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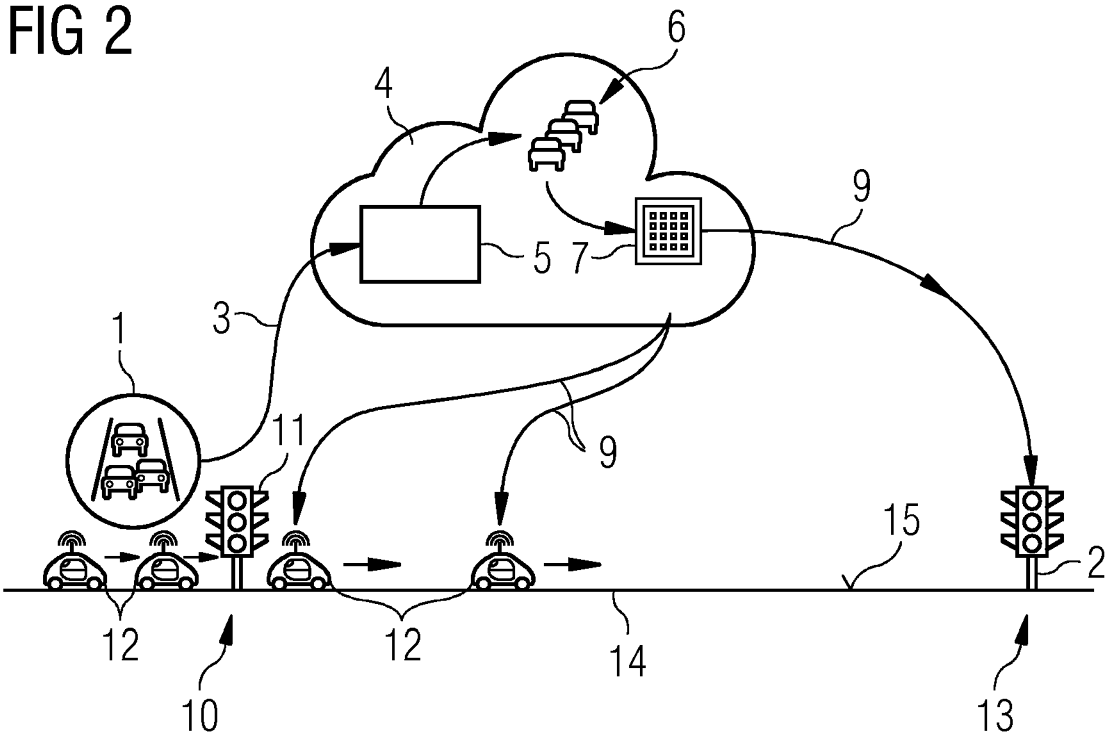
(71) Applicant: **Siemens Mobility GmbH**
81739 München (DE)

(72) Inventor: **HELMY, Noorhan**
11341 Cairo (EG)

(54) **METHOD FOR GENERATING A TRAFFIC CONTROL SIGNAL**

(57) Computer-implemented method for generating a traffic control signal for controlling a traffic approaching a traffic light, wherein at least one vehicle is detected at a first time at a first position of the road upstream the traffic light, wherein a prediction model predicts based on the detected first time a second time at which the vehicle will reach a second position, wherein the second position is closer at the traffic light than the first position, wherein the traffic control signal is generated considering the predicted second time.

FIG 2



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Description

[0001] The invention refers to a computer-implemented method for generating a traffic control signal for controlling a traffic approaching to a traffic light, a traffic controller for generating a traffic control signal, a processing unit and a computer readable memory.

[0002] It is known in the state of the art to detect the approaching of a vehicle with a detector which is located at a predetermined distance from a traffic light. The detector signal is delivered to a traffic controller. The traffic controller switches the light of the traffic light depending on the signal of the detector. In the case of state-of-the-art 'actuated' or 'adaptive' control methods, approaching vehicles are detected with detectors placed at, and right before, the entrance of an intersection, to measure the volume of vehicles at each direction of flow and generate an optimized traffic light schedule accordingly.

[0003] The aim of such a system is to minimize a global travel time of the vehicle and to minimize the fuel consumption of the vehicle at a signalized intersection. Furthermore, it is known in the state of the art to generate depending on the detector signal a green light optimal speed advice and an information about a time to green/red for a driver system of a vehicles. The global travel times for vehicles and fuel consumption are reduced at signalized intersections, by facilitating the use of green light optimal speed advice (GLOSA) and time-to-green/red (T2G/R) information. With actuated or adaptive controllers, the control output fluctuates with vehicle arrivals. Vehicles must first arrive at an intersection for the detectors to read them, and the controller to update its schedule accordingly. This results in similarly fluctuating GLOSA and T2G/R information, which causes user distrust in the reliability of the information.

[0004] It is an object of the proposed method, of the proposed traffic controller and of the method of calculating a control signal to improve the traffic flow which means for example to reduce a global travel time of the vehicles and to reduce a fuel consumption of the vehicles passing an intersection, whereby a traffic light is located at the intersection controlling the traffic passing the intersection.

[0005] The object of the invention is attained by the independent claims.

[0006] A computer-implemented method for generating a traffic control signal for controlling a traffic approaching to a traffic light is proposed. A first position of at least one vehicle is detected at a first time. The first position is located upstream on a road to the traffic light. Based on the detected first time the prediction model predicts at which second time the vehicle will reach a second position. The second position is located closer at the traffic light than the first position. The predicted arrival of the vehicle at the second time is used as a virtual detector information by a controller. Based on the virtual detector information a traffic control signal is generated. The second time may be a time interval of about some seconds.

[0007] In an embodiment, several vehicles are detected during a first time interval passing a first position of the road upstream the traffic light. The prediction model predicts based on the detected vehicles how many vehicles will arrive during a second time interval at a second position. The second position is closer at the traffic light than the first position. The traffic control signal is generated considering the predicted number of vehicles which will arrive the second position during the second time interval.

[0008] The invention refers to a computer-implemented method for generating traffic flow arrivals based on measured traffic flow departures; and using this generated traffic to trigger detector detectors in a simulated environment. This allows for traffic control programs to run their optimization in advance and generate a traffic signal output early. Using this information, valuable information can be provided to road users on upcoming traffic signals and how to approach them with the highest fuel efficiency.

[0009] The proposed method overcomes the obstacles of the state of the art by generating traffic arrivals in advance to trigger control fluctuations in advance, and therefore provide reliable advice to vehicles without having to change anything about the traffic control behaviour road driver of the vehicles are accustomed to and/or without having to change the installed detector infrastructure. For example, the new method can be used without changing a traffic control program providing GLOSA and/or T2G/R information.

[0010] A basic idea of the proposed method is to detect a traffic flow at the first position during a first time interval. The first position may be located hundreds of meters upstream from the traffic light. The prediction model predicts based on the detected number of vehicles during the first time interval at the first position how many vehicles will reach during a second time interval the second position. Depending on the used embodiment, the prediction model may be a simple model using a predetermined average speed of the vehicle to calculate the second time at which the vehicle will reach the second position under the assumption that the vehicle moves from the first position to the second position with the predetermined average speed.

[0011] However, the prediction model can also be more sophisticated and may be for example embodied as a neural network which is trained to determine more precisely the second time at which the vehicle reaches the second position.

[0012] The detection may be performed by a detector which is located on the road or which is located beside the road and which is able to detect several vehicles at the first position. The detector may be an electrical detector or an optical detector, for example a camera.

[0013] The information about the time at which the vehicles will arrive at the second position is available earlier than the arrival of the vehicle at the second position. Therefore, the controller can earlier determine the traffic control signal based on the predicted flow of the vehicles. The controller may be embodied as a controller which uses usually a signal of a detector. In this embodiment, the predicted arrival of the vehicles during the second time or second time interval can be used as virtual detector information. Therefore, it is not necessary to provide a further real detector at the second position. Since the traffic control signal is earlier available, the controlling of the traffic which means the controlling of single vehicles or platoons of vehicles can be improved.

[0014] The proposed method allows to convert currently deployed controllers from adaptive controllers to predictive controllers. Per simulating a virtual detector signal, according to short-term traffic flow arrival predictions, and feeding them to the controller, its outputs can be elicited earlier. For example, the proposed method can be used as a traffic flow prediction methodology proposed to measure vehicle platoon departures from upstream of the intersection for example by using stop line detectors as detectors at the first position. This information can be used to estimate the arrival of the same vehicle platoon flow profile at a next signalized intersection on its path which means at the next traffic light of the next intersection.

