Towards a numerical model for the representation of an urban transportation system

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Abstract. The paper discusses a method for modeling the operation of an urban transportation system. The proposed model models the bus operation in an urban transportation system with an equation system. The objective of the proposed model is to simulate the operation of an urban transport network. The network consists of a set of lines, a number of vehicles (buses) circulate on each line, where we consider some variables such as traffic conditions on the sections (bottling), the distribution of travelers on breakpoints, to see the impact of external environment on the network. The coordinates of the breakpoints of a given line are defined with respect to the filing. These points can define by the polynomial interpolation the displacement model in the line in question. The movement of vehicles is subject to a variable commercial speed and acceleration fixed in each segment. The speed depends entirely on a set of constraints related to traffic in the urban space. Finally, with an estimate of the filling of vehicles and the costs of travel related to spare parts, fuel, and payroll, we can deduce the economic profitability.

Keywords: urban transportation system (UTS); interpolation; displacement; commercial speed; filling; economic profitability.

1 Introduction

In the domain of Urban Transportation System (UTS), modeling is a complex task that requires the development of appropriate models to ensure customer satisfaction, namely, to propose an urban transportation service taking into account the operational constraints such as on-time theory, guarantee letters, reducing wait times, etc... This naturally led researchers to look at this problem and propose appropriate models. Several models have been compared in [2, 4]. Modeling of *UTS* was proposed by means of Petri Nets (*PN*). The *PN* were exploited to model the flow of travelers [5], where a model based on stochastic *PN* has been used for a bus network whose tokens represent the travelers. The Stochastic *PN* are an extension of "time" of ordinary *PN*. Stochastic Petri nets have been used for the modeling of matches in [1]. The work proposed in [10] describes an approach based on modeling of the flow. It presents the rates to be assigned to different routes of the road network in accordance with criteria representing the cost of roads (toll ticket for public transport) and the duration of the course. *UTS* is represented by a graph, on each arc, the flow and travel time are marked, and the thickness is the importance of the flow. Ngamchai [9] models the every route by series of nodes represented the sequence of the stop points, using genetic algorithms. Another model of urban transport systems is given using the Multi-Agent Systems (*MAS*). Several studies were conducted in [4, 8], the first work in this area were made to model urban traffic by F.A. Bomarius [3] where he proposed a multi-agent modeling scenarios of urban traffic at the intersections. Subsequently, F. C. Besma [2] has used *MAS* for monitoring and diagnosis of a transit system operator with a hybridization of evolutionists' algorithms. Another approach with *MAS* has been published in [6] where an application designed to monitor long-term users' information system in *UTS* has been proposed.

A comparison between the modeling approaches mentioned previously was presented in [4]. The modeling by *PN* mentioned before does not take into account the influence of the external environment on the rate of vehicles displacements during the journey, in addition, the system does not evolve in a continuous manner as the system needs an event to cross a transition in the *PN*. The modeling of travelers flow considers only the flow of users with the travel time and neglecting the economic charges of the system. The modeling of a route models the route by a sequence of nodes in a static manner, this implies that this model does not include the movement of vehicles with continuous function of time from beginning to end of service. Modeling using *MAS* takes into account scenarios of urban traffic at intersections, however, this model is a little heavy compared to the number of messages that slow circular between the agents of the system. However, none of these models is suitable for modeling the operation of a transit system in a continuous function of time along a path that can be not linear knowing only its position on some stop points and taking into account the constraints of movement, means and resources available with a mastery of traffic loads in order to provide an estimate of the economic viability of *UTS*. Hence, the work proposed in this paper presents a numerical modeling for the operation of *UTS.* For a better understanding of the parameters that determine the evolution of the transport system, the modeling is a very effective means. Indeed, a model provides a better vision which allows us to provide a first step, the evolution of the phenomenon from the initial conditions, and subsequently to make predictions about the system and order it. For a simplified and usable representation of urban transportation systems in order to exploit it, we define the flow of a bus in an urban space by a system of equations. The displacement model on a given line is defined by an interpolation of the coordinates of the breakpoints of this line. The resolution of the proposed system of equations can predict the distribution and coverage of lines of operations and the economic profitability. The paper is organized as follows. The problem is described in Section 2. Section 3 is reserved for the proposed model. The section 4 presents the implementation of the numerical proposed model. Finally, we end with a conclusion.

