The invention concerns tracking the number of vehicles in a queue using a loop detector (28) installed upstream from the start of the queue (26). Based on the data sensed by the sensor (28), the inflow rate to the queue is estimated and the outflow rate of the queue is also estimated. The number of vehicles in the queue is predicted (60) based on these flow estimates and a previous estimate of the number of vehicles in the queue. The estimated outflow rate also considers the impact of traffic control signals (32). In another aspect the invention estimates (64) the velocity of any vehicles passing the sensor (28) based on the sensor data. Then using this velocity estimate (64), updates 66 the queue length estimate. The use of a single loop detector reduces the costs of having to install video cameras or multiple loop detectors in order to determine a similarly improved estimate. It is able to provide an estimate of the number of vehicles in the queue when the queue is beyond the loop detector and when no vehicle passes over the loop detector. The improved estimate can be used by a traffic control management system so that a traffic signal (32) can be improved. The invention can be seen as a method, software and a computer system.
TRACKING THE NUMBER OF VEHICLES IN A QUEUE

Technical Field
The invention concerns tracking the number of vehicles in a queue. In particular, the invention concerns the tracking of vehicles in a queue that pass over a loop detector installed upstream from the start of the queue. Aspects of the method include methods, computer system, and software.

Background Art
The rapid growth in urban traffic congestion has been recognized as a serious problem in the major cities worldwide. Traffic congestion has significant effects on the economy and environment and causes delays for motorists.

Reducing traffic congestion requires effective and efficient traffic control and management. This will result in improved traffic flow, reliable travel times, fuel savings for motorists, and reduced environmental impact.

Loop detectors are widely used and may be located in the pavement of a road upstream from the start of the queue. Loop detectors are able to detect the presence of a vehicle on the pavement above. Information about detected vehicles is then used to improve the management of the traffic, such as planning road developments and controlling lights at intersections.

A critical task in traffic control and management is to estimate or track the traffic queue length, that is, the number of vehicles in a queue over time. For example, at a signalised intersection, it is necessary to estimate the traffic queue length of each approach in order to adjust the traffic light to optimize or even improve the flow of traffic at the intersection.

Summary of the Invention
In one aspect the invention provides a method of estimating number of vehicles in a queue, where the vehicles in the queue pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:

(a) receiving data from the sensor identifying the presence of a vehicle on the sensor;
(b) based on the received data, estimating an inflow rate to the queue;
(c) estimating an outflow rate of the queue, wherein

   (i) if traffic control signals prevent outflow from the queue, estimating that
       the outflow rate represents no flow, or

   (ii) if no traffic control signals prevent outflow from the queue and a
       previous estimate of the number of vehicles in the queue indicates that there is no
       queue, estimating the outflow rate based on the inflow rate, or

   (ii) if no traffic control signals prevent the outflow from the queue and a
       previous estimate of the number of vehicles in the queue is greater than zero, estimating
       the outflow rate based on a predetermined maximum outflow rate of the queue; and

   (d) predicting the number of vehicles in the queue based on a previous estimate
       of the number of vehicles in the queue, the estimated inflow rate and the estimated
       outflow rate.

It is an advantage of the invention that it is able to provide an improved estimate of the
number of vehicles in the queue using a single loop detector by taking into account the
outflow from the queue. The use of a single loop detector reduces the costs of having to
install video cameras or multiple loop detectors in order to determine a similarly
improved estimate.

The queue may be a queue formed at an intersection or a queue formed to exit or enter
a road. The intersection may be a roundabout. The queue may be one of a plurality of
legs that flow into the intersection from the start of the queue.

The predetermined maximum outflow rate is the saturation flow rate for the queue or
the saturation flow rate on the roundabout.

The method may comprise determining for each leg the flow rate of vehicles leaving
that leg and exiting at each of the other legs. This may be based on historical data.

The method may comprise determining for each segment of the roundabout between
two different legs, the flow rate for that segment.

In relation to step (c) (ii) estimating the outflow rate based on the inflow rate may be
estimating the outflow rate to be the minimum of the inflow rate and the maximum
outflow rate minus the flow rate for a segment that passes that queue.
In relation to step (c) (iii) determining the outflow rate based on the maximum outflow rate of the queue may be estimating the outflow rate to the maximum outflow rate minus the flow rate for a segment that passes that queue.

The method may comprise the step of initially selecting the leg of the roundabout that is least affected by traffic flow on the roundabout and estimating the outflow rate for that leg according to the method described above. The method may further comprise estimating the outflow of each of the remaining legs of the roundabout in series starting from the leg adjacent to the least affected leg and moving in the direction of traffic flow (e.g. clockwise for roundabouts in countries that drive on the left).

In another aspect the invention provides a computer system having an input port to receive the data of step (a) and a processor to perform the method described above. Yet another aspect of the invention is computer executable instructions stored on a computer readable medium that can operate a computer system to perform the method described above.

In a further aspect the invention provides a method of estimating a number of vehicles in a queue, where the vehicles in the queue over time pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:

(a) receiving data from the sensor identifying the presence or absence of a vehicle on the sensor;

(b) based on the received data, predicting the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, an estimate of inflow rate to the queue and an estimate of outflow rate of the queue;

(c) based on the received data, estimating the velocity of any vehicles passing the sensor; and

(d) updating the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles, or based on the absence of vehicles on the sensor.

It is an advantage of the invention that it is able to provide an estimate of the number of vehicles in the queue when the queue is beyond the loop detector and when no vehicle passes over the loop detector. It is a further advantage of the invention that the
improved estimate of the number of vehicles in the queue can be used by a traffic control management system so that a traffic signal can be controlled in an optimized and effective manner. Hence, traffic flow is improved and the average delay for vehicles can be reduced.

The sensor may be a loop detector.

