, when re-planning to improve the urban transportation network of Chabahar, a question about which traffic system is suitable for the features of this city arises. To answer, we suggested earlier a public transportation system with bus and minibus lines in Figure 4. The topographic situation of the city is such that the region can be considered a flat plain. This factor

with the climatic and environmental conditions dictates special attention in the design of intra-city traffic and the city's relationship with the surrounding. Since the bed of the streets and passages of the city is flat, it is possible to watch distant landscapes with necessary care in the design of the streets and boulevards without damaging the horizon. It is also possible to use the street system and accessibility of the city to make the city more attractive and touristic. We improve the environment with the use of climate-appropriate trees to combat climatic difficulties. The smooth streets put the use of bicycles on the agenda of the re-planning. It is necessary to design and install a suitable place for cyclists. The traffic in the city means coordination between transportation policies and the city's land policies [30] and [31]. The optimal traffic flow policy modeling in Figure 6 protects the environment and natural and economic resources. From analyzing the current situation of the transportation network system of Chabahar city by recognizing the problems and priorities, the opinions of officials and people, we found the followings:

- The transportation network system of Chabahar city is rudimentary and cannot take on the duties of an international port city that is worthy of its esteemed and expected ester position.
- Chabahar city transportation network system cannot use all its land, air, rail, and rail potentials because it lacks the necessary infrastructure commensurate with its role.
- The transportation network needs re-planning based on new needs and the latest regional, international, climatic, demographic, cultural, and economic changes.
- Existing systems of the Chabahar transportation network must use digital and up-to-date applications by managers and people.
- The existing transportation network needs a quantitative and qualitative development of public transportation.
- Chabahar transportation network system needs financial, technological, and scientific investment to perform the expected tasks.
- Chabahar transportation network system shall increase its management capacity skills, science, experience, and consulting.
- Chabahar city transportation network system It is necessary to coordinate with modern global transportation network systems by making its activities transparent, reporting to the public, and attracting public participation [32].

Therefore, to prepare the city for the post-Covid era, the existing transportation system of Chabahar needs several reforms regarding widening streets, connecting passages, widening sidewalks, correcting street slopes, improving sidewalk slopes. The system requires reconstruction of water canals and improvement of the geometry of intersections and squares. It also needs improvement of bus and taxi stations, the connection of train stations with the street network and airport, and development of parking lots. The mentioned upgrades are possible by more urban spaces, smartening and modernization of transportation plans, educating citizens for electronic life by installing public places. Figure 7 exhibits places that we shall perform the above-mentioned geometric corrections.

