Measuring the impact of freeway infrastructure on the accessibility of the city of Fez

Imane MOUFAD
Laboratory of Energy & Sustainable Development (LPE2D)
Sidi Mohamed Ben Abdellah University - EST,
Road of Imouzzer - BP: 2427 - Fez, Morocco
imane.moufad@gmail.com

Fouad JAWAB
LPE2D & Laboratory of International Management Decision techniques and Logistics
Sidi Mohamed Ben Abdellah University - EST,
Road of Imouzzer - BP: 2427 - Fez, Morocco
jawabf@gmail.com

Ismail AIT FASKA
Engineer in the field of the computing specialized in the logistics, in particular the air transport.

Abstract

The objective of this work is to measure the impact of the freeway construction on the accessibility of the city of Fez. Accessibility was measured in order to search for better logistics connectivity of the Moroccan economy with international markets. To reach our goal, we have organized this work into two parts. The first was accessibility's concept approach taking into account its potential and geographical dimensions and the second consisted of an application to the city of Fez from several regions of Morocco.
As for the methodological side, we used Shimbel index to measure geographic accessibility, the graph theory to model and assess the road network and Hansen model to measure the potential accessibility.
As a result, we estimate that Fez geographical and potential accessibilities were improved by 18% and 1% respectively after the Fez-Oujda freeway startup. We also note that a potential gain of 30% is possible if the Fez-Tetouan freeway project is achieved.

Keywords
Accessibility, infrastructure, road network, logistic connectivity

1. Introduction

Generally, the level of service in the transportation system is related to the accessibility of a site or a city. This accessibility varies from one city to another depending on the means put in place for serving these sites. Thus, by limiting itself to the study of the infrastructure that is part of the transportation system, accessibility is a measure that estimates the performance of this infrastructure. Also, accessibility allows us to measure the spatial impact of existing or planned transport networks.
The objective of this work is to present the notion of accessibility and the indicators used, to measure the impact of the Fez-Oujda motorway infrastructure on the accessibility of the city of Fez and finally to measure the potential impact of the project construction of the Fez Tetouan highway.

2. Theoretical framework: definitions & methodology

2.1 Definitions

a) The concept of a transport system:

The transport system is a complex system that operates correctly only by combining three elements: infrastructure, the transport industry and transport services. It consists of transporting from one place to another, people, goods and information, which have always been a crucial activity for man.

The growing importance of transport is mainly due to the growth in transport demand and the optimization of logistics costs. These two trends have increased the need for transport infrastructure (roads, highways, railways, etc.), hence the expansion of infrastructure. Consequently, it is interesting to evaluate the transport system, also to see the level of service offered by the infrastructures of the transport system, hence the notion of accessibility that will be dealt with in the next paragraph.

b) The concept of accessibility:

In the literature there are several definitions of accessibility, so some authors who have studied the problems posed by accessibility have defined this concept according to their motivations. It is a widely used concept in many disciplines. In some cases, accessibility makes it possible to deal with the difficulties encountered by people with reduced mobility in practicing transportation or access to public places. Another meaning of accessibility refers to the conditions under which individuals can travel the space and reach the premises, or the conditions under which goods can be conveyed (L'Hostis et al. 2010). It is in this second sense that we inscribe the present work.

One of the first appearances of the use of this concept is found in Hansen's work in 1959, which defined accessibility as "The potential of opportunities for interaction" (Richer & Palmier, 2011). Accessibility is then "an essentially spatial concept, which aims to account for the effort to be made to traverse space, in order to reach a place that harbors a resource" (L'Hostis et al. 2010). Also, accessibility, which is defined as the easiest way to reach a place "from one or more other places", is a primary factor in spatial planning, which explains the efforts made by the authorities public access to major areas of a country and to ensure better access to enclave areas.

It can be concluded that accessibility is a measure that estimates the performance of the transport network, but it remains to define how to measure and evaluate it.

2.2 Methodology

Two families of accessibility can be defined, namely:

c) Geographical accessibility: This method considers that the accessibility of a place is given by the sum of all the paths between each place and all the others.

d) Potential accessibility: to integrate the interest of destinations in the notion of accessibility. A simple declension of this potential indicator consists in determining the number of goods or services accessible under a given constraint (time, distance, costs, etc.) (L'Hostis et al. 2010).

a) Graph Theory:

e) Basic definition of the graph:

The transport networks can be represented by the theory of graphs. The main purpose of the latter is to encode the networks and measure their properties. A graph consists of a set of nodes (vertices) and arcs. The summit is a point of intersection at the level of a graph, it can represent a city, a prefecture, a region, a road intersection, an airport, a port, a bus station ... 'is a link between two vertices (i.e. between a starting summit and a final summit), an arc can represent the infrastructure of the transport system, roads, highways, airways ...

f) The Indices of graph theory:

The indices are methods used to represent the structural properties of a graph, among these indices are:

i. Departure Index:

It is a ratio between the direct distance of two vertices and the actual distance of course between these vertices. In a transport network, this index is a measure of efficiency as its ability to distance itself from distances. The more it tends to 1, the more spatially efficient a network is.

ii. Connectivity:

The measurement of connectivity makes it possible to evaluate the multiplicity of links provided in the system by the network.