The method may be performed in real time, and step (a) comprises receiving data in real time. Steps (b) to (d) may be iterated to track the number of vehicles in the queue over time, where each iteration relates to a particular time period. The estimate of the number of vehicles in the queue used in step (b) may be based on a previous iteration.

The estimate of the number of vehicles in the queue may be a probability distribution function. It is an advantage of this embodiment that the distribution provides variance in the measure. This enable variable safety margins to be specified in line with the uncertainty.

Step (b) may comprise estimating the inflow rate and the outflow rate, determining the shifted transition probability of the number of vehicles in the queue from the estimate of the previous iteration, and determining the prior probability distribution function.

Estimating the inflow rate may be based on a Kalman filter. For step (b), if the received data indicates that a car is present on the sensor longer than a predetermined period of time, determining the inflow rate based on historical data. If the received data indicates that a car has not passed the sensor for a predetermined period of time, determining that the end of queue has occurred and using the received data to update the inflow estimate. Otherwise, the inflow rate remains the same as the previous estimate.

The outflow rate from the queue may be determined according to the method described above.

The estimation of the velocity of step (c) may be the mean velocity.

The updating of step (d) may be based on Bayes' rule. For step (d), if the estimated velocity is larger than zero and less than the a predetermined maximum, updating the
predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles. If the received data indicates the absence of vehicles on the sensor for a period of time, updating the predicted number of vehicles in the queue to reduce the probability of the queue extending beyond the sensor. If estimated velocity indicates the presence of vehicles for a period of time (i.e. no velocity), updating the predicted number of vehicles in the queue to reduce the probability of the queue ending between the start of the queue and the sensor.

The method may further comprise providing the estimation of the number of vehicles in the queue to a traffic control system. It is an advantage of this embodiment that the improved estimate can be used by a traffic control system so that traffic signals can be controlled in an optimized and effective manner. Hence, traffic flow is improved and the average delay for vehicles can be reduced.

The method above may be performed by two neighbouring queues, such that the average queue length of the neighbouring queues is estimated. In this embodiment, step (b) is repeated for each queue, and step (d) is based on the determined velocities or absence of vehicles for each queue.

In another aspect the invention provides a computer system having an input port to receive the data of step (a) of the method directly above and a processor to perform the method described directly above. Yet another aspect of the invention is computer executable instructions stored on a computer readable medium that can operate a computer system to perform the method described directly above.

It is an advantage of at least one embodiment of the invention that it:
achieves accurate queue length estimation by taking into account inflow and out flow rates as well as the relationship between the queue length and vehicles’ speed
provides queue length estimation even if the queue is beyond the loop detector or no vehicles pass over the loop detector
is applicable for intersection and roundabouts
requires few model parameters
does not rely on camera technology which is not yet developed to a point that it can be robustly applied
helps improve safety as once the length is estimated appropriate action can be taken that will help shorten a long queue. This helps to avoid instances where a queue length reaches to back to fast moving vehicles on a highway or spilling into adjoining lanes
improvement in the efficiency of traffic flow, by allowing green time to be better utilised and avoiding turn-bay queues from blocking traffic through lanes
• using just one upstream sensor, existing infrastructure can be used more effectively and future capital investment and maintenance associated with the sensors is minimised.

Brief Description of the Drawings
An example of the invention will now be described with reference to the accompanying drawings, in which:
   Fig. 1 is a flowchart of the example of the invention;
   Fig. 2 is a schematic diagram of one leg of a roundabout that has a sensor of this example installed;
   Fig. 3 is an example loop signal where the sampling period is \( At = 30ms \);
   Fig. 4 is a schematic diagram of a roundabout at Albion with \( N \) legs, each of which has the approach and exit
   Fig. 5 graphically shows the queue estimated by this example, and compared with the ground truth;
   Fig. 6 graphically shows the average delay per vehicle compared to a system that uses a presence threshold at Albion Park, AM;
   Fig. 7 graphically shows the average delay per vehicle compared to the Sydney a system that uses a presence threshold at Albion park, PM;
   Fig. 8 schematically shows three legs of the roundabout at Albion park used in this example; and
   Fig. 9 is a lookup table that is used in this example to express the combination of segments that define the various outflow rates.

Best Modes of the Invention
This example relates to the use of the invention at an intersection, in this case a roundabout. One leg 20 of a roundabout is schematically shown in Fig. 2. The leg 20 has a single lane 22 approach and a single lane exit 24. A queue of vehicles can accumulate on the lane 22 starting at the start of the approach 26. A sensor 28, such as
a loop sensor, is installed some distance from the start of the queue 26. The number of vehicles in the lane 22 is determined by both current traffic flow on the roundabout 30 and a traffic control signal, such as a traffic control light 32.

The sensor 28 is able to detect the presence of a vehicle on the sensor, and the duration of that presence. Information from the sensor 28 is received by a computer system 40 at an input port. In this example, the data received by the sensor 28 is transmitted wirelessly and in real time. This transmission can be made using a local area network (LAN) or a wide area network (WAN) such as the internet and the input port of the computer system 40 is provided by its connection to that network. The server 40 is part of a traffic management system that is able to control the traffic control signals 32 again by sending control information in real time and wirelessly to the traffic control lights. The computer system 40 receives 58 information from the sensor information on each of the legs of the roundabout (not shown) over time. The processor executes pre-installed software to perform the method described here of estimating the number of vehicles in the queue at each leg approach (i.e. queue length). The estimate is a probability distribution of queue length. Based on the estimated queue lengths the processor of the computer server 40 determines optimal traffic control signals that will help traffic move through the intersection. These optimal traffic signals are then sent from the computer system 40 using the same connection to the network that is an input/output port. As will be appreciated by a person skilled in the art, there are a number of computer network designs that will enable the tracking of the queue length. For example, each sensor 28 may have an associated computer system that calculates the estimate and provides it to a central server that then controls the traffic control lights.

