

A Continuous Dynamic Traffic Assignment Model From Plate Scanning Technique

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ABSTRACT

This paper presents a methodology for the dynamic estimation of traffic flows on all links of a network from observable field data assuming the first-in-first-out (FIFO) hypothesis. The traffic flow intensities recorded at the exit of the scanned links are propagated to obtain the flow waves on unscanned links. For that, the model calculates the flow-cost functions through information registered with the plate scanning technique. The model also responds to the concern about the parameter quality of flow-cost functions to replicate the real traffic flow behaviour. It includes a new algorithm for the adjustment of the parameter values to link characteristics when its quality is questionable. For that, it is necessary the a priori study of the location of the scanning devices to identify all path flows and to measure travel times in all links. A synthetic network is used to illustrate the proposed method and to prove its usefulness and feasibility.

1. INTRODUCTION

The knowledge of the users travel time on a traffic network is a very valuable information for technical people in charge of analysing and managing the mobility of a city. There is currently heightened interest in dynamic traffic assignment models, as link flows and link travel costs are not necessarily constant over time. This entails to collect huge real-time data which is often a difficult and costly undertaking (Long et al., 2011; Xu et al., 2004). At the present moment, the state of the art of dynamic models is not yet completed and requires improvements related to domains, tractability and realism (García-Ródenas et al., 2006; Lin et al., 2004; Peeta and Ziliaskopoulos, 2001). In fact, the lack of data and resources has sometimes implied model proposals without sufficient revision or proper calibration (Hawas, 2002). For these reasons and for simplicity, comprehensibility, computational convenience and mathematical rigour, static traffic assignment models are still widely applied (Bliemer et al., 2014).

Other topic of intense research in transportation community is the flow-cost relationship. The flow-cost functions express the travel time or cost on a link as a function of traffic volume and several parameters, which describe link characteristics. A number of theoretical flow-cost functions have been proposed in literature (Moses et al., 2013; Mtoi and Moses, 2014; Dowling and Skabardonis, 2006), but the most applied ones generally satisfy first-in-

first-out (FIFO), and causality. Efforts have been made by various researchers to advance and modernize flow-cost functions for a different range of traffic conditions and environments. This has often implied the set of different parameter values from the usual ranges, calibrating them through available observed traffic information; and/or the addition to free flow travel time of extension or delay terms as new component to the function.

Trying to solve all aforementioned problems, a continuous dynamic traffic assignment model is developed in this paper. It is based on the FIFO rule consistent model proposed by Castillo et al. (2012), and the increasingly used plate scanning technique (Castillo et al., 2010, 2008; Mínguez et al., 2010; Sánchez-Cambroneró et al., 2011). This technique not only gives count information, but also provides data about travel times between scanned links and the route followed by the vehicle. Using data registered by scanning devices located optimally (plate numbers and passing times), the new model provides route and link travel times in a network, and adjusts, indirectly, the parameters of flow-cost functions. This way, the weaknesses of Castillo et al. model (2012) for its practice application are avoided: the complexity to have all path flow intensities at their origins, and the assumption of flow-cost functions.

3. PROPOSED MODEL: DYNAMIC ESTIMATION OF TRAFFIC FLOWS ON ALL LINKS OF A NETWORK

A dynamic traffic assignment model is developed from plate scanning data. The inputs required are: the network topology, and the information recorded. It comes from the minimum number of scanning devices optimally located which assure the full knowledge of all paths of the network.

A simple example of a network, which is composed by 6 nodes, 6 origin-destination pairs, 13 links, 17 paths and 8 scanned links is used as analysis case to facilitate the understanding of this model (see Figure 1). The devices located on path 6 ($\mathcal{L} \equiv \{4, 7, 8\}$) do not provide the traffic intensity at its origin (Castillo et al., 2012), but they give the traffic flow intensities $g_a^p(t)$ at the end of the scanned links. The scanned link intensities are used to determine the flow intensities of the unscanned links through the flow wave propagation of the closest scanned link. For example, link 6 intensity is obtained from the link 7 curve recorded. For that, the model estimates the link travel time functions $D_a(t)$, given some parameter values, calculating the link 6 traffic volume $x_6(t)$ and taking into account all paths which contains the link 6. As $D_a(t)$ and $x_a(t)$ are interrelated, an iterative process is required to finally evaluate the link 6 traffic volume and travel time and its intensity due to the path 6.

