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A STRATEGIC FORECASTING APPROACH TO IMPROVE FUTURE INTER-URBAN MOBILITY POLICIES

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ABSTRACT

Infrastructure has always played a vital role in the development of economies, and in this case, transport infrastructure. The latter constitute the support vector for intra- and inter-region mobility. Transport and mobility are becoming increasingly important in the sustainable management of land and are at the heart of the current debate. The modes of transport compete for the search for original and innovative solutions to stand out, increase their attractiveness and their competitiveness, and thus acquire an image that evokes development, modernity and respect for the environment. Given the various crises that the world has experienced and continue to experience, such as the 2008 financial crisis and the COVID-19 coronavirus pandemic, financial resources are becoming increasingly scarce. For that reason, solutions must be sought for a rational and judicious use of space as well as transport via a good control of mobility within the territory. Contrary to the various works carried out before, this paper is an attempt to create a tool to help strategic decision for national interurban mobility through the application, and for the first time in Morocco, of a dynamic modeling approach. It is about using a four-step modeling method, mounted on the TransCAD software, GIS-package with specific transportation analysis tools, supported with a certain flexibility in the configuration. Our contribution consists in investigating whether the proposed approach could succeed in the Moroccan context and contribute to the application of a dynamic modeling method, which links interurban mobility, all modes of transport, to the socio-economic parameters. That is using a Moroccan detailed, which is made up of the travel diary in 2016, enriched with many individual and domestic functions and data from the last General Population and Housing Census of 2014.This will give decision-makers better visibility on interurban mobility in Morocco.

Keywords: *Four-Step Modeling, Inter-urban Mobility, Mode Choice Prediction, Utility Function, Gravity Model, Multinomial Logit Model, and Linear Regression*

1. INTRODUCTION

Throughout the years, infrastructure projects, in particular transport, play a major role in the development of countries and their economies. These infrastructures constitute the pillars that ensure exchanges between the various regions inter and intra country. In other words, they guarantee the necessary movement of goods and people relating to the performance of daily socio-economic activities.

Also, these transport infrastructure projects represent one of the most recommended means in the literature and theory to stimulate economic activity and thus boost growth rates in favor of improving the well-being of citizens. These are projects that create value during the construction phase by making several trades and sectors work, as they serve socio-economic development from their start.

However, these projects are very demanding in terms of investments and weigh heavily on the general budget. Given the scarcity of financial resources that the world has been experiencing lately, particularly the developing countries, following the various crises and disruptive events in the economies, namely: the financial crisis of 2008, the pandemic crisis of Corona-virus COVID-19 [1] … Decision-makers must seek to optimize the programming of transport infrastructure projects while creating systems or decision-support tools in the prioritization of this type of projects. This prioritization must be made while ensuring an optimized response in favor of mobility needs.

Transport and mobility are increasingly important in the economic activity of each country and are at the heart of the current debate. Different modes of transport compete for original and innovative solutions to differentiate from each other, increase their attractiveness and their competitiveness. However, due to the lack of liquidity, it is no longer possible to support all investments in the infrastructure sector, and the complementarity between the different modes of transport as well as the efficiency of investments become a necessity for decision-makers around the world. In this sense, modeling and forecasting mobility trends, including interurban mobility is a strategic priority and an essential exercise for policymakers to manage an optimal balance between travel needs and funding capacity.

Morocco has always opted for types of static models, called Two-Step models, which only map mobility at a given time t. Also, the work already carried out in the Moroccan context focused on a single mode of transport. In fact, Morocco manages the different modes of transport via autonomous public establishments and consequently, each mode is treated separately to a certain limit and develops its strategy with a tendency much more monomodal than complementary.

This research paper is interested in the modeling of interurban mobility with a main objective to study interurban mobility, all transport modes, in the Kingdom of Morocco via the creation of a strategic decision-making tool in this area. Such a study helps decision-makers predict mobility, optimize it, and finally have empirical work on which to base the judicious and optimal planning of transport infrastructure projects.

More concretely, we propose in this work to apply the four-step modeling approach [2] to predict interurban mobility in Morocco and then to know how to decide on the choice of investments in transport infrastructure. It should be noted that, and across the world, this approach is used by many strategic departments and planners to monitor, predict and evaluate mobility [3].

Thus, we aim in the experiment to investigate whether the proposed approach could succeed in the Moroccan context and contribute to the application of a dynamic modeling method which links interurban mobility, all modes of transport, to all the socio-economic parameters available, and then captures the current mobility trends and their evolution in the future while following the evolution of these explanatory socio-economic parameters of the model.

This dynamic approach is supposed to give better results in the Moroccan context as well as provide decision-makers with the possibility of reviewing the priority choices in terms of infrastructure investment with a global, complementary and multimodal vision of interurban mobility trends.

It should be noted that this work will be realized using the TransCAD software tool. It is one of the tools most used by transportation planners to model, plan, streamline and improve the process of predicting transportation demand. In addition, it is effective as regards the distribution and the modal choice as well as the assignment of displacements envisaged during the generation step, see [4] [5].

2. LITERATURE REVIEW

In this section, we give a brief review on related works to our subject. Our aim is to present the work carried out in Morocco in recent years in the area of predicting mobility, all modes combined, the constraints and limits of this work, as well as current transport modeling practices and utility of using a four-step modeling approach in the Moroccan context.

In the national context, Morocco does not have a multimodal reference model. In fact, several administrations and public establishments have developed national models for their needs, in order to decide on the prioritization of future investments. We mainly cite the monomodal road model intended to assess toll revenues developed by Autoroutes du Maroc [6], the national model intended to assess the demand for rail trips in relation to the supply [7], the model intended to assess the bus transport request developed by the Road Transport and Road Safety Department and the international model for assessing passenger and freight traffic carried out by the National Society for the Study of the Strait of Gibraltar (see [8]).

In addition, it is necessary to cite the Road Plan for 2035 [9], the Study of the National Road Infrastructure Master Plan for the horizon 2035 [10] and other research works were interested in road

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mobility, as the dominant mode, and more precisely for grand taxis (see [11] and [12]).

Regarding all of the works cited, each served only a given mode of transport without taking into consideration the other available transport modes. However, predicting mobility, in this case interurban mobility, is mainly linked to the notions of multimodality and the complementarity between the different modes offered, as well as to socioeconomic parameters, which reflects the limits of the various studies carried out previously.

In international context, research work relating to the modeling of mobility, urban and interurban, is still one of the major concerns of researchers and professionals. Several works have been carried out in this sense with a multitude of scientific approaches established to correctly predict mobility and best serve the travel needs of citizens. However, all these approaches follow the same logic and often vary just in terms of how to approach the solution, to what scale or degree of precision and allow what level of dynamism with the guiding parameters [13].

The vast majority of models used to predict mobility are essentially based on the four questions relating to the four-step modeling approach (Why travel? Which destination? By which mode? Which route?) with many adaptations and improvements depending on the context [14].

The fundamentals of the analysis of transportation systems started with a basic structure introduced by Manheim 1979 (see [15]) and developed by Florian 1988 (see [16]). This provides a comprehensive paradigm in which to examine the four step model as mentioned by McNally, M. G. (2007) in [2].

