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(71) **Applicant: TOYOTA MOTOR EUROPE** [BE/BE]; Avenue du Bourget 60, 1140 BRUSSELS (BE).

(72) **Inventor: RATEAU, Aymeric**; c/o Toyota Motor Europe, European Technical Administration Division, Avenue du Bourget 60, 1140 BRUSSELS (BE).

(74) **Agent: BELL, James** et al.; Cabinet Beau De Lomenie, 158 Rue de l'Université, 75340 PARIS CEDEX 07 (FR).

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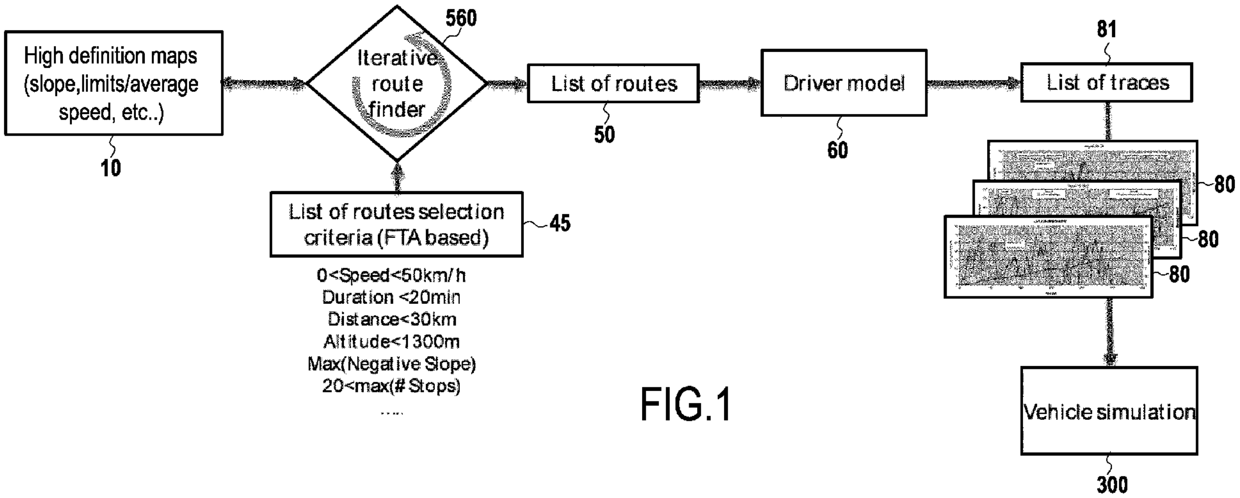

FIG.1

(57) **Abstract:** A method for obtaining simulated performance characteristics of a proposed vehicle design under real-life operating scenarios is provided. The method includes defining one or more route selection criteria based on one or more desired performance parameters of the vehicle design, determining a collection of map-based routes corresponding to the defined route selection criteria, applying one or more driver behavior models to the one or more map-based routes to obtain one or more reference traces reflecting a simulated driver behavior over one or more segments of the one or more map-based routes, and providing data of the one or more reference traces to a model powertrain associated with the proposed vehicle design to obtain simulated performance characteristics of the vehicle design over the one or more segments.

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SYSTEM AND METHOD FOR VEHICLE MODELLING AND SIMULATION

FIELD OF THE DISCLOSURE

[1] The present disclosure is related to vehicle simulation, and more particularly to a system and method for modelling one or more vehicle components in order to simulate performance of the vehicle design under various real-life operating scenarios.

BACKGROUND OF THE DISCLOSURE

[2] Today, assistive design systems are used for many applications in almost any kind of industry. Especially the automotive industry or the aviation industry as well as in computational industry assisting systems are commonly used to facilitate repetitive testing of a particular design.

[3] It is an intention of modern systems to provide and/or simulate a robust, sensitive and real-time approximation of human intention while operating a machine in a dynamically changing environment. Such machine may be any kind of system to be operated by a human, like e.g. an automobile, an aircraft, a ship, a machine etc. as well as computational systems like, e.g. a computer game, or the like. In the following, the term "system" should be understood as any kind of these.

[4] Simulation systems generally use virtual development methods and such methods are quickly gaining importance in the vehicle development process to cope with important business challenges: shortening time-to-market, optimizing product quality, performance & value, reducing production & development costs, dealing with ever stricter emission & safety regulations. For example, a particular challenge in the Engine and Powertrain field is the upcoming European "Real Driving Emissions" (RDE) regulation. RDE compliance requires control of vehicle exhaust emissions over a wide area of operating conditions. This heavily impacts the engine calibration process which was traditionally based on a fixed driving cycle.

[5] Virtualizing part of the calibration process allows evaluating the vehicle & engine behavior under various real-life driving conditions by running a physical or grey-box vehicle model over a virtual driving environment, operated by a virtual Driver Model.

[6] Perceptual/cognitive architectures with an artificial (i.e. implemented on a machine, or in or as a computer or in or as a tool) memory system are used as such assisting systems. They are particularly suited for understanding and controlling the dynamic behaviors of a tool in response to the human operator, especially for actual and safe interactions of operator and tool in real-time in a dynamically variable environment.

[7] US 2015/0202990 relates to a method of managing the energy consumed by a motor vehicle, and includes a simulation unit incorporating a vehicle model predicting behavior of the vehicle and a driver model predicting behavior of the driver of the vehicle, the driver model receiving a speed set point and the speed of the vehicle measured at successive instants, and supplying a motor torque set point to the vehicle model which is a function of the speeds and of the modelled driver behavior; an optimization algorithm interacting with the simulation unit; the method including trajectories composed of the trajectory of the speed set point and the trajectory of a set point for controlling an item of auxiliary equipment, the trajectory of a set point describing the variation of the set point as a function of the position of the vehicle, the trajectories being calculated with respect to given objectives according to the optimization algorithm whose variables are formed from the set points.

SUMMARY OF THE DISCLOSURE

[8] The present inventors have recognized that it would be beneficial to provide systems and methods that facilitate design tasks of a vehicle based on real world driving conditions and simulated driver behavior. In so doing, a vehicle design may be repeatedly and inexpensively tested to determine whether certain requirements such as, for example, power output and emissions, can be met by any proposed design.

[9] Therefore, according to embodiments of the present disclosure, a method for obtaining simulated performance characteristics of a proposed vehicle design under real-life operating scenarios, is provided. The method includes defining one or more route selection criteria based on one or more desired performance parameters of the vehicle design, determining a collection of map-based routes corresponding to the defined route selection criteria, applying one or more driver behavior models to the one or more map-based

routes to obtain one or more reference traces reflecting a simulated driver behavior over one or more segments of the one or more map-based routes, and providing data of the one or more reference traces to a model powertrain associated with the proposed vehicle design to obtain simulated performance characteristics of the vehicle design over the one or more segments.

[10] By providing such a system, various designs of a vehicle may be tested based on various driver behaviors on any number of route configurations to determine whether particular results are achieved by the design.

[11] Moreover, the chosen routes over which the vehicle design are to be tested, can be targeted to, for example, a particular geographic region, particular vehicle market, etc.

[12] The simulated performance characteristics may include at least one of vehicle tailpipe emissions and vehicle energy consumption.

[13] The one or more route selection criteria may include at least one of desired speed limit, desired duration, desired distance, desired altitude, and desired maximum slope, and optionally comprises a collection of desired worst-case driving conditions.

