ORIGINAL ARTICLE

ROUNDABOUT CAPACITY ESTIMATION USING SUPPORT VECTOR MACHINE ALGORITHM

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ABSTRACT

Background: Urban mobility plays an important role in the citizen's life quality. Good mobility management has a very important impact in facilitating travel and improving the city environment quality (climate). When we talk about mobility we will refer to any mode of motorized displacement or not. In the literature there are many essays that focus on the study of both pedestrian and vehicular mobility. One of the most conflictive points in the city are the roundabouts, and where more time is wasted. **Objectives**: In this article we will focus on the study of private vehicles mobility within the city of Tangier, and exactly at a specified roundabout. The intersections are a very conflicting point where all the vehicle flows converge. There are two types of intersections, those controlled by traffic lights and those not controlled, the latter are characterized by respecting some rules of priority, and the most important rule is to give way for vehicles that circulate within the roundabout. The most important parameter is the roundabout capacity, which is the hourly flow that enters in each leg (Q_f), that flow is expressed by the annular flow Q_c, and other parameters such as the geometry of the roundabout. The objective will be to estimate the roundabout capacity using SVM algorithm. **Methods:** We locate the study area through google maps, to identify the roundabout, we model the intersection as a graph form to facilitate the task of data collection, and using a video recording in peak hours we can identify the flow in each leg (Q_f) and the flow inside the roundabout (Q_c). Finally, we use SVM algorithm to estimate the roundabout capacity. **Results:** The result will be the estimation of traffic flow using SVM algorithm, and capacity simulation at various intervals of the day and in different months of the year. **Conclusions:** Machine learning algorithm it's a good tool to model vehicles flow, and the simulations show a good estimate using SVM algorithm. As an improvement for a future study, it will be interesting to compare the result of SVM model with other models, both linear and non-linear.

Keywords: *Roundabout capacity, Support Vector Machine Algorithm, Mobility in Tangier*.

1. INTRODUCTION

Urban mobility is causing more and more problems, such as atmospheric and noise pollution that have a serious impact on health [1]. Currently most of the studies focus on sustainable mobility, as a key to solve the problem of displacement within the city [2]. From a simplified approach, you can model a city as a graph, the edges constitute the different streets, and the nodes, corresponds to the streets intersections [3]. There are three types of nodes, a simple intersection with 'right priority', a signalized intersection and a roundabout with 'left priority' (vehicles entering a roundabout must give way to vehicles in the roundabout) [4]. The intersections in a city, is an essential transit point, when the driver wants to change directions, is also a point of convergence of different streets, causing congestion, which is translated into increasing amounts of pollutants, and vehicles accident.

How can an intersection be examined? Specifically, a roundabout with 'left priority'. The level of service in a roundabout is identified by the roundabout capacity and the time lost (delay) going through [4]. There are several models and methods to calculate the roundabout capacity.

In these last 10 years, the city of Tangier has known an interesting economic and demographic growth, traducing into more displacements [5]. The roundabout selected to present this study, is specified by its location in the center of the city, the location of attractive centers around it, such as the Mohamed 5 Hospital, the Spanish consulate, it is also a point of convergence of many directions and is a transit point towards the city center, as depicted in figure 2.

2. MATERIALS AND METHODS

2.1 Related works:

Many authors have studied the problem of estimating roundabouts capacity, as well as the different parameters that affect security, such as the critical gap, follow-up time, and the roundabout geometry [6]. There are 2 large families of methods, the empirical methods based on linear regression and the analytical or probabilistic methods based on gap acceptance theory [6]. There are some authors who support their studies using microscopic simulation [6]. Rui-Jun et al., (2009) have analyzed the difference between single-lane and double-lane roundabouts in China using analytics methods