[0015] For example, an average travel time of a vehicle between an upstream intersection and a downstream intersection may range from 20 seconds to 35 seconds on average. By using this prediction horizon, the controller or a service provider which may process the early controller output into useful in-vehicle information will also have 20 to 35 sec foresight on upcoming traffic light controller outputs, allowing for a more precise and stable green light optimal speed advice (GLOSA) and/or a more precise time to green/red switch (T2G/R). Furthermore, the early information about the predicted arrival of the vehicle or the predicted arrival of a vehicle platoon at the second location can be used to improve and to assure an optimized outputting of traffic light phase states on-street; since the first detector may be located on the road at a distance about 400 m to 600 m upstream to the traffic light of an intersection.

[0016] The used controllers may be predictive controllers and/or adaptive controllers. In one embodiment, the controller delivers the traffic control signal to the vehicles. The traffic control signal may comprise an information about an optimum speed to reduce the travel time of the vehicle passing the intersection with the traffic light and/or an information how to reduce the fuel consumption of the vehicle passing the intersection with the traffic light. For example, the traffic control signal may be a green light optimal speed advice (GLOSA) and/or an information about a time to green/red switch of the traffic light (T2G/R).

[0017] Depending on the used embodiment, there might also be other technical information delivered by the controller to the vehicles. The vehicles comprise a receiver which allows to receive the traffic control signal of the controller. According to the proposed method, it is possible to deliver the traffic control signal earlier to the vehicles since the virtual detector information at the second position is predicted earlier than the vehicles arrive indeed at the second position. This long foresight allows an improved information for the vehicles.

[0018] In a further embodiment, the traffic control signal is used for controlling the traffic light. This means that the light phase states of the traffic light can be changed and/or can be optimized depending on the traffic control signal considering the predicted second times at which the vehicles will reach the second position. Since this information is available very early, the long foresight can be used to adjust the phase states of the traffic lights earlier.

[0019] In a further embodiment, the prediction model predicts a third time at which the vehicle will reach a third position. The third position is located closer at the traffic light than the second position. The predicted third time provides a further information about the moving of the vehicle which is at least important if a vehicle platoon disperses or backs up. The third position may be for example at a position at which usually a long loop detector is located. The proposed method allows to dispense the long loop detector upstream of an intersection with a traffic light. Furthermore, the predicted third time may be considered by the controller for determining the traffic control signal for the vehicles and/or for the traffic lights.

[0020] In a further embodiment, the model makes a secondary prediction of what the traffic state is likely to be at the intersection when the platoon arrives. The model takes into consideration whether it is likely the intersection will have a queue due to a red light or due to congestion. If it predicts that a long loop detector will be occupied, that means there is a queue at the intersection. Accordingly, it will predict that the arriving platoon will have to slow down earlier to accommodate for that queue and hence will arrive at a later time and rate.

[0021] The traffic control signal may be an information for vehicles, wherein the traffic control signal comprises an information how fast the vehicle should move to have a green light at the time the vehicle reaches the traffic light signal. The traffic control signal may have the information about a duration of a green wave or a red wave of the traffic light.

[0022] Furthermore, the traffic control signal is a light control signal for the traffic light. The traffic control signal can be used to influence or to control a time during which the traffic light is displaying a green light

[0023] The prediction model may consider a vehicle platoon's flow profile and for example a flow of vehicles driving on different tracks of the road upstream the traffic light in direction to the traffic light. Furthermore, the prediction model may consider a spreading of the vehicle platoon and/or a backing up of the vehicles. Therefore, considering the different tracks individually and/or the spreading and/or the backing up it is possible to more precisely predict the second time.

[0024] Depending on the used embodiment, the controller may influence or control a phase cycle state of the traffic light depending on the second time. Therefore, it is possible to reduce the travel time of a vehicle passing the traffic light and/or to reduce the fuel consumption of the vehicle passing the traffic light.

[0025] In a further embodiment, a second detector is located at the second position of the road, wherein the second detector detects a real arrival time of the at least one vehicle during the second time interval. The second position is located closer at the traffic light than the first position. The detected real arrival time of the vehicle which means the detected number of vehicles during the second time interval is delivered to the controller. The controller compares the predicted arrival time of the vehicles with the real arrival time of the vehicles.

[0026] Depending on the used embodiment, not only the real arrival time of the vehicles is compared with the predicted arrival time but also the real detected number of vehicles is compared with the predicted number of vehicles using the second detector. Also, this comparison can be used to adapt and to improve the prediction model. The arrival time may be a time interval of about some seconds for example. Furthermore, the arrival of several vehicles may be detected within predetermined time intervals. The actual measurements are taken as feedback to adapt parameters of the prediction model and to improve future predictions.

[0027] A traffic controller is proposed, wherein the controller is embodied to receive a predicted virtual detector information. The virtual detector information is based on a detected first position of a vehicle on a road upstream to a traffic light. This means that the vehicle is moving toward the traffic light which is arranged for example at an intersection. The predicted virtual detector information is predicted by a prediction model based on the detected vehicle as an arrival time of the vehicle at the second position. The second position is located closer at the traffic light than the first position. The controller is embodied to calculate based on the virtual detector information a traffic control signal. The detector is embodied to deliver the traffic control signal to vehicles and/or to traffic light signals.

[0028] As discussed above, one advantage of the proposed traffic controller is that it uses a predicted arrival time of a vehicle as a virtual detector information. The prediction of the arrival time is available very early compared to the arrival of the vehicle at the second position. Therefore, the traffic controller has more time to use this information for determining a traffic control signal and to deliver the traffic control signal to vehicles and/or to a traffic light. Therefore, the vehicles and/or the traffic light get very early information which might be functional. For example, a driver of the vehicle may reduce or increase the speed of the vehicle to reach a green light of the traffic light considering the traffic control signal. Furthermore, depending on the used embodiment, the vehicle may use the traffic control signal to control the speed of the vehicle automatically. Furthermore, the traffic light may change a phase state to improve the flow of the vehicles. The change of the phase state may be for example extending a green light or moving the time for the green light to another time slot.

[0029] Furthermore, a processing unit is disclosed which is embodied to perform the computer-implemented.

[0030] Furthermore, a computer-readable memory is proposed which has computer-executable instructions adapted to cause the computer to perform the computer-implemented method.

[0031] The proposed features, properties and advantages of the proposed methods and the proposed controller are more clearly described according to the following examples and embodiments, wherein

FIG 1 shows a schematic drawing of a traffic control system,

FIG 2 shows a schematic drawing of a further embodiment of a traffic control system,

FIG 3 shows a schematic drawing of an intersection with detectors upstream to a traffic light,

FIG 4 shows in a schematic drawing a visualization of a predictive control proposal,

FIG 5 shows an example of a NARX network architecture,

FIG 6 shows a schematic view of a further embodiment of a traffic control system,

FIG 7 shows a schematic drawing of a vehicle platoon on a road with several tracks in front of an intersection, and

FIG 8 shows the vehicle platoon of FIG 7 at a later state.

[0032] FIG 1 shows a schematic view of a traffic control system with a first detector 1 which detects the arrival of a vehicle upstream a traffic light 2 which is driving towards the traffic light 2. The vehicle may be a car, a bus, a truck, a motorcycle, a bike or other vehicles. The traffic light may be in a simple embodiment a system with a light or a sign which stops the vehicle or allows a passing by of the vehicle by showing different lights or signs. The sign may be an optical sign, an acoustic sign or any other information. Furthermore, the traffic light may have a controller which is for example embodied as a computer with a control program which controls at least one traffic light or a system of traffic lights. The control program is embodied to consider traffic information. The traffic light may comprise at least one light group for example with three lights with different colours, for example with a red light, a yellow light and a green light. The traffic light may have two or more light groups for controlling traffic of different lanes of a road or for controlling the traffic driving in different directions. The controller may be an adaptive controller.

[0033] The proposed method may be designed for adaptive controllers i.e. to upgrade the controller to a predictive controller without changing the adaptive control program installed by only manipulating inputs from live to predicted inputs. The proposed method may be used in a predictive controller for example by assisting or replacing a prediction model included in the predictive controller, wherein the prediction model may use a neural network.

[0034] The traffic light 2 may be arranged at a road junction, a road intersection or any other place, where a controlling of traffic is useful. The traffic light 2 is used for controlling the flow of vehicles driving on a road in the direction to the traffic light 2.