The method of tracking the queue length will now be described with reference to the flow chart of Fig. 1.

Formulation
To define the queue length tracking problem, we consider the evolution of the state sequence of queue length \( \{x_k, k = 1, 2, \cdots, K\} \) given by a system model

\[
x_k = g(x_{k-1}, v_{k-1})
\]

where \( g(\cdot) \) is a function of the state \( x_{k-1} \) and \( v_{k-1} \) is the process noise. The objective of tracking is to recursively estimate \( x_k \) from observation data or measurements. The observation model is represented as
\[ z_k = h(x_k, w_k) \tag{2} \]

where \( h(\cdot) \) is a function of the state \( x_k \) and \( w_k \) is the measurement noise. From Bayesian perspective, queue length tracking is to recursively calculate some degree of belief in the state \( x_k \) at time \( k \) given the observation data or measurement \( z_{tk} \) up to time \( k \). Thus, it is required to construct the probability density function (pdf) \( p(x_k | z_{1:k}) \) that can be obtained recursively in two stages: prediction and update.

Suppose that the required pdf \( p(x_{k-1} | z_{1:k-1}) \) at time \( k-1 \) is available. The prediction stage 60 involves using the process model (1) to obtain the prior pdf of the state \( x_k \) at time \( k \) as follows:

\[
P(x_k | z_{1:k-1}) = \sum_{x_{k-1}} P(x_k | z_{1:k-1}, x_{k-1})P(x_{k-1} | z_{1:k-1}) \tag{3} \]

In the update stage 66, the measurement \( z_k \) at time \( k \) is used to update the prior via Bayes' rule:

\[
P(x_k | z_{1:k}) = \frac{VP(z_k | x_k)P(x_k | z_{1:k-1})}{\eta} \tag{4} \]

where \( \eta = p(z_k \setminus z_{1:k-1}) \) is the normalization constant.

### System and observation models

The formulation of queue length tracking is based on the system model in (1) and observation model in (2). In the system model, the state of queue length \( x_k \) is the number of vehicles in the queue at time \( k \) and it is related to the state \( x_{k-1} \) as well as the inflow rate \( f_{k-1}^i \) and outflow rate \( f_{k-1}^o \) at time \( k - 1 \). That is 60,

\[
x_k = x_{k-1} + f_{k-1}^i - f_{k-1}^o + v_{k-1} \tag{5} \]

The estimation of the inflow rate and outflow rate is set out in detail further below.

We use the mean vehicle velocity \( V_{mean} \), which is estimated from loop detector signal 64, as the observation data or measurement \( z_k \) at each time instant. Here we present a method for estimating 64 mean velocity from loop detector signal. The typical measurements from loop detector signal over time are vehicle count (VC), occupancy (O), velocity (V), and vehicle length (L). The relationship between them can be described as:

\[
o = \frac{1}{T} \sum_{t=1}^{n} \psi \frac{L_{t+1} - L_{t}}{V_t} \tag{6} \]

where \( L_{loop} \) is the length of loop detector and \( T \) is the duration of the measurement. In the update stage of queue length tracking, we assume that the velocity is constant in \( T \) and the mean vehicle length \( L_{mean} \) is computed from historical data. Hence, we have
\[ O = \frac{V C L_{loop} + L_{mean}}{T} V_{mean} \]

and the mean velocity \( V_{mean} \) can be written as

**Error! Objects cannot be created from editing field codes.**  \( (6) \)

This assumes one loop-detector is in place for that lane and the velocity is estimated based on the occupancy time of a vehicle on the loop. That is, the smaller the occupancy time the faster the vehicle is assumed to be travelling. The variance of this estimate is dependent on vehicle length. Since we do not know the vehicle length, the measurement variance can be high.

An alternative method for estimating the mean vehicle velocity takes advantage of the fact that loop-detectors are usually constructed as two loops. It is possible to physically separate the two loops and receive as input the sensor data from each loop separately, hence a "split-loop". This improves the estimate of velocity by measuring the time-interval between the activation of each loop as the front of a vehicle passes over the split-loop, or the time-interval between deactivation of each loop as the rear of a vehicle passes over the split-loop. The velocity \( V \) is now measured as

\[ V = \frac{\text{distance}}{\text{time interval}} \]

where \( \text{distance} \) is the distance between the start of each loop for activation and the distance between the end of the two loops for deactivation. The variance in this method is reduced (and the accuracy improved) because this method of measuring speed is not dependent on vehicle length (L).

The observation model in (2) relates the state of queue length \( x_k \) to the measurement \( z_k \).

**Queue length tracking**

We now describe the details of queue length tracking based on the above discussion.

It is assumed that \( x_{\text{max}} \) is the maximum number of vehicles in the queue. The state transition probability of the queue length \( p(x_k | X_{k-1}) \) in (3) can be expressed as:
where the parameter $\alpha$ controls the transition probability $p(x_k | x_{k-1})$. Considering the inflow rate $f_{k-1}^I$ and outflow rate $f_{k-1}^O$ in (5), the actual transition probability $p(x_k | x_{k-1})$ is shifted by $f_{k-1}^O - f_{k-1}^I$ toward the origin for $x_k$. Since the inflow rate and outflow rate usually are not integers, linear interpolation is employed during the shift of the transition probability.

As the observation model cannot be expressed analytically, the likelihood $p(z_k | x_k)$ in (4) is computed using an offline learning process. Specifically, we use a traffic simulator (e.g., Paramics) to generate a lookup table that describes the relationship between the number of vehicles in the queue and the mean velocity of vehicles which are passing over the loop detector 66. Using this lookup table, $p(z_k | x_k)$ in (4) can be directly obtained based on the measurement $z_k$ at time $k$. Therefore, the update stage in (4) can be calculated as follows:

$$P(x_k | z_k) = \eta P(z_k | x_k) P(x_k | u_{t-i}) = r_i P(z_k | x_k) \sum_{\eta=1}^{u_{t-i}} P(x_k | u_{t-i}) P(x_k | z_k)$$

Initially, $p(x_0)$ is set to be a flat distribution so that $p(x_0 | z_0) = \frac{1}{X_{mn}}$.