based on M3 distribution [7]. Also Bie et al., (2010) investigates a lane-based method, evaluating the entry capacity for each individual lane using the HCM formula and Kimber model [8]. The research work set up by Wang and Yang (2012) estimate the roundabout capacity by modelling weaving gap acceptance at the weaving section, where they have studied 21 roundabouts in Beijing [9]. In Slovakia the capacity evaluation of roundabout is studied according to Swiss empirical method and German guidelines, evaluating each roundabout by using LOS (Level Of Service) [10]. In another research work, the author provided the different traffic operation at roundabouts such as: distribution of circulation velocity, entry velocity, circulating gap and entry gap [11]. Also, in Argentina, Castellano (2013), uses the roundabout capacity calibration of HCM 2010 model, applying to the local conditions of Cordoba in Argentina in 4 roundabouts, the calibration parameters are the critical gap and the follow-up interval, to this purpose use ML (maximum likelihood), linear regression and direct measurement [12]. Kang and Nakamura, (2014) analyzed the estimating roundabout capacity taking into account, pedestrian approaching side and queueing vehicles blocked by pedestrians [13]. Ersoy and Celikoglu (2014) estimate roundabout capacity with the incorporate of HCM 2010 method and TRL method [14]. Lochrane et al (2014), provides design recommendation and simulation approach for mini-roundabout using FHWA (the Federal Highway Administration), and the only capacity model that is available for analyzing mini-roundabouts, is an empirical-based model from a study by the UK ARCADY (TRL) [15]. Zhaowei et al. (2014) highlights a review of roundabout capacity, estimating the different approach of roundabout capacity such as, empirical regression model, gap acceptance model, weaving theory (Wardrop) and model based on simulation [16]. Agyerman et al. (2015) studied 3 roundabouts in Sunyani in Ghana, using data collection during peak hours in interval of 15 min and using simulation to estimate capacities and LOS. The roundabout capacity is determined by Kimber formula [17]. In another article Arrgu et al. (2015), determined the roundabout capacity using various capacity formulas, such as, gap acceptance model (HCM 2010 USA), German model 2001, empirical regression model (TRRL, UK) and weaving models, also a microscopic simulation using VISSIM [18]. Mahech et al. (2014) examines the entry capacity of a roundabout under different circulating flows, using the HCM 2010 [19]. Ahmed and Rastogi (2016) presents a regression model which is developed to estimate entry capacity, the author has studied different approach of regression based linear and non-linear models [20]. Also the authors use correlation analysis to show how strongly is a statistical technique, and the results show that the central island diameter is correlated with the entry capacity and develop 2 models, linear and non-linear models. Another study, Mathew et al. (2017) investigates the suitability of HCM equations for determining the entry capacity of four-legged roundabout and propose model for entry capacity [21]. Brilon (2016), the critical gap is determined by using MLM (maximum likelihood method) [22].

In regards to traffic flow estimation, many authors developed the estimation model associated with flow prediction as clustering methods introduced by Caceres et al. (2012) [23], Kalman filter studied by Chu et al. (2005) [24], artificial neural networks (ANN) developed by Wei and Lee (2003) [25], and prediction mechanism based on the traffic flow space-time characteristics in Gaoerji (China) road, a one-way lane, using SVM algorithm applied by Mingheng et al. (2013) [26].

2.2 Capacity estimation:

There are 2 types of intersections, roundabouts, where circulating vehicles had priority over entering vehicles, and the rest of the intersections. The roundabouts with off-side priority, are intersections of 2 or more routes, the essential characteristics represented in figure 1. Currently, the roundabouts began to be considered as a sum of 'T' intersections, and the concept of global capacity is replaced by the capacity of each access. Therefore, the capacity is: The greatest number of vehicles that can enter to the roundabout from an access, during a period of time under certain traffic conditions and geometry. According to the different studies, the capacity represents the relationship between the circulating traffic (Q_c) and the maximum that could be incorporated in the entrance (Q_e) [6, 27]. There are two methodologies, empirical methods and analytical (probabilistic) methods. Most countries have adopted their capacity model based on one of these 2 methods, the regression base (United Kingdom) and the gap acceptance theory (Australia) [6, 27].