Throughout history, people need to move somewhere and that to satisfy a particular need linked to the different activities of life (work, health, administration, ...) [17]. For this reason, and in order to reduce forecasting mobility uncertainty, that Y. Zhao and K. M. Kockelman in [18] tried the use of socio-economic data to quantify travel demand. But, this work could be further improved by using the four step modeling approach. In fact, this approach predicts the mobility of people based on socio-economic parameters and makes it possible to boost these forecasts over time while following the evolution of these parameters trends [2].

The four step model is a strategic approach which deals with the whole mobility system and has just differed from the single-modal approach. It is developed to outline a global vision and help decision-makers prioritize projects with a major impact on mobility. It provides a mechanism consisting of four steps, each with appropriate modeling, to determine the equilibrium flows and provide a reliable vision for strategic purposes [2].

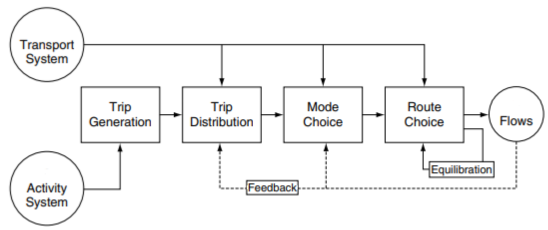

Figure 1: Four Step Model Approach Global Vision [2]

Among the experiences that have succeeded in adopting the four-step approach, we cite the model of travel integrated into the evaluation system of territorial policies of Catalonia [19] and the multimodal model of long-distance internal transport (called MODEV), created by France in 2001 and revised in 2007 and 2011 [20]. It is applied to assess huge projects and public policies in the field of transport.

In addition, and to apply all the aforementioned approaches with their different specificities, there was always recourse to computer tools and technologies. In terms of transport modeling and planning, several research works have been carried out in this direction.

The EMME software, which constitutes a particularly scalable multimodal demand and network modeling system, has been adopted for several transport modeling projects such as the new swedish national travel demand forecasting tool (see Beser, M. & Algers, S. (2002)) [21]) and the automatic calibration tool designed to find the optimal set of values for the parameters of the transport allocation model implemented in the transport planning software EMME / 2 (see Parveen, M ., Shalaby, A., & Wahba, M. (2007) in [22]), etc.

The PTV VISUM software, which also represents a complete traffic planning tool, used by many professionals around the world, has been an IT and technological refuge for several research projects in the field of transport.

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Among these works we cite the multi-agent transportation simulation carried out in 2003 by Raney, B. in [23], the development of applications concerning urban mobility and its plans progress in the municipalities of Romania while using the software PTV VISUM (see H.G. Crișan and N. Filip (2015) in [24]), etc.

The TransCAD Software, and as already pointed out before, is one of the most popular transport modeling tools in the field and it has been chosen for the accomplishment of several research works as well as other professionals related to the modeling. and the simulation of travel demand around the world.

It is based on the GIS System and among the scientific experiments in which the use of TransCAD has proved to be efficient and reliable, we cite the prediction of traffic flow based on TransCAD carried out by S. Bin and Y. Zhenzhou in 2006 in [25] and the use of this software to estimate the real origin-destination matrix, then used to calculate the trip production calibrated by the parameters of the gravity model carried out in China by WU Chunlei CHANG Yulin in 2008 (see [26]), etc.

Thus, we note that the field of scientific research in terms of transport modeling and simulation and even more generally that of predicting mobility, whether urban or interurban, has been developed thanks to the development of computer and technological tools and there are several software and applications developed in this sense including TransCAD.

The literature shows that all the software cited or otherwise have been shown to be efficient and reliable. However, and for reasons of ease of handling, of a twinning with the GIS system, of a very well answered use in favor of a very easy connectivity of data, lower price, … TransCAD was widely recommended for the four step modeling approach that the present paper is aiming to apply for the Moroccan case.

In fact, TransCAD is recommended as a Geographical Information System software package for planning, management, operation, and analysis of transportation systems and facilities (see Caliper, 1990 in [27]. The software can be used for many different applications including the various type of transport infrastructure, in other hand multi-modality. It can be very useful in planning, managing and forecasting urban and regional mobility with various modules for data handling, namely: entry, storage, analysis, and well presenting data (see P. Waerden & H. Timmermans, 1996 in [4]).

3. FOUR STEP MODEL: MOROCCAN CASE

3.1 Four-Step Model Added Value to The Moroccan Experience

In this section we will talk about the previous Moroccan approaches and experiences to predict the mobility, the methodology and the global mechanism of the proposed method, known as four-step modeling, as well as the added value that the latter can bring to the modeling and the simulation. of interurban mobility in Morocco.

The section begins with the previous approaches and works inscribed in the Moroccan experience as to the subject, then moves on to our approach that we are trying to experience, and for the first time, to the Moroccan context.

3.1.1 Previous Moroccan Works Limits

Regarding the modeling of interurban mobility in Morocco, all the previous works (cited in [6][7][8][9][10][11] and [12]) were limited to two steps or to a direct assignment that allows to represent a photograph of the current situation and to make it evolve linearly on different horizons.

Within the traditional modeling approach, and as shown in the figure 1 below, we have the following steps: Origin-Destination Matrix observed by mode, Assignment on the networks of each mode and the last one is Reproduction of the current situation.

The origin-destination matrix is constructed depending to each mode. In fact, for the road mode is based on road surveys while other modes already have their annual origin-destination matrix. The Assignment is made according to the characteristics of the offer (speeds, frequencies ...) and finally we reproduce the current situation. The changes that could be made are linear developments that do not consider the socio-economic evolution of the territories (see Figure 2 below).

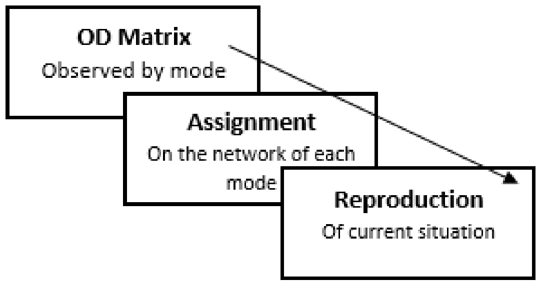

Figure 2: Traditional modeling approach

This modeling approach is not adapted to simulate the evolution of mobility following that of the socio-economic characteristics of the territories. Thus, the search for a new mechanism which takes into consideration more data, such as socio-economic parameters, has become a major priority for decision-makers and researchers. Such a mechanism should further broaden the use of available data and of course ensure better visibility on the subject of travel demand.

3.1.2 New Methodology to Simulate Mobility in Morocco: Four Step Model

Four-step modeling, and as already reported in the literature, is a widely used and recommended approach in this field and uses more data. It is based on explanatory variables of a socio-economic nature that we can simulate the evolution and subsequently see their impact on the mobility of travelers and goods. This will increase the reliability of the results and further improve the level of relevance of our forecasts.

As mentioned bellow, in the figure 2, this approach allows the simulation of the impact of socio-economic evolution on mobility. Travel still considered in theory as derived from the demand to participate in an activity (see Michael McNally, 2000 [28]).

To further explain the advantages of this method and emphasize its added value in terms of better simulation of travel demand, in other words mobility, we propose to present briefly its methodology as well as its different steps. This is the objective of Figure 3 below.

