Fuzzy adaptive traffic control: application to an isolated intersection

Mariagrazia Dotoli, Maria Pia Fanti
Politecnico di Bari, Dipartimento di Elettrotecnica ed Elettronica
Via Re David, 200, I-70125 Bari, Italy
Phone: +39-080-5963312, Fax +39-080-5963410
e-mail:{dotoli, fanti}@deemail.poliba.it

ABSTRACT: This paper investigates the issue of adaptive traffic control using a real time macroscopic model for signalized areas. A model describing urban traffic and queues is adopted. Moreover, an adaptive fuzzy control strategy determines in real time the green phases duration and the cycle length of the signal timing plan managing the intersection. The technique is applied to a real case study, consisting of an intersection located in the urban area of Bari (Italy). Results show the ability of the strategy to minimize traffic congestion in the area and is attractive for use in real applications.

KEYWORDS: traffic signal control, adaptive control, fuzzy logic, isolated intersection, queues, arrivals, signal timing plan.

INTRODUCTION

Urban traffic congestion undermines urban mobility in major cities. Traditionally, the congestion problem on surface streets was dealt by adding more lanes and new links to the existing transportation network. However, such a solution can no longer be considered for lack of space, hence greater emphasis is nowadays placed on traffic management. In particular, traffic signal control on surface street networks plays a central role in traffic management. Despite the large research efforts on the topic, the problem of urban intersection congestion remains an open issue [7, 11]. A major research focus in the field of adaptive traffic signal control has recently been on application of intelligent control techniques, that are able to deal with the intrinsic multi-objective nature of traffic control problems: conflicting objects such as different traffic streams in the same intersection require a compromise to determine a satisfactory allocation of the resources (the space in the intersection) for which they compete. Pappis and Mamdani [10] were the first to apply fuzzy logic to control an intersection of two one-way streets, introducing the so-called fuzzy extension principle: the fuzzy controller periodically monitors arrivals and queues in the intersection branches and performs accordingly a decision whether to terminate or extend the current green phase. Several researchers extended the seminal work presented in [10] to isolated intersections including left-turns and right-turns [2, 6, 13, 8, 9]. The interested reader may find reviews on the application of fuzzy logic to traffic signal control in [12, 5].

A common feature of adaptive traffic control strategies is that several detectors located on the intersections branches monitor traffic conditions and feed information on the actual system state to a real time controller, that selects the duration of the phases in the traffic lights cycle in order to optimize a given performance index. In particular, usually two detectors are installed on each branch of the controlled area: one sensor is located behind the traffic light to count the number of vehicles entering the intersection, while the second detector counts the vehicles passing the traffic light. Such a system of detectors is expensive and subject to failure: most sensors consist of inductive loops that detect the presence of vehicles, hence the presence of nearby parked cars may hinder the measurement. Therefore accurate measurement/computation of queue lengths on the approaches to a signalized intersection is a key factor in the vehicle actuated control strategies.

In this paper we apply to a real case study the adaptive fuzzy control technique proposed in [10], subsequently extended in [8, 9], in combination with an urban traffic model proposed in [1, 3, 4]. The queue computation algorithm requires only a single passage detector, located at the stop bar, hence it allows employing a reduced set of sensors, with savings in terms of costs and failure probabilities. The proposed case study is a real isolated junction, located in the urban area of Bari (Italy), with severe traffic congestion. Simulation results show that the proposed strategy is able to minimize congestion and is attractive for use in real applications.

The paper is organized as follows: the following section briefly reviews the adopted urban traffic model and the third section shows the fuzzy control strategy for an isolated intersection. Moreover, section four describes the case study and the simulation results. The paper is concluded by a discussion on the method, with suggestions for further research.
In this section we briefly review the approach proposed in [1, 3, 4] for modelling a generic signalized area both under congested and clear traffic.

A signalized urban area (or a single intersection) is controlled by traffic lights sharing a common semaphoric cycle of length \( C \). The area includes a set \( L = \{ L_i \mid i = 1, \ldots, I \} \) of \( I \) links (see figure 1). Each link models the space available between two subsequent traffic lights and may include one or several lanes. In particular, \( L_{in} \subset L \) and \( L_{out} \subset L \) respectively represent the sets of input links and output links, all with infinite capacity. In addition, set \( L \setminus (L_{in} \cup L_{out}) \) includes the finite capacity intermediate links, connecting intersections.