2 Positioning of the problem

Travel in an urban transportation system paths are trajectories traveled between the contexts of social activities, they are becoming more complex and difficult to control because it depends on several phenomena that determines the traffic flow and causes a significant lengthening of journey times, for example: congestion, intersections, inappropriate timing of traffic signals, public works, weather and so on.
The impact of the external environment and road conditions make monitoring and control of the transport system more hard hence the difficulty to model the behavior of a bus in a transit system throughout the journey and locate its position on the route and see that its speed depends on various constraints of urban space and to estimate the filling deduce its economic viability. Among the constraints that affect the functioning of the urban transport network, we cite the road paths that can be not linear, the traffic constraints affecting the traffic on the sections, and the distribution of travelers on the breakpoints that we consider in this work.
For this reason, we propose a numerical modeling for the urban transportation system mono modal (bus) to obtain a simplified visual representation of reality, and to study the network behavior with respect to various disturbances (public works, passage of a VIP motorcade, congestion, ...) that can divert the system to normal running on one side, and in order to estimate the economic yield of the network on the other side. The numerical model proposed can better represent reality by modeling the running of an urban network continuously with time.
The behavior of a vehicle is modeled by a system of equations. The vehicle is moving according to an equation with time unlike other models such as modeling by Petri nets or the multi-agent systems where the system must wait for the crossing of transactions, or the presence of an event and sending decisions between agents to operate.
In addition, the proposed model can provide a view of the urban network, namely the movement of vehicles (bus), speed, and filling every moment during the journey, and consequently the economic profitability of the urban transportation system.

3 Numerical modeling proposed

Modeling of urban transport provides a help in developing appropriate policies in terms of planning and programming. For this reason, the numerical model proposed enable to model the behavior of a bus in the urban transportation system, namely the network operated by the carrier of Oran city. The resolution of the proposed system of equations can predict the distribution and the coverage of operating lines. It also helps to optimize the running of the network to minimize the costs of rolling, and therefore, it offers a means of estimating the economic profitability of the urban transportation system. The urban network is characterized by: A set of lines: each line is characterized by a well defined length, it has a specific number of bus stops distributed along the line between two extreme cases (terminus); The travels between the breakpoints are provided by a number of vehicles affected for each line of the network; The bus of each line circulate in a certain frequency of passage; A distance deadhead (HLP):

between the deposit where the buses are parked and the point stop starting; Distribution of Judgments: The distances between the breakpoints of each line are not equidistant; The lines on the network must be projected in a coordinate system that ignores the urban fabric where a projection using the software (MapInfo) which is a geographic information system to extract and display of geographic data; The values of displacement are determined by taking as a basis only the values observed in the buses stop points.

The diagram shown in Fig.1 represents the nonlinear path of a bus on a given line. On this journey, we have n breakpoints which are known.

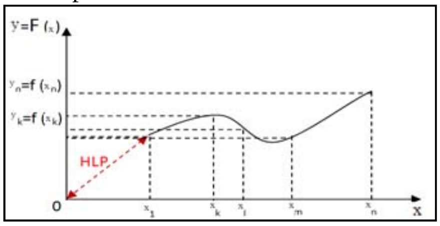

Fig. 1. Modeling of movement for a vehicle *v* on a line *l*

Considering this set of n breakpoints positions $(x_i, p(x_i))$ and a function *F* unknown, we determine a polynomial *P(x)* of degree *(n-1)* which interpolates *F* in the considered points. The *n* breakpoints that are known can define by the proposed model of interpolation, the displacement of the buses on the line in question. Therefore, the movement of vehicles (buses) of a given line is represented by (1).

$$P(x) = \sum_{k=1}^{n} \left[p(xk) * \prod_{\substack{j=1 \\ j \neq k}}^{n} \frac{x-xj}{xk-xj} \right] \qquad (1)$$

$Y = P(x)$ is an interpolation function to estimate the values of the displacements $(x_i,p(x_i))$ at each time *t* from start to finish by having an estimates of speed rolling *V(t)*. Due to the proposed model, we know the displacement $Y = P(x)$ of a vehicle (bus) *v* and locate it on the line along the route which is not linear as shown in Fig.1.

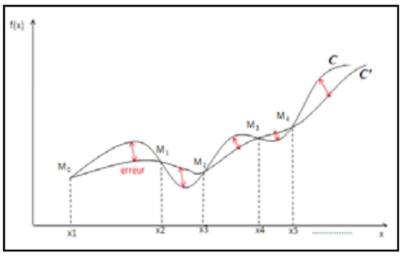

Fig. 2. Polynomial interpolation error

The landmark "*0*" of the Fig.1 corresponds to the deposit where the buses are parked initially. The HLP distance represents the distance between deposit and breakpoint of departure. The distances between the breakpoints $(x_i, p(x_i))$ are not equidistant, they are defined taking into account the density of the flow of travelers on the journey. The goal is to approximate as closely as possible the unknown function of the displacement of the urban reality in order to provide more accurate values as possible with minimum error. The Fig.2 illustrates the curve *"C"* of the polynomial obtained *P*(x) and the curve *"C'"* of the unknown function *F(x)* of the displacements in the real urban environment.