The gamma index (γ):

$$\gamma = 2 * e / V * (V-1)$$ **Equation 1: The gamma index**

With: "e": the number of edges of a network
"V": the number of vertices of the same network
It is the ratio between the number of edges of the network studied and the maximum number of edges that it could contain, which is to say with respect to the maximum capacity of this network. The value is between 0 and 1. A value of 1 indicates a fully connected network. This index allows us to evaluate the progress of a network over time (Ducruet, 2010).

The alpha (α) index:

$$\alpha = (e-V) / [V * (V-1) / 2 - (V-1)]$$ **Equation 2: The alpha**

With: "e": the number of edges of a network
"V": the number of vertices of the same network
The alpha index is the number of circuits that a network has in relation to the maximum number of circuits that this network can contain. This index varies between 0 and 1. The higher the index, the more the network is connected. A value of 1 indicates a fully connected network, except that it is very rare for a network to have an alpha value of 1 because this would involve serious redundancy (Ducruet, 2010).

b) Geographical accessibility:

The measurement of the geographical accessibility of a place is given by the summation of all the distances (the shortest paths between them) separating it from the other places, these distances are contained in a matrix, called accessibility matrix geographical. The lower its value, the more accessible it is (Raux et al, 2007).

$$A(G)_i = \sum_{j=1}^{n} d_{ij}$$ **Equation 3: Geographic accessibility**

- A (G) i = geographical accessibility of a location i.
- dij = the distance between place i and j via the shortest route.
- n = the number of locations.

This measure is also known as the Shimbel Index. This indicator makes it possible to compare accessibility measures for specific locations.

c) Potential accessibility:

The potential accessibility is a more developed measure than geographic accessibility because it combines the concept of distance weighted by the attributes (resources) of a place. This approach consists in integrating the interest of destinations in the notion of "simple" accessibility (as defined above). "Potential accessibility can be defined as the quantity of goods, jobs ... that an individual can reach from a given point, taking into account the level of transport supply and the attractiveness of destinations." (Setra, 2008).

This approach was developed by Hansen in 1959. Indeed, in the late 1950s, he showed that an accessibility index based on the severity model explained with a high level of correlation with population growth, jobs and the number of businesses in the metropolitan area of Washington (Setra, 2008).

In general, the potential accessibility corresponds to the product of the attractiveness and the friction of the space, whose attractiveness represents the potential of a place and the friction of the space represents the difficulty of reaching this place, this difficulty can represent the distance, the travel time, the transport costs...

In short, the following formula will be adopted for the rest of this project (Raux et al, 2007):

$$A(P)_i = \sum_{j=1}^{n} \frac{P_j}{d_{ij}}$$ **Equation 1 : Potential accessibility**

- A (P) i = the potential accessibility of a place i.
- dij = the distance between place i and place j.
- Pj = the attributes of location j, such as population, commercial surface, parking area, etc.
- n = the number of locations.
- The values Pj / dij are contained in a matrix called a potential accessibility matrix. Two notions underlying potential accessibility, namely emissivity and attractiveness.
- Emissivity is the ability to leave a place; the sum of the values of a row.
- Attractiveness is the ability to reach a place; the sum of the values of a column.

d) Gravity accessibility and the Geographic Information System:

i. Definition Geographic Information System (GIS):

A Geographic Information System (GIS) is a computerized system that allows, from various sources, to gather, organize, manage, analyze and combine, elaborate and present information geographically localized contributing in particular to space management. GIS are generally used to determine tourist routes, customer location, urban planning (roads, sanitation networks), mining prospecting and transport planning

ii. Calculation of accessibility:

Applying the formula of gravity accessibility defines:

$$Ai = \sum_j Dj \exp(-\beta cij)$$ **Equation 5: Gravity accessibility**

With: Dj: The potential attraction of destination j (number of jobs, populations ...)