![Figure 1. Example of a signalized urban area comprising junctions pertaining to a common semaphoric cycle.](image)

A generic link \( L_i \) \((i=1, \ldots, I)\) is described by the following variables: \( n_i(k) \), \( N_i \), \( u_i(k) \) and \( y_i(k) \) with \( k=1, \ldots, K \), representing respectively the number of vehicles in \( L_i \) at the beginning of the \( k \)-th semaphoric cycle in the pre-set modelling horizon (of length \( KC \)), the link capacity, the number of vehicles entering the link within the \( k \)-th cycle and the number of vehicles leaving it in the same time interval. The vehicles balance equation in \( L_i \) in the \( k \)-th cycle is:

\[
n_i(k) = n_i(k-1) + u_i(k-1) - y_i(k-1), \quad k=1, \ldots, K, \quad i=1, \ldots, I.
\]  

(1)

Clearly, traffic lights are associated only to input and intermediate links. In addition, let \( f=1, \ldots, F \) be the generic phase associated to a traffic light in the semaphoric cycle. Now, define for the generic links \( L_h, L_i, L_j \in L \) \( S^f_{h,i}(k) \) and \( S^f_{i,j}(k) \) with \( f=1, \ldots, F \) and \( k=1, \ldots, K \), representing respectively the number of vehicles travelling from \( L_h \) to \( L_i \) and from \( L_i \) to \( L_j \) in the \( f \)-th phase of the \( k \)-th cycle. Then, defining \( u^f_i(k) \) and \( y^f_i(k) \) as the number of vehicles respectively entering and leaving \( L_i \) in the \( f \)-th phase of the \( k \)-th cycle, it holds:

\[
u^f_i(k) = \sum_{f=1}^{F} u^f_i(k) \quad \quad y^f_i(k) = \sum_{f=1}^{F} y^f_i(k),
\]

\[
u^f_i(k) = \sum_{h \in L_{in}} S^f_{h,i}(k) \quad \quad y^f_i(k) = \sum_{j \in L_{out}} S^f_{i,j}(k),
\]

(2)

(3)

where \( L_{in} \) and \( L_{out} \) are respectively the set of incoming and outgoing links for \( L_i \). Moreover, let \( \beta_{i,j} \) be the percentage of vehicles travelling from \( L_i \) to \( L_j \). It holds:

\[
\sum_{j \in L_{out}} \beta_{i,j} = 1 \quad \forall (i, j) : j \in L_{out}.
\]

(4)

We assume that the turning movement fractions \( \beta_{i,j} \) are known and time variant: they may be computed experimentally, or determined on a Time Of Day (TOD) basis. Now, consider the average travelling time of link \( L_i \)}
given by $\tau_i = l_i/v_i$, where $l_i$ and $v_i$ are respectively the link length and average vehicles speed (assumed constant in the modelling horizon).

In addition, let $u_{go}^f(i,k)$ and $u_{stop}^f(i,k)$ be the number of vehicles entering $L_i$ in the $f$-th phase of the $k$-th cycle that are respectively able and unable to leave the link during the same phase. It holds:

$$u_{go}^f(i,k) = \begin{cases} u_i^f(k) & \text{if } \tau_i \leq t_f^f(k) \\ 0 & \text{if } \tau_i > t_f^f(k) \end{cases} \quad \text{with } i \in L, \ f = 1, \ldots, F, \ k = 1, \ldots, K, \quad (5)$$

$$u_{stop}^f(i,k) = u_i^f(k) - u_{go}^f(i,k) \quad \text{with } i \in L, \ f = 1, \ldots, F, \ k = 1, \ldots, K. \quad (6)$$

Moreover, $t_f^f(k)$ is the duration of phase $f$ in the $k$-th cycle. Under the assumption that the travelling time of the generic link is never greater than the length of two subsequent phases, define $n_f^f(k)$, representing the overall number of vehicles which can leave $L_i$ during phase $f$ of the $k$-th cycle, leaving aside the physical limitations imposed by the downstream links capacities. It holds:

$$n_f^f(k) = \begin{cases} n_i(k) + u_{go}^f(i,k) & \text{if } f = 1 \\ n_i^{f-1}(k) + u_{go}^f(i,k) + u_{stop}^{f-1}(i,k) - y_i^{f-1}(k) & \text{if } f = 2, \ldots, F \end{cases} \quad \text{with } i \in L, \ k = 1, \ldots, K. \quad (7)$$