The proposed approach to queue length tracking can be briefly described as follows:

**Prediction stage 60:**
- Calculate the inflow rate $f_{k-1}^I$ and outflow rate $f_{k-1}^O$;
- Calculate the shifted transition probability of the queue length $p(x_k | x_{k-1})$ using (7);

**Update stage 66:**
- Calculate the prior pdf of the state $x_k$, i.e., $p(x_k | z_{t-1})$, using (3);
- Estimate the mean velocity $z_k$ based on the loop detector signal (6) 64;
- Calculate $p(z_k | x_k)$ as follows:
  - If the velocity of a vehicle $z_k$ is larger than zero and less than the maximum speed limit, $p(z_k | x_k)$ is calculated using a lookup table based on the measurement $z_k$;
  - If the received data from the loop detector indicates the absence of vehicles for a period of time, $p(z_k | x_k)$ is formed so that the probability of the queue beyond the loop detector is low.
If the received data from the loop detector indicates the presence of stationary vehicles from a period of time, \( p(z_k \setminus x_k) \) is formed so that the probability of the queue within the range between the stop line and the loop detector is low. Calculate \( p(x_k \mid z_{vk}) \) using (8);

**Multiple lanes**

The queue length tracking described above is only for an individual lane with a single loop detector. As for two neighbouring lanes of the same road, we consider the correlation between them. The states of queue length for two neighbouring lanes at time \( k \) are represented by \( x^1_k \) and \( x^2_k \), respectively. The corresponding measurements of velocity are represented by \( z^1_k \) and \( z^2_k \), respectively. Since there exists the correlation between two neighbouring lanes, the queue length formed on one lane may be close to that on the other lane. Instead of modelling the queue length for each lane individually, we estimate the average queue length \( x_k = (x^1_k + x^2_k)/2 \). Therefore, the posterior \( p(x_k \mid z_{vk}) \) can be computed as

\[
P(x_k \mid z_{vk}) \approx \eta P(z^1_k \mid x_k)P(z^2_k \mid x_k) \sum_{l=0}^{N} P(x_k \mid z^{l-1}_k)P(z^l_k \mid x_k)
\]

where \( z_k = (z^1_k, z^2_k) \). We can see that the main difference is the computation of \( p(z_k \mid x_k) \) by comparison with the queue length tracking for a single lane. That is, \( p(z_k \mid x_k) \) is factorized into \( p(z^1_k \mid x_k)p(z^2_k \mid x_k) \).

As queue length tracker involves inflow rate and outflow rate, next we will describe how to estimate them.

The inflow rate estimation is based on Kalman filter that can be directly derived from the formulation presented above. By denoting \( f_k \) and \( c_k \) be the state of inflow rate and the measurement of average vehicle count, respectively, the system and observation model can be written as

\[
f'_k = A_k f'_{k-1} + u_{k-1} \quad (10)
\]

\[
c_k = B_k f'_k + w_k \quad (11)
\]

where \( A_k \) and \( B_k \) represent the state transition matrix and observation matrix, respectively. We assume that the system noise \( u_k \) and the observation noise \( w_k \) are white Gaussian noise with corresponding covariance:

\[
E(u \cdot u^T) = Q, \quad (12)
\]

\[
E(w \cdot w^T) = R, \quad (13)
\]
Let $P$ be the covariance matrix of state estimate. Kalman filter involves two major steps: (i) prediction and (ii) update. That is,

**Prediction:**

\[
F_{k} = F_{k-1} - \hat{C}_{k}^{-1} \hat{B}_{k} P_{k-1} \hat{B}_{k}^{T} + Q_{k-1}^{-1}
\]

\[
P_{k|k-1} = A_{k} P_{k-1|k-1} A_{k}^{T} + Q_{k-1}
\]

**Update:**

\[
F'_{k|k} = F_{k|k-1} + K_{k} \left[ C_{k} - B_{k} F_{k|k-1} \right]
\]

\[
P_{k|k} = \left( I - K_{k} B_{k} \right) P_{k|k-1} \left( I - K_{k} B_{k} \right)^{T} + K_{k} R_{k} K_{k}^{T}
\]

where $K_{k}$ is the Kalman gain matrix and can be calculated as follows:

\[
K_{k} = P_{k|k-1} B_{k}^{T} \left( B_{k} P_{k|k-1} B_{k}^{T} + R_{k} \right)^{-1}
\]

Now we consider using EoQ and long queue detection to determine if update is needed or not. Basically, if a long queue occurs, the estimate of inflow rate is updated by using the historical information, e.g., the inflow rate calculated one or two days ago. The estimation algorithm is summarized as follows:

*Step 1*: Set the state transition matrix $A_{k} \rightarrow$ and the observation matrix $B_{k} \rightarrow 1$;

*Step 2*: Initialize covariance matrices of the system and observation noise $Q$ and $R$;

*Step 3*: Perform initial state estimate and calculate $P$ using the first observation;

*Step 4*: Perform prediction for the state and covariance using (14) and (15);

*Step 5*: If EoQ occurs and EoQ(t)-EoQ(t-1) > $A T_{e}$, count the number of vehicles using the trailing edges of rectangles of loop signal, compute Kalman gain using (18), and perform update for the state estimate and covariance using (16) and (17) based on the new observation;

*Step 6*: If EoQ does not occur while long queue occurs, compute Kalman gain using (18), perform update for the state estimate and covariance using (16) and (17) based on the historical information;

*Step 7*: If both EoQ and long queue do not occur, no update is performed;

*Step 8*: Record the estimate of inflow rate;

*Step 9*: Go to Step 4.