[14] The method may include training one or more driver behavior models based on recorded behavior of one or more human beings, wherein the recorded behavior includes at least one of a selected gear, an engine speed, a vehicle speed, a clutch operation, a brake pedal position, and an accelerator pedal position.

[15] The one or more reference traces may include at least one of a speed trace and an acceleration trace.

[16] The model powertrain may be based on one of a diesel powertrain, a gasoline powertrain, a hybrid powertrain, a fuel cell powertrain, and an electric powertrain.

[17] The method may include providing to a user the one or more map-based routes, receiving a selection of the user of one of the one or more map-based routes, and applying one or more driver behavior models to the selected map-based route.

[18] The one or more driver behavior models may include a gear shifting sub-model, wherein the shifting sub-model takes as an input for any particular segment of the one or more segments, at least one of a segment length, an entrance angle to the segment, an exit angle from the segment, a vertical axis

angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment.

[19] The gear shifting sub-model may include a regression tree algorithm.

[20] According to further embodiments of the present disclosure, a system for obtaining simulated performance characteristics of a proposed vehicle design under real-life operating scenarios, is provided. The system includes receiving means configured to receive one or more route selection criteria based on one or more desired performance parameters of the vehicle design, route selection means configured to determine a collection of map-based routes corresponding to the defined route selection criteria, processing means configured to apply one or more driver behavior models to the one or more map-based routes to obtain one or more reference traces reflecting a simulated driver behavior over one or more segments of the one or more map-based routes, and output means configured to provide data of the one or more reference traces to a model powertrain associated with the proposed vehicle design to obtain simulated performance characteristics of the vehicle design over the one or more segments.

[21] The simulated performance characteristics may include at least one of vehicle tailpipe emissions and vehicle energy consumption.

[22] The one or more route selection criteria may include at least one of desired speed limit, desired duration, desired distance, desired altitude, and desired maximum slope, and optionally comprises a collection of desired worst-case driving conditions.

[23] The system may include a training module configured to obtain training information for one or more driver behavior models based on recorded behavior of one or more human beings, wherein the recorded behavior includes at least one of a selected gear, an engine speed, a vehicle speed, a clutch operation, a brake pedal position, and an accelerator pedal position.

[24] The one or more reference traces may include at least one of a speed trace and an acceleration trace.

[25] The model powertrain may be based on one of a diesel powertrain, a gasoline powertrain, a hybrid powertrain, and an electric powertrain.

[26] The system may include display means for providing to a user the one or more map-based routes, input means for receiving a selection of the

user of one of the one or more map-based routes, and the processing means may be configured to apply one or more driver behavior models to the selected map-based route.

[27] The one or more driver behavior models may include a gear shifting sub-model, wherein the shifting sub-model takes as an input for any particular segment of the one or more segments, at least one of a segment length, an entrance angle to the segment, an exit angle from the segment, a vertical axis angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment.

[28] The gear shifting sub-model may include a regression tree algorithm.

[29] According to further embodiments, a vehicle designed using the above described systems and methods is provided.

[30] It is intended that combinations of the above-described elements and those within the specification may be made, except where otherwise contradictory.

[31] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and together with the description, and serve to explain the principles thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[32] Fig. 1 shows a high level workflow related to a powertrain and driver simulation method according to embodiments of the present disclosure;

[33] Fig. 2 shows an exemplary route-finder interface configured for inputting of one or more route criteria and selection of corresponding routes;

[34] Fig. 3 shows one exemplary powertrain and exhaust treatment simulation and modelling scenarios according to embodiments of the present disclosure;

[35] Fig. 4A is a high level representation of a training method for a driver behavior simulator according to embodiments of the present disclosure;

[36] Fig. 4B is a high level representation of an exemplary simulation phase based on a simulated driver behavior over a selected route;

[37] Fig. 4C is a high level representation of exemplary processing within the driver simulator of Fig. 4B;

[38] Fig. 5 is an exemplary logical diagram of a system configured to carry out methods of the present disclosure; and

[39] Fig. 6 is a flowchart depicting an exemplary method for powertrain modelling and simulation.

DESCRIPTION OF THE EMBODIMENTS

[40] Reference will now be made in detail to exemplary embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[41] Fig. 1 shows a high level workflow related to a powertrain and driver simulation method according to embodiments of the present disclosure, while Fig. 6 is a flowchart depicting an exemplary method for powertrain modelling and simulation. As shown at Fig. 1, one or more maps 10 stored in a memory (not shown), e.g., a database, of a computer system may provide various information concerning real-world roads, such as, for example, speed limit on road segments, slope, altitude, traffic signals, traffic signs, etc. The one or more maps may be grouped by, for example, geographic region, or other suitable organization. Alternatively, a third-party map provider may be implemented such that map information is stored remotely by the third-party, and access thereto provided by means of an API, web service, or other suitable access method enabling criteria based selection of routes and return of data associated therewith.

[42] Selected routes 50 and the associated parameters may be combined with a driver model 60 to result in traces indicating a driver desired speed over segments of the route, as will be described below. The traces may then be provided to a powertrain simulator 300, or other desirable simulator (e.g., lateral/linear acceleration simulator) for determination of various design and output characteristics of any vehicle model 425 under consideration.

[43] Fig. 5 is an exemplary logical diagram of a system 500 configured to carry out methods of the present disclosure. Such a system may include, for example, an input device 510, one or more sensors 520, an output device 530, and a processing unit 1. Input device 510 may comprise a keyboard, a mouse, a microphone, a steering wheel, one or more pedals, and any other suitable device capable of facilitating input of information to processing unit 1.

[44] One or more sensors 520 may be implemented to provide additional information to processing unit 1. For example, sensors related to an operator's reactions during training, e.g., brake pedal operation, accelerator operation, steering operation, gear shift operation, etc., may be provided to enable recording of user behavior with regard to a particular chosen route 50 during a training phase.

[45] Output device 530 may comprise, for example, a visual output, audio output, magnetic output, optical output, and/or any other output suitable for conveying and/or storing driver behavior information, route information, trace information for a simulation, etc. For example, output device 530 may comprise a plurality of devices, a display, a speaker, and a disk drive, among others.

[46] Recording module 580 may comprise memory storage, both persistent and volatile, as well as code modules configured to receive and store information in the memory storage. For example, a hard drive with a database thereon may receive information related to driver actions, vehicle, actions, etc. from processor 5 and cause such information to be stored in the data base. One of skill will recognize that other suitable storage methods and algorithms may be implemented without departing from the scope of the present disclosure.

[47] Processing unit 1 may comprise a processor 5 along with various modules comprising instructions which when executed by the processor 5, may cause particular tasks to be performed. Processor 5 may be any available processor, such as a x64 processor, ASIC, i386, RISC, or of any other suitable architecture capable of carrying out instructions compatible with the present disclosure.

[48] Route selector module 560 may be configured to receive a number of desired route criteria from input device 510, and to select one or more routes 50 that meet at least a portion of the input criteria. Route selector module 560 may comprise a third-party software package or may be a custom-built solution, or a combination thereof, as desired.

[49] Fig. 2 shows an exemplary route-finder interface configured for inputting of one or more route criteria and selection of corresponding routes. Such an interface may be implemented by, for example, route selector module 560 for display on output device 530, among others.

[50] As shown, criteria table 45 of route finder interface 40 may facilitate entry of one or more criteria related to a desired test route, and on which route selection by route finding module 20 should be performed. Such criteria can be manually entered, selected from a list, selected from a map location, etc.