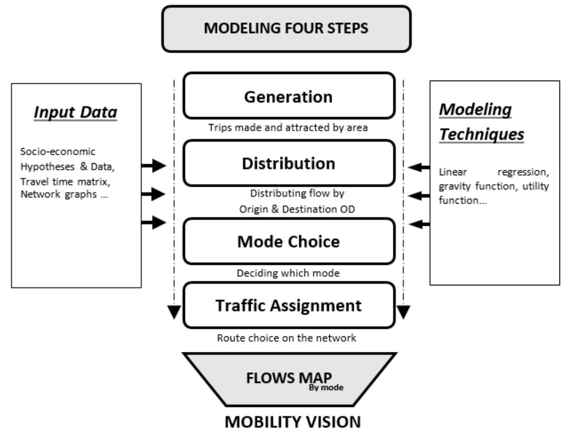

Figure 3: The Proposed Model Architecture.

For the trip generation step, its functions use variables representing activities and the whole socio-economic side such as demography, employment, tourism and other variables (Nakkash, T. Z. 1969 [29]).

Moving on to the second step known as trip distribution, we opt for gravity functions that use the travel times between zones, depending on the chosen mode. The travel time factor represents the effect of travel time on trip interchanges. In its use in gravity model studies, the travel time factor is an empirical hand-down curve that is considered constant over time (Ashford, N., & Covault, D. O. 1969 [30]).

Arriving at the modal choice, our approach is based on utility functions that measure the individual satisfaction of each traveler according to a set of parameters and socio-economic data, namely: education level, the possession of a vehicle, age, socio-occupational category, the cost of the trip ... combining this utilities functions with probabilistic function's give us a useful solution to predict traveler's mode choice such as the logit model.

Since the contribution by Warner in [31] (and Evanston in [32], 1962) who studied travel demand as a problem in discrete binary choice, there has been a growing interest in the application of probabilistic choice models to the analysis of travel. The econometric properties of multinomial logit models have received particular attention (Nerlove and Press [33] and McFadden, 1973 in [34]), and major applications of these to travel demand have appeared (see Charles River Associates, 1967 [35] and Domencich and McFadden, 1975 [36]).

Thus, and to conclude, the present and concise presentation of the methodology, which we intend to follow in this work to model mobility in the Moroccan context, highlights the added value that this proposed approach could bring to the control and forecasting of mobility future trends. In fact, this approach encompasses several techniques and different models nested and adapted to each of the steps of the whole process of the travel demand creation.

In addition, the four-step modeling is based on the use and analysis of more data, of different types and above all the parameters of socio-economic activities considered as the key factor in the evolution of mobility between regions.

The next section will be devoted to the experimental application of this approach to the Moroccan context and will give more explanation on the methodology followed for an empiric realization of the four-step model.

3.2 Information requirements and experimental approach for the Moroccan proposed four step model

This section will be devoted, on the one hand, to present the whole methodology used, on the other hand, to explore the different inputs that we will use to adapt the different models involved in the four predefined steps.

Before starting the four steps of modeling, we note that a zoning has been adopted for the realization of this research work. This zoning divided the national territory into a set of regional zones with the focus on 16 zones, the results of which will be extrapolated automatically by the TransCAD tool to other similar zones (having the same socioeconomic characteristics). The model also takes into consideration a set of mobility injectors, namely: ports, airports and border crossings whose data (Origin-Destination matrix) are exhaustive and injected directly into the model.

In what follows, we will try to present, in a clear and concise manner, all the steps followed and adopted for the implementation of the four-step approach in the Moroccan national context.

3.2.1 Generation

For the trips generation between zones, the approach uses linear regression relationships to capture both the trips made and attracted by an area x, and this via explanatory variables reflecting the socio-economic parameters (population, employment, tourism ...) responsible for the generation of these trips. Indeed, the traffics emitted or attracted by this area can be represented as functions of socio-economic parameters, of which the general form is linear:

$$\mathbf{Flow}_{im} = \boldsymbol{\alpha}_{im}\, \boldsymbol{Vi} + \boldsymbol{\varepsilon} \qquad (1)$$

Where:

$\mathbf{Flow}_{mi}$ is a flow (emitted or attracted) by the zone i and related to a trip motive m;

$\boldsymbol{\alpha}_{im}$ is a mobility coefficient related to the trip motive m and zone type i;

$\boldsymbol{Vi}$ is the explanatory variable of the flow $\mathbf{Flow}_{mi}$, which can be a composite variable (several variables).

$\boldsymbol{\varepsilon}$ is the term randomness of the flow. It represents the margin of error within the statistical model proposed and in the present case, it is assumed that this term follows a standard normal distribution.

In practice, all the experiments already carried out have revealed a fairly limited number of explanatory variables, due to the constraint of the unavailability of data, especially in developing countries such as Morocco.

These variables are often: population, active population, employment, establishments open to the public with specific size indicators: surface area for shops, beds for hospitals, commercial beds for tourist sites, etc.

The coefficient α_{im} is calculated from the various data collected relating to the area in question, using the estimation methods of linear regression (see Monzon, J., Goulias, K., & Kitamura, R. (1989) in [37]).

The Travel Generation Analysis calculates the volume of trips generated and attracted by area via traffic analysis. The latter is calculated from linear relationships with socio-economic factors such as the quantitative characteristics of households (Kearney, J. K., Grechkin, T., 2006 in [38]).

$$\boldsymbol{Em_i} = \textstyle\sum_k \boldsymbol{\alpha_{ik} X_{ik}} \qquad (2)$$

$$\boldsymbol{At_i} = \textstyle\sum_k \boldsymbol{\theta_{ik} Y_{ik}} \qquad (3)$$

Where:

X_{ik} et Y_{ik} are selected socio-economic variables;

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And α_{ik} et θ_{ik} are emission and attraction parameters.

Concerning the selected socio-economic variables, it is necessary to point out that we retained those being available for all the chosen zones as it is shown in the table below:

Table 1: Selected Socio-Economic Variables.

Motive	Emission	Attraction
Professional	Active Population	Total Employment
Other	Adult Population	Tertiary Employment
Tourist	Adult Population	Tourist Beds

a. Generation step: EMISSIONS

In order to calculate the emission by zone, we will use for each reason the statistics of the High Commission for Planning, the official source of the data in Morocco. Calculations will be done as follow:

$$\mathbf{PE} = \boldsymbol{\lambda_{pro}}\ \boldsymbol{\alpha_{pro}}\ \boldsymbol{AP_{2014}} \quad (4)$$

Where:
PE : Professional Emission.
AP_{2014} : Active Population (2014)
α_{pro}: the emitting capacity of the zone for the professional reason, this factor is calculated from the surveys and data available.

λ_{pro}: corrective factor initialized to 1, which will allow the calibration later.

$$\boldsymbol{A_dE} = \boldsymbol{\lambda_{per}}\ \boldsymbol{\alpha_{per}}\ \boldsymbol{A_dP_{2014}} \quad (5)$$

Where:
A_dE: Adult Emission.
A_dE_{2014}: Adult Population (2014).
α_{per}: the emitting capacity of the zone for the personal reason, this factor is calculated from the surveys.
λ_{per}: corrective factor initialized to 1, which allows subsequent calibration.

$$\mathbf{TE} = \boldsymbol{\lambda_T}\ \boldsymbol{\alpha_T}\ \boldsymbol{A_dP_{2014}} \quad (6)$$

Where:
TE : Tourist Emission.
A_dE_{2014} : Adult Population (2014).
α_T: the emitting capacity of the zone for the tourist reason, this factor is calculated from the surveys.
λ_T: corrective factor initialized to 1 which allows calibration later.