Next sections detail how to find out the link 6 traffic intensity based on the link 7 wave propagation. In the first one (Hypothesis I), the parameters of the flow-cost functions are considered accurate, while in the second one (Hypothesis II) they are questionable. This means to perform other iterative process that adjusts the parameters to observable field data.

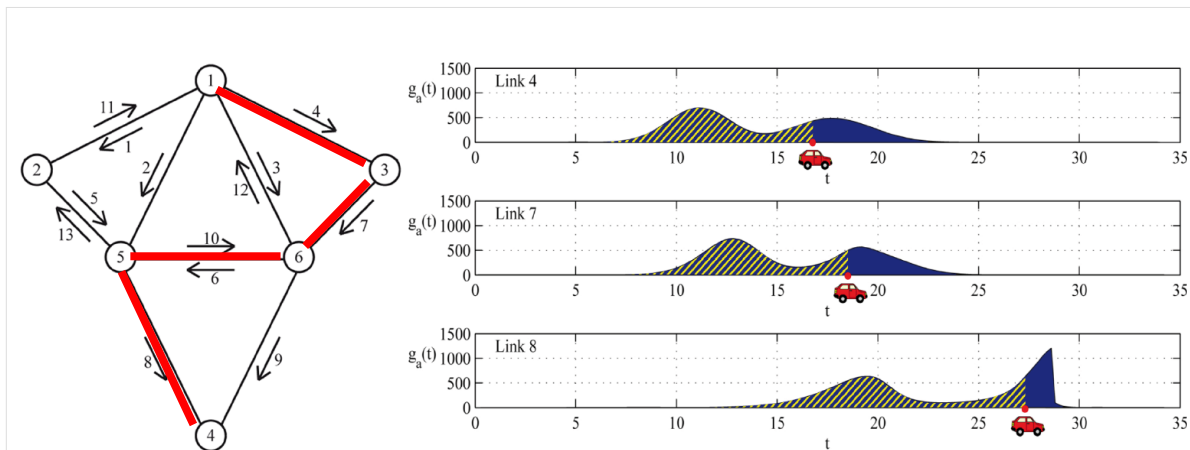


Fig. 1 – Network and flow intensity curves due to path 6 at the end of the scanned links 4, 7 and 8 for the illustrative example. Data based on (Castillo et al., 2012)

3.1 Hypothesis I: Parameters of flow-cost functions are considered accurate

The knowledge of the parameter values of the flow-cost functions is really important to replicate the traffic flow real behaviour. The availability of reliable parameters simplifies the estimation of traffic flows on all links, as it is reduced to solve a continuous dynamic model.

The use of scanning devices implies to modify the algorithm proposed by Castillo et al. (2012) to calculate all link traffic volumes. For illustration purposes, it is considered that $D_a(t)$ is defined by the BPR function (BPR, 1964), where α_a is the free-flow travel time, β_a and γ_a are the link saturation factor and exponent, respectively, $x_a(t)$ is the link traffic volume, and x_a^{max} is the number of vehicles on link a leading to a travel time $\alpha_a(1 + \beta_a)$.

The changes performed in the original algorithm lead to consider two algorithms: forwards and backwards algorithms. The choice of one process or another depends on the distance between the studied link and the scanned devices. In order to satisfy FIFO rule, only one scanned link of each path is selected as reference link b , from which the flow wave is propagated. The criterion followed is to use the scanned link located in the central position of its path. To calculate $x_a(t)$ and $D_a(t)$ in each instant, the reference link flow wave is propagated downstream or upstream. Forwards algorithm is related to a downstream propagation, while backwards algorithm uses an upstream one. As Castillo et al. (2012) proposed, monotone spline approximations are used to estimate the leaving time. These approximations are evaluated through sets of pairs of discrete exit-entry times (t_k, t_{ak}^{in}) and discrete entry-exit times (t_k, t_{ak}^{out}) .