[51] One or more routes selected by route finder module 20 may be provided as a list, or in other suitable format for selection, to a user, to enable the user to select one or more of the routes for a testing simulation. The one or more routes may be provided in any suitable format, for example, Google Earth (.KML), .GPX, etc., with descriptive information enabling selection by a user of the system.

[52] Such a listing of route information may be provided, as well as, for example, route visualization 50 on one of the one or more maps 10, as shown in Fig. 2. Selected routes may be highlighted or otherwise indicated, such that a user may point and click to obtain additional information about a route and/or to select a route for addition to the list for testing the vehicle design.

[53] Training module 570 may be configured to carry out actions related to a training phase of system 500, for example, with regard to driver behavior in particular route conditions, in other words training related to simulation in the context of real world driving. Fig. 4A is a high level representation of a training method for a driver behavior simulator according to embodiments of the present disclosure that may be used with respect to training module 570.

[54] For example, a training module 570 of a processing unit 500 installed in an ECU of an actual vehicle, may be configured to record various human activities for purposes of training a driver simulation module 550 in order to create and/or apply a driver simulation model for a particular driver type. Such driver types may include, for example, normal, aggressive, relaxed, etc., and such types may impact, for example, acceleration, both linear and lateral, stop time, reaction time, etc.

[55] GPS data may be linked to human recorded data, as well as data associated with the operation of the vehicle, and these data recorded, for example, by recording module 580, in order to train driver behavior simulation module 550. For example, vehicle speed, steering position, accelerator/brake operation, shift operation and gear selection, are among some of the human based information that may be recorded.

[56] Further, during the training, driving context information may be extracted over various segments of the route 50, such as, for example, a segment length, an entrance angle to the segment, an exit angle from the segment, a vertical axis angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment. Such information is taken into account for developing a driver model 60 with regard to actions of the human driver.

[57] Driver behavior simulation module 550 may be configured to simulate a driver behavior based on a driver model over one or more selected routes provided by route selector module 560. For example, following training using, for example, training module 570, various contextual driver behaviors may be recorded by recording module 580 and stored in a memory associated with system 500. Driver simulation module 550 may then be configured to take contextual parameters from a particular selected route and implement such parameters to recognize and apply a trained driver behavior.

[58] Fig. 4B is a high level logical representation of an exemplary simulation phase based on a simulated driver behavior over a selected route. According to some embodiments of the present disclosure, the simulation phase may be performed online, in other words, a server may be provided which implements the functionality of simulation modules 555 and 550, and data transmitted between a client and the server via a network. Alternatively, simulation may be executed locally.

[59] Vehicle simulation according to a vehicle model 425 will be discussed in greater detail below.

[60] Fig. 4C shows a high level representation of an exemplary flow within driver behavior simulation module 550. For any particular segment 450 of a route 50 provided by route finder 40, various parameters associated with the segment 450 may be input to driver behavior simulation module 550 to enable behavior recognition based on the provided parameters. For example, as shown at Fig. 4C, nine parameters may be implemented, a segment length an entrance angle to the segment, an exit angle from the segment, a vertical axis angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment.

[61] C-tSNE and regression tree algorithms of a two-dimensional bi-directional map 470 may then be implemented to result in one or more recognizable dimensional models 475 (e.g., two-dimensional) of driver behavior, including, for example, a gear shift model, a vehicle speed model, along with probabilities of changes in each of these models, among others.

[62] Route trace generator 590 may be configured to generate one or more reference route traces 80 by applying one or more driver behavior models 60 to the one or more map-based routes 50 reflecting a simulated driver behavior over one or more segments of the one or more map-based routes 50. These route traces 80 may contain a variety of information relative to time and position along the route and/or route segment, for example, a vehicle speed at any point along the segment, a distance travelled, time over the segment, vehicle gear changes, etc. Route traces 80 may contain more or fewer data point as desired.

[63] Route traces 80 as generated above can be provided to one or more vehicle modelling packages 300 configured to model and enable tuning of engine, powertrain, emissions treatment, and suspension/chassis designs, among others. For example, because route traces 80 may contain a driver desired speed through a particular segment of a route 50, the desired vehicle speed from any particular point on a reference trace 80 may be provided to powertrain simulator 300 loaded with a proposed powertrain model, and a simulated torque and engine RPM value determined based on the engine/transmission combination currently implemented in vehicle simulator 300.

[64] Fig. 3 shows one exemplary powertrain and exhaust treatment modelling simulator 300 according to embodiments of the present disclosure. For example, a diesel HV model 310 implemented in Simulink may be provided with a speed trace resulting from the reference traces 80, and an engine speed and output torque simulated in order for the vehicle model 425 to meet the demands for the desired speed. One of skill will recognize that diesel HV model 310 is exemplary only, and that other models related to a gasoline engine, a natural gas engine, hybrid powertrains, electric power trains, etc. may all be implemented.

[65] The powertrain and, for example, an exhaust gas treatment system, may then, as desired, be iteratively modified and re-simulated to arrive at a

desired performance/emissions design. One of skill will recognize that such simulations and reference traces can be applied to simulate other vehicle characteristics, such as, for example, linear and lateral acceleration, among others.

[66] According to some embodiments, vehicle simulation module 555 may carry out functions related to simulation of a vehicle model 425 (e.g., powertrain, suspension, etc.) and may be provided with a particular vehicle model 425 (i.e., a vehicle design under consideration) to be simulated. Vehicle simulation module 555 may then output various parameters of the simulated vehicle model 425 based on vehicle simulator 300 at any given point along the route having the parameters associated with the route as determined by route trace 80.

[67] One example of a vehicle simulator 300 is the open source solution provided by the Alliance for Sustainable Energy LLC, and entitled Advanced Vehicle Simulator, based on MATLAB and/or Simulink. Other suitable solutions may include Carmaker or X-Pack4 from IPG Automotive, and/or GT Suite/GT Power from Gamma Technologies. Output files may be generated by a datalogger, for example, in Panel3, INCA, Racelogic, etc.).

[68] Vehicle simulation module 555 may be configured to simulate operation of a vehicle model 425 during a simulation phase by applying vehicle simulator 300 over the one or more routes provided by route selector module 560, based on the reference traces 80 output from route trace generator 590 based on driver behavior simulation module 550, and more particularly, the output reference traces of the one or more recognizable models 475 over a route segment.

[69] Vehicle simulator may further include dynamic map data 320, for example, related to engine speed and torque output, based on training and/or bench testing. For example, such data may be prepared in advance based on a particular powertrain or vehicle design, and stored in map (e.g., in a database) for access during a simulation phase by vehicle simulation module 555.

[70] According to the embodiment under consideration, exhaust gas trace generator 330 may then simulate point-in-time exhaust emissions based on the vehicle model 425, and torque and engine speed output by dynamic data map 320.

[71] Returning to Fig. 6, a flow for implementation of a method according to embodiments of the present disclosure is described. A user may input one or more criteria by which it is desired to find one or more routes over which a vehicle model 425 is to be tested (step 605). For example, an engineer may wish to test a vehicle model 425 over a city road where congestion is heavy and stops frequent, with a maximum speed limit of 50 km/h. As another example, a mountain road, having many hills and valleys, with, for example, a 90 km/h speed limit may be desired. Or still further, an autoroute with a speed limit of 130 km/h and generally flat without traffic lights may be desired.