$\exp(-\beta cij)$: A function of resistance to the displacement, with cij the generalized cost of displacement from the zone i to the zone j.

e) Summary

Table 1. The methods for calculating the accessibility

<table>
<tr><th>Methods</th><th>Input data</th><th>Output data</th><th>Difficulty</th></tr>
<tr><td>Indices of graph theory</td><td>Road Network Modeled</td><td>Structural properties of the road network</td><td>Network modeling</td></tr>
<tr><td rowspan="2">Geographical accessibility</td><td rowspan="2">Geographic Accessibility Matrix (Shortest Path Distance Matrix)</td><td>Measuring the geographical accessibility of a destination</td><td rowspan="2">Construction of the distance matrix</td></tr>
<tr><td>Evaluation of the evolution of accessibility following an infrastructure construction</td></tr>
<tr><td rowspan="2">Potential accessibility</td><td rowspan="2">Potential accessibility matrix
Data on population, number of jobs ...</td><td>Measuring the potential accessibility of a destination</td><td rowspan="2">Availability of updated population data, number of jobs ...</td></tr>
<tr><td>Evaluation of the evolution of accessibility following an infrastructure construction</td></tr>
<tr><td rowspan="3">Gravity accessibility and the Geographic Information System</td><td rowspan="3">Geographic data available in digital format.</td><td>Measuring the potential accessibility of a destination</td><td rowspan="3">Lack of geographic data available in format digital.</td></tr>
<tr><td>Evaluation of the evolution of accessibility following an infrastructure construction</td></tr>
<tr><td>Cartographic illustration of potential accessibility</td></tr>
</table>

3. Measuring the impact of the Fez Oujda motorway

3.1 Measuring geographical accessibility

a) Modeling the road network of the regions studied:

Using the "GeoGebra" software, which is a dynamic geometry program, we have modeled the road network linking the different cities. Note that the network represents the shortest paths in terms of time, the latter are calculated using Google Maps.

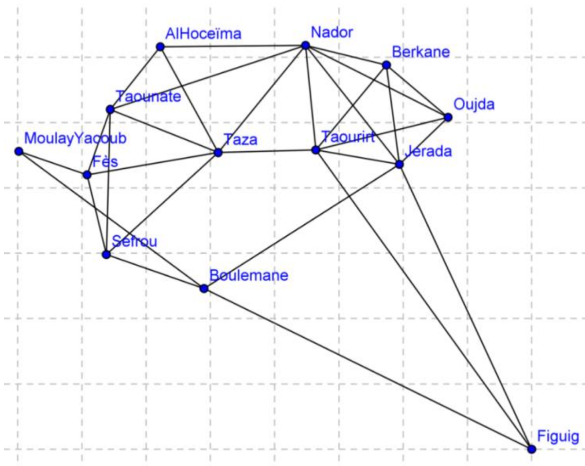

Figure 1. Modeling of the road network before the commissioning of the Fez Oujda motorway

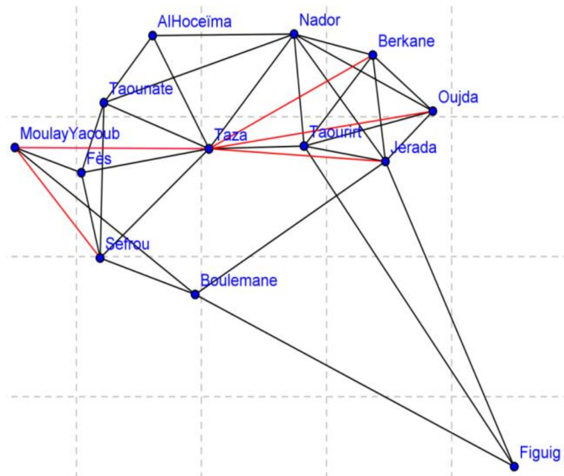

Figure 2. Modeling of the road network after the commissioning of the Fez Oujda motorway

It will be noted that following the commissioning of the highway new links are created, these links are represented by red arcs in Figure 2. Moreover, the construction of the geographical accessibility matrix is done by calculating the travel time (shortest route) between the different cities studied. For this reason we used the Google Maps web application. For the construction of the matrix after the Fez Oujda highway is commissioned, the options for calculating the routes: "Avoid highways" and "Avoid toll sections" (at Google Maps) are unchecked to calculate the new journey time using the Fez Oujda motorway.

b) Indicator of geographical accessibility before and after commissioning of the motorway:

Table 2. Comparison of the results of figures 1 & 2

Cities	Before the motorway (hours: minutes)	After the motorway (hours: minutes)	Accessibility gain (in time hours: minutes)	Accessibility gain (in %)
Al Hoceima	45:18	43:28	1:50	4%
Taounate	39:48	35:41	4:07	10%
Taza	31:40	27:05	4:35	14%
Oujda	40:23	32:50	7:33	19%
Berkane	41:46	34:53	6:53	16%
Figuig	78:30	77:00	1:30	2%
Jerada	41:00	35:26	5:34	14%
Nador	39:54	33:43	6:11	15%
Taourirt	32:10	27:43	4:27	14%
Fez	38:32	31:33	6:59	18%
Boulemane	46:08	40:38	5:30	12%
Moulay Yacoub	41:50	33:46	8:04	19%
Sefrou	39:21	31:42	7:39	19%
Total	556H 20MIN	485H 28MIN	70H 52MIN	**13%**
	23days 4 hours 20 minutes	20 days 05 hours 28 minutes	2 days 22 hours 52 minutes	

Note that the values of accessibility indicator was improved for all the cities studied, this resulted in the accessibility gains ranging from 2% to 19% for Figuig and Moulay Yacoub, Sefrou and Oujda. This shows a total gain of 13% and an improvement in terms of time of 02 days 22 hours and 52 minutes, this shows the positive impact of the construction of the Fez Oujda motorway on the three regions studied. Moreover, to the city of Fez we see that has a gain of 6 hours and 59 min, that is to say a gain of 18% compared to its accessibility before the highway commissioning.
Thus the calculation of the indicator has allowed us to see a clear improvement due to the construction of the new road infrastructure.

c) Comparison of the service times of the city of Fez in the first and second cases:

The measurements in the table below are in Hours and minutes.

Table 3. Comparison of the service times of the city of Fez in the 1st and 2nd cases

	Hoceima	Taounate	Taza	Oujda	Berkane	Figuig	Jerada	Nador	Taourirt	Boulemane	Moulay Yacoub	Sefrou
Before	3:42	1:10	1:41	4:32	4:40	8:03	4:35	4:21	3:07	1:37	0:25	0:39
After	3:24	1:10	1:25	3:10	3:24	7:26	3:27	3:09	2:17	1:37	0:25	0:39
Gain (Time)	**0:18**	**0:00**	**0:16**	**1:22**	**1:16**	**0:37**	**1:08**	**1:12**	**0:50**	**0:00**	**0:00**	**0:00**
Gain (%)	**8%**	**0%**	**16 %**	**30%**	**27%**	**8%**	**25%**	**28%**	**27%**	**0%**	**0%**	**0%**

It can be deduced from the table that the greatest gain in terms of travel time between Fez and other cities is 1 hour and 22 minutes with a percentage of 30% (between Fez and Oujda) followed by a reduction in recorded time compared to Nador of 1H12Min with a rate of 28%. In the same context, it can be said otherwise that after the construction of the motorway, the cities of Oujda and Nador have approached respectively 30% and 28%.

d) Index of detour between the cities Fez and Oujda:

- Before the motorway is put into service:

The distance between Fez and Oujda is 293 Km. As for the actual distance, it is 344 Km, hence the detour index is equal to 0.85.

- After commissioning of the motorway:

It has the same distance as the crow flies, however the actual distance is 329 Km, so the detour index is 0.89.
It can be seen that the detour index improved by 4.7% compared to the value of the index before the Fez Oujda highway, thus improving the spatial efficiency of the Fes Oujda route thanks to the highway.

e) Connectivity:

This section will evaluate the impact of the highway on the connectivity of the road network of the cities studied, by measuring the multiplicity of links provided by the network.

- The gamma index (γ):

By applying equation 1 defined above, the following results are obtained:

Table 4. Calculation of the gamma index

	number of network edges "e"	number of vertices of network "V"	**Gamma Index**
Before the motorway	29	13	**37%**
After the motorway	34	13	**44%**

The results indicate that the road network in the first case (before the motorway is put into service) contains 37% of the edges (connections between cities) that are effectively connected to the maximum capacity of this network. In the second case, there are 44% of edges that are connected, so there is a gain in the number of stops (number of connections) of 17% after commissioning of the motorway.

- The alpha index (α):

By applying equation 2 defined above, we have the following results:

Table 5. Calculation of the alpha index

	number of network edges "e"	number of vertices of network "V"	**Alpha Index**
Before the motorway	29	13	**24%**
After the motorway	34	13	**32%**

In the first case, the alpha index is 24%, that is to say that 24% of the circuit exists in relation to the maximum number of circuits that can be contained in the road network. The second case is 32%. The gain is 31%, it can be said that after the Fez Oujda highway, there is a gain in number of circuits of 31%. In general, the connectivity of the road network is markedly improved by the Fez Oujda highway.