Now, the effective time $t_{eff}^{i,j}(k)$ is defined, representing the actual fraction of $t_f^f(k)$ available in the $f$-th phase in the $k$-th cycle for vehicles to leave $L_i$ for $L_j$:

$$t_{eff}^{i,j}(k) = t_f^f(k) - \sum_{(h,z) \in P_{i,j}} S_{h,z}^f(k) \cdot \frac{y_{h,z}}{v_{h,z}}, \quad (8)$$

where $x_{h,z}$ and $v_{h,z}$ are the distance covered by the generic vehicle and its average speed while travelling from $L_i$ to $L_j$. In addition, $P_{i,j}$ is the set of link pairs $(h,z)$ such that $S_{h,z}^f(k)$ has right of way over $S_{i,j}^f(k)$, with $f \in \{1, \ldots, F\}$.

Hence, (8) models precedence in the area. Now, define the following function:

$$Q_{i,j} \left( t_{eff}^{i,j}(k) \right) = \Phi_{i,j} \cdot t_{eff}^{i,j}(k), \quad (9)$$

which represents the number of vehicles leaving $L_i$ to $L_j$ during the $f$-th phase of the $k$-th cycle. In particular, (9) is a linear approximation of the actual variation of $Q_{i,j}$ with $t_{eff}^{i,j}(k)$, where parameter $\Phi_{i,j}$ represents the linear approximation slope and the current traffic scenario [3]. The following equation completes the model by computing the number of vehicles $S_{i,j}^f(k)$ going from link $L_i$ to $L_j$ in the $f$-th phase of the $k$-th cycle:

$$S_{i,j}^f(k) = \min \left\{ \beta_{i,j} \cdot n_i^f(k), \beta_{i,j} \cdot p_{i,j} \cdot Q_{i,j}, N_j - n_i^f(k) + u_{go}^f_j(k) - \sum_{(h,j) \in P_{i,j}} S_{h,j}^f(k) + y_j^f(k) \right\}, \quad (10)$$

with $i \in L, \ j \in L_{out}, \ f = 1, \ldots, F, \ k = 1, \ldots, K$ and $p_{i,j}^f$ representing the state of the traffic lights in $L_i$ during phase $f$ (1 for green and 0 otherwise). In the previous minimum expression the number of vehicles leaving $L_i$ towards $L_j$ comprises three factors, representing respectively: the number of vehicles directed to link $j$ that are in link $i$ at the beginning of the phase; the maximum number of vehicles transmitted to $L_j$ taking into account the finite phase duration as well as the effective time due to precedence constraints; the maximum number of vehicles that $L_j$ may accommodate in its finite capacity in the phase.

Equations (1) to (10) define a closed-form model of the signalized area. The block diagram of the generic link $L_q \in L$ is
depicted in figure 2. In other words, measuring the input variables \( S_{h,i}(k) \), i.e., the number of vehicles going from \( L_h \) to \( L_i \), the urban area model is self-contained. In particular, such a number of vehicles may easily be determined by locating a single passage detector at the stop bar of each lane in the area.

![Figure 2. Block diagram of the generic link \( L_i \in L \).](image)

**COMPUTATION OF QUEUES AND ARRIVALS**

Now, consider a generic urban traffic network including \( I \) links \( L_i \in L \) with a common semaphoric cycle \( C \) and described by equations (1) to (10). We define at time \( \Delta t \) after the beginning of the \( f \)-th phase of the \( k \)-th cycle for each link \( L_i \), the queues \( q^f(k,\Delta t) \) and arrivals \( a^f(k,\Delta t) \) in the link. The queue \( q^f(k,\Delta t) \) is the number of vehicles in \( L_i \) waiting for a green signal when the \( f \)-th phase is red for that link, \( \Delta t \) seconds after the beginning of that phase. Arrivals \( a^f(k,\Delta t) \) are the number of vehicles entering \( L_i \) while the \( f \)-th phase is green or amber for that link, \( \Delta t \) seconds after the beginning of that phase. It should be noted that using the model given by equations (1) to (10) the queues and arrivals in the area may be easily be determined using respectively (1) when \( f \) is a red phase and (2) when \( f \) is a green or amber phase:

\[
q^f_i(k,\Delta t) = \frac{n_i(k)}{C} \Delta t = \frac{n_i(k-1) + u_i(k-1) - y_i(k-1)}{C} \Delta t, \quad k = 1 \ldots K, \quad i = 1 \ldots I, \quad f \text{ is a red phase,} \quad (11)
\]

\[
a^f_i(k,\Delta t) = \frac{u_i(k)}{C} \Delta t = \frac{\sum_{j=1}^F u^f_{ij}(k)}{C} \Delta t, \quad k = 1 \ldots K, \quad i = 1 \ldots I, \quad f \text{ is a green or amber phase.} \quad (12)
\]