[72] One or more maps 10 may be accessed by route finder module 20 to identify routes that meet the one or more input criteria for route selection (step 610). According to some embodiments, an iterative route finder module may be implemented such that the desired criteria may be entered by a user and used for iterative selection of one or more proposed routes for selection. Therefore, it may be possible to predetermine criteria for route selection based on a desired level of testing for a simulation. The route selection criteria may be selected from among a desired speed limit, a desired duration, a desired distance, a desired altitude, desired maximum slope, desired minimum slope, and turn curvature, among others. Notably, a collection of desired "worst-case" driving conditions may be selected that may test the vehicle design at or near its presupposed limits, so as to obtain a worst-case indication of performance.

[73] Following selection of one or more routes (step 610), one or more driver behavior models 60 may be applied to the one or more map-based routes, or over segments of the selected one or more map-based routes 50 and driver operations simulated based on the (step 615).

[74] Following simulation of the vehicle model 425 with a particular driver model 60, a list 81 of one or more reference traces 80 may be generated to indicate behavior of the vehicle model 425 over the route 50 with the driver behavior (step 620).

[75] The resulting reference traces 80 may then be fed to a powertrain modelling simulator 300 in order to obtain instantaneous values at any point along the route, of exhaust emissions, power output, fuel consumption, engine rotational speed, etc. (step 625).

[76] One of skill in the art will recognize that the presently described systems and methods may have applications in addition to the

powertrain/emissions example provided herein. For example, lateral and linear accelerations and performance characteristics of a vehicle may be modelled and optimized in a similar manner for any particular route segment. Such may involve tuning of a suspension system, vehicle chassis/body, etc.

[77] For example, embodiments could be applied to many development purposes, such as, turbocharger development. In certain circumstances it could be desirable to know "worst case" thermal profiles to estimate durability of a turbocharger. In such embodiments, route criteria can be selected with maximum slope up and down and altitude variations in order to maximise thermal cycles. These "worst case" routes can then be virtually driven and thermal response of the turbocharger simulated in order to estimates its durability.

[78] Further, vehicle stability control can act on powertrain hybrid control in curves. "Worst case" with maximum slopes, maximum number of slopes and narrowest curves (for example, near Turin, IT, in the Alps) can be identified for evaluation. These routes can be virtually driven for confirmation by measurement that implemented control strategies are or are not effective, while maintaining desired drivability and performance.

[79] In yet another example, exhaust after treatment development can be improved via simulation. Again, worst-case routes may be selected by, for example, defining criteria where temperature of exhaust is at a minimum during a Real Driving Emission regulation test. Typically urban and country driving phase downhill and low speed succeeded by a highway. These routes can be virtually driven and various temperatures simulated to obtain performance information related to the exhaust after treatment design.

[80] Still further examples may related to braking conditions (e.g., with high levels of downhill driving) and/or roundabout handling (e.g., lateral acceleration).

[81] Throughout the description, including the claims, the term "comprising a" should be understood as being synonymous with "comprising at least one" unless otherwise stated. In addition, any range set forth in the description, including the claims should be understood as including its end value(s) unless otherwise stated. Specific values for described elements should be understood to be within accepted manufacturing or industry tolerances known to one of skill in the art, and any use of the terms "substantially" and/or

"approximately" and/or "generally" should be understood to mean falling within such accepted tolerances.

[82] Although the present disclosure herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present disclosure.

[83] Importantly, while processing unit 1 is shown as a single unit at Fig. 5, one of skill in the art will recognize that the functions described herein relative to processing unit 1 may be carried out at more than one location by more than one processing unit 1. In other words, training functionality may occur at one location and on a first processing unit 1, while simulation functionality may be carried out at another location on a second processing unit 1. Any such configuration is intended to fall within the scope of the present disclosure.

[84] It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims.

CLAIMS

1. A method for obtaining simulated performance characteristics of a proposed vehicle design under real-life operating scenarios, comprising:

defining one or more route selection criteria based on one or more desired performance parameters of the vehicle design;

determining a collection of map-based routes corresponding to the defined route selection criteria;

applying one or more driver behavior models to the one or more map-based routes to obtain one or more reference traces reflecting a simulated driver behavior over one or more segments of the one or more map-based routes; and

providing data of the one or more reference traces to a model powertrain associated with the proposed vehicle design to obtain simulated performance characteristics of the vehicle design over the one or more segments.

2. The method according to claim 1, wherein the simulated performance characteristics include at least one of vehicle tailpipe emissions and vehicle energy consumption.

3. The method according to any of claims 1-2, wherein the one or more route selection criteria comprise at least one of desired speed limit, desired duration, desired distance, desired altitude, and desired maximum slope, and optionally comprises a collection of desired worst-case driving conditions.

4. The method according to any of claims 1-3, comprising training one or more driver behavior models based on recorded behavior of one or more human beings, wherein the recorded behavior includes at least one of a selected gear, an engine speed, a vehicle speed, a clutch operation, a brake pedal position, and an accelerator pedal position.

5. The method according to any of claims 1-4, wherein the one or more reference traces comprise at least one of a speed trace and an acceleration trace.

6. The method according to any of claims 1-5, wherein the model powertrain is based on one of a diesel powertrain, a gasoline powertrain, a hybrid powertrain, a fuel cell powertrain, and an electric powertrain.

7. The method according to any of claims 1-6, comprising:

providing to a user the one or more map-based routes;

receiving a selection of the user of one of the one or more map-based routes; and

applying one or more driver behavior models to the selected map-based route.

8. The method according to any of claims 1-7, wherein the one or more driver behavior models comprise a gear shifting sub-model, wherein the shifting sub-model takes as an input for any particular segment of the one or more segments, at least one of a segment length, an entrance angle to the segment, an exit angle from the segment, a vertical axis angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment.

9. The method according to claim 8, wherein the gear shifting sub-model comprises a regression tree algorithm.

10. A system for obtaining simulated performance characteristics of a proposed vehicle design under real-life operating scenarios, comprising:

receiving means configured to receive one or more route selection criteria based on one or more desired performance parameters of the vehicle design;

route selection means configured to determine a collection of map-based routes corresponding to the defined route selection criteria;

processing means configured to apply one or more driver behavior models to the one or more map-based routes to obtain one or more reference traces reflecting a simulated driver behavior over one or more segments of the one or more map-based routes; and output means configured to provide data of the one or more reference traces to a model powertrain associated with the proposed vehicle design to obtain simulated performance characteristics of the vehicle design over the one or more segments.

11. The system according to claim 10, wherein the simulated performance characteristics include at least one of vehicle tailpipe emissions and vehicle energy consumption.

12. The system according to any of claims 10-11, wherein the one or more route selection criteria comprise at least one of desired speed limit, desired duration, desired distance, desired altitude, and desired maximum slope, and optionally comprises a collection of desired worst-case driving conditions.

13. The system according to any of claims 10-12, comprising a training module configured to obtain training information for one or more driver behavior models based on recorded behavior of one or more human beings, wherein the recorded behavior includes at least one of a selected gear, an engine speed, a vehicle speed, a clutch operation, a brake pedal position, and an accelerator pedal position.

14. The system according to any of claims 10-13, wherein the one or more reference traces comprise at least one of a speed trace and an acceleration trace.

15. The system according to any of claims 10-14, wherein the model powertrain is based on one of a diesel powertrain, a gasoline powertrain, a hybrid powertrain, a fuel cell powertrain, and an electric powertrain.