[0035] The first detector 1 detects a vehicle and sends the information that the vehicle is passing the first detector 1 at a first time as a first information 3 to a processing unit 4 which may be part of a controller or may be independent of the controller. The processing unit 4 is embodied to execute a prediction model 5. The prediction model 5 receives the first information and predicts based on the first information a second time at which the vehicle will pass a second position of the road, wherein the second position is located closer at the traffic light 2. The prediction model 5 may use instead of a first time and a second time a first time interval and a second time interval. Therefore, the prediction model may take in vehicle counts (i.e. volumes) within a certain time interval (e.g. 5 seconds) from the upstream detector, and then predicts the volume of vehicles arriving, within this same time interval (e.g. 5 seconds), after a certain prediction horizon e.g. after 30s, if that's how long it takes on average to reach the downstream intersection.

[0036] The prediction model 5 is embodied to calculate depending on the first information 3 of the first detector 1 which is a traffic information for example the first time at which the vehicle passes or departs the first position of the first detector 1. The first information may also comprise measured speed of the vehicle at the first position. Furthermore, the first information may comprise first times for several vehicles which pass the first position.

[0037] The prediction model may be a simple model which calculates based for example on a predetermined speed of the vehicle and the knowledge of the distance between the first position of the first detector and a second position a second time which it will take for the vehicle to reach the second position. Depending on the used embodiment however, the prediction model may use highly sophisticated methods for calculating the second time.

[0038] The prediction model may use instead of first times and second times first time intervals and second time intervals. The prediction model may for example predict how many vehicles are expected to arrive at a certain second time interval at the second position. For example: at time stamp 0, which could be the first time interval from 0-5s, 5 vehicles were detected exiting the upstream intersection. If they all were traveling at the same speed and if it takes, on average, 30s for a vehicle to arrive to the second position i.e. downstream intersection point then at time stamp 6, which would therefore be the second time interval from time 25-30s, 5 vehicles should be detected arriving downstream as well. However, this may not always be the case. Due to platoon dispersion, which may occur as a result of different driving speeds, lane changes, congestion, etc., for example only 2 vehicles might be detected arriving at the second position downstream within the second time interval at time stamp 6.

[0039] Furthermore, the model may be configured to determine a combination between departure and arrival patterns for different traffic conditions and different intersection configurations, to be able to estimate how vehicles progress from one position to the next, and therefore be able to estimate the number of vehicle arrivals (i.e. the volume of vehicles) for each time stamp.

[0040] For example, the prediction model 5 may use a short-term traffic flow prediction model that is robust to different traffic condition and lane configurations of the road. The prediction model may for example be embodied as a neural network for example a recurrent neural network. The neural network has for example be trained with thousands of real traffic situations passing the traffic light for the road intersection at which the traffic light is located. Furthermore, it is useful to use a prediction model which is programmed to predict a behaviour of a vehicle platoon which means a group of vehicles driving to the traffic light. For example, the prediction model is programmed and trained for predicting a flow rate of a vehicle platoon at a second position based on vehicle platoon flow measurements at an upstream first position. For example, the prediction model is programmed as a traffic flow progression model. In a further embodiment, the prediction model forecasts how a detected vehicle platoon will move in both space and time.

[0041] Furthermore, the prediction model is programmes to predict depending on detected traffic conditions a vehicle platoon dispersion on a road with several lanes and at a junction or intersection. There are two dimensions to platoon dispersion. The lateral dimension, which refers to the split of the vehicle platoon amongst different traffic streams at an intersection, and longitudinal, which refers to the spread of vehicle headways in a platoon, due to varying driver speeds. The lateral platoon dispersion depends on the different movement directions and speeds of the vehicles in a platoon, which are estimated using probability distributions of origin-destination pairs. The lateral spread of vehicles impacts longitudinal dispersion, which is a function of vehicle interactions, road way geometries, road side activities, different driving habits, downstream signal states, and other impedances to the flow of traffic. Due to these disturbances, flows released from upstream intersection stop lines in type platoons, with short-time headways, spread out at seemingly stochastic rates.

[0042] Accordingly, longitudinal dispersion is a focus of traffic flow progression modelling, and lateral dispersion is included as a model input parameter or as an extension of the model. There are different prediction models known which describe a traffic flow progression of a vehicle platoon. One example of such a prediction model is described by Qiao, F., et al., 2001, "Intelligent simulation and prediction of traffic flow dispersion", Transportation Research Part B: Methodological, page 843-863. This prediction model uses a neural network which is specifically trained to attain a high accuracy to predict arrival flows at a certain prediction horizon.

[0043] According to our experiments, it has been shown that a NARXNET can be used for a neural network for traffic flow modelling. The NARXNET can be described by the following basic equation.

[0044] The general equation for the NARXNET, defined based on the concluded configuration to be used for the neural network is the following:

$$q_{aj}(t+i) = f(q_{aj}(t-n), p_j(t-n), c_j(t-n), o_m(t-n), q_{dy}(t-r), tod(t), dow(t))$$

m = 1, ... , l
n = 0 , ... , 5
r = 0,..., x
y = 1,..., k

Where:
$q_{aj}(t+i)$ = The predicted arrival flow at the downstream intersection, at traffic stream "j", at time "t".

- i = the average number of time steps it takes for a platoon of vehicles to travel from the upstream intersection to the downstream intersection, which is derived from the travel time to travel between both intersections at 80% of the free flow speed.
- n = number of time steps into the past for the downstream intersection. Only five time-steps of memory were found to be needed for the model to detect a pattern of downstream arrivals.
- j = index of the downstream flow direction (or traffic stream) being predicted.
- m = downstream lane index number for flow direction (or traffic stream) "j".
- l = the total number of downstream lanes.
- p_j =percentage contribution of flow headed towards the lane in question (i.e. lane "j").
- c_j = the downstream controller's external phase cycle (WUC) applicable to lane "j" at the time step in question (i.e. the color displayed to the vehicles at time stamp "(t - n)").
- o_j = the long loop detector occupancy on the lane in question (i.e. lane "j") included as a binary value, where "1" means the loop detector is occupied and "0" means unoccupied at time stamp "(t - n)".
- q_{dy} = the measured departure flows from the upstream intersection at lane "y".
- r = number of time steps into the past for the upstream intersection.
- x = the number of time steps it takes for a vehicle traveling at 20km/h, which is the assumed lower limit for speed, to travel from the upstream intersection to the downstream intersection.
- y = upstream lane index number.
- k = the total number of upstream lanes.
- *tod* = time of day.
- *dow* = day of week.

[0045] The following is a description of an example for a training and adaption of the prediction model.

- Back propagation is used for learning.
- The loss function used is the mean-squared error (MSE).
- The activation function used is the tan-sigmoid function.
- The training function used for weight/bias optimization is the Levenberg-Marquardt (L-M) function.
- The method used to prevent over-fitting of the model is early stopping. After six iterations within which the model's ability to predict the validation dataset does not improve, the model stops training.
- The final output layer of the neural network contains linear transfer functions, which output the weighted sum + bias of their inputs.
- The data division is as follows: 60% is used for training, 20% for validation and 20% for testing.

- The length of the prediction horizon is the average travel time it takes to travel between two successive intersections, which is derived from the distance between the intersections and 80% of the free flow speed between them.

[0046] The final neural network architecture may be designed to be pretty scalable to different types of intersection configurations. So long as the needed inputs and outputs are available, the network parameters can be easily adapted to a new intersection. The following process can be followed for using the proposed neural network at a new intersection:

- Set the Number of Input Nodes to the number of upstream stop line detectors that are on lanes supporting traffic streams heading towards the direction of the target, case study intersection. Each input node must be connected to one of these relevant upstream stop line detectors to receive input from its detector count logging.

- There may be three different outputs of a prediction model. One main output and three supporting outputs, as per the multi-task learning feature of this model. The main output is the traffic flow arrivals at the far away loop detectors, while the supporting outputs are the detector occupancies of the long loop detectors, the percentage contribution of flow to the traffic stream and the external (WUS) output of the traffic light controller. While evaluations for the accuracy of supporting outputs was not made, their effect on the main output's performance was monitored and was found to be positive.