Note that in (11) and (12) we assume that in the time interval \( \Delta t \) the flow of vehicles is constant, hence given the modeled queue \( n_i(k) \) or arrival \( u_i(k) \) in the current cycle, with a known duration \( C \), it is possible to compute accordingly the number of vehicles queuing or arriving in link \( L_i \) in \( \Delta t \).

Thus, expressions (11) and (12) may be employed in combination with equations (1) to (10) to determine the queue and arrivals modelling algorithm for the considered signalized area and, in particular, for a given isolated intersection containing \( I \) links.

We remark that expressions (11) and (12) compute the queues and arrivals in the area for a fixed cycle of duration \( C \). Nevertheless, the proposed modelling strategy may easily be employed to model traffic in an urban signalized area with a common signal timing plan of varying duration \( C(k) \). Indeed, it is possible to approximate the current cycle duration in the denominators of equations (11) and (12) by the known duration of the previous cycle \( C(k-1) \).

**FUZZY ADAPTIVE TRAFFIC CONTROL**

In real time traffic signal control of a signalized urban area an adaptive controller adjusts on-line the green phases and cycle times of the signal timing plan, as well as offsets between intersections in the case of area wide control [9]. The objective is to maximize a given performance index. However, a traffic management problem is multi-objective in nature. For instance, reducing a red phase in a traffic network may be advantageous for some branches of an intersection, but it may simultaneously disadvantage other vehicle streams in the same intersection, e.g. saturate the corresponding lanes. In addition, it should be remarked that the inputs to the optimization problem, i.e., the queues and arrivals detected or computed are generally affected by imprecision. Hence, the performance of a conventional traffic control strategy may significantly improve when a fuzzy inference mechanism is introduced in the real time controller, due to the ability of fuzzy control to deal with imprecision and multi-objective tasks.
A major research focus in the field of adaptive traffic signal control has recently been on application of intelligent control techniques, and in particular adaptive fuzzy control strategies. Based on the seminal work of Pappis and Mamdani [10], the most notable traffic signal control techniques adopting fuzzy logic employ the so-called fuzzy extension principle [2, 6, 13, 8, 9]: the fuzzy controller periodically monitors arrivals and queues in the intersection branches and performs a decision whether to terminate or extend the current green phase. Hence, the real time decision objectives are to determine on-line the green phases and the cycle duration based on information on the system state. In the following we employ the control scheme depicted in figure 3. On the basis of information on the current phase, i.e., green or amber for some approaches of the intersection and red for the others, the real time controller determines the queues and arrivals using (11) and (12), i.e., by using the information fed by detectors located by the stop lines. The fuzzy controller processes the current queues and arrivals thus computed first by fuzzyfying the corresponding values and then by linguistically processing by means of an inference engine the fuzzyfied inputs. The fuzzy output is then defuzzyfied and the resulting crisp output is the extension time: if the extension time is equal to zero the current phase is aborted and the next phase in the traffic light cycle is selected, otherwise the current phase is extended for a time equal to the determined extension time. In the sequel for sake of simplicity we adopt the typical choices of a Mamdani-type controller: the selected queues and arrivals membership functions are piecewise linear, the conjunction operator is the minimum t-norm, the implication operator is the minimum or Mamdani implication, the aggregation operator is the maximum t-conorm and the defuzzification method is the well known center of gravity. Moreover, the adopted fuzzy rule base proposed in [10, 9] is reported in Table I, where we denote for sake of simplicity by Q and A the fuzzy controller inputs, namely the queues and arrivals, and by E the fuzzy controller output, i.e., the extension time. We remark that the chosen fuzzy labels of the above input and output variables are as follows:

$$A = \{\text{Zero, Small, Medium, Big}\}$$

$$C = \{\text{Small, Medium, Big}\}$$

$$E = \{\text{Zero, Small, Medium, Big}\}.$$  

In particular, the rule base includes five rule sets, each active a given time interval after the beginning of the current green phase. More precisely, for a given minimum time $T_{\text{min}}$ in the sequel selected equal to 5 s, the adaptive controller is not effective, since it would be counterproductive and even dangerous to change phase just after the beginning of the green phase. After $T_{\text{min}}$ seconds the fuzzy controller is effective and the first subset of rules is active. If during the subsequent fuzzy controller operation the green phase is extended, after the first extension the second subset of rules is active, otherwise the current phase is terminated. The real time controller operation proceeds similarly until the fifth extension, after which the current green phase is terminated.

