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# Prioritizing Urban Corridors for Multilevelization Using Benefit-Cost Analysis

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*Abstract*

Providing sufficient supply considering future demand is one of transportation management policies these days. Urban multilevel highways can positively affect congested streets by increasing network operational speed and decreasing delay time though it is costly. The current paper aims to present a methodology for comparing the multilevelization capability of urban corridors considering transportation and economic parameters. Mashhad which is one of the main cities of Iran is chosen as the case study. Primary corridors are identified among the most effective main streets of the city. As a result, 6 selected corridors are modeled in a macroscopic software and analyzed. Benefit assessment is done based on two factors: network total traveled time (Vehicle. Hour of travel) and network total traveled distance (Vehicle. Kilometer). Next, the benefit to cost ratio is calculated for a 10-years period employing VHT reduction and decrease in fuel consumption and air pollution as benefits, and construction and maintenance costs as cost. The results show that the best scenario is multileveling Ferdowsi street.

*Keywords:* Multilevel corridors, Benefit to cost, VHT, fuel consumption, air pollution

## 1. Introduction

Studying current transportation problems and possible solutions to satisfy future demand is an important issue. So, transportation planning plays an important role by making decisions about related policies for necessary revisions. The decisions could help consistent improvement of land use, trip pattern, and general social goals. One of these decisions is increasing facilities. However, it needs precise studies due to high construction and maintenance costs. Urban land use texture mostly do not let the corridors to become wider, hence, making multilevel corridors could be considered. Multilevel highways raise network capacity, improve traffic conditions, and reduce travel time, fuel consumption, and vehicle depreciation [1]. The most important advantage of multilevel highways is improving traffic conditions of congested corridors which affect total network directly [2]. These corridors increase operational speed and decrease delay time and queue length on crowded corridors [3, 4]. Improved traffic congestions significantly reduce fuel consumption and emission [1]. Although multilevel corridors might result in visual pollution, due to transferring traffic load to another level without disturbing around land uses, can make it able to build up new urban service centers. The new level directly connects origins and destinations so high-speed vehicles prefer to use the new level and there will be more space for pedestrians on the ground level. Therefore, vehicle speed decreases and pedestrian safety increases on the ground level [5]. Moreover, weaving and, consequently, crashes are reduced, whereas, widening corridors works vice versa [3].

Multilevel corridors are mostly built in the USA or south-east Asia. However, there are a few tunneled multilevel cases in Europe too [6]. The highway network of Tokyo includes 24 highways 322.5 kilometers long which are mostly multilevel (bridge or tunnel) because of several mountains and lack of space in this city [1].

Whereas south-east Asian countries mostly use multilevel highways as a modernism sign or a solution of developing facilities on a limited space (supply management), USA mostly use these highways to manage several existing vehicles [1]. 87% of daily trips and 88% of job trips are done by personal cars in the USA and annual fuel and time cost of traffic jams is estimated as $63 billion [7]. In recent decades, widening highways has been the single solution in the USA resulting in highways with more than 8 lanes in some states which cannot deal with the problem and add new troubles such as safety and long cycles of traffic lights [3]. Therefore, multilevel highways have been becoming popular on some states. Emabarcadero highway is an example of unsuccessful experiences while central arterial tunnel is of successful ones [8]. Although several studies have been done about benefit to cost of rail projects [9, 10], a few ones are done about multilevel corridors. Although performing benefit-to-cost analysis is costly, if the benefits and costs of projects are examined and prioritized accordingly, the projects with the highest net economic benefits could be selected and implemented first [11].

The Minnesota transportation department provides an approach to evaluate highways' benefit-to-cost analysis. The guide mentions that "The objective of a benefit-cost analysis is to translate the effects of an investment into monetary terms and to account for the fact that benefits generally accrue over a long period of time while capital costs are incurred primarily in the initial years." It also believes that one of the main aspects of benefit about new highways is travel time [12].

Due to high costs of constructing multilevel corridors, fore-studies of corridor selection seems quite important. Previous studies showed that inappropriate site selection can have improper results [6]. This study aims at providing a practical approach of doing feasibility studies and assessment of urban multilevel corridors.

City of Mashhad is the second biggest city in Iran with a congested corridor network with low widening availability. On the other hand, population and demand growth is not manage-able with only demand management policies [13].

First, 6 of the most effective corridors are chosen and 6 scenarios are generated. Next, each scenario is modeled separately and effect of adding a new level to each corridor is figured out by finding out changes in network total traveled distance (VKT) and network total travelled time (VHT). Total benefit is calculated using benefit of VHT reduction, and decreased fuel consumption and air pollution. Total cost is calculated as construction and maintenance costs. The benefit to cost ratio is figured out as the net present worth (NPW) of benefits and costs in a ten-year period. Next section is the methodology used in this paper. Third section is the case study and the last part presents the conclusion.