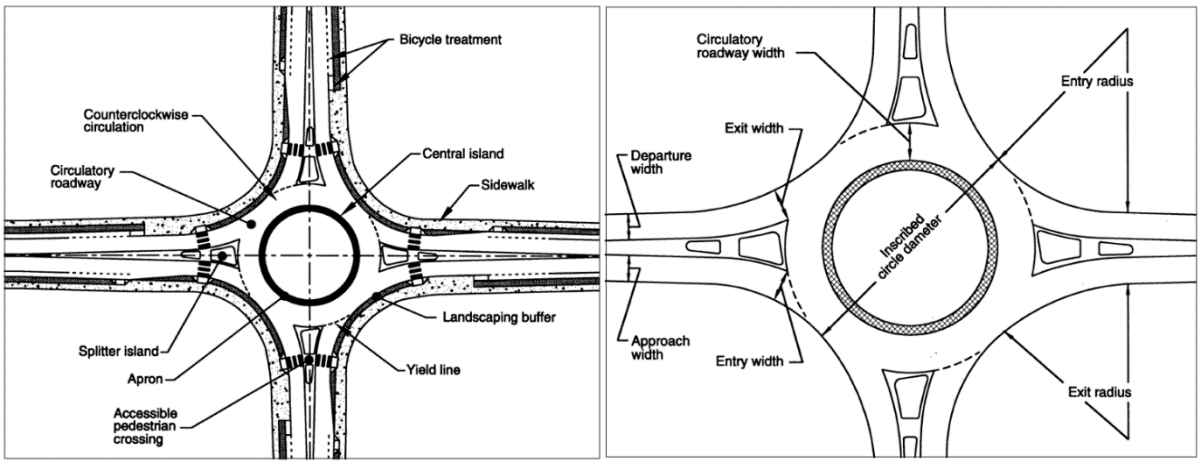

Figure 1: The figure presents the roundabout geometry and the different influential parameters.

2.3 Study area and data collection:

The city center area where most of the vehicle flows converge, as shown in the figure 2 (a). The four-leg roundabout is identified by red circle within the study area, is the intersection between Habib Bourguiba avenue, Sidi Amar avenue and Elouchak avenue. We model the roundabout to facilitate data collection as depicted in figure 2 (b). The data collection was done using video recordings, in different months of the year (April, July and October) and during a week of every month from Monday to Sunday during 7 time intervals in 30 min of recording {7h45-8h15, 9h45-10h15, 11h45-12h15, 13h45-14h15, 15h45-16h15, 17h45-18h15, 19h45-20h15}.

Figure 2: The figure presents the roundabout site (a) and modeling (b).

2.4 Support vector machine model:

Machine learning model learns from the past input data and makes future prediction as output. We can divide machine learning algorithms into three main groups based on their purpose: a supervised learning, unsupervised learning and reinforcement learning [28]. Support Vector Machine algorithm abbreviated as SVM is specific to supervised learning is a powerful method for regression and classification introduced by Vapink (1995) [29]. The SVM maps the input data (R^2) into (R^3) space via a nonlinear map, constructing a hyperplane with maximum margin. The following shows the SVM algorithm [30]:

Consider a given training set $\{x_i, y_i : i = 1, \cdots l\}$ randomly and independently generated from an unknown function, where $x_i \in X \subseteq R^n, y \in Y \subseteq R$ and l is the total number of training data.