3.2 Measuring the potential accessibility

a) Input data

For the calculation of the potential accessibility, equation 4 is applied. Thus, as input data of the geographic matrix already constructed in the previous chapter and the attributes considered as potential of each city, it is necessary. The attribute used is:

• The number of employed and unemployed workers who have already worked, which reflects the size of the workforce available in the urban labor market.

Table 6. Size of employed and unemployed persons who have already worked by city
Source: General Population and Housing Census 2004 / http://www.hcp.ma

Cities	**Employed and unemployed who have already worked**
Al Hoceima	120 234
Taounate	233 536
Taza	203 775
Oujda	126 002
Berkane	76 853
Figuig	32 453
Jerada	22 458
Nador	201 504
Taourirt	55 791
Fez	303 250
Boulemane	50 618
Moulay Yacoub	49 629
Sefrou	78 232

b) Measurement of the potential accessibility of the Fez Oujda motorway

- Potential accessibility with the attribute of the number of employed and unemployed workers who have already worked before and after the commissioning of the motorway:

From the potential accessibility matrix we have the following results:

- *Emissivity:*

Table 7. The gain in emissivity

Cities	**Emissivity before (Pi)**	**Emissivity after (Pi)**	**Gain in %**
Berkane	86987,84	88206,43	**1,40%**
Boulemane	60309,87	60952,95	**1,07%**

Fez	315615,31	316780,46	**0,37%**
Figuig	36255,11	36320,41	**0,18%**
Al Hoceima	128468,29	128690,43	**0,17%**
Jerada	32049,77	33073,17	**3,19%**
Moulay Yacoub	70107,70	71550,68	**2,06%**
Nador	209763,07	211015,77	**0,60%**
Oujda	134611,20	136134,12	**1,13%**
Sefrou	94307,46	95855,45	**1,64%**
Taounate	244383,56	244837,64	**0,19%**
Taourirt	67855,86	69810,38	**2,88%**
Taza	214661,15	216604,84	**0,91%**

- *Attractivity :*

Table 8. The gain in the attractivity

Cities	Attractivity before (Pj)	Attractivity after (Pj)	Gain in %
Berkane	83162,19	83748,87	**0,70%**
Boulemane	54251,09	54511,87	**0,48%**
Fez	341694,57	344713,72	**0,88%**
Figuig	33495,75	33509,04	**0,04%**
Al Hoceima	127464,68	127708,18	**0,19%**
Jerada	24221,85	24362,64	**0,58%**
Moulay Yacoub	55036,72	55697,77	**1,19%**
Nador	217665,43	219279,31	**0,74%**
Oujda	137056,93	138324,29	**0,92%**
Sefrou	86310,29	87466,40	**1,32%**
Taounate	252449,58	253599,36	**0,45%**
Taourirt	60941,57	61625,23	**1,11%**
Taza	221625,54	225286,03	**1,62%**

Taking into account the employed and unemployed who have already worked, there is a clear improvement in terms of potential accessibility for the city of Fez. Indeed, we have + 0.37% in emissivity and + 0.88% in attractiveness. On the other hand, the maximum of the surplus is 3.19% in emissivity for the city of Jerada and 1.62% in attractiveness for the city of Taza.

4. Conclusion

At the beginning of this work, we defined the concept of the transport system and the accessibility as well as the tools used. A transportation system is a combination of three elements; the transportation industry, transportation services and infrastructure. Accessibility is considered to be the greater or lesser ease with which a place can be reached from one or more other places.
In this context, the objective of our study is to measure the contribution of the motorway infrastructure on the accessibility of the city of Fez, by comparing the before and after opening of the motorway infrastructure .

To achieve this objective, we used the Shimbel index to measure geographic accessibility, graph theory to model and evaluate the road network, and Hansen's approach to measuring accessibility.
The measurement of the indicators reveals several conclusions. The commissioning of the Fez Oujda highway has resulted in a positive gain in terms of geographical and potential accessibility. On the other hand, a potential gain is possible if the project of the Fez Tetouan highway is realized.
It is important to note that accessibility is essential for infrastructure planning. It helps determine in advance the utility of building a new infrastructure or not, by measuring its potential impact on road network connectivity.
In addition, other research could be done, such as the study of transit accessibility or the transportation of goods. In addition, accessibility indicators can be improved by taking into account other criteria, in addition to travel time or distance, for example transport costs, coefficients reflecting the difficulty of the journey, can be determined from interviews and surveys.

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