[0047] Traffic flow arrivals (main task): number of output nodes is equal to the number of far away loops associated with the target traffic stream the neural network is attempting to predict.
[0048] Turning percentages: this output is dependent on a calculation that must be made online on how much percentage of flow is going to the different traffic streams of a certain side of an intersection, after the lane expansion point. For this secondary prediction task, one output node is needed.
[0049] Controller phase cycle state (WUS): A single output node is needed for this secondary prediction task, as only one signal head controls each traffic stream. This output node is connected to the live v-log logging of the target controller.
[0050] O Long loop detectors: The number of nodes for this final secondary output correspond to the number of long loop detectors there are for the target traffic stream. The number of long loop detectors usually directly corresponds to the number of lanes supporting a particular traffic stream. These nodes are connected to the long loop detectors to evaluate detector occupancy.
[0051] With regards to the number of memory nodes included, a standard 4-5 nodes of memory are defined for the feedback loops from the outputs, while the number of memory cells needed for inputs corresponds to the extra time steps needed for vehicles traveling at the lower bound speed limit of 20 km/h to arrive to the target intersection.
[0052] The defined prediction horizon is the time it takes for vehicles to travel from one intersection to the next at free flow speed, which can be taken as 80% of the speed limit.
[0053] The size of the modelling time step can be defined as per the preference of the user, although the smaller the time steps are, the less accurate the model's performance is. Accordingly, very simple calibrations needed to different intersections, which are basically to define the correct prediction horizon, number of memory cells and the modelling time step desired. This is significantly more simple and user friendly than the computationally intensive calibration process needed to optimize the parameters of other known predictions models as for example the Robertson's prediction model.
[0054] An advantage of this traffic flow progression methodology is that validation checks on the model's performance are fed back into the prediction model itself, rather than just to the predictive controller. That means that this model received inputs from the actual conditions downstream, and is able to, accordingly, better adapt its predictions to these conditions. More importantly though, when long queues propagate backwards, past the far away loop detector, this traffic state will be recognized by the prediction model itself, and as part of the adaptive characteristic of the neural network, it is able to adjust its predictions to this state. This can be seen by the very significant improvements made to the RMSE for long queue conditions of directions, which experience this traffic state. Accordingly, a predictive controller operating on this model will not need to identify a long queue such as this as a "system failure" and resort to the fail-safe control method. This is concurred by the fact that under no conditions, including when the intersection sides were saturated, was there an experienced system failure in the form of a queue spill back,
without the use of corrective measures. This results in a secondary advantage, which is that the model is more flexible to far away loop detector placements. With this system however, loop detectors can be placed closer to the stop line, as is with the case of many already installed adaptive controllers (i.e. detectors are placed 80 - 100m from the stop line), with less severe reproductions to a predictive controller's functionality. Lastly, the calibration of this prediction model is much less computationally intensive than the model used in state-of-the-art predictive controllers, making it more user friendly.
[0055] The proposed prediction model is based on a NARXNET neural network that may have the following features: The number of input nodes corresponds to the number of first detectors which are for example upstream stop line detectors at upstream traffic lights. The first detectors are located on lanes supporting traffic streams heading towards

the direction of the traffic light. Each input node of the neural network should be connected to one of these relevant upstream detectors to receive input from its detector count logging. A main output of the used model is the traffic flow arrivals at a second position which corresponds for example with a position of the far away loop detector. A further information which is predicted by the model is whether a long loop detector will be occupied or not at a prediction horizon of the model. The predicted second time may correspond to a time of occupancy of the second detector which may correspond to the long loop detector.

[0056] A further output of the model may be the percentage contribution of flow to the traffic stream and the external output of the traffic light controller. The number of output nodes of the neural network may be identical to the number of the virtual detectors (far away loop detectors). A further interesting output of the model is the information about the percentage of vehicles which really reach the second position. Also, for this information at least one output node should be used. Depending on the traffic situation, some vehicles may stop, leave or turn between the first and the second position. With regards to vehicles exiting or entering a road link through an undetected side street, the model may be able to consider the probability of either case happening when making its prediction. This is possible since, by the nature of a neural network, flow in does not necessarily equal flow out, which is a limiting constraint of analytical prediction models.

[0057] Furthermore, depending on the used embodiment, also a third detector (long loop detector) is used. If the third detector is used, then for each third detector a node of the neural network should be provided. The number of the second and/or the third detectors usually directly corresponds with the number of lanes supporting that particular traffic stream in direction to the traffic light. With regard to the number of memory nodes included, a standard 4 - 5 nodes of memory are defined for the feedback loops from their outputs, while the number of memory cells needed for inputs corresponds to the extra time steps needed for vehicles travelling at the lower bound speed limit of for example 20 km/h to arrive the target intersection which means the traffic light.

[0058] A predefined prediction horizon is the time it takes for vehicles to travel from an intersection to the next which means from the first position to the traffic light at a free flow speed, which can be taken as 80% of the speed limit. The size of the modelling time step can be defined as per the preference of the user, the smaller the time steps are, the less accurate the models performance is. However, with smaller time steps, less time is allocated to flow measurement, and therefore a longer time horizon is available to give relevant driver assistance information to the first vehicle of a platoon before it arrives to the downstream intersection.

[0059] The second information 6 which may comprise the second time at which the vehicle will reach the second position is delivered to a traffic controller 7. The second information 6 is for example a predicted volume of vehicles within a certain time stamp. This information is translated to a number of detector pulses within that time stamp used to trigger the virtual detectors.

[0060] Depending on the used embodiment, the second information 6 may also be delivered to a central processing unit 8. Furthermore, early control outputs may be sent from the traffic controller 7 to the central processing unit 8.

[0061] The traffic controller 7 is embodied to receive the second information 6 as a virtual detector information. The traffic controller 7 is embodied to determine based on the virtual detector information a traffic control signal 9. The traffic control signal 9 may be delivered to vehicles or may be used to control the traffic light 2. The traffic controller may be embodied as an adaptive controller.

[0062] Depending on the used prediction model, the prediction model predicts a third time at which the vehicle will reach a third position. The third position is closer at the traffic light than the second position. For example, the third position may be the position at which usually long loop detectors are located. Therefore, the second information may comprise additionally to the second time also a third time which refers to an arrival of the vehicle at a third position. The more information the traffic controller 7 receives from the prediction model, the better is the traffic control signal. Instead or additional to the third time, the model predicts whether there will be a queue covering the long loop detectors or not at a certain prediction horizon as it will affect the behaviour of the platoon arrival at the intersection.

[0063] The traffic control signal may be an information for the vehicles, wherein the traffic control signal comprises the information how fast the vehicle should drive to have a green light at the time the vehicle reaches the traffic light.

[0064] In a further embodiment, the traffic control signal is a light control signal for the traffic light. The traffic controller 7 may influence or control the traffic light function, wherein for example the traffic controller 7 controls with the traffic control signal the time and/or the time phase at which the traffic light is displaying a green light.

[0065] Depending on the used embodiment, the prediction model considers a flow of vehicles on different lanes of the road upstream of the traffic light in direction to the traffic light. For this embodiment, there are several first detectors which are arranged on the different lanes and which detect the arrival or the passing of vehicles at the first position of the first detectors.

[0066] In a further embodiment, the prediction model considers a group of vehicles which means a platoon of vehicles, wherein the prediction model predicts the moving of the platoon of vehicles towards the second and/or the third position in direction to the traffic light. Considering the moving or dispersion of a platoon of vehicles increases the accuracy of the times at which the vehicles pass the second and/or the third position.

[0067] In a further embodiment, the traffic controller 7 controls a phase cycle state of a light group of the traffic light to improve the flow of the vehicles depending on the second information 6 which is delivered from the prediction model to the traffic controller 7.

[0068] The traffic control signal 9 may be embodied as a green/red (T2G/R) information or a green light optimal speed advice (GLOSA) which is delivered by the traffic controller 7 to the vehicles. Furthermore, the prediction model 5 may deliver the second information 6 to the central processing unit 8. The central processing unit 8 may be located far away from the position of the traffic light 2. The central processing unit 8 may also be embodied to determine based on the second information 6 the same traffic control signal 9 as the traffic controller 7. The central processing unit 8 may also be embodied to deliver the traffic control signal 9 to the vehicles and/or to the traffic light 2.

[0069] The traffic controller 7 and/or the central processing unit 8 may be embodied to store the traffic control signal 9 and to control the function of the traffic light 2 at the time at which the vehicles will reach the traffic light 2. Depending on the traffic control signal 9 the traffic light 2 will display signal lights to control the passing of the vehicles.

[0070] The traffic controller 7 is therefore embodied to receive a predicted virtual detector information, wherein the virtual detector information is based on a detected first position of a vehicle on the road upstream to the traffic light. The first position may correspond to a position of a stop detector of an upstream traffic light. The second position may be a position at which usually a far away loop detector is located upstream to the traffic light. The second position is nearer at the traffic light than the first position. The traffic controller is embodied to deliver the traffic control signal to the vehicles and/or to a traffic light.