In addition to the motive segmentation, we consider it necessary and important to divide the population by socio-professional categories. This will be a very useful asset for the modal choice and assignment steps. Indeed, the socio-professional categories, and for the same reason of displacement, may not behave in the same way.

The distribution of the population by Socio-Professional Category was carried out considering the results of the 2014 General Population and Housing Census (see [39] [40] [41]). Thus, we can base our study on an exhaustive data in order to fit well our results.

Also, and within each socio-professional category one distinguishes the travelers having a vehicle or not. In fact, this data has a direct and indirect impact on the decision to travel and in which mode or in what way.

The socio-professional categories are available in the table below:

Table 3: Socio-Professional Categories [40].

N°	Socio-Professional Category Description
1	Assets higher professions
2	Assets intermediate professions
3	Assets: manual workers and trades
4	15 to 59 years old schooled
5	15 to 59 years old inactive or demand of employment
6	60 years old and over inactive

These mobility coefficients per motive (α_{pro}, α_{per} and α_T) correspond to the ratio of emissions observed per zone per motive and the active or adult population according to the motive studied. This, all modes confused.

Table 2: Population Data by Zone [41].

Zone	Active Population	Adult Population
1	327 214	692 548
2	189 944	357 808
3	481 458	747 832
4	214 652	399 871
5	364 853	648 044
6	213 417	376 948

7	211 864	343 941
8	1 280 423	2 313 318
9	130 808	1 089 948
10	154 210	268 600
11	127 137	212 382
12	521 894	860 748
13	280 514	420 370
14	220 912	393 622
15	199 035	353 379
16	66 813	157 550

The values of these coefficients were obtained by evaluating the number of emissions from each zone through all the road, rail and air data collected.

We get emissions through extensive travel diary data of Morocco, established by the year 2016, enriched with numerous individual and household features.

Table 4: Total Emissions of Surveyed Areas.

Zone	Total Emissions		
	Professional Emission	Adult/Personal Emission	Tourism Emission
1	31937	6606	2812
2	14561	6576	997
3	48346	17334	4571
4	44978	9292	3835
5	45074	9264	3871
6	44891	9247	3900
7	3813	11329	6075
8	121164	49661	10743
9	120218	50008	10273
10	120085	49740	9759
11	119269	49007	9791
12	13009	40597	23202
13	12649	2933	959
14	5935	19164	6927
15	5977	19269	6909
16	1817	72	1096

Once the total emission has been calculated, the mobility coefficients (α_{pro}, α_{per} and α_T) can be obtained by dividing this emission by the active or adult population according to the motive. Thus, we get the results shown in the table below:

Table 5: Mobility Coefficients of Surveyed Areas.

Zone	Mobility		
	Professional	Personal	Tourism
1	0,0976	0,0095	0,0041
2	0,0767	0,0200	0,0040
3	0,1004	0,0250	0,0070
4	0,2095	0,0250	0,0110
5	0,1235	0,0160	0,0070
6	0,2103	0,0270	0,0120
7	0,0180	0,0360	0,0200
8	0,0946	0,0240	0,0060
9	0,9190	0,4760	0,1040
10	0,7787	0,1960	0,0430
11	0,9381	0,2470	0,0540
12	0,0249	0,0510	0,0290
13	0,0451	0,0080	0,0030
14	0,0269	0,0170	0,0190
15	0,0300	0,0580	0,0220
16	0,0272	0,0010	0,0080

b. Generation step: ATTRACTIONS

To calculate the attraction of the area, we used for each motive the statistics of the High Commission for Planning or other statistics depending on the motive. We describe bellow the data used and how we used it:

$$\begin{cases} A_{Pro} = \textbf{Total Employment} & (7) \\ A_{per} = \textbf{Tertiary Employment} & (8) \\ A_T = \textbf{Number Tourist Bed} & (9) \end{cases}$$

Where:
A_{pro}: Professional Attraction.
A_{per}: Personal or other Attraction.
A_T: Tourist Attraction.

These statistics, used as a tool of weighting the attractions between the zones, the employment and the tourist capacity, give a correct idea of the difference of attractiveness between zones.

Given that generation is a process of emission and attraction between areas, we must have an overall balance between the two concepts. Thus, the total emissions must be equal to that of the attractions of all zones. That's why we perform a balance operation of the attractions that we align to the calculated emissions. This operation therefore gives us the attraction calculated by zone.

3.2.2 Distribution

The analysis of the distribution of trips determines the distribution of flows by origin-destination torque of the displacement volume from the previous generation step: to each origin-destination is now attached a number of displacements.

Following the trips generation, we now move to the distribution of travelers across all available areas in our model.

To do this, we opted for the TransCAD software via the various networks parameterized and introduced on this software, in order to calculate impedance matrix between the different zones. It should be noted that the impedance matrix is a matrix of travel time calculated automatically by the software.

Thus, we obtain three matrixes of impedance (road, rail and air). Then we sum these matrixes to have a single matrix by multiplying for each pair Origin-Destination the travel time given by the matrix of each mode and the modal part of this mode.

We therefore followed the same logic to determine a multimodal impedance matrix that would allow us to distribute all the displacements between the modeled zones.

It is also necessary to remember that the distribution model is a gravity model that is based on the principle of attraction between zones. In this sense, two nearby areas are likely to exchange more flows than two remote areas.

$$\mathbf{Flow}_{ij} = \boldsymbol{\beta}_{ij} * \mathbf{Flow}_i * \boldsymbol{Att}_j * \boldsymbol{f}(\boldsymbol{Imp}_{ij}) \quad (10)$$

Where:
$\boldsymbol{Flow}_{ij}$: Displacement flow from zone i to zone j;
$\boldsymbol{Flow}_i$: Traffic flow from zone i (for the given pattern and segment combination);
$\boldsymbol{Att}_j$: Volume of traffic attracted by zone j (for the given pattern and segment combination);
$\boldsymbol{f(Imp_{ij})}$: Impedance Function. We consider that f is a function inverse power of coefficient 0.3;
$\boldsymbol{\beta ij}$: A positive multiplier coefficient. In the present case, the β is taken equal to 1.

The distributed flows are expressed as follows:

$$\mathbf{Flow}_{ij} = \frac{\mathbf{Flow}_i * \boldsymbol{Att}_j}{\boldsymbol{Imp}_{ij}^{0.3}} \quad (11)$$

With $\boldsymbol{Imp}_{ij}$ the matrix of the minimum travel times (Obtained by the procedure of the search of the shortest way). Then, a new balancing operation is performed on TransCAD to balance all flows on the territory.

3.2.3 Mode Choice

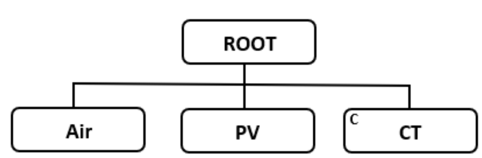
The modal choice step amounts to distributing the traffic between the different modes in competition. Therefore, we consider the following alternatives according to the trip distance.

