US012391285B2

US01239285B2

(12) **United States Patent**
     Goto et al.

(10) **Patent No.:** **US 12,391,285 B2**
(45) **Date of Patent:** **Aug. 19, 2025**

(54) **VEHICLE CONTROL DEVICE, STORAGE MEDIUM STORING COMPUTER PROGRAM FOR VEHICLE CONTROL, AND METHOD FOR CONTROLLING VEHICLE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 160 days.

(21) Appl. No.: **18/448,379**

(22) Filed: **Aug. 11, 2023**

(65) **Prior Publication Data**

US 2024/0067227 A1   Feb. 29, 2024

(30) **Foreign Application Priority Data**

Aug. 25, 2022   (JP) 2022-134081

(51) **Int. Cl.**
     B60W 60/00   (2020.01)
     B60W 40/04   (2006.01)
(52) **U.S. Cl.**
     CPC *B60W 60/0051* (2020.02); *B60W 40/04* (2013.01); *B60W 2520/10* (2013.01)
(58) **Field of Classification Search**
     CPC B60W 60/0051; B60W 40/04; B60W 2520/10; B60W 2552/10; B60W 2556/50; B60W 30/182; B60W 2554/4042; B60W 2554/408; B60W 40/105
     See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0170514 A1*	6/2015	Stenneth	....	G08G 1/0125
2018/0113450 A1*	4/2018	Sherony	....	G05D 1/0022
2019/0189004 A1*	6/2019	Suzuki	....	G08G 1/0133
2019/0367034 A1	12/2019	Okajima et al.		
2020/0257294 A1*	8/2020	Ishioka	....	G05D 1/0088
2022/0319309 A1*	10/2022	Al-Nadawi	....	G08G 1/0133
2023/0166754 A1*	6/2023	Okuno	....	B60W 50/14
2023/0177963 A1*	6/2023	Joo	....	G08G 1/167

FOREIGN PATENT DOCUMENTS

JP	2003288674 A	10/2003
JP	2004272839 A	9/2004
WO	2018138768 A1	1/2017

* cited by examiner

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(57)   **ABSTRACT**

A vehicle control device has a processor configured to calculate an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed, to determine whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and to estimate whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested, and to decide to drive the vehicle by automatic control when the traveling road as a whole is congested.
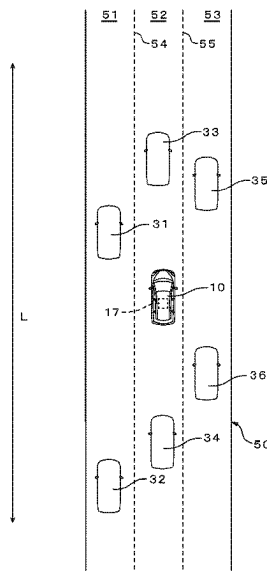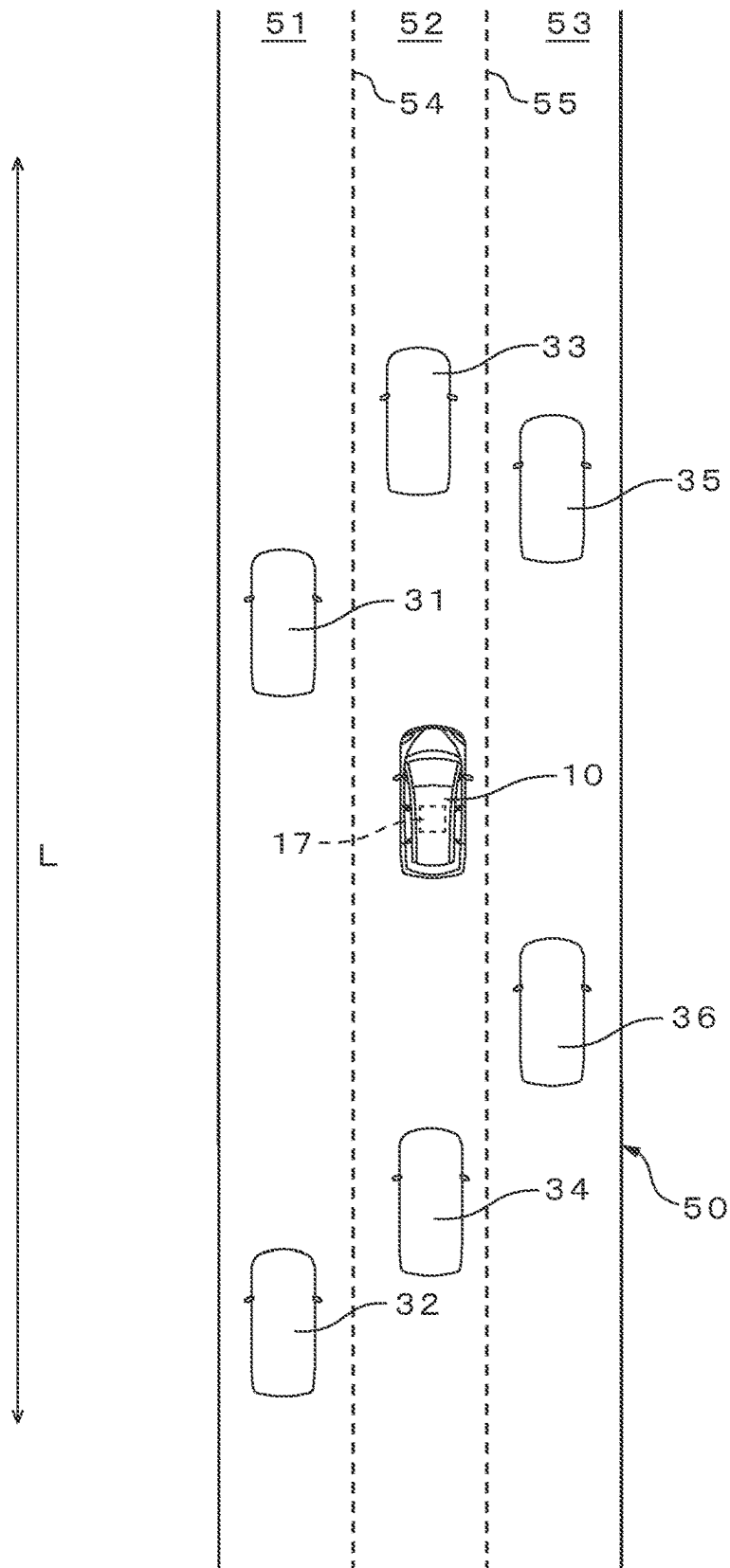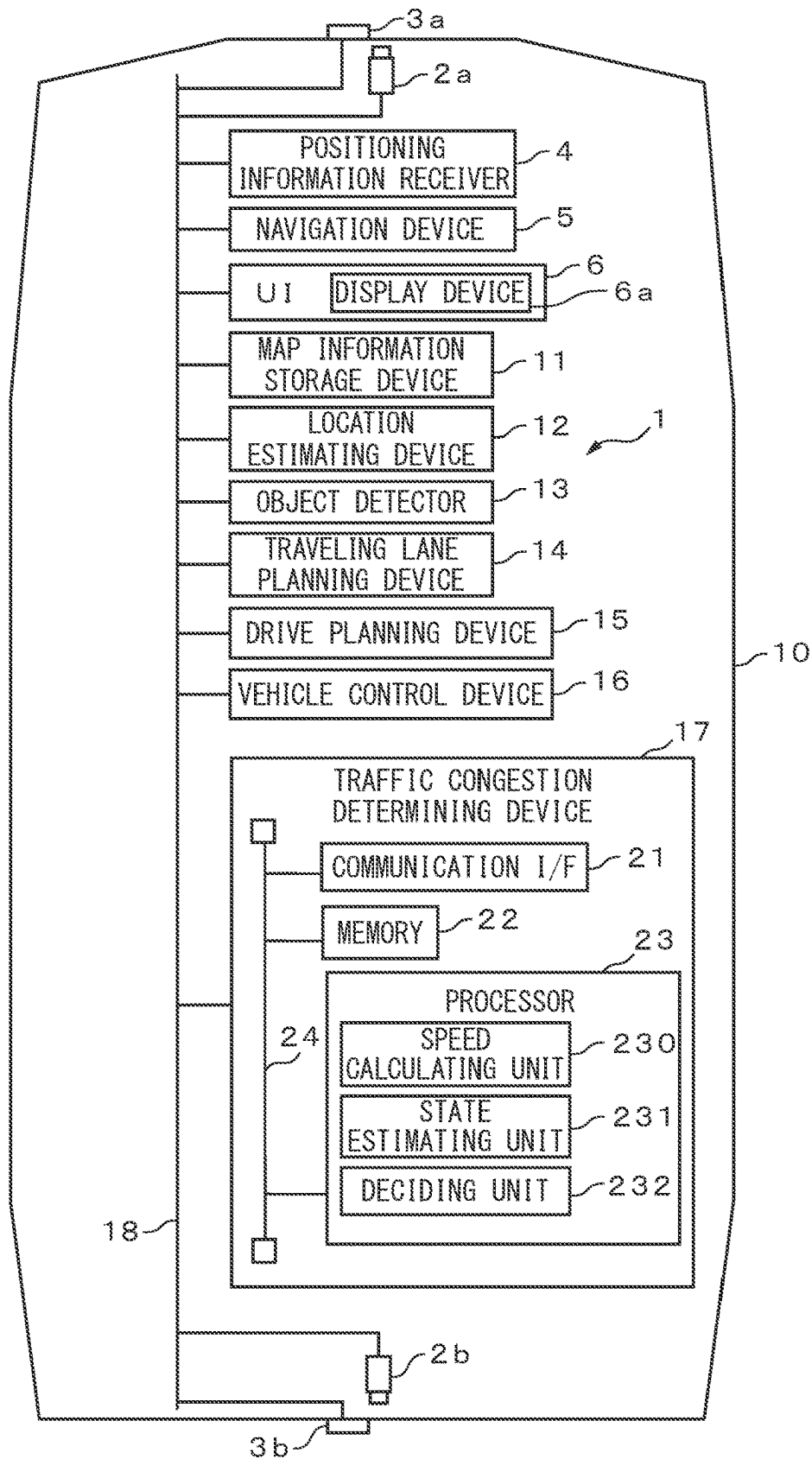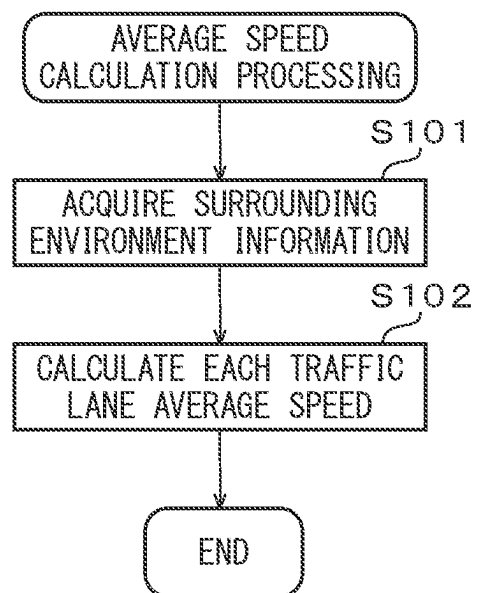
7 Claims, 12 Drawing Sheets