[0071] The traffic controller may be an actuated controller. This type of controller optimizes its schedule online, in response to detected vehicle counts in real time. The controller may be embodied as an adaptive controller. The proposed method may be used to upgrade the adaptive controller to a predictive controller without changing the hardware.

[0072] Half-fixed, actuated and adaptive traffic control strategies are all variations of this type of controller with the difference between them lying in their level of adaptability to arriving and departing flows of vehicles. Half-fixed controllers output a minimum green time that rotates in a cycle, then extend the green cycle for a certain signal group of the traffic light if traffic has been detected at a related traffic stream, to clear a queue.

[0073] Alternatively, both actuated and adaptive controllers can reshuffle their signal groups to give the non-conflicting traffic streams with the most pressing demands for green a green phase as soon as possible. A basic difference between an actuated and an adaptive controller then is that an adaptive controller takes in an extra input through the existence of a far away loop which allows it to further extend its green time if needed to account for incoming traffic.

[0074] In a further embodiment, the controller may be embodied as a predictive controller. The predictive controller has a line of vision which extends much further back than an adaptive controller, in both space and time, allowing it to anticipate short-term traffic flow arrivals within a certain prediction horizon before the actual arrival times. By knowing what the future demands will be on all its traffic streams, this type of controller is capable further optimizing its schedules.

[0075] Accordingly, when several predictive controllers exist in a network, it is possible to create network optimized control strategies using the prediction abilities of the controllers for flow movements. However, these control strategies are additionally highly complex as they must include highly sophisticated validation and fail-safe processes to overcome the unreliability of short-term traffic flow prediction modelling under certain traffic conditions.

[0076] The traffic light comprises a signal group which is a set of traffic light heads that output identical traffic light indications for example colours to permit the simultaneous flow of non-conflicting traffic streams within an intersection and accordingly prevent the flows from conflicting traffic streams to avoid collisions of vehicles at the intersection.

[0077] The proposed method may be used to improve the function of an adaptive traffic controllers. An advantage of the proposed method is that the output of the adaptive controller's schedule is received early enough for the operational use of a traffic control information for the vehicles which is for example a green light optimal speed advice (GLOSA) and/or a time to green/red (T2G/R) driver system information without having to change anything about the control logic of the adaptive controller.

[0078] Since fluctuations of the traffic in an adaptive controller schedule are a response to traffic flow arrivals and departures, traffic movements along an intersection can be forecasted early and distributed along detectors in a simulation environment of the isolated intersection in question. The traffic flow predictions will be in the short-term, by forecasting the progression of traffic from an upstream to downstream intersection. For example, by using detected inputs from a stop line detector of the directly upstream intersection, a prediction model can be used to forecast how vehicles will arrive at a nearer point for example at a far away loop detector of the target intersection. Through simulation modelling, the predicted vehicles at the far away loop detector can be distributed out over the remaining detectors, triggering them, and therefore the controller, for an output. Hence, the form of inputs the controller will take will remain the exact same, then with the difference being that the detector triggers will be predicted and simulated in a virtual space. The actual arrival flows measured by a second detector for example by a far away loop detector at the target intersection, can be used to calibrate that prediction model and later to verify that prediction accuracies as well.

[0079] The traffic controller takes the input from the simulated virtual detector and begins to respond as it normally does, providing fluctuating outputs until the controller decides to end a green phase and switch to a new traffic stream. With short-term traffic arrival flow predictions, the traffic controller will continue to be online optimized and reactive to relevant traffic conditions. However, the prediction horizon will allow service providers by using a central processing unit to have schedule information early, so that a traffic control information can be delivered to vehicles via the central processing unit.

[0080] Since the traffic controller outputs will be elicited early, there will need to be stored for the duration of the prediction horizon, then outputted at the correct time to the traffic light when vehicles will arrive in real time.

[0081] FIG 2 shows a schematic view of a further embodiment of a traffic control system. Vehicles 12 are driving on a road 14 in direction to the traffic light 2 which is arranged at an intersection 13. At the intersection 13 the road 14 crosses for example another road or goes over in another road. Therefore, the traffic light 2 is necessary to control the flow of the vehicles 12 at the intersection 13. Upstream of the traffic light 2 there is a second traffic light 11 which is arranged at a second intersection 10. The second traffic light 11 is used for controlling the flow of vehicles 12 passing the second intersection 10. At the second intersection 10, the road 14 may also cross another road. Usually, upstream of traffic lights there is arranged a first detector 1 which may be embodied as a stop detector. The first detector 1 is usually located in the road or beside the road upstream the second traffic light 11. The first detector 1 can be embodied as a camera or as an electrical sensor, for example. The first detector 1 measures the traffic flow of vehicles 12 upstream to the second traffic light 11. The traffic flow measurements are delivered to the processing unit 4. Depending on the used embodiment, the processing unit 4 is located nearby the second intersection 10 or far away at a central position. Therefore, the first detector 1 delivers the traffic flow measurements for example wireless to the processing unit 4.

[0082] The processing unit 4 executes a prediction model 5 as explained above and delivers information about the traffic in future at a second location 15 which is a second position upstream to the traffic light 2. The second location 15 is arranged between the first and the second traffic light 2, 11. Furthermore, the first detector 1 may be located at a distance for example between 400 m and 600 m upstream to the traffic light 2.

[0083] The second information 6 which is for example the information about the arrival of the vehicles 12 in future at the second location 15 is delivered from the prediction model 5 to the traffic controller 7. The traffic controller 7 now determines based on the second information 6 the traffic control signal 10 as discussed above for informing the vehicles 12 upstream the traffic light 2 and/or for controlling the signalling of the traffic light 2.

[0084] FIG 3 shows a schematic view of a section of a road 14. The road 14 is guided to the intersection 13 at which the road 14 crosses another road 16. A vehicle 12 is driving on the rod 14 in direction to the traffic light 2. Usually, upstream to traffic lights 2 there may be a stop line detector 17. The stop line detector 17 is connected with a traffic controller 7 which may be located at the traffic light 2. The stop line detector 17 is used for requesting a green light from the traffic light 2 if a vehicle 12 is detected nearby the stop line detector 17.

[0085] Upstream to the stop line detector 17 there is a long loop detector 18 located. The long loop detector 18 is used for detecting a queue of vehicles 12. If the long loop detector 18 detects a queue of vehicles, then it requests from the traffic controller 7 to clear the queue which means to activate the traffic light 2 with a green light.

[0086] Furthermore, there may be arranged a far away detector 19 which is located upstream to the long loop detector 18. The far away detector 19 is used for requesting a green time extension if a vehicle 12 is detected nearby the far away detector 19. The far away detector 19 is also for example wireless connected with a traffic controller 7.

[0087] Depending on the used embodiment, the prediction model may predict traffic information for example the arrival of a vehicle at the position of the stop line detector 17, the long loop detector 18 and/or the far away detector 19. Additionally, the real detection of that stop line detector 17, the long loop detector 18 and/or the far away detector 19 of a vehicle can be used to calibrate or estimate the accuracy of the prediction of the prediction model 5.

[0088] FIG 4 depicts a schematic visualization of the proposed method. In a lower section there is depicted the real space 21. Furthermore, there is a time line 20 which shows the development of the time. The time line 20 separates the real space 21 from a virtual space 22. There is depicted a schematic view of the road 14, wherein the road 14 comprises upstream to a second intersection 10 four lanes 23, 24, 25, 26. At the four lanes there are several vehicles passing the second intersection 10. A second traffic light 11 is located at the second intersection 10. At the second intersection 10 there are arranged several detectors which are not shown but which detect the vehicles and the flow of the vehicles. This information is delivered as a first information 3 to a prediction model 5 which is depicted in the virtual space 22. The prediction model 5 determines the second information 6 which is depicted as an arrangement of vehicles 12 in front of the intersection 13 at which the traffic light 2 is arranged. This means that the prediction model 5 predicts the traffic situation in future for a time at which the vehicles 12 will reach the intersection 13 and the traffic light 2. This information is delivered as a traffic control signal 9 to the vehicles 12 and to the traffic light 2 for controlling the signal phases of the traffic light. The traffic control signal 9 may influence or determine for example the start of the next signal phase of the traffic light 2 and the duration of the next signal phase.

[0089] FIG 5 depicts a schematic view of a NARXNET neural network, which may be used for performing the prediction model.