Figure 2 shows how the iterative process works to determine the final splines and, with them, $x_a(t)$ and $D_a(t)$.

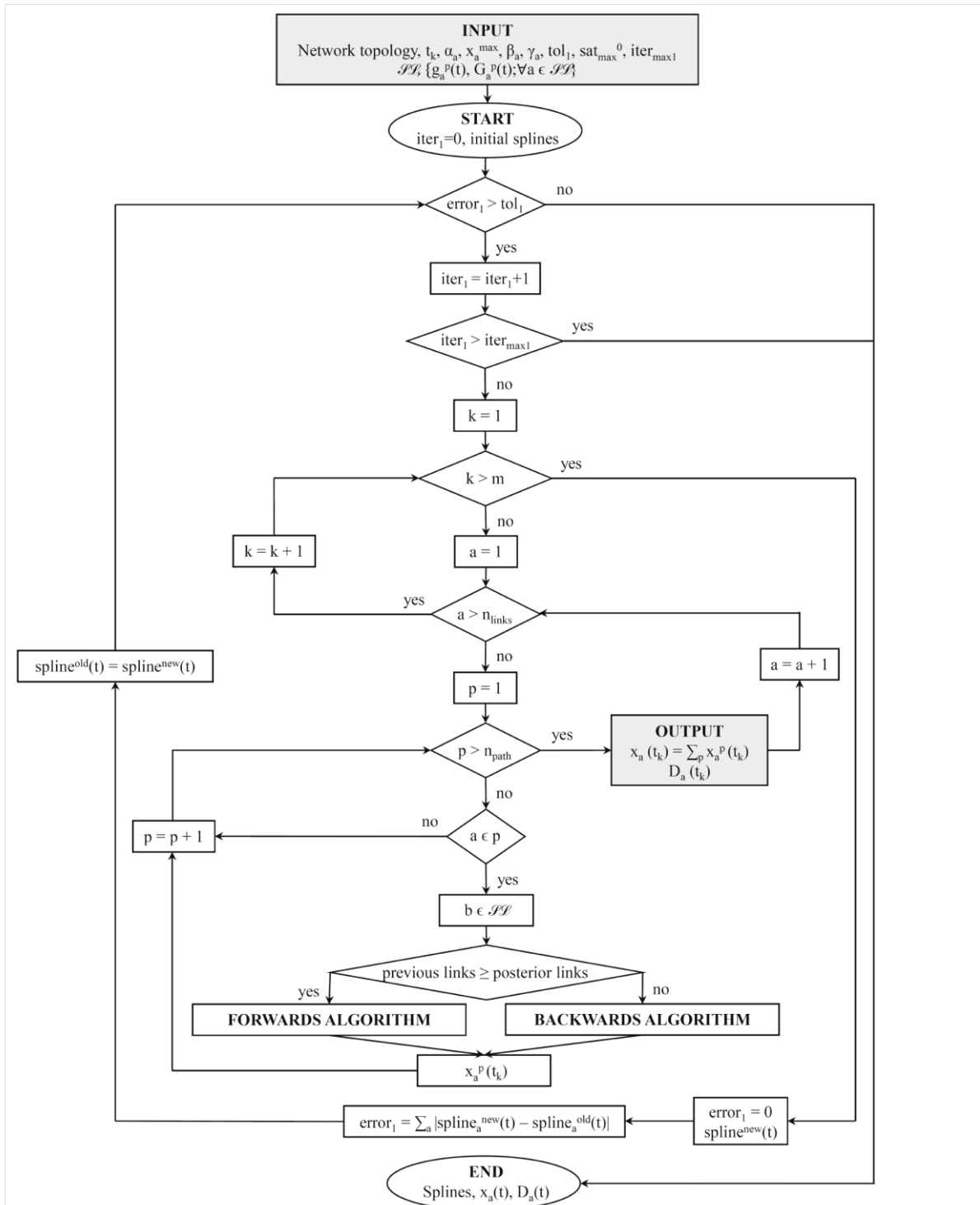


Fig. 2 – Link traffic volume and travel time quantification

3.2 Hypothesis II: Parameters of flow-cost functions are unreliable

The lack of information about link saturation conditions implies that the parameters $\vec{\xi}_a$ of the flow-cost functions could take very different values to the considered ones. Therefore, they have an important influence on $D_a(t)$, overall if their values are unreliable.

The proposed model includes a new algorithm for the adjustment of flow-cost functions in the case that the quality of the parameters is questionable. For that, it is absolutely essential

to study a priori the optimal location of the scanning devices to identify all path flows and to measure travel times in all links. Figure 3 shows schematically the complete organigram to find out the link 6 traffic intensity based on the scanned link 7 wave propagation for this case. After processing the data registered, and supposing some initial parameter values, it is carried out the estimation of the link 6 traffic volume by means of the iterative process described throughout Section 3.1. Next, the parameters of flow-cost functions are adjusted. For that, the model contrasts the link travel times derived from the flow-cost functions T^{7-8} and the travel times observed \hat{T}^{7-8} between the scanned links 7 and 8. A minimization of the differences between travel times observed and