## 2. Methodology

This paper studies multilevel corridors by multiple analyses (Figure 1). The first step in this study is drawing the city network in a macroscopic modelling software. The software of VISSUM is chosen for this approach. The city network is drawn and an extra level is added to each of six most important corridors of the city separately and different scenarios are made. Second, trip demand is assigned to the network of each scenario.

Further analyses are done by the software and two indices of total travelled vehicle-hour and total travelled vehicle-kilometer is calculated for each scenario. Next, benefit to cost analysis is done using cost of construction and benefits of decreasing fuel consumption, air pollution, and total vehicle-hour. The benefits are figured out as explained below.

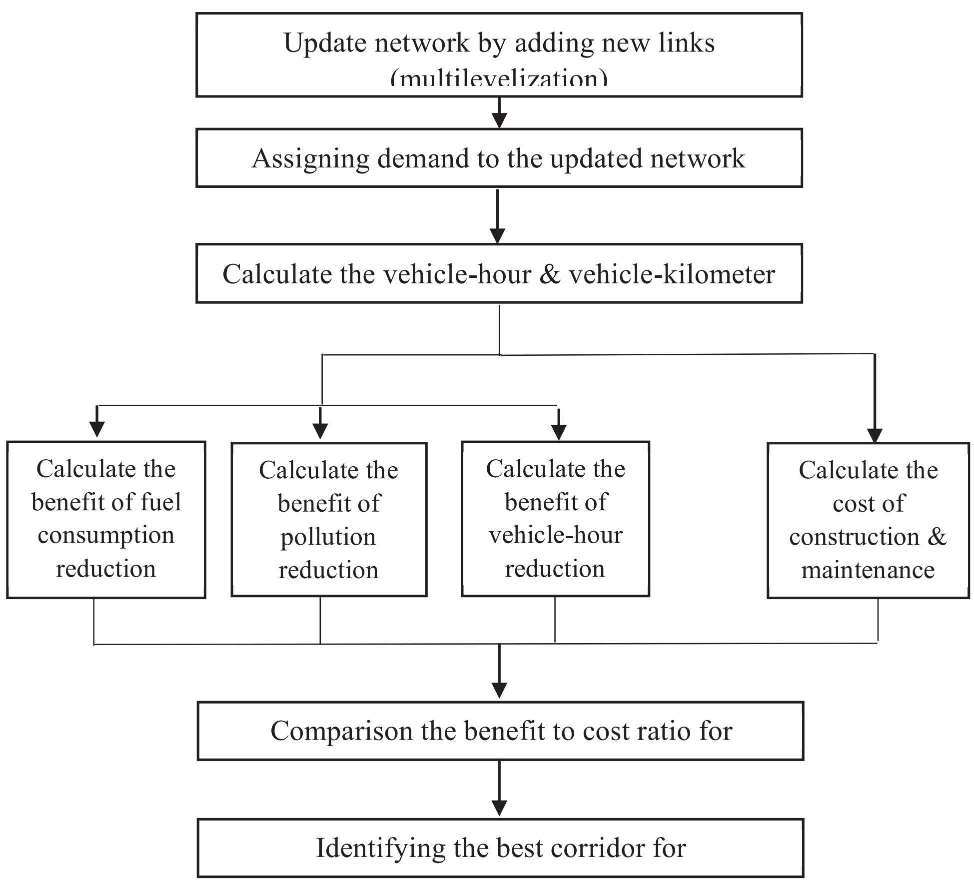


Fig. 1. Methodology flowchart of the current paper

First, each scenario's effect on network is studied by calculating total decreased traveled time (vehicle.hour of travel), and network total traveled distance (vehicle.kilometer) reduction.
Next, the benefits are calculated. $B_1$ in Equation 1 is the benefit of network total traveled time (VHT) reduction which is calculated in money units using value of time (VOT) and average rate of passenger (ARP).

$$B_1 = VHT \times VOT \times ARP \quad (1)$$

The parameters' units are as following:
$B_1$: Dollars
VHT: Decrease of vehicle.hour
VOT: Dollars /person.hour
ARP: person/vehicle

$B_2$ in Equation 2 is the benefit of network total traveled distance (VKT) reduction which is calculated in money units using average fuel consumption (AFC) and average fuel price (AFP).

$$B_2 = VKT \times AFC \times AFP \quad (2)$$

The parameters' units are as following:
$B_2$ : Dollars
VKT: Decrease of vehicle.kilometer
AFC: Liter/vehicle.kilometer
AFP: Dollars /Liter