With reference to the rule base in Table I, we remark that the operators less than ($lt$) and more than ($mt$) are defined as follows [9]. If $A$ is a fuzzy set defined on the real line $R^l = \{x_i\}$, then $\mu_A(x_i)$ is the grade of membership of $x_i$ to $A$. Now, let $x_0$ be the element of $R^l$ such that $\mu_A(x_0)$ is maximum; it holds:

$$\mu_{lt(A)}(x_i) = \begin{cases} 0 & \text{for } x_i \geq x_0 \\ 1 - \mu_A(x_i) & \text{for } x_i < x_0 \end{cases}.$$  

Figure 3. The real-time traffic control scheme.

![Fuzzy Logic Control Scheme](image-url)
Finally, we remark that the strategy proposed in [10] and subsequently extended in the previously cited works may be applied using two alternative strategies. First, all the green phases can be changed in the cycle employing a timing plan with a varying duration. Second, a fixed duration timing plan of length $C$ can be used, i.e. $F-1$ green phases of the cycle vary as chosen by the fuzzy controller and the remaining one is determined at each cycle as the complement to $C$ of the summation of the computed phases, employing no extension for the corresponding branch. The latter strategy is less computationally expensive than the former and may be adopted to control an intersection including a branch that is usually less congested than the others. Moreover, the second strategy is called semi-actuated, since the queues and arrivals in the branch with the $F^{th}$ green phase do not need to be estimated.

Table 1. Rule base of adaptive fuzzy controller

<table>
<thead>
<tr>
<th>Rules set 1 (active after minimum green $T_{\text{min}}$)</th>
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<tbody>
<tr>
<td>If A is Zero then E is Zero</td>
</tr>
<tr>
<td>If A is Small and C is Small than E is Small</td>
</tr>
<tr>
<td>If A is more than Small than E is Medium</td>
</tr>
<tr>
<td>If A is Medium then E is Big</td>
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<table>
<thead>
<tr>
<th>Rules set 2 (active after first extension)</th>
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</thead>
<tbody>
<tr>
<td>If A is Zero then E is Zero</td>
</tr>
<tr>
<td>If A is Small and C is Small than E is Small</td>
</tr>
<tr>
<td>If A is Medium then E is Medium</td>
</tr>
<tr>
<td>If A is Big then E is Big</td>
</tr>
</tbody>
</table>

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<tr>
<th>Rules set 3 (active after second extension)</th>
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</thead>
<tbody>
<tr>
<td>If A is Zero then E is Zero</td>
</tr>
<tr>
<td>If A is Small and C is Small than E is Small</td>
</tr>
<tr>
<td>If A is Medium and C is less than Medium then E is Medium</td>
</tr>
<tr>
<td>If A is Big and C is less than Medium then E is Big</td>
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<thead>
<tr>
<th>Rules set 4 (active after third extension)</th>
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</thead>
<tbody>
<tr>
<td>If A is Zero then E is Zero</td>
</tr>
<tr>
<td>If C is Big then E is Zero</td>
</tr>
<tr>
<td>If A is more than Small and C is Small than E is Small</td>
</tr>
<tr>
<td>If A is Medium and C is less than Medium then E is Medium</td>
</tr>
<tr>
<td>If A is Big and C is less than Small then E is Big</td>
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<table>
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<tr>
<th>Rules set 5 (active after fourth extension)</th>
</tr>
</thead>
<tbody>
<tr>
<td>If A is Zero then E is Zero</td>
</tr>
<tr>
<td>If C is Big then E is Zero</td>
</tr>
<tr>
<td>If A is more than Small and C is Small than E is Small</td>
</tr>
<tr>
<td>If A is Medium and C is less than Small then E is Medium</td>
</tr>
<tr>
<td>If A is Big and C is less than Small then E is Big</td>
</tr>
</tbody>
</table>

