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(57) Abrégé(suite)/Abstract(continued):

vehicle positions to a traffic service center. The traffic service center collects the road traffic data from all vehicles that travel in the roadway system and installed with the devices, processes the data and provide a real-time traffic forecast and digitised road network. The in-vehicle equipped devices receive the real-time traffic forecast and the digitised road network, and provide route guidance services based on the traffic forecast for the drivers. The traffic forecast is based on normal traffic conditions in a historic period and adjusted by factors related to real-time abnormal traffic situations. The system provides a practical and economic solution for building such an intelligent vehicle highway system in a wide area and providing a general and complete traffic forecast for the public.
ABSTRACT OF THE DISCLOSURE

A remote traffic data exchange and intelligent vehicle highway system is provided. In-vehicle equipped devices locate time-related vehicle positions on a digitized road network using information received from a global position system and send the time-related vehicle positions to a traffic service center. The traffic service center collects the road traffic data from all vehicles that travel in the roadway system and installed with the devices, processes the data and provide a real-time traffic forecast and digitised road network. The in-vehicle equipped devices receive the real-time traffic forecast and the digitised road network, and provide route guidance services based on the traffic forecast for the drivers. The traffic forecast is based on normal traffic conditions in a historic period and adjusted by factors related to real-time abnormal traffic situations. The system provides a practical and economic solution for building such an intelligent vehicle highway system in a wide area and providing a general and complete traffic forecast for the public.
REMOTE ROAD TRAFFIC DATA EXCHANGE
AND INTELLIGENT VEHICLE HIGHWAY SYSTEM

TECHNICAL FIELD

This invention relates to a traffic data exchange and intelligent vehicle highway system and, in particular, to a system and method for remotely collecting dynamic traffic data using global positioning systems to provide real-time traffic forecast and travel guidance for drivers.

BACKGROUND OF THE INVENTION

Modern automobile travel has long been plagued by excessive traffic congestion and resulting air pollution from continuously increasing automobile use. Drivers have long sought optimum travel routes to minimize driving time. Local area radio and television stations have transmitted "SIG-ALERTS" to inform drivers of blocked or congested traffic routes so that drivers familiar with various routes to their respective destinations can alter and reroute their planned route to minimize driving time which is often unproductive and represents an aggregate burden on society. Such "SIG-ALERTS" disadvantageously require real-time
receptions by the drivers prior to entering the congested traffic area. Such "SIG-ALERTS" are often missed when drivers are not tuned into the transmitting station at the proper time. Moreover, drivers tend to learn and routinely follow the same route day after day without becoming familiar with alternate routes even in the face of heavy recurring congestion. Roadside signs have also long been used to warn drivers and re-direct traffic during road construction or traffic congestion. For example, posted detour signs and electronic roadside billboards have been used to suggest or require alternative routes. Some electronic billboards have been posted on main traffic arteries, warning of a pending traffic blockage or congestion. However, these signs and billboards also suffer from being posted too near to the point of congestion or blockage preventing meaningful re-evaluation of the planned route or an alternate route, primarily because of the required close proximal relationship between the sign location and the point of congestion or blockage. There exists a continuing need to improve the reception of accurate traffic congestion and alternate routing information.

Governmental agencies have provided emergency care service in response to roadside vehicle accidents,
as is well known. Governmental agencies have adopted the well-known 911 emergency call method through which road accidents are reported and followed by the dispatching of the emergency care services including police, fire and paramedic services using dedicated emergency RF radio systems. Such RF radio systems and methods often require the reporting of the accident by private citizens who are typically either witnesses of the accident or are involved in the accident. However, such systems and methods fail when such victims are decapitated by injury or when such witnesses are unable to quickly locate an operating phone especially in remote areas. Moreover, critical time is often lost when searching for a telephone to place the 911 call on a remote telephone. Further still, misinformation may be inadvertently given by those reporting victims and witnesses unfamiliar with the location of the accident, thereby directing the emergency care provider to the wrong location. There exists a continuing need to more expeditiously provide accurate vehicle traffic accident information to emergency care providers.

Automobiles have also been adapted with experimental local area road-map systems which display a map portion of interest with no global positioning system.
(GPS) information. The driver can locate departure and destination points on the map, and then visually follow the displayed map respecting the current position of the vehicle, as the driver travels toward the desired destination point. The map system displays a cursor to locate the current position of the moving vehicle on the display map. The portion of the map that is displayed is periodically adjusted to keep the current position cursor in the centre of the displayed map portion. The map systems use a compass and a wheel sensor odometer to move the current position from one location to another as the vehicle travels on the road. The use of such map display systems require the driver to repetitively study the map and then mentally and repetitively determine and select travel routes devoting attention away from the safe operation of the vehicle. The display of the map with a current position cursor tends to increase traffic accidents, rather than promote safe operation. Also, the compass and wheel odometer technology causes map position error drifts over distance, requiring re-calibration after travelling only a few miles. Moreover, the use of such a map system disadvantageously requires the entry of the departure point each time the driver begins a new route.
Additionally, the map system does not perform route guidance including a route through which the driver should take to reach a particular destination point. The map system is not dynamically updated with current traffic information, such as detours for road construction, blocked routes due to accidents and delayed travel times due to heavy traffic congestion. There exists a continuing need to improve map systems with a driver friendly interface which reduces diversion away from the safe attentive operation of the vehicle to promote accident free dynamic route guidance vehicle operation.

Certain experimental integrated vehicle dynamic guidance systems have been proposed. For example, Motorola has disclosed an intelligent vehicle highway system in block diagram form in copyright dated in a 1993 brochure, and DELCO Electronics has disclosed another intelligent vehicle highway system also in block diagram form in Automotive News published on April 12, 1993. These systems use compass technology for vehicle positioning. However, displacement wheel sensors are plagued by tire slippage, tire wear and are relatively inaccurate, requiring re-calibration of the current position. Compasses suffer from drafting particularly
when driving on a straight road for an extended period. These intelligent vehicle highway systems appear to use global positioning systems (GPS) satellite reception to enhance vehicle tracking on road-maps as part of a guidance and control system. These systems use GPS to determine when draft errors become excessive and to indicate that re-calibration is necessary. However, the GPS reception is not used for automatic accurate re-calibration of current vehicle positioning.