The SVM approximates the unknown function:

$$f(x) = \langle w, \Phi(x) \rangle + b \qquad (1)$$

Where $\langle , \rangle$ is the dot product, w and b are the estimated parameters and Φ is a nonlinear function is used to map the original input space R^n to high dimensional feature space. The optimization goal of standard SVM is formulated as:

$$\text{Minimize} \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{l}(\xi_i + \xi_i^*) \qquad (2)$$

Subject to:

$$y_i - \langle w, \phi(x_i) \rangle - b \le \varepsilon + \xi_i,$$
$$\langle w, \phi(x_i) \rangle + b - y_i \le \varepsilon + \xi_i^*,$$
$$\xi_i^*, \xi_i \ge 0, i = 1, \ldots\ldots, l.$$

Where the constant $C > 0$ determines the tradeoff between the flatness of f and the amount up to which deviations larger than are ε tolerated and ξ_i^*, ξ_i are slack variables and they are introduced to accommodate, respectively, the positive and the negative errors on the training data. ε-insensitive cost function:

$$|\xi|_\varepsilon := \begin{cases} 0 & \text{if } |\xi| < \varepsilon \\ |\xi| - \varepsilon & \text{otherwise} \end{cases}$$

Maximizing the margin m is a quadratic programming problem QP and can be solved by its dual problem by introducing Lagrange multipliers $\alpha_i, \alpha_i^*, \beta_i, \beta_i^*$:

$$\mathrm{L_P}(\mathrm{w}, \xi, \xi^*, \alpha, \alpha^*, \beta, \beta^*) = \frac{1}{2}\langle \mathrm{w.w} \rangle + C.\sum_{i=1}^{l}(\xi_i + \xi_i^*) - \sum_{i=1}^{l}\alpha_i.\langle w, \phi(x_i)\rangle - y_i + b + \varepsilon + \xi_i)$$

$$-\sum_{i=1}^{l}\alpha_i^*.(y_i - \langle w, \phi(x_i)\rangle) - b + \varepsilon + \xi_i^*) - \sum_{i=1}^{l}(\beta_i.\xi_i + \beta_i^*.\xi_i^*) \qquad \textbf{(3)}$$

By minimization the Lagrangian with respect to the primal variables we obtain:

$$w = \sum_{i=1}^{l}(\alpha_i - \alpha_i^*).\phi(x_i) \qquad \textbf{(4)}$$

And $\sum_{i=1}^{l}(\alpha_i - \alpha_i^*) = 0, \quad 0 \le \alpha_i \le C,\ 0 \le \alpha_i^* \le C,\ i = 1, \ldots\ldots, l$

The dual problem is obtained by introducing (3.1) in (3) and it is expressed as:

$$\text{maximize} \quad -\frac{1}{2}\sum_{i,j=1}^{l}(\alpha_i - \alpha_i^*).(\alpha_j - \alpha_j^*).K(x, x_i) + \sum_{i=1}^{l}(\alpha_i - \alpha_i^*).y_i - \sum_{i=1}^{l}(\alpha_i - \alpha_i^*).\varepsilon \qquad \textbf{(5)}$$

Subject to :

$$\sum_{i=1}^{l}(\alpha_i - \alpha_i^*) = 0,\ 0 \le \alpha_i \le C,\ 0 \le \alpha_i^* \le C,\ i = 1, \ldots\ldots, l$$

Finally, the nonlinear function is obtained as:

$$f(x) = \sum_{i=1}^{l}(\alpha_i - \alpha_i^*).K(x, x_i) + b \qquad \textbf{(6)}$$

Where $K(x_i, x_j) = \langle \phi(x_i), \phi(x_j) \rangle$ is defined as the kernel function. Any function that satisfies Mercer's theorem can be used as the kernel function.

3. SVM SIMULATION FOR ROUNDABOUT CAPACITY PREDICTION

3.1 The input matrix and the output vector to apply the SVM method:

We construct the input matrix and the output vector to apply the SVM method:
<u>The input matrix</u>:

- For the input, we used a matrix that contains the following elements: [Q_c, day, month, hour, section].
- For the day we used the numbers: 1,2, 3,..7 to identify Monday, Tuesday,…Sunday.
- For months we used 4, 7, 10 to identify, April, july, October.
- For hours we used numbers 1,2,3,4… to identify time interval 7h45-8h15, 9h45-10h45…7h45-8h15.
- We use 1,2,3,4 to identify four-leg roundabout A,B,C,D.