[0090] The neural network has an input layer 28 with several nodes, a memory layer 29 with several nodes, a hidden layer 30 with several nodes and an output layer 31 with several nodes. The nodes of the input layer have the following input parameter: q_{aj} (t), p_j(t), cj(t), O_1(t), O_1(t), q_{d1}(t), q_{dk}(t), dow(t) und tod(t), which have been explained in the above equation.

[0091] The memory layer 29 stores several values of the input parameter. Each node of the hidden layer 30 is connected with each node of the memory layer 29. Each node of the hidden layer 30 is connected with each node of the output layer 31. The output layer 31 has the following output parameter: $q_{aj}(t+i)$, $p_j(t+i)$, cj(t+i), $O_1(t+i)$ und $O_1(t+i)$, which have been explained in the above equation.

[0092] The output parameter are feed back to the input nodes as input parameters.

[0093] FIG 6 depicts a further embodiment of the proposed method, wherein the proposed method is basically the same as shown in FIG 1. In contrast to the explained method of FIG 1, the method according to FIG 6 comprises a verification and/or a correction of the prediction model in a feedback block 27. The feedback block 27 depicts schematically that depending on the used embodiment, the prediction model 5 considers the real arrival times of the vehicles 12 at the second position and/or the real number of vehicles arriving at the second position upstream of intersection 13 and compares the real situation with the predicted arrival times and/or the predicted number of vehicles. Depending on the difference between the predicted arrival flow of the vehicles at the intersection 13 and the real detected arrival flow of the vehicles at the intersection 13, the prediction model is adapted. Therefore, it is possible to improve the accuracy of the prediction model. Even after improvements to the neural networks accuracy are made, a verification and corrective measures system may be added to the controller. This assures the robustness of this type of controller under any conditions that may lead to a sudden failure with regards to predictions. It may also be recommended that corrective measures may be applied in the form of changes to control inputs, so as to maintain the original goal of keeping the adaptive controller fully intact. An example of a corrective measure for inputs would be to add a ghost vehicle in the next time step, to trigger the controller to give a green phase cycle state to a missed, unseen, vehicle.

[0094] FIG 7 shows a vehicle platoon profile at a time t. The vehicles 12 are driving in direction to the intersection 13 and the traffic light 2.

[0095] FIG 8 shows the vehicle platoon profile at a later time t+1. It can be seen that the distance between the vehicles 12 changed compared to the time t. Furthermore, the road 14 comprises at the intersection 13 the two lanes 23, 24 and an additional third lane 25. The third lane 25 is dedicated for turning left. Therefore, the vehicles 12 following the third lane 25 are controlled by another signal group of the traffic light 2 than the vehicles 12 following the first and the second lane 23, 24. The prediction model may be embodied to predict the number of vehicles of the vehicle platoon which will follow the first and second lane 23, 24 at the intersection 13.

[0096] A basic functionality of the prediction model 5 is that the prediction model is able to be based on a measured traffic flow at one location and predict how this vehicle flow will progress and arrive at a second point downstream at a traffic light of an intersection.

Claims

1. Computer-implemented method for generating a traffic control signal for controlling a traffic approaching a traffic light, wherein at least one vehicle is detected at a first time at a first position of the road upstream the traffic light, wherein a prediction model predicts based on the detected first time at which second time the vehicle will reach a second position, wherein the second position is closer at the traffic light than the first position, wherein the traffic control signal is generated considering the arrival of the vehicle at the second time at the second position.

2. The method of claim 1, wherein the traffic control signal is delivered to vehicles and/or to the traffic light and/or to a central processing unit.

3. The method of any one of the preceding claims, wherein several vehicles are detected during a first time interval passing the first position of the road upstream the traffic light, wherein the prediction model predicts based on the detected vehicles how many vehicles will arrive during a second time interval at the second position, wherein the second position is closer at the traffic light than the first position, wherein the traffic control signal is generated considering the predicted number of vehicles which will arrive the second position during the second time interval.

4. The method of any one of the preceding claims, wherein the traffic control signal is an information for vehicles, wherein the traffic control signal comprises an information about a green wave or a red wave of the traffic light or an information how fast the vehicle should move to have a green light at the time the vehicle will reach the traffic light.

5. The method of any one of the preceding claims, wherein the traffic control signal is a light control signal for controlling the traffic light, wherein the light control signal for example controls a time during which the traffic light is displaying a green light or a red light.

6. The method of any one of the preceding claims, wherein the prediction model considers several vehicles at the first position on different tracks of the road upstream of the traffic light and driving in direction to the traffic light, wherein the prediction model predicts how many vehicles will arrive during the second time interval at the second position.

7. The method of any one of the preceding claims, wherein the traffic control signal influences or controls a phase cycle state of the traffic light to improve the flow of the vehicles.

8. The method of any one of the preceding claims, wherein at the second position of the road a real arrival time of vehicles is detected, wherein the real arrival time of the vehicle is compared with the predicted arrival time of the vehicle, wherein depending on the result of the comparison the prediction model is adapted.

9. The method of any one of the preceding claims, wherein the prediction model uses a neural network for example a recurrent neural network.

10. A traffic controller 7, wherein the controller 7 is embodied to receive an information 6, wherein the information 6 is a predicted number of vehicles which will arrive a second position 17, 18, 19 upstream a traffic light during a second time interval, wherein the controller is embodied to determine based on the information 6 a traffic control signal 9, wherein the controller 7 is embodied to deliver the traffic control signal 9 to vehicles 12 and/or to the traffic light 2 and/or to a central processing unit 8.

11. The controller of claim 10, wherein the controller 7 is an adaptive controller 7, wherein the adaptive controller 7 is embodied to receive the information as a virtual detector information 6, wherein the adaptive controller 7 is embodied to determine based on the virtual detector information the traffic control signal 9, wherein the adaptive controller 7 functions as a predictive adaptive controller 7 and is embodied to deliver the traffic control signal 9 to vehicles 12 and/or to a traffic light 2 and/or to a central processing unit 8.

12. The controller of claim 10 or 11, wherein the controller 7 is embodied to receive a number of detected vehicles 12 which pass during a first time interval the first position of the road upstream the traffic light, wherein the controller 7 is embodied to perform the prediction model 5 predicting based on the detected number of vehicles how many vehicles will arrive during a second time interval at a second position 17, 18, 19, wherein the second position is closer at the traffic light 2 than the first position, wherein the controller 7 is embodied to generate the traffic control signal 9 considering the predicted number of vehicles 12 which will arrive the second position 17, 18, 19 during the second time interval.

13. Processing unit, which is embodied to perform the method according to any one of the claims 1 to 9.

14. Computer-readable memory with computer-executable instructions which are adapted to cause the computer to perform the computer-implemented method according to any one of the claims 1 to 9.