calculated are performed. These new parameter values are imposed again as initial conditions, and the global process is repeated until it converges. In each iteration, the flow-cost functions, their parameters, and the intensity curves are updated. The convergence of this process gives as results, among others, the traffic intensity at the end of the link 6 due to the path 6, and new values for its flow-cost function parameters which are more consistent with reality.

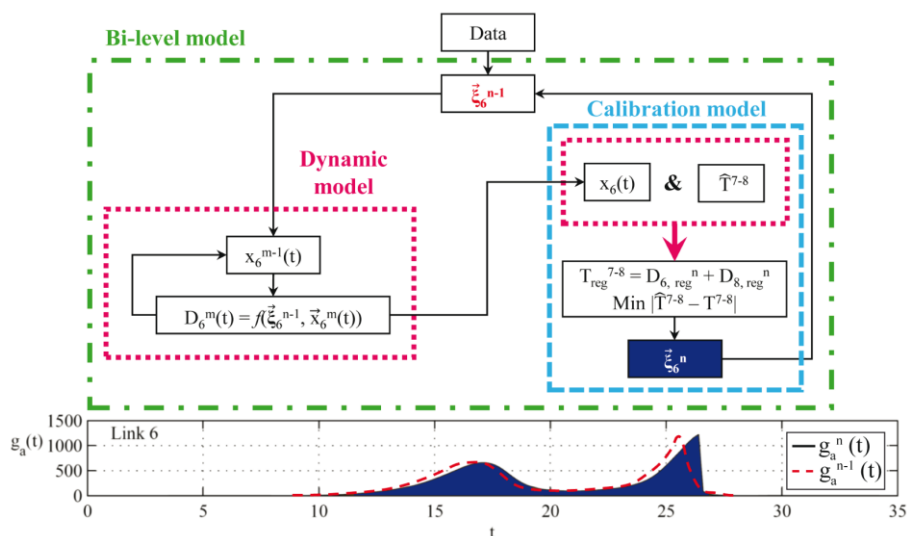


Fig. 3 – Model organigram to obtain, when the quality of the parameters is questionable, the link 6 traffic intensity from link 7 data for the illustrative example

This process is really quite complex. For this reason, the extra steps added are detailed.

3.2.1 Optimal location of the traffic plate scanning devices

Considering no budget restrictions, the knowledge of network traffic flow is achieved with a full route observability. Between the possible combinations which satisfy this condition, the best option is those which provide information about all link travel times. This means that all links must have at least one scanner in a previous link and other in itself or in a posterior one in at least one route that contains both. For that, the location model used by Castillo et al. (2010, 2008) and Mínguez et al. (2010) have to be completed with two new constraints. They impose on model to have enough travel times information as tool to estimate them later, although they do not ensure the direct measurement of all link travel times.