The size of this matrix is [11200 lines, 5 columns].
<u>The output vector</u>

For the output vector: contains capacity prediction Qf, its size is: [11200 lines, 1 column]
<u>Construction of test elements and training</u>

The input matrix and the output vector are divided into two parts: one for the training and the other for the test, whose test represents 30% of the input matrix, chosen in a random manner (and the same thing for the output).
The kernel used is RBF, three parameters associated should be determined (C, ε, γ). with C=100, ε=0,1 and for RBF the parameter is 0,2.

3.2 Simulations

For simulations, we represent each month in a separate table and for each hourly interval during the day, as seen in the figures 3,4 and 5. The estimated data is represented with red color and the observed data with green color, using Matlab simulation. The aim is to approximate the prediction performance based on the knowledge of the training set.
The results show that the methodology makes good use of historical data, with the Mean Absolute Relative Error MARE=13,61%.

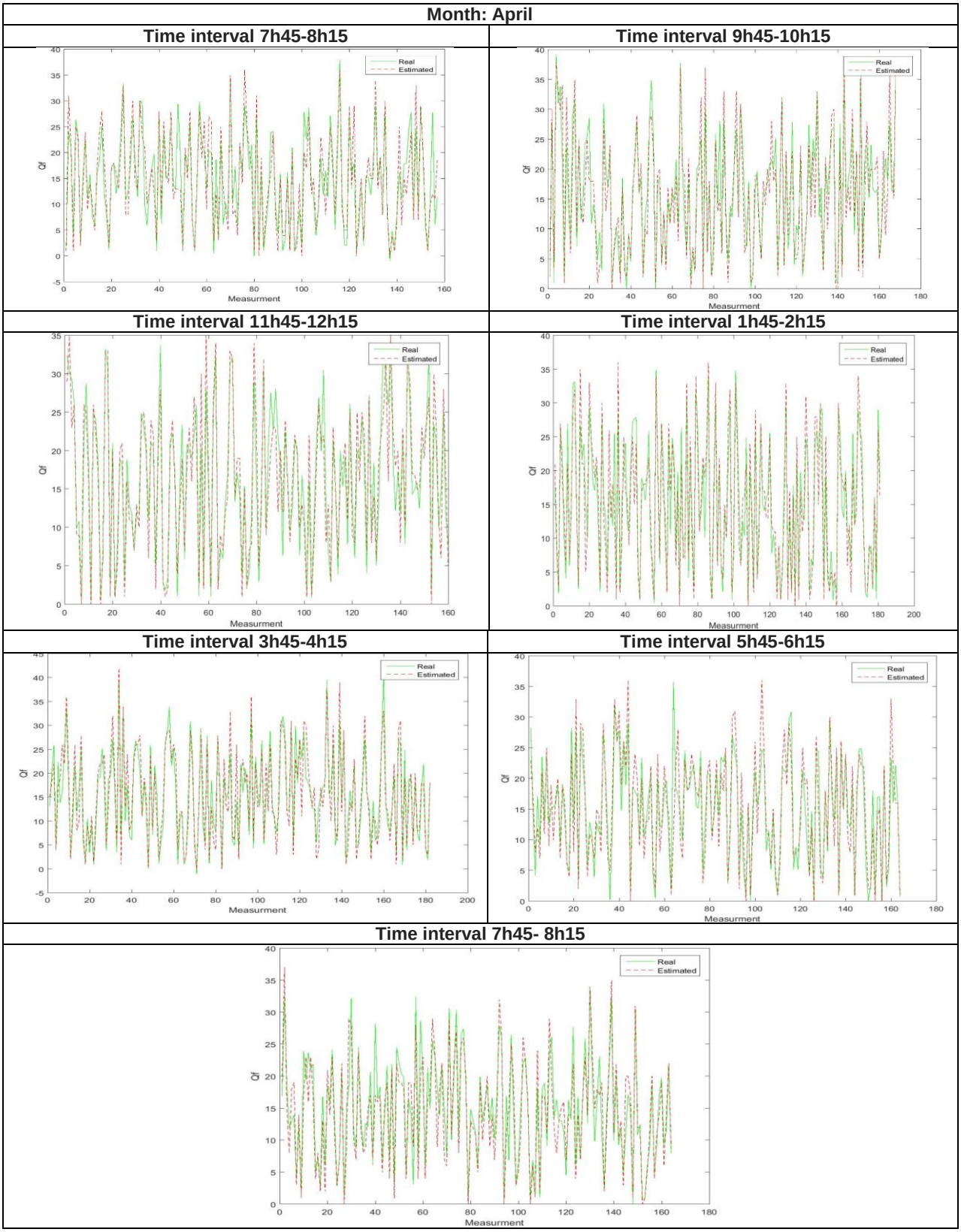

Figure 3: The figure presents the the simulation result for April in 7 time intervals.

In the simulation result for July, the results show that the methodology makes good use of historical data, with the Mean Absolute Relative Error MARE=12,2%.