These intelligent vehicle highway systems also use RF receivers to receive dynamic road condition information for dynamic route guidance, and contemplate infrastructure traffic monitoring, for example, a network for road magnetic sensing loops, and contemplate the RF broadcasting of dynamic traffic conditions for dynamic route guidance. The disclosed two-way RF communication through the use of a transceiver suggests a dedicated two-way RF radio data system. While two-way RF communication is possible, the flow of necessary information between the vehicles and central systems appears to be exceedingly lopsided. It seems that the amount of the broadcasted dynamic traffic flow information from a central traffic radio data control system to the vehicles would be far greater than the
information transmitted from the vehicles to the central traffic control centre. For example, roadside incidents or accident emergency messages to a central system may occur far less than the occurrences of congested traffic points on a road map having a large number of road coordinate points.

To overcome the above disadvantages and to meet the existing needs, United States Patent No. 5,504,482, entitled AUTOMOBILE NAVIGATION GUIDANCE, CONTROL AND SAFETY SYSTEM issued to K.D. Schreder on April 2, 1996, discloses an automobile route guidance system. In this system, an automobile is equipped with an inertial measuring unit and GPS satellite navigational unit and a local area digitized street map system for precise electronic positioning and route guidance between departures and arrivals, is equipped with RF receivers to monitor updated traffic condition information for dynamic re-routing guidance with a resulting reduction in travel time, traffic congestion and pollution emissions, is also equipped with vehicle superseding controls substantially activated during unstable vehicle conditions sensed by the inertial measuring unit to improve the safe operation of the automobile so as to reduce vehicle accidents, and is further equipped with telecommunications through which
emergency care providers are automatically notified of the precise location of the automobile in the case of an accident so as to improve the response time of roadside emergency care.

Nevertheless, Schreder fails to address, in this United States patent, how the traffic data is collected for broadcasting the road traffic condition on which the system is based to provide the navigation guidance. Another disadvantage of the system relates to correction of the positioning error on the road map. A map-matching smoothing process is disclosed by Schreder, which adjusts the display output so that the vehicle is displayed exactly on a road rather than elsewhere based upon the errors of the navigation positioning and road map. The process does the adjustment in a manner in which the cursor representing the current position of the vehicle is simply moved to the nearest available map road position. This may cause a mistaken position on a wrong road, particularly in the case where more than one road are about equally close to the cursor.

There are several basic techniques for collecting traffic data. In the most common, different sensing systems are used to collect traffic volume and vehicle speed. Sensors for counting purposes are
installed along highways to count traffic volume. Video cameras, color machine vision technology and pulsed laser range imaging technology are used to generate advanced traffic parameters such as driving speed and travel time. These technologies are disclosed, for example, in United States Patent No. 5,546,188, entitled INTELLIGENT VEHICLE HIGHWAY SYSTEM SENSOR AND METHOD and issued to Wangler et al. on August 13, 1996. In other applications, multifunctional roadway reference systems are suggested, in which either discrete marks installed in the centre of a traffic lane code one or more bits of information, such as geographical position, upcoming road geometry and the like. An example of roadway reference systems is disclosed in United States Patent No. 5,347,456 which is entitled INTELLIGENT ROADWAY REFERENCE SYSTEM FOR VEHICLE LATERAL GUIDANCE AND CONTROL. This patent issued to Zhang et al. on September 13, 1994.

Given the size of a continent highway system, using sensor and/or cameras to collect road traffic data for each and every public road in a continent is extremely expensive, inconvenient and impractical. With these technical considerations and the system costs in mind, techniques for collecting dynamic traffic data using equipment installed in vehicles have to be
developed. Furthermore, in the prior art there does not 
exist a general road network traffic forecast system for 
broadcasting road traffic forecasts available for drivers 
to plan a trip in advance. An improved remote road 
traffic data collection and traffic forecast system is 
desirable.

SUMMARY OF THE INVENTION

An object of the invention is to provide a 
remote traffic data collection and intelligent vehicle 
highway system.

Another object of the invention is to provide a 
road network traffic forecasting system.

Yet another object of the invention is to 
provide drivers of automobiles with a route guidance 
system.

Yet another object of the invention is to 
provide a route guidance system which uses information 
from a global positioning system (GPS) and accurately 
positions a vehicle within a digitized road network.

Still another object of the invention is to 
provide a route guidance system which computes optimum 
routes between departure and destination points based on
road traffic forecast and updated current road condition information.

A further object of the invention is to provide an economical system for remote collection of road traffic data in a wide area for road traffic forecasts.

Yet a further object of the invention is to provide a system which exchanges road traffic forecast information and road traffic data between a traffic service center and moving vehicles.

In general terms, a remote road traffic data exchange and intelligent vehicle highway system comprises a road traffic data collection sub-system, a communication sub-system, a traffic service centre that stores and processes road traffic information and provides real-time road traffic forecast for drivers, and a route guidance sub-system. The road traffic data collection sub-system and the route guidance sub-system are incorporated into in-vehicle equipments installed in a plurality of vehicles. The road traffic data collection sub-system uses geographic position information received from a global position system (GPS) to locate the vehicle on a digitized road network and a communication system sends the vehicle position data to the traffic service centre to be processed for the road
traffic forecasts. The road traffic forecast is based on a time period of weeks. The road traffic data collected in a given time on a given day of a week for a specific road segment is processed so that an average travel time or speed for this road segment at the given time on the given day of the week is determined and is used to forecast the travel time or speed in normal road conditions for this road segment at the same time on the same day of a future week.

Road traffic varies from time to time in a day or in a week. However, in a normal condition that is not affected by any abnormal situation, such as traffic accidents, road construction, bad weather, holidays or public activities, a road traffic pattern of one week is similar to that of another week. This fact provides a base for road traffic forecasts in a normal condition. The road traffic forecast will be more practical when it is adjusted by factors associated with specific abnormal situations that occur at a time the forecast is made.

The method of accurately locating a vehicle on the digitized road network that is formed with nodes and the links between the nodes comprises obtaining a geographic position of a vehicle and moving the geographic position point to a near link in accordance
with information associated with a node as a last known node which the vehicle last passed to avoid moving the geographical position point to a wrong road.