We notice in Fig.2 a small gap between the two curves, the latter represents the interpolation error that we control in order to observe the quality of this approximation. For this purpose, equations (2, 3) show how we calculate the error of interpolation. Since F is a function $(n+1)$ differentiable on the interval $[a, b]$ and $x \in [a, b]$ and let $I = [min\ (x1, xn), max\ (x1, xn)]$, then:

$$\exists\ \xi\ \in I\ /\ E(x) = P(x) - F(x) = \frac{F^{n+1}\ \xi}{(n+1)!}\ \Phi\ (x) \tag{2}$$

$$\text{Where} \qquad \Phi\ (x) = (x - x1) * (x - x2) * \ldots * (x - xn) \tag{3}$$

To minimize this error, we propose to decompose the nonlinear path of a given line a set of small linear sections in order to trace the curve in a more realistic with à minimal error (see Figure 3).

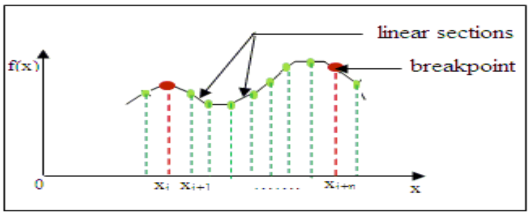

Fig. 3. Decomposition of the way into a set of sections

In the previous figure, we define a step *"H"* expressing the length of each section and we vary it not to have a minimum interpolation error.

In urban areas, several constraints affect the speed of the circulation of the bus. The speed varies from one point to another with a fixed acceleration by segment. The equation (4) shows how we model the change in speed during the journey.

$$V\ (t) = A\ t + V_0 \tag{4}$$

The speed *V (t)* of a bus that moves on a line from one point to another depends on several constraints of the external environment. "V_0" represents the commercial speed the start point. "*A*" symbolizes the vehicle's acceleration.

The vehicle acceleration is variable along the way. It is experimentally fixed on each linear segment from of the starting point to the ending point according to the state of the vehicle traffic on the sections.

On each linear segment of the trip, we have a speed *V (t)* varies with a fixed acceleration *''A''*. The function of displacement on this segment can be modeled by the function $h(t) = ½ A t^2 + V(t) + h_0$. Differentiating this function *h (t),* we obtain the speed $V(t) = A t + V$ where *V* approaches V_0.
The speed depends on the acceleration and the nature of the line. The acceleration is defined experimentally as a function of variables called disruptive that can happen wind happen in a race, for example: the density of traffic, bad weather, an accident in the road, large flow of passengers, a failure or temporary immobilization (damage) of a vehicle, peak hours, special events (VIP passage of a procession or parties), etc..
In our context, race is defined as travel between two extreme terminuses (forward or reverse direction). As the proposed model can model the operation of a bus all the way from the initial stop to the terminal stop of arrival, we just need to increment the number of strokes each time the bus in question happens to stop terminal in order to know the number of race made by him during the day. The objective of the proposed model is to model the operation of *UTS* also with an optimization of the economic profitability. For this reason, we try to calculate the formula *RC* of a bus during its commissioning in a day according to (5), where *NPM* is the number of people going up every time the bus comes to a stop-point and *PU* indicates the unit price that a traveler has to pay.

$$RC = RC + (NPM * PU) \tag{5}$$

The number of passengers on board a vehicle that travels from one point to another, is generated by the system according to a survey that was done on ground to see the distribution of passengers on the bus's breakpoints throughout the path of a given line, where we affect a rate of climb and a another of descent of passenger for each breakpoint.

Knowing the costs of running *CdR* (spare parts for vehicles, fuel, and payroll) to a given bus, and knowing his recipe *RC* during the day, we can deduce its economic profitability *RE* according to (6).

$$RE = RC / CdR \tag{6}$$

Using the proposed model, we can know at any time (t):
The position of the bus on the way: The polynom *P(x)* is an interpolation function of the positions of a given bus in *n* breakpoints known throughout the journey, with an estimated speed of the roll at this moment, we can know its position on the route; The running speed is influenced by the constraints of movement (Will disruptive variables); The number and direction of strokes (or return); Filling to infer the economic profitability.

4 Implementation of the proposed model

The goal of any modeling and design is to produce a software tool to prove our statements of theoretical departure. We have developed our simulator mono post, operator interface Microsoft Windows in the programming language C++ Builder 6 and using a geographic information system (MapInfo) to extract and display map data.