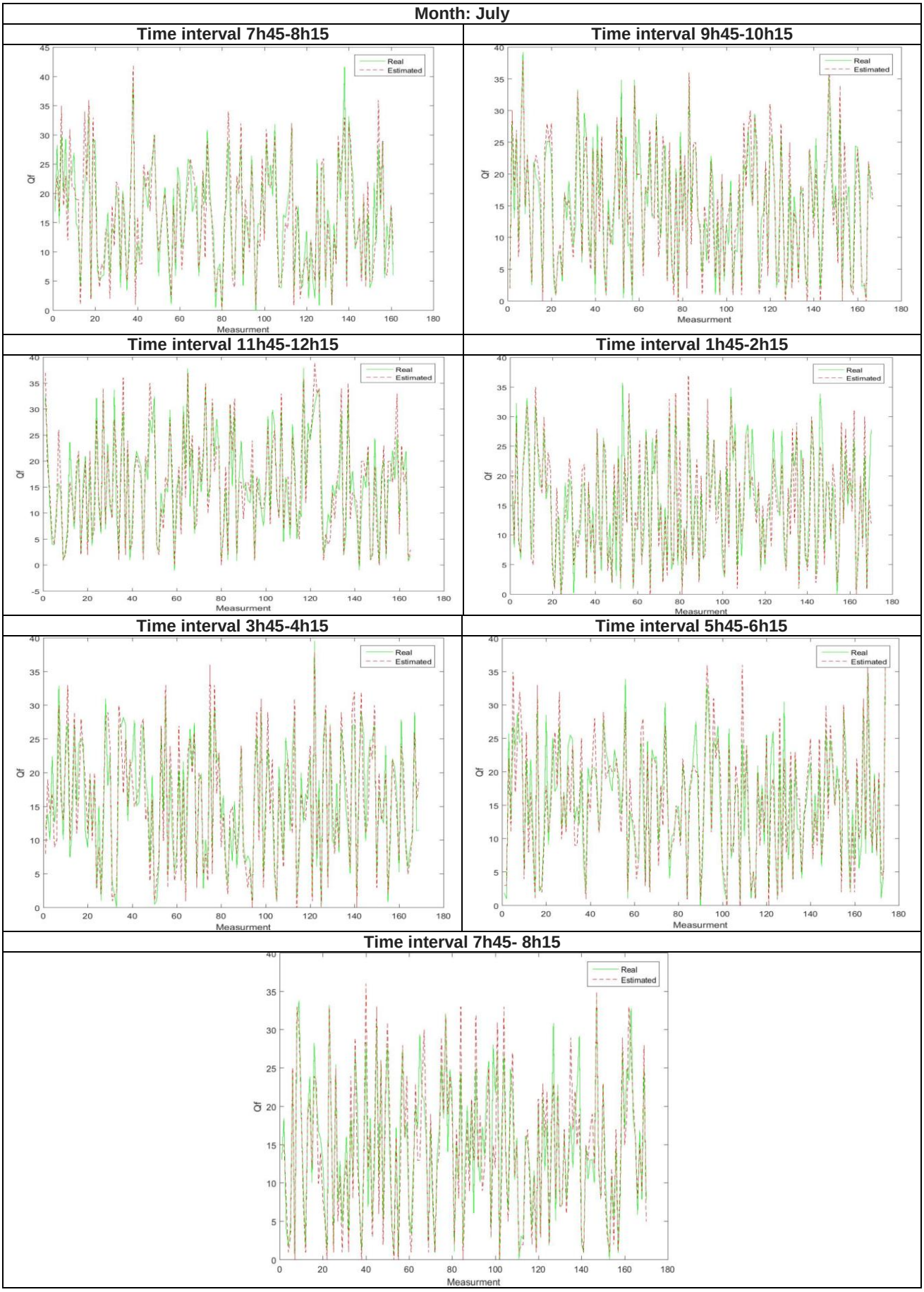

Figure 4: The figure presents the simulation result for July in 7 time intervals.

In the simulation result for October. The results show that the methodology makes good use of historical data, with the Mean Absolute Relative Error MARE=14,43%.