3.2.2 Bi-level model and adjustment of parameters of flow-cost functions

It is really difficult to define in advance reliable parameters, overall for urban networks. There are not reference values for them due to the generalized application of flow-cost functions used in highways, and the questionability of the few documented mobility studies in this infrastructure type.

The proposed model also allows to adjust the parameters of flow-cost function through an iterative process based on registers obtained with the plate scanning technique, given that $D_a(t)$ and $\vec{\xi}_a$ are interrelated. For the purposes, a register *reg* is defined as a pair of records taking by two different scanned devices and related to a single vehicle. This new contribution represents a second level for this model, corresponding the first one to the resolution of a dynamic model (Hypothesis I) assumed some initial values for the parameters. In the second level, $D_a(t)$ is estimated for each register by means of $x_a(t)$ calculated in the first one. With this information and the recorded data, an optimization model is solved and $\vec{\xi}_a$ is updated. The bi-level process is repeated with the new values until its convergence.

The algorithm shown in Figure 4 describes more exhaustively the adjustment of parameters. In this case, the algorithm is described applying the widely-used BPR function (BPR, 1964; Sánchez-Rico, 2014) in order to facilitate the understanding of this model stage. Therefore, this only implies the calibration of the link saturation parameters β_a and γ_a .

4. EXAMPLE OF APPLICATION

The proposed method is applied to the illustrative example to prove that it is appropriate and useful in real practice. To reproduce the field data, the model proposed in Castillo et al. (2012) has been used, assuming that the link behaviour are adjusted to BPR functions (BPR, 1964). The application has started considering $\beta_a^0 = 0.5$ and $\gamma_a^0 = 1$, which are clearly inadequate. Also, it has been imposed an extended day of 32 h, tolerances $tol_1 = 0.1$ and $tol_2 = 0.001$, and maximum number of iterations $iter_{max1} = 100$ and $iter_{max2} = 10$.

The illustrative problem has been solved for 3 days with different congestion level, and 2 possible scenarios. The network has been subjected to a traffic load for the first day, and the double and triple of it for the second and third day, respectively. β_a and γ_a have been established taking into account or not the results obtained in successive days. That is, $\beta_a^{dayi} = \beta_a^{dayi-1}$ and $\gamma_a^{dayi} = \gamma_a^{dayi-1}$, or $\beta_a^{dayi} = \beta_a^0$ and $\gamma_a^{dayi} = \gamma_a^0$, respectively. The convergence of this model has been achieved in all cases. It is highlighted that the process has required less number of iterations when it was based on the adjusted parameters of the previous day, although the final results obtained has been the same in both scenarios. Thus, the number of global iterations for all calculations depends on the link flows and the degree of link saturation, oscillating between 3 and 15 iterations.