It should be noted that in Morocco journeys of less than 400 km present as means of travel: the private vehicle, the train, the taxi (Grand Taxi), and the bus to which is added the alternative plane for journeys of more than 400km.

The choice of the 400 km threshold was based on an already existing exploratory time / distance analysis of the airlines. The shortest domestic airline (time and distance) is Casablanca - Agadir, which is around 400 km (400,62 km as the crow flies).

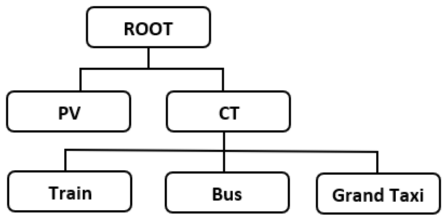
This segmentation of the supply between short-distance and medium distance (≤400 km) and long-distance (> 400 km) interurban trips is intended to further standardize the observed behavior: Indeed, a person who will make a trip of 700 km will not make his choice of the means of transportation in the same way as a person who will travel 120 km.

Thus, and as explained in the two tables below, the present approach considers two levels of segmentations and subsequently two models: Multinomial Logit Model for long Distance Travel (level 1) and Multinomial Logit Model for Short and Medium Distance Travel (level 2).



*PV: Private Vehicle, CT: Common Transport.

Figure 4: Multinomial Logit Model for Long Distance Travel



*PV: Private Vehicle, CT: Common Transport

Figure 5: Multinomial Logit Model for Short and Medium Distance Travel

The maritime supply of domestic travel is almost non-existent in Morocco. So, we decided to exclude this alternative within this work.

The modal choice was evaluated from a disaggregated model of discrete choice of "logit" type [42].

The disaggregated approach means that the model will base its estimates on a set of individual behaviors and choices, based on individual socio-economic characteristics and specific transportation offerings for these individuals. This approach is opposed to estimates based on averaged characteristics (aggregated approach).

To be noted, this work is realized by the use of extensive Moroccan travel diary data in the year 2016, enriched with numerous individual and household features.

From these data, we will try to predict the behavior of individuals confronted with a modal choice from the theory of discrete choices. The decision criterion of the individuals between the alternatives is based on the maximization of their satisfaction, which is translated theoretically by the concept of utility [43]. Individuals are considered rational and maximize their well-constrained beings (Bentham 1776 in [44]).

The utility of an alternative depends on both the respondent (preferences, constraints) and the characteristics of the mode. The utility functions used in discrete choice models are random; the utility is broken down into two parts: A deterministic part explained by the parameters of the model and a second part, called the random or error term, which reflects the different sources of bias caused by the survey process and all of the characteristics, individual or alternatives, influencing the chain decision and not considered in the model [42].

For an alternative i, the utility is expressed as follows:

$$S_i = D_i + \varepsilon_i \qquad (12)$$

Where:
S_i: The utility of mode i;
D_i: The deterministic expression of utility;
ε_i: The term randomness of utility. In the present case, it is assumed that this term follows a Gumbel (0, 1) law.

Neglecting second-order and higher interactions, we assume that the deterministic part has a linear formulation. It will therefore express itself as follows:

For an alternative i:

$$D_i = \sum \beta_j . u_{ij} + MC_i \qquad (13)$$

Where:
(u_{ij}) the vector of explanatory variables;
(β_j) the vector of the estimated parameters of each of the parameters;
MC_i the modal constant.

To determine the explanatory variables, three parameters are used to judge the relevance of the results obtained. The first one is the t-test: It allows defining the probability threshold at which the hypothesis H_0 "The coefficient β_j of the variable x_j is zero" cannot be rejected [45]. In the present case, a threshold of 5% is considered. Thus, a t-test value of +/- 1.96 means that the parameter is different from zero at a confidence level of about 95%. In a t-test of +/- 1.50, the confidence level drops to 85%, which is a lower limit usually recommended to consider a significant parameter.

The second one is the sign of the parameters: It is essential that the sign conform to the economic logic [46]. For example, if we consider the alternative private vehicle and the explanatory variable rate of motorization, we must expect a positive β: the more a motorized individual, the more the utility of the private vehicle mode tends to increase. In general, variables with the wrong sign should always be dropped from the model, even if the parameters pass the t-test.

Third and finally, McFadden R^2 (Also known as Rho-squared): in regression, R^2 is a good measure of regression quality by expressing the percentage of variance explained by the model.

However, the maximum likelihood method does not allow the calculation of an identical indicator. Also, define the R² of McFadden as follows [47]:

$$\rho^2 = 1 - \frac{l(\bar{\beta})}{l(0)} \quad (14)$$

Where (β) is the maximum logarithmic value of the likelihood function that is obtained for the parameter vector β, and l(0) is the logarithmic value of the likelihood function in which all the coefficients of the parameter vector are zero.

The model chosen for the modal choice is a "Multinomial Logit" model [48]. It is characterized by an extremely simple formulation of the probability of choice of an alternative.

However, it is based on a number of restrictive assumptions [49]. The first one is known as the assumption of "independence from irrelevant alternatives". This assumes that the traveler ignores the similarities in positioning between the alternatives when choosing a mode of Transport. Therefore, if we add to the alternatives a new alternative similar to an already existing alternative, the new alternative will reduce the probabilities of all the alternatives rather than dividing the probability of the one it looks like (Meyer, 1991 [50])

The second assumption can be expressed in the way that the model does not allow for a change in perception of an attribute of the utility function due to unobserved characteristics of the individual (ie not present in the deterministic part of utility). In other words, the perception of time/cost of travel must be identical for all individuals.

The third hypothesis concerns the structure of the variance - covariance matrix of the error term between the alternatives. In concrete terms, this means that the variation due to the factors not observed (and therefore not considered in the deterministic part of the utility) is identical between the individuals.

These assumptions are, of course, not always respected. Moreover, it is the first hypothesis especially and its corollary that strongly condition the quality of the model.

Now we pass to analyze the frequency as an explanatory variable of the modal choice of travelers. For example, and in 1981, Richard A. Ippolito has reported in [51] that flight frequency represents an important factor of demand. In fact, the frequency of a mode constitutes, intuitively, an important determinant of the modal choice: The more a mode is frequent, the more the probability of choosing the mode in question is important and this observation is valid for all modes of public transport.

Moreover, the impact of frequency on the choice decision is different depending on whether the mode, in question, is "frequent" or "infrequent". By "frequent" mode we mean any modal alternative whose frequency is sufficiently important not to induce a cancellation of the displacement or a postponement of more than one day thereof. In the opposite case, we speak of an "infrequent" mode [52].

Indeed, when a mode is frequent, the waiting time is strongly correlated to the frequency. If we consider the simplistic model where it is assumed that the traveler arrives at the station by ignoring the schedules, the waiting time follows a uniform law (In fact, the distribution of the probabilities of occurrence on an interval is the same) [53]. In this case, the average waiting time (the expectation of the statistical distribution) is equal to the frequency / 2.

The latter is therefore considered indirectly in the calculation of the generalized costs and cannot be introduced as an explanatory variable of the utility function because of the Multinomial Logit independence from irrelevant alternatives property [54].

However, if the mode is infrequent (this is particularly the case of domestic airlines with a frequency of less than one flight per day), two new parameters intervene: the frequency delay and the stochastic delay [55] [56].