4.1 Treatment of mapping and collection of geographic data

From the map of Oran city (see Fig.4 (A)), we determine the roads and then we identify the paths of the lines of the bus transport company of Oran where we position the buses stop pointes of each line.

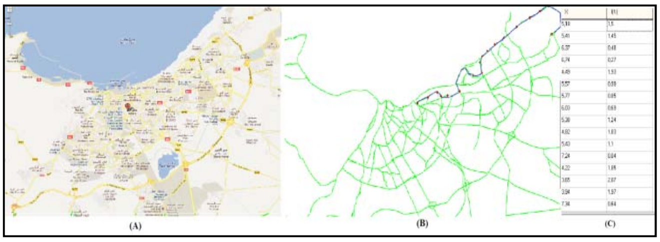

Fig. 4. Treatment of the Map of Oran

After the screening of the main roads of the city of Oran and the identification of the route with the positioning of the stops of each line of the Urban Transport Company of Oran, we generate a new map using MapInfo software. Figure.4 (B) illustrates the mapping generated, where the green lines represent the major routes of Oran. To simplify and clarify the picture, we have shown schematically in blue the way of one line "*P1*" on the urban transportation system of Oran, and symbolized with red points the bus stops points on this line.
To illustrate the results of the proposed model, we consider the path of the line "*P1*" where we have a vehicle "v_i" circulating on this line with 17 breakpoints (see Fig.4(B)), which means that we know the position"$(x_i, p\ (x_i))$" bus to each of these 17 points (see Fig.4(C)).

4.2 Execution of the proposed model

Having located the stops and find their positions $(x_i, p\ (x_i))$, we turn to the performance of the model to find the displacement function $Y = P(x)$ that locates the bus "v_i" to each point $(x_i, p\ (x_i))$ for the journey. By applying the proposed model, we obtain the polynomial function of displacement whose curve is shown in Fig.5.

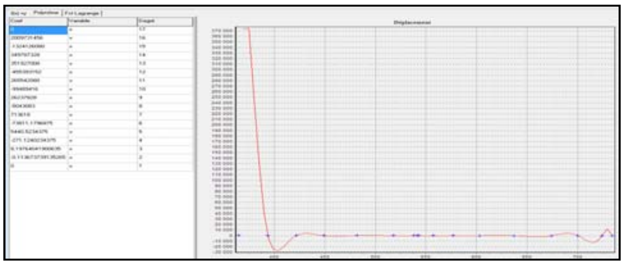

Fig. 5. Curve of displacement function $Y = P(x)$

To locate a bus and find its position in the path, it suffices to know the velocity can be estimated using (2). If we have accelerations of $A = 2km/h^2$, then $v\ (t) = 2t + v_0$, where "v_0"is the initial speed of *5 km/h*, so after 4 hours ($t = 4{:}00$), speed is *13km/h*. Also, as we have broken the journey in a series of small sections then the linear distance "D" is linear and each section can be estimated by *''D = ½ At2+vt+ d0=56km''*so the bus will be in the *4th* race because the distance of the line *"P1"* is *15km*, so the bus droves *11km* in the *4th* race and he is 4km to arrives at terminus. By replacing this value in the $x = 11km$ displacement function obtained, we can deduce the position $(x_i, p\ (x_i))$ of the bus on the non-linear way of the line in question after *4* hours of service. After finding the polynomial that corresponds to the displacement function per-putting to locate the position $(x_i, p(x_i))$ of the bus, we turn to the calculation error of interpolation according to (2).

Regarding the filling, every time that the vehicle (bus) comes to a stop point, we update the number of persons on board (the number of people coming down and getting on is random, but according to the periods in the course of a day, for example during peak hours: 08:00, 17:00, we have more people on board and hang the other periods of a day) and each time we calculate the following formula *RC* (5) as *PU = 15DA*, and at the end of service we calculate the economic profitability *RE* of the bus with an estimation of its traffic loads *CdR* during the day according to (6).

5 Conclusion

Like any model, the modeling of urban transport system responds primarily to the need for knowledge. The model gives a representation of a complex phenomenon, allowing a better understanding of its internal mechanisms and parameters that determine its evolution. The proposed numerical modeling defines the behavior of the bus in an observed line of the urban transportation system. It allows us to study the exogenous variables that are not part of the system (the original from the outside) and that affect the system variables such as urban traffic, and the endogenous variables that are part of the system such that: the frequency of passage, the number of vehicles, commercial speed etc.

To go further in the development of this model applied to an urban transportation system, we plan to integrate a module responsible for the regulation of this transportation network in case of perturbations in schedules and also we think to enrich the proposed model to move in a multimodal modeling (bus, tram ...).

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