CASE STUDY DESCRIPTION AND SIMULATION RESULTS

Figure 4 depicts the schematics of a signalized intersection located in the urban area of Bari (Italy), with severe traffic congestion. In particular, the area is regularly crossed by cars, trucks, public transportation buses and mopeds. Adopting the formalism reported in section II, we model the signalized area in figure 4 with 6 links, including 3 input links ($L_1, L_2, L_3$) and 3 output links ($L_4, L_5, L_6$). The whole area is usually congested in rush hours, with occasional spillback phenomena. In particular, links $L_1$ and $L_2$ are often congested, so that the last vehicles in the queues generally cross the corresponding intersection only after two semaphoric cycles. The capacities of the input links $L_1, L_2$ and $L_3$, expressed in terms of passenger car units (PCUs) are as follows: $c_1=44$, $c_2=5$ and $c_3=22$. Moreover, experimental data show that link $L_2$ is usually less congested than the other signalized links of the junction.

Figures 5 and 6 respectively report the turning movements succession and the fixed signal timing plan currently adopted to control the intersection. We remark that the original cycle length equals $C=105$ seconds. In addition, the signal timing plan comprises five green phases, three amber phases (with fixed duration equal to 4 seconds) and two all-red clearance phases (with fixed duration equal to 2 seconds).
Due to the characteristics of the junction, we adopt the semi-actuated control strategy discussed in the previous section, i.e., we employ a fixed semaphoric cycle of length $C=105$ seconds and let all the green phases of the signalized links in the intersection vary freely, but for the green phase associated to link $L_2$, which is the less congested of the junction. More precisely, the green phase associated to $L_2$ is determined at each cycle as the complement to $C=105$ s of the summation of the computed green phases.

The testing of the adaptive fuzzy control scheme is carried out in the Matlab-Simulink environment based on the model described by equations (1)-(12). Moreover, the introduced fuzzy control algorithm is applied for $K=5$ cycles during the 10 am – 5 pm TOD period. As an example, figure 7 depicts the signal timing plan obtained under the proposed control strategy at the fifth cycle. The figure shows that the adaptive real time controller assigns at the fifth cycle about 8 seconds extension time for the green phase of link 1, a zero extension for the green phase of link 2 (which is not actuated) and an extension with duration of about 10 seconds for the green phase of link 3. In figures 8 and 9 we report the arrivals computed adopting (12) for the input links $L_1$, $L_2$, $L_3$. We remark that at each cycle the maximum number of vehicles in the arrivals are never greater than the corresponding link capacities: the maximum number of arriving vehicles for $L_1$ equals at the fourth cycle about 24 incoming vehicles, which is much lower than $c_1=44$ PCUs; the maximum number of arriving vehicles for $L_2$ equals at the fifth cycle about 4.5 incoming vehicles, which is lower than $c_2=5$ PCUs and the maximum number of arriving vehicles for $L_3$ equals at the fourth cycle about 9 incoming vehicles, which is by far lower than $c_3=22$ PCUs. Hence, the obtained results show the ability of the fuzzy control strategy to contain the vehicle queue lengths in the intersection.

![Figure 4](image4.png)

**Figure 4.** The case study: a real intersection located in the urban area of Bari, Italy.

![Figure 5](image5.png)

**Figure 5.** The turning movements succession for the case study.

<table>
<thead>
<tr>
<th>Time intervals</th>
<th>Link</th>
<th>$i=1$</th>
<th>$i=2$</th>
<th>$i=3$</th>
<th>$i=4$</th>
<th>$i=5$</th>
<th>$i=6$</th>
<th>$i=7$</th>
<th>$i=8$</th>
<th>$i=9$</th>
<th>$i=10$</th>
</tr>
</thead>
</table>

**Figure 6.** Fixed signal timing plan for the case study.
CONCLUSIONS

In this paper the issue of adaptive traffic control is investigated for signalized intersections. A macroscopic model proposed in the related literature is considered to describe traffic in the signalized urban area and to determine a queue/arrivals model. The queue computation algorithm requires only a single passage detector, located at the stop bar of each branch, hence it allows employing a reduced set of sensors, with savings in terms of costs and failure probabilities. An adaptive fuzzy control strategy proposed in related literature is adopted in combination with the queue/arrivals model to determine the signal timing plan. A case study urban intersection located in the city of Bari (Italy) is analyzed. The simulated results show the ability of the real time control strategy to contain the vehicle queue lengths and the traffic congestion in the intersection. The intent is to use the proposed approach in the future to control signalized traffic networks encompassing several junctions.
REFERENCES