The frequency delay is the time difference between the desired start time and the nearest available start time. This parameter also intervenes for frequent modal alternatives but has very little influence on the choice decision because of the important frequency of the mode in question. However, the Stochastic delay [57] results from the fact that there are no more places available for the desired trip.

Several studies have been undertaken since the 1970s to evaluate the impact of the two previous parameters on choice decisions (like for airline transport in [58] and [59]). For example, the works

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of (Douglas & Miller, 1974 in [60]) and those of (Anderson & Kraus, 1980 in [61]) are cited. Works as different as it may be, in terms of approach or context, agree on the difficulty of establishing the link between the delay (with its two components) and the modal split for two reasons:

- At the risk of having very inconsistent estimates, it is necessary to have multi-year time series because of the strong seasonality of demand for the air mode. In addition, the more the demand is segmented, the more time series to collect must be consistent;
- The work of the literature dealing with the problem is based exclusively on an aggregated approach for demand modeling (based demand models [62][63]), an approach that has shown its limits today.

In addition, given the level of analysis in which the study is located, which consists in defining a demand potential, introducing the frequency as an explanatory variable of the modal choice will bias the analysis. Indeed, the frequency is an output data and not an input data: It is deduced directly from the potential of the demand and the capacity of the vehicles.

For all these reasons and in view of the current market for air and its potential market according to the most optimistic projections, the precision and finesse provided by this approach remain relatively low and therefore do not justify the use thereof.

Given this hierarchy, several combinations of variables were tested. However, keep in mind that despite the concern for statistical validity sought here, it is the common sense of the transport expert that must prevail: It is therefore not enough to have a combination of variables that maximizes the statistical indicators, but rather a combination that makes sense then validated statistically.

The variables selected are: Cost, Time, Generalized Cost, Motorization and Socio-Professional Category. The frequency was not considered as an explanatory variable of the modal choice at the risk of violating the independence from irrelevant alternatives property. Indeed, the frequency is already included in the computation of the modal times.

Table 6: Choice Model Results (1/2).

	Level 1 Scene 1 (S&M D)		Level 1 Scene2 (S&M D)		Level 1 Scene 3 (S&M D)		Level 1 Scene 4 (S&M D)	
	PV	CT	PV	CT	PV	CT	PV	CT
Cost	0.0143		0.731	1.405				
Time	0.0049		0.0039	0.044				
Generalized Cost					0.000069	0.000002	0.000041	0.000114
Motorization								
SPC					-0.403			
Constant						-0.842		-2.501
T-student	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
Sign Coherence	No	No	No	No	No	No	No	No
McFadden R^2	0.120		0.597		0.091		0.493	

*S&M D: Short & Medium Distance.
**PV: Private Vehicle, CT: Common Transport, SPC: Socio-Professional Category.

Table 7: Choice Model Results (2/2).

	Level 1 Scene 5 (S&M D)		Level 2 Scene 1 (S&M D)			LD Level 1		
	PV	CT	Train	Bus	Grand Taxi	Plane	PV	CT
Cost								
Time								
Generalized Cost	- 0.000 206	- 0.000 202	-0.00039	- 0.000 25	- 0.000 029	- 0.000 7	- 0.000 0019	- 0.000 16
Motorization	x							
SPC	x	x						
Constant		-3.801	-0.401					0.762 141
T-student	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
Sign Coherence	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
McFadden R^2	0.732		0.7215			0.3301		

*S&M D: Short & Medium Distance.
** LD: Long Distance.
***PV: Private Vehicle, CT: Common Transport, SPC: Socio-Professional Category

Thus, and after having analyzed the results displayed in tables 6 and 7, and for the case of Short and Medium Distance, we retain scenario 5 (level 1), showing an R^2 Mc Fadden of more than 70%, which realizes a sharing between the private vehicle and common transport and the utility function is only explained by an explanatory variable, namely: the generalized cost.

However, and in order to de-correlate the generalized costs, we have thought of using the ration: Private Vehicle Generalized Cost /Motorization Rate. In addition, we add the discrete variable Socio-Professional Category as being a parameter closely linked to the choice of modes by travelers. Also, since this is a discrete variable, the database was first segmented by Socio-Professional Category, then the utility function was estimated on each segment.

This logic is the same followed for Level 2 and Long-Distance Traveler Model. This is how it has now become possible to proceed with the calculation of the different modal shares. Concretely, we estimate several logit models in an embedded way: The choice among the alternatives of the same level is made using a multinomial logit, and the level itself constitutes an alternative whose utility is equal to the logsum of the utilities of the alternatives that compose it.

The probabilities are calculated as follows (Take the example of the probability of choosing the Grand Taxi in the case of short-distance trips) :

$$P(\mathbf{G.Taxi/CT}) = \frac{e^{D\ G.Taxi}}{e^{D\ G.Taxi} + e^{D\ Bus} + e^{D\ Train}} \quad (15)$$

Where:
G. Taxi: Grand Taxi;
CT: Common Transport.

3.2.4 Traffic Assignment

The previous step, the modal choice, made it possible to produce origin-destination matrices of individual displacements. However, the road assignment model requires matrices to move vehicles. It is therefore necessary to convert the matrices of movements of individuals into matrices of vehicle movements. The conversion is done through the vehicle occupancy rate, deduced from the collected data (See table below).

Table 8: Average occupancy rate per motive.

Motive	Occupancy Rate
Professional	1.8
Tourists	2.3
Other	2.2

Then, all that remains is to sum up the flows of each segment to know the daily traffic of vehicles on a given origin-destination.

The steps of generation and distribution cover a period of 24 hours. However, the supply of transport is so much differentiated according to the time of day. For the private vehicle, for example, road network performance is better during off-peak periods than at the peak due to a lower load on road infrastructure.

The transition to the peak period is done via the percentage of daily trips taking place during the peak period. These coefficients are calculated by pattern, since the daily rhythms are strongly differentiated according to the pattern.

4. EXPLORING THE RESULTS TO PREDICT MOBILITY ON A MODEL AXIS.

In this part, we will use the experimental results of the model developed to predict mobility on an example axis which links two large areas of the country. This axis links zone A to zone B over a length of 350 km, with a view to sweeping all modes of transport.

We will predict, on this axis, mobility in future horizons under the assumption of keeping the same existing infrastructure and this in order to project into future situations and have a strategic visibility to decide on infrastructure projects and know how to determine the priority and optimal choices for a better public investment.

In order to optimize our strategic choices, we will consider the criteria recognized in the field to determine if a lane or a road is saturated or not yet, as follows:

Table 9: Road Traffic Thresholds [64].

Road Type	Discomfort Threshold (Expressed in PVU/D)	Saturation Point (Expressed in PVU/D)
2 Lanes	8 500	15 000
3 Lanes	12 000	20 000
2x2 Lanes	25 000	45 000
2x3 Lanes	40 000	65 000

*PVU/D: Private Vehicle Unit per Day.

Following the same logic, we went to find the saturation thresholds of the railway lines relating to Moroccan territory, and according to the National Railway Office, we have the following table:

Table 10: Railway Traffic Thresholds in Morocco [65].

Infrastructure Type	Minimum Traffic Threshold
High Speed Line	450 PAX/Hour/Sense
Classic Line	135 PAX/Hour/Sense

It should be noted that the chosen axis is 350 km long (to simplify the example) and contains 6 sections with use of all modes of transport except air transport. Indeed, and as already indicated before, the air mode does not weigh on our model, which due to the dimensions of the national territory.