FIG. 1

FIG. 2

FIG. 3

```
┌─────────────────────────────┐
│      AVERAGE  SPEED         │
│  CALCULATION  PROCESSING    │
└─────────────────────────────┘
              │
              ▼           S101
┌─────────────────────────────┐
│    ACQUIRE  SURROUNDING     │
│  ENVIRONMENT  INFORMATION   │
└─────────────────────────────┘
              │           S102
              ▼
┌─────────────────────────────┐
│   CALCULATE  EACH  TRAFFIC  │
│    LANE  AVERAGE  SPEED     │
└─────────────────────────────┘
              │
              ▼
         ┌─────────┐
         │   END   │
         └─────────┘
```

FIG. 4

FIG. 5

```
        ┌─────────────────────────┐
        │   TRAFFIC CONGESTION    │
        │ DETERMINATION PROCESSING│
        └─────────────────────────┘
                     │
                     │        S301
                   ◇ AT OR ◇
              BELOW REFERENCE        No
                SPEED VALUE ───────────────┐
                     ?                      │
                   Yes  S302                │ S303
        ┌─────────────────┐      ┌─────────────────┐
        │  TRAFFIC LANE   │      │  TRAFFIC LANE   │
        │  IS CONGESTED   │      │  NOT CONGESTED  │
        └─────────────────┘      └─────────────────┘
                     │                      │
                     │◄─────────────────────┘
                     │
              ┌────────────┐
              │    END     │
              └────────────┘
```
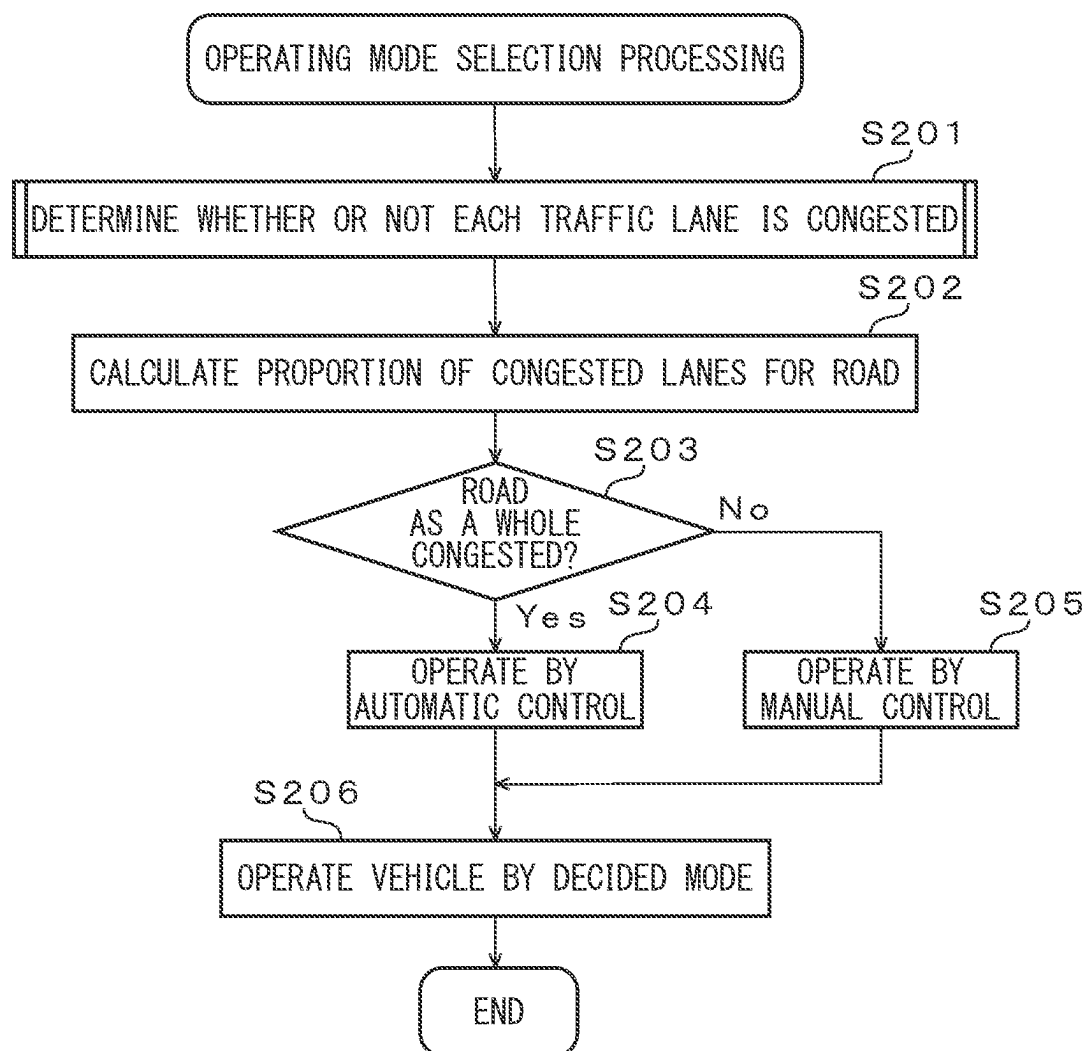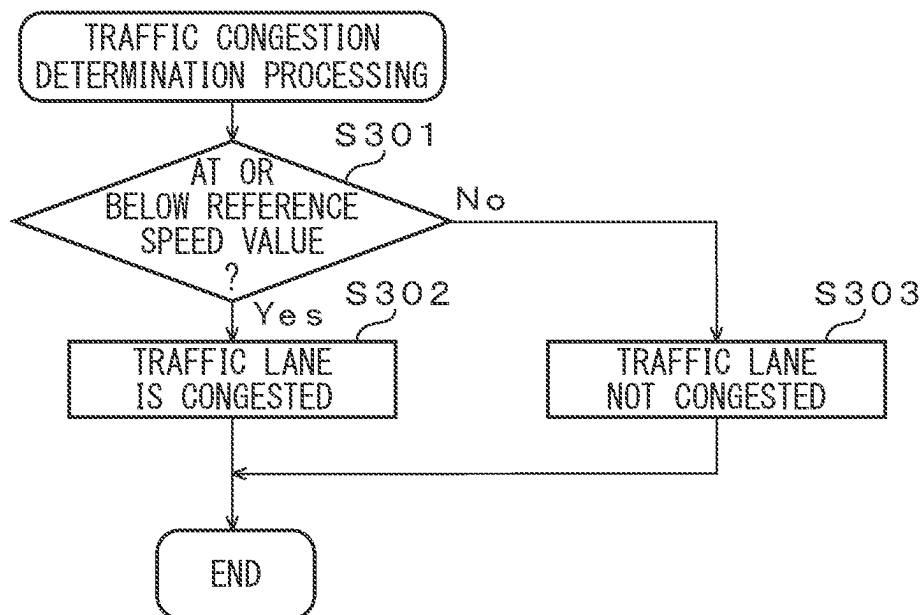
FIG. 6

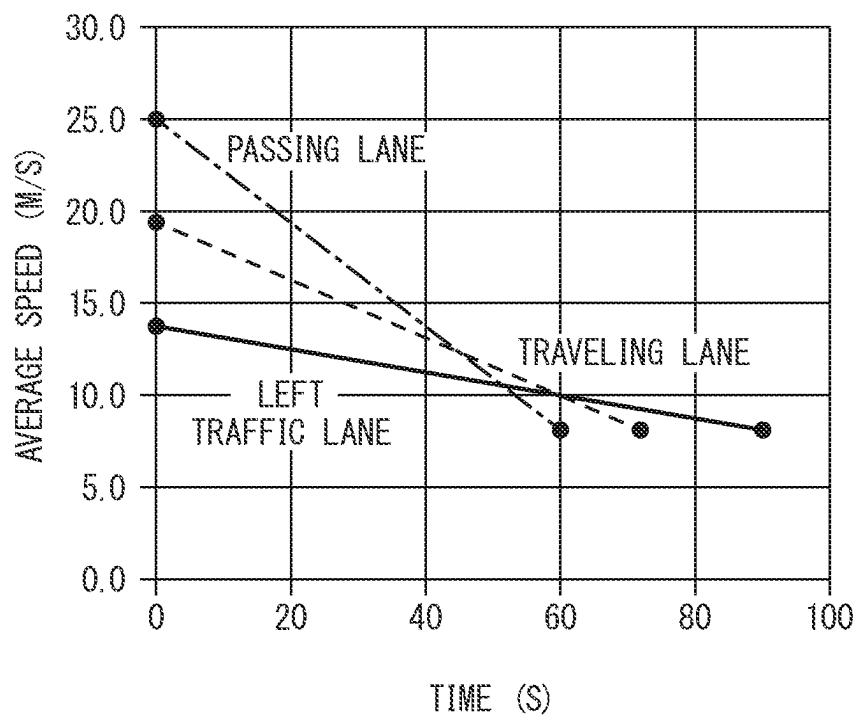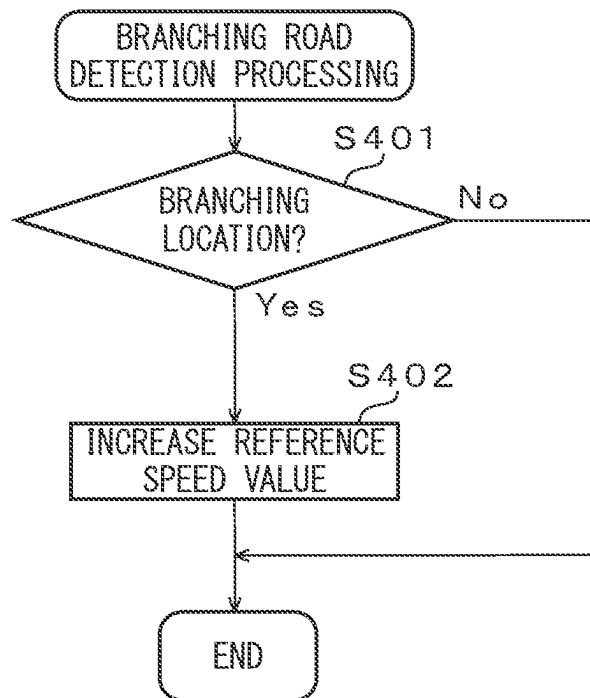|	LEFT TRAFFIC LANE	TRAVELING LANE	PASSING LANE
AVERAGE VALUE FOR TRAFFIC LANE AVERAGE SPEED (KM/S)	50	70	90
REFERENCE DECREASE	15	21	30
REFERENCE SPEED VALUE (KM/S)	35	49	60

