Analysis of passenger traffic in Bohai Strait Tunnel

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Abstract. China envisages building a new undersea tunnel called Bohai Strait Tunnel to connect Dalian to Yantai, for the purpose of solving the detour problem in transportation. This paper analyses the passenger traffic in Bohai Strait Tunnel. A modified negative exponent network flow assignment model and an increasing rate method are used to predict the network flow assignment and passenger traffic volume after the completion of Bohai Strait Tunnel in 2050. Two formulas of economic benefits are employed to evaluate the effect of undersea tunnel on passenger traffic. The result indicates that the new undersea tunnel can shorten the distance, reduce the transport cost, save travel time, and produce good economic benefits. Tunnel transportation will attract a large number of passengers and become main transportation way. The analysis result can provide technical storage and references for the future undersea tunnel construction.

1. Introduction
Bohai Strait is located between the Bohai Sea and Yellow Sea, as shown in the figure 1. Bohai Strait is a major route of transportation in China, and is situated in a very important geographical position of coastal defense. The western area of Bohai Strait includes the capital of China, Beijing and an important industrial center, the city of Tianjin. The northern region is the old industrial base of Northeast China. Southern district is the biggest agriculture province of Shandong. Bohai Sea and the three regions constitute Bohai economic circle, which has become the center of economy, politics and culture of Northern China. But there is a defect for Bohai Strait, which hinders Northeast China from connecting to Shandong Peninsula. The straight-line distance from Dalian to Yantai is only 165 km. However, due to the Bohai Strait, the passengers and cargos have to take a detour by land and the distance becomes 1805 km. Even by sea, the sea transportation is inefficient, small scale and slow speed. So, the long distance and slow speed transportation have become the “bottle-neck” of Bohai economic circle development. In order to change this situation, China envisages building a new undersea tunnel to connect Dalian to Yantai. The new undersea tunnel can reduce the transportation distance, save travel time for passengers and freight transportation, decrease traffic pressure of Beijing-Tianjin-Hebei region, strengthen the economic ties between Northeast China and central plain area, boost tourism, push port development, promote the economic developments of Bohai economic circle and eastern coastal area. The construction of the Bohai Strait Tunnel project is a complicated system engineering. The project is in engineering feasibility study period and the preliminary research work of this project is particularly crucial [1]. Future transport capacity and economic evaluation of the undersea tunnel are most important contents for preliminary research work. This paper predicts passenger traffic volume, network flow assignment and economic benefits after the
completion of Bohai Strait Tunnel in 2050, and evaluate the effect of undersea tunnel on passenger traffic.

Figure 1. The geographical position of Bohai Strait.

2. Traffic assignment model
Traffic assignment problem is that the traffic volume is distributed into a set of paths based on some plans and models, and people can estimate the traffic demand of each path. According to Wardrop’s first principle and second principle [2], traffic assignment models are divided into equilibrium model and disequilibrium model. These models include shortest path algorithm [3], logit model [4], probit model [5] etc. In this paper, a modified negative exponent network flow assignment model (NENFA model) [6], which is one of the disequilibrium model, was used to predict the network flow assignment. This model means that when multimodal transports occur, people tend to choose the minimum-cost path; besides, people also consider other selection factors [7], such as travel time, safety, traffic congestion situation, custom, weather condition, road maintenance, etc. The NENFA model can be evaluated as follows:

\[
K_i = A \cdot B_i \cdot e^{-\frac{C_0}{D_i}} \quad (1)
\]

\[
A = \frac{1}{\sum B_i \cdot e^{-\frac{C_0}{D_i}}} \quad (2)
\]

where:
- \(K_i\) is the ratio of passenger traffic volume in one path to the total passenger traffic volume,
- \(A\) is influencing factors that affect passenger’s preferences, such as travel time, safety, transport distance, traffic congestion situation, custom, weather condition, road maintenance etc,
- \(e\) is exponent,
- \(C_0\) is the cost parameter, which reflects passenger’s sensitivity to transport cost,
- \(D_i\) is the transport expense in path \(i\),
- \(D_j\) is the minimum transport expense in all paths,
- \(B_i\) is preference parameter, which affects the choice of path \(i\).
The preference parameter $B_i$ is influenced by many factors, including passenger capacity, transportation cost, transport speed, continuity, flexibility and security, etc. $B_i$ can be obtained by comprehensive assessment method, as listed in reference [8].

3. Economic benefits of passenger transportation

Economic evaluation of transportation project is an essential part of project feasibility study and determines whether the construction scale and time are reasonable, whether the project has good economic benefit, and whether the project is feasible[9].