Table 11: Chosen axis infrastructures details.

Section	Infrastructure	Present Profile	Code
1	Rural Road	2x1	RR1
	Highway RC	2x3	H11
	National Road RC	2x1	NR1
	Highway Ct1	2x2	H12
	Classic Railway line	-	CRL1
	Railway High Speed Line	-	RHSL1
2	Rural Road	2x1	RR2
	Highway RC	2x3	H21
	National Road RC	2x1	NR2
3	Rural Road	2x2	RR3
	Highway Ct3	2x2	H31
	Urban Highway	2x3	H32
	National Road RC	2x2	NR31
	National Road N	2x1	NR32
	Classic Railway line	-	CRL3
4	Highway CB	2x2	H4
	National Road N	2x1	NR4
	RMA	2x2	RMA
	Classic Railway line	-	CRL4
5	Highway BS	2x2	H5
	National Road N	2x1	NR5
	Classic Railway line	-	CRL5
6	Highway SM	2x2	H6
	National Road N	2x1	NR6
	Classic Railway line	-	CRL6

We will use the model established under the TransCAD software tool [66] to predict mobility at different horizons in the future. The objective is to see the probable evolution of traffic following the evolution of the various socio-economic parameters taken into account by the modeling, and this under the assumption of keeping the same existing infrastructures in order to see the probable priorities in terms of mobility in the future.

Using the model gives us the results shown in the following table:

Table 12: Estimation of Annual Average Daily Traffic Using the Established Model

Section	Infrastructure Code	2023	2030	2035	2040
1	**RR1**	7050	9467	11587	12875
	H11	58956	68758	76250	77576
	NR1	16754	20725	23587	25612
	H12	25403	27858	32523	38263
	CRL1	35458	39795	45689	54089
	RHSL 1	25658	32287	37658	42548
2	**RR2**	7206	9678	12986	14489
	H21	56497	64568	72348	75079
	NR2	8 708	12322	14854	16700
3	**RR3**	22445	25568	28705	33 319
	H31	58990	64587	71214	74658
	H32	46700	47524	53587	62258
	NR31	14457	19775	23012	26 643
	NR32	14457	18718	19004	21958
	CRL3	47858	55087	64879	73658
4	**H4**	50925	57050	63119	64558
	NR4	19500	21584	22685	23847
	RMA	30045	32854	37584	43658
	CRL4	21658	24248	26487	31584
5	**H5**	30137	34235	36658	40685
	NR5	20584	25685	31548	34587
	CRL5	15887	22457	26879	28457
6	**H6**	23937	28035	29858	34548
	NR6	16584	21845	23354	27948
	CRL6	11547	16548	17845	19215

* for the railway traffic is estimated in double sense.

As already indicated before, the chosen axis connects two large areas between which the flow of travel is increasing sharply for all activities: economic, industrial, tourist...

The results indicate future saturations concerning several sections of this axis and for all modes.

5. RESULTS DISCUSSION

First and foremost, and before we start the discussions about the chosen axis, we will discuss the established model. Four-step modeling is an experiment that has successfully identified and captured the urban and interurban mobility trends in many countries around the world. This work comes to illustrate this experience for the case of Morocco and to contribute further to scientific research in this field by adding the results of a new experiment relating to a new territory characterized by different parameters and particularities.

This work, and based on different theoretical and practical works, comes with a new contribution to the world of scientific research by establishing several nested models of several types while following the approach of four-step modeling and this to apply this innovative approach for the

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Moroccan case. This experience will not only contribute to the world of research but also to the professional world by allowing it, in a developing country like Morocco, to adopt an innovative approach to weave the right strategies in terms of mobility which is a vital thing for the development of all economic activities in the country.

When developing the Moroccan model, we limited ourselves to a reduced number of socio-economic variables, to comply with the statistical tests and rules of modeling and due to the unavailability of data and especially for all regions. However, and since the model is strategic and tries to capture all modes, we have allowed ourselves a certain tolerance for precision. In fact, the objective of this experience is to draw up a global and strategic trend concerning all mobility, all modes combined, and subsequently know how to orientate oneself for more specific work to achieve the results.

In addition, and to be satisfied with the results of the model, the approach followed brought out results very close to actual experience. This will be illustrated through the presentation and discussion of the results relating to the example of the axis chosen and experimented within the previous part.

As we cannot present all the results of the model relating to the entire territory of the country, we have opted for a strategic axis as an example to illustrate and evaluate the outputs of our model.

Figure 6: Traffic forecasting - 2 Lanes Infrastructures

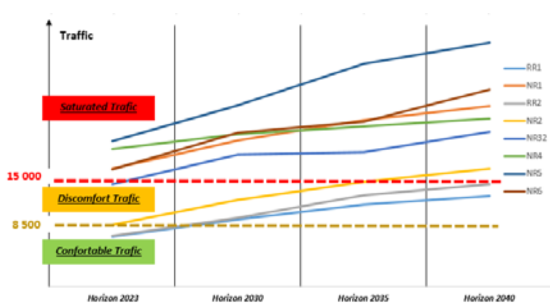


Figure 7: Traffic forecasting - 2x2 Lanes Infrastructures

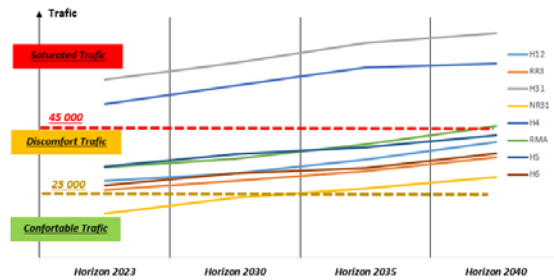
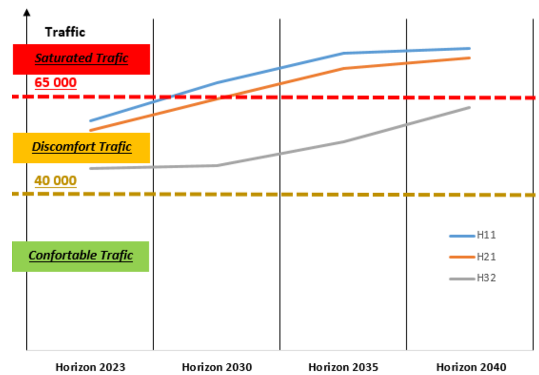


Figure 8: Traffic forecasting - 2x3 Lanes Infrastructures



Before starting the significant sections one by one, we opt for a graphic display of all the results according to the three graphs: Figures 6, 7 and 8, below, respectively presenting the predictions of future flows at the different horizons taken into consideration by studying the three types of infrastructure (2 lanes, 2x2 lanes and 2x3 lanes).

This graphic display shows an impeded and saturated flow at the level of most of the sections along the chosen axis, and this from the 2023 horizon. Saturation takes place in the three types of infrastructure, in particular for 2 lanes sections, which raises the alarm to the decision makers to consider extensions.

For the 2x2 lane type sections, we especially notice an obstructed flow for all horizons with a slight increase in traffic without reaching saturation level. This can be explained by a poor management of mobility at the level of these sections and perhaps the extension is not a solution but rather, and to solve the problem, we must look for good mobility practices such as multi- modality, intermodality and encouragement of public transport.