FIG. 7

FIG. 8
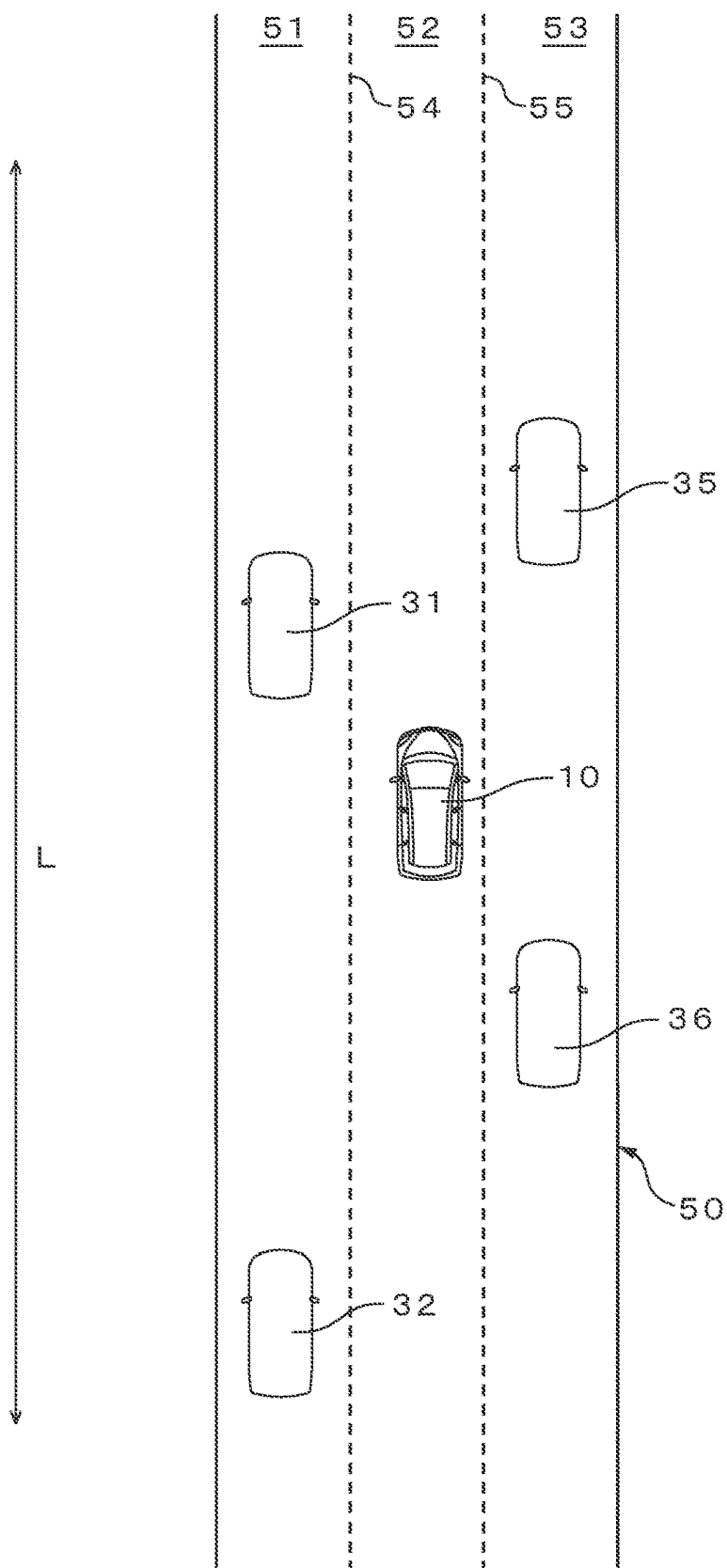
FIG. 9
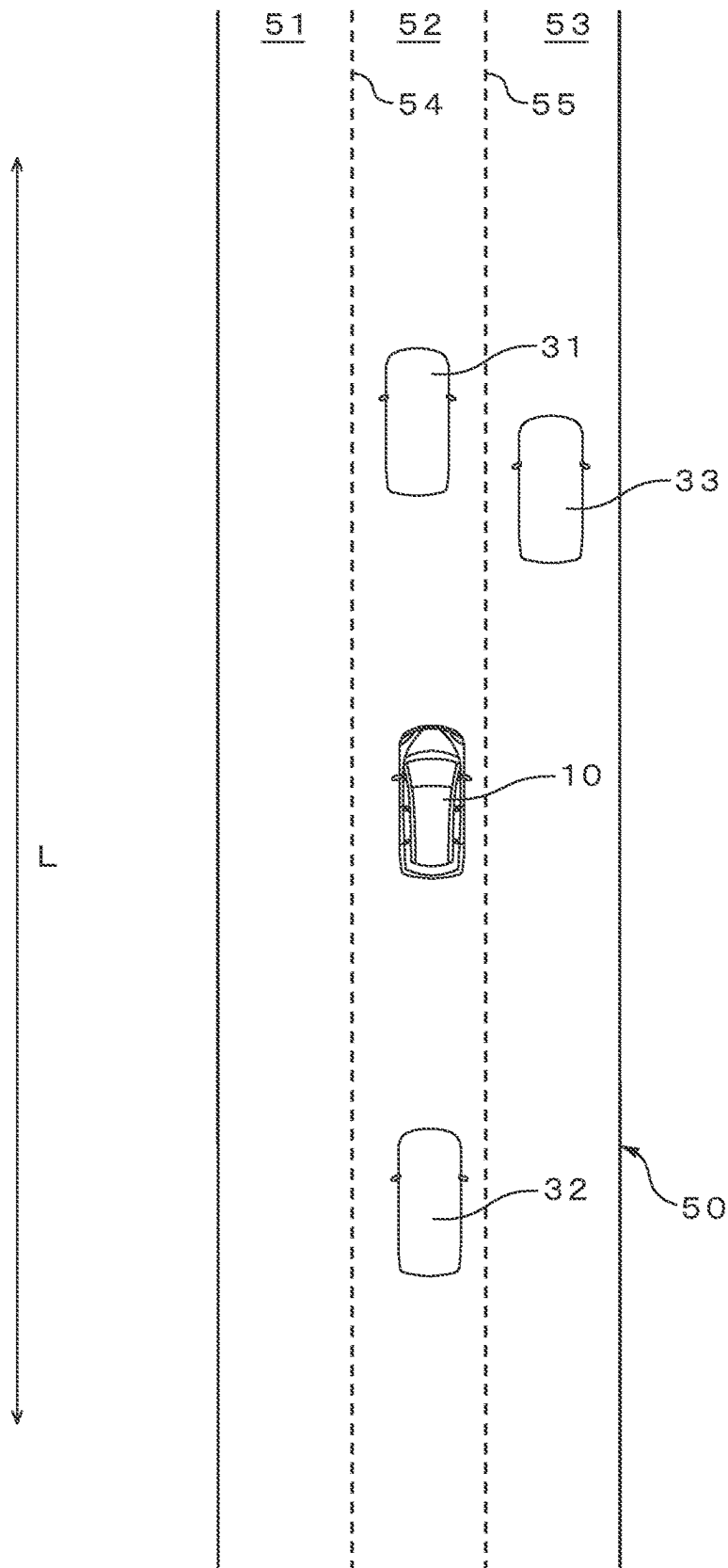
FIG. 10
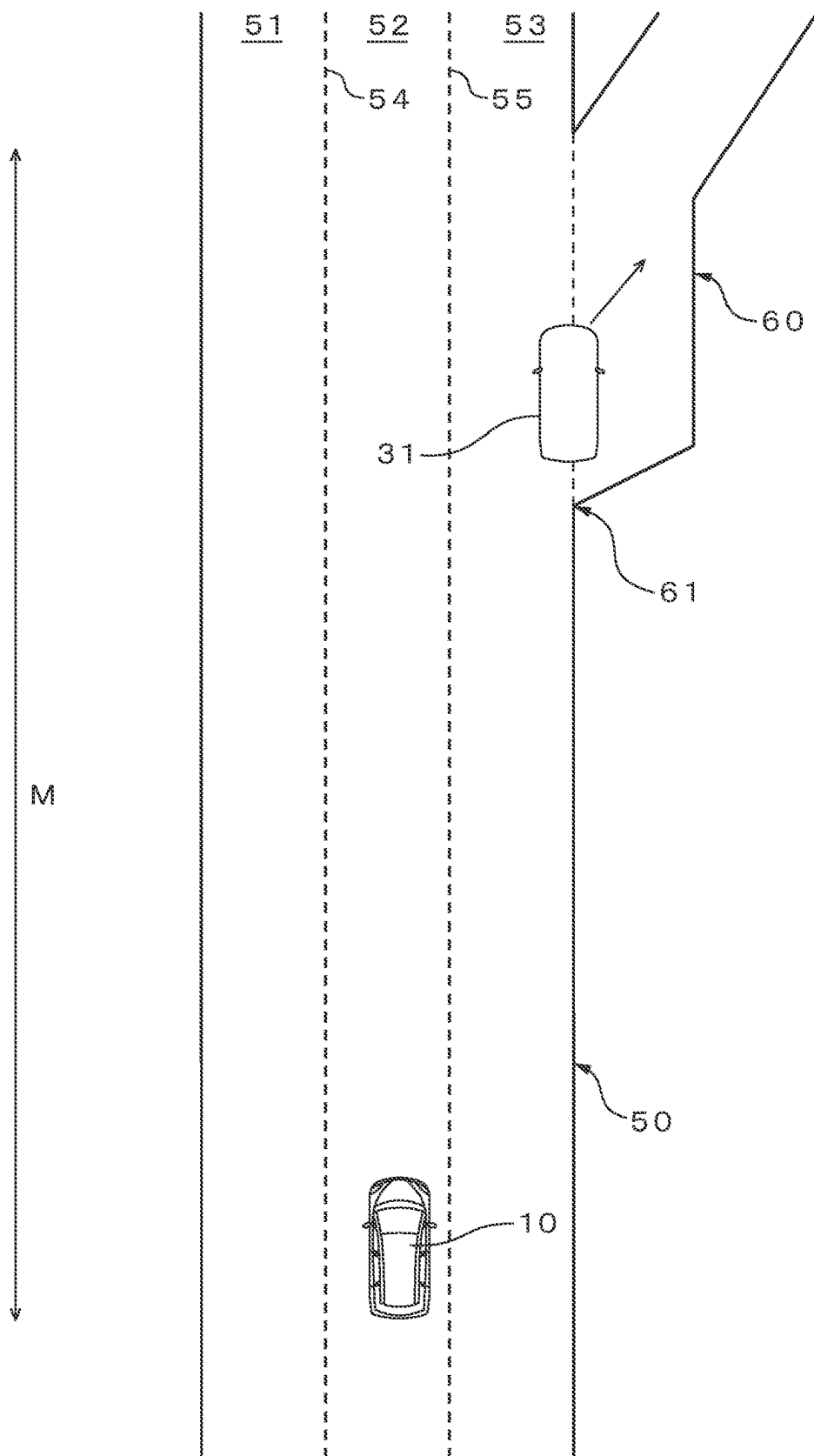
```
        ╭─────────────────────────╮
        │   BRANCHING ROAD        │
        │ DETECTION PROCESSING    │
        ╰─────────────────────────╯
                    │
                    │              S401
                    ▼
              ╱───────────╲              No
          ╱     BRANCHING    ╲─────────────────┐
          ╲     LOCATION?    ╱                  │
              ╲───────────╱                     │
                    │ Yes                        │
                    │                            │
                    │            S402            │
                    ▼                            │
        ┌─────────────────────────┐             │
        │ INCREASE REFERENCE      │             │
        │     SPEED VALUE         │             │
        └─────────────────────────┘             │
                    │                            │
                    │◄───────────────────────────┘
                    ▼
              ╭───────────╮
              │    END     │
              ╰───────────╯
```