**Outflow rate estimation**

The outflow rate estimation is to estimate the flow rate at which vehicles enter a roundabout or an intersection from the approach. Our algorithm for outflow rate estimation is based on decision trees.
We firstly consider a roundabout with $N$ legs, each of which consists of the approach and exit. Both the approach and exit can be a single lane or multiple lanes (see Figure 2). The approach of each leg is controlled by a traffic signal. If the traffic signal is red for the approach of a leg, all the vehicles on it must stop. Otherwise, they are free to enter the roundabout but they have to obey the rule of giving way. It is assumed that there is a leg assigned to be leg 1 if its outflow is not influenced by the traffic on the roundabout coming from other legs. In other words, the traffic flows from other legs that bypass leg 1 are almost zero.

Now we can define the turn ratio $r(j \mid i)$ as the percentage of the total number of vehicles that leave the roundabout at the exit of leg $j$, among those that enter the roundabout at the approach of leg $i$. We have $\sum_{j=1}^{N} r(j \mid i) = 1$. In practice, the turn ratio can be obtained from historical data. We further define the maximum flow rate of a roundabout $f_{\max}$ as the saturation flow rate on the roundabout. It is assumed that $f_{\max}$ is a constant anywhere on the roundabout regardless of legs and is identical to the saturation outflow rate of any incoming approaches. Finally, we define the segment flow rate $f_{ij}^{s}$ as the actual flow rate on the segment $(i,j)$ of the roundabout between leg $i$ and leg $j$, where $j - i = 2$ (see Figure 2). For example, the segment flow rate from leg 2 to leg 4, $f_{24}^{s}$, is the sum of the outflow rates from leg 1 and leg 2 to leg $k$ ($k = 4, 5, \ldots, N$). In general, the segment flow rate $f_{ij}^{s}$ can be computed as

$$f_{ij}^{s} = \sum_{k=1}^{i-1} \sum_{m=j}^{N} f_{k}^{s} r(m \mid k) + f_{j}^{s} \sum_{k=j}^{N} r(k \mid i)$$

Now we describe our outflow rate estimation algorithm for a roundabout. The outflow rate of the leg $f_{j}^{o}$, $f_{j}^{o}$, is related to the traffic signal, the maximum flow rate $f_{\max}$, the segment flow rate $f_{1,1+j+1}^{s}$, the inflow rate $f_{j}^{i}\backslash$, and the state of the queue length $q_{j}$. Obviously, if the traffic signal is red for the approach of leg $j$, the outflow rate $f_{j}^{o}$ is zero 60(i). If the traffic signal is green and the state of the queue length is almost zero, the outflow rate $f_{j}^{o}$ is limited by the segment flow rate $f_{j-1,1+j+1}^{s}$ as vehicles have to give way 60(H). Hence, the actual outflow rate $f_{j}^{o}$ is bounded by $f_{\max} - J_{1,1+j+1}^{s}$ As leg 1 is not influenced by other legs, the outflow rate of leg 1, $f_{1}^{o}$, is equal to the inflow rate $f_{1}^{i}$ if the state of queue length is almost zero. Otherwise, $f_{1}^{o}$, is equal to the maximum
flow rate of the roundabout $l_{mX}$ 60(iii). In general, the outflow rate of leg $j$ can be calculated as follows:

$$f_j^o = \begin{cases} 0, \text{ if } \text{Light}(j) = \text{Red} \\
\min(l, l_{mX} - f_j^{i-1} - t_{j-1}), \text{ if } \text{Light}(j) = \text{Green} & q_j > 0 \\
\text{max}(l, f_j^{i-1} - t_{j-1}), \text{ if } \text{Light}(j) = \text{Red} & q_j = 0 
\end{cases}$$  \hspace{1cm} (20)

In order to calculate $l^o$, the value for $l$ is needed. To calculate $f_j^o$, the values of $f_j^{i-1}$ and $l^o$ are required. Generally speaking, the calculation of $f^o$ requires the previous calculated values of $l_p, l_2, \ldots, f^o_{-1}$.

It is noted that the algorithm presented above is directly applicable to outflow rate estimation at an intersection by ignoring the segment flow rate. The outflow rate of an approach at an intersection is related to the traffic signal, the maximum flow rate, the inflow rate, and the state of the queue length. Based on the above analysis, if the turn ratio is known, the outflow rate can be obtained using decision trees.

**Outflow rate estimation in Albion Park project**

The example above was applied to simulate the traffic control for the roundabout at Albion Park, New South Wales, Australia, see Fig. 4. The northern and western approaches have one loop detector separately. The southern approach has two loop detectors and each of them is for an individual lane. Therefore, there are four loop detectors in total. The distance between loop detector and stop-line for each approach ranges from 70 meters to 150 meters. Our queue length tracker takes into account four loop detectors and outputs the probabilistic distribution of queue length.

Referring now to Fig. 8, traffic signals are setup at point A and B on this roundabout to control the traffic from the North and South. There is no traffic signal for the western approach. According to observation, this roundabout has the following characteristics:

The majority of the traffic coming from North goes to West
The majority of the traffic coming from South goes to North
The majority of the traffic coming from West goes to North

In addition, the main conflicts at the roundabout are:
Traffic coming from South in conflict with traffic coming from North, the later takes precedence.
Traffic coming from West in conflict with traffic coming from South, the later takes precedence.