In specific terms, in accordance with one aspect of the invention, there is provided a method for forecasting road traffic comprising the steps of: (a) collecting at a traffic service center from time to time dynamic vehicle position data reported by vehicles travelling roads, the vehicles being adapted to receive geographic position data thereof from a global positioning system (GPS) and to convert the geographic position data into relative position data associated with a digitised road network represented as nodes and links between the nodes, the relative position data comprising the dynamic vehicle position data to be reported; (b) computing real travel times of vehicles travelling each of the links using information from the dynamic vehicle position data; (c) determining a set of real travel time samples for a link L1 from travel times of vehicles that travel the link L1 within a given time interval starting at a time instance t on a given day D of a week; (d) calculating an average travel time T1 for the link L1 using the set of travel time samples for predicting
travel time for the link L1 at the time instance t on the day D of a future week.

Preferably, the method further comprising steps of repeating steps of (c) and (d) to calculate an average travel time T2 for a link L2 at a time instance (t + T1), an average travel time T3 for a link L3 at a time instance (t + T1 + T2) and up to an average travel time Tn for a link Ln at a time instance (t + T1 + T2 + ... + Tn-1); calculating an average travel time TR of a route R including continuous links L1, L2, L3, ... and Ln at the departure time t by summing up the average travel times T1, T2, T3, ... and Tn for predicting a travel time for route R at the departure time t on the day D of the future week.

In accordance with another aspect of the invention, a remote traffic data exchange and intelligent vehicle highway system is provided. The system comprises a remote traffic data collection sub-system including a plurality of in-vehicle equipped devices, each of the devices being adapted to receive from time to time geographic position data of the vehicle from a Global Positioning System (GPS) and to convert the geographic position data into dynamic vehicle position data.
associated with a digitized road network represented as nodes and links between the nodes;

    a traffic service center adapted for processing the dynamic vehicle position data and determining an average travel time or speed for a specific link at a time instance on a day of a week and forecasting the average travel time or speed for the same link at the same time instance on the same day of a future week; and

    a communication sub-system for exchanging the road traffic data and the road traffic forecast between the vehicles and the traffic service center.

The system provides a practical and economic solution for building such an intelligent vehicle highway system in a wide area and providing a general and complete traffic forecast for the public.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention is further disclosed in details of a preferred embodiment by way of example only with reference to the accompanying drawings, in which:

    FIG. 1 is a schematic view of a configuration of the preferred embodiment of the invention;
FIG. 2 is a schematic diagram showing a configuration of an in-vehicle equipped device used in the embodiment of FIG. 1;

FIG. 3 is a schematic diagram showing a configuration of the traffic service center;

FIG. 4 is a schematic view of a roadway system;

FIG. 5 is a schematic view of a digitized road network representing the roadway system of FIG. 4;

FIG. 6 is a diagram showing a link slope angle;

FIG. 7 is a diagram showing a method of locating a vehicle position onto the digitized road network of FIG. 5.

FIG. 8 is a diagram showing a method for locating a position to a node; and

FIG. 9 is a diagram showing a data collecting and reporting sequence.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, a traffic data remote exchange and intelligent vehicle highway system generally indicated by reference numeral 8, is illustrated. A group of vehicles 20 travel in a roadway system 10, which may be a metropolitan highway system, a regional highway system, national expressway system or a cross-continent
expressway system. Each vehicle 20 is installed with an in-vehicle equipped device 21 which receives dynamic geographical position data of the vehicle from satellites 42 of a Global Positioning System (GPS) 40. The in-vehicle equipped device 21 converts the geographic position data into dynamic positions of the vehicle relating to a digitized road network that represents the roadway system in which the vehicle is travelling. The digitized road network must be provided with a reference system (latitude and longitude) consistent with the reference system used by the GPS 40. The in-vehicle equipped device 21 sends the dynamic road positions of the vehicle in radio frequency data to a communication station 50 and the communication station 50 in turn sends the dynamic positions of the vehicle through cable connection 52 to a traffic service centre 60. The traffic service centre 60 is also connected through cables or telephone lines 72 to External Party Data Sources (EPDS) 70 which may include information departments of police stations, the 911 service centre and government agencies such as weather departments, highway and traffic administration departments. The traffic service centre 60 uses the dynamic road positions of all vehicles 20 and the information obtained from the
external party data sources to provide the real-time road traffic forecasts for the roadway system 10 and broadcast the road traffic forecasts via the communication station. The in-vehicle equipped device 21 on each vehicle 20 receives the road traffic forecasts from the broadcast and processes information included in the road traffic forecasts, providing route guidance to the driver, recommending a real-time optimum travel route based on the real-time road traffic forecasts.

The in-vehicle equipped device 21, as illustrated in FIG. 2, includes a GPS receiver 22 and receives positioning signals from a constellation of satellites 42 in orbit above the earth, which forms the global positioning system 40. The GPS receiver 22 locates the vehicle on earth, providing a geographic position of the vehicle.

Global positioning system technology plays a critical role in this invention. GPS consists of 24 satellites orbiting the earth, each satellite emitting timing positioning signals. The GPS satellites 42 are arranged so that there are always more than three satellites in the field of view of any pertinent place on the earth. The precise position of a point can be determined by measuring the time required for the
positioning signals of at least three satellites to reach that point. The GPS satellites 42 transmit timing positioning signals to the GPS receivers 22 installed in the vehicles 20. Each receiver 22 interprets the signals from three or more satellites 42 and determines a geographic position in accuracy within an average of 20 metres, which is considered to be a positioning error. Differential GPS systems may provide even greater accuracy using geographic benchmark correction.

The existence of this error means that a geographical position of a vehicle moving on a road determined by the GPS signals may be located, for example, in a ditch or even on the top of a roadside building. To correct this error, a method of converting this geographical position to a location on a corresponding roadmap, particularly on a digitized road network is developed and will be disclosed below.

A vehicle supporting sub-system 30 is provided in the in-vehicle equipped device 21 and includes a road network locator 32 and a road explorer 34. A mobile radio sub-system 24 is provided for exchanging information in radio frequency data with the traffic service centre 60 via the communication station 50. Also included in the in-vehicle equipped device 21 are a
computer system 26 for running the road network locator 32 and road explorer 34 as well as storing a digitized road network and temporarily storing data for processing, and a driver interface 28 that includes a microphone, data entry pad, screen display and loud-speaker for the drivers to interact with the system 8.