FIG. 11

FIG. 12

MERGING ROAD
DETECTION PROCESSING

S501

MERGING LOCATION?   No
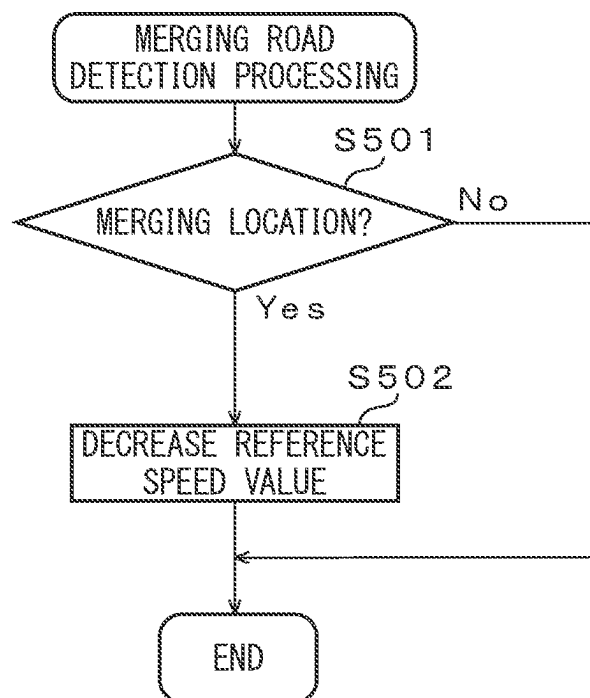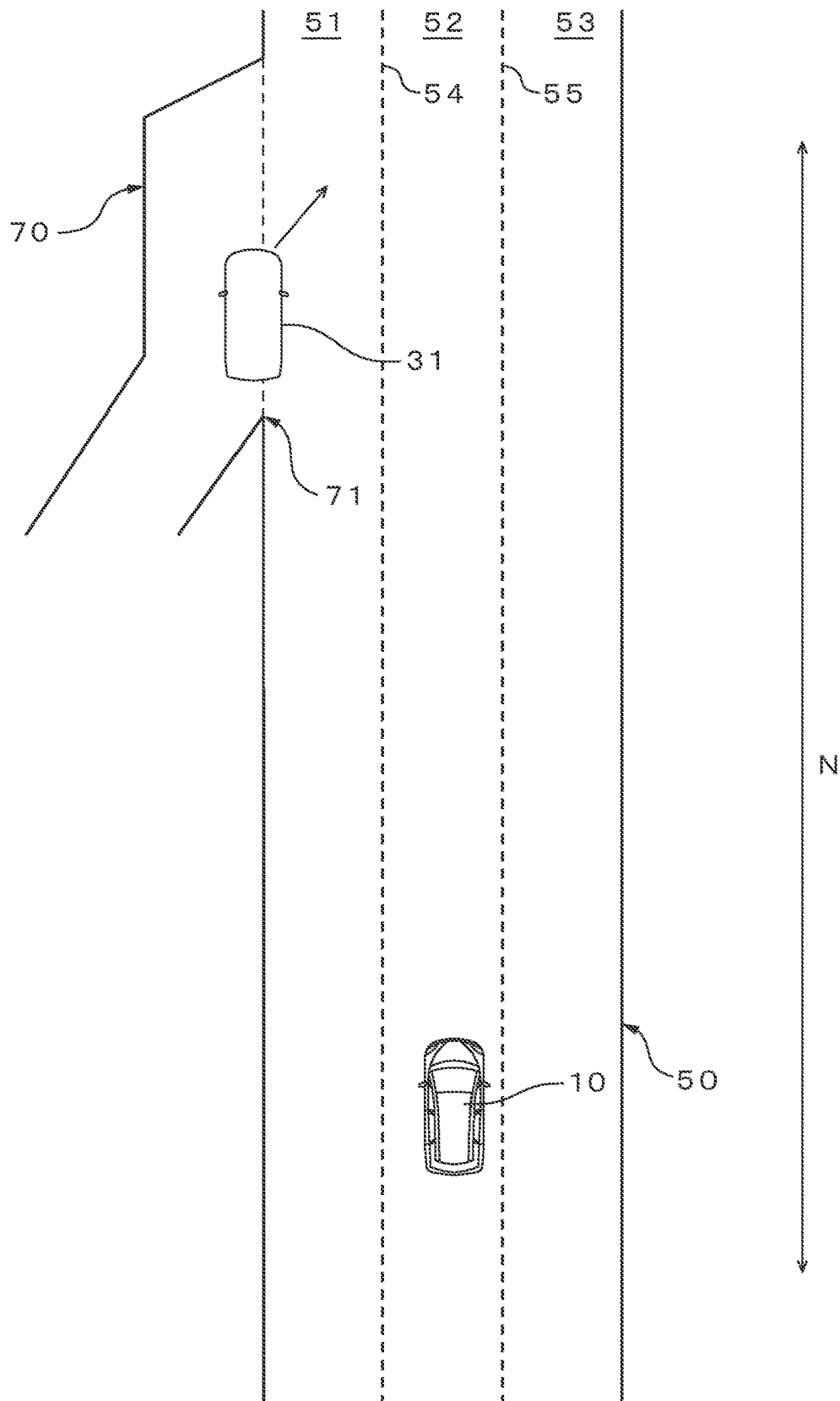
Yes

S502

DECREASE REFERENCE
SPEED VALUE

END

FIG. 13

VEHICLE CONTROL DEVICE, STORAGE MEDIUM STORING COMPUTER PROGRAM FOR VEHICLE CONTROL, AND METHOD FOR CONTROLLING VEHICLE

FIELD

The present disclosure relates to a vehicle control device, a storage medium storing a computer program for vehicle control, and a method for controlling a vehicle.

BACKGROUND

Vehicle-mounted automatic control systems acquire vehicle status information such as speed using a sensor mounted in the vehicle, and control operation of the vehicle based on the vehicle status information. For example, an automatic control system detects the flow of vehicles in a traveling lane in which the vehicle is traveling based on the vehicle speed, and begins automatic control of the vehicle when the speed of the vehicle falls below a predetermined reference speed. This can release the driver from the burden of driving the vehicle when the road is congested, for example.

When the road on which the vehicle is traveling has multiple lanes, the flow of vehicles may differ depending on the traffic lane.

For example, Japanese Unexamined Patent Publication No. 2003-288674 proposes a traffic congestion determining device that uses a millimeter wave sensor installed on a road to measure vehicle speeds, and calculates the average speed for the road as a whole from the number of vehicles passing on each lane and the total speed within the measuring range, determining that the road is congested when the average speed for the road as a whole is lower than a traffic congestion speed.

SUMMARY

However, since vehicle speeds differ between passing lanes and traffic lanes that are not passing lanes, it is possible that an accurate judgment of the state of a road with multiple lanes cannot be made when traffic congestion is determined based on the average speed of the road as a whole.

It is therefore an object of the present disclosure to provide a vehicle control device that estimates the overall state of the road on which the vehicle is traveling based on the average speed of each of its multiple lanes, and can appropriately reflect the state of the road as a whole for controlling the vehicle.

(1) One embodiment of the invention provides a vehicle control device. The vehicle control device has a processor configured to calculate an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed, determine whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimate whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested, and decide to drive the vehicle by automatic control when the traveling road as a whole is congested.

(2) In the vehicle control device of (1), it is preferable that the processor is further configured to determine, for each of the multiple traffic lanes of the traveling road,

that the traffic lane is congested when the traffic lane average speed is at or below a reference speed value set for each traffic lane.

(3) In the vehicle control device of (2), it is preferable that the processor is further configured to set the reference speed value for each traffic lane based on the average value for the traffic lane average speed between predetermined reference time points, for each of the multiple traffic lanes of the traveling road.

(4) In the vehicle control device of (2) or (3), it is preferable that the processor is further configured to increase the reference speed value for each of the multiple traffic lanes of the traveling road, when a branching location where another road branches from the traveling road is within a first range from the current location of the vehicle toward the traveling direction.

(5) In the vehicle control device of any of (2) to (4), it is preferable that the processor is further configured to decrease the reference speed value for each of the multiple traffic lanes of the traveling road, when a merging location where another road merges with the traveling road is within a second range from the current location of the vehicle toward the traveling direction.

(6) According to another embodiment, a computer-readable, non-transitory storage medium is provided which stores a computer program for vehicle control. The computer program for vehicle control causes a processor to execute a process, and the process includes calculating an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed, determining whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimating whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested and deciding to drive the vehicle by automatic control when the traveling road as a whole is congested.