The outflow rate of the northern approach. As seen from Fig. 8, the majority of vehicles from the North enter the roundabout at point A, pass through point B, and eventually leave the roundabout at point C. If the traffic signal at point A is red, the outflow rate is zero. When it is green, vehicles from the North block the vehicles coming from the South that enter the roundabout at point B. That is because vehicles coming from the South have to give way. Therefore, to determine the outflow of point B, we need to consider the outflow rate \( f'(North) \) at point A. It is obvious that as the outflow rate at point A increases, the outflow rate at point B must decrease. Here we define the maximum flow rate of the roundabout \( f_{max} \) that represents the maximum numbers of vehicles that can pass a point on the roundabout. We assume that \( f_{max} \) is a constant anywhere on the roundabout regardless of legs. Bounded by \( f_{max} \), the outflow rate \( f^o(North) \) of the northern approach can be determined as

\[
f^o(North) = \begin{cases} 0, & \text{if } \text{Light}(North) = \text{Red} \\ f'(North), & \text{if } \text{Light}(North) \neq \text{Red} & \text{and } f'(North) < f_{max} & \text{and } q(North) = 0 \\ f_{max}, & \text{otherwise} \end{cases}
\]

The outflow rate of the southern approach \( f^o(South) \) can be obtained similarly. The vehicles entering the roundabout at point B are only constrained by the traffic flow entering the roundabout at point A. Once these vehicles are already on the roundabout, they will block the traffic from the West. In addition, \( f^o(South) \) is affected by the traffic density on the common roundabout segment. That is, the less vehicles travel from the North to the West, the more vehicles enter the roundabout from the South, and vice versa. Because the roundabout segment BC (see Fig. 8) is shared by the vehicles from both the North and the South, we must ensure that the sum of the inflow rate from the South and the flow rate on the roundabout segment AB is \( f_{max} \). Hence, the outflow rate \( f^o(South) \) of the southern approach can be computed as

\[
P^o(South) = \begin{cases} 0, & \text{if } \text{Light}(South) = \text{Red} \\ \min(P^o(South), \max(f_{max} - f^o(North), 0)), & \text{otherwise} \end{cases}
\]
Since there is no traffic signal for the western approach, its outflow rate $f^\circ(\text{West})$ depends only on the traffic flow rate on the roundabout segment CD, which is equivalent to the actual outflow rate of the southern approach. The outflow rate $f^\circ(\text{West})$ can be determined as

$$f^\circ(\text{West}) = \min(f^\circ(\text{West}), \max(f_{\text{max}}^\circ f^\circ(\text{South}), 0))$$

From the above analysis, we can see that the outflow rate $f^\circ(\text{North})$ is a function of its inflow rate $f^\circ(\text{North})$. The outflow rate $f^\circ(\text{South})$ is a function of both $f^\circ(\text{North})$ and $f^\circ(\text{South})$. The outflow rate $f^\circ(\text{West})$ is a function of both $f^\circ(\text{South})$ and $f^\circ(\text{West})$. Such analysis leads us to a lookup table approach. We divide the range of the possible inflow rates into numerous segments and calculate the outflow rates with respect to all the combination of these segments of inflow rates. The lookup table can be expressed as shown in Fig. 9.

**Results**

Fig. 5 depicts the comparison of estimated queue length (lighter-coloured curve) and the ground truth (darker-coloured curve) for the northern approach. The horizontal and vertical axes represent simulation time and queue length, respectively. We can see that the pattern of estimated queue length is consistent with that of the ground truth.

The queue length estimation produced is provided to a traffic controller to control the traffic from the northern and southern approaches. We use the average delay per vehicle (ADV) to measure the performance. For comparison purposes, we compute the ADV when using a traffic controller that uses a presence threshold. We performed 30 runs of simulations. Fig. 6 and Fig. 7 show the comparison of ADV in terms of different time period, i.e., AM and PM. The light coloured line represents the presence threshold controller and the larger line shows the controller based on this example of the invention. It is seen that our queue length tracker improves the performance of traffic controller so that the ADV is smaller.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the scope of the invention as broadly described.

The invention can be applied to turning bays, lighted intersections, roundabouts and freeway on or off ramps. In the example of ramps, the ramps may be installed with
control lights that regulate traffic flow entering motorways with the queue length as a consideration

It should be understood that the techniques of the present invention might be implemented using a variety of technologies. For example, the methods described herein may be implemented by a series of computer executable instructions residing on a suitable computer readable medium. Suitable computer readable media may include volatile (e.g. RAM) and/or non-volatile (e.g. ROM, disk) memory, carrier waves and transmission media (e.g. copper wire, coaxial cable, fibre optic media). Exemplary carrier waves may take the form of electrical, electromagnetic or optical signals conveying digital data steams along a local network or a publically accessible network such as the internet.

It should also be understood that, unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "estimating" or "updating" or "predicting", or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that processes and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.
CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of estimating number of vehicles in a queue, where the vehicles in the queue pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:
   (a) receiving data from the sensor identifying the presence of a vehicle on the sensor;
   (b) based on the received data, estimating an inflow rate to the queue;
   (c) estimating an outflow rate of the queue, wherein
      (i) if traffic control signals prevent outflow from the queue, estimating that the outflow rate represents no flow, or
      (ii) if no traffic control signals prevent outflow from the queue and a previous estimate of the number of vehicles in the queue indicates that there is no queue, estimating the outflow rate based on the inflow rate, or
      (ii) if no traffic control signals prevent the outflow from the queue and a previous estimate of the number of vehicles in the queue is greater than zero, estimating the outflow rate based on a predetermined maximum outflow rate of the queue; and
   (d) predicting the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, the estimated inflow rate and the estimated outflow rate.

2. The method of claim 1, wherein the queue is one of a plurality of legs that flow into an intersection from the start of the queue and the method further comprises determining for each leg the flow rate of vehicles leaving that leg and exiting the intersection at each of the other legs.

3. The method according to claim 2, wherein the method further comprises for each segment of the roundabout between two different legs, the flow rate for that segment.

4. The method according to any one of the preceding claims, wherein step (c) (ii) of estimating the outflow rate based on the inflow rate comprises estimating the outflow rate to be the minimum of the inflow rate and the maximum outflow rate minus the flow rate for a segment that passes that queue.