Economic evaluation of transportation project can be obtained by analyzing its economic benefits by cost-benefit analysis principle. Economic benefits of passenger transportation include economic benefit from shortening distance and reducing transport cost $B_{kd}$ and economic benefit from saving travel time $B_{ks}$.

$$B_{kd} = C_{k0}Q_k (L_0 - L_n)$$  \hspace{1cm} (3)

where:
- $B_{kd}$ is the economic benefit from shortening distance and reducing transportation cost after the completion of Bohai Strait Tunnel (thousands of yuan),
- $C_{k0}$ is the unit transport cost of passenger traffic before the implementation of undersea tunnel (yuan/people×kilometer),
- $Q_k$ is the predicted passenger traffic volume (thousands of people),
- $L_0$ is the transport distance before the implementation of the undersea tunnel (kilometers),
- $L_n$ is the transport distance after the completion of the undersea tunnel (kilometers).

$$B_{ks} = \alpha I_k Q_k T_{ks}$$  \hspace{1cm} (4)

where:
- $B_{ks}$ is the economic benefit from saving travel time (thousands of yuan),
- $\alpha$ is the ratio of passenger travel time for work to the total travel time,
- $I_k$ is the national income per head and per hour in planning year (yuan/hour),
- $Q_k$ is the passenger traffic volume (thousands of people),
- $T_{ks}$ is the total saving travel time of passengers after the completion of Bohai Strait Tunnel (hours).

4. Transport paths

Three logistic transport paths were used to predict the network flow assignment and economic benefits in the year 2050, including Tongliao-Yantai, Dandong-Yantai, Shenyang-Yantai. Analysis and comparison between “before the implementation of undersea tunnel” and “after the completion of the undersea tunnel” were performed.

Multiple transportation ways were considered including road, rail, air, sea and their intermodal transportation. Among them, high-speed rail was used in rail transportation. The details were listed in table 1 and table 2.

The passenger traffic volume of each origin-destination pair (OD pair) was predicted using an increasing rate method, the result was presented in table 3.

$$Q_i^n = Q_i^0 \left(1 + R_i\right)^n$$  \hspace{1cm} (5)

where:
- $Q_i^n$ is the predicted passenger traffic volume in year $i$;
- $Q_i^0$ is the passenger traffic volume in base year;
- $R_i$ is rate of growth in year $i$. 



Table 1. The transport distance before the implementation of undersea tunnel.

| OD pair       | Path                     | Transport distance (km) |
|---------------|--------------------------|-------------------------|
| Tongliao-Yantai | Tongliao-Shenyang-Dalian-Yantai way | HS  RS  HA  RA distance 824 938 899 1013 |
| Tongliao-Yantai | Tongliao-Chifeng-Beijing-Yantai way | H  R  A distance 1629 1816 1221 |
| Dandong-Yantai | Dandong-Dalian-Yantai way | HS  RS  HA  RA distance 485 457 560 532 |
| Dandong-Yantai | Dandong-Shenyang-Beijing-Yantai way | H  R  A distance 1670 1926 1424 |
| Shenyang-Yantai | Shenyang-Dalian-Yantai way | HS  RS  HA  RA  A distance 561 560 636 635 593 |
| Shenyang-Yantai | Shenyang-Beijing-Yantai way | H  R distance 1430 1719 |

Notes: H= highway transport, R= rail transport, A= air transport, HS= highway-sea intermodal transport, RS= rail-sea intermodal transport, HA= highway-air intermodal transport, RA= rail-air intermodal transport.

Table 2. The transport distance after the completion of the undersea tunnel.

| OD pair       | Path                     | Transport distance (km) |
|---------------|--------------------------|-------------------------|
| Tongliao-Yantai | Tongliao-Shenyang-Dalian-Yantai way | HT  RT  HS  RS  HA  RA distance 820 934 824 938 899 1013 |
| Tongliao-Yantai | Tongliao-Chifeng-Beijing-Yantai way | H  R  A distance 1629 1816 1221 |
| Dandong-Yantai | Dandong-Dalian-Yantai way | HT  RT  HS  RS  HA  RA distance 481 453 485 457 560 532 |
| Dandong-Yantai | Dandong-Shenyang-Beijing-Yantai way | H  R  A distance 1670 1926 1424 |
| Shenyang-Yantai | Shenyang-Dalian-Yantai way | HT  RT  HS  RS  HA  RA  A distance 557 556 561 560 636 635 593 |
| Shenyang-Yantai | Shenyang-Beijing-Yantai way | H  R distance 1430 1719 |

Notes: HT= highway-undersea tunnel intermodal transport, RT= rail-undersea tunnel intermodal transport

Table 3. The predicted passenger traffic volume of OD pair in 2050.

| OD pair       | Passenger traffic volume in 2050 (thousands of people) |
|---------------|-------------------------------------------------------|
| Tongliao-Yantai | 2139.9                                                |
| Dandong-Yantai | 716.1                                                 |
| Shenyang-Yantai | 4205.9                                                |
5. Prediction results

5.1. The results of traffic assignment model

The results of network flow assignment are shown in figures 2 - 4. For the OD pair of Tongliao-Yantai, before the implementation of undersea tunnel, the transportation ways mainly are highway-sea intermodal transport (HS) and rail-sea intermodal transport (RS), the ratios of traffic volume $K_i$ are 40.7% and 39.5%, respectively. Other transportation ways, highway transportation (H) and high speed rail transportation (R), have a certain portion of 8.1% and 6.3%. The sum of $K_i$ by air transportation (HA, RA and AT) is only 5.3%. After the completion of the undersea tunnel, highway-undersea tunnel intermodal transport (HT) and rail-undersea tunnel intermodal transport (RT) become most dominating transportation ways, the sum of $K_i$ by tunnel transportation (HT and RT) reaches up to 90.2%. Meanwhile the sum of $K_i$ by highway-sea intermodal transport (HS) and rail-sea intermodal transport (RS) reduces to 3.1%. The ratio of traffic volume in other transportation ways, such as HA, RA, H and R, and A, is very small, only 1.2%. It is clearly seen that the undersea tunnel has great influence on transportation network and the undersea tunnel is passenger’s top choice.