16. The system according to any of claims 10-15, comprising: display means for providing to a user the one or more map based routes;

input means for receiving a selection of the user of one of the one or more map-based routes; and wherein the processing means is configured to apply one or more driver behavior models to the selected map-based route.

17. The system according to any of claims 10-16, wherein the one or more driver behavior models comprise a gear shifting sub-model, wherein the shifting sub-model takes as an input for any particular segment of the one or more segments, at least one of a segment length, an entrance angle to the segment, an exit angle from the segment, a vertical axis angle of the segment, a speed limit of the segment, an average speed over the segment, a junction type, presence of a traffic signal on the segment, and presence of a yield on the segment.

18. The system according to claim 17, wherein the gear shifting sub-model comprises a regression tree algorithm.

19. A vehicle designed using the method according to any of claims 1-9.

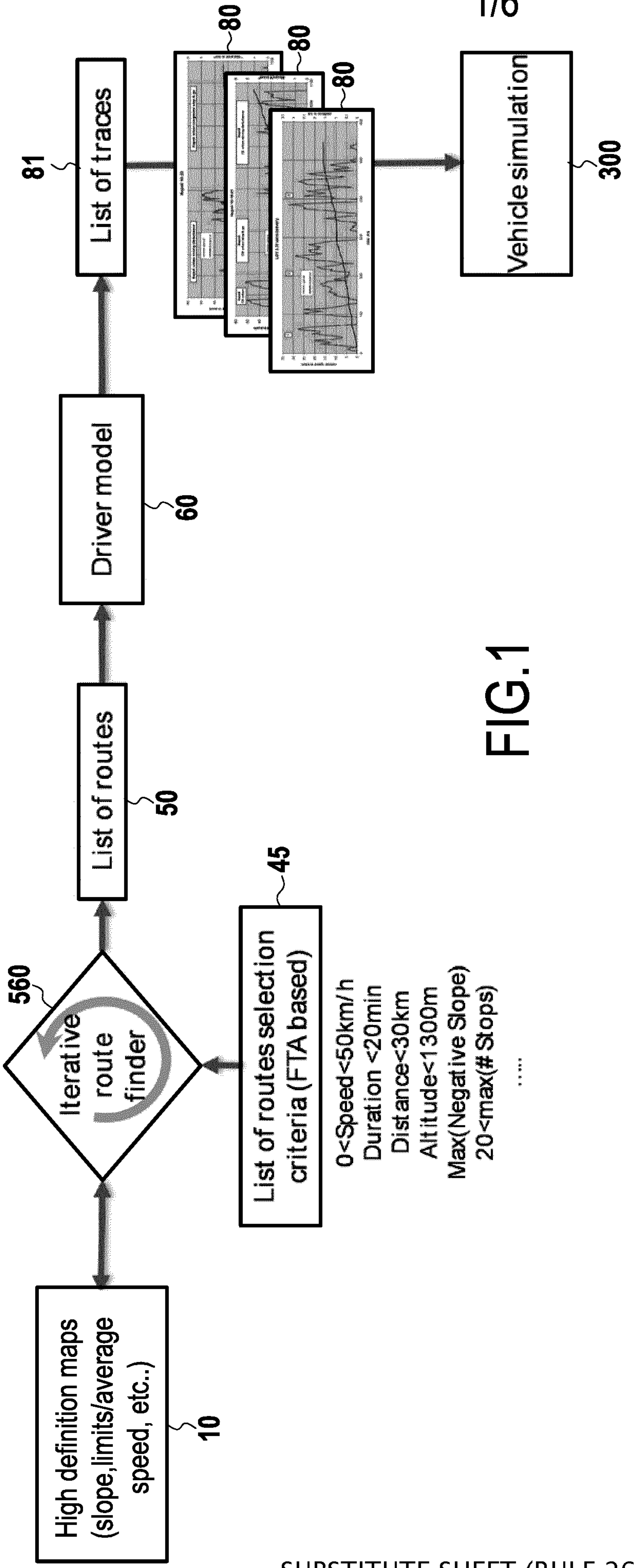

High definition maps
(slope,limits/average
speed, etc..)
10
Iterative
route
finder
560
List of routes selection
criteria (FTA based)
0<Speed<50km/h
Duration <20min
Distance<30km
Altitude<1300m
Max(Negative Slope)
20<max(# Stops)
.....
45
List of routes
50
Driver model
60
List of traces
81
80
80
80
Vehicle simulation
300

FIG.1

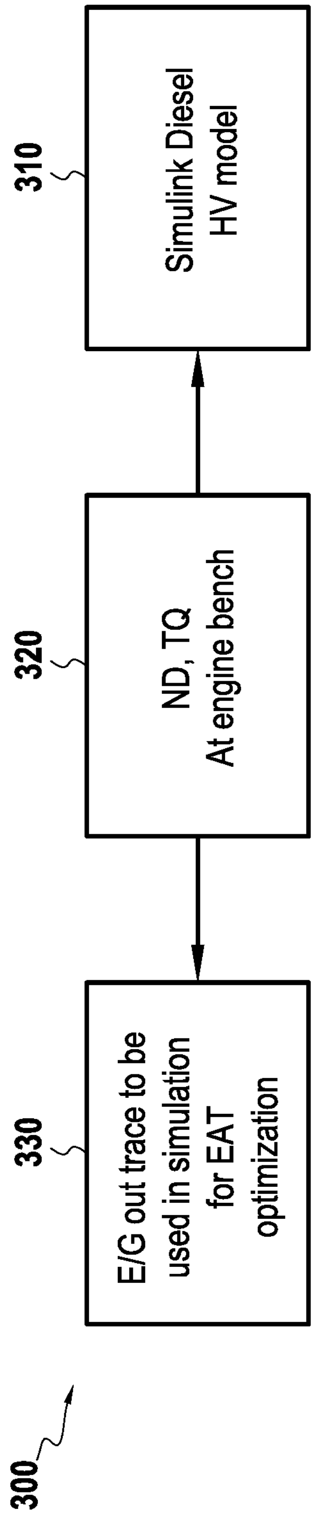

300
E/G out trace to be
used in simulation
for EAT
optimization
330
ND, TQ
At engine bench
320
Simulink Diesel
HV model
310