FIG 1

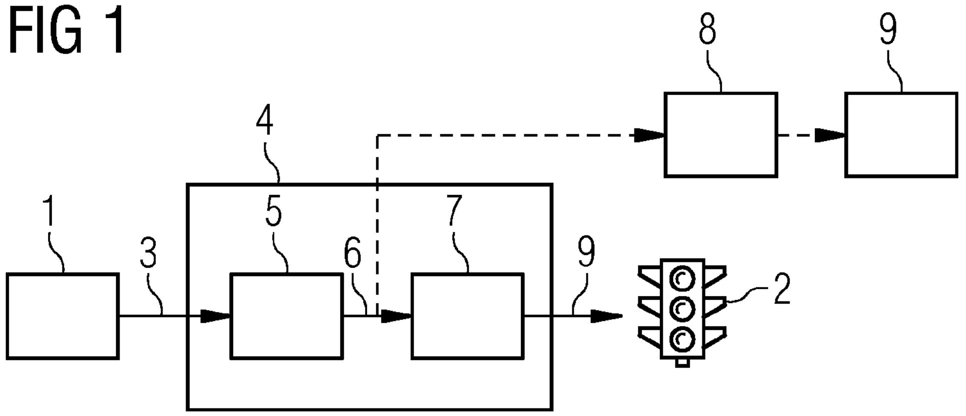


FIG 2

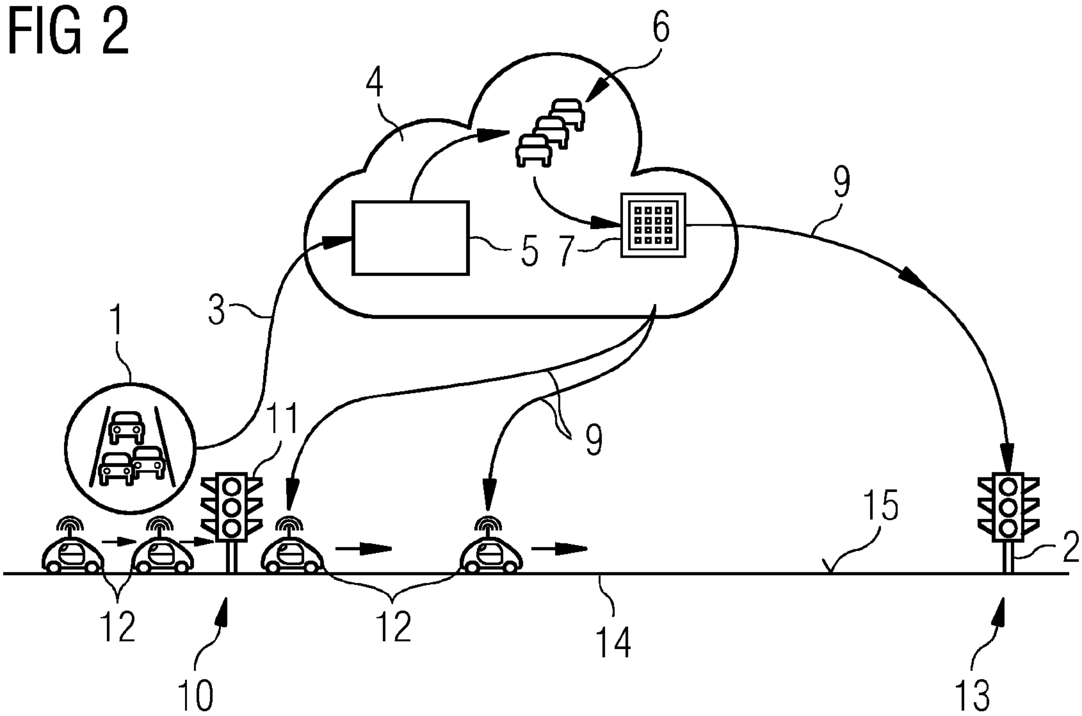


FIG 3

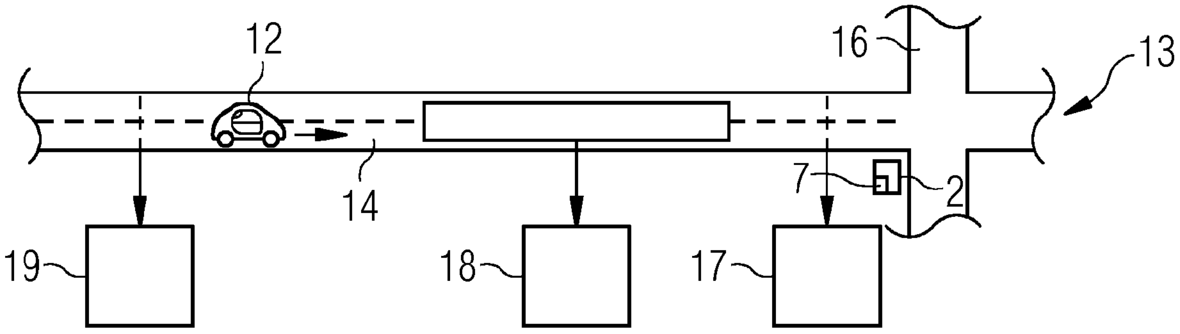


FIG 4

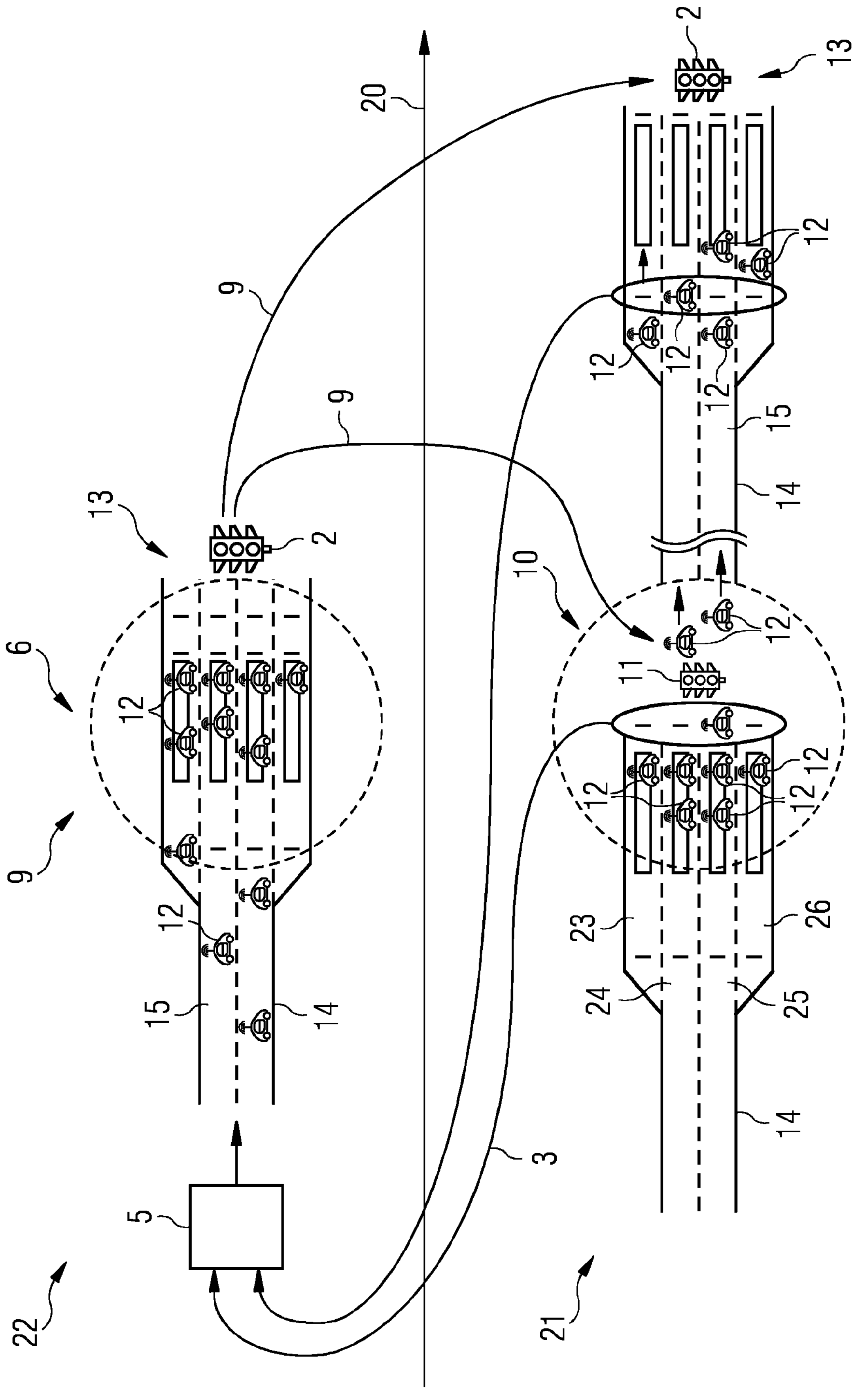
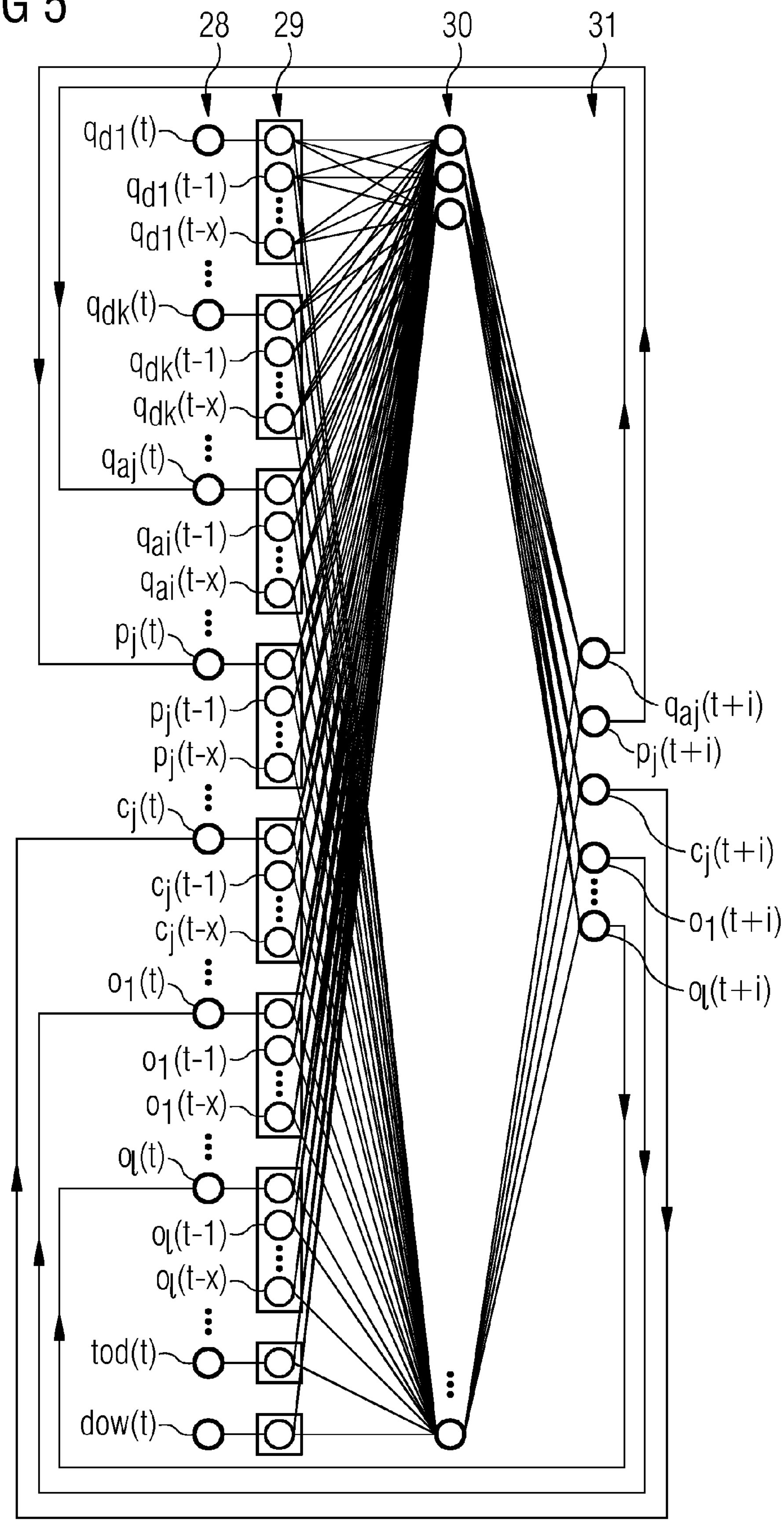