$B_3$ in Equation 3 is the benefit of pollution reduction which is calculated in monetary units using emission rate per kilometer and emission cost of CO2, NOx, and CO.

$$B_3 = VKT \times emission\ rate \times emission\ cost \quad (3)$$

The parameters' units are as following:
$B_3$ : Dollars
VKT: Decrease of vehicle.kilometer
Emission rate: Kilogram/vehicle.kilometer
Emission cost: Dollars /kilogram

The benefit-to-cost analysis is done for mid-term period of 10 years in this paper. The project is going to start working in 2015 and, hence, the 10-year period is finished in 2025. The benefit is calculated for each individual year and is converted to net present worth (NPW) using interest and inflation rates. The eventual benefit is figured out by summing up NPW of all 10 years.
The costs contain expenses of acquisition, construction, and maintenance. Construction and maintenance costs are taken into account for the same 10-year period. Annual maintenance cost is estimated as 5% of construction cost and its NPW is figured out using the same interest and inflation rates used in benefit calculation. Eventually, the best scenario is determined that is the corridor with the highest benefit to cost ratio.

## 3. Results and discussion

The city of Mashhad is selected as the case study in the current research. Six corridors, which play the most effective role in the city traffic, are selected through the city network (Figure 2). The corridors are all of main streets in the city. Each corridor is modeled as a multilevel street separately and the demand is assigned to the network in all 6 scenarios to compare the effect of adding a new level to each corridor.
Each scenario is modeled by VISUM employing calibrated network of comprehensive transportation studies of Mashhad [13] and defining new links performance function similar to based network links. Next, network total traveled time (vehicle-hour of travel), and network total traveled distance (vehicle-kilometer) is compared to the base network after demand assignment to both networks (without and with multilevel corridors). Value of time in Mashhad was estimated 9.12 $ in a research conducted in 2007 that is converted to VOT in each year using a growth rate of 17% mentioned in Mashhad comprehensive studies. Also, AFC, AFP, and ARP are respectively assumed 0.13 liter, 2 $, and 2.28 person/vehicle [14]. Other parameters are VISUM outputs.
As a result, annual benefit of VHT improvement is figured out for each scenario using equation 1 and the NPW of the benefit is calculated considering a ten-year period. Table 1 shows the results for one of the corridors named Vahdat as a sample.

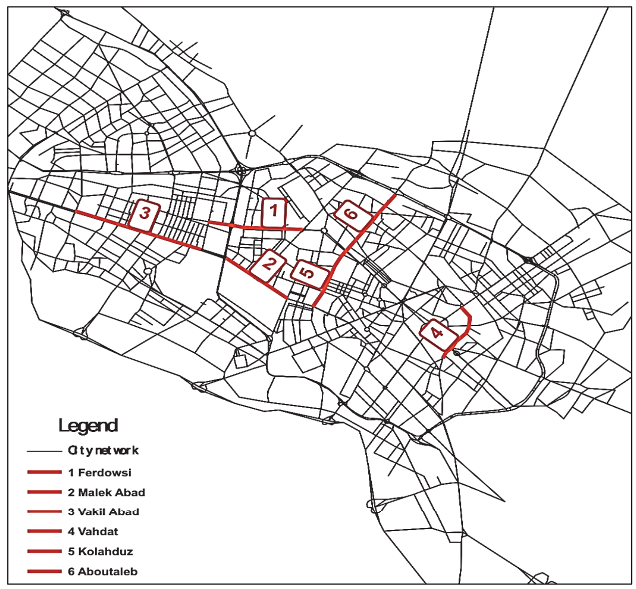


Fig. 2. Final selected single routes

The benefits of fuel consumption and air pollution are calculated based on VKT improvement in each scenario, using equations 1 and 2 and the NPW of the benefits are calculated considering a ten-year period. Table 2 indicates the results for the same sample corridor (Vahdat).
As mentioned before, average cost of recent tunnel constructions is assumed as multilevel corridors' construction cost in the first year and 5% of it is assumed as annual maintenance expenses in next 9 years. All expenses are converted to net present worth. Each scenario's benefit, cost, and the benefit to cost ratio is illustrated in Table 3. The total benefit is obtained by summing up all three benefits ($B_1$, $B_2$, and $B_3$). As seen in Table 3, the corridor of Ferdowsi owns the highest rank in benefit-to-cost analysis.