FIG.3

2/5

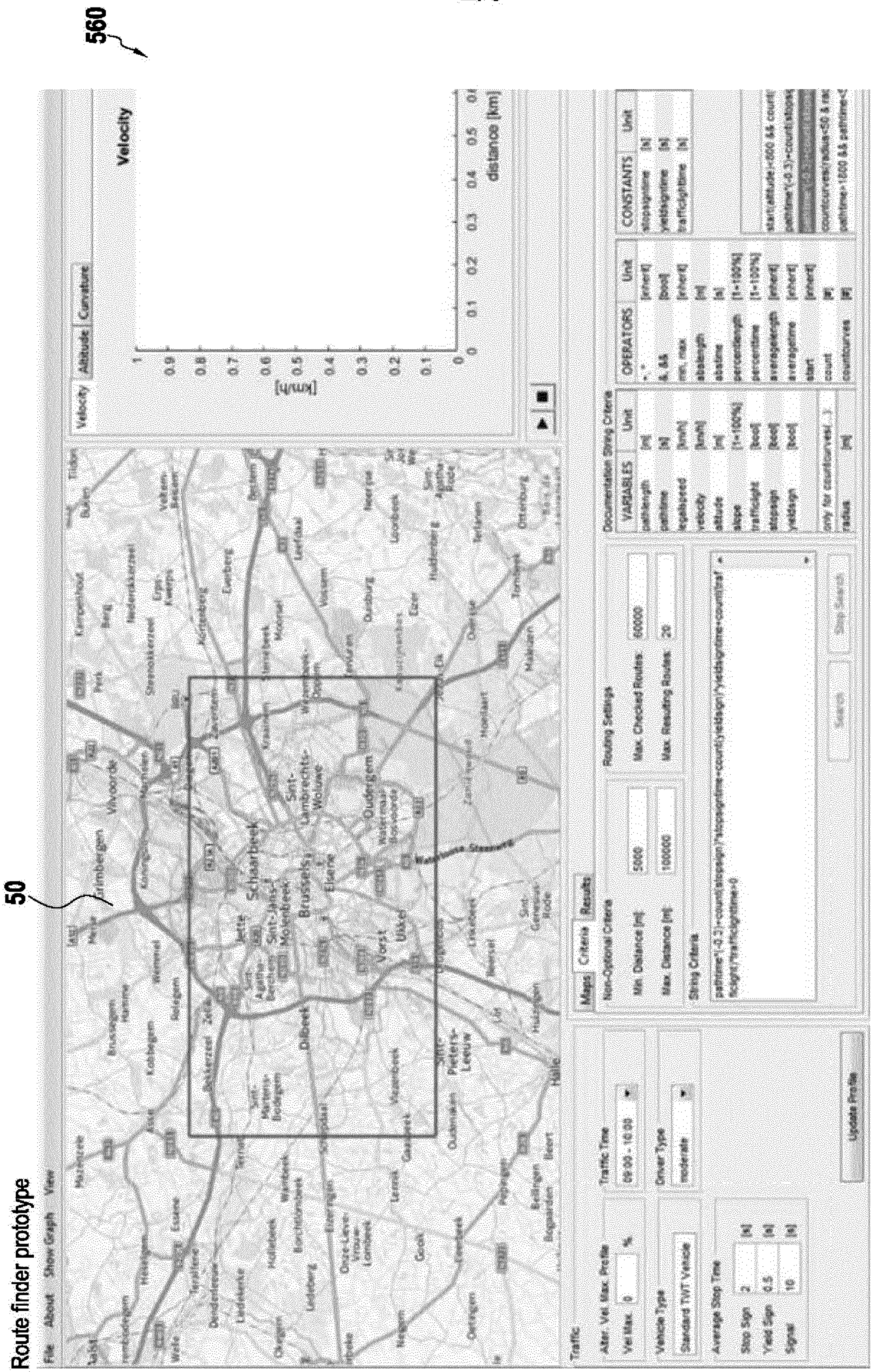


FIG.2

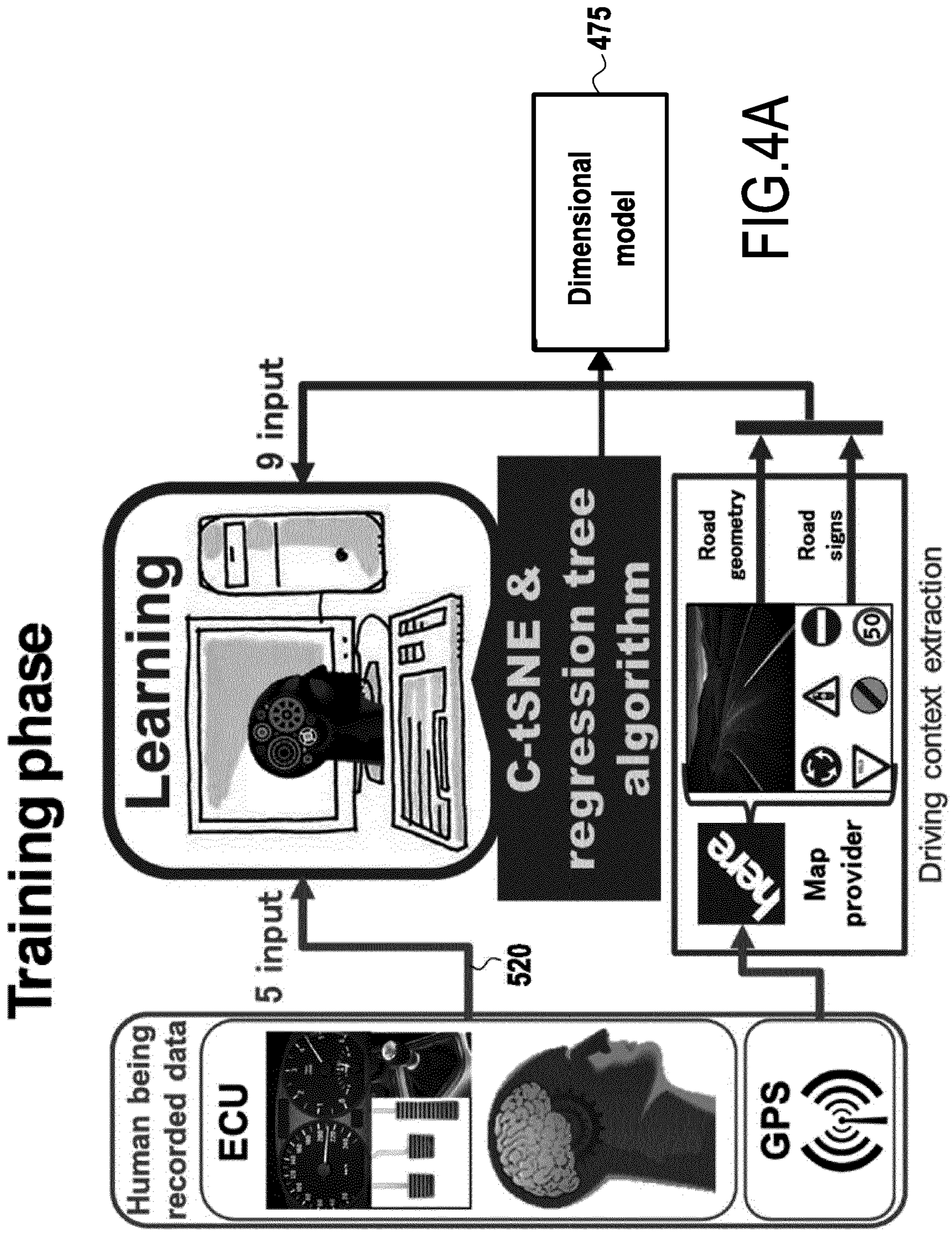
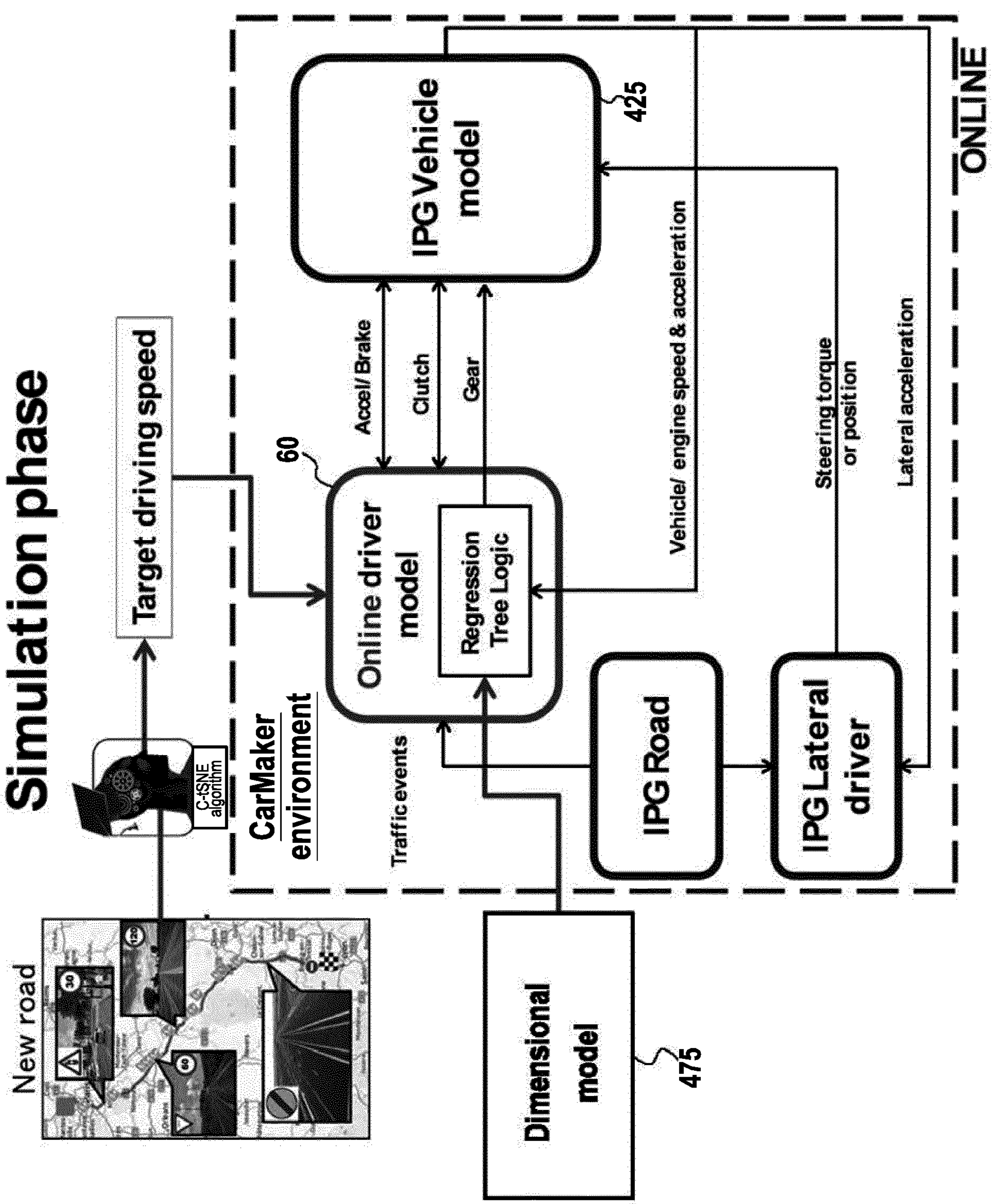