(7) Another embodiment of the invention provides a method for controlling a vehicle. The method for controlling a vehicle is carried out by a vehicle control device and includes calculating an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed, determining whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimating whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested and deciding to drive the vehicle by automatic control when the traveling road as a whole is congested.

Since the vehicle control device of the disclosure estimates the overall state of the road on which the vehicle is traveling based on the average speed of each of its multiple lanes, it can appropriately reflect the overall state of the road for controlling the vehicle.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims. It is to be understood that both the foregoing general description and

the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagram illustrating in overview the operation of a vehicle control system having a traffic congestion determining device of the embodiment.

FIG. 2 is a general schematic drawing of a vehicle in which the traffic congestion determining device of the embodiment is mounted.

FIG. 3 is an example of an operation flow chart for average speed calculation processing by a traffic congestion determining device of the embodiment.

FIG. 4 is an example of an operation flow chart for operating mode selection processing by a traffic congestion determining device of the embodiment.

FIG. 5 is an example of an operation flow chart for traffic congestion determination processing by a traffic congestion determining device according to the embodiment.

FIG. 6 is a table showing reference speed values set for each traffic lane.

FIG. 7 is a diagram illustrating an example of traffic congestion determination processing.

FIG. 8 is a diagram illustrating an example of traffic congestion determination processing.

FIG. 9 is a diagram illustrating another example of traffic congestion determination processing.

FIG. 10 is an example of an operation flow chart for branching road detection processing by a traffic congestion determining device.

FIG. 11 is a diagram illustrating branching road detection processing by a traffic congestion determining device.

FIG. 12 is an example of an operation flow chart for merging road detection processing by a traffic congestion determining device.

FIG. 13 is a diagram illustrating merging road detection processing by a traffic congestion determining device.

DESCRIPTION OF EMBODIMENTS

FIG. 1 is a diagram illustrating in overview the operation of a vehicle control system having a traffic congestion determining device 17 of the embodiment. The traffic congestion determining device 17 is an example of the vehicle control device. Operation relating to traffic congestion determination processing by the traffic congestion determining device 17 disclosed herein will now be described in overview with reference to FIG. 1.

The vehicle 10 has an automatic control operating mode in which the vehicle 10 is operated by automatic control, and a manual control operating mode in which the driver operates the vehicle manually. The vehicle 10 is currently being controlled in the manual control operating mode, with the driver operating the vehicle 10. The vehicle 10 may also be an autonomous vehicle.

The vehicle 10 is traveling on one traffic lane 52 of the road 50 having traffic lanes 51, 52, 53. The traffic lane 51 and traffic lane 52 are divided by a lane marking line 54, and the traffic lane 52 and traffic lane 53 are divided by a lane marking line 55.

The traffic lane 51 is the lane to the left of the traffic lane 52 in which the vehicle 10 is traveling, with other vehicles 31, 32 traveling in the traffic lane 51. Another vehicle 33 is located ahead of the vehicle 10 in the traffic lane 52 in which the vehicle 10 is traveling, and another vehicle 34 is also

located behind the vehicle 10. The traffic lane 53 is a passing lane, and other vehicles 35, 36 are traveling in the traffic lane 53.

The traffic congestion determining device 17 of the vehicle 10 uses a sensor mounted in the vehicle 10 to acquire vehicle status information for the vehicle 10, and to calculate the speed of the vehicle 10 traveling in the traffic lane 52.

The traffic congestion determining device 17 also uses a sensor mounted in the vehicle 10 to acquire surrounding environment information for the vehicle 10, and based on the information, calculates the speeds of the other vehicles traveling in the traffic lanes 51, 52, 53, within a predetermined range L from the vehicle 10.

The traffic congestion determining device 17 calculates the average speed of the other vehicles 31, 32 traveling in the traffic lane 51, as the average speed for the traffic lane 51. The traffic congestion determining device 17 also calculates the average speed of the vehicle 10 and the other vehicles 33, 34 traveling in the traffic lane 52, as the average speed for the traffic lane 52. The traffic congestion determining device 17 further calculates the average speed of the other vehicles 35, 36 traveling in the traffic lane 53, as the average speed for the traffic lane 53.

The traffic congestion determining device 17 determines whether or not the traffic lanes are congested based on the traffic lane average speed for each of the three traffic lanes 51, 52, 53 of the road 50. In the example shown in FIG. 1, the traffic congestion determining device 17 determines that each of the three traffic lanes 51, 52, 53 of the road 50 are congested.

The traffic congestion determining device 17 also estimates whether or not the entire road 50 is congested, based on the proportion of congested traffic lanes in the traveling road 50. In the example shown in FIG. 1, all of the traffic lanes 51, 52, 53 of the road 50 are congested, and therefore the traffic congestion determining device 17 estimates that the road 50 as a whole is congested.

Since the road 50 as a whole is congested, the traffic congestion determining device 17 decides to operate the vehicle 10 by the automatic control and selects control of the vehicle 10 by the automatic control operating mode. The traffic congestion determining device 17 notifies the driver that the operation will switch from the manual control operating mode to the automatic control operating mode, and begins operating the vehicle 10 in the automatic control operating mode.

When the entire road 50 is not congested, on the other hand, the traffic congestion determining device 17 selects the control of the vehicle 10 by the manual control operating mode. The vehicle 10 continues the current state of the operation in the manual control operating mode.

For example, even with a high average speed of the traffic lane 52 in which the vehicle 10 is traveling, it can happen that the average speed in the traffic lane 53 which is a passing lane is actually decreasing, leading to start of traffic congestion for the entire road. In such cases, the traffic congestion determining device 17 is able to rapidly detect that traffic congestion is starting for the entire road.

Since the traffic congestion determining device 17 estimates the state of the entire road 50 based on the average speed of each of the multiple traffic lanes 51, 52, 53 of the road 50, the traffic congestion determining device 17 can rapidly detect start of congestion for the road 50 as a whole, allowing the control of the vehicle 10 to appropriately reflect the state of the road 50 as a whole.

FIG. 2 is a general schematic drawing of a vehicle 10 in which the vehicle control system 1 is mounted. The vehicle

control system **1** has cameras **2a**, **2b**, LiDAR sensors **3a**, **3b**, a positioning information receiver **4**, a navigation device **5**, a user interface (UI) **6**, a map information storage device **11**, a location estimating device **12**, an object detector **13**, a traveling lane planning device **14**, a drive planning device **15**, a vehicle control device **16** and a traffic congestion determining device **17**. The vehicle control system **1** may also have a radar sensor, as another distance sensor (not shown) for measurement of the distance of the vehicle **10** to surrounding objects.

The cameras **2a**, **2b**, LiDAR sensors **3a**, **3b**, positioning information receiver **4**, navigation device **5**, UI **6**, map information storage device **11**, location estimating device **12**, object detector **13**, traveling lane planning device **14**, drive planning device **15**, vehicle control device **16** and traffic congestion determining device **17** are connected in a communicable manner through an in-vehicle network **18** that conforms to controller area network standards.

The cameras **2a**, **2b** are examples of imaging units provided in the vehicle **10**. The camera **2a** is mounted inside the vehicle **10** and directed toward the front of the vehicle **10**. The camera **2b** is mounted inside the vehicle **10** and directed toward the rear of the vehicle **10**. Each of the cameras **2a**, **2b**, for example, captures a camera image in which the environment of a predetermined region ahead of or behind the vehicle **10** is shown, at a predetermined cycle. The camera image can show the road in the predetermined region ahead of or behind the vehicle **10**, and road features such as surface lane marking lines on the road. A camera image captured by the camera **2a** may also have other vehicles located at the left front, front and right front of the vehicle **10**. A camera image captured by the camera **2b** may have other vehicles located at the left rear, rear and right rear of the vehicle **10**. The cameras **2a**, **2b** each have a 2D detector composed of an array of photoelectric conversion elements with visible light sensitivity, such as a CCD or C-MOS, and an imaging optical system that forms an image of the photographed region on the 2D detector.

Each time a camera image is captured, the cameras **2a**, **2b** output camera images and camera image photograph times at which the camera images were captured, through the in-vehicle network **18** to the location estimating device **12** and object detector **13**. The camera images are also used for processing at the location estimating device **12** to estimate the location of the vehicle **10**. At the object detector **13**, the camera images are used for processing to detect other objects surrounding the vehicle **10**.

Each of the LiDAR sensors **3a**, **3b** is mounted on the outer side of the vehicle **10**, for example, being directed toward the front or rear of the vehicle **10**. The LiDAR sensors **3a**, **3b** respectively synchronize and emit a pulsed laser ahead and to the rear of the vehicle **10**, at a reflected wave information acquisition time set with a predetermined cycle, and receive a reflected wave that has been reflected from a reflector. The time required for the reflected wave to return contains information for the distance between the vehicle **10** and other objects located in the direction in which the laser has been emitted. Each of the LiDAR sensors **3a**, **3b** outputs the reflected wave information that includes the laser emission direction and the time required for the reflected wave to return, together with the reflected wave information acquisition time at which the laser was emitted, through the in-vehicle network **18** to the object detector **13**. At the object detector **13**, the reflected wave information is used for processing to detect other objects surrounding the vehicle **10**.

The positioning information receiver **4** outputs positioning information that represents the current location of the vehicle **10**. The positioning information receiver **4** may be a GNSS receiver, for example. The positioning information receiver **4** outputs positioning information and the positioning information acquisition time at which the positioning information has been acquired, to the navigation device **5** and map information storage device **11**, etc., each time positioning information is acquired at a predetermined receiving cycle.

Based on the navigation map information, the destination location of the vehicle **10** input through the UI **6**, and positioning information representing the current location of the vehicle **10** input from the positioning information receiver **4**, the navigation device **5** creates a navigation route from the current location to the destination location of the vehicle **10**. When the destination location has been newly set or the current location of the vehicle **10** has exited the navigation route, the navigation device **5** creates a new navigation route for the vehicle **10**. Every time a navigation route is created, the navigation device **5** outputs the navigation route to the location estimating device **12** and the traveling lane planning device **14**, etc., via the in-vehicle network **18**.