The road network locator 32 places the geographic position of the vehicle, determined by the GPS receiver 22, onto the digitized road network which is broadcasted from the traffic service center 60 via the communication station 50 and is stored in the computer system 26, and moves the geographic position of the vehicle to a relevant road segment using a novel method in accordance with the invention to correct positioning errors. From time to time, the mobile radio sub-system 24 transmits the road traffic data processed by the road network locator 32 in radio frequencies to the communication station 50 which sends road traffic data reported from all vehicles 20 travelling in the roadway system 10 to the traffic service centre 60 to be further processed for forecasting the road traffic conditions at a future time. The mobile radio system 24 in the vehicle 20 also receives radio frequency data broadcasted by the communication station 50, the broadcasted data including
the digitized road network and the road traffic forecasts. The data received by the mobile radio subsystem 24 is temporarily stored in the computer system 26 and the road network explorer 34 uses the data in the computer system 26 and driver's instructions received from the drivers interface 28 to make an intelligent decision for route guidance. The intelligent decision on route guidance such as an optimum travel route based on the real-time road traffic forecast is displayed on the screen display of the driver interface 28.

For the purpose of location report and route guidance, the digital road network used includes only intersections and road segments with indicated traffic directions. The size of a digitized road network is positively proportional to the population of the area. For an area, for example, with a population around one million, its road network is about 10,000 intersections and 40,000 road segments in one-way traffic direction. It is assumed that 20 bytes is needed for an intersection or a road segment in one-way traffic direction. Therefore, one megabyte is needed to digitize the road network of the area. It is not necessary to keep the whole continent roadway system in vehicles since metropolitan areas are separated from one another and are
connected by the continent expressway system. The digitized road network may be broadcasted on a regional basis and each vehicle keeps only two digitized road networks at any time. One is the continent expressway network and the other a local regional/metropolitan roadway network. When a vehicle travels from one region to another, it gets away from its previous roadway network, and moves around on the continent expressway network. Meanwhile, it receives a new roadway network of the upcoming region.

FIG. 3 illustrates the configuration of the traffic service centre 60. A data exchange interface 62 is provided for connection of the communication station 50 through the cable 52 for receiving the collected road traffic data and sending the data respecting the digitized road network and real-time road traffic forecast which are to be broadcasted. An external party interface 64 is also provided to connect the external party data source 70 for receiving the real-time information about weather or road conditions which is processed by an external party data integrator 65 to be incorporated into a real-time road traffic forecast. The real-time road traffic forecast is completed by a traffic forecaster 68 using the collected road traffic
data for a normal road condition. The collected road traffic data received from the data exchange interface 62 is stored in a database 66 to be processed by the traffic forecaster 68. A TSC server 67 is also provided for running the traffic forecaster 68 as well as storing the digitized road network and temporarily storing the real-time road traffic forecast. An operator interface 69 including a microphone, loud-speaker, data entry pad and screen display permits an operator to interact with the system 8.

The roadway system 10 is illustrated in FIG. 4, presented as a road map for travellers. In the roadway system 10, each road is indicated by reference numeral 11. Generally, each road 11 is a two-way traffic road permitting vehicles to travel in opposite directions. Each one-way road marked by arrows 12 indicates the traffic direction allowed on this road. As discussed above, the roadway system 10 has to be digitized and include only intersections and road segments oriented in the traffic direction to be kept at an adequate data size to be broadcasted and stored in the computer system 26 of in-vehicle equipped device 21. A digitized road network 13 representing the roadway system 10 of FIG. 4 is illustrated in FIG. 5. The digitized
road network 13 is an abstract representation of a roadway system which includes intersections, road segments, parking lots, ramps, bridges, overpasses, tunnels, highways and special points. Although there are many physical elements in a roadway system, there are only two classes of elements represented in the digital road network 13: nodes 14 and links 16 oriented in the traffic direction. The node 14 may present an intersection of two or more roads, an entry of a parking lot, a junction of a highway and an entry or exit ramp, a starting or an endpoint of a bridge, a tunnel, an overpass and an arbitrary location on a road. A link 16 represents a road segment with an orientation, which connects two nodes 14 of the road network. A node from which a link exits is called a source node of the link and a node towards which a link is orientated is called a sink node. Further, the link is said to be an outgoing link of the source node and an incoming link of the sink node.

When a road segment allows only one-way traffic, this road segment may be represented by one link with an orientation which is the same as the traffic direction on the road segment. When a road segment allows two-way traffic, this road segment may be
represented by two links with opposite orientations to each other.

A road segment may be either straight or curved. In the digitized road network representation, however, all links are treated as straight. Therefore, necessary adjustments have to be done to make the digitized road network representation more meaningful. When a road segment is curved, some arbitrary nodes may be placed somewhere on the segment to create several shorter segments so that each shorter segment is treated as straight. Criteria may be set up for determining what curves are considered to be treated as straight. One criterion, for example, is suggested as follows: a straight line is created to connect the two end points of a curve C and the curve C is treated as straight if \( \frac{L_s}{L_c} \) is sufficiently close to 1, wherein \( L_c \) is the length of the curve C and \( L_s \) is the length of the straight line. A predetermined parameter 0.97, for example, may be given. If 0.97 < \( \frac{L_s}{L_c} \) < 1, the curve C is treated as straight.

In FIG. 6, a unique character, the slope angle of each link is illustrated. A link 16 has a source node NA and a sink node NB in the digitized road network 13. An arbitrary link 15 is placed on the digitized road network, outgoing from the source node NA
horizontally towards the right, representing due east orientation. The slope angle \( \alpha \) of the link 16 is defined by computing the angle of rotation between the link 16 and the arbitrary link 15. The slope angle \( \alpha \) of the link 16 is between \( \pm 180^\circ \), being represented as a positive angle if the link 16 is in an up quadrant with respect to the arbitrary link 15 and as a negative angle if the link 16 is in a lower quadrant. The unique character of the sloping angle of each link provides a base for correcting the errors in locating a geographic position onto the digitized road network. The method of locating a geographic position onto the digitized road network is disclosed below.