Training phase
Human being recorded data
ECU
GPS
5 input
520
Learning
9 input
C-tSNE & regression tree algorithm
Dimensional model
475
Map provider
Road geometry
Road signs
50
Driving context extraction

FIG.4A



Simulation phase
New road
C-tSNE algorithm
Target driving speed
CarMaker environment
Traffic events
60
Online driver model
Regression Tree Logic
Accel/ Brake
Clutch
Gear
IPG Vehicle model
425
Vehicle/ engine speed & acceleration
Steering torque or position
Lateral acceleration
IPG Road
IPG Lateral driver
ONLINE
Dimensional model
475

FIG.4B

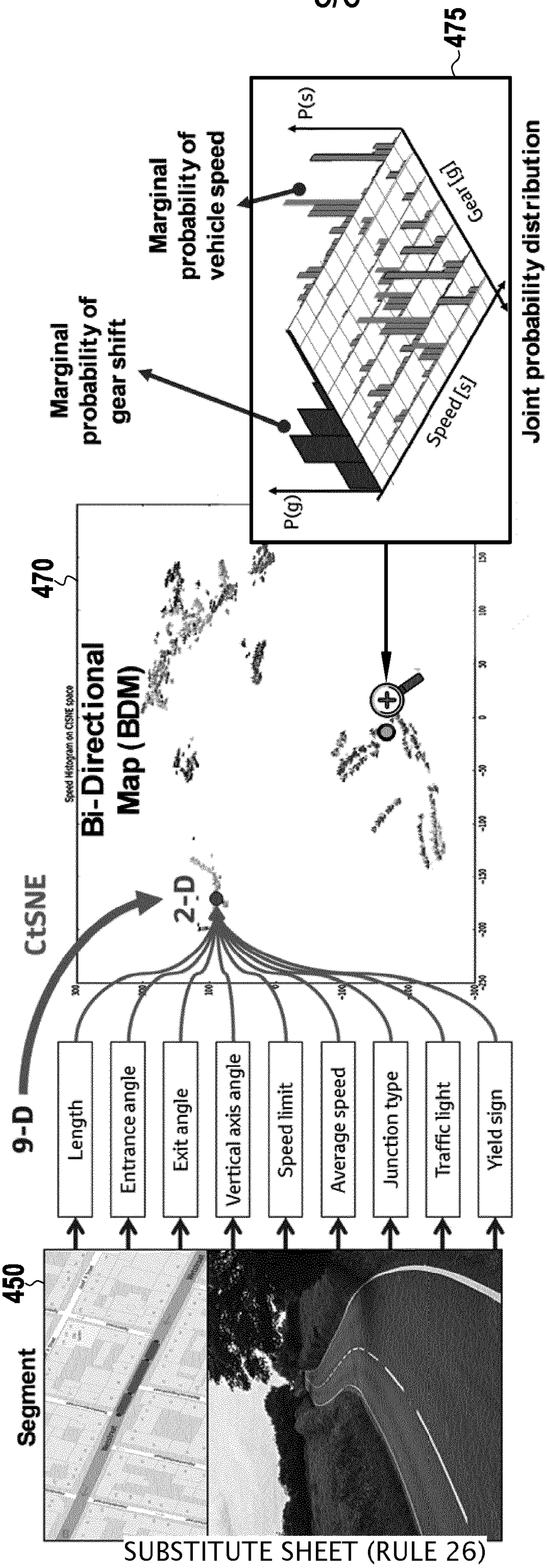

Segment
450
9-D
Length
Entrance angle
Exit angle
Vertical axis angle
Speed limit
Average speed
Junction type
Traffic light
Yield sign
CtSNE
2-D
470
Bi-Directional Map (BDM)
475
Marginal probability of gear shift
Marginal probability of vehicle speed
P(g)
P(s)
Speed [s]
Gear [g]
Joint probability distribution