The UI **6** is an example of the notification unit. The UI **6**, controlled by the navigation device **5** and traffic congestion determining device **17**, notifies the driver of the vehicle **10** traveling information and provides a control change notification indicating that operation of the vehicle **10** is to change from the manual control to the automatic control. The UI **6** also generates an operation signal in response to the operation of the vehicle **10** by the driver. The traveling information of the vehicle **10** includes information relating to the current location of the vehicle and the current and future route of the vehicle, such as the navigation route. The UI **6** has a display device **6a** such as a liquid crystal display or touch panel, for display of the traveling information. The UI **6** may also have an acoustic output device (not shown) to notify the driver of traveling information. The UI **6** also has a touch panel or operating button, for example, as an input device for inputting operation information from the driver to the vehicle **10**. The operation information may be, for example, a destination location, transit points, vehicle speed or other control information for the vehicle **10**. The UI **6** outputs the input operation information to the navigation device **5**, the vehicle control device **16** and the traffic congestion determining device **17**, etc., via the in-vehicle network **18**.

The map information storage device **11** stores wide-area map information for a relatively wide area (an area of 10 km^2 to 30 km^2, for example) that includes the current location of the vehicle **10**. The map information preferably has high-precision map information including three-dimensional information for the road surface, information for the types and locations of structures and road features such as road lane marking lines, and the legal speed limit for the road. The map information storage device **11** receives the wide-area map information from an external server via a base station, by wireless communication through a wireless communication device (not shown) mounted in the vehicle **10**, in relation to the current location of the vehicle **10**, and stores it in the storage device. Each time positioning information is input from the positioning information receiver **4**, the map information storage device **11** refers to the stored wide-area map information and outputs map information for a relatively narrow area including the current location represented by the positioning information (for example, an

area of 100 m² to 10 km²), through the in-vehicle network 18 to the location estimating device 12, object detector 13, traveling lane planning device 14, drive planning device 15, vehicle control device 16 and traffic congestion determining device 17, etc.

The location estimating device 12 estimates the location of the vehicle 10 at the camera image photograph time, based on the road features surrounding the vehicle 10 represented in the camera image captured by the camera 2a. For example, the location estimating device 12 compares lane marking lines identified in the camera image with lane marking lines represented in the map information input from the map information storage device 11, and determines the estimated location and estimated declination of the vehicle 10 at the camera image photograph time. The location estimating device 12 estimates the road traveling lane where the vehicle 10 is located, based on the lane marking lines represented in the map information and on the estimated location and estimated declination of the vehicle 10. Each time the estimated location, estimated declination and traveling lane of the vehicle 10 are determined at the camera image photograph time, the location estimating device 12 outputs this information to the object detector 13, traveling lane planning device 14, drive planning device 15, vehicle control device 16 and traffic congestion determining device 17, etc. The location estimating device 12 may estimate the location of the vehicle 10 based on the two camera images taken by the camera 2a and camera 2b.

The object detector 13 detects other objects at the left front, front and right front of the vehicle 10, and their type, based on the camera image captured by the camera 2a. The object detector 13 also detects other objects at the left rear, rear and right rear of the vehicle 10, and their type, based on the camera image captured by the camera 2b. Other objects also include other vehicles traveling around the vehicle 10. The object detector 13 has a classifier that detects objects represented in the camera image, by inputting the image, for example. The classifier may use a deep neural network (DNN) that has been trained to detect objects represented in input images, for example. The object detector 13 used may also be a classifier other than a DNN. For example, the classifier used by the object detector 13 may be a support vector machine (SVM) that has been trained to output a confidence factor for representation of objects to be detected in the window, with the input being a feature descriptor (such as Histogram of Oriented Gradients, HOG, for example) calculated from a window set in the camera image. Alternatively, the object detector 13 may detect an object region by template matching between the image and a template in which an object to be detected is represented.

The object detector 13 also detects other objects at the left front, front and right front of the vehicle 10, based on reflected wave information output by the LiDAR sensor 3a, and detects other objects at the left rear, rear and right rear of the vehicle 10, based on reflected wave information output by the LiDAR sensor 3b. The object detector 13 can also determine the orientation of another object with respect to the vehicle 10 based on the location of the other object in the camera image, and may determine the distance between the other object and the vehicle 10, based on the orientation and on the reflected wave information output by the LiDAR sensors 3a, 3b. The object detector 13 estimates the location of the other object represented in a world coordinate system based on the current location of the vehicle 10, and the distance of the other object from the vehicle 10 and its orientation, for example. The object detector 13 also tracks other objects to be detected from an updated image, by

matching other objects detected in the updated camera image with objects detected in previous images, according to a tracking process based on optical flow. The object detector 13 also calculates the trajectory of another object being tracked, based on the location of the object in an image updated from a previous image, represented in the world coordinate system. The object detector 13 estimates the speed of another object with respect to the vehicle 10, based on changes in the location of the object over the course of time. The object detector 13 can also estimate the acceleration of another object based on changes in the speed of the object over the course of time. In addition, the object detector 13 identifies the traveling lanes in which the other objects are traveling, based on the lane marking lines represented in the map information and the locations of the objects. The object detector 13 also determines, for example, whether another object is traveling in a traffic lane defined by two mutually adjacent lane marking lines situated on either side of the center location of the other object in the lateral direction. The object detector 13 outputs object detection information which includes information representing the types of other objects that were detected, information indicating their locations, and also information indicating their speeds, accelerations and traveling lanes, to the traveling lane planning device 14, drive planning device 15, vehicle control device 16 and traffic congestion determining device 17, etc. The detection area in which other objects can be detected by the object detector 13 is set based on the conditions and resolving power of the cameras 2a, 2b and LiDAR sensors 3a, 3b.

At a traveling lane-planning creation time set in a predetermined cycle, the traveling lane planning device 14 selects a traffic lane on the road on which the vehicle 10 is traveling, within the nearest driving zone (for example, 10 km) selected from the navigation route, based on the map information, the navigation route and surrounding environment information and the current location of the vehicle 10, and creates a traveling lane plan representing the scheduled traveling lane for traveling of the vehicle 10. For example, the traveling lane planning device 14 creates a traveling lane plan for the vehicle 10 to travel on a traffic lane other than a passing traffic lane. Each time a traveling lane plan is created, the traveling lane planning device 14 outputs the traveling lane plan to the drive planning device 15.

The traveling lane planning device 14 also determines whether or not a lane change is necessary within the nearest driving zone selected from the navigation route, based on the traveling lane plan, the map information, the navigation route and the current location of the vehicle 10, and generates a lane change plan in accordance with the assessment results. The lane change plan includes a lane change schedule zone in the lane in which the vehicle 10 is traveling, where it is scheduled to move to an adjacent lane. Specifically, the traveling lane planning device 14 determines whether or not a lane change is necessary for moving to a traffic lane toward the destination location of the vehicle 10, based on the navigation route and the current location of the vehicle 10. The traveling lane planning device 14 determines whether or not the vehicle 10 is approaching another road that merges ahead from the traveling road on which it is currently traveling (merge), or the vehicle 10 is exiting onto another road branching out ahead from the traveling road (branch). Since merging and branching involve movement of the vehicle from a lane of the traveling road to a lane in another road, a lane change is carried out. The traveling lane planning device 14 may further utilize surrounding environment information or vehicle status information to determine

whether or not a lane change is necessary. The surrounding environment information includes the locations and speeds of other vehicles traveling around the vehicle **10**. The vehicle status information includes the current location of the vehicle **10**, and the vehicle speed, acceleration and traveling direction. The traveling lane planning device **14** also generates a lane change plan in response to a driver request. Information indicating the speed of the vehicle **10** and its acceleration is acquired using a sensor (not shown) mounted on the vehicle **10**.

At a driving plan creation time set with a predetermined cycle, the drive planning device **15** carries out driving plan processing in which it creates a driving plan representing the scheduled traveling trajectory of the vehicle **10** up until a predetermined time (for example, 5 seconds), based on the traveling lane plan, the map information, the current location of the vehicle **10**, the surrounding environment information and the vehicle status information. The driving plan is represented as a combination of the target location of the vehicle **10** and the target vehicle speed at the target location, at each time from the current time until the predetermined time. The cycle in which the driving plan is created is preferably shorter than the cycle in which the traveling lane plan is created. The drive planning device **15** generates a driving plan to maintain a spacing of at least a predetermined distance between the vehicle **10** and other vehicles. The drive planning device **15** outputs the driving plan to the vehicle control device **16** for each driving plan generated.

The vehicle control device **16** has the automatic control operating mode in which the vehicle **10** is operated by the automatic control, and the manual control operating mode in which the driver operates the vehicle manually. When the automatic control operating mode has been applied, the vehicle control device **16** enables the automatic control of all vehicle operation including driving, braking and steering, based on the driving plan.

When the vehicle **10** is operated in the automatic control operating mode, the vehicle control device **16** controls each unit of the vehicle **10** based on the current location of the vehicle **10** and the vehicle speed and yaw rate, as well as on the driving plan generated by the drive planning device **15**. For example, the vehicle control device **16** determines the steering angle, acceleration and angular acceleration of the vehicle **10** according to the driving plan and the speed and yaw rate of the vehicle **10**, and sets the amount of steering, and the accelerator or brake level so as to match that steering angle, accelerator level and angular acceleration. The vehicle control device **16** also outputs a control signal corresponding to a set steering amount, to an actuator (not shown) that controls the steering wheel for the vehicle **10**, via the in-vehicle network **18**. The vehicle control device **16** also determines the amount of fuel injection according to a set accelerator level, and outputs a control signal corresponding to the amount of fuel injection to a drive unit (not shown) of the engine of the vehicle **10**, via the in-vehicle network **18**. Alternatively, the vehicle control device **16** may output a control signal corresponding to a set brake level to the brake (not shown) of the vehicle **10**, via the in-vehicle network **18**.

In the manual control operating mode, on the other hand, the driver can use the steering wheel, accelerator pedal and brake pedal (not shown) for traveling by the manually controlled operation of the vehicle. When the vehicle **10** is operated by the manual control, the vehicle control device **16** controls the steering wheel, drive unit or brake according to the amount of driver-operated steering, accelerator or brake level. In the manual control operating mode, at least

one operation of the vehicle **10** from among driving, braking and steering is controlled manually. A change from the automatic control to manual control is possible, depending on the request by the driver.

When the vehicle control device **16** in the automatic control operating mode has judged that the vehicle **10** cannot safely travel by the automatic control, and the driver has acknowledged the control change notification that a change from the automatic control to the manual control is required, operation of the vehicle **10** is switched from the automatic control operating mode to the manual control operating mode. Under conditions where the vehicle **10** cannot safely travel by the automatic control, therefore, the driver can use the steering wheel, accelerator pedal and brake pedal (not shown) for traveling by the manually controlled operation of the vehicle. The driver may also notify the vehicle control device **16** of a control change request for request of a change from the automatic control to the manual control, to switch the operation of the vehicle **10** from the automatic control operating mode to the manual control operating mode.