There are similar trends for the OD pairs of Dandong-Yantai and Shenyang-Yantai. After the completion of the undersea tunnel, the ratios of traffic volume in highway-sea intermodal transport (HS) and rail-sea intermodal transport (RS) are greatly decreased. And the intermodal transport of HT and RT become main transport ways. The ratios of traffic volume by tunnel transportation for the two OD pairs are more than 90%. Therefore, shortening the transport distance and saving travel time are greatest advantages for Bohai Strait Tunnel.

![Figure 2](image2.png)

(a) Before the implementation of undersea tunnel (b) After the completion of the undersea tunnel

*Figure 2*. The result of network flow assignment in the path of Tongliao-Yantai.

![Figure 3](image3.png)

(a) Before the implementation of undersea tunnel (b) After the completion of the undersea tunnel

*Figure 3*. The result of network flow assignment in the path of Dandong-Yantai.
Figure 4. The result of network flow assignment in the path of Shenyang-Yantai.

5.2. The results of economic benefits of passenger transportation

From the tables 4 - 5, for the three OD pairs of Tongliao-Yantai, Dadong-Yantai and Shenyang-Yantai, economic benefits from shortening distance and reducing transportation cost $B_{kd}$ are 1003.27 million yuan, 633.53 million yuan, and 2649.36 million yuan, respectively. Economic benefits from saving travel time $B_{ks}$ are 35.93 million yuan, 16.67 million yuan, and 74.01 million yuan, respectively.

So, it can be concluded that undersea tunnel can achieve great economic benefits in passenger transportation. Especially for long distance or large traffic volume cites, such as Shenyang-Yantai, undersea tunnel will bring them greater economic benefits.

Table 4. Economic benefit from shortening distance and reducing transportation cost $B_{kd}$ in 2050.

| OD pair      | Transport way | $Q_k$ (thousands of people) | $L_0$ (kilometers) | $L_n$ (kilometers) | $B_{kd}$ (millions of yuan) | Total (millions of yuan) |
|--------------|---------------|----------------------------|--------------------|--------------------|-----------------------------|--------------------------|
| Tongliao-Yantai | HT            | 1227.1                     | 1629.00            | 820.00             | 557.89                      | 1003.27                  |
|               | RT            | 704.3                      | 1816.00            | 934.00             | 445.38                      |                          |
| Dadong-Yantai | HT            | 274.1                      | 1670.00            | 481.00             | 183.14                      | 633.53                   |
|               | RT            | 426.5                      | 1926.00            | 453.00             | 450.39                      |                          |
| Shenyang-Yantai | HT           | 1813.3                     | 1430.00            | 557.00             | 889.65                      | 2649.36                  |
|               | RT            | 2110.5                     | 1719.00            | 556.00             | 1759.71                     |                          |
| Sum (millions of yuan) | | | | | | 4286.16 |

Table 5. Economic benefit from saving travel time $B_{ks}$ in 2050.

| OD pair      | Transport way | $Q_k$ (thousands of people) | $T_{ks}$ (hour) | $B_{ks}$ (millions of yuan) | Total (millions of yuan) |
|--------------|---------------|----------------------------|-----------------|-----------------------------|--------------------------|
| Tongliao-Yantai | HT            | 1227.1                     | 6.74            | 28.95                       | 35.93                    |
|               | RT            | 704.3                      | 2.83            | 6.98                        |                          |
| Dadong-Yantai | HT            | 274.1                      | 9.91            | 9.50                        | 16.67                    |
|               | RT            | 426.5                      | 4.80            | 7.17                        |                          |
| Shenyang-Yantai | HT           | 1813.3                     | 7.28            | 46.17                       | 74.01                    |
|               | RT            | 2110.5                     | 3.77            | 27.84                       |                          |
| Sum (millions of yuan) | | | | | 126.61 |
6. Conclusion
This paper predicts passenger traffic volume, network flow assignment, and economic benefits in the year 2050.

After the completion of Bohai Strait Tunnel, the intermodal transport of HT and RT become main transport ways. The ratios of traffic volume by tunnel transportation for the three OD pairs are more than 90%. The results indicate that the new undersea tunnel can change the transportation network, attract passengers, mitigate traffic pressures of Beijing area and Tianjin area, and become a main transportation way.

Economic benefits from shortening distance and saving travel time of three OD pairs in 2050 are 4286.16 million of yuan and 126.61 million of yuan, respectively. So, the tunnel can produce good economic benefits.

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