FIG.4C

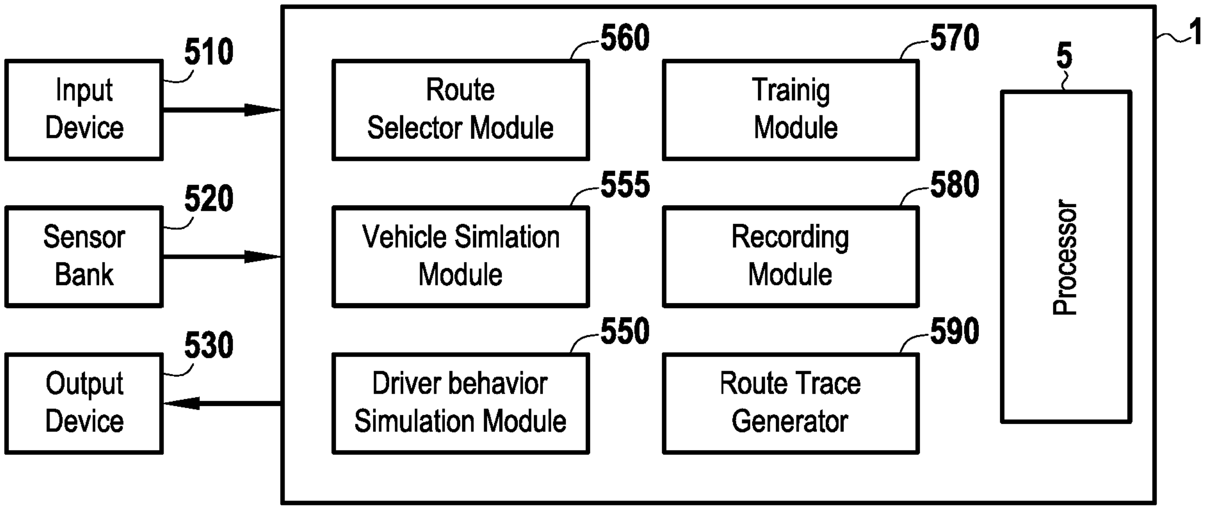

510
Input Device
520
Sensor Bank
530
Output Device
560
Route Selector Module
570
Trainig Module
555
Vehicle Simlation Module
580
Recording Module
550
Driver behavior Simulation Module
590
Route Trace Generator
5
Processor
1

FIG.5

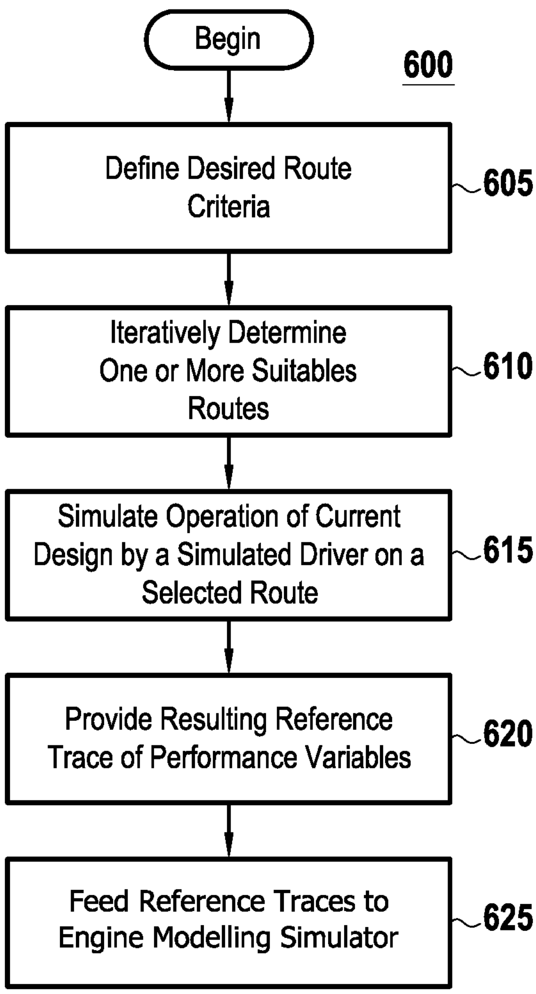

Begin
600
Define Desired Route Criteria
605
Iteratively Determine One or More Suitables Routes
610
Simulate Operation of Current Design by a Simulated Driver on a Selected Route
615
Provide Resulting Reference Trace of Performance Variables
620
Feed Reference Traces to Engine Modelling Simulator
625

FIG.6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/070590

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F17/50
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/046526 A1 (YUECEL SERMET [US] ET AL) 21 February 2013 (2013-02-21) abstract optimal vehicle model design; paragraphs [0002], [0007] - [0008], [0022] route models, driver models and vehicle designs; paragraphs [0026] - [0028], [0030] - [0034]; figures 29-30, 32 regression-based training of driver models; paragraph [0114] vehicle and route models; paragraphs [0115] - [0117]; figure 29 optimal vehicle model; paragraph [0122]; figure 31 the whole document ----- -/--	1-19

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 March 2018	06/04/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Alexe, Mihai

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2013/041552 A1 (MACNEILLE PERRY ROBINSON [US] ET AL) 14 February 2013 (2013-02-14) abstract claims 1, 14; figures 1-4 summary of the invention; paragraphs [0005] - [0009], [0017] VISSIM vehicle simulation; paragraphs [0021] - [0025], [0078] - [0079] driver behavior models; paragraphs [0035] - [0056], [0075] vehicle model parameter optimization; paragraph [0061] total energy cost functions, polynomial regression; paragraph [0093] the whole document -----	1-3,5-7, 10-12, 14-16,19 4,8,9, 13,17,18
X A	US 2015/298689 A1 (SCHWARTZ DAVID E [US] ET AL) 22 October 2015 (2015-10-22) abstract summary of the invention; paragraphs [0002], [0004], [0005] performance-optimized vehicle design, including a powertrain model; paragraphs [0026] - [0027], [0034] - [0037], [0041] - [0047], [0050] - [0054]; figures 1-3, 6-8 route selection criteria; route map generation; optimal vehicle design; paragraphs [0062] - [0063]; figure 10 vehicle reconfiguration according to driver behavior (performance); figure 11 the whole document ----- -/--	1-3,5-7, 10-12, 14-16,19 4,8,9, 13,17,18

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/070590

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2013/253782 A1 (SALTSMAN BENJAMIN J [US] ET AL) 26 September 2013 (2013-09-26) abstract figures 1, 6, 11, 12, 13 technical field and summary of the invention; paragraphs [0001], [0009], [0012] - [0013] analyzer unit (including driveline model) for duty cycle construction; paragraphs [0079] - [0080], [0083], [0085] - [0086]; figure 6 fuel-map based shifting strategy; paragraphs [0105], [0110] - [0115]; figure 10 realistic driving cycles using road data from a map system; paragraphs [0146], [0149], [0151]; figures 11-12 performance-estimation of vehicle design variants; paragraphs [0152] - [0157]; figure 13 the whole document -----	1-3,5-7, 10-12, 14-16,19 4,8,9, 13,17,18
X A	MARKEL T ET AL: "ADVISOR: a systems analysis tool for advanced vehicle modeling", JOURNAL OF POWER SOURCES, vol. 110, no. 2, 22 August 2002 (2002-08-22), pages 255-266, XP004393625, ISSN: 0378-7753, DOI: 10.1016/S0378-7753(02)00189-1 the entire document, in particular section 6 (p. 264-265), table 1 and figures 19-21 -----	19 1-18
X A	RAJA SANGILI VADAMALU ET AL: "Methodology for model-based development, validation and calibration of connected electrified powertrain systems", CONFERENCE ON FUTURE AUTOMOTIVE TECHNOLOGY, 4 May 2016 (2016-05-04), pages 1-8, XP055462244, the entire document, and in particular section II.B (pages 2-3), figure 1, and conclusions (p. 7-8) -----	19 1-18

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/070590

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2013142508 A2	26-09-2013