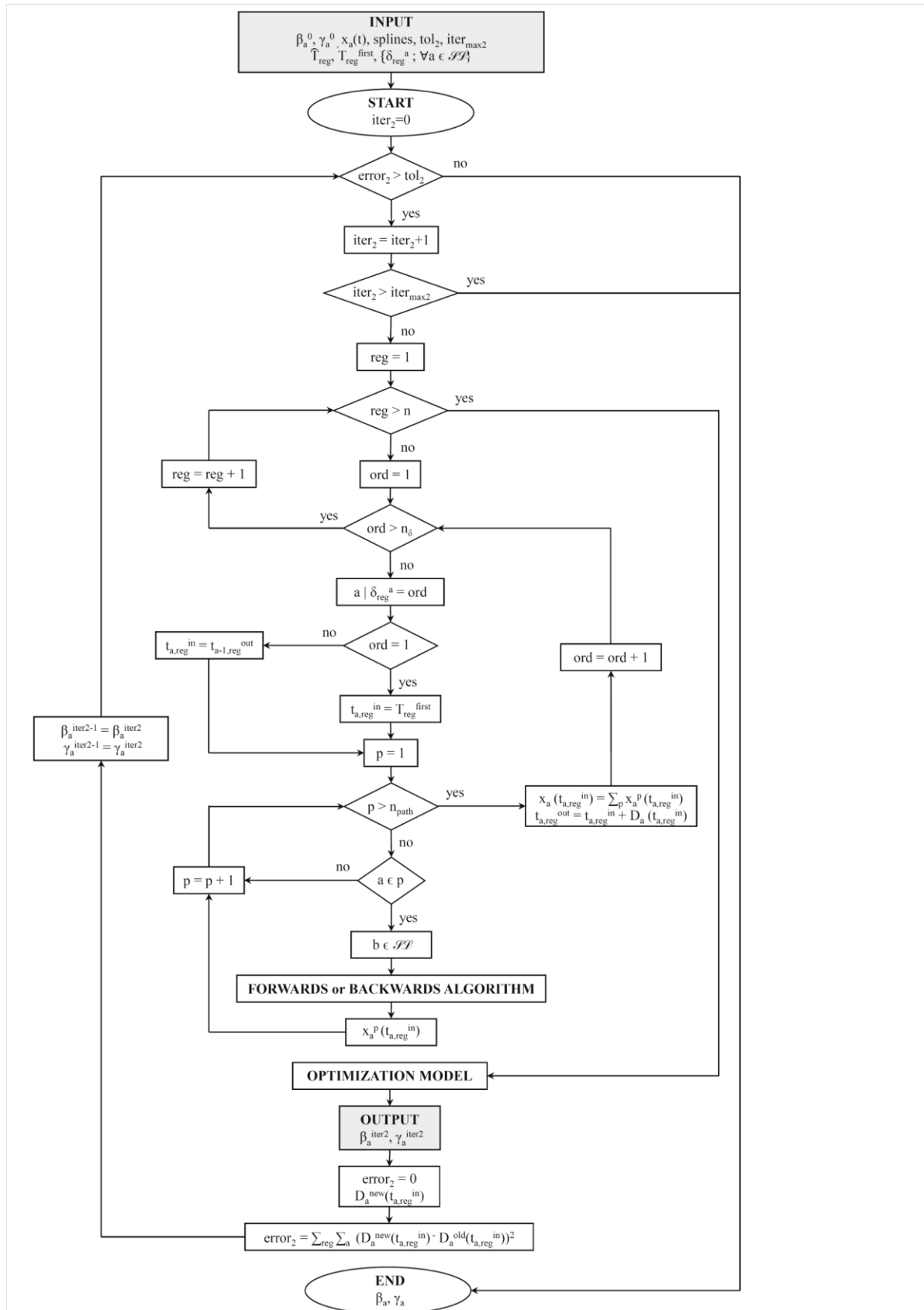


Fig. 4 – Calibration of link saturation

Table 1 indicates the calibrated parameters of the flow-cost function for links 6 and 8. Note that the model adjusts the parameter values to the available information according to the link

saturation level. As seen, the link 6 flow-cost function calculated at third day represents the real link characteristics for any traffic conditions. This is due to the high degree of congestion reached this day. The data recorded during those 32 h include both low and high saturations. This distribution allows to adjust the flow-cost function to the two tails of the BPR function which defines the real traffic flow behaviour in this example. With the parameters established, the resulting link intensity functions, among others, can be obtained. As can be seen in Figure 5, the proposed model describes accurately the traffic intensities (and hence the travel times) for all degree of saturations. The differences between the real and estimated flow intensities, which are shown in solid and dashed lines, respectively, are negligible in all cases. This is not amazing taking into account that the records have been created with the same flow-cost function (BPR function) as the supposed one in the implementation of the model (hidden hypothesis). The link 6 congestion level affects the number of iterations but not the quality of the results of the continuous dynamic model, as expected. The number of iterations required for convergence increases with higher traffic flows (larger congestion).