5. The method according to any one of the preceding claims, wherein step (c) (iii) of determining the outflow rate based on the maximum outflow rate of the queue
comprises estimating the outflow rate to the maximum outflow rate minus the flow rate for a segment that passes that queue.

6. The method according to any one of claims 4 to 7, wherein the method comprises the step of initially selecting the leg of the roundabout that is least affected by traffic flow on the roundabout and estimating the outflow rate for that leg according to the method described above, estimating the outflow of each of the remaining legs of the roundabout in series starting from the leg adjacent to the least affected leg and moving in the direction of traffic flow.

7. A computer system having an input port to receive the data of step (a) of claim 1 and a processor to perform the method according to any one of the preceding claims.

8. Software being computer executable instructions stored on a computer readable medium that when executed causes a computer system to perform the remainder of the method according to any one of claims 1 to 6.

9. A method of estimating a number of vehicles in a queue, where the vehicles in the queue over time pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:

   (a) receiving data from the sensor identifying the presence or absence of a vehicle on the sensor;

   (b) based on the received data, predicting the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, an estimate of inflow rate to the queue and an estimate of outflow rate of the queue;

   (c) based on the received data, estimating the velocity of any vehicles passing the sensor; and

   (d) updating the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles, or based on the absence of vehicles on the sensor.

10. The method according to claim 9, wherein the method is performed in real time, and step (a) comprises receiving data in real time, and steps (b) to (d) are iterated to track the number of vehicles in the queue over time, where each iteration relates to a particular time period and data received in that time period.
11. The method according to claim 9 or 10, wherein the estimate of the number of vehicles in the queue used in step (b) is based on a previous iteration.

12. The method according to any one of claims 9 to 11, wherein the estimate of the number of vehicles in the queue is a probability distribution function, and step (b) comprises estimating the inflow rate and the outflow rate, determining the shifted transition probability of the number of vehicles in the queue from the estimate of the previous iteration, and determining the prior probability distribution function.

13. The method according to any one of claims 9 to 12, wherein estimating the inflow rate may be based on a Kalman filter.

14. The method according to any one of claims 9 to 13 and limited by 10, wherein for step (b):
   if the received data indicates that a car is present on the sensor longer than a predetermined period of time, determining the inflow rate based on historical data;
   if the received data indicates that a car has not passed the sensor for a predetermined period of time, determining that the end of queue has occurred and using the received data to update the inflow estimate; or
   otherwise, the inflow rate remains the same as the previous estimate.

15. A method according to any one of claims 9 to 14, wherein the outflow rate from the queue is estimated based on:
   (i) if traffic control signals prevent outflow from the queue, estimating that the outflow rate represents no flow, or
   (ii) if no traffic control signals prevent outflow from the queue and a previous estimate of the number of vehicles in the queue indicates that there is no queue, estimating the outflow rate based on the inflow rate, or
   (ii) if no traffic control signals prevent the outflow from the queue and a previous estimate of the number of vehicles in the queue is greater than zero, estimating the outflow rate based on a predetermined maximum outflow rate of the queue;

16. A method according to any one of claims 9 to 15, wherein the updating of step (d) is based on Bayes' rule.
17. A method according to any one of claims 9 to 16, wherein for step (d):
   if the estimated velocity is larger than zero and less than the a predetermined maximum, updating the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles;
   if the received data indicates the absence of vehicles on the sensor for a period of time, updating the predicted number of vehicles in the queue to reduce the probability of the queue extending beyond the sensor; or
   if estimated velocity indicates the presence of vehicles for a period of time, updating the predicted number of vehicles in the queue to reduce the probability of the queue ending between the start of the queue and the sensor.

18. A method according to any one of claims 9 to 17, wherein the method further comprises providing the estimation of the number of vehicles in the queue to a traffic control system.

19. A method according to any one of claims 9 to 18, wherein the method is performed by two neighbouring queues, such that the average queue length of the neighbouring queues is estimated.

20. A computer system having an input port to receive the data of step (a) of claim 9 and a processor to perform the remainder of the method according to any one of claims 9 to 19.

21. Software being computer executable instructions stored on a computer readable medium that when executed causes a computer system to perform the method according to any one of claims 9 to 19.
CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of estimating number of vehicles in a queue, where the vehicles in the queue pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:
   (a) receiving data from the sensor identifying the presence of a vehicle on the sensor;
   (b) based on the received data, estimating an inflow rate to the queue;
   (c) estimating an outflow rate of the queue, wherein
      (i) if traffic control signals prevent outflow from the queue, estimating that the outflow rate represents no flow, or
      (ii) if no traffic control signals prevent outflow from the queue and a previous estimate of the number of vehicles in the queue indicates that there is no queue, estimating the outflow rate based on the inflow rate, or
      (iii) if no traffic control signals prevent the outflow from the queue and a previous estimate of the number of vehicles in the queue is greater than zero, estimating the outflow rate based on a predetermined maximum outflow rate of the queue; and
   (d) predicting the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, the estimated inflow rate and the estimated outflow rate.

2. The method of claim 1, wherein the queue is one of a plurality of legs that flow into an intersection from the start of the queue and the method further comprises determining for each leg the flow rate of vehicles leaving that leg and exiting the intersection at each of the other legs.

3. The method according to claim 2, wherein the method further comprises for each segment of the roundabout between two different legs, the flow rate for that segment.

4. The method according to any one of the preceding claims, wherein step (c) (ii) of estimating the outflow rate based on the inflow rate comprises estimating the outflow rate to be the minimum of the inflow rate and the maximum outflow rate minus the flow rate for a segment that passes that queue.

5. The method according to any one of the preceding claims, wherein step (c) (iii) of determining the outflow rate based on the maximum outflow rate of the queue
comprises estimating the outflow rate to the maximum outflow rate minus the flow rate for a segment that passes that queue.