When the vehicle control device **16** in the manual control operating mode has estimated that the entire road in which the vehicle **10** is traveling is congested, it gives the driver a control change notification proposing a change from the manual control to the automatic control. Once the control change notification has been acknowledged by the driver, the vehicle control device **16** switches the operation of the vehicle **10** from the currently applied manual control operating mode to the automatic control operating mode. As a result, the operation of the vehicle is controlled by the vehicle control device **16**, releasing the driver from the burden of driving the vehicle when the road is congested.

The traffic congestion determining device **17** carries out speed calculation processing, state estimation processing and decision processing. For this purpose, the traffic congestion determining device **17** has a communication interface (IF) **21**, a memory **22** and a processor **23**. The communication interface **21**, memory **22** and processor **23** are connected via signal wires **24**. The communication interface **21** has an interface circuit to connect the traffic congestion determining device **17** with the in-vehicle network **18**.

All or some of the functions of the traffic congestion determining device **17** are functional modules driven by a computer program operating on the processor **23**, for example. The processor **23** has a speed calculating unit **230**, a state estimating unit **231** and a selecting unit **232**. Alternatively, the functional module of the processor **23** may be a specialized computing circuit in the processor **23**. The processor **23** comprises one or more CPUs (Central Processing Units) and their peripheral circuits. The processor **23** may also have other computing circuits such as a logical operation unit, numerical calculation unit or graphic processing unit. The memory **22** is an example of a memory unit, and it has a volatile semiconductor memory and a non-volatile semiconductor memory, for example. The memory **22** stores an application computer program and various data to be used for information processing carried out by the processor **23** of each device. Other details regarding operation of the traffic congestion determining device **17** are described below.

In FIG. **2**, the map information storage device **11**, location estimating device **12**, object detector **13**, traveling lane planning device **14**, drive planning device **15**, vehicle control device **16** and traffic congestion determining device **17**, were explained as separate devices, but all or some of them may be constructed in a single device.

FIG. **3** is an example of an operation flow chart for average speed calculation processing by the traffic congestion determining device **17** of the embodiment. The average speed calculation processing by the traffic congestion determining device **17** will now be explained with reference to FIG. **3**. The traffic congestion determining device **17** carries out the average speed calculation processing according to the operation flow chart shown in FIG. **3**, at an average speed calculating time having a predetermined cycle.

First, the speed calculating unit **230** acquires the speeds of the other vehicles traveling in the traffic lanes of the road on which the vehicle **10** is traveling, from the object detector **13**, as surrounding environment information (step S**101**). The speed calculating unit **230** also acquires information indicating the speed of the vehicle **10**, as vehicle status information, from a sensor (not shown) mounted on the vehicle **10**.

The speed calculating unit **230** then calculates the traffic lane average speed for each traffic lane of the road on which the vehicle **10** is traveling, within a predetermined range L from the vehicle **10**, and the series of processing steps is complete (step S**102**). Based on map information, the speed calculating unit **230** acquires the number of traffic lanes on the road on which the vehicle **10** is traveling. The speed calculating unit **230** also acquires the speeds of the other vehicles traveling in each of the traffic lanes of the road on which the vehicle **10** is traveling, from the object detector **13**. The predetermined range L corresponds to a detection range in which the object detector **13** is able to detect other vehicles.

From among the traffic lanes of the road on which the vehicle **10** is traveling, the speed calculating unit **230** calculates the average value for the speeds of the other vehicles traveling on traffic lanes other than the traffic lane in which the vehicle **10** is traveling, as the traffic lane average speed for each. For the traffic lane in which the vehicle **10** is traveling, the speed calculating unit **230** calculates the average value for the speed of the vehicle **10** and the speeds of the other vehicles traveling in that traffic lane, as the traffic lane average speed. The speed calculating unit **230** may also use the most recent average speed for each vehicle as the speed of the vehicle **10** and the speeds of the other vehicles. The most recent average speed may be the average speed for the previous 5 to 10 seconds, for example. When the road on which the vehicle **10** is traveling has only a single lane, the speed calculating unit **230** calculates the traffic lane average speed for the lane in which the vehicle **10** is traveling.

FIG. **4** is an example of an operation flow chart for operating mode selection processing by the traffic congestion determining device **17** of the embodiment. The operating mode selection processing by the traffic congestion determining device **17** will now be explained with reference to FIG. **4**. When the vehicle **10** is being operated in the manual control operating mode, the traffic congestion determining device **17** carries out vehicle the control processing according to the operation flow chart shown in FIG. **4**, at an operating mode selection time having a predetermined cycle. The cycle for the operating mode selection time is preferably equal to or longer than the cycle for the average speed calculating time.

First, the state estimating unit **231** determines whether or not the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the road on which the vehicle **10** is traveling (step S**201**). The state estimating unit **231** determines that traffic lanes without any other traveling vehicles, among the traffic lanes other

than the traffic lane in which the vehicle **10** is traveling, are non-congested traffic lanes. When the road on which the vehicle **10** is traveling has only a single lane, the state estimating unit **231** determines whether or not the traffic lane in which the vehicle **10** is traveling is congested. The details regarding traffic congestion determination processing by the state estimating unit **231** will be described below.

The state estimating unit **231** then calculates the proportion P of congested lanes within the road on which the vehicle **10** is traveling (step S**202**). For example, the state estimating unit **231** calculates the proportion P of congested lanes to be the number n of traffic lanes determined to be congested among the traffic lanes of the road on which the vehicle **10** is traveling, divided by the number m of traffic lanes of the road on which the vehicle **10** is traveling (n/m), multiplied by 100 (n/m*100).

The state estimating unit **231** then estimates whether or not the road as a whole is congested, based on the proportion P of congested lanes in the road on which the vehicle **10** is traveling (step S**203**). The state estimating unit **231** determines that the road as a whole is congested when the proportion P of congested lanes in the road on which the vehicle **10** is traveling is at least a predetermined reference proportion. The predetermined reference proportion may be 50%, for example. However, the predetermined reference proportion may alternatively be a different value.

The state estimating unit **231** may also change the predetermined reference proportion based on the most recent average speed of the vehicle **10**. When the average speed of the vehicle **10** is faster than the predetermined reference speed, the predetermined reference proportion (such as 50%) may be changed to a lower value. When the average speed of the vehicle **10** is slower than the predetermined reference speed, on the other hand, the predetermined reference proportion (such as 50%) may be changed to a higher value.

When the road as a whole is congested (step S**203**—Yes), the deciding unit **232** decides to operate the vehicle **10** by the automatic control (step S**204**). The deciding unit **232** selects the operation of the vehicle **10** in the automatic control operating mode. Since the vehicle **10** is currently being operated in the manual control operating mode, the deciding unit **232** gives the driver of a control change notification via the UI **6**, proposing to switch from the manual control to the automatic control. Once the control change notification has been acknowledged by the driver through the UI **6**, the deciding unit **232** controls the vehicle control device **16** so as to begin operation of the vehicle **10** in the automatic control operating mode (step S**206**). When the control change notification has not been acknowledged by the driver through the UI **6**, the vehicle control device **16** continues the current state of control of the vehicle **10** in the manual control operating mode.

When the road as a whole is not congested (step S**203**—No), on the other hand, the deciding unit **232** decides to operate the vehicle **10** by the manual control (step S**205**). The deciding unit **232** selects the control of the vehicle **10** in the manual control operating mode.

The vehicle control device **16** continues the current state of control of the vehicle **10** in manual control operating mode (step S**206**).

FIG. **5** is an example of an operation flow chart for traffic congestion determination processing by the traffic congestion determining device **17** of the embodiment. The traffic congestion determination processing by the state estimating unit **231** will now be described with reference to FIG. **4**.

First, the state estimating unit **231** determines whether or not the traffic lane average speed is at or below the reference speed value set for each traffic lane, for each of the multiple traffic lanes of the road **50** on which the vehicle **10** is traveling (step S**301**).

When the traffic lane average speed is at or below the reference speed value set for each traffic lane (step S**301**—Yes), the state estimating unit **231** determines that the traffic lane is congested (step S**302**).

If the traffic lane average speed is not at or below the reference speed value set for each traffic lane (step S**301**—No), on the other hand, the state estimating unit **231** determines that the traffic lane is not congested (step S**303**).

FIG. **6** is a table showing reference speed values set for each traffic lane. When the road **50** on which the vehicle **10** is traveling has three traffic lanes **51**, **52**, **53**, as in the example shown in FIG. **1**, the state estimating unit **231** sets a reference decrease for each of the left traffic lane **51**, center traffic lane **52** and passing lane **53**. The state estimating unit **231** sets the reference decrease at a reference decrease setting time having a predetermined reference decrease setting cycle (an example of a predetermined reference setting time).

The state estimating unit **231** sets the reference speed value for each traffic lane based on the average value for the traffic lane average speed during the reference decrease setting cycle for each of the left traffic lane **51**, center traffic lane **52** and passing lane **53**. The state estimating unit **231** acquires the traffic lane average speed during the reference decrease setting cycle from the speed calculating unit **230**, and calculates the average value for the traffic lane average speed. The reference decrease is preferably set to be larger for a greater average value for the traffic lane average speed. In the example shown in FIG. **6**, the reference decrease is set to be 30% of the average value for the traffic lane average speed. The proportion of reference decrease with respect to the average value for the traffic lane average speed is not limited to this example.

The reference decrease setting cycle may be a fixed time period. The fixed time period may be 5 to 10 minutes, for example. The reference decrease setting cycle may also be decided by changing the fixed time based on the most recent average speed of the vehicle **10**. In this case, the reference decrease setting cycle may be changed so as to be a longer fixed time when the most recent average speed of the vehicle **10** is slower.

The state estimating unit **231** sets the reference speed value for each traffic lane to be the value of the reference decrease subtracted from the traffic lane average speed, for each of the left traffic lane **51**, center traffic lane **52** and passing lane **53**.

FIG. **7** is a diagram illustrating an example of traffic congestion determination processing. In the example shown in FIG. **6**, the road on which the vehicle **10** is traveling has a left traffic lane, a center traffic lane and a passing lane, the left traffic lane average speed being 50 km/h (13.8 m/s), the center traffic lane average speed being 70 km/h (19.4 m/s) and the passing traffic lane average speed being 90 km/h (25 m/s). The road is congested 1 km ahead of the current location of the vehicle **10**, where the average speed is 30 km/h (8.3 m/s) for the entire road.