In fact, the object of this research paper is to show the added value of four-step modeling to capture and predict mobility trends in Morocco and

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then put in the hands of decision-makers a visibility tool in terms of mobility. This is how we will focus on the accuracy and reliability of this model by comparing its outputs with real facts. To do this, we analyze sections one by one and compare these analyzes with the perspectives of the departments concerned.

The first three sections of the chosen axis present rural roads with traffic, which will experience discomfort traffic from 2030 on the first two sections, and traffic, which has already exceeded the saturation point at the 3rd section. Indeed, this road is under widening at the level of the three sections which confirms the results of the model with the concerned department forecasts.

In addition, the results show a motorway axis, with discomfort traffic from 2023 on the first two sections and which will reach the saturation threshold in 2030 at section 1 and in 2035 at section 2. These results are in line with the forecasts of the authorities concerned, whose strategy provides for the launch of a second motorway axis in parallel with that in question.

The results also show two national roads passing through all the sections of the axis and presenting a discomfort traffic and reaching the saturation threshold on all the sections and for different horizons except for the section 3, where the National Road RC provides for normal traffic until the year 2040 corresponding to the start of discomfort traffic.

These roads are the subject of a set of expressway projects which once again proves the conformity of the results of the model with the strategic and decision-making trends in the matter.

The forecasts show very clear traffic congestion for the Highway CB and Highway Ct1, which are the subject of widening projects by the authorities.

These forecasts also show a discomfort traffic, for almost all horizons, in the axes Highway Ct1, Urban Highway, RMA and Highway SM which pushes us to think as of now to prepare alternative solutions in favor of mobility. Indeed, and in contrary to the old single-mode works which show an upward trend in traffic, the proposed approach shows for these axes a discomfort traffic for several years without reaching the saturation thresholds. This is why we have to think of practical solutions to optimize mobility on these axes by using good practices in the matter, to know: multi-modality, intermodality, carpooling ...

For the rail lines, we note that the forecast shows uptrends at all sections even for the high speed line. This increase is explained by an increasing demand for the rail mode and especially for professional reasons. The high-speed line has already achieved success since its launch and forecasts show increased traffic for the next few years.

The railway lines presented throughout the said sections are the subject of a series of doubling and modernization projects on the part of the National Railways Office. Regarding the high-speed line, the model foresees a need for an extension of this line along the entire chosen axis.

Thus, the results obtained for the chosen axis show logical trends in traffic and above all visions in agreement, and to a large extent, with the various strategies already outlined by the transport sectors in question. This proves a certain level of confidence and reliability of the outputs of the established model and subsequently confirms the research hypothesis of this paper supporting four-step modeling as one of the best approaches to simulate mobility and Morocco a successful application case.

Moreover, and considering the entire era of the study, the results of the experiment also call for the revision of some decisions based on single-mode models relating to a number of projects. In fact, the four-step modeling approach, which is based on a global logic and an optimization mechanism oriented towards multi-modality and intermodality between the different modes of transport, brings out innovative and optimal solutions in the subject of mobility management.

The choice of these solutions proposed by this approach is essentially based on the predicted traffic and the capacity of the infrastructure, on territorial equity and the environmental footprint and in particular the cost of implementation. In addition, this model proposes to change motorway projects by expressways and this for insufficient predicted traffic on the sections concerned and to cancel or change infrastructure type of other railway line projects for reasons of insufficient of request. As for high-speed rail lines, this approach reinforced this choice and also drew attention to a set of unused airlines, which have great potential.

To summarize the outputs of this research experience, we find that by limiting itself to the chosen axis, this global model, established following the four-step modeling approach, displays an alignment with all the results of the others monomodal experiments. In addition, it deals with all modes of transport in a logic of convergence, complementarity and multimodality. Also, and at the level of the entire era of the study, the proposed approach reveals a set of points to be corrected, either by replacing, changing or deleting the projects programmed by the monomodal sector studies.

The four-step modeling method opens up the way for improving sector strategies and studies already undertaken in this sense. It is essentially based on two strengths: an overall vision including all available modes of transport and recourse to the evolution of socioeconomic parameters which are the key factors of mobility. This research work has therefore validated our initial hypothesis which supports the fact that four-step modeling, an approach that has succeeded in modeling mobility in advanced countries, can also serve developing countries, including Morocco, giving better results in terms of predicting mobility than other single-mode methods.

However, the success of this work leaves some points to be discussed and cannot succeed in reproducing 100% the international experiences of advanced countries (Spain, France, Germany … see [19] [20] [67] and [68]). In fact, the proposed approach is an empirical method based primarily on data (availability, quality, consistency throughout the study area, etc.). It is also composed of a set of nested modeling methods, which could increase the margin of error of the whole approach.

Thus, and to summarize on the limits of this approach, we point out that the reliability, quality and relevance of the results are binding on the improvement of the database, its quality and its level of disaggregation. In fact, the Moroccan experience was limited to the availability of data and above all to their consistency over the whole of the national territory, while the literature presents a recourse to more explanatory variables and to a higher level as regards the reliability of these data in advanced countries.

6. CONCLUSION

In this paper, we investigate the effectiveness of using the four-step modeling approach to simulate the interurban mobility in Morocco. Experimental results show that the proposed approach, used and tested in different case studies over the world (Spain [19], France [20], Germany [67] [68], …), offers a great performance concerning the interurban mobility simulation in Morocco. These results also suggested reviewing some decisions about a set of projects programmed in the master plans and sector strategies. They suggest canceling projects and changing the type of infrastructure for others, with an optimizing view and multimodal management of mobility.

Thus, we can conclude that the use of socio-economics parameters via the four step modeling approach, considered as a dynamic and multimodal method, allows us to better predict Moroccan interurban mobility and offers decisions-makers the opportunity to reach a strategic decision tool that aims to enhance future visions in the field.

Also, and for the first time in Morocco, the said approach succeeded in simultaneously predicting all modes of transport and providing a global vision for better mobility management. In fact, all of the previous works have worked on a single-mode approach. The latter, single-mode approach, created a sort of cannibalization between the different modes of transport and further aggravated the problem of the sector's divergence, contrary to the government's strategic orientations in this sense.

These results, and despite the data issues relating to the various activities in Morocco, have contributed to scientific research on mobility in Morocco and have shown good signs for the use of four-step modeling to simulate mobility. This will help decision-makers to offer themselves better visibility for mobility in the country and subsequently allow themselves properly optimizing infrastructure projects, especially in the present economic situation. The latter is marked by a real problem of liquidating due to the various crises through which the world is passing, namely: the financial crisis of 2008 and its impact, the pandemic crisis relating to the coronavirus COVID 19...

Concerning the limits of this work, it should be noted that the reliability, quality and relevance of the results are binding on the improvement of the database, its quality and its level of disaggregation. In fact, the Moroccan experience was limited to the availability of data and above all to their consistency over the whole of the national territory, while the literature presents a recourse to more explanatory variables and to a higher level as regards the reliability of these data in advanced countries.

Finally, to benefit more from these results and following data issues, future works should focus on the application of this approach for new case studies related to developing countries. Also, and in the same sense, the use of other innovative methods in the modal choice step, such as approaches based on machine learning techniques, can further improve results [69] and give a better vision of mobility as well as for improving the application of four-step modeling in this field.

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