Table 1- Calculation the benefit of vehicle-hour reduction for the corridor of Vahdat

| Year | Decrease of VHT per day (vehicle-minute) | Decrease of VHT per year (vehicle-minute) | Benefit of VHT decrease ($) | Equivalent benefit in the base year 2015 ($) |
|---|---|---|---|---|
| 2025 | 372830.00 | 136082950.00 | 7.96E+08 | 1.66E+08 |
| 2024 | 342589.47 | 125045157.97 | 6.25E+08 | 1.52E+08 |
| 2023 | 314801.78 | 114902649.68 | 4.91E+08 | 1.40E+08 |
| 2022 | 289267.97 | 105582807.99 | 3.86E+08 | 1.29E+08 |
| 2021 | 265805.22 | 97018905.78 | 3.03E+08 | 1.18E+08 |
| 2020 | 244245.56 | 89149628.21 | 2.38E+08 | 1.09E+08 |
| 2019 | 224434.61 | 81918633.77 | 1.87E+08 | 9.97E+07 |
| 2018 | 206230.55 | 75274150.80 | 1.47E+08 | 9.16E+07 |
| 2017 | 189503.03 | 69168606.93 | 1.15E+08 | 8.42E+07 |
| 2016 | 174132.30 | 63558288.38 | 9.05E+07 | 7.74E+07 |
| 2015 | 160008.29 | 58403027.06 | 7.11E+07 | 7.11E+07 |
| | | Total | | $B_1$ = 1.24E+09 |

Table 2- Calculation the benefit of fuel consumption reduction and pollution reduction for the corridor of Vahdat

| Year | Decrease of VKT per day (kilometer) | Decrease of VKT per year (kilometer) | Benefit of reduced fuel consumption ($) | Equivalent benefit (redced fuel) in the base year 2015 ($) | Benefit of reduced pollution ($) | Equivalent benefit (reduced pollution) in the base year 2015 ($) |
|---|---|---|---|---|---|---|
| 2025 | 29710.60 | 10844369 | 2819535.94 | 586568.88 | 189642.581 | 39452.7 |
| 2024 | 28822.73 | 10520296.22 | 2735277.017 | 665776.652 | 183975.308 | 44780.3 |
| 2023 | 27961.39 | 10205908.02 | 2653536.085 | 755680.306 | 178477.396 | 50827.2 |
| 2022 | 27125.79 | 9900914.989 | 2574237.897 | 857724.168 | 173143.783 | 57690.7 |
| 2021 | 26315.17 | 9605036.359 | 2497309.453 | 973547.600 | 167969.56 | 65481.0 |
| 2020 | 25528.77 | 9317999.756 | 2422679.937 | 1105011.338 | 162949.962 | 74323.3 |
| 2019 | 24765.87 | 9039540.946 | 2350280.646 | 1254227.38 | 158080.371 | 84359.6 |
| 2018 | 24025.76 | 8769403.591 | 2280044.934 | 1423592.924 | 153356.302 | 95751.2 |
| 2017 | 23307.78 | 8507339.011 | 2211908.143 | 1615828.872 | 148773.407 | 108681.0 |
| 2016 | 22611.25 | 8253105.962 | 2145807.55 | 1834023.547 | 144327.467 | 123356.8 |
| 2015 | 21935.54 | 8006470.404 | 2081682.305 | 2081682.305 | 140014.39 | 140014.4 |
| | | Total | | $B_2$ = 13153663.97 | | $B_3$ = 884718.21 |

Table 3- Benefit, cost, and their ratio for the corridors

| Corridor | Total benefit ($) | Total cost ($) | Benefit-to-cost ratio |
|---|---|---|---|
| Ferdowsi | 7.69E+09 | 1.13E+09 | 6.811 |
| Malek-Abad | 5.60E+09 | 1.69E+09 | 3.305 |
| Vakil-Abad | 6.23E+09 | 3.17E+09 | 1.967 |
| Vahdat | 1.25E+09 | 5.86E+08 | 2.135 |
| Kolahduz-Abutaleb | 2.53E+09 | 1.69E+09 | 1.502 |
| Kolahduz | 2.43E+09 | 7.82E+08 | 3.105 |

## 4. Conclusion

Several ways are suggested these days to deal with increasing city population and vehicle count from transportation point of view. Multilevel highways are one of these suggestions. Due to high expenses of such projects, fore-studies are significantly important. This paper aims at providing a method for feasibility studies of urban multilevel highways using economic and transportation analyses. The city of Mashhad is chosen as the case study and the methodology is used for it.
To start the studies, six of the most effective main corridors of the city are chosen. Each corridor is a candidate of multilevelization and the effect of adding a level to each corridor is studied as a scenario in this paper. The scenarios are modeled using VISUM software and total travelled time (VHT) and total travelled distance (VKT) are compared to the base network. Next, benefit-to-cost analysis is conducted considering reduced VHT, fuel consumption, and air pollution as benefits and net present worth of construction and maintenance expenses as costs in a 10-year period. Benefit-to-cost analysis shows adding a level to Ferdowsi street is the best one among all 6 scenarios.

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