FIG 5


28
29
30
31
qd1(t)
qd1(t-1)
qd1(t-x)
qdk(t)
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qaj(t)
qai(t-1)
qai(t-x)
pj(t)
pj(t-1)
pj(t-x)
cj(t)
cj(t-1)
cj(t-x)
o1(t)
o1(t-1)
o1(t-x)
ol(t)
ol(t-1)
ol(t-x)
tod(t)
dow(t)
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ol(t+i)

FIG 6

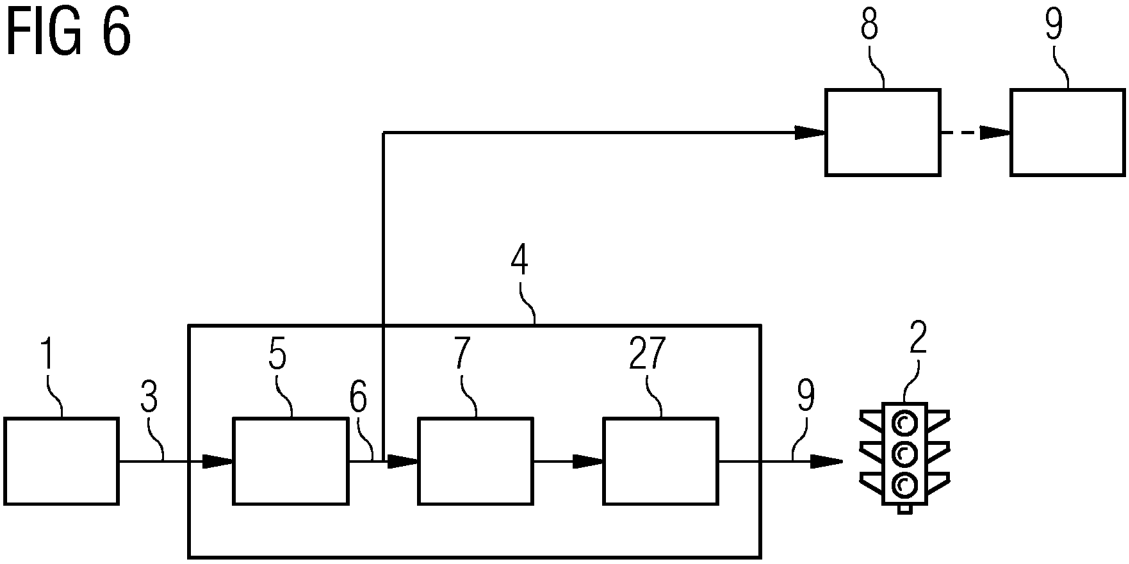


FIG 7

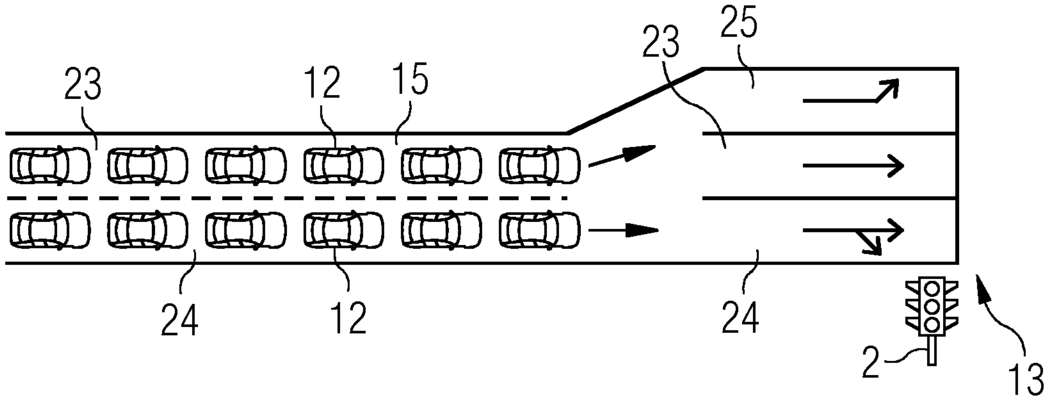
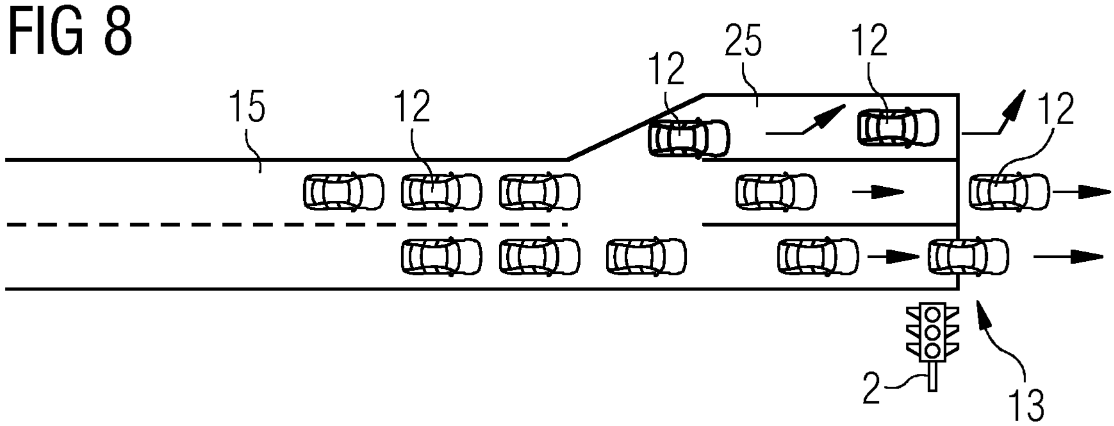


FIG 8



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EUROPEAN SEARCH REPORT

Application Number
EP 18 18 2422

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1

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The Hague	18 January 2019	de la Cruz Valera, D

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