	sat_{max6}	β_6	γ_6	sat_{max8}	β_8	γ_8
Day 1	0.23	0.50	1.60	0.11	0.50	1.67
Day 2	0.48	0.88	1.86	0.21	0.59	1.70
Day 3	0.85	1.00	2.00	0.30	0.82	1.85

Table 1 – Parameter values for links 6 and 8 adjusted to the different congestion levels for the illustrative example

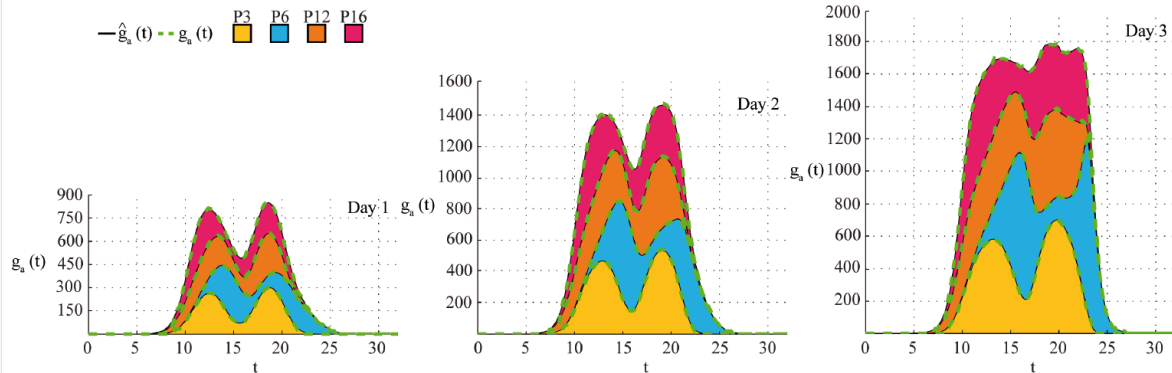


Fig. 5 – Real and estimated flow intensities at the exit of link 6 for the illustrative example

As important as what is shown is to indicate that the model adjusts with similar precision the travel times of the other links of the network (for example the link 8 whose congestion level is very low), but it does not provide good final values for the corresponding parameters of the flow-cost functions. This simply proves that the available field data only allows to adjust the tail of the curve closest to the origin of coordinates.

Since the aim is not to give instantaneous information but efficient tools to cities, this example guarantees that if the proposed method is applied systematically during a period of time, any link which reaches a degree of saturation can be subjected to a calibration of the

parameters of its flow-cost function with this model.

5. CONCLUSIONS

The main conclusions that can be drawn from this paper are the followings:

- 1) The proposed model is based on the interesting results of Castillo et al. (2012) but adapting more to the practical possibilities for obtaining field data. For that, the new model includes the plate scanning technique.
- 2) Its practice application requires to make a previous hypothesis about the characteristics of flow-cost functions. As the quality of the results depends on how they represent the real data, the model is completed with an algorithm which allows to check the reliability of the initial parameter values of the flow-cost functions.
- 3) For the adjustment of parameters, the proposed method needs a location model of scanning devices with more constraints than the commonly used to guarantee the knowledge of the travel times in all links. This iterative process converges the parameters of the flow-cost functions to the vehicle travel times observed in field.
- 4) The reliability of the calibrated parameters of the flow-cost functions greatly improves in those links with a high congestion level. However, the estimation of flows and travel times is good in any case.
- 5) This method is not proposed to provide real-time results. But it can be very useful for local authorities to know the real network behaviour, because it reduces the cost of transportation planning. Its application in successive days allows to achieve the flow-cost functions which represent reality in any situation. This implies that medium-sized cities, which are often with limited resources, can access to technical studies of urban mobility. Furthermore, since the use of BPR function is simply instrumental, this leads researches to compare the flow-cost functions found in literature, propose new alternative formulas and decide new parameters that better reproduce the reality of urban environments. Future research is needed to discuss the advantages and disadvantages of using existing or new flow-cost functions, and also to calibrate the best option.

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