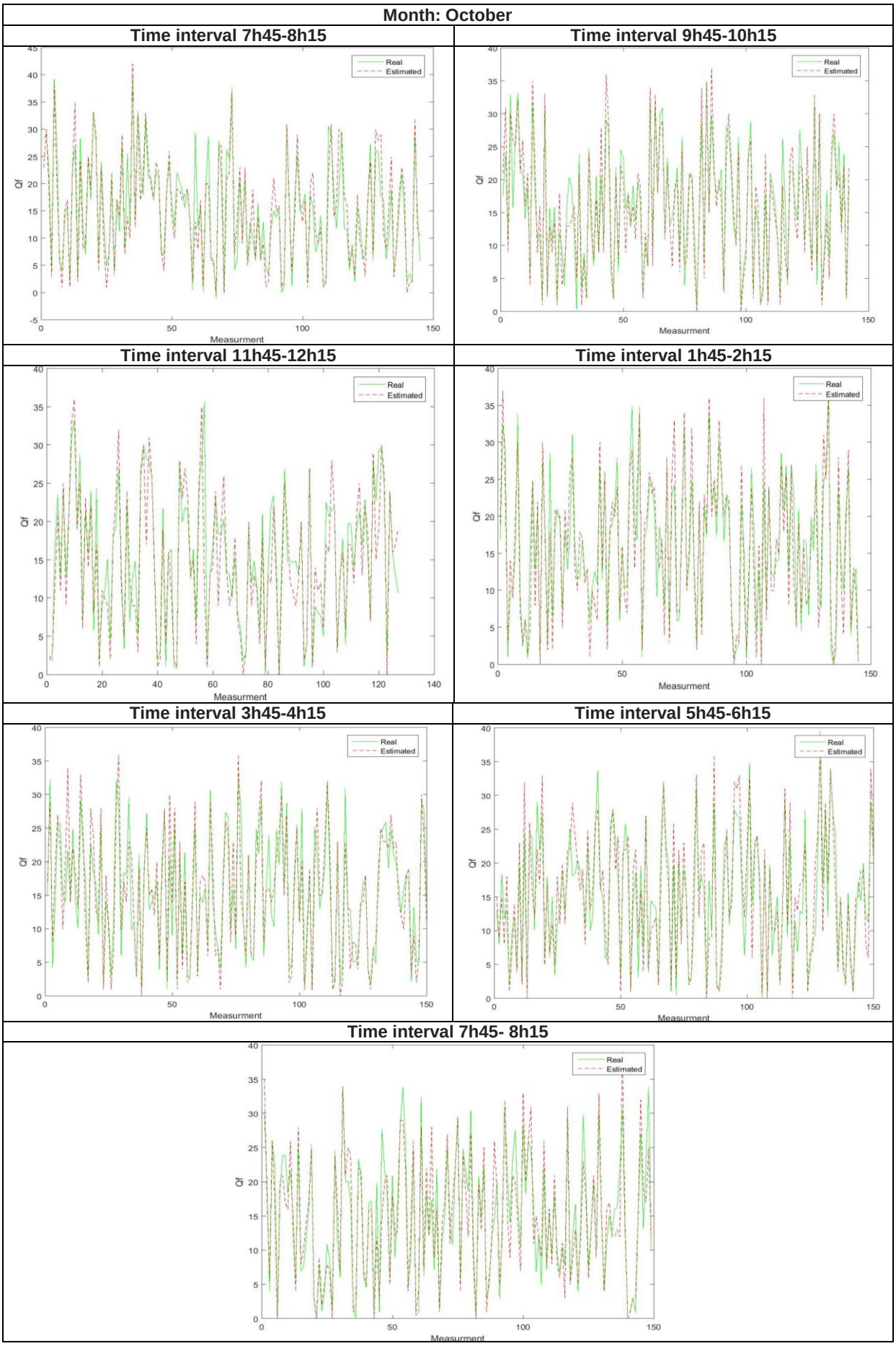

Figure 5: The figure presents the simulation result for October in 7 time intervals.

Now we can represent the total capacity estimation as shown in figure 6.

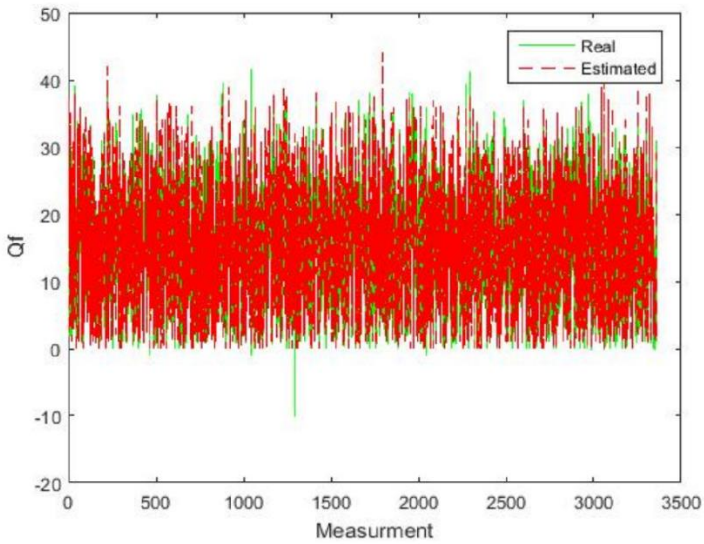

Figure 6: The figure presents the total roundabout capacity estimation.

From the results, it can be seen that the prediction curves agree well with the actual observing data.

4. CONCLUSION

Urban mobility plays a very important role in the lives of citizens. Good mobility management influences time travels. The studied area is characterized by its central location, such that the vehicles flow come from all directions. The methodology is based first on data collection using video recording in 3 months of the year (April, July and October) throughout the week. In order to predict traffic flow or roundabout capacity, this paper proposed a SVM model for the capacity prediction. The results achieved show a good representation of our data through SVM and a good ability for capacity prediction. In further study we can compare the SVM model with other linear and non-linear models, also we can simulate the different methods of capacity calculation, such as the French method, the English model (Kimber), HCM 2010, the German ... to see who fits more to our data.

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