In FIG. 7, node 14 represents an intersection of four roads that are represented by links 16 and marked with A1 to A4, individually. Point P represents a current geographic position determined from the GPS information and the node 14 is a last known node that the vehicle last passed and is determined by previous steps of the locating process. A position link 17 is additionally made from the last known node 14 to the current position P. Slope angles of the position link 17 and each of links A1 to A4 are calculated using the method described in the last paragraph. In this example,
the slope angle of a position link 17 is beta, the slope angles of links A1 to A4 are 0°, 90°, 180° and -90°, respectively. One of the links A1 to A4 is selected as a nearest link to the current geographic position P when the difference is smallest between the absolute values of the slope angles of the selected link and the position link 17. In this case, link A1 is selected. A last step of the method is to move the current geographic position P to point Q on the selected link A1 and maintain a length between node 14 and point Q equal to the length between the node 14 and the point P. In this method, the adjustment of a vehicle position on the digitized road network is always associated with a last known node information and a mistake to locate the geographical position to a wrong road is avoided. This advantage will be clearer in a further description of the process of remote traffic data collection.

A process for remotely collecting traffic flow speed and travel time using the remote traffic data exchange and intelligent vehicle highway system 8 is disclosed in detail below.

Each vehicle 20 equipped with the GPS receiver 21 aligned to receive positioning signals from the selected constellation of satellites 42 receives the
positioning signals and uses the information included in the positioning signals to determine a vehicle's geographical position. Before the geographical position is to be located on the digitized road network 13 which is received by the mobile radio sub-system 24 in radio frequency broadcast data and stored in the computer system 26, a start point of the vehicles dynamic positions has to be determined because a last known node has to be provided for further locating a current geographic position onto the digitized road network 13. The road network locator 32 places a first geographic position to the digitized road network and compares the distance between the current geographic position and a nearest node with a predetermined small length. The road network locator 32 moves the current geographical position to the nearest node as a start point to be used as a last known node in the following process steps when the distance is smaller than the predetermined length. The road network locator 32 drops the current geographical position when the distance is greater than the predetermined length, and repeats the above steps using a following geographic position until the distance between a new geographical position and a nearest node is smaller than the predetermined length. The newly
determined nearest node is a start point and is to be used as a last known node for the following process steps. The predetermined length is used to control the accuracy of the positioning process. An example is illustrated in FIG. 8, in which points C1 to C9 on links 16 represent the individual geographical positions related to a time instance sequence at which the geographical position data is collected. The first geographical position C1 has a distance from the nearest node N1 and the distance is greater than a predetermined length d1 and therefore the C1 is dropped. Similarly, C2 and C3 are dropped. However, the fourth geographic position C4 is within the predetermined distance d1 from a nearest node N2 and the C4 is moved to the node N2 that serves as a start point to be used as a last known node in further locating processing steps. After the start point is determined, the road network locator 32 uses a method illustrated in FIG. 7 to locate the dynamic geographic positions to the links 16 in the digitized road network 13 if these geographic positions are not on the links 16.

However, the start point is not necessary to be located at the beginning of each trip. It is recommended that in-vehicle equipped devices 21 are kept on to
continue receiving the real-time traffic forecasts when
the vehicles complete their last trip and are parked.
The reason for doing that is to let drivers have the real
time traffic forecasts and the route guidance services
right away when they start their trips and do not need to
wait a short period of time to receive all data
respecting the local roadway system. Therefore, the
standby status of the in-vehicle equipped devices 21
keeps the last known node data of the previous trip and
this last known node is usually a start point of the same
vehicles for a following trip. There are a few
exceptions. For example, the vehicle drives into one
entry of an underground garage and exits from an exit
that is different from the original entry and may be
located on another street. In these exceptional cases, a
start point has to be determined by the method disclosed
above.

Generally, the geographical positions of the
vehicle located on the links are not always matched with
nodes. In a digitized road network, there are only two
classes of elements: links and nodes, and the
information associated with each node is more important
and useful. An adjustment is necessary to ensure that
traffic information on each node is collected. An
example is illustrated in FIG. 8. C5 to C9 are dynamic geographic positions and are correctly located on the links 16. A predetermined small length d2 is compared with the distance between each of the positions C5 to C9 and a nearest node 14. A position remains on the link 16 in its original place if the distance is greater than the predetermined length d2, as C5 to C8 is this case. A position, however, is moved to a nearest node if the distance is smaller than the predetermined length d2, in which case, the position C9 is moved to node N3. Therefore, the position information related to C9 is now associated with node N3. In a general situation, a proper data collecting interval which is to be further discussed below, and an adequately predetermined d2 ensure that more than one position should be located on each link and most nodes should be provided with traffic data after the adjustment is done.

The collected data respecting the vehicle’s positions is not reported to the traffic service centre 60 at each collection and is temporarily stored in the computer system 26 of the in-vehicle equipped device 21 to be sent in groups later. A time interval CI in seconds known as Collecting Interval and a time interval RI in seconds known as Reporting Interval are
predetermined. An example of a traffic data collecting and reporting sequence is illustrated in FIG. 9. Within a period of time, the dynamic positions of a vehicle 20 located in the digitized road network 13 are points C10 to C20 and the time interval from one position to the next one is CI. The CI is a predetermined constant time interval to collect the dynamic position status, and the distance between two adjacent positions may not be constant because the travel speed of the vehicle may change. The predetermined time interval RI for reporting the dynamic position data to the traffic service centre 60 are two times of CI, that is, the vehicle reports a group of dynamic position data including a last position and a current position at every second data collection. Practically, one RI may include more CIs, for example, 5 CIs and each report includes more position data so that the transmission of data from the vehicle 20 to the traffic service centre 60 is much more efficient than data transmission at each collecting time. Furthermore, for a digitized road network, only the information associated with nodes is important. The position data reported from each vehicle 20 to the traffic service centre 60 may only include the position data relating to nodes 14. In this example, the first
report includes position C10 that relates to node N11 and the second group of position data includes C11 and C12 which does not relate to a node, and is not reported. The third group of positions includes C13, C14 and only C13 relates to node N12. The position C13 is reported in this reporting pattern. The positions C16, C18 and C20 which relate to node N13, N14 and N15 respectively are reported and the rest of the positions are not reported. Therefore, the volume of the data transmitted is decreased significantly and, of course, the traffic service centre 60 stores and processes much less data.

It is a simple calculation for the traffic forecaster 68 of the traffic service centre 60 to determine the travel time of a vehicle for a specific link or the vehicle travel speed on that link. The traffic forecaster 68 retrieves traffic data of two adjacent nodes from the database 66 and determines a time the vehicle was on the source node of the link and another time the vehicle was on the sink node of the link. The travel time of the vehicle for this link is further determined by calculating the difference of the two times. The vehicle travel speed for this link is determined by dividing the length of the link by the travel time of the vehicle. The data including the
travel time of each link or vehicle travel speed on each link are collected from time to time from every vehicle 20 of the group travelling around in the roadway system 10, and provide a database to forecast the road traffic conditions for the roadway system 10.

The road traffic forecast is based generally on the fact that in a normal condition, road traffic varies from time to time in one week but it does not change too much from one week to the next if no abnormal situations occur, such as traffic accidents, bad weather, road constructions, holidays or special public activities. Therefore, an average traffic condition for a specific link or route which is formed by continuous links, at a given time on a given day of a week may be used as a basic traffic condition for this link or route in a normal situation at the same time on the same day of a future week. The average traffic condition is further adjusted by special factors associated with any abnormal condition occurrences at the time the real-time road traffic forecast is made. The method for forecasting the travel time for a link or a route at a time instance t on a given day D of a week is disclosed in detail with reference to the following example.

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The traffic forecaster 68 retrieves from the database 66 time-varied vehicle locations and computing link travel times of the vehicles. The day is divided into predetermined equal time intervals as a Forecast Interval (FI) which should be a factor 60, for example, 5 minutes. One of the time intervals is determined to contain the given time instance \( t \), for example, the time interval from 3:00pm to 3:05pm that contains the given time instance 3:00pm of a given day, for example, Monday.

A set of travel time samples for a link \( L \) at the time interval from 3:00pm to 3:05pm on Monday of the week is selected and an average travel time for the link \( L \) within the time interval 3:00pm to 3:05pm on Monday of the week is determined by summing up all travel times of the samples and being further divided by the number of samples. This is the predicted travel time for the link \( L \) at time instance 3:00pm on Monday of the next week. The week in which the traffic data is collected and processed in the above-described method for predicting the traffic conditions in a future week is referred to as a "historic period". However, because of abnormal conditions which occur in the historic period, the average travel time for the link at the time instance may not really represent a normal, average traffic
condition. For example, a traffic accident occurs on the link L at 2:45pm on Monday and the traffic on the link L between 3:00pm and 3:05pm is affected. Therefore, the average travel time for the link L within that time interval does not represent a normal traffic condition at this time. To minimize the effect of an abnormal condition to the road traffic forecast, a longer historic period is suggested. For example, a historic period of eight weeks is taken and eight average travel times are determined for the link L at the time instance of 3:00pm on Monday, each from one week of the eight week historic period. The predicted travel time for the link L at time instance 3:00pm on Monday is determined by averaging the eight average travel times for the link. The predicted travel time for the link L at that time instance is only for the week following the historic period. For a further week, a new historic period is taken and the data collected within the new historic period has to be processed for the forecast for that further week. A weighted average method is also suggested for forecasting the link travel time. For example, a historic period of eight weeks is taken for the data collection and process to forecast a road traffic condition in the following week. A series of 1/2, 1/4, 1/8, 1/16, 1/32, 1/64, 1/128
and 1/128 is taken as decreasing weighting factors. The eight average travel times for the link from the weeks within the historic period are timed by the series of the weighting factors respectively, beginning with the average travel time from the most recent week in the historic period timed by 1/2 so that the travel conditions in more recent weeks affects the forecast more than those travel times from earlier previous weeks in the historic period. Different weighting methods can be used for the forecast in different conditions and different considerations.

Real-time abnormal traffic conditions may be classified by a plurality of factors. A closed road segment, for example, may be classified as a factor 1000 which is to be used to time a predicted link travel time. Therefore, the broadcast shows that link travel time is 1000 times greater than a normal travel time and the drivers must realize the link is practically closed. A factor 5, for another example, may be taken to adjust a travel time for links which are associated with light, snowy weather. A database may be established for factors associated with all possible abnormal traffic conditions.

In respect to an average travel time of a route R which is formed by a series of continuous
links L1 to Ln departing at the time instance t on the
given day D of the week, the road explorer 34 computes
the sum of an average travel time T1 for link L1 at the
time instance t, average travel time T2 for link L2 at
time instance (t + T1)...., and average travel time TN for
link Ln at a time instance (t + T1 + T2 + ..... + Tn-1).
It should be noted that this calculation is completed by
the road explorer 34 of the in-vehicle equipped device 21
rather than the traffic forecaster 68 of the traffic
service centre 60 so that the computing task of the
traffic forecaster 68 is greatly shared by the plurality
of the in-vehicle equipped devices 21.

A method is developed for efficiently
broadcasting travel time forecasts from the traffic
service centre 60. A time interval in minutes known as
Network Broadcasting Interval (NBI) is selected and the
digitized road network 13 is broadcast every NBI minute.
The contents of broadcasting include: node information
including node index, the latitude and longitude of the
node, block number where the node is located, etc.; link
information including link index, block number where the
link is located, source node and sink node of this link,
etc.; and left turn information including turn index,
incoming and outgoing links of this turn. Another time
interval in minutes is known as Traffic Broadcasting Interval (TBI) and the average travel time forecast is broadcasted every TBI minute. This forecast is done in real time and the contents of this broadcasting include: current time; link traffic information that includes link index, block index, travel times in the next 60 minutes, minute by minute; and left turn traffic information that includes turn index, block index, travel times in the next 60 minutes, minute by minute.

A method for receiving and storing traffic forecast data by the in-vehicle equipped device is also developed. The digitized road network broadcasted from the traffic service centre is received at the in-vehicle equipped device 21 and is stored in the computer system 26. The current vehicle's position is located on the digitized road network 13 using the method disclosed above and the block which the vehicle is in currently is determined. A destination of the trip may be entered by the drivers through the driver interface 28. The road network locator 32 executes a program to find a block chain that starts from the block where the vehicle is in currently, and ends at the block where the destination is located. These chained blocks are marked. The travel time forecast is received from the broadcast and link and
left-turn traffic data relating to the marked blocks is stored in the computer system 26. The data not relating to the marked blocks is ignored.
CLAIMS:

1. A method for forecasting road traffic comprising the steps of:

   (a) collecting at a traffic service center from time to time dynamic vehicle position data reported by vehicles travelling roads, the vehicles being adapted to receive geographic position data thereof from a global positioning system and to convert the geographic position data into relative position data associated with a digitized road network represented as nodes and links between the nodes, the relative position data comprising the vehicle position data;

   (b) computing real travel times of vehicles travelling each of the links using information from the dynamic vehicle position data;

   (c) determining a set of real travel time samples for a link L1 from travel times of vehicles that travel the link L1 within a given time interval starting at a time instance t on a given day D of a week;

   (d) calculating an average travel time T1 of the link L1 using the set of travel time samples for predicting travel time for the link L1 at the time instance t on the day D of a future week.
2. A method as claimed in claim 1 further comprising the steps of:

   (a) repeating steps (c) and (d) to calculate an average travel time \( T_2 \) for a link \( L_2 \) at a time instance \( (t + T_1) \), an average travel time \( T_3 \) for a link \( L_3 \) at a time instance \( (t + T_1 + T_2) \) and up to an average travel time \( T_n \) for a link \( L_n \) at a time instance \( (t + T_1 + T_2 + \ldots + T_{n-1}) \); and

   (b) calculating an average travel time \( T_R \) of a route \( R \) including continuous links \( L_1, L_2, L_3, \ldots \) and \( L_n \) at the departure time \( t \) by summing up the average travel times \( T_1, T_2, T_3, \ldots \) and \( T_n \) for predicting a travel time for route \( R \) at the departure time \( t \) on the day \( D \) of the future week.

3. A method as claimed in claim 1 or 2 wherein the given day \( D \) is within a predetermined historic period comprising \( M \) continuous weeks from week \( w_1 \) to week \( w_m \), and the predicted travel time \( T_1 \) for the link \( L_1 \) at the time instance \( t \) on the day \( D \) of a future week is forecasted by:

   (a) repeating steps (c) and (d) to calculate travel times \( T_{w1}, T_{w2}, \ldots \) and \( T_{wm} \) for the link \( L_1 \) at the
given time instance t on the given day D of weeks w1, w2, … and wM;

(b) averaging Tw1, Tw2, … and TwM to determine T1.

4. A method as claimed in claim 3 wherein a weighted average method is used for averaging Tw1, Tw2, … and TwM.

5. A method as claimed in claim 4 wherein the future week immediately follows the historic period and a series of decreasing weighting factors beginning from the most recent week of the historic period is used in the weighted average method.

6. A method as claimed in claim 1 wherein the given time interval is selected from time intervals which are predetermined equal intervals of the day D.

7. A method as claimed in claim 1 wherein the average travel time T1 for the link L1 at the time instance t on the given day D of the week is converted to an average travel speed on link L1.
8. A method as claimed in claim 2 wherein the average travel time for route R at the departure time t on the given day D of the week is converted to an average travel speed on the route R.

9. A method as claimed in claim 1 wherein the predicted travel time is multiplied by a predetermined factor associated with road and weather conditions to adjust the predicted travel time for link L1 at the time instance t on the day D of the future week when the road and weather conditions are abnormal.

10. A method as claimed in claim 1 wherein the geographic position data is received and converted into the relative position on the digitized road network at a predetermined collection interval (CI) and the vehicle position data is reported at a predetermined reporting interval (RI), wherein RI > CI.

11. A method as claimed in claim 10 wherein the vehicle position data reported includes only data related to nodes on the digitized road network.
12. A method as claimed in claim 10 wherein the reporting interval RI is an integer multiple of the collection interval CI.

13. A method as claimed in claim 1 wherein the digitized road network is a radio frequency broadcast of digital data via air from the traffic service center received by radio frequency receivers in the vehicles.

14. A method as claimed in claim 13 wherein the radio frequency broadcast of digital data is sent every time at a predetermined time interval and includes node information, link information and left-turn information.

15. A method as claimed in claim 1 wherein a reference system of the digitized road network is the same as a reference system used by the global positioning system.

16. A method as claimed in claim 13 wherein each road in the digitized road network is segmented into links by the nodes, each of the links being represented by a straight line that exits from an source node to a sink node, the link indicating traffic direction.
17. A method as claimed in claim 16 wherein each one-way road in the digitized road network is represented by a continuous series of the links oriented in a traffic direction and each two-way road in the digitized road network is represented by a continuous series of pairs of oppositely oriented, parallel links, each pair connecting two adjacent nodes.

18. A method as claimed in claim 16 wherein each of the links is referenced by computing an angle of rotation between the position link and an arbitrary link oriented towards due east, the slope angle being represented as a positive angle if the position link is in an upper quadrant with respect to the arbitrary link and as a negative angle if the position link is in a lower quadrant, the slope angle of the link being in an angle between $\pm 180^\circ$.

19. A method as claimed in claim 18 wherein each of the vehicles is located on the digitized road network by steps of:

receiving a current geographic position of the vehicle from the global positioning system;
placing the geographic position on the digitized road network;
locating a node of the digitized road network which the vehicle last passed as a last known node;
making a position link from the last known node to the geographic position of the vehicle on the digitized road network;
determining a slope angle of the position link by computing an angle of rotation between the position link and an arbitrary link oriented towards due east, the slope angle being represented as a positive angle if the position link is in an upper quadrant with respect to the arbitrary link and as a negative angle if the position link is in a lower quadrant, the slope angle of the link being in an angle between ±180°;
comparing the slope angle of the position link with slope angles of all links outgoing from the last known node respectively and selecting one of the links having an absolute value of the slope angle closest to the absolute value of the slope angle of the position link; and
moving the geographic position to the selected link while maintaining a distance between the geographic position and the last known node.
20. A method as claimed in claim 19 wherein a start point of the vehicle is located by the steps of:

(a) receiving a current geographic position of the vehicle from the global positioning system;

(b) placing the current geographic position to the digitized road network as a start GP point;

(c) selecting a node of the digitized road network that is closest to the start GP point; and

(d) moving the start GP point to the selected node as the start point adapted to serve as a last known node for locating a following vehicle position on the digitized road network.

21. A method as claimed in claim 20 wherein the start point of the vehicle is located by adding further steps between the steps (c) and (d):

   comparing a distance between the start GP point and the selected node with a predetermined small distance; and

   repeating steps (a) to (c) if the distance between the start point and the selected node is greater than the predetermined small distance until the distance between the last used start GP point and the last
selected node is smaller than the predetermined small distance.

22. A method as claimed in claim 19 wherein the vehicle is located on the digitized road network by the further steps:

   comparing the distance between the GP point and the last known node with a length of the selected link; and

   further moving the GP point on the selected link to the sink node of the selected link if the difference between length and the distance is smaller than a predetermined length or retaining the GP point on the link if the difference is greater than the predetermined length.

23. A remote traffic data exchange and intelligent vehicle highway system comprising:

   a remote traffic data collect sub-system including a plurality of in-vehicle equipped devices, each of the devices being adapted to receive from time to time geographic position data of the vehicle from a Global Positioning System (GPS) and to convert the geographic position data into dynamic vehicle position
data associated with a digitized road network represented as nodes and links between the nodes;

a traffic service center adapted for processing the dynamic vehicle position data and determining average travel times or speed for a specific link at a time instance on a day of a week and forecasting the average travel time or speed for the same link at the same time instance on the same day of a future week; and

a communication sub-system for exchanging the road traffic data and the road traffic forecast between the vehicles and the traffic service center.

24. A system as claimed in claim 23 wherein the traffic service center comprising:

a vehicle highway database for storing the dynamic vehicle position data received from the vehicles travelling roads;

a traffic forecaster for processing the dynamic vehicle opposition data and resulting in the average travel time $T_1$ for the link $L_1$ and adapted to sum up average travel times of links of a route to result in an average travel time of the route;

a server for running the traffic forecaster and storing the digitized road network;
a data exchange interface for connection of the communication sub-system which transmits the data respecting average travel times for links and routes into air and receives from air the dynamic vehicle data reported from each of the vehicles travelling roads.

25. A system as claimed in claim 24 wherein the communication sub-system comprises a communication station.

26. A system as claimed in claim 25 wherein the communication station transmits the digitized road network and real-time traffic forecasts received from the traffic service station into air.

27. A system as claimed in claim 24 wherein the service center comprises an external party interface adapted to connect to external parties for road and weather information, and an external party integrator adapted to integrate the road and weather information with the road traffic forecast.

28. A system as claimed in claim 23 wherein each of the remote data exchange devices comprises:
a global positioning system receiver for receiving geographic position data of the vehicle equipped with the receiver from satellites of the global positioning system;

a mobile radio sub-system adapted to exchange data via air with the traffic service center;

a driver interface for a driver of the vehicle to interact with the remote data exchange device; and

a vehicle support system having:

a vehicle position locator for locating the vehicle onto the digitized road network using the geographic position data, and

a computer system for running the vehicle position locator, and storing the digitized road network received from the traffic service center and other data to be temporarily stored;

29. A system as claimed in claim 28 wherein the vehicle support system further comprises a road explorer running on the computer system, adapted to guide the vehicle using information respecting the road traffic forecast.
30. A system as claimed in claim 29 wherein the driver interface includes a data entry mechanism for the driver to enter a destination point, and a display mechanism for displaying a recommended travel route between a departure point and the destination point.

31. A system as claimed in claim 30 wherein the road explorer computes a predicted travel time for a route using predicted travel times for links which form the route.

32. A system as claimed in claim 26 wherein the digitized road network is a metropolitan area roadway network.

33. A system as claimed in claim 26 wherein the digitized road network is a regional roadway network.

34. A system as claimed in claim 26 wherein the digitized road network is a continent expressway network.

35. A method for locating dynamic positions of a vehicle travelling roads on a digitized road network
using dynamic geographic positions of the vehicle comprising:

retrieving the digitized road network wherein each road segment illustrated by a link represented as a straight arrow line from one node as a source node to an adjacent node as a sink node to indicate the traffic direction, each one-way road in the digitized road network being represented by a continuous series of the links oriented in a traffic direction, and each two-way road in the digitized road network being represented by a continuous series of pairs of oppositely oriented, parallel links, each pair connecting two adjacent nodes;

locating one of the geographic position of the vehicle on the digitized road network; and

moving the geographic position of the vehicle to a nearest link associated with a node which the vehicle last passed as a last known node while maintaining a distance between the geographic position and the last known node.

36. A method as claimed in claim 35 wherein the nearest link associated with the last known node is determined by:
retrieving or determining a slope angle of each link from the last known node, the slope angle being determined by computing an angle of rotation between the link and an arbitrary link oriented towards due east, the slope angle being represented as a positive angle if the link is in an upper quadrant with respect to the arbitrary link and as a negative angle if the link is in a lower quadrant, the slope angle of the link being in an angle between ±180°;

making a position link from the last known node to the geographic position of the vehicle on the digitized road network;

determining a slope angle of the position link by computing an angle of rotation between the position link and an arbitrary link oriented towards due east, the slope angle being represented as a positive angle if the position link is in an upper quadrant with respect to the arbitrary link and as a negative angle if the position link is in a lower quadrant, the slope angle of the link being in an angle between ±180°;

comparing the slope angle of the position link with slope angles of all links outgoing from the last known node respectively and selecting one of the links having an absolute value of the slope angle most close to
the absolute value of the slope angle of the position link;

37. A method as claimed in claim 36 further comprising steps of:

   receiving a current geographic position of the vehicle from time to time from a global positioning system;

   repeating the steps for locating positions on the digitized road network until the dynamic positions of the vehicle are located on the digitized road network.

38. A method as claimed in claim 35 wherein a start node of the vehicle is located by steps of:

   (a) receiving a current geographic position of the vehicle from the global positioning system;

   (b) placing the current geographic position to the digitized road network as a start GP point;

   (c) selecting a node of the digitized road network that is closest to the start GP point; and

   (d) moving the start GP point to the selected node as the start node adapted to serve as a last known node for locating a following vehicle position on the digitized road network.
39. A method as claimed in claim 38 wherein the start node of the vehicle is located by adding further steps between the steps (c) and (d):

comparing a distance between the start GP point and the selected node with a predetermined small distance; and

repeating steps (a) to (c) if the distance between the start point and the selected node is greater than the predetermined small distance until the distance between the last used start GP point and the last selected node is smaller than the predetermined small distance.

40. A method as claimed in claim 35 wherein the vehicle is located on the digitized road network by further steps:

comparing a length of the position link with a length of the selected link; and

further moving the geographic position on the selected link to the sink node of the selected link if the length difference between the selected link and the position link is smaller than a predetermined length, or
retaining the geographic position on the link if the difference is greater than the predetermined length.

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Figure 4