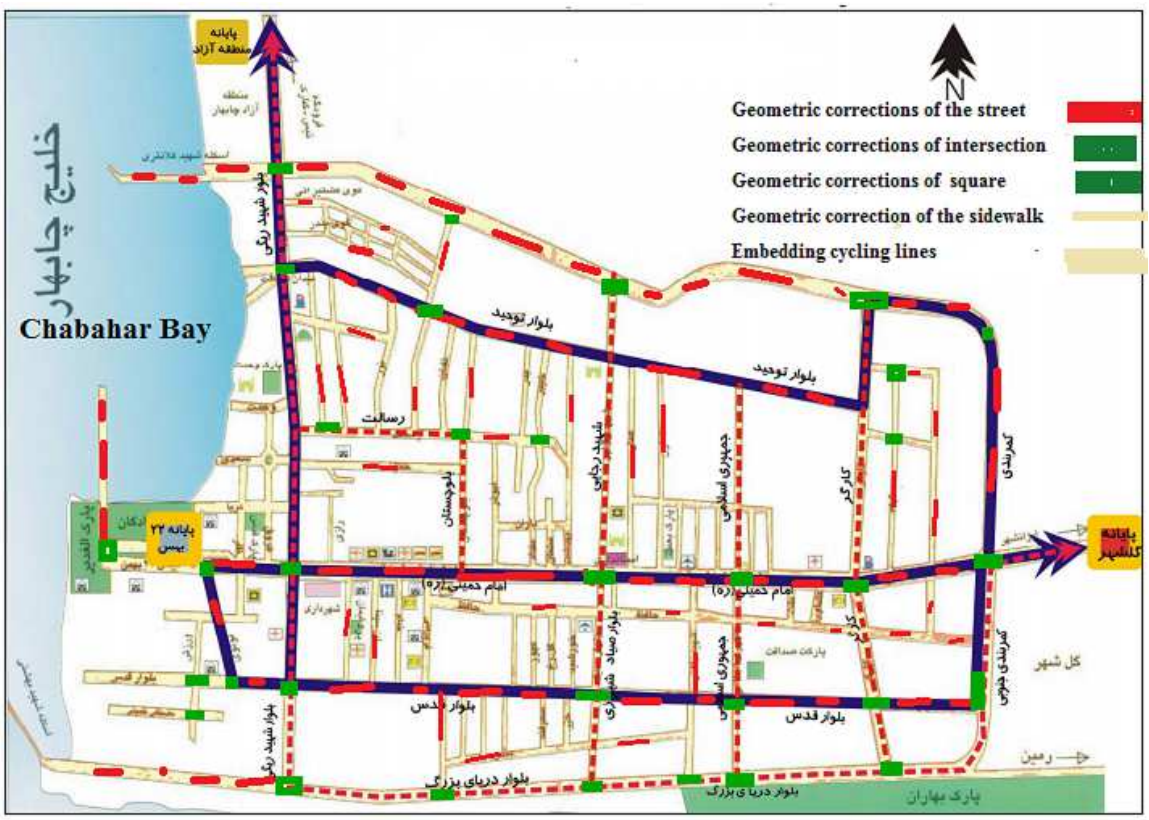

Figure 7 Network map exhibits streets, intersections, and squares of Chabahar city showing the type of necessary geometric correction. Source: Author's work

Considering the results from the re-planning for the transportation network system of Chabahar, which is reflected in Figure 7, sidewalks, streets, street intersections, plazas and squares, and offices need geometric corrections as the following:

- Snape colored places required geometric correction in the sidewalks to wide and improve them
- Snape-colored sites required designing bicycle lines.
- Red-colored locals need geometric correction in the streets.
- Green colored points require geometric correction at the intersections of streets
- The green-colored place need geometric correction in urban squares
- Every mark on the map needs geometric correction to increase the quality and safety of pedestrians.
- We shall build pedestrian bridges with suitable flooring, considering the elderly and the physically disabled [33].

Economically, the re-planning and redesign of the transportation network of Chabahar are for opening regional economic activities and overcoming the current transportation crisis. You can see experiences of India in Amodeo's research [34]. The first aspect is the completion of the internal market in Iran. The Iranian integration will effectively connect the national economy to China and Euro Asian countries. Iran is a big market with 85 million consumers. The Iranian economy will operate in both geographically and economically larger markets. The competition will be severer. Consequently, many firms will effort to exist in the market. All such developments would emphasize the new planning and design of the Chabahar transportation infrastructure networks.

The second economic advantage of the Silk Road project and redesigning Chabahar transportation infrastructure is the declining average distance over which goods and passengers transport from Iran to the Far East countries, Europe, and different provinces of Iran. The best alternative mode in Iran is Train from Chabahar to Tehran and the West regions of Iran. Nevertheless, maritime and air transportation will be suitable for far distances like the corridor of Shanghai-Chabahar- Paris-London, which are in the Silk Road project.

5. Conclusions

This study hypothesized that the size and dimensions of transport infrastructure in some countries were not suitable for new needs. For this reason, we suggested the re-planning of the

Chabahar transport system as a requirement for the economic development and integration of Iran and its peripheral economies.

For this reason, we analyzed the current state of the Chabahar transportation system. After recognizing the current situation and considering the practical developments and opinions of local experts, we proposed several geometric corrections to improve its status.

We also considered the economic and development needs of the indigenous people in linking the Chabahar region to the Silk Road project.

This paper found that the COVID-19 pandemic and recent changes in the world required re-planning and design in sidewalks, streets, intersections, plazas, terminals. It recognized the role of the infrastructure redesign for economic growth and suggested the necessary upgrading of the transportation network.

The novelty of this research was its comprehensive transportation model composed of maritime, aviation, railroad, and ground corridors.

The outcome of this paper was qualitative and quantitative upgrading in the Chabahar strategic transportation system, which was important from economics of scale perspective as well.

Finally, the re-planning and new design model presented in this paper assists planners, engineers, and managers everywhere in the world to improve their transportation systems according to new requirements.

Conflict of interest statement:

The author of this research article verifies that there is no conflict of interest due to this paper.

Author Contributions:

The author of this paper designed this research and conducted the data analysis and interpretation, writing, editing, and review of this paper.

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