As shown in FIG. **7**, the amount of change in each traffic lane average speed in the range up to 1 km ahead of the current location of the vehicle **10** is larger in the order: left traffic lane, center traffic lane, passing lane. In other words, the amount of change in the traffic lane average speed is greater with a faster average speed at the current location of

the vehicle **10**. By concentrating on the change in speed in the traffic lane with faster average speed, therefore, it is possible to more rapidly detect development of traffic congestion. The size of the reference decrease is thus set to be larger for a higher traffic lane average speed, as mentioned above. The size of the reference decrease will generally be larger in the order: left traffic lane, center traffic lane, passing lane.

A specific example of operation of the traffic congestion determining device **17** will now be explained with reference to FIG. **1**, FIG. **8** and FIG. **9**.

In the example shown in FIG. **1**, the state estimating unit **231** determines that each of the three traffic lanes **51**, **52**, **53** of the road **50** are congested. Since the proportion P of congested lanes in the road on which the vehicle **10** is traveling (100%) is greater than the predetermined reference proportion (50%, for example), the state estimating unit **231** determines that the road as a whole is congested. Since the road **50** as a whole is congested, the deciding unit **232** decides to operate the vehicle **10** by the automatic control and selects control of the vehicle **10** by the automatic control operating mode. The deciding unit **232** notifies the driver that the operation will be switched from the manual control operating mode to the automatic control operating mode, and controls the vehicle control device **16** so as to start the control of the vehicle **10** in the selected automatic control operating mode. Since the traffic congestion determining device **17** estimates the state of the entire road on which the vehicle is traveling based on the average speed of each of its multiple lanes, it can rapidly detect the start of congestion for the entire road, and this can be reflected in control of the vehicle **10**.

In the example shown in FIG. **8**, from among the three traffic lanes **51**, **52**, **53** of the road **50**, the state estimating unit **231** determines that the traffic lane **51** and traffic lane **53** are congested and that the traffic lane **52** in which the vehicle **10** is traveling is not congested. Since the proportion P of congested lanes in the road on which the vehicle **10** is traveling (67%) is greater than the predetermined reference proportion (50%, for example), the state estimating unit **231** determines that the road as a whole is congested. Since the road **50** as a whole is congested, the deciding unit **232** decides to operate the vehicle **10** by the automatic control and selects the control of the vehicle **10** by the automatic control operating mode. The deciding unit **232** notifies the driver that the operation will be switched from the manual control operating mode to the automatic control operating mode, and controls the vehicle control device **16** so as to start the control of the vehicle **10** in the selected the automatic control operating mode. Since the traffic lane **51** and traffic lane **53** are congested, even though the traffic lane **52** in which the vehicle **10** is traveling is not congested, the traffic congestion determining device **17** estimates that the road **50** as a whole is congested, and can rapidly detect the start of congestion of the road as a whole, which may be reflected in control of the vehicle **10**.

In the example shown in FIG. **9**, from among the three traffic lanes **51**, **52**, **53** of the road **50**, the state estimating unit **231** determines that the traffic lane **52** in which the vehicle **10** is traveling is congested, and that the traffic lane **51** and traffic lane **53** are not congested. Since the proportion P of congested lanes in the road on which the vehicle **10** is traveling (33%) is less than the predetermined reference proportion (50%, for example), the state estimating unit **231** determines that the road as a whole is not congested. Since the road **50** as a whole is not congested, the deciding unit **232** selects the control of the vehicle **10** by the manual

control operating mode. The vehicle control device **16** continues the current state of the control of the vehicle **10** in the manual control operating mode. Since the traffic lane **51** and traffic lane **53** are not congested, even though the traffic lane **52** in which the vehicle **10** is traveling is congested, the traffic congestion determining device **17** estimates that the road as a whole is not congested, and can accurately detect the state of the road as a whole which may be reflected in control of the vehicle **10**.

Since the vehicle control device of this embodiment estimates the overall state of the road on which the vehicle is traveling based on the average speed of each of its multiple lanes, as explained above, the vehicle control device can appropriately reflect the state of the road as a whole for controlling the vehicle.

For the embodiment described above, the state estimating unit **231** had a fixed reference speed value used for determining whether or not the traffic lanes are congested. However, when the traveling road of the vehicle **10** has a branching location where another road branches off allowing another vehicle to exit from the traveling road of the vehicle **10** (such as an interchange exit or junction-connecting branch road), then the traffic lane average speed may be expected to increase as the other vehicle exits onto the branching road. In such cases, a fixed reference speed value can potentially prevent accurate detection of the state of the road as a whole. The vehicle control device may therefore change the reference speed value when a branching road is present ahead of the current location of the vehicle **10**, as explained below.

FIG. **10** is an example of an operation flow chart for branching road detection processing by a traffic congestion determining device **17**. The traffic congestion determining device **17** carries out the branching road detection processing shown in FIG. **10** at a branching road detection time having a predetermined cycle.

First, based on the current location of the vehicle **10** and map information, the state estimating unit **231** determines whether or not the branching location is within a predetermined range M (such as 5 km) from the current location of the vehicle **10** in the traveling direction (step S**401**).

FIG. **11** is a diagram illustrating branching road detection processing by the traffic congestion determining device **17**. The branching location **61** where a branching road **60** branches from the road **50** is within a first range M from the current location of the vehicle **10** in the traveling direction. Another vehicle **31** can exit from the road **50** at the branching location **61**.

When a branching location exists within the predetermined range M from the current location of the vehicle **10** in the traveling direction (step S**401**—Yes), the state estimating unit **231** increases the reference speed value for each of the multiple traffic lanes of the road on which the vehicle **10** is traveling, and the series of processing steps is complete (step S**402**).

When no branching location exists within the predetermined range M from the current location of the vehicle **10** in the traveling direction (step S**401**—No), on the other hand, the state estimating unit **231** completes the series of processing steps (step S**403**).

After the vehicle **10** has passed the branching location, the state estimating unit **231** returns the reference speed value to the original value before increase.

When another road where another vehicle can enter the traveling road of the vehicle **10** (such as an interchange entrance or junction-connecting merging road) exists at a merging location that merges with the traveling road of the

vehicle **10**, then the traffic lane average speed may be expected to decrease as the other vehicle enters from the merging road to the traveling road of the vehicle **10**. In such cases, a fixed reference speed value can potentially prevent accurate detection of the state of the road as a whole. The vehicle control device may therefore change the reference speed value when a merging road is present ahead of the current location of the vehicle **10**, as explained below.

FIG. **12** is an example of an operation flow chart for merging road detection processing by a traffic congestion determining device **17**. The traffic congestion determining device **17** carries out the merging road detection processing shown in FIG. **12** at a merging road detection time having a predetermined cycle.

First, based on the current location of the vehicle **10** and map information, the state estimating unit **231** determines whether or not the merging location is within a predetermined range (such as 5 km) from the current location of the vehicle **10** in the traveling direction (step S**501**).

FIG. **13** is a diagram illustrating merging road detection processing by a traffic congestion determining device **17**. The merging location **71** where a merging road **70** merges onto the road **50** is within a predetermined range N from the current location of the vehicle **10** in the traveling direction. Another vehicle **31** can enter onto the road **50** at the merging location **61**.

When a merging location exists within the predetermined range from the current location of the vehicle **10** (step S**501**—Yes), the state estimating unit **231** decreases the reference speed value for each of the multiple traffic lanes of the road on which the vehicle **10** is traveling, and the series of processing steps is complete (step S**502**).

When no merging location exists within the predetermined range from the current location of the vehicle **10** (step S**501**—No), on the other hand, the state estimating unit **231** completes the series of processing steps (step S**503**).

After the vehicle **10** has passed the merging location, the state estimating unit **231** returns the reference speed value to the original value before decrease.

The vehicle control device, the computer program for vehicle control and the method for controlling a vehicle according to the embodiment described above may incorporate appropriate modifications that are still within the gist of the disclosure. Moreover, the technical scope of the disclosure is not limited to these embodiments, and includes the invention and its equivalents as laid out in the Claims.

The invention claimed is:

1. A vehicle control device comprising:
a processor configured to
calculate an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed,
determine whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimate whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested, and
control the vehicle by automatic control when the traveling road as a whole is congested;
and wherein the processor is further configured to:
determine that the traveling road as a whole is congested when the proportion of congested lanes in the traveling road is equal to or above a predetermined reference proportion, and

change the predetermined reference proportion based on the average speed of the vehicle.

2. The vehicle control device according to claim **1**, wherein the processor is further configured to determine, for each of the multiple traffic lanes of the traveling road, that the traffic lane is congested when the traffic lane average speed is at or below a reference speed value set for each traffic lane.

3. The vehicle control device according to claim **2**, wherein the processor is further configured to set the reference speed value for each traffic lane based on the average value for the traffic lane average speed between predetermined reference time points, for each of the multiple traffic lanes of the traveling road.

4. The vehicle control device according to claim **2**, wherein the processor is further configured to increase the reference speed value for each of the multiple traffic lanes of the traveling road, when a branching location where another road branches from the traveling road is within a first range from the current location of the vehicle toward the traveling direction.

5. The vehicle control device according to claim **2**, wherein the processor is further configured to decrease the reference speed value for each of the multiple traffic lanes of the traveling road, when a merging location where another road merges with the traveling road is within a second range from the current location of the vehicle toward the traveling direction.

6. A computer-readable, non-transitory storage medium storing a computer program for vehicle control, which causes a processor to execute a process, the process comprising:

calculating an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed;

determining whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimating whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested;

controlling the vehicle by automatic control when the traveling road as a whole is congested;

determining that the traveling road as a whole is congested when the proportion of congested lanes in the traveling road is equal to or above a predetermined reference proportion; and

changing the predetermined reference proportion based on the average speed of the vehicle.

7. A method for controlling a vehicle carried out by a vehicle control device, the method comprising:

calculating an average speed of a vehicle traveling in a traffic lane and another vehicle in a predetermined range from the vehicle, for each of multiple traffic lanes of a traveling road on which the vehicle is traveling, as a traffic lane average speed;

determining whether the traffic lanes are congested based on the traffic lane average speed for each of the multiple traffic lanes of the traveling road and estimating whether the traveling road as a whole is congested based on a proportion of traffic lanes of the traveling road that are congested;

controlling the vehicle by automatic control when the traveling road as a whole is congested;

determining that the traveling road as a whole is congested when the proportion of congested lanes in the traveling road is equal to or above a predetermined reference proportion; and

changing the predetermined reference proportion based on the average speed of the vehicle.

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