6. The method according to any one of claims 4 to 7, wherein the method comprises the step of initially selecting the leg of the roundabout that is least affected by traffic flow on the roundabout and estimating the outflow rate for that leg according to the method described above, estimating the outflow of each of the remaining legs of the roundabout in series starting from the leg adjacent to the least affected leg and moving in the direction of traffic flow.

7. A computer system having an input port to receive the data of step (a) of claim 1 and a processor to perform the method according to any one of the preceding claims.

8. Software being computer executable instructions stored on a computer readable medium that when executed causes a computer system to perform the remainder of the method according to any one of claims 1 to 6.

9. A method of estimating a number of vehicles in a queue, where the vehicles in the queue over time pass over a sensor installed upstream from the start of the queue, the method comprising the steps of:
   (a) receiving data from the sensor identifying the presence or absence of a vehicle on the sensor;
   (b) based on the received data, predicting the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, an estimate of inflow rate to the queue and an estimate of outflow rate of the queue;
   (c) based on the received data, estimating the velocity of any vehicles passing the sensor; and
   (d) updating the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles, or based on the absence of vehicles on the sensor.

10. The method according to claim 9, wherein the method is performed in real time, and step (a) comprises receiving data in real time, and steps (b) to (d) are iterated to track the number of vehicles in the queue over time, where each iteration relates to a particular time period and data received in that time period.
11. The method according to claim 9 or 10, wherein the estimate of the number of vehicles in the queue used in step (b) is based on a previous iteration.

12. The method according to any one of claims 9 to 11, wherein the estimate of the number of vehicles in the queue is a probability distribution function, and step (b) comprises estimating the inflow rate and the outflow rate, determining the shifted transition probability of the number of vehicles in the queue from the estimate of the previous iteration, and determining the prior probability distribution function.

13. The method according to any one of claims 9 to 12, wherein estimating the inflow rate may be based on a Kalman filter.

14. The method according to any one of claims 9 to 13 and limited by claim 10, wherein for step (b):
   if the received data indicates that a car is present on the sensor longer than a predetermined period of time, determining the inflow rate based on historical data;
   if the received data indicates that a car has not passed the sensor for a predetermined period of time, determining that the end of queue has occurred and using the received data to update the inflow estimate; or
   otherwise, the inflow rate remains the same as the previous estimate.

15. A method according to any one of claims 9 to 14, wherein the outflow rate from the queue is estimated based on:
   (i) if traffic control signals prevent outflow from the queue, estimating that the outflow rate represents no flow, or
   (ii) if no traffic control signals prevent outflow from the queue and a previous estimate of the number of vehicles in the queue indicates that there is no queue, estimating the outflow rate based on the inflow rate, or
   (iii) if no traffic control signals prevent the outflow from the queue and a previous estimate of the number of vehicles in the queue is greater than zero, estimating the outflow rate based on a predetermined maximum outflow rate of the queue;

16. A method according to any one of claims 9 to 15, wherein the updating of step (d) is based on Bayes' rule.
17. A method according to any one of claims 9 to 16, wherein for step (d):
   if the estimated velocity is larger than zero and less than the a predetermined maximum, updating the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the estimated velocity of the vehicles;
   if the received data indicates the absence of vehicles on the sensor for a period of time, updating the predicted number of vehicles in the queue to reduce the probability of the queue extending beyond the sensor; or
   if estimated velocity indicates the presence of vehicles for a period of time, updating the predicted number of vehicles in the queue to reduce the probability of the queue ending between the start of the queue and the sensor.

18. A method according to any one of claims 9 to 17, wherein the method further comprises providing the estimation of the number of vehicles in the queue to a traffic control system.

19. A method according to any one of claims 9 to 18, wherein the method is performed by two neighbouring queues, such that the average queue length of the neighbouring queues is estimated.

20. A computer system having an input port to receive the data of step (a) of claim 9 and a processor to perform the remainder of the method according to any one of claims 9 to 19.

21. Software being computer executable instructions stored on a computer readable medium that when executed causes a computer system to perform the method according to any one of claims 9 to 19.
receiving data from the sensor identifying the presence or absence of a vehicle on the sensor

based on the received data, **predicting** the number of vehicles in the queue based on a previous estimate of the number of vehicles in the queue, an estimate of inflow rate to the queue and an estimate of outflow rate to the queue. In relation to estimating the outflow rate:

(i) if traffic control signals prevent outflow from the queue, estimating that the outflow rate represents no flow, or

(ii) if no traffic control signals prevent outflow from the queue and a previous estimate of the number of vehicles in the queue indicates that there is no queue, estimating the outflow rate based on the inflow rate, or

(iii) if no traffic control signals preventing the outflow from the queue and a previous estimate of the number of vehicles in the queue is greater than zero, estimating the outflow rate based on a predetermined maximum flow rate of the queue

based on the received data, estimating the velocity of any vehicles passing sensor

**updating** the predicted number of vehicles in the queue based on a predetermined relationship between the predicted number of vehicles in the queue and the determined velocity of the vehicles or the absence of vehicles on the sensor

Fig. 1
Fig. 3
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Fig. 9
**INTERNATIONAL SEARCH REPORT**

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According to International Patent Classification (IPC) or to both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPDOC, WIPO, ESPACE, USPTO, Google, Google Patents. Search terms: vehicle, car, number, rate, flow, velocity, traffic, queue, estimate, predict, calculate, intersection, junction, round about, sensor, loop detector, control, signal, and other similar terms.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>US 6, 470, 262 B2 (KERNER et al) 22 October 2002</td>
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<td>See for example abstract, claims 1-3, and Figure 1.</td>
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<td>See for example abstract, paragraphs [0003]-[0005] and [0045]-[0093], Figure 4.</td>
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Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
  "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search: 19 November 2009

Date of mailing of the international search report: 25 NOV 2009

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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX