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(54) **METHOD FOR CONTROLLING A POWERED SYSTEM BASED ON MISSION PLAN**

(57) Various methods are disclosed for controlling a rail vehicle or other powered system based on an optimized mission plan. One embodiment relates to method for determining a mission plan for a powered system when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit. The method

comprises identifying a desired parameter prior to creating a mission plan, wherein the desired parameter may be unobtainable and/or in violation of a predefined limit, and notifying an operator of the powered system and/or a remote monitoring facility of the desired parameter.

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Alerting at least one of an operator and a remote monitoring facility that the desired parameter is at least one of unobtainable and exceeds a predefined limit.

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Receiving a feedback command from at least one of the operator and the remote monitoring facility.

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Revising the mission plan and replanning the mission plan based on the feedback command.

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FIG. 32

Description

FIELD OF THE INVENTION

5 **[0001]** Embodiments of the invention relate to methods for controlling vehicles and other powered systems.

BACKGROUND OF THE INVENTION

10 **[0002]** Certain powered systems (e.g., trains and other rail vehicles, marine vessels, stationary diesel powered power generation units, and mining vehicles, agricultural vehicles, and other off-highway vehicles) include a diesel-fueled unit as a power source. With respect to rail vehicle systems, the diesel-fueled unit may be a diesel internal combustion engine that is housed in a locomotive. The locomotive may be part of a train that includes other locomotives and a plurality of rail cars, such as freight cars. Locomotives are complex systems with numerous subsystems, with each subsystem being interdependent on other subsystems.

15 **[0003]** An operator is usually on board a locomotive to ensure the proper operation of the locomotive, and when there is a locomotive consist, the operator is usually on board a lead locomotive. A locomotive "consist" is a group of locomotives that are operated or controlled together for moving a train. In addition to ensuring proper operations of the locomotive, or locomotive consist, the operator is also responsible for determining operating speeds of the train and forces within the train. To perform this function, the operator generally must have extensive experience with operating the locomotive and various trains over the specified terrain. This knowledge is needed to comply with prescribed operating parameters, such as speeds, emissions, and the like that may vary with the train location along the track. Moreover, the operator is also responsible for ensuring that in-train forces remain within acceptable limits.

20 **[0004]** In marine applications, an operator is usually aboard a marine vessel to ensure the proper operation of the vessel, and when there is a vessel consist, the operator is usually in control of a lead vessel. As with the locomotive example cited above, a vessel consist is a group of vessels that operate together in carrying out a combined mission. In addition to ensuring proper operations of the vessel, or vessel consist, the operator also is responsible for determining operating speeds of the consist and forces within the consist. To perform this function, the operator generally must have extensive experience with operating the vessel and various consists over the specified waterway or mission. This knowledge is needed to comply with prescribed operating speeds and other mission parameters that may vary with the vessel location along the mission. Moreover, the operator is also responsible for ensuring that intra-vessel and inter-vessel forces and mission location remain within acceptable limits.

25 **[0005]** When operating a train, train operators typically call for the same notch settings when operating the train, which in turn may lead to a large variation in fuel consumption and/or emissions output, such as, but not limited to, NO_x, CO₂, etc., depending on the number of locomotives powering the train. Thus, the operator usually cannot operate the locomotives so that the fuel consumption is minimized and emissions output is minimized for each trip, since the size and loading of trains vary, and locomotives and their power availability may vary by model type.

30 **[0006]** However, with respect to a locomotive, even with knowledge to ensure safe operation, the operator cannot usually operate the locomotive so that the fuel consumption and emissions are minimized for each trip. For example, other factors that must be considered may include emissions output, operator environmental conditions like noise/vibration, a weighted combination of fuel consumption and emissions output, etc. This is difficult to do because the size and loading of trains vary, locomotives and their fuel/emissions characteristics are different, and weather and traffic conditions vary.

35 **[0007]** Similar issues arise when an operator attempts to optimize the speed of a train. Though an operator may be skilled at operating various train configurations, ensuring an optimized mission speed is not uniformly possible across various train configurations. Furthermore, situations may arise where improper information is initially provided when establishing a mission plan. Though not detrimental to the operation of the train, having improper information may result in less than desirable performance.

40 **[0008]** A train owner usually owns a plurality of trains, wherein the trains operate over a network of railroad tracks. Since individual operators are required for each train, with operator skill levels varying from operator to operator, the number of factors relating to ensuring optimization of fuel use, emissions output, and speed, to ensure proper use of all resources in the network, increases exponentially. Because of the integration of multiple trains running concurrently within the network of railroad tracks, wherein scheduling issues must also be considered with respect to train operations, train owners would benefit from a way to optimize fuel efficiency and emissions output in real time so as to save on overall fuel consumption, while minimizing emissions output of multiple trains, and while meeting mission trip time constraints.

BRIEF DESCRIPTION OF THE INVENTION

[0009] Embodiments of the invention relate to a system and method for controlling a powered system. The method comprises determining a mission plan for a powered system when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit, so that optimized fuel efficiency, emission output, vehicle performance, and/or infrastructure and environment mission performance of the powered system is realized. The method further comprises identifying a desired parameter prior to creating a mission plan, where the desired parameter may be unobtainable and/or in violation of a predefined limit. An operator of the powered system and/or a remote monitoring facility of the desired parameter is notified.

[0010] In another embodiment, the method comprises creating a mission plan. A desired parameter in the mission plan that is unobtainable and/or exceeds a predefined limit is identified. A determination is made whether to temporarily exceed the predefined limit, identify an obtainable parameter proximate the desired parameter, and/or alert an operator and/or a remote monitoring facility for feedback on a course of action to take.

[0011] Other embodiments of the invention relate to a method for controlling a powered system by optimizing a range of an operating mode that a powered system encounters during a mission. The method comprises determining an amount of time the powered system enters a range of at least one operating mode prior to beginning a mission and/or while performing the mission. Notification is provided to an operator of the powered system and/or a remote monitoring facility regarding the amount of time the powered system enters the range of the at least one operating mode while performing the mission and/or will enter the range of the at least one operating mode prior to beginning the mission.

[0012] In another embodiment, the method comprises adjusting at least one operating parameter of the powered system to approximate a desired operating setting. The method may further comprise determining a minimum speed threshold and creating a mission plan using the minimum speed threshold.

[0013] Another embodiment relates to a method for determining a mission plan based on a target reference speed and/or a target reference power. The method comprises creating a mission plan with a target reference speed and/or a target reference power identified for an entire mission and/or a section of the mission. The target reference speed and/or the target reference power is adhered to and/or proximately adhered to.

[0014] Another embodiment also relates to a method for determining a mission plan based on a target reference speed and/or a target reference power. Here, the method comprises determining a reference target speed and a target reference power. A mission plan is created with the reference target speed and/or a target reference power determined for an entire mission and/or a section of the mission. The powered system is operated to provide power proximate the reference target speed.

[0015] Another embodiment relates to a method for minimizing a range of at least one operation mode of a powered system provided with a mission plan. The method comprises creating an original mission plan and identifying a time period of operation in the range of the at least one operation mode. The range of the at least one operating mode in the mission plan is identified. The mission plan is revised to provide for a power setting outside of the range of the at least one operation mode during a period the at least one operation mode is within a chosen range of a power operation period.

[0016] Another embodiment relates to a method for controlling a powered system having a first power generating unit and a second power generating unit, where power settings for the first power generating unit are decoupled from power settings for the second power generating unit. The method comprises developing a power operating plan which is independent of a coupled power setting, determining a power setting responsive to the power operating plan, and operating the first and/or second power generating units based on the determined power setting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] A more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof that are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, exemplary embodiments of the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 is a flowchart showing a method of trip optimization, according to an embodiment of the present invention;
 FIG. 2 depicts a simplified mathematical model of a powered system that may be employed in connection with the present invention;
 FIG. 3 is a schematic diagram of a powered system;
 FIG. 4 depicts an exemplary embodiment of a fuel-use/travel time curve;
 FIG. 5 depicts an exemplary embodiment of segmentation decomposition for trip planning;
 FIG. 6 depicts another exemplary embodiment of a segmentation decomposition for trip planning;
 FIG. 7 is a flowchart showing a method of trip optimization, according to another embodiment of the present invention;

FIG. 8 depicts an embodiment of a dynamic display for use by an operator;
 FIG. 9 depicts another embodiment of a dynamic display for use by the operator;
 FIG. 10 depicts another embodiment of a dynamic display for use by the operator;
 FIG. 11 depicts a network of railway tracks with multiple trains;
 5 FIG. 12 is a flowchart of a method for improving fuel efficiency of a train through optimized train power makeup, according to an additional embodiment of the invention;
 FIG. 13 depicts a block diagram of exemplary elements included in a system for optimized train power makeup;
 FIG. 14 depicts a block diagram of a transfer function for determining a fuel efficiency and emissions for a diesel powered system;
 10 FIG. 15 is a flowchart depicting a method for determining a configuration of a diesel powered system having at least one diesel-fueled power generating unit;
 FIG. 16 depicts an exemplary embodiment of a closed-loop system for operating a rail vehicle;
 FIG. 17 depicts the closed loop system of FIG. 16 integrated with a master control unit;
 FIG. 18 depicts an exemplary embodiment of a closed-loop system for operating a rail vehicle integrated with another
 15 input operational subsystem of the rail vehicle;
 FIG. 19 depicts another exemplary embodiment of the closed-loop system with a converter which may command operation of the master controller;
 FIG. 20 depicts another exemplary embodiment of a closed-loop system;
 FIG. 21 is a flowchart illustrating a method for operating a powered system, according to an embodiment of the
 20 present invention;
 FIG. 22 is a flowchart illustrating a method for operating a rail vehicle in a closed-loop process, according to an embodiment of the present invention;
 FIG. 23 depicts a speed versus time graph comparing current operations to emissions optimized operation;
 FIG. 24 depicts a modulation pattern compared to a given notch level;
 25 FIG. 25 is a flowchart illustrating a method for determining a configuration of a diesel powered system;
 FIG. 26 depicts a system for minimizing emission output;
 FIG. 27 depicts a system for minimizing emission output from a diesel powered system;
 FIG. 28 depicts a method for operating a diesel powered system having at least one diesel-fueled power generating unit;
 30 FIG. 29 depicts a block diagram of an exemplary system operating a diesel powered system having at least one diesel-fueled power generating unit;
 FIGS. 30-31 are flowcharts illustrating respective methods for determining a mission plan for a powered system, according to two embodiments of the present invention;
 FIG. 32 is a flowchart illustrating a method for identifying a desired parameter in a mission plan that is unobtainable
 35 and/or exceeds a predefined limit;
 FIG. 33 is a flowchart illustrating a method for optimizing a range of at least one operating mode of a powered system provided in a mission plan;
 FIG. 34 is a flowchart illustrating a method for optimizing a range of at least one operating mode of a powered system provided in a mission plan;
 40 FIG. 35 is a flowchart illustrating a method for determining a mission plan based on a maximum speed limit and/or a minimum speed threshold;
 FIG. 36 is a flowchart illustrating a method for optimizing a range of an operating mode provided in a mission plan of a powered system;
 FIG. 37 is a flowchart illustrating a method for determining a mission plan based on a maximum speed limit and/or
 45 a minimum speed threshold;
 FIG. 38 is a flowchart illustrating a method for optimizing a range of an operation mode of a powered system provided with a mission plan;
 FIG. 39 depicts a three dimensional graph illustrating an exemplary embodiment for providing decoupled power settings;
 50 FIG. 40 depicts a three dimensional graph illustrating another exemplary embodiment for providing decoupled power settings;
 FIG. 41 depicts a three dimensional graph illustrating another exemplary embodiment for providing decoupled power settings;
 FIG. 42 depicts a flowchart illustrating an exemplary embodiment for providing decoupled power settings; and
 55 FIG. 43 depicts a flowchart illustrating another exemplary embodiment for providing decoupled power settings.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Reference will now be made in detail to the embodiments consistent with the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numerals used throughout the drawings refer to the same or like parts.

[0019] Though exemplary embodiments of the present invention are described with respect to rail vehicles, or railway transportation systems, specifically trains and locomotives having diesel engines, exemplary embodiments of the invention are also applicable for other uses, such as but not limited to off-highway vehicles, marine vessels, stationary units, and other vehicles such as agricultural vehicles and transport buses, each which may use at least one diesel engine, or diesel internal combustion engine. Towards this end, when discussing a specified mission, this includes a task or requirement to be performed by the diesel powered system. Therefore, with respect to railway, marine, transport vehicles, agricultural vehicles, or off-highway vehicle applications this may refer to the movement of the system from a present location to a destination.

[0020] In the case of stationary applications, such as but not limited to a stationary power generating station or network of power generating stations, a specified mission may refer to an amount of wattage (e.g., MW/hr) or other parameter or requirement to be satisfied by the diesel powered system. Likewise, operating conditions of the diesel-fueled power generating unit may include one or more of speed, load, fueling value, timing, and the like. Furthermore, though diesel powered systems are disclosed, those skilled in the art will readily recognize that embodiments of the invention may also be utilized with non-diesel powered systems, such as but not limited to natural gas powered systems, bio-diesel powered systems, etc.

[0021] Furthermore, as disclosed herein, such non-diesel powered systems, as well as diesel powered systems, may include multiple engines, other power sources, and/or additional power sources, such as, but not limited to, battery sources, voltage sources (such as but not limited to capacitors), chemical sources, pressure based sources (such as but not limited to spring and/or hydraulic expansion), electrical current sources (such as but not limited to inductors), inertial sources (such as but not limited to flywheel devices), gravitational-based power sources, and/or thermal-based power sources. Additionally, the power source may be external, such as but not limited to, an electrically powered system, such as a locomotive or train, where power is sourced externally from overhead catenary wire, third rail, and/or magnetic levitation coils.

[0022] In one example involving marine vessels, a plurality of tugs may be operating together where all are moving the same larger vessel, where each tug is linked in time to accomplish the mission of moving the larger vessel. In another example, a single marine vessel may have a plurality of engines. Off-highway vehicle (OHV) applications may involve a fleet of vehicles that have a same mission to move earth, from location "A" to location "B," where each OHV is linked in time to accomplish the mission. With respect to a stationary power generating station, a plurality of stations may be grouped together for collectively generating power for a specific location and/or purpose. In another exemplary embodiment, a single station is provided, but with a plurality of generators making up the single station. In one example involving locomotive vehicles, a plurality of diesel powered systems may be operated together, where all are moving the same, larger load, e.g., a plurality of rail cars, and where each system is linked in time to accomplish the mission of moving the larger load. In another exemplary embodiment a locomotive vehicle may have more than one diesel powered system.

[0023] Exemplary embodiments of the invention solves problems in the art by providing a system, method, and computer implemented method, such as a computer software code, for determining a mission plan for a powered system when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit, so that optimized fuel efficiency, emissions output, vehicle performance, and/or infrastructure and environment mission performance of the diesel powered system is realized. With respect to locomotives, exemplary embodiments of the present invention are also operable when the locomotive consist is in distributed power operations.

[0024] Persons skilled in the art will recognize that an apparatus, such as a data processing system, including a CPU, memory, I/O, program storage, a connecting bus, and other appropriate components, could be programmed or otherwise designed to facilitate the practice of the method of the invention. Such a system would include appropriate program means for executing the method of the invention.

[0025] Also, an article of manufacture, such as a pre-recorded disk or other similar computer program product, for use with a data processing system, could include a storage medium and program means recorded thereon for directing the data processing system to facilitate the practice of the method of the invention. Such apparatus and articles of manufacture also fall within the spirit and scope of the invention.

[0026] Broadly speaking, a technical effect is to determine a mission plan for a powered system when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit, so that optimized fuel efficiency, emissions output, vehicle performance, infrastructure and environment mission performance of the diesel powered system is realized. Though a mission plan is disclosed above, the term "mission plan" is not provided as a limitation. Specifically, the term "mission plan" encompasses an automatic or autonomous mission plan and/or planning, a manual mission plan and/or planning, as well as a combination of the two.

[0027] To facilitate an understanding of the exemplary embodiments of the invention, it is described hereinafter with reference to specific implementations thereof. Exemplary embodiments of the invention may be described in the general context of computer-executable instructions, such as program modules, being executed by any device, such as but not limited to a computer, designed to accept data, perform prescribed mathematical and/or logical operations usually at high speed, where results of such operations may or may not be displayed. Generally, program modules include routines, programs, objects, components, data structures, etc. that performs particular tasks or implement particular abstract data types. For example, the software programs that underlie exemplary embodiments of the invention can be coded in different programming languages, for use with different devices, or platforms. In the description that follows, examples of the invention may be described in the context of a web portal that employs a web browser. It will be appreciated, however, that the principles that underlie exemplary embodiments of the invention can be implemented with other types of computer software technologies as well.

[0028] Moreover, those skilled in the art will appreciate that exemplary embodiments of the invention may be practiced with other computer system configurations, including hand-held devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, minicomputers, mainframe computers, and the like. Exemplary embodiments of the invention may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote computer storage media including memory storage devices. These local and remote computing environments may be contained entirely within the locomotive, or adjacent locomotives in consist, or off-board in wayside or central offices where wireless communication is used.

[0029] Throughout this document the term "locomotive consist" is used. As used herein, a locomotive consist may be described as having one or more locomotives in succession, connected together so as to provide motoring and/or braking capability. In many cases, the locomotives are connected together where no train cars are in between the locomotives. The train can have more than one locomotive consist in its composition. Specifically, there can be a lead consist and one or more remote consists, such as midway in the line of cars and another remote consist at the end of the train. Each locomotive consist may have a first locomotive and trail locomotive(s). Though a first locomotive is usually viewed as the lead locomotive, those skilled in the art will readily recognize that the first locomotive in a multi locomotive consist may be physically located in a physically trailing position.

[0030] Though a locomotive consist is usually viewed as involving successive locomotives, those skilled in the art will readily recognize that a group of locomotives may also be recognized as a consist even when one or more rail cars separate the locomotives, such as when the locomotive consist is configured for distributed power operation, wherein throttle and braking commands are relayed from the lead locomotive to the remote trains by a radio link or physical cable. Towards this end, the term locomotive consist should be not be considered a limiting factor when discussing multiple locomotives within the same train.

[0031] As disclosed herein, the idea of a consist may also be applicable when referring to other types of powered systems, including, but not limited to, marine vessels, off-highway vehicles, and/or stationary power plants, that operate together so as to provide motoring, power generation, and/or braking capability. Therefore, even though the term locomotive consist is used herein in regards to certain illustrative embodiments, this term may also apply to other powered systems. Similarly, sub-consists may exist. For example, the diesel powered system may have more than one diesel-fueled power generating unit. For example, a power plant may have more than one diesel electric power unit where optimization may be at the sub-consist level. Likewise, a locomotive may have more than one diesel power unit.

[0032] The term "notch" may be used herein. Though notch is generally interpreted as pre-set throttle settings, in the context of this invention the term is defined to include pre-set throttle settings and/or a continuous resolution throttle application, where notch is any throttle value.

[0033] Referring now to the drawings, embodiments of the present invention will be described. Exemplary embodiments of the invention can be implemented in numerous ways, including as a system (including a computer processing system), a method (including a computerized method), an apparatus, a computer readable medium, a computer program product, a graphical user interface, including a web portal, or a data structure tangibly fixed in a computer readable memory. Several embodiments of the invention are discussed below.

[0034] Embodiments of the present invention relate to a method for controlling a train, other vehicle, or other powered system, and to a trip optimizer system 12 that implements the method for controlling a train, other vehicle, or other powered system. (The system 12 is generally applicable for controlling the mission of a powered system, and is not limited to controlling vehicles on trips.)

[0035] FIG. 1 is a flowchart illustrating a method for controlling a powered system through trip/mission optimization. FIGS. 3 and 7 show various elements of a powered system (e.g., train) that includes a trip or mission optimizer system 12 configured to carry out the method shown in FIG. 1. As illustrated, instructions are input specific to planning a trip either on board or from a remote location, such as a dispatch center 10. Such input information includes, but is not limited to, train position, consist description (such as locomotive models), locomotive power description, performance of locomotive traction transmission, consumption of engine fuel as a function of output power, cooling characteristics,

the intended trip route (including information relating to effective track grade and curvature as function of milepost, and/or an "effective grade" component to reflect curvature following standard railroad practices), the train represented by car makeup and loading together with effective drag coefficients, trip desired parameters including, but not limited to, start time and location, end location, desired travel time, crew (user and/or operator) identification, crew shift expiration time, and route.

[0036] This data may be provided to the locomotive 42 (see FIG. 3) in a number of ways, such as, but not limited to, an operator manually entering this data into the locomotive 42 via an onboard display, inserting a memory device such as a hard card and/or USB flash drive containing the data into a receptacle aboard the locomotive, and transmitting the information via wireless communication from a central or wayside location 41, such as a track signaling device and/or a wayside device, to the locomotive 42. Locomotive 42 and train 31 load characteristics (e.g., drag) may also change over the route (e.g., with altitude, ambient temperature, and condition of the rails and rail-cars), and the plan may be updated to reflect such changes as needed by any of the methods discussed above and/or by real-time autonomous collection of locomotive/train conditions. This includes, for example, changes in locomotive or train characteristics detected by monitoring equipment on or off board the locomotive(s) 42.

[0037] The track signal system determines the allowable speed of the train. There are many types of track signal systems and operating rules associated with each of the signals. For example, some signals have a single light (on/off), some signals have a single lens with multiple colors, and some signals have multiple lights and colors. These signals can indicate that the track is clear and the train may proceed at a maximum allowable speed. They can also indicate that a reduced speed or stop is required. This reduced speed may need to be achieved immediately, or at a certain location (e.g., prior to the next signal or crossing).

[0038] The signal status is communicated to the train and/or operator through various means. Some systems have circuits in the track and inductive pick-up coils on the locomotives. Other systems have wireless communications systems. Signal systems can also require the operator to visually inspect the signal and take the appropriate actions.

[0039] The track signaling system may interface with the on-board signal system and adjust the locomotive speed according to the inputs and the appropriate operating rules. For signal systems that require the operator to visually inspect the signal status, the operator screen will present the appropriate signal options for the operator to enter based on the train's location. The type of signal systems and operating rules, as a function of location, may be stored in an onboard database 63.

[0040] Based on the specification data input into the trip optimizer system, an optimal plan which minimizes fuel use and/or emissions produced subject to speed limit constraints along the route with desired start and end times is computed to produce a trip profile 12a. The profile contains the optimal speed and power (notch) settings the train is to follow, expressed as a function of distance and/or time, and such train operating limits, including but not limited to, the maximum notch power and brake settings, and speed limits as a function of location, and the expected fuel used and emissions generated. (Thus, as should be appreciated, the trip profile is a set or list of control settings of a train or other vehicle for implementing or following a trip plan.) In an exemplary embodiment, the value for the notch setting is selected to obtain throttle change decisions about once every 10 to 30 seconds. Those skilled in the art will readily recognize that the throttle change decisions may occur at a longer or shorter duration, if needed and/or desired to follow an optimal speed profile. In a broader sense, it should be evident to ones skilled in the art that the profiles provide power settings for the train, either at the train level, consist level, and/or individual train level. Power comprises braking power, motoring power, and airbrake power. In another embodiment, instead of operating at the traditional discrete notch power settings, a continuous power setting, determined as optimal for the profile selected, may be selected. Thus, for example, if an optimal profile specifies a notch setting of 6.8, instead of operating at notch setting 7 (assuming discrete notch setting of, e.g., 6, 7, 8, and so on), the locomotive 42 can operate at 6.8. Allowing such intermediate power settings may bring additional efficiency benefits as described below.

[0041] The procedure used to compute the optimal profile can be any number of methods for computing a power sequence that drives the train 31 to minimize fuel and/or emissions subject to locomotive operating and schedule constraints, as summarized below. In some cases the required optimal profile may be close enough to one previously determined, owing to the similarity of the train configuration, route and environmental conditions. In these cases it may be sufficient to look up the driving trajectory within a database 63 and attempt to follow it. When no previously computed plan is suitable, methods to compute a new one include, but are not limited to, direct calculation of the optimal profile using differential equation models which approximate the train physics of motion. The setup involves selection of a quantitative objective function, commonly a weighted sum (integral) of model variables that correspond to rate of fuel consumption and emissions generation plus a term to penalize excessive throttle variation.

[0042] An optimal control formulation is set up to minimize the quantitative objective function subject to constraints including but not limited to, speed limits and minimum and maximum power (throttle) settings and maximum cumulative and instantaneous emissions. Depending on planning objectives at any time, the problem may be implemented flexibly to minimize fuel subject to constraints on emissions and speed limits, or to minimize emissions, subject to constraints on fuel use and arrival time. It is also possible to establish, for example, a goal to minimize the total travel time without

constraints on total emissions or fuel use where such relaxation of constraints would be permitted or required for the mission.

[0043] Throughout the document exemplary equations and objective functions are presented for minimizing locomotive fuel consumption. These equations and functions are for illustration only as other equations and objective functions can be employed to optimize fuel consumption or to optimize other locomotive/train operating parameters.

[0044] Mathematically, the problem to be solved may be stated more precisely. The basic physics are expressed by:

$$= T_e(u, v) - G_a(x) - R(v); v(0)$$

$$= 0.0; v(T_f) = 0.0$$

where x is the position of the train, v its velocity and t is time (in miles, miles per hour, and minutes or hours, as appropriate) and u is the notch (throttle) command input. Further, D denotes the distance to be traveled, T_f the desired arrival time at distance D along the track, T_e is the tractive effort produced by the locomotive consist, G_a is the gravitational drag which depends on the train length, train makeup, and terrain on which the train is located, and R is the net speed dependent drag of the locomotive consist and train combination. The initial and final speeds can also be specified, but without loss of generality are taken to be zero here (e.g., train stopped at beginning and end). Finally, the model is readily modified to include other important dynamics such the lag between a change in throttle, u , and the resulting tractive effort or braking. Using this model, an optimal control formulation is set up to minimize the quantitative objective function subject to constraints including but not limited to, speed limits and minimum and maximum power (throttle) settings. Depending on planning objectives at any time, the problem may be set up flexibly to minimize fuel subject to constraints on emissions and speed limits, or to minimize emissions, subject to constraints on fuel use and arrival time.

[0045] It is also possible to implement, for example, a goal to minimize the total travel time without constraints on total emissions or fuel use where such relaxation of constraints would be permitted or required for the mission. All these performance measures can be expressed as a linear combination of any of the following: $\tau_f \min \int_0^{T_f} u(t) dt$ - Minimize total fuel consumption (1)

..(0 o

min T_f - Minimize Travel Time $u(t)$ J

min $V (U_1 - u \Delta)^2$ - Minimize notch jockeying (piecewise constant input)

min $\int_0^{T_f} (du/dt)^2 dt$ - Minimize notch jockeying (continuous input)

..(0 J

It is possible to replace the fuel term F in (1) with a term corresponding to emissions

production. For example, for emissions $\min \int_0^{T_f} E(u(t)) dt$ - Minimize total emissions

..(0 J production. In this equation E is the quantity of emissions in gm/hphr for each of the notches (or power settings).

In addition, a minimization could be done based on a weighted total of fuel and emissions.

[0046] A commonly used and representative objective function is thus: $\tau_f \min \int_0^{T_f} CLx J F(u(t)) dt + a_3 T_f + a_2 \int_0^{T_f} (du/dt)^2 dt$ (OP) $u(t)$ o o

The coefficients of the linear combination depend on the importance (weight) given to each of the terms. Note that in equation (OP), $u(t)$ is the optimizing variable that is the continuous notch position. If discrete notch is required, e.g. for older locomotives, the solution to equation (OP) is discretized, which may result in lower fuel savings. Finding a minimum time solution (X_1 set to zero and α_2 set to zero or a relatively small value) is used to find a lower bound for the achievable travel time ($T_f = T_{fmin}$). In this case, both $u(t)$ and T_f are optimizing variables. In one embodiment, equation (OP) is solved for various values of T_f with $T_f > T_{fmin}$ with X_3 set to zero. In this latter case, T_f is treated as a constraint.

[0047] For those familiar with solutions to such optimal problems, it may be necessary to adjoin constraints, e.g., the speed limits along the path: or when using minimum time as the objective, that an end point constraint must hold, e.g., total fuel consumed must be less than what is in the tank, e.g. via:

$$0 < \int_0^{T_f} F(u(t)) dt < W_F$$

Here, W_F is the fuel remaining in the tank at T_f . Those skilled in the art will readily recognize that equation (OP) can be in other forms as well and that what is presented above is an exemplary equation for use in the exemplary embodiment of the present invention. For example, those skilled in the art will readily recognize that a variation of equation (OP) is required where multiple power systems, diesel and/or non-diesel, are used to provide multiple thrusters, such as, but not limited to, those that may be used when operating a marine vessel.

[0048] Reference to emissions in the context of the exemplary embodiment of the present invention is actually directed towards cumulative emissions produced in the form of oxides of nitrogen (NO_x), carbon oxides (CO_x), unburned hydrocarbons (HC), particulate matter (PM), etc. However, other emissions may include, but not be limited to a maximum

value of electromagnetic emission, such as a limit on radio frequency (RF) power output, measured in watts, for respective frequencies emitted by the locomotive. Yet another form of emission is the noise produced by the locomotive, typically measured in decibels (dB). An emission requirement may be variable based on a time of day, a time of year, and/or atmospheric conditions such as weather or pollutant level in the atmosphere. Emission regulations may vary geographically across a railroad system. For example, an operating area such as a city or state may have specified emission objectives, and an adjacent area may have different emission objectives, for example a lower amount of allowed emissions or a higher fee charged for a given level of emissions.

[0049] Accordingly, an emission profile for a certain geographic area may be tailored to include maximum emission values for each of the regulated emissions included in the profile to meet a predetermined emission objective required for that area. Typically, for a locomotive, these emission parameters are determined by, but not limited to, the power (notch) setting, ambient conditions, and engine control method. By design, every locomotive must be compliant with EPA emission standards, and thus in an embodiment of the present invention that optimizes emissions this may refer to mission-total emissions, for which there is no current EPA specification. Operation of the locomotive according to the optimized trip plan is at all times compliant with EPA emission standards. Those skilled in the art will readily recognize that because diesel engines are used in other applications, other regulations may also be applicable. For example, CO₂ emissions are considered in certain international treaties.

[0050] If an objective during a trip mission is to reduce emissions, the optimal control formulation, equation (OP), would be amended to consider this trip objective. A key flexibility in the optimization setup is that any or all of the trip objectives can vary by geographic region or mission. For example, for a high priority train, minimum time may be the only objective on one route because it is high priority traffic. In another example, emission output could vary from state to state along the planned train route.

[0051] To solve the resulting optimization problem, in an exemplary embodiment, a dynamic optimal control problem in the time domain is transcribed to an equivalent static mathematical programming problem with N decision variables, where the number 'N' depends on the frequency at which throttle and braking adjustments are made and the duration of the trip. For typical problems, this N can be in the thousands. For example, suppose a train is traveling a 172-mile (276.8 kilometers) stretch of track in the southwest United States. Utilizing the trip optimizer system, an exemplary 7.6% saving in fuel used may be realized when comparing a trip determined and followed using the trip optimizer system versus an actual driver throttle/speed history where the trip was determined by an operator. The improved savings is realized because the trip optimizer system produces a driving strategy with both less drag loss and little or no braking loss compared to the trip plan of the operator.

[0052] To make the optimization described above computationally tractable, a simplified mathematical model of the train may be employed, such as illustrated in FIG. 2 and the equations discussed above. As illustrated, certain set specifications, such as but not limited to information about the consist, route information, train information, and/or trip information, are considered to determine a profile, such as an optimized profile. Such factors incorporated in the profile include, but are not limited to, speed, distance remaining in the mission, and/or fuel used. As disclosed herein, other factors that may be included in the profile are notch setting and time. One possible refinement to the optimal profile is produced by driving a more detailed model with the optimal power sequence generated, to test if other thermal, electrical, and mechanical constraints are violated. This leads to a modified profile with speed versus distance that is closest to a run that can be achieved without harming locomotive or train equipment, i.e., satisfying additional implied constraints such as thermal and electrical limits on the locomotive and inter-car forces in the train. Those skilled in the art will readily recognize how the equations discussed herein are utilized with FIG. 2.

[0053] Referring back to FIG. 1, once the trip is started at 12a, power commands are generated 14 to put the mission plan in motion. Depending on the operational set-up of the trip optimizer system, one command is for the locomotive to follow the optimized power command 16 so as to achieve the optimal speed. The trip optimizer system obtains actual speed and power information 18 from the locomotive consist of the train. Owing to the inevitable approximations in the models used for the optimization, a closed-loop calculation of corrections to optimized power is obtained to track the desired optimal speed. Such corrections of train operating limits can be made automatically or by the operator, who always has ultimate control of the train.

[0054] In some cases, the model used in the optimization may differ significantly from the actual train. This can occur for many reasons, including, but not limited to, extra cargo pickups or setouts, locomotives that may become inoperable in route, and errors in the initial database 63 or data entry by the operator. For these reasons a monitoring system is in place that uses real-time train data to estimate locomotive and/or train parameters in real time 20. The estimated parameters are then compared to the assumed parameters used when the trip was initially created 22. Based on any differences in the assumed and estimated values, the trip may be re-planned 24, should large enough savings accrue from a new plan.

[0055] Other reasons a trip may be re-planned include directives from a remote location, such as dispatch, and/or the operator requesting a change in objectives to be consistent with more global movement planning objectives. Additional global movement planning objectives may include, but are not limited to, other train schedules, allowing exhaust to

dissipate from a tunnel, maintenance operations, etc. Another reason may be due to an onboard degradation of a component. Strategies for re-planning may be grouped into incremental and major adjustments depending on the severity of the disruption, as discussed in more detail below. In general, a "new" plan must be derived from a solution to the optimization problem equation (OP) described above, but frequently faster approximate solutions can be found, as described herein.

[0056] In operation, the locomotive 42 will continuously monitor system efficiency and continuously update the trip plan based on the actual efficiency measured, whenever such an update would improve trip performance. Re-planning computations may be carried out entirely within the locomotive(s) or fully or partially moved to a remote location, such as dispatch or wayside processing facilities where wireless technology is used to communicate the plans to the locomotive 42. In one embodiment, the trip optimizer system may also generate efficiency trends that can be used to develop locomotive fleet data regarding efficiency transfer functions. The fleet-wide data may be used when determining the initial trip plan, and may be used for network- wide optimization tradeoff when considering locations of a plurality of trains. For example, the travel-time fuel use tradeoff curve as illustrated in FIG. 8 as discussed in detail below, reflects a capability of a train on a particular route at a current time, updated from ensemble averages collected for many similar trains on the same route. Thus, a central dispatch facility collecting curves like FIG. 8 from many locomotives could use that information to better coordinate overall train movements to achieve a system-wide advantage in fuel use or throughput. As disclosed above, those skilled in the art will recognize that various fuel types, such as but not limited to diesel fuel, heavy marine fuels, palm oil, bio-diesel, etc. may be used.

[0057] Furthermore, as disclosed above, those skilled in the art will recognize that various energy storage devices may be used. For example, the amount of power withdrawn from a particular source, such as a diesel engine and batteries, could be optimized so that the maximum fuel efficiency/emission, which may be an objective function, is obtained. As further illustration, suppose the total power demand is 2000 horse power (HP), where the batteries can supply 1500 HP and the engine can supply 4400 HP. The optimum point could be when batteries are supplying 1200 HP and engine is supplying 200 HP.

[0058] Similarly, the amount of power may also be based on the amount of energy stored and the need for the energy in the future. For example, if there is a long high demand coming for power, the battery could be discharged at a slower rate. For example, if 1000 horsepower hour (HP_{hr}) is stored in the battery and the demand is 4400 HP for the next 2 hours, it may be optimum to discharge the battery at 800 HP for the next 1.25 hours and take 3600 HP from the engine for that duration.

[0059] Many events in daily operations can lead to a need to generate or modify a currently executing plan, where it desired to keep the same trip objectives, for example when a train is not on schedule for a planned meet or pass with another train and it needs to make up time. Using the actual speed, power, and location of the locomotive, a comparison is made between a planned arrival time and the currently estimated (predicted) arrival time 25. Based on a difference in the times, as well as the difference in parameters (detected or changed by dispatch or the operator), the plan is adjusted 26. This adjustment may be made automatically according to a railroad company's desire for how such departures from plan should be handled, or alternatives may be manually proposed for the on-board operator and dispatcher to jointly decide the best way to get back on plan. Whenever a plan is updated, in the case where the original objectives (such as, but not limited to, arrival time) remain the same, additional changes may be factored in concurrently, e.g., new future speed limit changes, which could affect the feasibility of ever recovering the original plan. In such instances, if the original trip plan cannot be maintained, or in other words the train is unable to meet the original trip plan objectives, as discussed herein other trip plan(s) may be presented to the operator and/or remote facility, or dispatch.

[0060] A re -plan 24, or an adjustment to a plan 26, as illustrated in FIG. 1 may also be made when it is desired to change the original objectives. Such re-planning can be done at either fixed preplanned times, manually at the discretion of the operator or dispatcher, or autonomously when predefined limits, such as train operating limits, are exceeded. For example, if the current plan execution is running late by more than a specified threshold, such as thirty minutes, the exemplary embodiment of the present invention can re -plan the trip to accommodate the delay at the expense of increased fuel use, as described above, or to alert the operator and dispatcher how much of the time can be made up at all (e.g., what minimum time to go or the maximum fuel that can be saved within a time constraint). Other triggers for re-plan can also be envisioned based on fuel consumed or the health of the power consist, including but not limited time of arrival, loss of horsepower due to equipment degradation (such as operating too hot or too cold), and/or detection of gross setup errors, such as in the assumed train load. That is, if the change reflects impairment in the locomotive performance for the current trip, these may be factored into the models and/or equations used in the optimization.

[0061] Changes in plan objectives can also arise from a need to coordinate events where the plan for one train compromises the ability of another train to meet objectives and arbitration at a different level, e.g., the dispatch office, is required. For example, the coordination of meets and passes may be further optimized through train-to-train communications. Thus, as an example, if a train knows that it is behind schedule in reaching a location for a meet and/or pass, communications from the other train can notify the late train (and/or dispatch). The operator can then enter information pertaining to being late into the trip optimizer system, wherein the system will recalculate the train's trip plan.

[0062] The trip optimizer system can also be used at a high level, or network level, to allow a dispatch to determine which train should slow down or speed up should it be the case that a scheduled meet and/or pass time constraint may not be met. As discussed herein, this is accomplished by trains transmitting data to the dispatch to prioritize how each train should change its planning objective. A choice could be based on either schedule, fuel saving benefits and/or emission output, depending on the situation.

[0063] Therefore, as explained herein, a re-plan 24 or adjustment to a plan 26, as illustrated in FIG. 1, may be carried out either independent of dispatch or in coordination with dispatch. Furthermore, as disclosed herein, a re-plan may be initiated, in whole or in part, based on information received at the powered system from dispatch or on information that originates from other sources, such as, but not limited to another powered system passing nearby and/or a wayside device or equipment.

[0064] With respect to a train 31, one example relates to a situation where dispatch 60 determines that a train operator has entered incorrect information for optimizing a mission plan. In this example, when information is entered by the operator, such as, but not limited to, through a control counsel and/or display 68, for generating an optimized trip plan, the information is transmitted to dispatch 60, which is remote from the train. A wired and/or wireless communication system 47 is used for communicating with dispatch 60. Dispatch verifies the information. Dispatch may be an individual at a remote location or a remote system having a processor that is able to determine if the information provided is correct for the intended mission. If the information is incorrect, the trip/mission plan originally generated using the incorrect information may be adjusted, re-planned, or otherwise revised using new, correct, and/or corrected information (collectively, updated information). The source of this second information may come from the dispatch and/or any other system that may provide information updates to the train. Verification and, if required, re-plan may occur prior to commencing the mission, and/or while the mission is progressing.

[0065] Changes to the optimized mission plan may also be made when updated information has a bearing on the currently implemented mission. One example of when such updated information may be used includes, but is not limited to, when the train is performing other than as contemplated with a current mission plan, e.g., the train's performance degrades at some point while an original mission plan is being followed. The change in performance may also be attributed to degraded operation capability of a rail infrastructure (or route infrastructure), crew change, timeout, if the operator decides to manually operate the train and then returns control for autonomous operation, etc. In another example, updated information is received from at least one of another train, such as through inter-train communication, a wayside device, and/or another localized source. When information is being transferred train-to-train, when the transmitting train has needed information. This information can include, but is not limited to, information learned based on track that the transmitting train has recently traversed and/or information relayed to the transmitting train when it was in communication with dispatch for transmitting to other trains that are unable to communicate with dispatch due to a communication interruption. In yet another example, such updated information may include a change in the mission objective, e.g., the train is reclassified from a high priority level to a low priority level. Where the train is operating with other trains (such as, but not limited to, on multi-section tracks in an intersecting railroad network), the updated information may provide for further optimizing the particular train's mission to insure that all trains using the same network of railways are operated safely and where no prolonged delays to any trains are realized, such as having to wait too long at a meet and pass location.

[0066] Re-planning may be performed on board the train, even when dispatch is unaware of the information that causes the re-planning to take place. In such a situation, dispatch is subsequently informed of the re-plan.

[0067] For any of the manually or automatically initiated re-plans, exemplary embodiments of the present invention may present more than one trip/mission plan to the operator. In an exemplary embodiment, the trip optimizer system presents different profiles to the operator, allowing the operator to select the arrival time and understand the corresponding fuel and/or emission impact. Such information can also be provided to the dispatch for similar consideration, either as a simple list of alternatives or as a plurality of tradeoff curves such as illustrated in FIG. 4.

[0068] The trip optimizer system has the ability to learn and adapted to key changes in the train and power consist, which can be incorporated either in the current plan and/or in future plans. For example, one of the triggers discussed above is loss of horsepower. When building up horsepower over time, either after a loss of horsepower or when beginning a trip, transition logic is utilized to determine when desired horsepower is achieved. This information can be saved in the locomotive database 61 for use in optimizing either future trips or the current trip should loss of horsepower occur again.

[0069] Likewise, in a similar fashion where multiple thrusters are available, each may need to be independently controlled. For example, a marine vessel may have many force producing elements, or thrusters, such as but not limited to propellers. Each propeller may need to be independently controlled to produce the optimum output. Therefore, utilizing transition logic, the trip optimizer system may determine which propeller to operate based on what has been learned previously and by adapting to key changes in the marine vessel's operation.

[0070] As noted above, FIG. 3 depicts various elements that may part of an exemplary trip optimizer system, according to an embodiment of the invention. A locator element 30 to determine a location of the train 31 is provided. The locator element 30 can be a GPS sensor, or a system of sensors, that determines a location of the train 31. Examples of such other systems include, but are not limited to, wayside devices, such as radio frequency automatic equipment identification

(RF AEI) tags, dispatch, and/or video determination. Another system may include the tachometer(s) aboard a locomotive and distance calculations from a reference point. As discussed previously, a wireless communication system 47 may also be provided to allow for communications between trains and/or with a remote location, such as dispatch 60. Information about travel locations may also be transferred from other trains.

[0071] A track characterization element 33, which provides information about a track, principally grade and elevation and curvature information, is also provided. The track characterization element 33 may include an on-board track integrity database 36. Sensors 38 are used to measure a tractive effort 40 being hauled by the locomotive 42, throttle setting of the locomotive consist 42, locomotive consist 42 configuration information, speed of the locomotive consist 42, individual locomotive configuration, individual locomotive capability, etc. In an exemplary embodiment, the locomotive consist 42 configuration information may be loaded without the use of a sensor 38, but is input in other manners as discussed above. Furthermore, the health of the locomotives in the consist may also be considered. For example, if one locomotive in the consist is unable to operate above power notch level 5, this information is used when optimizing the trip plan.

[0072] Information from the locator element may also be used to determine an appropriate arrival time of the train 31. For example, if there is a train 31 moving along a track 34 towards a destination and no train is following behind it, and the train has no fixed arrival deadline to adhere to, the locator element, including, but not limited to, RF AEI tags, dispatch, and/or video determination, may be used to gage the exact location of the train 31. Furthermore, inputs from these signaling systems may be used to adjust the train speed. Using the on-board track database, discussed below, and the locator element, such as GPS, the trip optimizer system can adjust the operator interface to reflect the signaling system state at the given locomotive location. In a situation where signal states would indicate restrictive speeds ahead, the planner may elect to slow the train to conserve fuel consumption.

[0073] Information from the locator element 30 may also be used to change planning objectives as a function of distance to destination. For example, owing to inevitable uncertainties about congestion along the route, "faster" time objectives on the early part of a route may be employed as a hedge against delays that statistically occur later. If it happens on a particular trip that delays do not occur, the objectives on a latter part of the journey can be modified to exploit the built-in slack time that was banked earlier, and thereby recover some fuel efficiency. A similar strategy could be invoked with respect to emissions restrictive objectives, e.g., approaching an urban area.

[0074] As an example of the hedging strategy, if a trip is planned from New York to Chicago, the system may have an option to operate the train slower at either the beginning of the trip or at the middle of the trip or at the end of the trip. In one embodiment, the trip optimizer system would optimize the trip plan to allow for slower operation at the end of the trip since unknown constraints, such as, but not limited to, weather conditions and track maintenance, may develop and become known during the trip. As another consideration, if traditionally congested areas are known, the plan is developed with an option to have more flexibility around these traditionally congested regions. Therefore, the trip optimizer system may also consider weighting/penalty as a function of time/distance into the future and/or based on known/past experience. At any time during the trip, planning and re-planning may also take into consideration weather conditions, track conditions, other trains on the track, etc., wherein the trip plan is adjusted accordingly.

[0075] FIG. 3 further discloses other elements that may be part of the trip optimizer system 12. The trip optimizer system is configured to compute an optimized trip plan for the train 31 based on parameters involving the locomotive 42, train 31, track 34, and objectives of the mission as described above. The trip optimizer system comprises a processor 44 that is operable to receive information from the locator element 30, track characterization element 33, and sensors 38. (The processor 44 may be a general purpose control unit in the train, or specific to the trip optimizer system 12.) An algorithm 46 (computer program) operates within the processor 44 for implementing certain functional elements of the trip optimizer system. In an exemplary embodiment, the trip plan is established based on models for train behavior as the train 31 moves along the track 34 as a solution of non-linear differential equations derived from physics with simplifying assumptions that are provided in the algorithm. The trip optimizer system 12 has access to the information from the locator element 30, track characterizing element 33, and/or sensors 38 to create a trip plan minimizing (or at least reducing) fuel consumption of a locomotive consist 42, minimizing (or at least reducing) emissions of a locomotive consist 42, establishing a desired trip time, ensuring proper crew operating time aboard the locomotive consist 42, and/or otherwise optimizing an operating parameter of the train or other vehicle. In an exemplary embodiment, a controller element 51 (and/or driver or operator) is also provided. As discussed herein, the controller element 51 is used for controlling the train as it follows the trip plan. In an exemplary embodiment discussed further herein, the controller element 51 makes train operation decisions autonomously. In another exemplary embodiment, the operator may be involved with directing the train to follow the trip plan.

[0076] A feature of an exemplary embodiment of the trip optimizer system is the ability to initially create and quickly modify "on the fly" any plan that is being executed. This includes creating the initial plan when a long distance is involved, owing to the complexity of the plan optimization algorithm. When a total length of a trip profile exceeds a given distance, an algorithm 46 may be used to segment the mission, wherein the mission may be divided by waypoints. Though only a single algorithm 46 is discussed, those skilled in the art will readily recognize that more than one algorithm may be used (and/or that the same algorithm may be executed a plurality of times) where the algorithms may be connected

together. The waypoints may include natural locations where the train 31 stops, such as, but not limited to, sidings where a meet with opposing traffic (or pass with a train behind the current train) is scheduled to occur on a single-track rail, or at yard sidings or industry where cars are to be picked up and set out, and locations of planned work. At such waypoints, the train 31 may be required to be at the location at a scheduled time and be stopped or moving with speed in a specified range. The time duration from arrival to departure at waypoints is called "dwell time."

[0077] In an exemplary embodiment, the trip optimizer system is able to break down a longer trip into smaller segments in a special systematic way. Each segment can be somewhat arbitrary in length, but is typically picked at a natural location such as a stop or significant speed restriction, or at key mileposts that define junctions with other routes. Given a partition, or segment, selected in this way, a driving profile is created for each segment of track as a function of travel time taken as an independent variable, such as shown in FIG. 4. The fuel used/travel-time tradeoff associated with each segment can be computed prior to the train 31 reaching that segment of track. A total trip plan can be created from the driving profiles created for each segment. The exemplary embodiment of the invention distributes travel time amongst all the segments of the trip in an optimal way so that the total trip time required is satisfied and total fuel consumed over all the segments is as small as possible. An exemplary three-segment trip is disclosed in FIG. 6 and discussed below. Those skilled in the art will recognize, however, that although segments are discussed, the trip plan may comprise a single segment representing the complete trip.

[0078] FIG. 4 depicts an exemplary embodiment of a fuel-use/travel time curve 50. As mentioned previously, such a curve 50 is created when calculating an optimal trip profile for various travel times for each segment. That is, for a given travel time 49, fuel used 53 is the result of a detailed driving profile computed as described above. Once travel times for each segment are allocated, a power/speed plan is determined for each segment from the previously computed solutions. If there are any waypoint constraints on speed between the segments, such as, but not limited to, a change in a speed limit, they are matched up during creation of the optimal trip profile. If speed restrictions change in only a single segment, the fuel use/travel-time curve 50 has to be re-computed for only the segment changed. This reduces time for having to re-calculate more parts, or segments, of the trip. If the locomotive consist or train changes significantly along the route, e.g., from loss of a locomotive or pickup or set-out of cars, then driving profiles for all subsequent segments must be recomputed, thereby creating new instances of the curve 50. These new curves 50 would then be used along with new schedule objectives to plan the remaining trip.

[0079] Once a trip plan is created as discussed above, a trajectory of speed and power versus distance is used to reach a destination with minimum fuel use and/or emissions at the required trip time. There are several ways in which to execute the trip plan. As provided below in more detail, in an exemplary embodiment, when in an operator "coaching" mode, information is displayed to the operator for the operator to follow to achieve the required power and speed determined according to the optimal trip plan. In this mode, the operating information includes suggested operating conditions that the operator should use. In another exemplary embodiment, acceleration and maintaining a constant speed are autonomously performed. However, when the train 31 must be slowed, the operator is responsible for applying a braking system 52. In another exemplary embodiment, commands for powering and braking are provided as required to follow the desired speed-distance path.

[0080] Feedback control strategies are used to provide corrections to the power control sequence in the profile to correct for events such as, but not limited to, train load variations caused by fluctuating head winds and/or tail winds. Another such error may be caused by an error in train parameters, such as, but not limited to, train mass and/or drag, when compared to assumptions in the optimized trip plan. A third type of error may occur with information contained in the track database 36. Another possible error may involve un-modeled performance differences due to the locomotive engine, traction motor thermal deration, and/or other factors. Feedback control strategies compare the actual speed as a function of position to the speed in the desired optimal profile. Based on this difference, a correction to the optimal power profile is added to drive the actual velocity toward the optimal profile. To assure stable regulation, a compensation algorithm may be provided which filters the feedback speeds into power corrections so that closed-performance stability is assured. Compensation may include standard dynamic compensation as used by those skilled in the art of control system design to meet performance objectives.

[0081] The trip optimizer system provides the simplest and therefore fastest means to accommodate changes in trip objectives, which is the rule, rather than the exception in railroad operations. In an exemplary embodiment, to determine the fuel-optimal trip from point "A" to point "B" where there are stops along the way, and for updating the trip for the remainder of the trip once the trip has begun, a sub-optimal decomposition method is usable for finding an optimal trip profile. Using modeling methods, the computation method can find the trip plan with specified travel time and initial and final speeds, so as to satisfy all the speed limits and locomotive capability constraints when there are stops. Though the following discussion is directed towards optimizing fuel use, it can also be applied to optimize other factors, such as, but not limited to, emissions, schedule, crew comfort, and load impact. The method may be used at the outset in developing a trip plan, and more importantly to adapting to changes in objectives after initiating a trip.

[0082] As discussed herein, exemplary embodiments of the present invention may employ a setup as illustrated in the exemplary flowchart depicted in FIG. 5, and as an exemplary three-segment example depicted in detail in FIG. 6.

As illustrated, the trip may be broken into two or more segments, T1, T2, and T3. (As noted above, it is possible to consider the trip as a single segment.) As discussed herein, the segment boundaries may not result in equal segments. Instead, the segments may use natural or mission specific boundaries. Optimal trip plans are pre-computed for each segment. If fuel use versus trip time is the trip object to be met, fuel versus trip time curves are built for each segment. As discussed herein, the curves may be based on other factors, wherein the factors are objectives to be met with a trip plan. When trip time is the parameter being determined, trip time for each segment is computed while satisfying the overall trip time constraints. FIG. 6 illustrates speed limits 97 for an exemplary three-segment, 200-mile (321.9 kilometers) trip. Further illustrated are grade changes 98 over the 200-mile (321.9 kilometers) trip. A combined chart 99 illustrating curves for each segment of the trip of fuel used over the travel time is also shown.

[0083] Using the optimal control setup described previously and the computation methods described herein, the trip optimizer system can generate the trip plan with specified travel time and initial and final speeds, so as to satisfy all the speed limits and locomotive capability constraints when there are stops. Though the following detailed discussion is directed towards optimizing fuel use, it can also be applied to optimize other factors as discussed herein, such as, but not limited to, emissions. A key flexibility is to accommodate desired dwell time at stops and to consider constraints on earliest arrival and departure at a location as may be required, for example, in single-track operations where the time to be in or get by a siding is critical.

[0084] Exemplary embodiments of the present invention find a fuel-optimal trip from distance D0 to DM, traveled in time T, with M-1 intermediate stops at D1,...,DM-1, and with the arrival and departure times at these stops constrained by:

$$t_{mm}(i) < \hat{x}(D1) < \hat{x}(I) - At1 \text{ tarr}(Dl) + Ml$$

$$\leq \hat{A} \leq \hat{x}(0 \text{ } i=1, \dots, M-1$$

where tarr (D1), tdep (D1), and At1 are the arrival, departure, and minimum stop time at the iA stop, respectively. Assuming that fuel-optimality implies minimizing stop time, therefore tdep (D1) = tarr (D1) + At1 which eliminates the second inequality above. Suppose for each i=1,...,M, the fuel-optimal trip from D1 to D1 for travel time t, $\hat{mn}(0 \text{ } t - \hat{max}(0 \text{ } J)$ is known. Let F1 (t) be the fuel-use corresponding to this trip. If the travel time from D, j to Dj is denoted T, then the arrival time at D1 is given by:

$$t_{arr}(D1) = \sum (Tj + At^1)$$

where At0 is defined to be zero. The fuel-optimal trip from D0 to DM for travel time T is then obtained by finding T1, i= 1, ..., M, which minimize

$$\sum F1(O \text{ } T_{mm}(i) < T1 < Z \hat{x}(O \text{ } t=1$$

subject to

$$t^{\wedge}(i) < \sum (Tj + Atj_{-1}) < t_{mAX}(i) - At1 \text{ } i = 1, \dots, M-1$$

$$J=1 \\ M$$

$$\sum (Tj + Atj_{-1}) = T$$

$$J=1$$

[0085] Once a trip is underway, the issue is re-determining the fuel-optimal solution for the remainder of a trip (originally from D0 to DM in time T) as the trip is traveled, but where disturbances preclude following the fuel-optimal solution. Let the current distance and speed be x and v, respectively, where $D1 \Delta < x < D1$. Also, let the current time since the beginning of the trip be tact. Then the fuel-optimal solution for the remainder of the trip from x to DM, which retains the original

arrival time at DM, is obtained by finding $T_1, T_{j,j} = i + 1, \dots, M$, which minimize

$$F_1(T_1^v) + \sum_{j=i+1}^M F_1(T_j)$$

subject to

$$A_{t,k} = i + 1, \dots, M-1$$

$$M \text{ tact} + T_1 + \sum_{j=i+1}^M (T_j + A_{t,j-1}) = T_j$$

Here, $F_t(t, x, v)$ is the fuel-used of the optimal trip from x to D_1 , traveled in time t , with initial speed at x of v .

[0086] As discussed above, an exemplary way to enable more efficient re-planning is to construct the optimal solution for a stop-to-stop trip from partitioned segments. For the trip from $D_{1,i}$ to D_1 , with travel time T_1 , choose a set of intermediate points D_j , $j = 1, \dots, N_t-1$. Let $D_{1,0} = D_1$ and $D^A = D_1$. Then express the fuel-use for the optimal trip from $D_{1,i}$ to D_1 as

where $f_j(t, v_{j-1}, v_j)$ is the fuel-use for the optimal trip from $D_{1,j-1}$ to $D_{1,j}$, traveled in time t , with initial and final speeds of v_{j-1} and v_j . Furthermore, t_j is the time in the optimal trip corresponding to distance $D_{1,j}$. By definition, $t_{N_t} - t_{1,0} = T_1$. Since the train is stopped at $D_{1,0}$ and D_{1,N_t} , $v_{1,0} = v_{N_t} = 0$.

[0087] The above expression enables the function $F_1(T)$ to be alternatively determined by first determining the functions $f_j(t, v_{j-1}, v_j)$, $1 \leq j < N_1$, then finding

$T_{1,j}$, $1 \leq j < N_1$ and v , $1 \leq j < N_1$, which minimize

$$F_1(O = L_{f,j}(T_v > v; j-i > v_v)) \quad j=i$$

subject to

$$v \cdot \text{mm} (V_i' J_i) < -v_{vj} < -v_{K_{\max}} (V_i' J_i) / J = 11 V_J N_{Jv} : -1 -1$$

$$V_{1,0} = V = 0$$

By choosing D_j (e.g., at speed restrictions or meeting points), $V_n^x(i, j) - v_{mm}(i, j)$ can be minimized, thus minimizing the domain over which $f_j(t, v_{j-1}, v_j)$ needs to be known.

[0088] Based on the partitioning above, a simpler suboptimal re-planning approach than that described above is to restrict re-planning to times when the train is at distance points D , $1 \leq i < M$, $1 \leq j < N_1$. At point $D_{1,i}$, the new optimal trip from D_j to D_M can be determined by finding $\tau_{1,k,j} < k \leq N_1$, $v_{1,k,j} < k < N_1$, and $\tau_{mn,i} < m < M$, $v_{mn,i} < m < M$, $1 \leq n < N_1$, which minimize

$N_1 M N_m$

$$\sum_{t=1}^M (\tau_{t,v_{\alpha-i} > v^*}) + \sum_{t=1}^M (\tau_{t,v_{\alpha-i} > v^*}) \quad k=j+1 \quad m=t+1 \quad k=1$$

subject to

N_1

$$\Delta n (0 \leq \text{tact} + \sum \tau, k \leq \text{max} (0 \leq \Delta f, k=j+1)$$

where

$$N_m T_m = \Delta / J_{mn} \quad k=1$$

[0089] A further simplification is obtained by waiting on the re-computation of $T1n, i < m < M$, until distance point $D1$ is reached. In this way, at points Du between $D1.!$ and $D1$, the minimization above needs only be performed over $\tau_{ik} > J < k - N1, v_{lk}, JKkKN1$. $T1$ is increased as needed to accommodate any longer actual travel time from $D1. i$ to $D1$, than planned. This increase is later compensated, if possible, by the re-computation of $T1n, i < m < M$, at distance point $D1$.

[0090] With respect to the closed-loop configuration disclosed above, the total input energy required to move a train 31 from point A to point B consists of the sum of four components, specifically, difference in kinetic energy between points A and B; difference in potential energy between points A and B; energy loss due to friction and other drag losses; and energy dissipated by the application of brakes. Assuming the start and end speeds to be equal (e.g., stationary), the first component is zero. Furthermore, the second component is independent of driving strategy. Thus, it suffices to minimize the sum of the last two components.

[0091] Following a constant speed profile minimizes drag loss. Following a constant speed profile also minimizes total energy input when braking is not needed to maintain constant speed. However, if braking is required to maintain constant speed, applying braking just to maintain constant speed will most likely increase total required energy because of the need to replenish the energy dissipated by the brakes. A possibility exists that some braking may actually reduce total energy usage if the additional brake loss is more than offset by the resultant decrease in drag loss caused by braking, by reducing speed variation.

[0092] After completing a re-plan from the collection of events described above, the new optimal notch/speed plan can be followed using the closed loop control described herein. However, in some situations there may not be enough time to carry out the segment decomposed planning described above, and particularly when there are critical speed restrictions that must be respected, an alternative is needed. Exemplary embodiments of the present invention accomplish this with an algorithm referred to as "smart cruise control." The smart cruise control algorithm is an efficient way to generate, on the fly, an energy-efficient (hence fuel-efficient) sub-optimal prescription for driving the train 31 over a known terrain. This algorithm assumes knowledge of the position of the train 31 along the track 34 at all times, as well as knowledge of the grade and curvature of the track versus position. The method relies on a point-mass model for the motion of the train 31, whose parameters may be adaptively estimated from online measurements of train motion as described earlier.

[0093] The smart cruise control algorithm has three principal components, specifically, a modified speed limit profile that serves as an energy-efficient (and/or emissions efficient or any other objective function) guide around speed limit reductions; an ideal throttle or dynamic brake setting profile that attempts to balance between minimizing speed variation and braking; and a mechanism for combining the latter two components to produce a notch command, employing a speed feedback loop to compensate for mismatches of modeled parameters when compared to reality parameters. Smart cruise control can accommodate strategies in exemplary embodiments of the present invention that do no active braking (e.g., the driver is signaled and assumed to provide the requisite braking) or a variant that does active braking.

[0094] With respect to the cruise control algorithm that does not control dynamic braking, the four exemplary components are a modified speed limit profile that serves as an energy-efficient guide around speed limit reductions, a notification signal directed to notify the operator when braking should be applied, an ideal throttle profile that attempts to balance between minimizing speed variations and notifying the operator to apply braking, a mechanism employing a feedback loop to compensate for mismatches of model parameters to reality parameters.

[0095] Also included in exemplary embodiments of the trip optimizer system is an approach to identify key parameter values of the train 31. For example, with respect to estimating train mass, a Kalman filter and a recursive least-squares approach may be utilized to detect errors that may develop over time.

[0096] FIG. 7 is a schematic diagram, showing information flow between elements, of an embodiment of the trip optimizer system. As discussed previously, a remote facility, such as a dispatch 60, can provide information. As illustrated, such information is provided to an executive control element 62. Also supplied to the executive control element 62 is information from a locomotive modeling database 63 ("Loco Models"), information from a track and/or segment database 36 (including, for example, track grade information and speed limit information, and estimated train parameters such as, but not limited to, train weight and drag coefficients), and fuel rate tables from a fuel rate estimator 64. The executive control element 62 supplies information to the trip optimizer system 12, which is disclosed in more detail in FIG. 1. Once a trip plan has been calculated, the plan is supplied to a driving advisor, driver/operator, or controller element 51. The trip plan is also supplied to the executive control element 62 so that it can compare the trip when other new data is provided.

[0097] As discussed above, the controller element 51 can automatically set a notch power, either a pre-established notch setting or an optimum continuous notch power. In addition to supplying a speed command to the train 31, a display 68 is provided so that the operator can view what the planner has recommended. The operator also has access to a control panel/stand 69. Through the control panel 69 the operator can decide whether to apply the notch power recommended. Towards this end, the operator may limit a targeted or recommended power. That is, at any time the operator always has final authority over what power setting the locomotive consist will operate at. This includes deciding whether to apply braking if the trip plan recommends slowing the train 31. For example, if operating in dark territory, or where information from wayside equipment cannot electronically transmit information to a train and instead the operator views

visual signals from the wayside equipment, the operator inputs commands based on information contained in the track database and visual signals from the wayside equipment. Based on how the train 31 is functioning, information regarding fuel measurement is supplied to the fuel rate estimator 64. Since direct measurement of fuel flows is not typically available in a locomotive consist, all information on fuel consumed so far within a trip and projections into the future following optimal plans is carried out using calibrated physics models such as those used in developing the optimal plans. For example, such predictions may include, but are not limited to, the use of measured gross horsepower and known fuel characteristics and emissions characteristics to derive the cumulative fuel used and emissions generated.

[0098] The train 31 also has a locator element 30 such as a GPS sensor, as discussed above. Information is supplied to the train parameters estimator 65. Such information may include, but is not limited to, GPS sensor data, tractive/braking effort data, braking status data, speed, and any changes in speed data. With information regarding grade and speed limit information, train weight and drag coefficients information is supplied to the executive control element 62.

[0099] Exemplary embodiments of the present invention may also allow for the use of continuously variable power throughout the optimization planning and closed loop control implementation. In a conventional locomotive, power is typically quantized to eight discrete levels. Modern locomotives can realize continuous variation in horsepower, which may be incorporated into the previously described optimization methods. With continuous power, the locomotive 42 can further optimize operating conditions, e.g., by minimizing auxiliary loads and power transmission losses, and fine tuning engine horsepower regions of optimum efficiency, or to points of increased emissions margins. Example include, but are not limited to, minimizing cooling system losses, adjusting alternator voltages, adjusting engine speeds, and reducing number of powered axles. Further, the locomotive 42 may use the on-board track database 36 and the forecasted performance requirements to minimize auxiliary loads and power transmission losses to provide optimum efficiency for the target fuel consumption/emissions. Examples include, but are not limited to, reducing a number of powered axles on flat terrain and pre-cooling the locomotive engine prior to entering a tunnel.

[0100] Exemplary embodiments of the trip optimizer system may also use the on-board track database 36 and the forecasted performance to adjust the locomotive performance, such as to insure that the train has sufficient speed as it approaches a hill and/or tunnel. For example, this could be expressed as a speed constraint at a particular location that becomes part of the optimal plan generation created solving the equation (OP). Additionally, the trip optimizer system may incorporate train- handling rules, such as, but not limited to, tractive effort ramp rates and maximum braking effort ramp rates. These may be incorporated directly into the formulation for optimum trip profile or alternatively incorporated into the closed loop regulator used to control power application to achieve the target speed.

[0101] In one embodiment, the trip optimizer system is only installed on a lead locomotive of the train consist. Even though exemplary embodiments of the present invention are not dependant on data or interactions with other locomotives, it may be integrated with a consist manager, as disclosed in U.S. Patent No. 6,691,957 and U.S. Patent No. 7,021,588 (owned by the Assignee and both incorporated by reference), and/or a consist optimizer functionality to improve efficiency. Interaction with multiple trains is not precluded, as illustrated by the example of dispatch arbitrating two "independently optimized" trains described herein.

[0102] Trains with distributed power systems can be operated in different modes. One mode is where all locomotives in the train operate at the same notch command. So if the lead locomotive is commanding motoring - N8, all units in the train will be commanded to generate motoring - N8 power. Another mode of operation is "independent" control. In this mode, locomotives or sets of locomotives distributed throughout the train can be operated at different motoring or braking powers. For example, as a train crests a mountaintop, the lead locomotives (on the down slope of mountain) may be placed in braking, while the locomotives in the middle or at the end of the train (on the up slope of mountain) may be in motoring. This is done to minimize tensile forces on the mechanical couplers that connect the railcars and locomotives. Traditionally, operating the distributed power system in "independent" mode required the operator to manually command each remote locomotive or set of locomotives via a display in the lead locomotive. Using the physics based planning model, train set-up information, on-board track database, onboard operating rules, location determination system, real-time closed loop power/brake control, and sensor feedback, the system is able to automatically operate the distributed power system in "independent" mode.

[0103] When operating in distributed power, the operator in a lead locomotive can control operating functions of remote locomotives in the remote consists via a control system, such as a distributed power control element. Thus, when operating in distributed power, the operator can command each locomotive consist to operate at a different notch power level (or one consist could be in motoring and another could be in braking), wherein each individual locomotive in the locomotive consist operates at the same notch power. In an exemplary embodiment, with the trip optimizer system installed on the train and in communication with the distributed power control element, when a notch power level for a remote locomotive consist is desired as recommended by the optimized trip plan, the trip optimizer system will communicate this power setting to the remote locomotive consists for implementation. As discussed below, the same is true regarding braking.

[0104] Exemplary embodiments of the present invention may be used with consists in which the locomotives are not contiguous, e.g., with one or more locomotives up front and others in the middle and/or at the rear for train. Such

configurations are called "distributed power," wherein the standard connection between the locomotives is replaced by radio link or auxiliary cable to link the locomotives externally. When operating in distributed power, the operator in a lead locomotive can control operating functions of remote locomotives in the consist via a control system, such as a distributed power control element. In particular, when operating in distributed power, the operator can command each locomotive consist to operate at a different notch power level (or one consist could be in motoring and other could be in braking), wherein each individual in the locomotive consist operates at the same notch power.

[0105] In an exemplary embodiment, with the trip optimizer system installed on the train and in communication with the distributed power control element, when a notch power level for a remote locomotive consist is desired as recommended by the optimized trip plan, the trip optimizer system will communicate this power setting to the remote locomotive consists for implementation. As discussed below, the same is true regarding braking. When operating with distributed power, the optimization problem previously described can be enhanced to allow additional degrees of freedom, in that each of the remote units can be independently controlled from the lead unit. The value of this is that additional objectives or constraints relating to in-train forces may be incorporated into the performance function, assuming the model to reflect the in-train forces is also included. Thus, exemplary embodiments of the present invention may include the use of multiple throttle controls to better manage in-train forces as well as fuel consumption and emissions.

[0106] In a train utilizing a consist manager, the lead locomotive in a locomotive consist may operate at a different notch power setting than other locomotives in that consist. The other locomotives in the consist operate at the same notch power setting. The trip optimizer system may be utilized in conjunction with the consist manager to command notch power settings for the locomotives in the consist. Thus, based on the trip optimizer system, since the consist manager divides a locomotive consist into two groups, namely, lead locomotive and trail units, the lead locomotive will be commanded to operate at a certain notch power and the trail locomotives are commanded to operate at another certain notch power. In an exemplary embodiment, the distributed power control element may be the system and/or apparatus where this operation is housed.

[0107] Likewise, when a consist optimizer is used with a locomotive consist, the trip optimizer system can be used in conjunction with the consist optimizer to determine notch power for each locomotive in the locomotive consist. For example, suppose that a trip plan recommends a notch power setting of 4 for the locomotive consist. Based on the location of the train, the consist optimizer will take this information and then determine the notch power setting for each locomotive in the consist. In this implementation, the efficiency of setting notch power settings over intra-train communication channels is improved. Furthermore, as discussed above, implementation of this configuration may be performed utilizing the distributed control system.

[0108] Furthermore, as discussed previously, exemplary embodiments of the present invention may be used for continuous corrections and re-planning with respect to when the train consist uses braking based on upcoming items of interest, such as, but not limited to, railroad crossings, grade changes, approaching sidings, approaching depot yards, and approaching fuel stations, where each locomotive in the consist may require a different braking option. For example, if the train is coming over a hill, the lead locomotive may have to enter a braking condition, whereas the remote locomotives, having not reached the peak of the hill may have to remain in a motoring state.

[0109] FIGS. 8, 9 and 10 are illustrations of dynamic displays 68 for use by the operator, according to various embodiments of the present invention. As shown in FIG. 8, a trip profile 72 may be provided as part of the dynamic display 68. Within the profile a location 73 of the locomotive is provided. Such information as train length 105 and the number of cars 106 in the train is provided. Display elements are also provided regarding track grade 107, curve and wayside elements 108, including bridge location 109, and train speed 110. The display 68 allows the operator to view such information and also see where the train is along the route. Information pertaining to distance and/or estimated time of arrival to such locations as crossings 112, signals 114, speed changes 116, landmarks 118, and destinations 120 is provided. An arrival time management tool 125 is also provided to allow the user to determine the fuel savings that is being realized during the trip. The operator has the ability to vary arrival times 127 and witness how this affects the fuel savings. As discussed herein, those skilled in the art will recognize that fuel saving is an example of only one objective that can be reviewed with a management tool. Towards this end, depending on the parameter being viewed, other parameters discussed herein can be viewed and evaluated with a management tool that is visible to the operator. The operator is also provided information about how long the crew has been operating the train. In exemplary embodiments time and distance information may either be illustrated as the time and/or distance until a particular event and/or location, or it may provide a total elapsed time.

[0110] As illustrated in FIG. 9, an exemplary display provides information about consist data 130, an events and situation graphic 132, an arrival time management tool 134, and action keys 136. Similar information as discussed above is provided in this display as well. This display 68 also provides action keys 138 to allow the operator to re-plan, as well as to disengage 140 the trip optimizer system.

[0111] FIG. 10 depicts another exemplary embodiment of the display. Data typical of a modern locomotive including air-brake status 71, analog speedometer with digital insert 74, and information about tractive effort in pounds force (or traction amps for DC locomotives) is visible. An indicator 74 is provided to show the current optimal speed in the plan

being executed, as well as an accelerometer graphic to supplement the readout in mph/minute. Important new data for optimal plan execution is in the center of the screen, including a rolling strip graphic 76 with optimal speed and notch setting versus distance compared to the current history of these variables. In this exemplary embodiment, the location of the train is derived using the locator element. As illustrated, the location is provided by identifying how far the train is away from its final destination, an absolute position, an initial destination, an intermediate point, and/or an operator input.

[0112] The strip chart provides a look-ahead to changes in speed required to follow the optimal plan, which is useful in manual control, and monitors plan versus actual during automatic control. As discussed herein, such as when in the coaching mode, the operator can follow either the notch or speed suggested by exemplary embodiments of the present invention. The vertical bar gives a graphic of desired and actual notch, which are also displayed digitally below the strip chart. When continuous notch power is utilized, as discussed above, the display will simply round to the closest discrete equivalent. The display may be an analog display so that an analog equivalent or a percentage or actual horse power/tractive effort is displayed.

[0113] Critical information on trip status is displayed on the screen, and shows the current grade the train is encountering 88, either by the lead locomotive, a location elsewhere along the train, or an average over the train length. Also displayed are a distance traveled so far in the plan 90, cumulative fuel used 92, where the next stop is planned 94 (and/or a distance to the next planned stop), and current and projected arrival time 96 for the next stop. The display 68 also shows the maximum possible time to destination possible with the computed plans available. If a later arrival was required, a re-plan would be carried out. Delta plan data shows status for fuel and schedule ahead or behind the current optimal plan. Negative numbers mean less fuel or early compared to plan, positive numbers mean more fuel or late compared to plan, and typically trade-off in opposite directions (slowing down to save fuel makes the train late and conversely).

[0114] At all times, these displays 68 give the operator a snapshot of where the train stands with respect to the currently instituted driving plan. This display is for illustrative purpose only as there are many other ways of displaying/conveying this information to the operator and/or dispatch. Towards this end, the information disclosed above could be intermixed to provide a display different than the ones disclosed.

[0115] Other features that may be included in the trip optimizer system include, but are not limited to, allowing for the generation of data logs and reports. This information may be stored on the train and downloaded to an off-board system at some point in time. The downloads may occur via manual and/or wireless transmission. This information may also be viewable by the operator via the locomotive display. The data may include information such as, but not limited to, operator inputs, the time the system is operational, fuel saved, fuel imbalance across locomotives in the train, train journey off course, and system diagnostic issues such as if a GPS sensor is malfunctioning.

[0116] Since trip plans must also take into consideration allowable crew operation time, exemplary embodiments of the present invention may take such information into consideration as a trip is planned. For example, if the maximum time a crew may operate is eight hours, then the trip is fashioned to include stopping location for a new crew to take the place of the present crew. Such specified stopping locations may include, but are not limited to, rail yards, meet/pass locations, and the like. If, as the trip progresses, the trip time may be exceeded, the trip optimizer system may be overridden by the operator to meet criteria as determined by the operator. Ultimately, regardless of the operating conditions of the train (e.g., high load, low speed, and train stretch conditions), the operator remains in control to command a speed and/or operating condition of the train.

[0117] Using the trip optimizer system, the train may operate in a plurality of operational manners/configurations. In one operational concept, the trip optimizer system may provide commands for commanding propulsion and dynamic braking. The operator then handles all other train functions. In another operational concept, the trip optimizer system may provide commands for commanding propulsion only. The operator then handles dynamic braking and all other train functions. In yet another operational concept, the trip optimizer system may provide commands for commanding propulsion, dynamic braking, and application of the airbrake. The operator then handles all other train functions.

[0118] The trip optimizer system may also be used to notify the operator of upcoming items of interest and/or of actions to be taken. Specifically, using the forecasting logic of exemplary embodiments of the present invention, the continuous corrections and re-planning to the optimized trip plan, and/or the track database, the operator can be notified of upcoming crossings, signals, grade changes, brake actions, sidings, rail yards, fuel stations, etc. This notification may occur audibly and/or through the operator interface.

[0119] Specifically, using the physics based planning model, train set-up information, on-board track database, on-board operating rules, location determination system, real-time closed loop power/brake control, and sensor feedback, the system presents and/or notifies the operator of required actions. The notification can be visual and/or audible. Examples include notifying of crossings that require the operator to activate the locomotive horn and/or bell, and notifying of "silent" crossings that do not require that the operator activate the locomotive horn or bell.

[0120] In another exemplary embodiment, using the physics based planning model discussed above, train set-up information, on-board track database, on-board operating rules, location determination system, real-time closed power/brake control, and sensor feedback, the operator may be presented with information (e.g., a gauge on display) that allows the operator to see when the train will arrive at various locations, as illustrated in FIG. 9. The system allows the

operator to adjust the trip plan (e.g., target arrival time). This information (actual estimated arrival time or information needed to derive off-board) can also be communicated to the dispatch center to allow the dispatcher or dispatch system to adjust the target arrival times. This allows the system to quickly adjust and optimize for the appropriate target function (for example trading off speed and fuel usage).

[0121] FIG. 11 depicts an exemplary embodiment of a network of railway tracks with multiple trains. In the railroad network 200, it is desirable to obtain an optimized fuel efficiency and time of arrival for the overall network of multiple interacting tracks 210, 220, 230, and trains 235, 236, 237. As illustrated, multiple tracks 210, 220, 230 are shown with a train 235, 236, 237 on each respective track. Though locomotive consists 42 are illustrated as part of the trains 235, 236, 237, those skilled in the art will readily recognize that any train may only have a single locomotive consist having a single locomotive. As disclosed herein, a remote facility 240 may also be involved with improving fuel efficiency and reducing emissions of a train through optimized train power makeup. This may be accomplished with a processor 245, such as a computer, located at the remote facility 240. In another exemplary embodiment a hand-held device 250 may be used to facilitate improving fuel efficiency of the train 235, 236, 237 through optimized train power makeup. Typically in either of these approaches, configuring of the train 235, 236, 237 usually occurs at a hump, rail yard, or the like, when the train is being compiled.

[0122] Alternatively, as discussed below, the processor 245 may be located on the train 235, 236, 237 or aboard another train, wherein train setup may be accomplished using inputs from the other train. For example, if a train has recently completed a mission over the same tracks, input from that train's mission may be supplied to the current train as it either is performing and/or is about to begin its mission. Thus, configuring the train may occur at train run time, and even during the run time. For example, real time configuration data may be utilized to configure the train locomotives. One such example is provided above with respect to using data from another train. Another example entails using other data associated with trip optimization of the train as discussed above. Additionally, the train setup may be performed using input from a plurality of sources, such as, but not limited to, a dispatch system, a wayside system 270, an operator, an off-line real time system, an external setup, a distributed network, a local network, and/or a centralized network.

[0123] FIG. 12 is a flowchart depicting an exemplary embodiment of a method for improving fuel efficiency and reducing emission output through optimized train power makeup. As disclosed above, to minimize fuel use and emissions while preserving time arrival, acceleration and matched breaking may be minimized. Undesired emissions may also be minimized by powering a minimal set of locomotives. For example, in a train with several locomotives or locomotive consists, powering a minimal set of locomotives at a higher power setting while putting the remaining locomotives into idle, unpowered standby, or an automatic engine start- stop ("AESS") mode as discussed below, will reduce emissions. This is at least partly because exhaust emissions after-treatment devices on the locomotives (e.g., catalytic converters) are at a temperature below which they optimally operate, when locomotives are run at lower power settings (e.g., notch 1-3). Therefore, using the minimum number of locomotives or locomotive consists to make the mission on time, operating at high power settings will allow for the exhaust emission treatment devices to operate at optimal temperatures, thereby further reducing emissions.

[0124] The method illustrated in flowchart 500 in FIG. 12 provides for determining a train load, at 510. When the engine is used in other applications, the load is determined based on the engine configuration. The train load may be determined with a load, or train load, estimator 560, as illustrated in FIG. 13. In an exemplary embodiment, the train load is estimated based on information obtained as disclosed in a train makeup docket 480, as illustrated in FIG. 11. For example, the train makeup docket 480 may be contained in the processor 245 (illustrated in FIGS. 11 and 13), wherein the processor 245 makes the estimation, or may be on paper wherein an operator makes the estimation. The train makeup docket 480 may include information such as the number of cars, car weight, car content, car age, etc. In another exemplary embodiment, the train load is estimated using historical data, such as, but not limited to, prior train missions making the same trip, and similar train car configurations. As discussed above, using historical data may be accomplished with a processor or manually. In yet another exemplary embodiment, the train load is estimated using a rule of thumb or table data. For example, the operator configuring the train 235, 236, 237 may determine the train load required based on established guidelines such as, but not limited to, a number of cars in the train, types of cars in the train, weight of the cars in the train, and an amount of products being transported by the train. This same rule of thumb determination may also be accomplished using the processor 245.

[0125] Referring back to FIG. 12, identifying a mission time and/or duration for the diesel power system, at 520, is disclosed. With respect to engines used in other applications, identifying a mission time and/or duration for the diesel power system may be equated to defining the mission time within which the engine configuration is expected to accomplish the mission. A determination is made about a minimum total amount of power required based on the train load, at 530. The locomotive is selected to satisfy the minimum required power while yielding improved fuel efficiency and/or minimized emission output, at 540. The locomotive may be selected based on a type of locomotive (based on its engine) needed and/or a number of locomotives (based on a number of engines) needed. Similarly, with respect to diesel engines used in other power applications, such as but not limited to marine, OHV, and stationary power stations, multiple units of each are used to accomplish an intended mission unique for the specific application.

[0126] Towards this end, a trip mission time determinator 570, as illustrated in FIG. 13, may be used to determine the mission time based on information such as, but not limited to, weather conditions, track conditions, and the like. The locomotive makeup may be based on the types of locomotives needed, as a function of power output or otherwise, and/or a minimum number of locomotives needed. For example, based on the available locomotives, a selection is made of those locomotives that just meet the total power required. Towards this end, as an example, if ten locomotives are available, a determination of the power output from each locomotive is made. Based on this information, the fewest number and type of locomotives needed to meet the total power requirements are selected. For example, the locomotives may have different horse power (HP) ratings or starting tractive effort (TE) ratings. In addition to the total power required, the distribution of power and type of power in the train can be determined. For example, to limit the maximum coupler forces on heavy trains, the locomotives may be distributed within the train. Another consideration is the capability of the locomotive. It may be possible to put four DC locomotives on the head end of a train; however, four AC units with the same HP may not be used at the head end since the total drawbar forces may exceed designated limits.

[0127] In another exemplary embodiment, the selection of locomotives may not be based solely on reducing a number of locomotives used in a train. For example, if the total power requirement is minimally met by five of the available locomotives when compared to also meeting the power requirement by the use of three of the available locomotives, the five locomotives are used instead of the three. In view of these options, those skilled in the art will readily recognize that a minimum number of locomotives may be selected from a sequential (and random) set of available locomotives. Such an approach may be used when the train 235, 236, 237 is already compiled and a decision is being made at run time and/or during a mission wherein the remaining locomotives are not used to power the train 235, 236, 237, as discussed in further detail below.

[0128] While compiling the train 235, 236, 237, if the train 235, 236, 237 requires backup power, incremental locomotive 255, or locomotives, may be added (see FIG. 11). However, this additional locomotive 255 is isolated to minimize fuel use, emission output, and power variation, but may be used to provide backup power in case an operating locomotive becomes inoperable, and/or to provide additional power to accomplish the trip within an established mission time. The isolated locomotive 255 may be put into an AESS mode to minimize fuel use while having the locomotive be available when needed. In an exemplary embodiment, if a backup, or isolated, locomotive 255 is provided, its dimensions (e.g., weight) may be taken into consideration when determining the train load.

[0129] Thus, as discussed above in more detail, determining minimum power needed to power the train 235, 236, 237 may occur at train run time and/or during a run (or mission). In this instance, once a determination is made as to optimized train power and the locomotives or locomotive consists 42 in the train 235, 236, 237 are identified to provide the requisite power needed, the additional locomotive(s) 255 not identified for use are put in the idle, or AESS, mode.

[0130] In an exemplary embodiment, the total mission run may be broken into a plurality of sections, or segments, such as but not limited to at least 2 segments, such as segment A and segment B as illustrated in FIG. 11. Based on the amount of time taken to complete any segment, the backup power provided by the isolated locomotive 255 is made available in case incremental power is needed to meet the trip mission objective. Towards this end, the isolated locomotive 255 may be utilized for a specific trip segment to get the train 235, 236, 237 back on schedule and then switched off for subsequent segments, if the train 235, 236, 237 remains on schedule.

[0131] Thus, in operation, the lead locomotive may put the locomotive 255 provided for incremental power into an isolation mode until the power is needed. This may be accomplished by use of wired or wireless modems or communications from the operator, usually on the lead locomotive, to the isolated locomotive 255. In another exemplary embodiment, the locomotives operate in a distributed power configuration and the isolated locomotive 255 is already integrated in the distributed power configuration, but is idle, and is switched on when the additional power is required. In yet another embodiment, the operator puts the isolated locomotive 255 into the appropriate mode.

[0132] In an exemplary embodiment, the initial setup of the locomotives, based on train load and mission time, is updated by the trip optimizer, as disclosed above, and adjustments to the number and type of powered locomotives are made. As an exemplary illustration, consider a locomotive consist 42 of three locomotives having relative available maximum power of 1, 1.5 and 0.75, respectively. (Relative available power is relative to a "reference" locomotive, which is used to determine the total consist power. For example, in the case of a '3000HP' reference locomotive, the first locomotive has 3000 HP, the second 4500 HP, and the third 2250 HP.) Suppose that the mission is broken into seven segments. Given the above scenario, the following combinations are available and can be matched to the track section load: 0.75, 1, 1.5, 1.75, 2.25, 2.5, 3.25, which is the combination of maximum relative HP settings for the consist. Thus, for each respective relative HP setting mentioned above, for the 0.75 setting the third locomotive is on and the first and second are off, for 1 the first locomotive is on and the second and third are off, etc. In one embodiment, the trip optimizer selects the maximum required load and adjusts via notch calls while minimizing an overlap of power settings. Hence, if a segment calls for between 2 and 2.5 (times 3000 HP) then locomotive 1 and locomotive 2 are used while locomotive 3 is in either idle or in standby mode, depending on the time it is in this segment and the restart time of the locomotive.

[0133] In another exemplary embodiment, an analysis may be performed to determine a trade off between emission output and locomotive power settings to maximize higher notch operation where the emissions from the exhaust after

treatment devices are more optimal. This analysis may also take into consideration one of the other parameters discussed above regarding train operation optimization. This analysis may be performed for an entire mission run, segments of a mission run, and/or combinations of both.

[0134] FIG. 13 depicts a block diagram of elements included in a system for optimized train power makeup, according to one aspect of the present invention. As illustrated and discussed above, a train load estimator 560 is provided. A trip mission time determinator 570 is also provided. A processor 245 is also provided. As disclosed above, though directed at a train, similar elements may be used for other engines not being used within a rail vehicle, such as but not limited to off-highway vehicles, marine vessels, and stationary units. The processor 245 calculates a total amount of power required to power the train 235, 236, 237 based on the train load determined by the train load estimator 560 and a trip mission time determined by the trip mission time determinator 570. A determination is further made of a type of locomotive needed and/or a number of locomotives needed, based on each locomotive power output, to minimally achieve the minimum total amount of power required based on the train load and trip mission time.

[0135] The trip mission time determinator 570 may segment the mission into a plurality of mission segments, such as a segment A and a segment B, as discussed above. The total amount of power may then be individually determined for each segment of the mission. As further discussed above, an additional locomotive 255 is part of the train 235, 236, 237 and is provided for backup power. The power from the back-up locomotive 255 may be used incrementally as a requirement is identified, such as but not limited to providing power to get the train 235, 236, 237 back on schedule for a particular trip segment. In this situation, the train 235, 236, 237 is operated to achieve and/or meet the trip mission time.

[0136] The train load estimator 560 may estimate the train load based on information contained in the train makeup docket 480, historical data, a rule of thumb estimation, and/or table data. Furthermore, the processor 245 may determine a trade off between emission output and locomotive power settings to maximize higher notch operation where the emissions from the exhaust after-treatment devices are optimized.

[0137] FIG. 14 depicts a block diagram of a transfer function for determining a fuel efficiency and emissions for a diesel powered system. Such diesel-powered systems include, but are not limited to, locomotives, marine vessels, OHV, and/or stationary generating stations. As illustrated, information pertaining to input energy 580 (such as power, waste heat, etc.) and information about an after treatment process 583 are provided to a transfer function 585 (" $f(x,y)$ "). The transfer function 585 utilizes this information to determine an optimum fuel efficiency 587 and emission output 590.

[0138] FIG. 15 depicts an exemplary embodiment of a method for determining a configuration of a diesel-powered system having at least one diesel-fueled power generating unit. As shown in flowchart 600, the method includes determining a minimum power required from the diesel-powered system in order to accomplish a specified mission, at 605. An operating condition of the diesel-fueled power generating unit is determined such that the minimum power requirement is satisfied while yielding at least one of lower fuel consumption and/or lower emissions for the diesel powered system, as at 610. As disclosed above, the method illustrated in flowchart 600 is applicable for a plurality of diesel-fueled power generating units, such as, but not limited to, locomotives, marine vessels, OHVs, and/or stationary generating stations. Additionally, this flowchart 600 may be implemented using a computer software program that may reside on a computer readable media.

[0139] FIG. 16 depicts an exemplary embodiment of a closed-loop system for operating a rail vehicle. As illustrated, the system includes an optimizer 650, a converter 652, a rail vehicle 653, and at least one output 654 from gathering specific information, such as, but not limited to, speed, emissions, tractive effort, horse power, and a friction modifier technique (e.g., applying sand). The output 654 may be determined by a sensor 656 that is part of the rail vehicle 653, or in another exemplary embodiment independent of the rail vehicle 653. Information initially derived from information generated from the trip optimizer 650 and/or a regulator is provided to the rail vehicle 653 through the converter 652. Locomotive data gathered by the sensor 656 from the rail vehicle is then communicated back to the optimizer 650 over a close-loop communication pathway 657.

[0140] The optimizer 650 determines operating characteristics for at least one factor that is to be regulated, such as speed, fuel, emissions, etc. The optimizer 650 determines at least one of a power and/or torque setting based on a determined optimized value. The converter 652 is provided to convert information about power, torque, speed, emissions, a friction modifying technique (such as but not limited to applying sand), setup, configurations, etc. into a form suitable for applying to the control inputs for the rail vehicle 653, usually a locomotive. Specifically, this information or data may be converted to an electrical signal.

[0141] As discussed in further detail below, the converter 652 may interface with any one of a plurality of devices, such as a master controller, remote control locomotive controller, a distributed power drive controller, a train line modem, analog input, etc. FIG. 17 depicts the closed loop system integrated with a master control unit or controller 651. The converter, for example, may selectively disconnect or disable the output of the master controller (or actuator) 651. (The master controller 651 is normally used by the operator to command the locomotive, as relating to power, horsepower, tractive effort, implementation of a friction modifying technique (such as but not limited to applying sand), braking (including at least one of dynamic braking, air brakes, hand brakes, etc.), propulsion, and the like. Those skilled in the art will readily recognize that the master controller may be used to control both hard switches and software-based switches used in

controlling the locomotive.) Once the master controller 651 is disconnected, the converter 652 then generates control signals in place of the master controller 651. The disconnection of the actuator 651 may be by electrical wires, software switches, a configurable input selection process, etc. A switching device 655 is illustrated to perform this function. More specifically, the operator control input of the master controller 651 is disconnected.

[0142] Though FIG. 17 discloses a master controller 651, this is specific to a locomotive. Those skilled in the art will recognize that in other applications, such as those disclosed above, other devices may provide a function equivalent to that of the master controller as used in a locomotive. For example, an accelerator pedal is used in an OHV or transportation bus, and an excitation control is used on a generator. With respect to marine vessels, there may be multiple force producers (e.g., propellers), in different angles/orientation, that are controlled in a closed-loop manner.

[0143] As discussed above, the same technique may be used for other devices, such as a control locomotive controller, a distributed power drive controller, a train line modem, analog input, etc. Though not illustrated, those skilled in the art will readily recognize that the converter similarly could use these devices and their associated connections to the locomotive for applying input control signals to the locomotive. The communication system 657 for these other devices may be either wireless or wired. More specifically, the converter may be interfaced with devices (such as a drive controller, a modem, etc.) other than the master controller 651.

[0144] FIG. 18 depicts an exemplary embodiment of a closed-loop system for operating a rail vehicle integrated with another input operational subsystem of the rail vehicle. For example, the distributed power drive controller 659 may receive inputs from various sources 661 (such as, but not limited to, the operator, train lines, and locomotive controllers) and transmit the information to locomotives in the remote positions. The converter 652 may provide information directly to the input of the DP controller 659 (as an additional input) or break one of the input connections and transmit the information to the DP controller 659. A switch 655 is provided to direct how the converter 652 provides information to the DP controller 659 as discussed above. The switch 655 may be a software -based switch and/or a wired switch. Additionally, the switch 655 is not necessarily a two-way switch. The switch may have a plurality of switching directions based on the number of signals it is controlling.

[0145] In another exemplary embodiment, the converter may command operation of the master controller, as illustrated in FIG. 23. The converter 652 has a mechanical means for moving the actuator 651 automatically based on electrical signals received from the optimizer 650.

[0146] Sensors 656 are provided aboard the locomotive to gather operating condition data 654, such as speed, emissions, tractive effort, horse power, etc. Locomotive output information from the sensors 656 is then provided to the optimizer 650, usually through the rail vehicle 653, thus completing the closed loop system.

[0147] Figure 20 depicts another closed loop system, but where an operator is in the loop. The optimizer 650 generates the power/operating characteristic required for the optimum performance. The information is communicated to the operator 647, through a human machine interface (HMI) and/or display 649 or the like. Information could be communicated in various forms including audio, text or plots, or video displays. The operator 647 in this case can operate the master controller or pedals or any other actuator 651 to follow the optimum power level.

[0148] If the operator follows the plan, the optimizer continuously displays the next operation required. If the operator does not follow the plan, the optimizer may recalculate/re-optimize the plan, depending on the deviation and the duration of the deviation of power, speed, position, emission, etc. from the plan. If the operator is unable to meet an optimized plan to an extent where re-optimizing the plan is not possible or where safety criteria have been or may be exceeded, in an exemplary embodiment the optimizer may take control of the vehicle to ensure optimized operation, announce a need to consider the optimized mission plan, or simply record the occurrence for future analysis and/or use. In such an embodiment, the operator could retake control by manually disengaging the optimizer.

[0149] The embodiments disclosed herein may also be used where a powered system is part of a fleet and/or a network of powered systems. FIG. 21 shows a flowchart 320 depicting an exemplary embodiment of a method for operating a powered system having at least one power generating unit, where the powered system may be part of a fleet and/or a network of powered systems. Evaluating an operating characteristic of at least one power generating unit is disclosed, at 322. The operating characteristic is compared to a desired value related to a mission objective, at 324. The operating characteristic is autonomously adjusted in order to satisfy a mission objective, at 326. As disclosed herein, autonomous adjustment may be performed using a closed-loop technique.

[0150] FIG. 22 shows a flowchart 660 that depicts an exemplary embodiment of a method for operating a rail vehicle in a closed-loop process. The method includes determining an optimized setting for a locomotive consist, at 662. The optimized setting may include a setting for any setup variable such as, but not limited to, at least one of power level, optimized torque emissions, and/or other locomotive configurations. The optimized power level and/or the torque setting is converted to a recognizable input signal for the locomotive consist, at 664. At least one operational condition of the locomotive consist is determined when at least one of the optimized power level and the optimized torque setting is applied, at 667. The at least one operational condition is communicated to an optimizer within a closed control loop, for further use in optimizing at least one of power level and torque setting, at 668.

[0151] As disclosed above, the method shown in flowchart 660 may be performed using a computer software code

having one or more computer software modules. Therefore, for rail vehicles that may not initially have the ability to utilize the method(s) disclosed herein, electronic media containing the computer software modules may be accessed by a computer on the rail vehicle so that the software modules may be loaded onto the rail vehicle for implementation. Electronic media is not meant to be limiting, since any of the computer software modules may also be loaded through an electronic media transfer system, including a wireless and/or wired transfer system, such as but not limited to using the Internet to accomplish the installation.

[0152] Locomotives produce emissions at rates based on notch levels. In reality, a lower notch level does not necessarily result in a lower emission per unit output, e.g., gm/hp-hr, and the reverse is true as well. Such emissions may include, but are not limited to, particulates, exhaust, and heat. Similarly, noise levels from a locomotive also may vary based on notch levels, in particular noise frequency levels. Therefore, when emissions are mentioned herein, those skilled in the art will readily recognize that exemplary embodiments of the invention are also applicable for reducing noise levels produced by a diesel powered system. Therefore, even though both emissions and noise are disclosed at various times herein, the term emissions should be read to also include noise.

[0153] When an operator calls for a specific horse power level, or notch level, the operator is expecting the locomotive to operate at a certain traction power or tractive effort. In an exemplary embodiment, to minimize emission output, the locomotive is able to switch between notch/power/engine speed levels while maintaining the average traction power desired by the operator. For example, suppose that the operator calls for notch setting 4 or 2000 HP. Then the locomotive may operate at notch 3 for a given period, such as a minute, and then move to notch 5 for a period and then back to notch 3 for a period such that the average power produced corresponds to notch 4. The locomotive moves to notch 5 because the emission output of the locomotive at this notch setting is already known to be less than when at notch 4. During the total time that the locomotive is moving between notch settings, the average is still notch 4, thus the tractive power desired by the operator is still realized.

[0154] The time for each notch is determined by various factors, such as but not limited to, the emissions at each notch, power levels at each notch, and the operator sensitivity. Those skilled in the art will readily recognize that embodiments of the invention are operable when the locomotive is being operated manually, and/or when operation is automatically performed, such as but not limited to when controlled by an optimizer, and during low speed regulation.

[0155] In another exemplary embodiment, multiple set points are used. These set points may be determined by considering a plurality of factors such as, but not limited to, notch setting, engine speed, power, and engine control settings. In another exemplary embodiment, when multiple locomotives are used but may operate at different notch/power settings, the notch/power setting are determined as a function of performance and/or time. When emissions are being reduced, other factors that may be considered for a tradeoff include, but are not limited to, fuel efficiency and noise. Likewise, if the desire is to reduce noise, emissions and fuel efficiency may be considered. A similar analysis may be applied if fuel efficiency is what is to be improved.

[0156] FIG. 23 depicts an embodiment of a speed versus time graph comparing current operations to emissions optimized operation. The speed change compared to desirable speed can be arbitrarily minimized. For example, if the operator desires to move from one speed (S1) to another speed (S2) within a desired time, it can be achieved with minor deviations.

[0157] FIG. 24 depicts a modulation pattern that results in maintaining a constant desired notch and/or horsepower. The amount of time at each notch depends on the number of locomotives and the weight of the train and its characteristics. Essentially, the inertia of the train is used to integrate the tractive power/effort to obtain a desired speed. For example, if the train is heavy, the time between transitions of notches 3 to 5 (and vice versa) in the example can be large. In another example, if the number of locomotives for a given train is great, the times between transitions need to be smaller. More specifically, the time modulation and/or cycling will depend on train and/or locomotive characteristics.

[0158] As discussed previously, emission output may be based on an assumed notch distribution, but the operator/rail road is not required to have that overall distribution. Therefore, it is possible to enforce the notch distribution over a period of time, over many locomotives over a period of time, and/or for a fleet locomotives over a period of time. By being provided with emission data, the trip optimizer described herein compares the desired notch/power setting with emission output based on notch/power settings and determines the notch/power cycle to meet the speed required while minimizing emission output. The optimization could be explicitly used to generate the plan, or the plan could be modified to enforce, reduce, and/or meet the emissions required.

[0159] FIG. 25 depicts a flowchart 700 of an exemplary embodiment of a method for determining a configuration of a diesel powered system having at least one diesel- fueled power generating unit. The flowchart 700 provides for determining a minimum power, or power level, required from the diesel powered system in order to accomplish a specified mission, at 702. An emission output based on the minimum power, or power level, required is determined, at 704. Using at least one other power level that results in a lower emission output wherein the overall resulting power is proximate the power required, at 706, is also disclosed. Therefore, in operation, the desired power level with at least another power level may be used, and/or two power levels, not including the desired power level, may be used. In the second example, as disclosed above, if the desired power level is notch 4, the two power levels used may include notch 3 and notch 5.

[0160] As disclosed, emission output data based on notch speed is provided to the trip optimizer system. If a certain notch speed produces a high amount of emission, the trip optimizer can function by cycling between notch settings that produce lower amounts of emission output so that the locomotive will avoid operating at the particular notch while still meeting the speed of the avoided notch setting. For example, applying the same example provided above, if notch 4 is identified as a less than optimum operational setting because of emission output, but notch 3 and 5 produce lower emission outputs, the trip optimizer may cycle between notch 3 and 5 where that the average speed equates to speed realized at notch 4. Therefore, while providing speed associated with notch 4, the total emission output is less than the emission output expected at notch 4.

[0161] Therefore, when operating in this configuration, although speed constraints imposed based on defining notch limitations may not actually be adhered to, total emission output over a complete mission may be improved. More specifically, although a region may impose that rail vehicles are not to exceed notch 5, the trip optimizer may determine that cycling between notch 6 and 4 is preferable to reach the notch 5 speed limit but while also improving emission output, because emission outputs for the combination of notch 6 and 4 are better than when operating at notch 5 since either notch 4 or notch 6 or both are better than notch 5.

[0162] FIG. 26 illustrates a system 722 for minimizing emission output, noise level, etc. from a diesel powered system having at least one diesel-fueled power generating unit, while maintaining a specific speed. The system 722 includes a processor 725 for determining a minimum power required from the diesel-powered system, such as the train 31, in order to accomplish a specified mission. The processor 725 may also determine when to alternate between two power levels. A determination device 727 is used to determine an emission output based on the minimum power required. A power level controller 729 for alternating between power levels to achieve the minimum power required is also included. The power level controller 729 functions to produce a lower emission output while the overall average resulting power is proximate the minimum power required.

[0163] FIG. 27 illustrates a system 730 for minimizing one or more outputs (e.g., emission output and noise output) from a diesel powered system having at least one diesel-fueled power generating unit, while maintaining a specific speed. The system includes the determination device 727 for determining a power level required by the diesel-powered system in order to accomplish a specified mission. The determination device 727 may also determine an emission output based on the required power level. The system also includes an emission comparison device 731. The emission comparison device 731 compares emission outputs for other power levels with the emission output based on the power level required. The emission output of the diesel-fueled power generating unit, such as a train 31, is reduced based on the power level required by alternating between at least two other power levels which produce less emission output than the power level required, wherein alternating between the at least two other power levels produces an average power level proximate the power level required while producing a lower emission output than the emission output of the power level required. As disclosed herein, alternating power levels in this manner may simply result in using at least one other power level. Therefore, although characterized as an alternating operation, this term is not meant to be limiting. Towards this end, the system 730 may include a device (not shown) for alternating between the at least two power levels and/or using at least one other power level.

[0164] Although the above examples illustrate cycling between two notch levels to meet a third notch level, those skilled in the art will readily recognize that more than two notch levels may be used when seeking to meet a specific desired notch level. Therefore, three or more notch levels may be included in cycling to achieve a specific desired net level to improve emissions while still meeting speed requirements. Additionally, one of the notch levels that are alternated with may include the desired notch level. Therefore, at a minimum, the desired notch level and another notch level may be the two power levels that are alternated between.

[0165] FIG. 28 discloses a flowchart 800 that illustrates an exemplary embodiment of a method for operating a diesel powered system having at least one diesel-fueled power generating unit, to meet at least one mission objective. The mission objective may include consideration of at least one of total emissions, maximum emission, fuel consumption, speed, reliability, wear, forces, power, mission time, time of arrival, time of intermediate points, and/or braking distance. The mission objective may further include other objectives based on the specific mission of the diesel powered system. For example, as disclosed above, a mission objective of a locomotive is different than that of a stationary power generating system. Therefore the mission objective is based on the type of diesel powered system the method of flowchart 800 is utilized with.

[0166] The method of flowchart 800 comprises evaluating an operating characteristic of the diesel powered system, at 802. The operating characteristic may include at least one of emissions, speed, horse power, friction modifier, tractive effort, overall power output, mission time, fuel consumption, energy storage, and/or condition of a surface upon which the diesel powered system operates. Energy storage is important when the diesel powered system is a hybrid system having for example a diesel fueled power generating unit as its primary power generating system, and an electrical, hydraulic, or other power generating system as its secondary power generating system. With respect to speed, this operating characteristic may be further subdivided with respect to time varying speed and position varying speed.

[0167] The operational characteristic may further be based on a position of the diesel powered system when used in

conjunction with at least one other diesel powered system. For example, in a train, when viewing each locomotive as a diesel powered system, a locomotive consist may be utilized with a train. Therefore, there will be a lead locomotive and a remote locomotive. For those locomotives that are in a trail position, trail mode considerations are also involved. The operational characteristic may further be based on an ambient condition, such as but not limited to temperature and/or pressure.

[0168] The method of flowchart 800 also comprises comparing the operating characteristic to a desired value to satisfy the mission objective, at 804. The desired value may be determined from at least one of the operational characteristic, capability of the diesel powered system, and/or at least one design characteristic of the diesel powered system. With respect to the design characteristics of the diesel powered system, there are various modules of locomotives where the design characteristics vary. The desired value may be determined at a remote location, such as but not limited to a remote monitoring station, and/or at a location that is a part of the diesel powered system.

[0169] The desired value may be based on a location and/or operating time of the diesel powered system. As with the operating characteristic the desired value is further based on at least one of emissions, speed, horse power, friction modifier, tractive effort, ambient conditions including at least one of temperature and pressure, mission time, fuel consumption, energy storage, and/or condition of a surface upon which the diesel powered system operates. The desired value may be further determined based on a number of diesel-fueled power generating units that are either a part of the diesel powered system and/or a part of a consist, or at the sub-consist level as disclosed above.

[0170] The method of FIG. 28 further comprises adjusting the operating characteristic to correspond to the desired value with a closed-loop control system that operates in a feedback process to satisfy the mission objective, at 806. The feedback process may include feedback principles readily known to those skilled in the art. In general, but not to be considered limiting, the feedback process receives information and makes determinations based on the information received. The closed-loop approach allows for the implementation of the method of flowchart 800 without outside interference. However, if required due to safety issues, a manual override is also provided. The operating characteristic may be adjusted based on an ambient condition. As disclosed above, the method of flowchart 800 may also be implemented in a computer software code where the computer software code may reside on a computer readable media.

[0171] Fig. 29 discloses a block diagram of an exemplary system 810 for operating a diesel powered system having at least one diesel-fueled power generating unit. The system 810 includes a sensor 812 that is configured for determining at least one operating characteristic of the diesel powered system. In an exemplary embodiment, a plurality of sensors 812 are provided to gather operating characteristics from a plurality of locations on the diesel powered system and/or a plurality of subsystems within the diesel powered system. Those skilled in the art will also recognize that the sensor 812 may be an operation input device. Therefore, the sensor 812 can gather operating characteristics, or information, about emissions, speed, horse power, friction modifier, tractive effort, ambient conditions including at least one of temperature and pressure, mission time, fuel consumption, energy storage, and/or the condition of a surface upon which the diesel powered system operates. A processor 814 is in communication with the sensor 812. A reference generating device 816 is provided and is configured to identify the preferred operating characteristic. The reference generating device 816 is in communication with the processor 814. When the term "in communication" is used, those skilled in the art will readily recognize that the form of communication may be facilitated through a wired communication system/device and/or through a wireless communication system/device. The reference generating device 816 may be remote from the diesel powered system, a part of the diesel powered system, or both (i.e., part of the device 816 may be remote, another part local).

[0172] The processor 814 is outfitted/programmed with an algorithm 818 that operates in a feedback process for comparing the operating characteristic to the preferred operating characteristic, to determine a desired operating characteristic. A converter 820, in closed loop communication with the processor 814 and/or algorithm 818, is further provided to implement the desired operating characteristic. The converter 820 may be a master controller, a remote control controller, a distributed power controller, and/or a train line modem. More specifically, when the diesel powered system is a locomotive system, the converter may be a remote control locomotive controller, a distributed power locomotive controller, and a train line modem.

[0173] As further illustrated, the system 810 may include a second sensor 821. The second sensor is configured to measure at least one ambient condition, information about which is provided to the algorithm 818 and/or processor 814 to determine a desired operating characteristic. As disclosed above, examples of an ambient condition include, but are not limited to, temperature and pressure.

[0174] Another embodiment relates to a method for controlling operations of a train. The method is also applicable to controlling other vehicles or other powered systems. According to the method, the train is controlled based on an optimized mission plan, typically for reducing fuel use and/or reducing emissions output. For calculating the mission plan, the following steps may be carried out. First, route data and train data is received, e.g., from a database or otherwise. The route data includes data relating to one or more characteristics of a track on which the train is to travel along a route and data relating to at least one speed limit along the route. The train data relates to one or more characteristics of the train. The mission plan is created onboard the train at any time during travel of the train along the route. The mission

plan is created at a first point along the route based on the received data, and covers at least a segment of the route extending to a second point further along the route than the first point. The mission plan is created for covering the entirety of the segment based on, and regardless of, all the different geographic features or other characteristics of the route along the segment for which data is available. By this, it is meant: (i) the mission plan takes into consideration all the different geographic features or other characteristics of the route segment for which data is available, and (ii) the mission plan is created regardless of what particular geographic features or other characteristics of the route are along the segment. Thus, no matter what known geographic features or other route characteristics are along a route segment, a mission plan is created for that segment.

[0175] Another embodiment relates to a method for operating a vehicle. The method comprises receiving route data and vehicle data at the vehicle. The route data includes data relating to one or more characteristics of a route along which the vehicle travels, and the vehicle data relates to one or more characteristics of the vehicle. The method further comprises creating on-board the vehicle a mission plan at any time during travel of the vehicle along the route. The mission plan is created at a first point along the route based on the received data and covers at least a segment of the route extending to a second point further along the route than the first point. The mission plan is created for covering the entirety of the segment based on, and regardless of, all the different geographic features or other characteristics of the route along the segment for which data is available. The method further comprises controlling the vehicle according to the mission plan as the vehicle travels along the route segment. The mission plan is configured for reducing fuel use of the vehicle and/or reducing emissions produced by the vehicle along the route segment.

[0176] Subsequent to creating the mission plan, it is determined whether the mission plan is correct to satisfy at least one mission objective of the vehicle. If it is determined that the mission plan is not correct to satisfy the at least one mission objective, the method further comprises updating the received data that was used to create the mission plan. The mission plan is then revised based on the updated received data, to satisfy the at least one mission objective. Subsequent to revising the mission plan, the method further comprises operating the powered system based on the revised mission plan.

[0177] As should be appreciated, any description herein relating to a "trip plan" is also applicable to a "mission plan," since a trip plan is one species of a mission plan, i.e., a trip plan is a mission plan for a vehicle. The same is true for "trip" and "mission" generally, i.e., a trip is a particular species of mission.

[0178] FIG. 30 is a flowchart illustrating an exemplary embodiment of a method for controlling a powered system, e.g., by determining a mission plan for a powered system (the powered system having at least one primary power generating unit) when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit. The method of flowchart 400 includes identifying a desired parameter prior to creating a mission plan, wherein the parameter may be unobtainable and/or in violation of a predefined limit, at 402. (The "desired" parameter is a particular parameter that the system and/or operator would like to achieve or meet.) An operator of the powered system and/or a remote monitoring facility are notified of the desired parameter, at 404. A determination is made whether to exceed the predefined limit and/or whether to identify an obtainable parameter proximate the desired parameter, at 406. The mission plan may be created, at 408. Thus, instead of foregoing creation of a mission plan that involves a parameter that may be unobtainable or in violation of a predefined limit, a plan is created exceeding the limit or using an obtainable parameter proximate to the unobtainable parameter. "Proximate" means a parameter closest in value to the unobtainable parameter that is still obtainable.

[0179] The operator and/or the remote monitoring facility may be notified about whether to exceed the predefined limit and/or to identify an obtainable parameter proximate the desired parameter. The operator and/or the remote monitoring facility are allowed to remove the predefined limit so that the mission plan is feasible, and/or functional, and/or to modify at least one other parameter to make the mission plan feasible, and/or functional, at 410. When notifying the operator and/or the remote monitoring facility, they may be advised that exceeding the predefined limit is inevitable in a certain region of a mission. The operator and the remote monitoring facility may be advised of at least one parameter to modify to produce the mission plan.

[0180] The mission plan created may be implemented where the predefined limit is exceeded and/or the obtainable parameter proximate the desired parameter is used, at 412. A determination is made whether to exceed the predefined limit and/or whether to identify an obtainable parameter proximate the desired parameter when the mission plan may be accomplished proximate an intended objective of the mission plan, at 414.

[0181] A determination may also be made regarding whether the desired parameter has at least one of a hard limit and a soft limit, at 416. This may result in temporarily exceeding the predefined limit when the desired parameter has a soft limit, at 418. The method further comprises determining a time period and/or a condition to temporarily exceed the desired parameter when the desired parameter has the soft limit, at 420. Additionally, the method comprises determining the obtainable parameter proximate the desired parameter without exceeding the hard limit, at 421. "Hard limit" refers to a limit that cannot be exceeded, at least according to one or more rules or operational constraints. "Soft limit" refers to a limit that is not to be exceeded except possibly under certain circumstances or conditions.

[0182] The desired parameter may include, but is not limited to, at least one character associated with at least one

element of the powered system and a parameter associated with a mission being performed by the mission plan. The desired parameter may include, but is not limited to, a throttle limit, a brake rate limit, a start speed for a mission and/or a segment of the mission, an end speed for the mission and/or the segment of the mission, an operation time for the mission and/or the segment of the mission, a desired speed setting at a defined point in the mission, a start notch setting for the mission and/or the segment of the mission, an end notch setting for the mission and/or the segment of the mission, and dynamic braking.

[0183] In one example, which is meant to be illustrative and not limiting, the desired parameter is an operation time for the mission. It is identified that the mission operation time may be unobtainable, e.g., because the powered system is too far away from an end point of the mission to reach the end point within designated speed limits. It might be possible to achieve the mission operation time by exceeding the designated speed limits, but this would be in violation of a predefined limit, namely, the speed limits. A determination is then made of whether to (i) identify an obtainable parameter proximate the desired parameter, e.g., arrive at the mission end point in the time closest to the desired mission operation time that does not require exceeding speed limits, or (ii) exceed the designated speed limits. A mission plan is then created based on this determination.

[0184] The steps of identifying the mission plan, identifying the desired parameter, and determining whether to exceed the predefined limit and/or identify an obtainable parameter proximate the desired parameter (or any two of those steps) may be performed using a closed loop control implementation without operator intervention.

[0185] FIG. 31 is a flowchart of another embodiment of a method for controlling a powered system e.g., by determining a mission plan for a powered system having at least one primary power generating unit when a desired parameter of the mission plan is unobtainable and/or exceeds a predefined limit. The method of flowchart 422 comprises creating a mission plan, at 424. A desired parameter in the mission plan is identified that is unobtainable and/or exceeds a predefined limit, at 426. A determination is made whether to temporarily exceed the predefined limit, identify an obtainable parameter proximate the desired parameter, and/or alert an operator and/or a remote monitoring facility for feedback on a course of action to take, at 428.

[0186] The mission plan may be revised based on whether to temporarily exceed the predefined limit and/or identify an obtainable parameter proximate the desired parameter, at 430. A determining may be made whether the desired parameter has a hard limit and/or a soft limit, at 432. Temporarily exceeding the predefined limit when the desired parameter has a soft limit may be accomplished, at 434. Additionally, a determination may be made of a time period and/or a condition to temporarily exceed the desired parameter when the desired parameter has a soft limit, at 436. When a hard limit is present, a determination may be made as to the obtainable parameter that is proximate the desired parameter without exceeding the hard limit, at 438. A second desired parameter in the mission plan (and/or a function of a component of the powered system to adjust) may be identified when the desired parameter in the mission plan is unobtainable and/or exceeds a predefined limit, and/or adjusting the second desired parameter in the mission plan and/or the function of a component of the powered system to accomplish the mission plan, at 439.

[0187] In another embodiment, the operator is alerted to the presence of a parameter that is either unobtainable and/or exceeds a predefined limit. The operator can then make a determination of whether to allow the system to temporarily exceed the limit, either for a period of time or over a region of space and/or mission duration. Alternatively, the operator may decide to modify another parameter that makes the mission feasible and/or operable. For example, in the case of a train drawn by a diesel-powered locomotive consist, it may be impossible to satisfy a constraint that notch rate of change be less than 1000 notches per hour if it is specified that the trip be completed in 2 hours. In this case, the operator could be alerted and could decide to relax the notch rate of change constraint to another notch, such as, for example, 1500 notches per hour. This approach is equivalent to identifying a parameter proximal to a desired parameter. In another example, the operator may change the trip time to such a time as will allow the constraint on notch rate of change to be satisfied. This is equivalent to changing another parameter so that the original mission becomes feasible and/or operable. In another example, the operator may allow the notch rate constraint to be exceeded either for a small amount of time or in a particular section of the track.

[0188] In all of the examples disclosed above, those skilled in the art will recognize that these embodiments may be implemented with a computer software code operable with a processor and configured to reside on a computer readable media.

[0189] For example, in another exemplary embodiment, as illustrated in FIG. 32, a computer-readable instruction, and/or algorithm, illustrated as a flowchart 440, is provided that when executed by a processor causes the processor to identify a desired parameter in the mission plan that is unobtainable and/or exceeds a predefined limit. The software then alerts the operator to the situation, such as disclosed above, at 442. A feedback command is received from the operator and/or the remote monitoring facility, at 444. Based on the operator's feedback, the processor, acting under control of the software code, revises and/or re-plans the mission plan, at 446.

[0190] Those skilled in the art will recognize that the mission plan realized when implementing exemplary embodiments of this invention, whether an original or a re-planned version, may result in a mission plan that is less optimized than originally desired. However, the resulting mission plan is one that is functional/achievable whereas the mission plan

originally desired may not be functional for reasons discussed above.

[0191] FIG. 33 is a flowchart illustrating an embodiment of a method for controlling a powered system by optimizing a range of at least one operating mode of the powered system as provided in a mission plan. This method may be used, for example, to maintain a powered system above a minimum speed for purposes of avoiding stalling. The method may also be used to reduce the amount of time that a powered system remains in an idle or neutral throttle setting as part of an optimized mission plan, to reduce the likelihood of an operator feeling that the powered system is "floating" along a route (e.g., traveling in an automobile set in neutral may result in a feeling that the operator is not fully in control of the vehicle).

[0192] As disclosed above, optimization may involve maximizing or minimizing the at least one operating mode, or something there in between. The intent of using the term "optimizing" is not to limit the range of the operating mode, but instead to identify that the value may be set based on a plurality of reasons/factors. The method of flowchart 1400 includes determining an amount of time the powered system enters a range of at least one operating mode, at 1402. ("Enters a range" means entering the operating mode or coming within a certain range or limit of the operating mode.) This is done prior to beginning a mission and/or while performing the mission. While performing the mission, an operator of the powered system and/or a remote monitoring facility is notified of the amount of time the powered system enters the range of the at least one operating mode, at 1403. Alternatively or in addition, prior to beginning the mission, an operator of the powered system and/or a remote monitoring facility is notified of the amount of time that the powered system will enter the range of the at least one operating mode, again at 1403. The remote monitoring facility may be a dispatcher, depot, etc. In general, the remote monitoring facility is a location remote from the powered system. Notifying the operator and/or remote monitoring facility may further include notifying the operator and/or remote monitoring facility of adjusting the operating parameter of the powered system to approximate a desired operating setting.

[0193] Determining the amount of time the powered system is in the range of the operation mode further includes determining an amount of time spent in a low motoring power mode and/or a low braking power mode. (Any other operation mode may be considered.) The operating parameter of the powered system may be adjusted to approximate a desired operating setting, at 1404. Approximating the desired operating setting may include a plurality of approaches. For example, a setting proximate a desired operating setting may be selected. In another example, multiple operating settings may be switched between where the average is close to the desired operating setting.

[0194] FIG. 34 is a flowchart illustrating another embodiment of a method for controlling a powered system by optimizing a range of at least one operating mode of the powered system as provided in a mission plan. The method of flowchart 1406 comprises adjusting the operating parameter of the powered system to approximate a desired operating setting, at 1408. The operating parameter may include, but is not limited to, a fuel rate, specific fuel consumption, and horse power. Adjusting the operating parameter may include, but is not limited to, adjusting a fuel rate to minimize low power operation mode of the powered system. Adjusting the operating parameter may further include adjusting the operating parameters to approximate a desired powering mode. Just as with respect to the desired operating setting discussed above, a plurality of approaches is possible to approximate the desired powering mode. Furthermore, adjusting the operating parameter may include automatically, and/or autonomously adjusting the operating parameter to a different value when the operating mode is detected.

[0195] The method of FIG. 34 may further comprise determining an amount of time the powered system enters a range of the operating mode prior to beginning a mission and/or while performing the mission, at 1410. An operator of the powered system and/or a remote monitoring facility is notified of the amount of time the powered system enters the range of the operating mode while performing the mission and/or will enter the range of the at least one operating mode prior to beginning the mission, at 1412. Adjusting the one operating parameter may further include automatically or autonomously adjusting the operating parameter and creating a mission plan based on the adjusted operating parameter.

[0196] FIG. 35 is a flowchart 1414 illustrating a method for determining a mission plan based on a maximum speed limit and/or a minimum speed threshold. The method of flowchart 1414 comprises determining a minimum speed threshold, at 1418. A maximum speed limit may already be provided, under the rules of a relevant transportation system or otherwise. A mission plan is created using the minimum speed threshold, at 1420. The minimum speed threshold is further determined using a lower speed limit as a function of an upper speed limit, and a lower speed limit as a constant value throughout a mission and/or a part of a mission. Furthermore, determining the minimum speed threshold may mean having the minimum speed threshold already provided.

[0197] FIG. 36 is a flowchart 1422 illustrating a method for determining a mission plan based on at least one of a target reference speed and/or a target reference power. The method of flowchart 1422 comprises creating a mission plan with at least one of a target reference speed and target reference power identified for at least one of an entire mission and a section of the mission, at 1424. The target reference speed and/or the target reference power are adhered to and/or proximately adhered to, at 1428.

[0198] FIG. 37 is a flowchart 1430 illustrating a method for determining a mission plan based on at least one of a target reference speed and target reference power. The method of flowchart 1430 comprises determining a reference speed profile and/or a target reference power, at 1432. A mission plan is created with the target reference speed and/or the

target reference power determined for an entire mission and/or a section of the mission, at 1433. The powered system is operated to provide power proximate the reference target speed, at 1434. A target speed and/or a target power are established, at 1436. When the powered system is operated the target speed and/or the target power is adhered to so as to provide power proximate the reference target speed.

[0199] FIG. 38 is a flowchart 1444 illustrating a method for minimizing a range of an operation mode of a powered system provided with a mission plan. The method of flowchart 1444 comprises creating an original mission plan having a time period of operation in the range of the at least one operation mode, at 1446. In one example, the operation mode is an idle or neutral throttle setting. The range of the operating mode in the mission plan is identified, at 1448. The mission plan is revised to provide for a power setting outside of the range of the at least one operation mode during a period the at least one operation mode is within a chosen range of a power operation period, at 1450. In the indicated example, the power setting might be positive (propulsion) or negative (braking) throttle setting to one side of idle/neutral. The mission plan is also revised to average the power setting outside of the range of the at least one operation mode over a greater part of the mission plan, wherein a resulting energy for the greater part of the mission plan is proximate the original mission plan, at 1452. The resulting energy may also be considered a total power. Identifying the range of operating mode may be determined by taking into account the amount of time the powered system enters the range of operating mode.

[0200] The embodiments disclosed in FIG. 33 through 38 may also be implemented with a computer software code operable with a processor and configured to reside on a computer readable media.

[0201] FIGS. 39-43 relate to a method for controlling a powered system independent of a coupled power setting in the powered system. If the powered system is a train, for example, the train may include a consist of locomotives and a plurality of non-powered railcars. The locomotives are connected to one another (at least adjacent locomotives) through multiple unit (MU) cables, and are typically operated together through a single power command that is input in the lead locomotive and then communicated to all of the trailing locomotives. Mission plans may be established to operate with traditional throttle or power levels, such as, but not limited to, 8 discreet power levels ranging between notch 1 to notch 8. However, in the method(s) illustrated in FIGS. 39-42, an optimized mission may be completed if the controller is not constrained to only adhere to the traditional coupled power levels. These power commands for each locomotive may be decoupled from their traditional coupled levels. A plurality of approaches may be applied to decouple the power levels. Therefore, although a few exemplary embodiments are disclosed below, these approaches should not be considered limiting.

[0202] When there are two or more power generating units, such as, but not limited to, a lead locomotive and a plurality of trail locomotives in a train, one approach is to allow lead and trail notch commands to differ by a certain number of notches, such as, but not limited to, one notch. FIG. 39 is a three-dimensional graph illustrating an exemplary embodiment of a variance between the lead notch 2450 and the trail notch 2452. A first area 2454 representing normal operation of the powered system is disclosed. A second area 2456 represents operation under one embodiment of the present invention. If more power is required and the current lead and trail notches are identical, either the lead or trail notch may be increased by a given amount, such as but not limited to by one notch, and then the other is increased on subsequent requests for more power. Similarly, for the case where less power is required, the converse logic can be applied.

[0203] FIG. 40 discloses a three-dimensional graph illustrating another exemplary embodiment for providing decoupled power settings. As illustrated, a power setting operating procedure (and/or map) 2458 may be developed, such as in 2-dimensional space. Certain constraints are included when developing the map. For example, though not to be considered limiting, the map may be generated by minimizing fuel use for each desired power level, emission output for each desired power level, a change in power between notch settings, a maximum notch deviation from the lead command to the trail notch command, etc. This mapping may additionally be different for the increasing and decreasing power case and may be a function of an operating parameter such as, but not limited to, current power setting, current speed, etc. Furthermore, the notch operating plan may be a function of the expected future power demand.

[0204] FIG. 41 discloses a three-dimensional graph illustrating another exemplary embodiment for providing decoupled power settings. As illustrated, all notch combinations 2460 may be employed with various restrictions, such as, but not limited to, minimizing fuel use for a desired power level, emission output for a desired power level, a change in power between notch settings, a maximum notch deviation from the lead not command to the trail notch command, a maximum notch excursion, minimum time to change power settings, and a desired transient response. This mapping may also be a function of an operating parameter, the mission plan, and the past notch path history.

[0205] The exemplary examples disclosed in FIG. 39 through FIG. 41 may utilize an additional axis of freedom when distributed power (DP) is used for a consist power management approach. The DP consist command notch may be independent of both the lead and trailing locomotives commands and various constraints, as disclosed above, may be used for load balancing and other train handling considerations.

[0206] Additionally, for cases where the trailing locomotives in a given consist are connected to the lead locomotive by independent MU cables or some other form of communications, such as but not limited to communications using radio frequency such as used with distributed power units, additional axes of freedom are gained and similar methods

employed.

[0207] FIG. 42 is a flowchart 2400 illustrating a method for controlling a powered system, where throttle commands for the powered system are decoupled from predefined throttle settings. The method of flowchart 2400 comprises identifying at least one characteristic to minimize and/or at least one constraint for a power operating plan, at 2402. The power operating plan is developed responsive to the one characteristic and/or the one constraint, at 2404. At least one power setting is determined which is responsive to the power operating plan, at 2406. A plurality of throttle settings may be determined for a plurality of throttle settings responsive to all parts, or segments, of a mission plan, at 2408. As disclosed above, the characteristic may include, but is not limited to, a maximum power setting, minimum power setting, fuel burn rate for a desired power level, maximum change in power setting, minimum time to change between a first and a second power setting, desired transient response, etc.

[0208] FIG. 43 is a flowchart illustrating another embodiment of a method for controlling a powered system where throttle commands for the powered system are decoupled from predefined throttle settings. The method of flowchart 2410 comprises developing a power operating plan that is independent of a coupled power setting, at 2412. A power setting is determined responsive to the power operating plan, at 2414. The method further comprises identifying one characteristic, parameter, and/or constraint for the power operating plan, at 2416. When the power operating plan is static, the throttle or power setting may vary in response to varied power settings, where varying may include increasing and/or decreasing the throttle setting. As disclosed above with respect to FIG. 42, a power setting restriction may be imposed when developing the power operating plan, at 2418. A restriction and/or constraint may be used to balance a load of the powered system and/or a handling characteristic of the powered system, at 2420. When the powered system is a rail transportation system, the railway transportation system is operated in a distributed power mode wherein developing the power operating plan and/or determining the power setting are established for the distributed power mode, at 2422.

[0209] The methods illustrated in FIG. 42 and FIG. 43 are applicable to a train operating in a distributed power mode and to those configured as a trainline. With respect to the trainline, the methods are applicable to both wired tramlines and wireless tramlines. As disclosed above with respect to FIG. 39 through FIG. 40, when operating in the distributed power mode, a fourth axis is provided for distributed power notch, thus resulting in one more degree of freedom. With the automatic controller, a constraint may be used to balance a load of the powered system and/or to control a handling characteristic of the powered system. Furthermore, when under automatic, or autonomous, control the lead, or a first, locomotive may operate with an analog throttle control, or more specifically it is free to operate at throttle settings decoupled from preset throttle settings. The trail locomotives may still operate using the standard fixed throttle settings. Therefore, the throttle setting for the second unit is in response to the throttle setting of the lead locomotive. However, the throttle setting for the second locomotive may also be set independent of the first locomotive.

[0210] In an exemplary embodiment such as but not limited to a plurality of locomotives operating as a consist and/or being individually part of a train, coupling forces exist at coupling joints, or connectors. These forces also exist where the locomotive is coupled to a rail car. When determining throttle settings responsive to the mission, consideration in selecting these settings may be given to the coupling forces expected to be exerted.

[0211] As with the other methods described herein, those disclosed in FIG. 42 and FIG. 43, and any variations thereof, may also be implemented with a computer software code operable with a processor and configured to reside on a computer readable media. Furthermore, though a train is used to explain distributed power operations, distributed power is also applicable to other groups of powered systems.

[0212] While exemplary embodiments of the invention have been described herein, it will be understood by those skilled in the art that various changes, omissions and/or additions may be made and equivalents may be substituted for elements thereof without departing from the spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, unless specifically stated any use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

Claims

1. A method for controlling a powered system, the method comprising:

creating a mission plan;
identifying a desired parameter in the mission plan that is at least one of unobtainable or exceeds a predefined limit;
determining whether to at least one of temporarily exceed the predefined limit, identify an obtainable parameter

proximate the desired parameter, or alert at least one of an operator and a remote monitoring facility for feedback on a course of action to take; and
operating the powered system based at least in part on the mission plan.

- 5 **2.** The method according to claim 1, wherein at least two of creating the mission plan, identifying the desired parameter, and determining are performed using a closed loop control implementation without operator intervention.
- 10 **3.** The method according to claim 1, further comprising revising the mission plan based on the determination of whether to at least one of temporarily exceed the predefined limit or identify an obtainable parameter proximate the desired parameter.
- 15 **4.** The method according to claim 3, further comprising determining whether the desired parameter has at least one of a hard limit and a soft limit, and temporarily exceeding the predefined limit when the desired parameter has a soft limit.
- 20 **5.** The method according to claim 3, further comprising identifying at least one of a second desired parameter in the mission plan and a function of a component of the powered system to adjust when the desired parameter in the mission plan is at least one of unobtainable and exceeds a predefined limit, and adjusting the at least one of the second desired parameter in the mission plan and the function of a component of the powered system to accomplish the mission plan.
- 25 **6.** The method according to claim 3, wherein the desired parameter comprises at least one character associated with at least one of the powered system and a parameter associated with a mission being performed according to the mission plan, and wherein the desired parameter comprises at least one of a throttle limit, a brake rate limit, a start speed for at least one of a mission and a segment of the mission, an end speed for at least one of the mission and the segment of the mission, an operation time for at least one of the mission and the segment of the mission, a desired speed setting at a defined point in the mission, a start notch setting for at least one of the mission and the segment of the mission, an end notch setting for at least one of the mission and the segment of the mission, and dynamic braking.
- 30 **7.** The method according to claim 3, wherein revising the mission plan results in a mission plan that is less optimized than an original mission plan.
- 35 **8.** A method for controlling a powered system, the method comprising: prior to creating a mission plan for controlling the powered system, identifying a desired parameter of the mission plan which may be at least one of unobtainable and in violation of a predefined limit; and notifying at least one of an operator of the powered system and a remote monitoring facility of the desired parameter.
- 40 **9.** A method for controlling a powered system, the method comprising: determining an amount of time a powered system enters a range of at least one operating mode prior to beginning a mission and/or while performing the mission; and notifying at least one of an operator of the powered system and a remote monitoring facility of the amount of time the powered system at least one of enters the range of the at least one operating mode while performing the mission and will enter the range of the at least one operating mode prior to beginning the mission.
- 45 **10.** A method for controlling a powered system, the method comprising: adjusting at least one operating parameter of a powered system to approximate a desired operating setting, so as to minimize a range of at least one operating mode provided in a mission plan for the powered system; and operating the powered system based at least in part on the adjusted operating parameter.
- 50 **11.** A method for controlling a powered system, the method comprising: determining a minimum speed threshold; creating a mission plan based on the minimum speed threshold and a maximum speed limit; and controlling the powered system based on the mission plan.
- 55 **12.** The method according to claim 11, wherein determining a minimum speed threshold further comprises including at least one of a lower speed limit as a function of an upper speed limit, and/or a lower speed limit as a constant value throughout at least one of a mission and a part of a mission.
- 13.** A method for controlling a powered system, the method comprising: determining at least one of a reference target

speed and a target reference power; creating a mission plan with at least one of the target reference speed and the target reference power determined for at least one of an entire mission and a section of the mission; and operating a powered system to provide power proximate the reference target speed.

5 **14.** The method according to claim 13, further comprising establishing at least one of a target speed and a target power, wherein operating the powered system further comprises adhering to at least one of the target speed and target power to provide power proximate the reference target speed.

10 **15.** A method for controlling a powered system having a first power generating unit and a second power generating unit, the method comprising:

developing a power operating plan which is independent of a coupled power setting between the first power generating unit and the second power generating unit;

15 determining a power setting responsive to the power operating plan; and

operating the first power generating unit and/or the second power generating unit based on the power setting.

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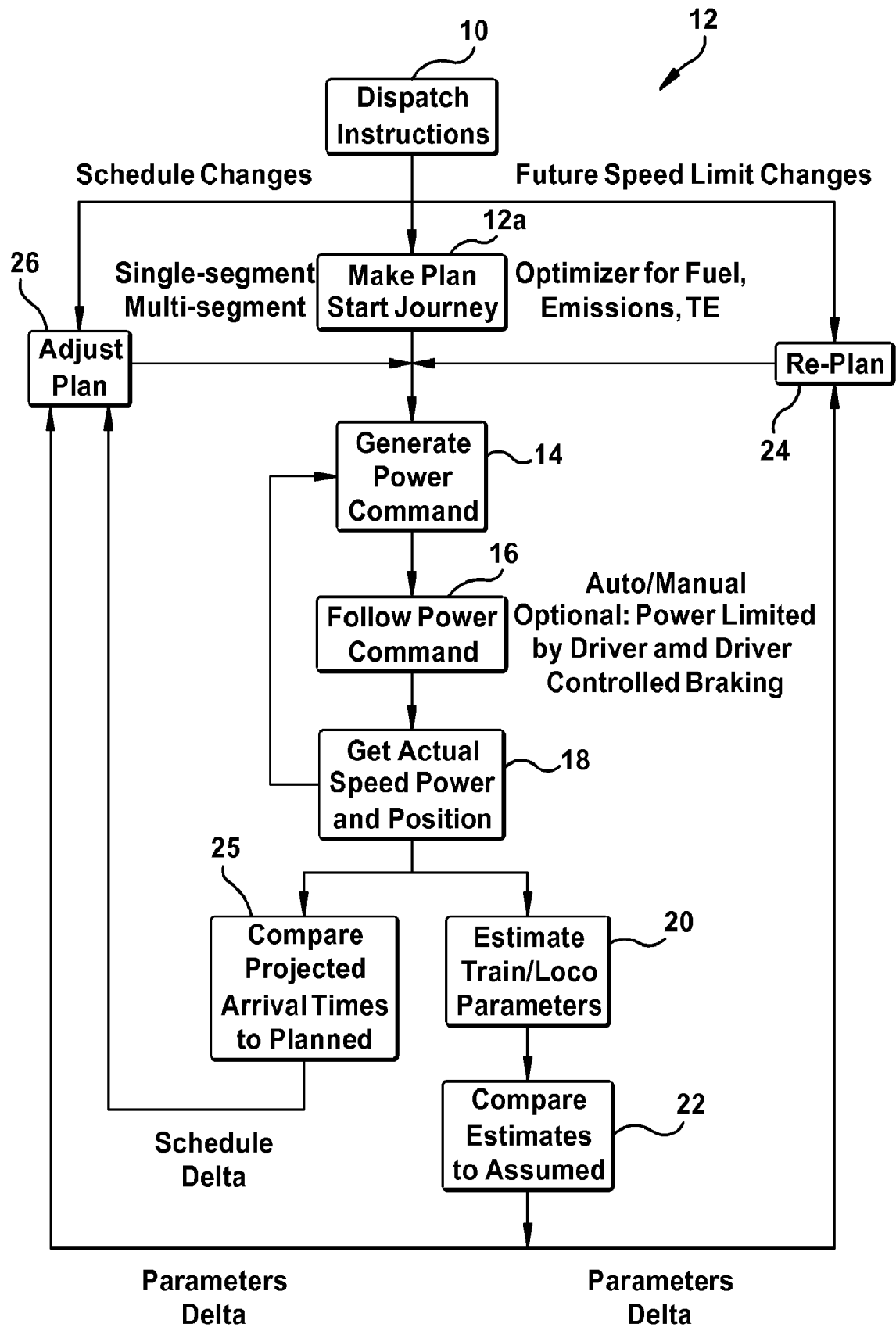
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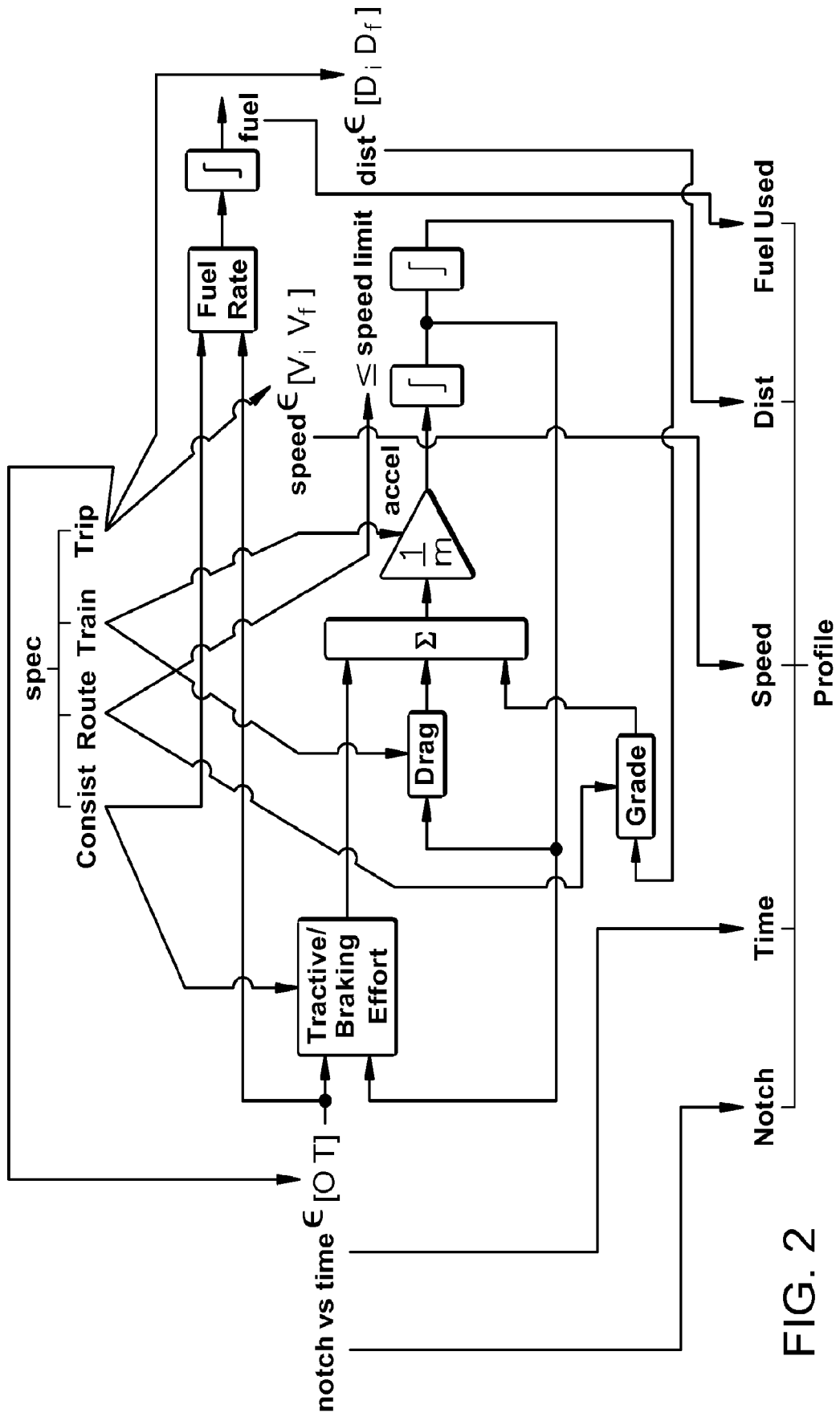
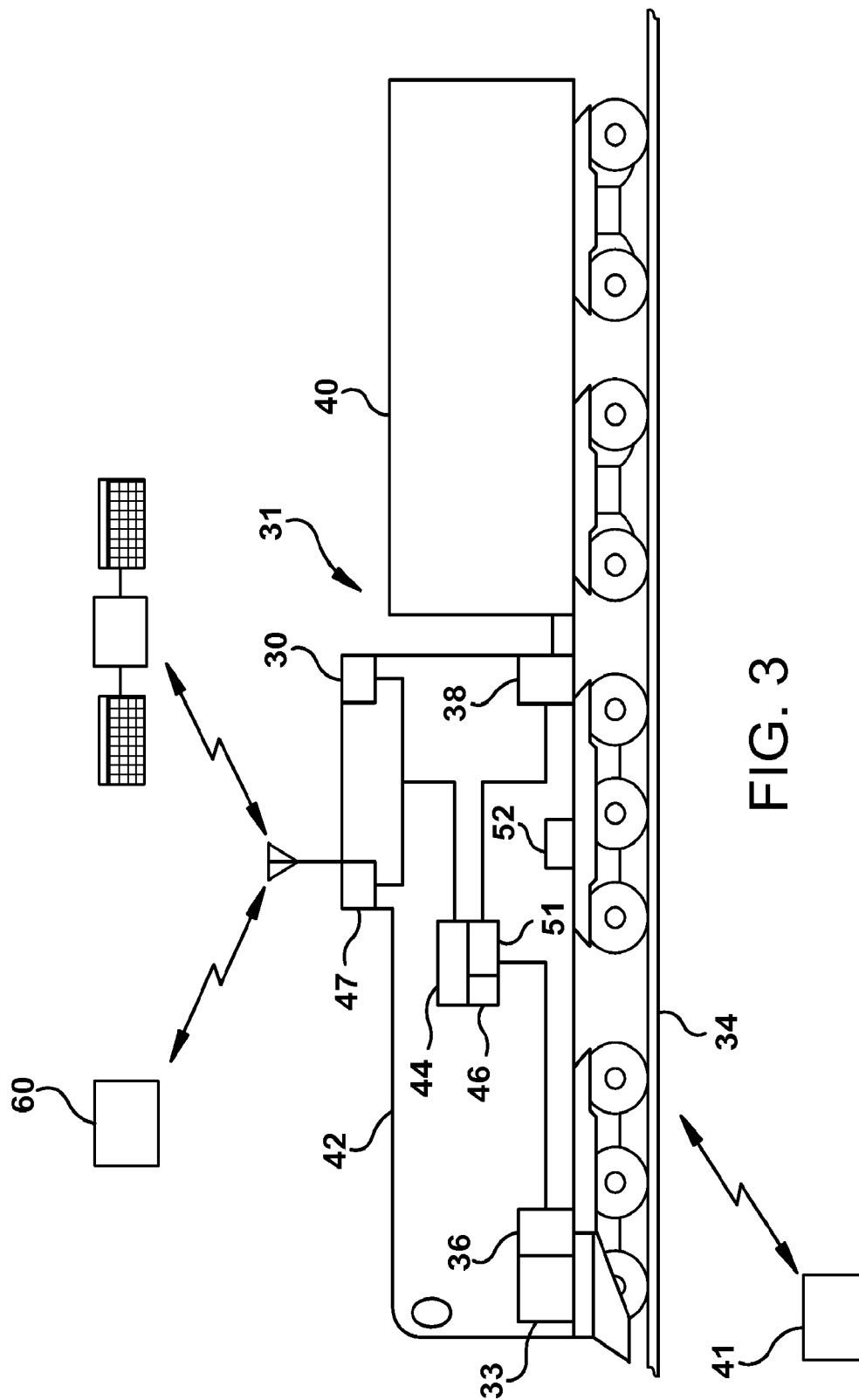


FIG. 2



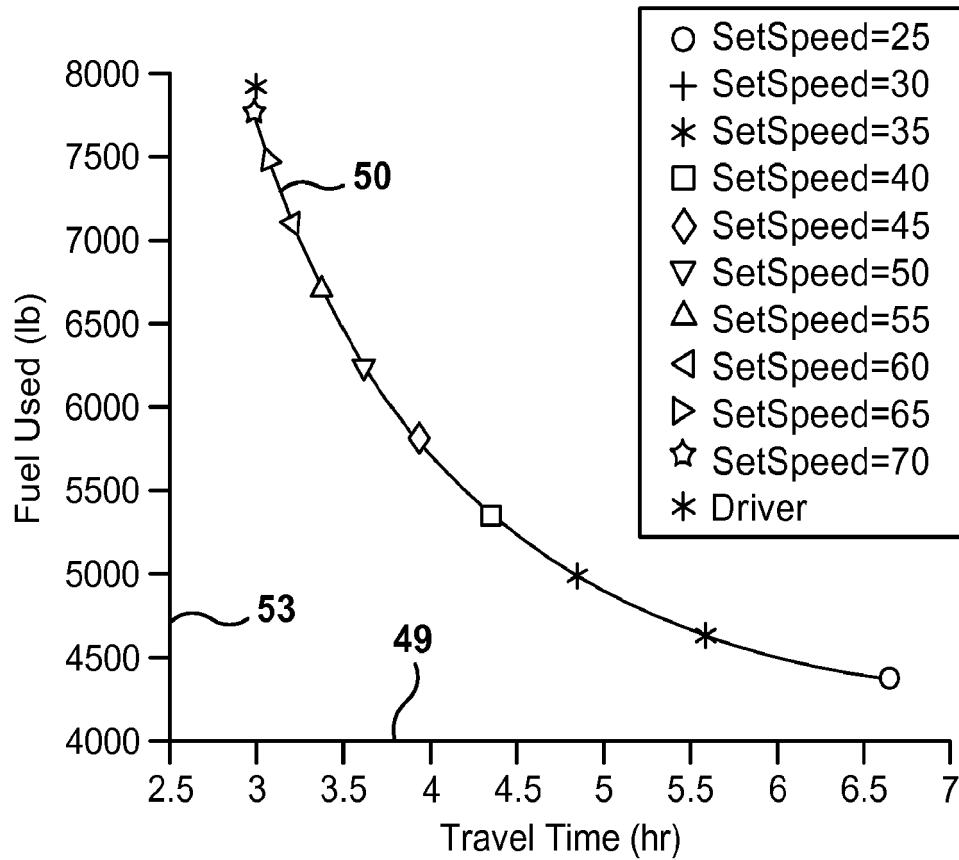


FIG. 4

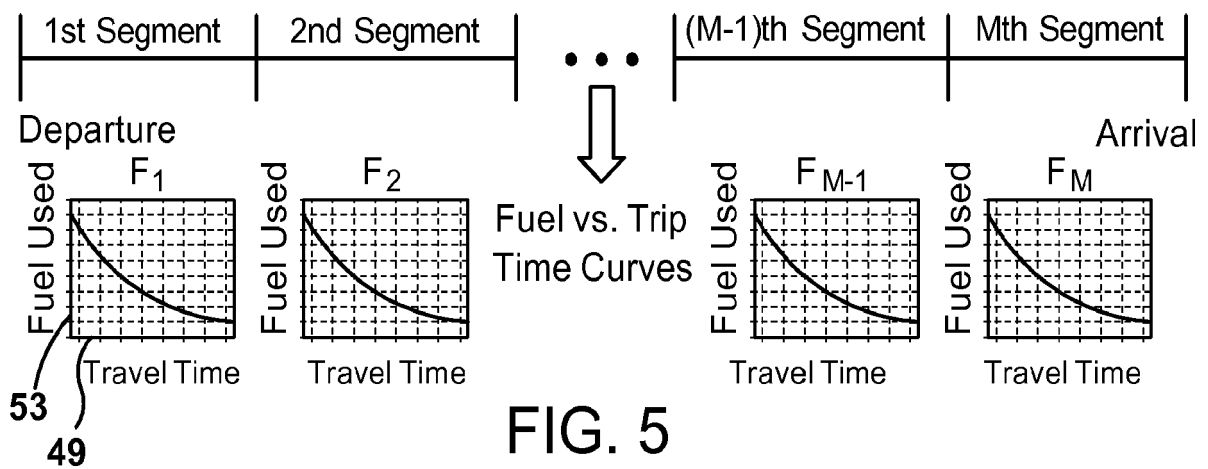


FIG. 5

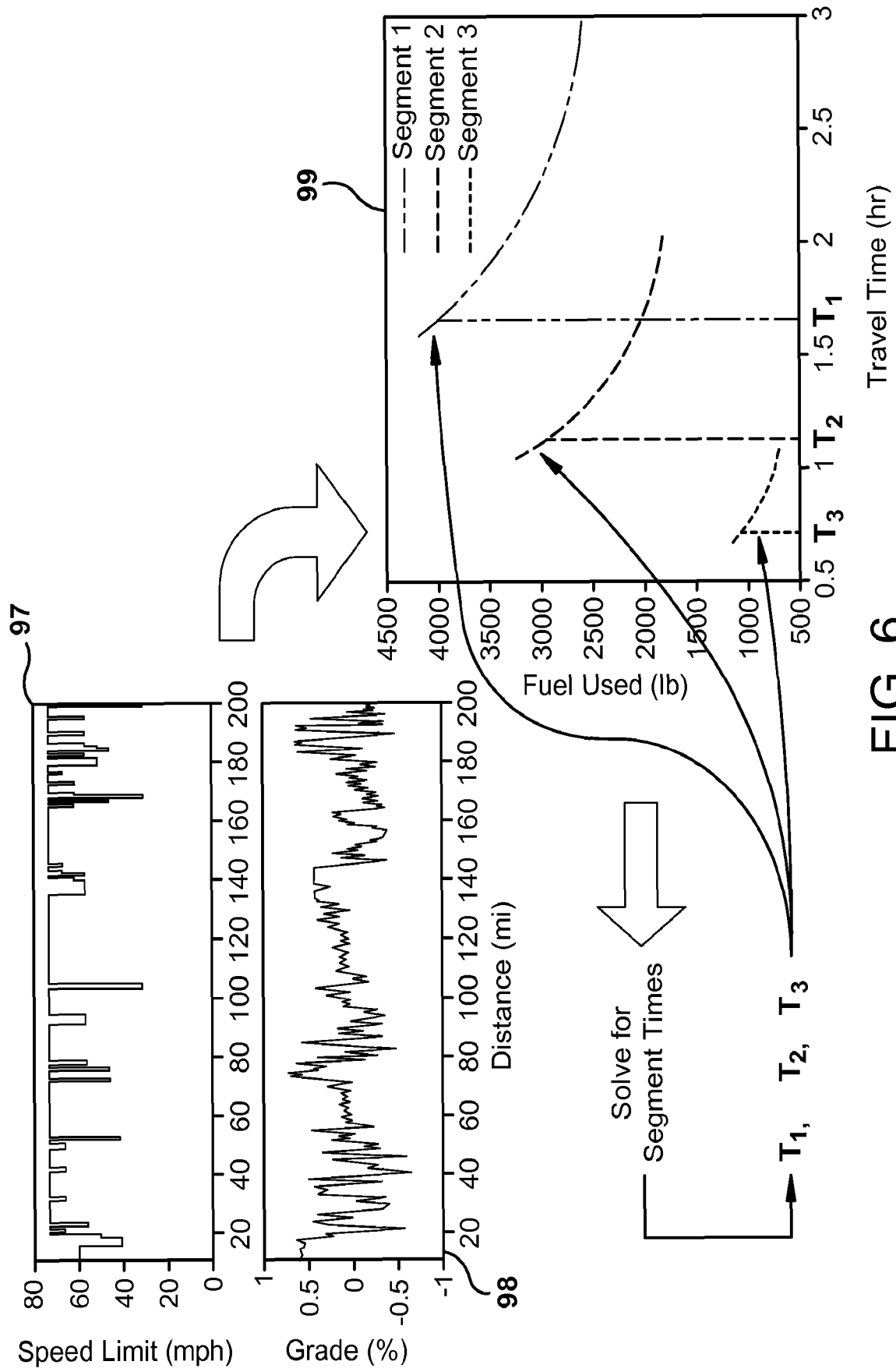


FIG. 6

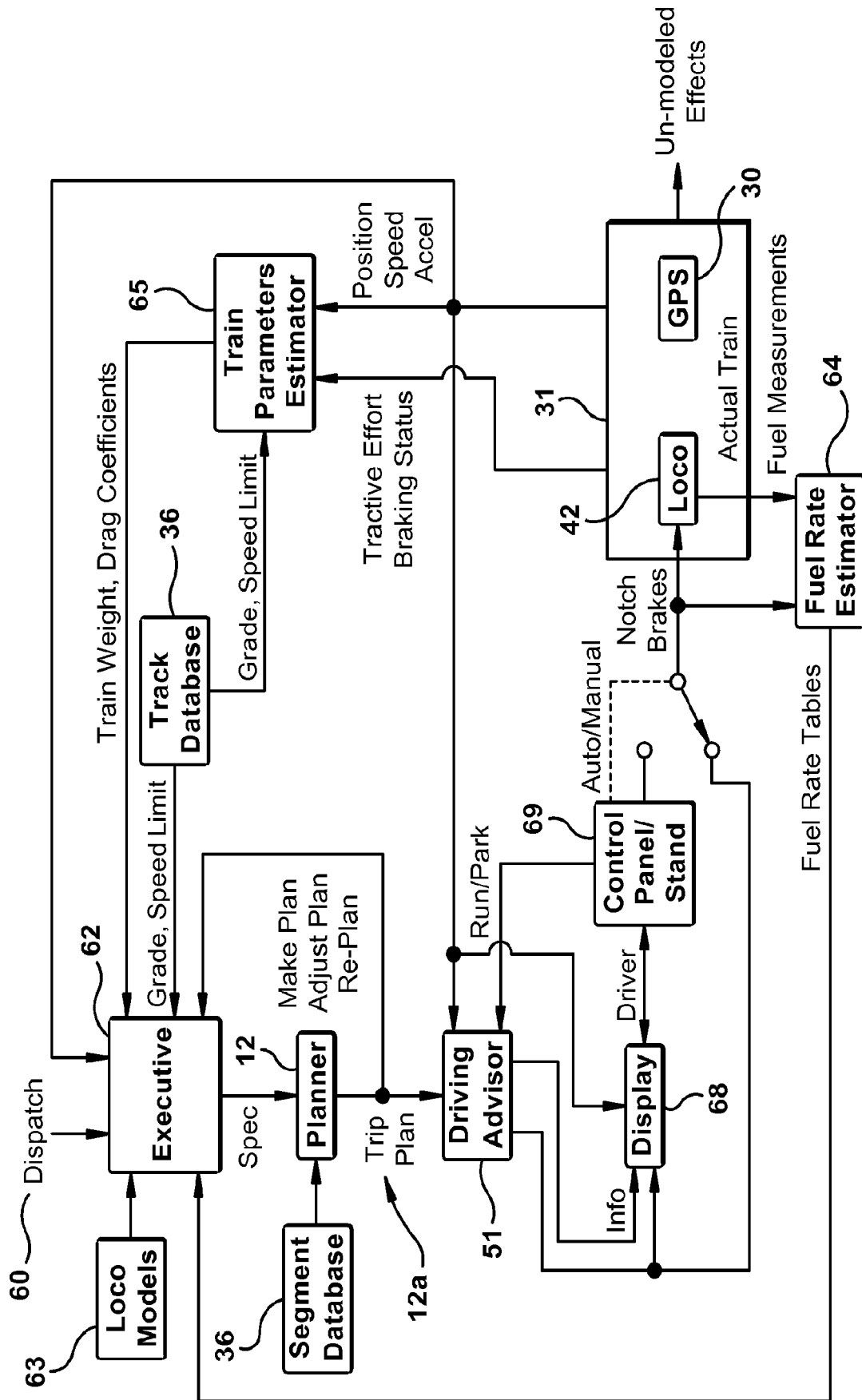


FIG. 7

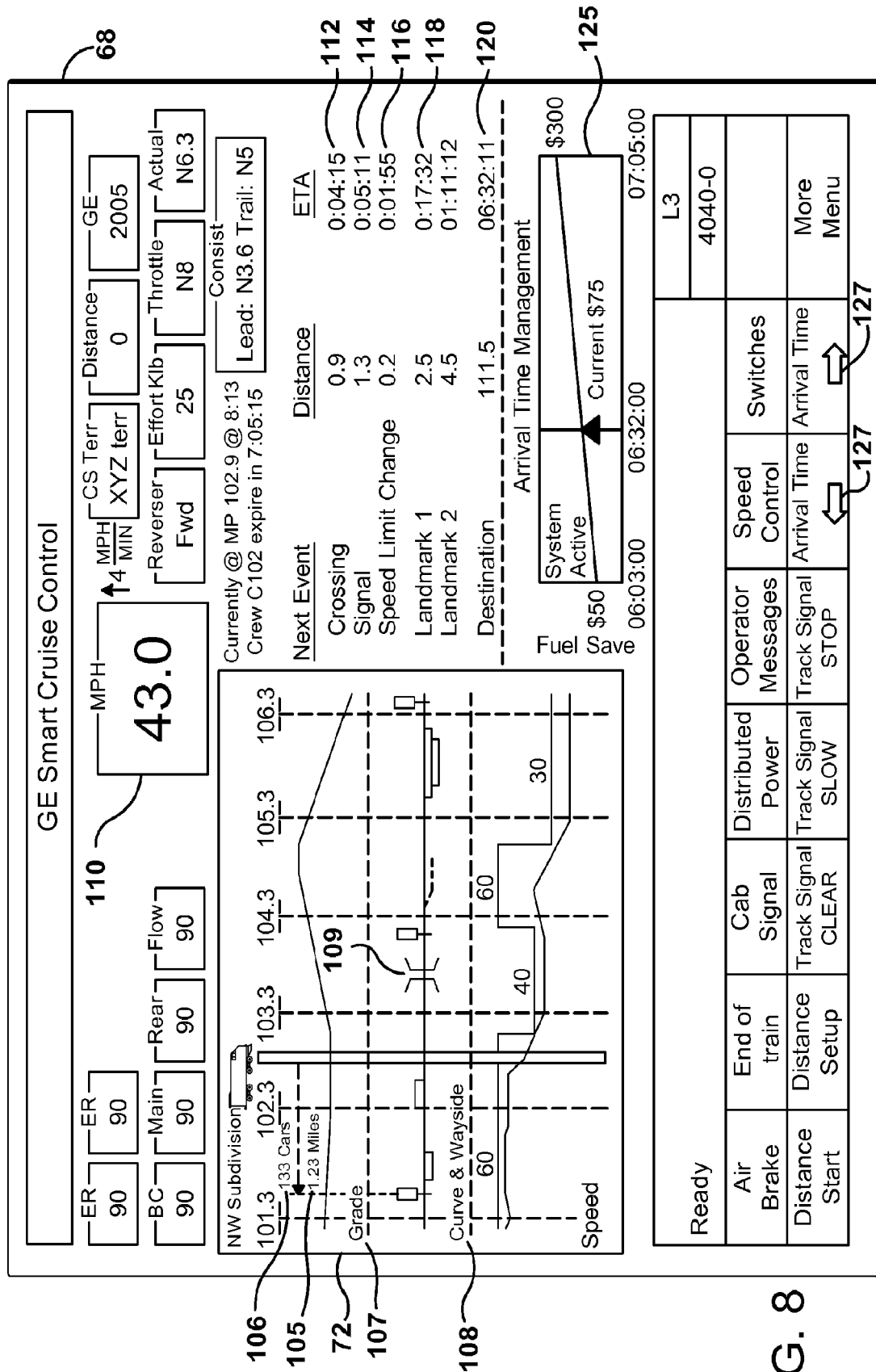
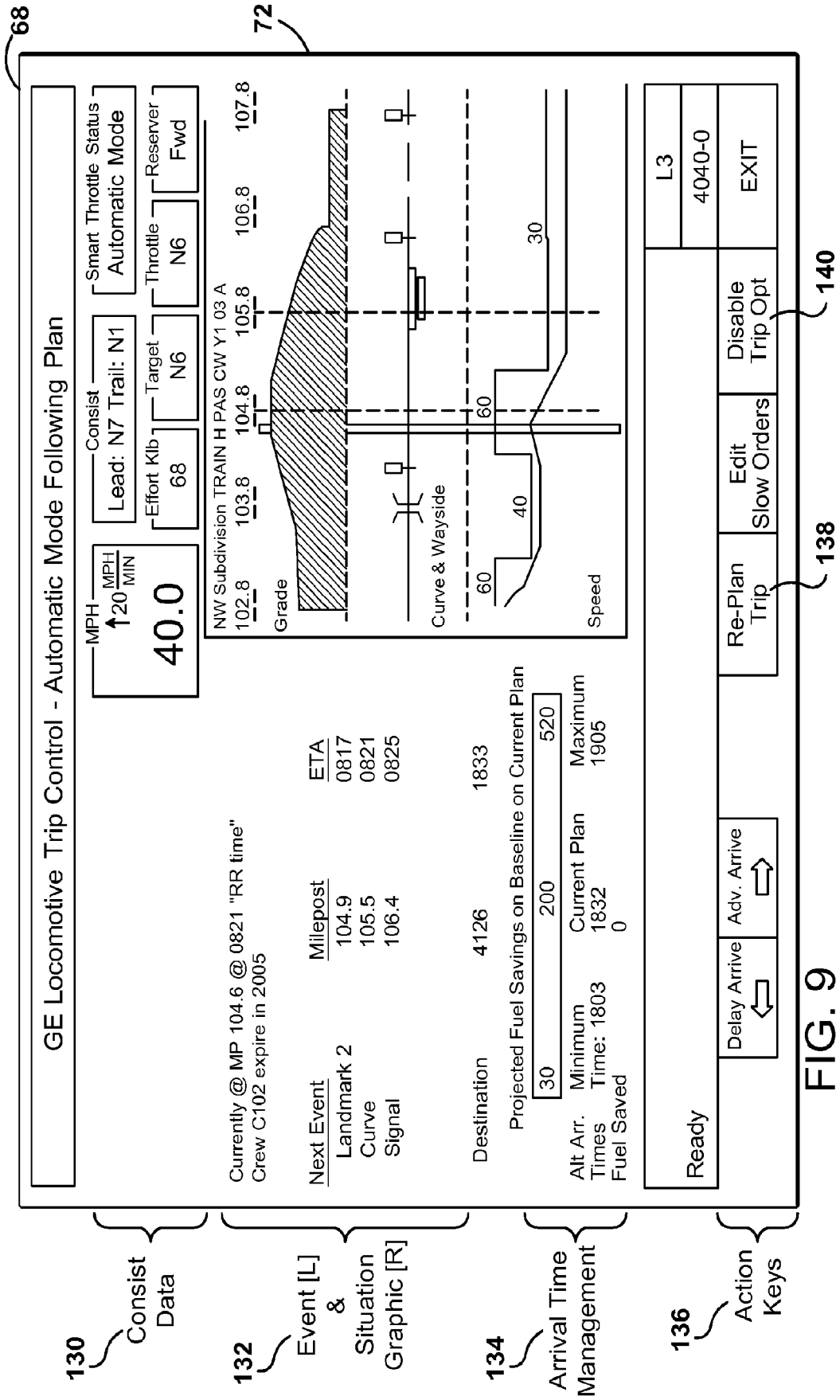
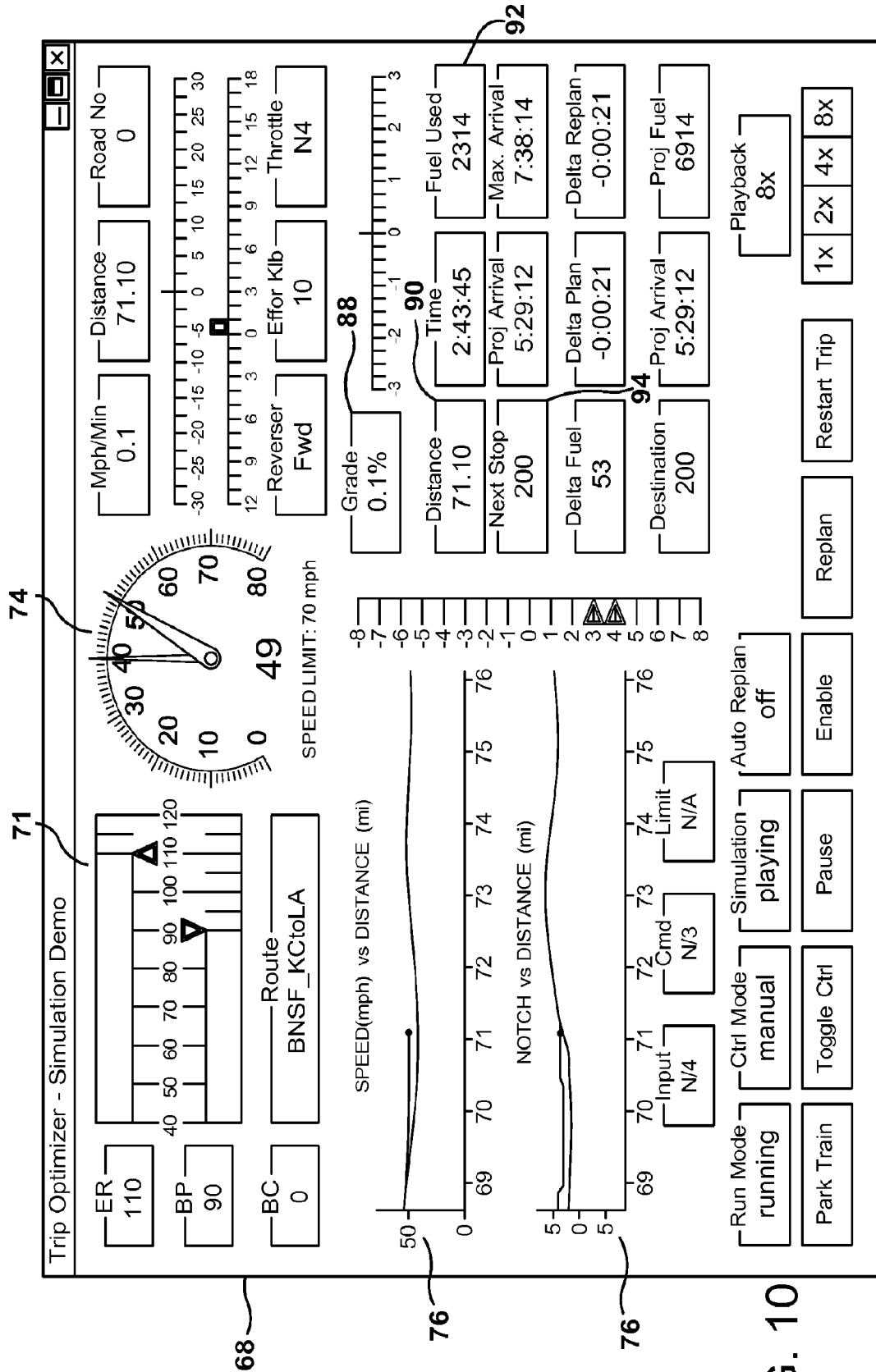


FIG. 8





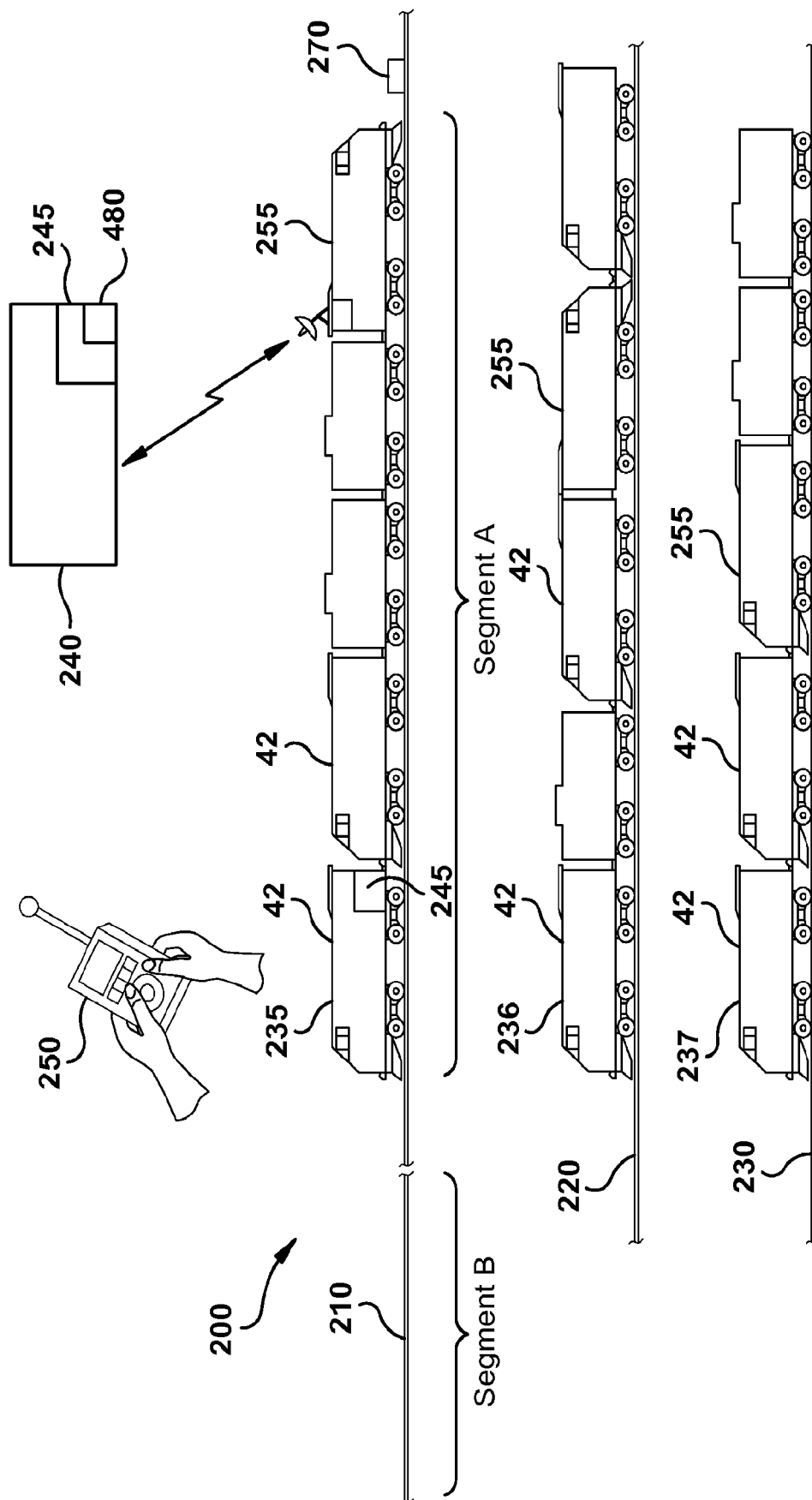


FIG. 11

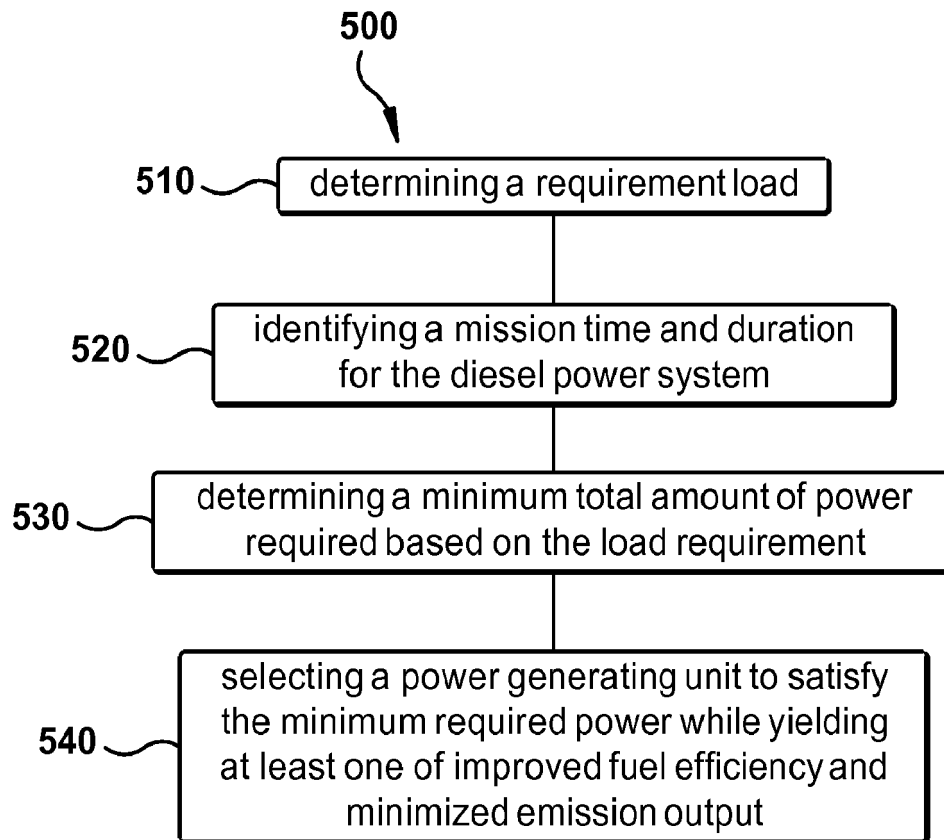


FIG. 12

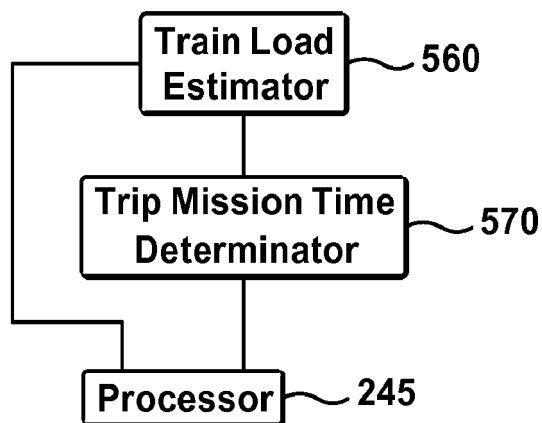


FIG. 13

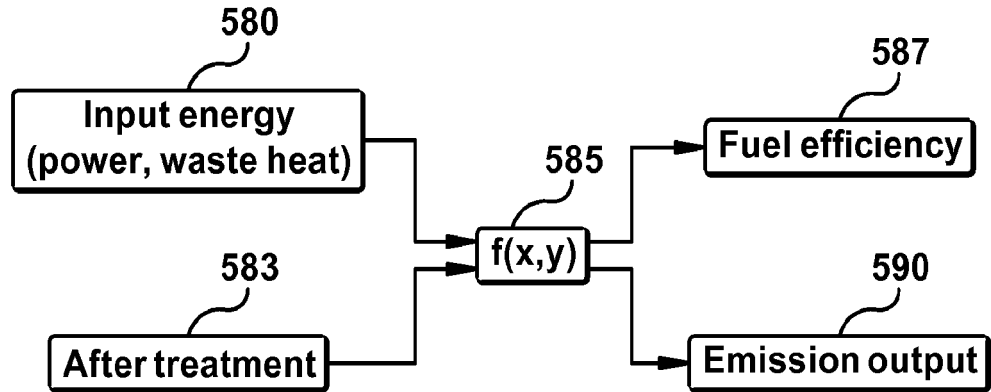


FIG. 14

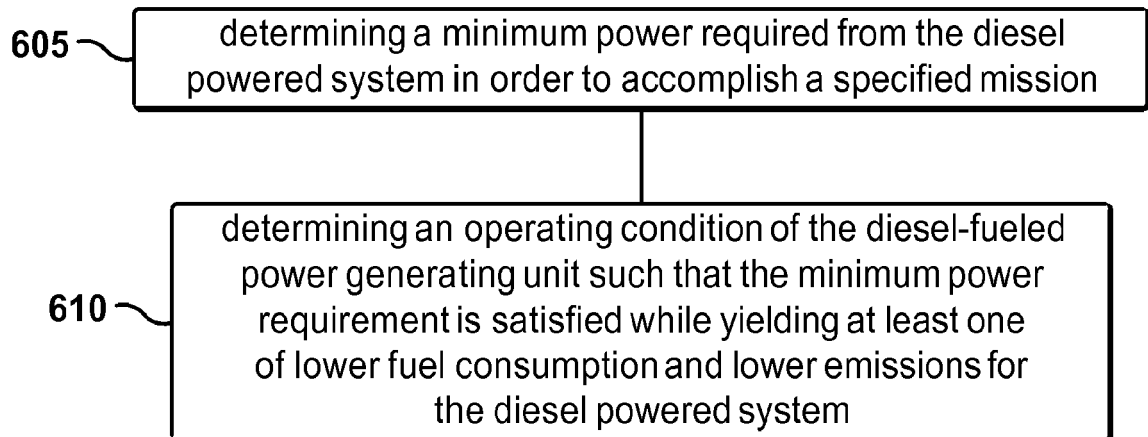


FIG. 15

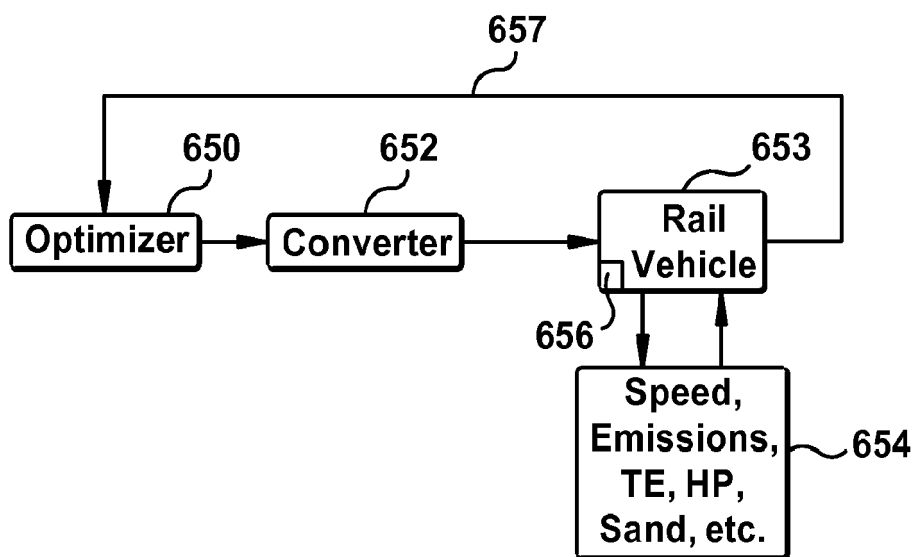


FIG. 16

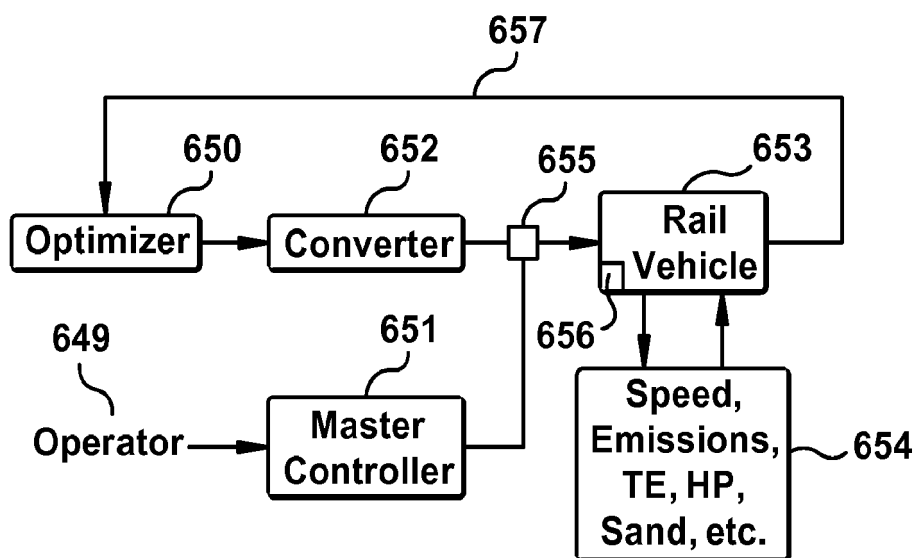


FIG. 17

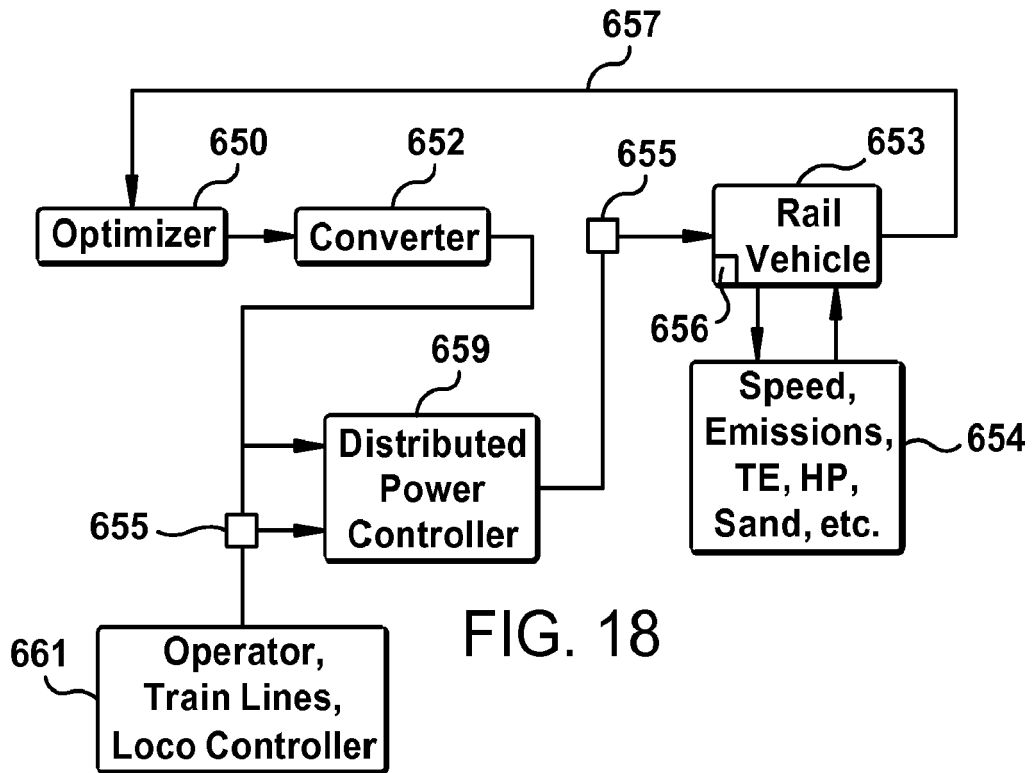


FIG. 18

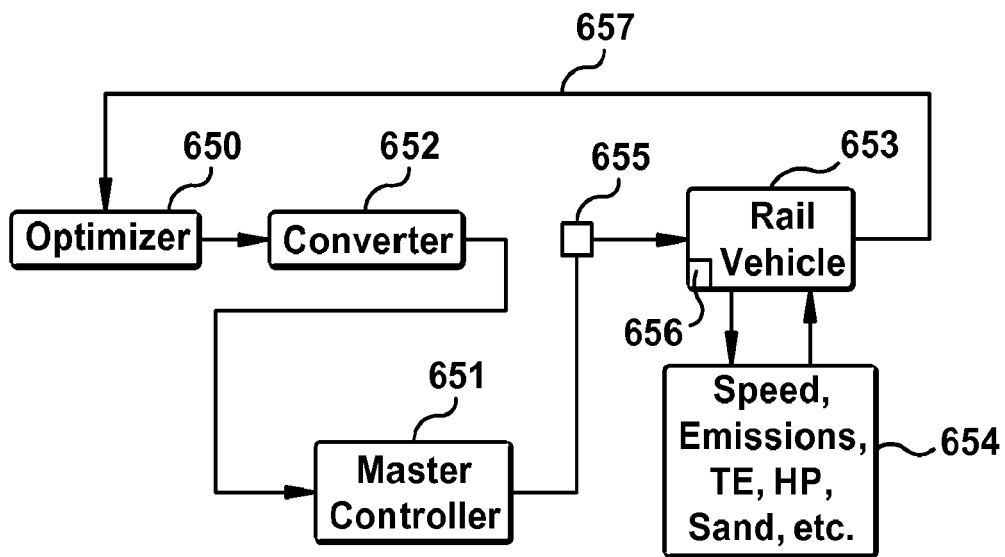


FIG. 19

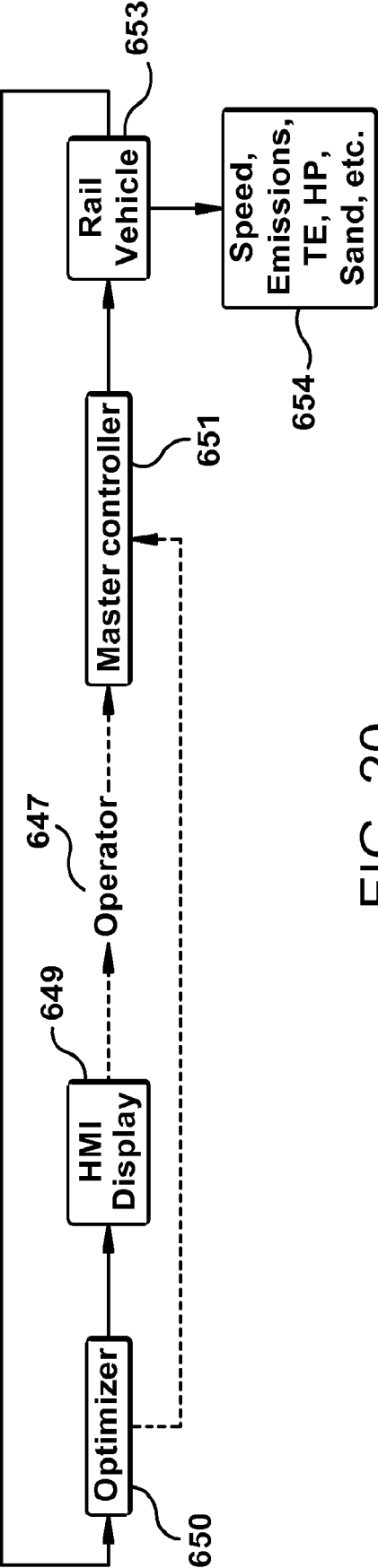


FIG. 20

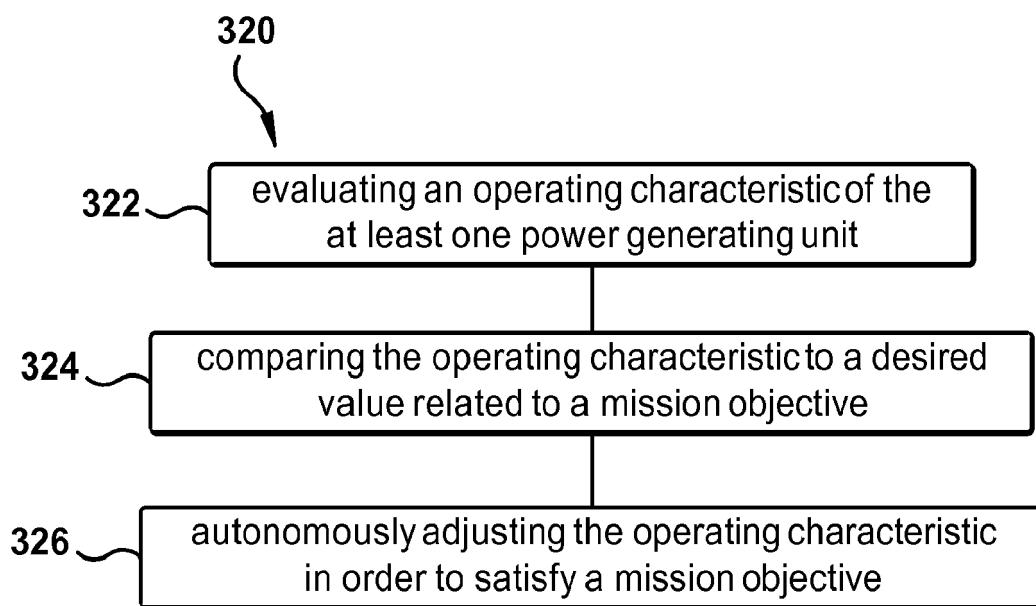


FIG. 21

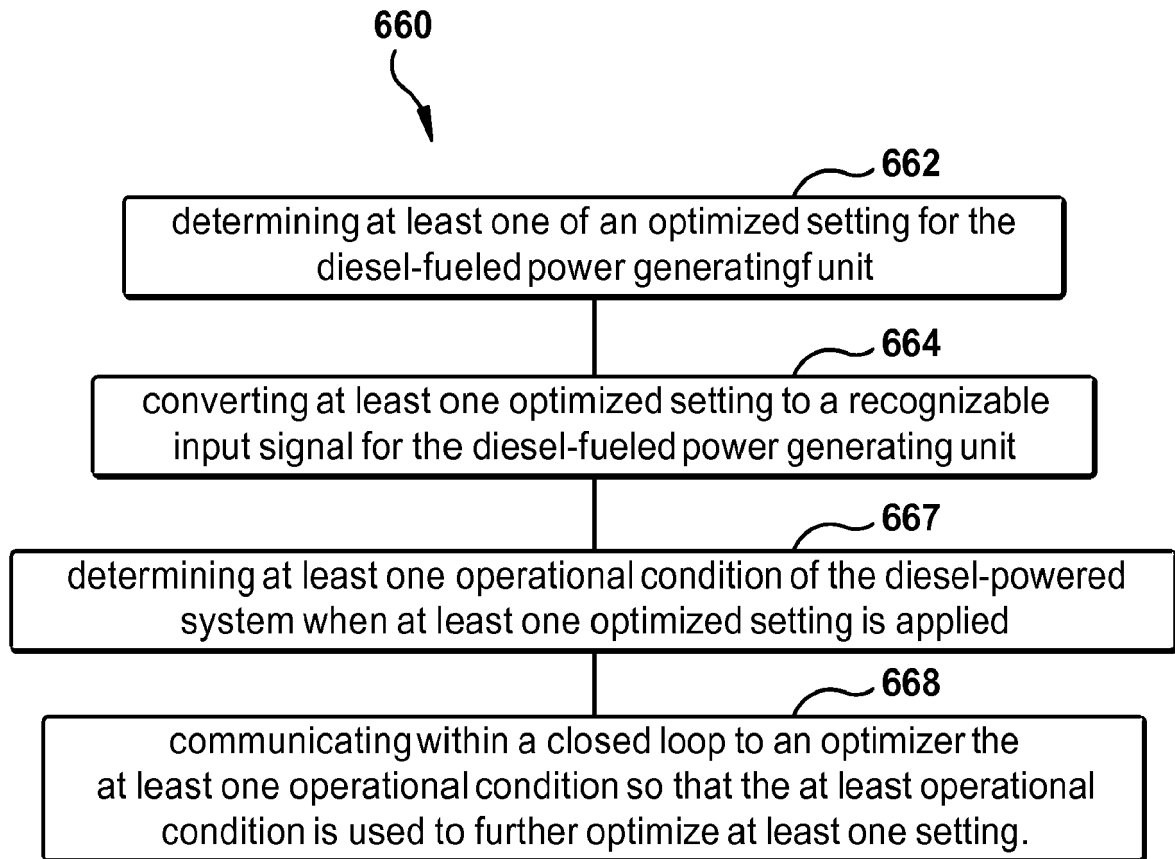


FIG. 22

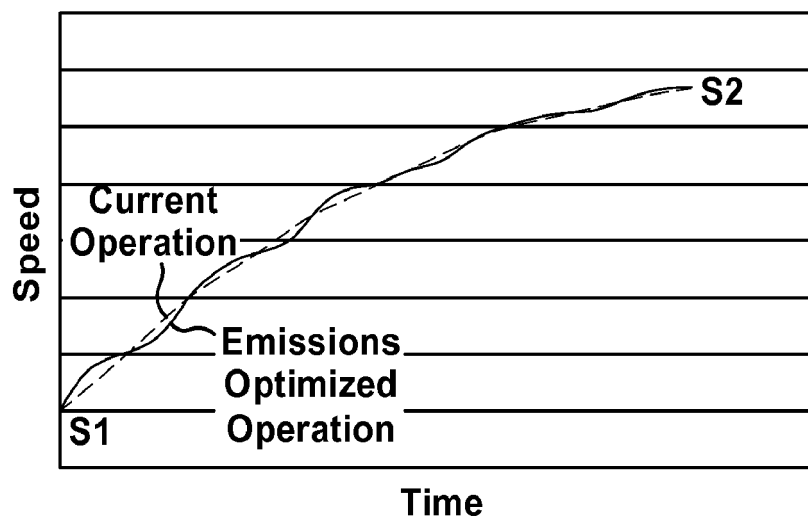


FIG. 23

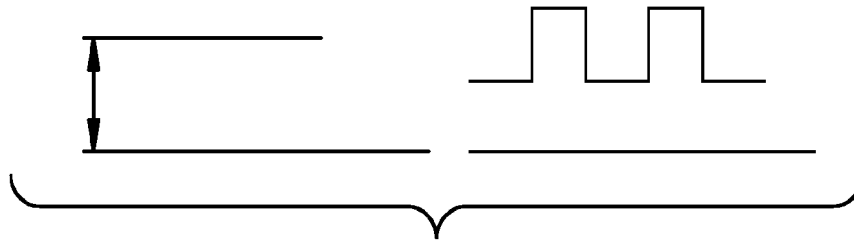


FIG. 24

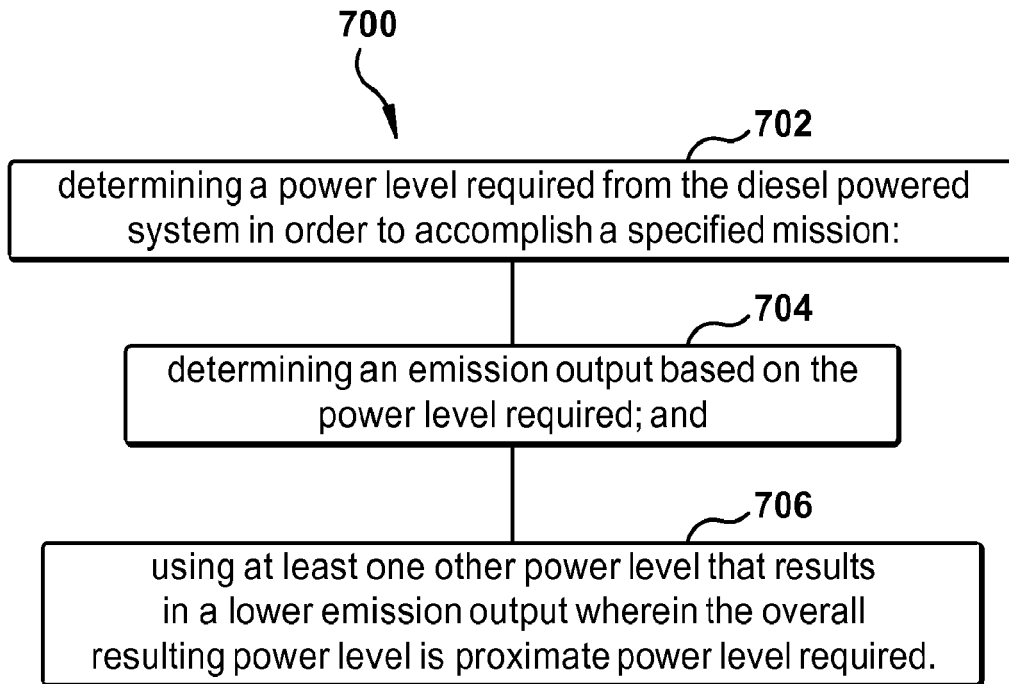


FIG. 25

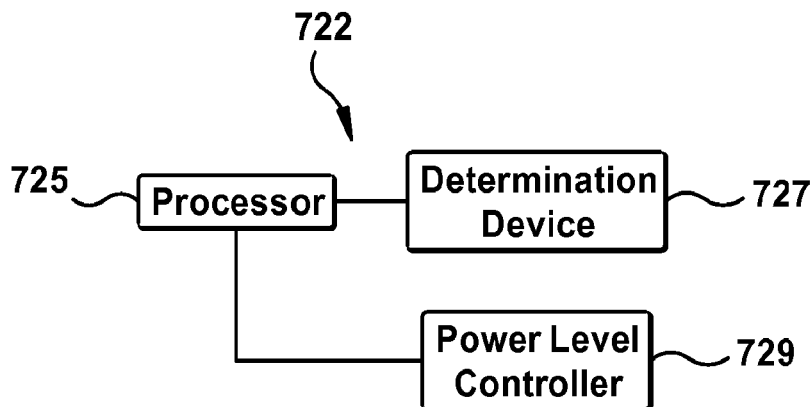


FIG. 26

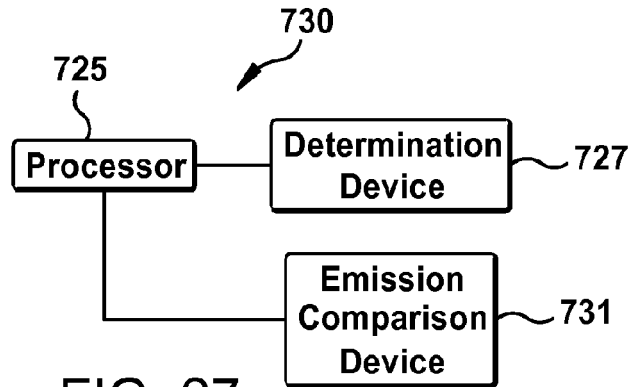


FIG. 27

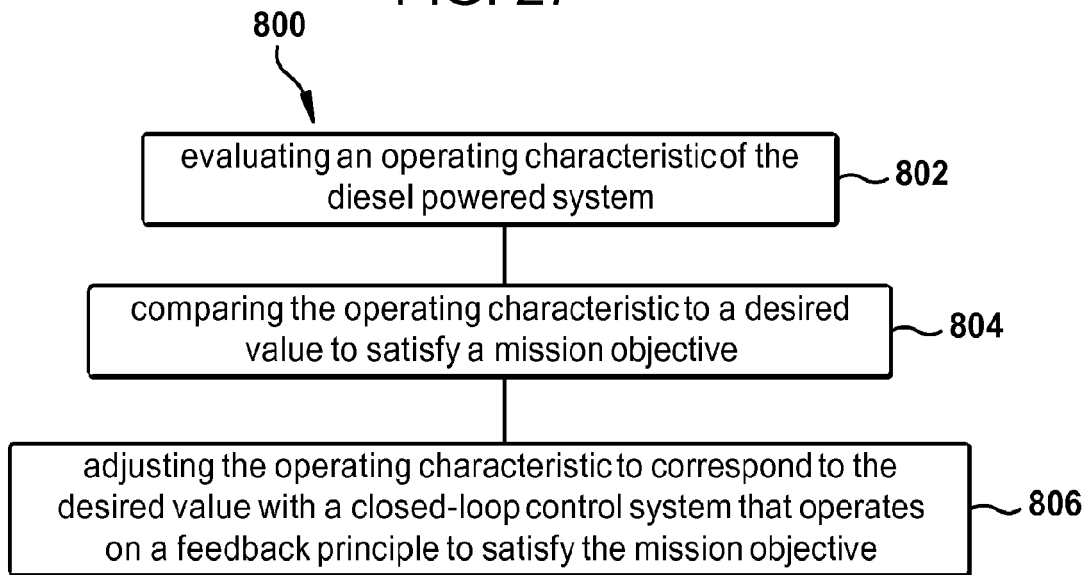


FIG. 28

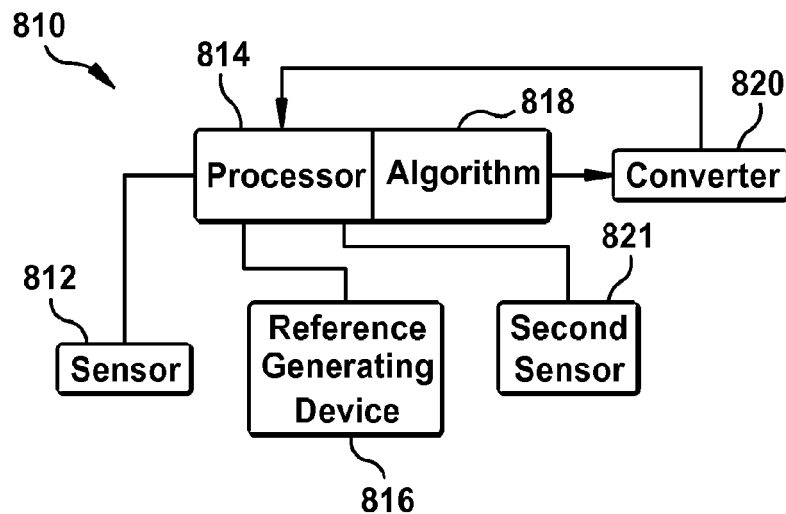


FIG. 29

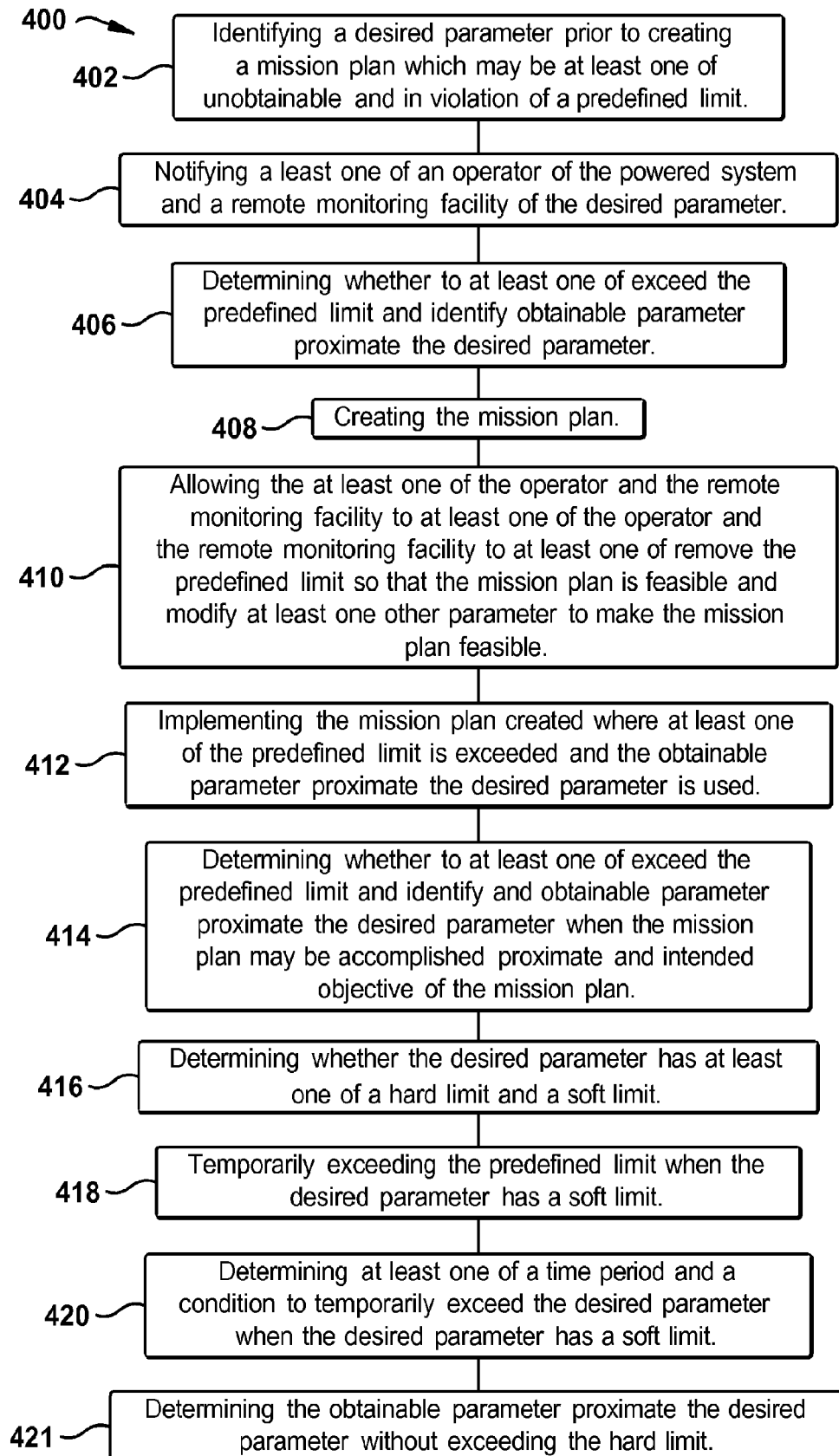


FIG. 30

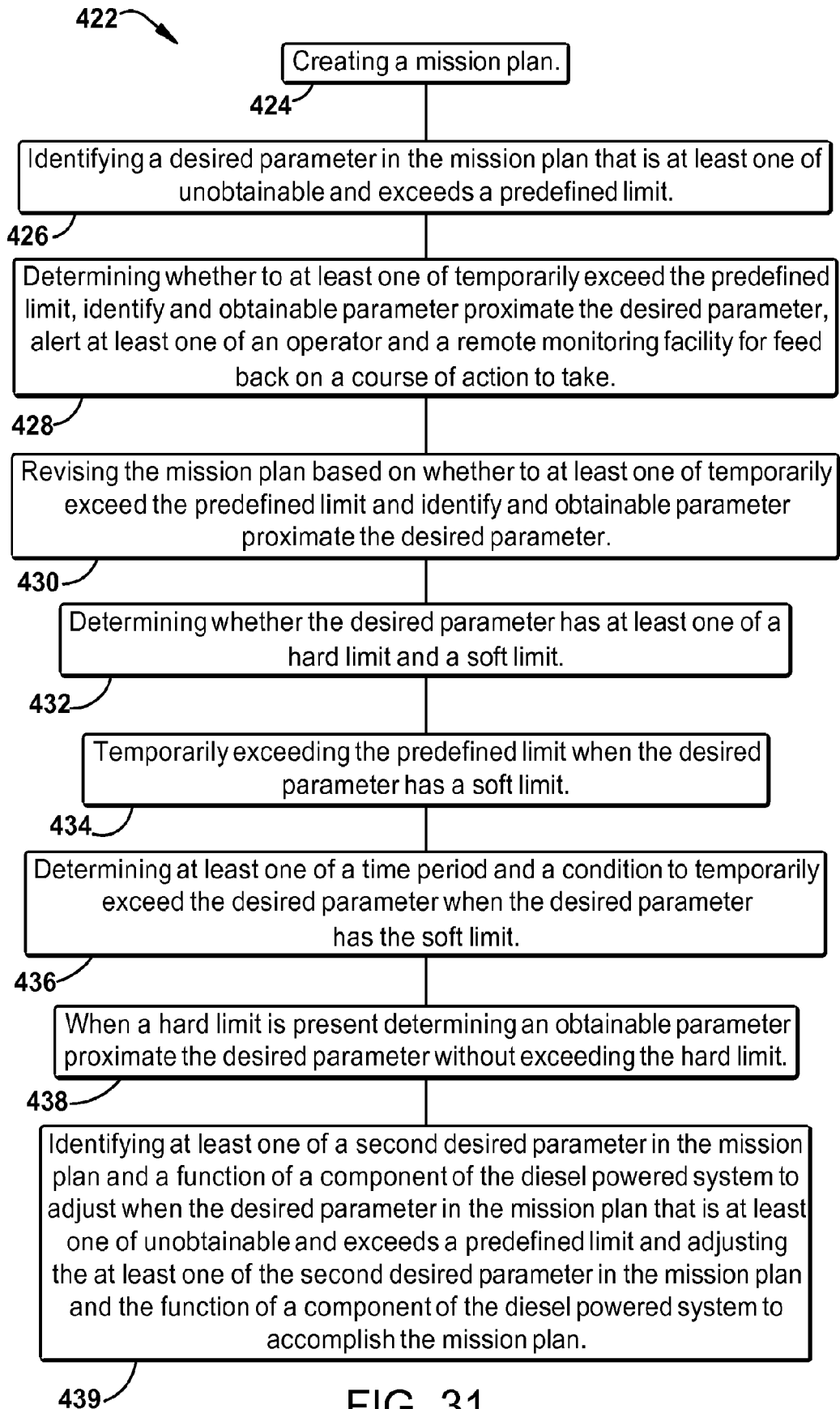
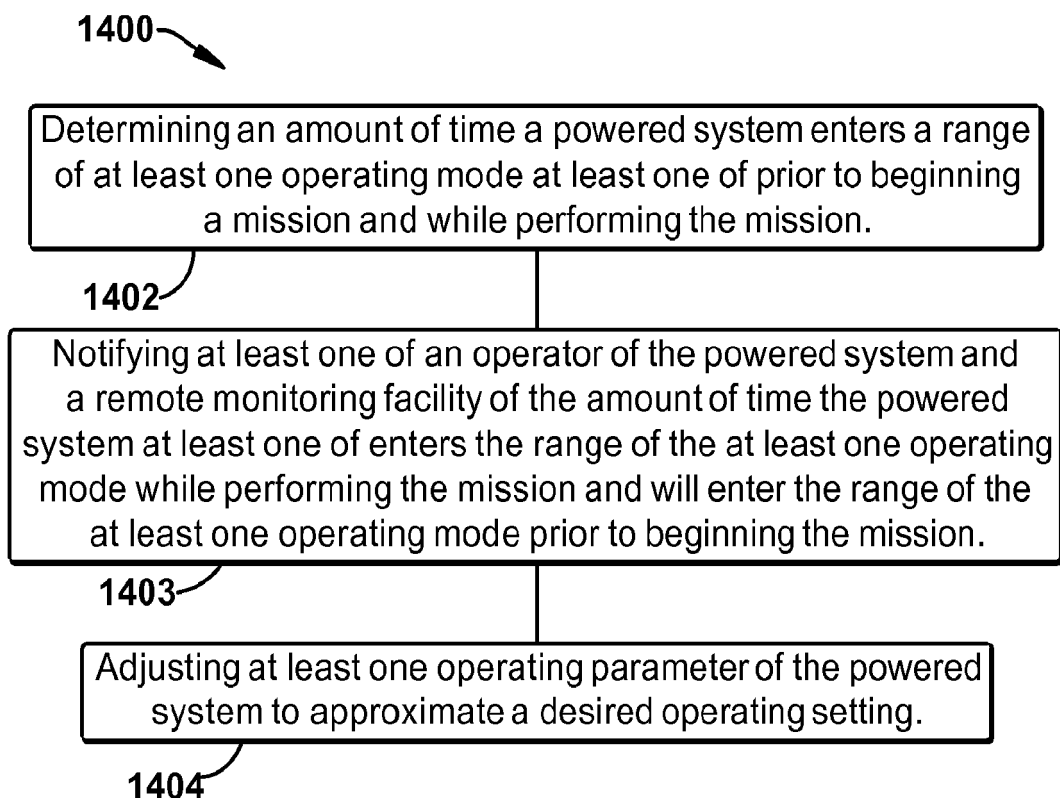
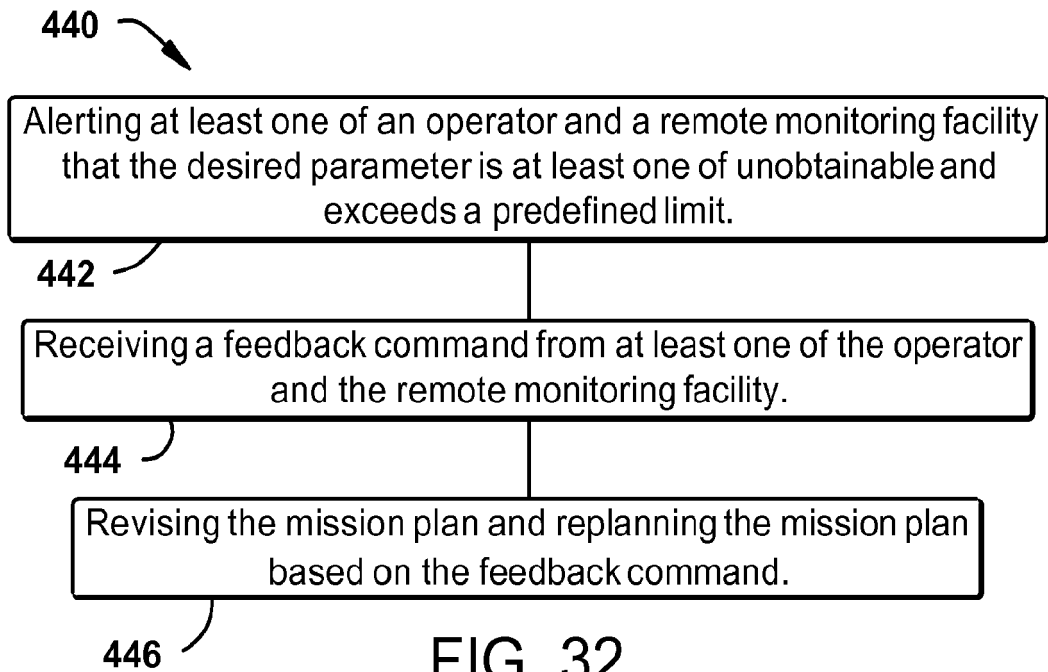


FIG. 31



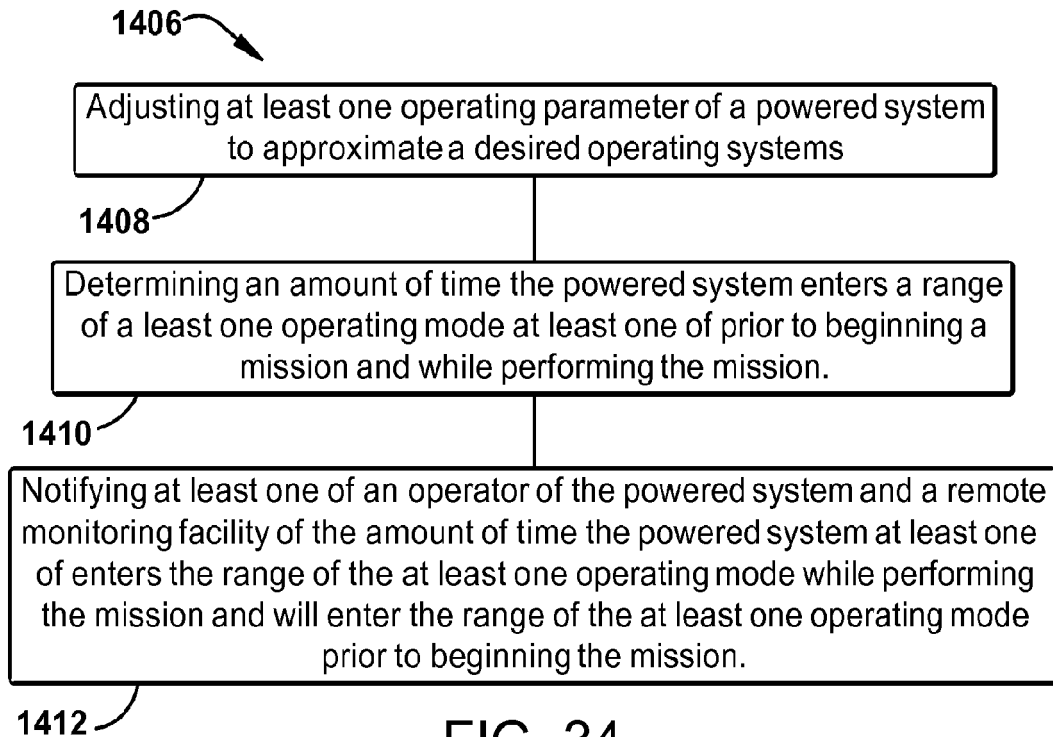


FIG. 34

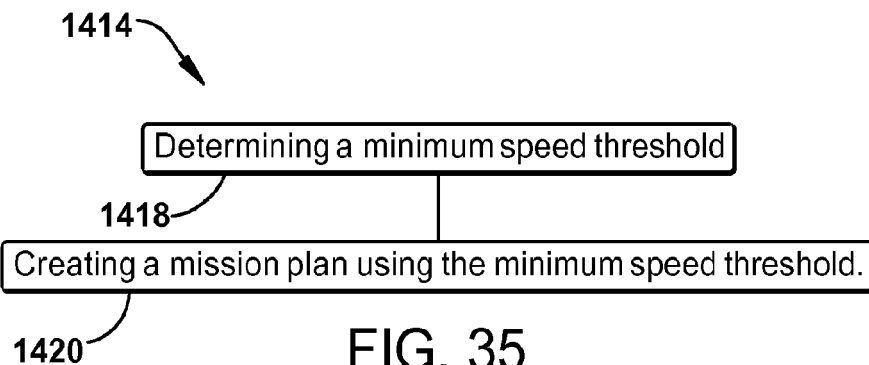


FIG. 35

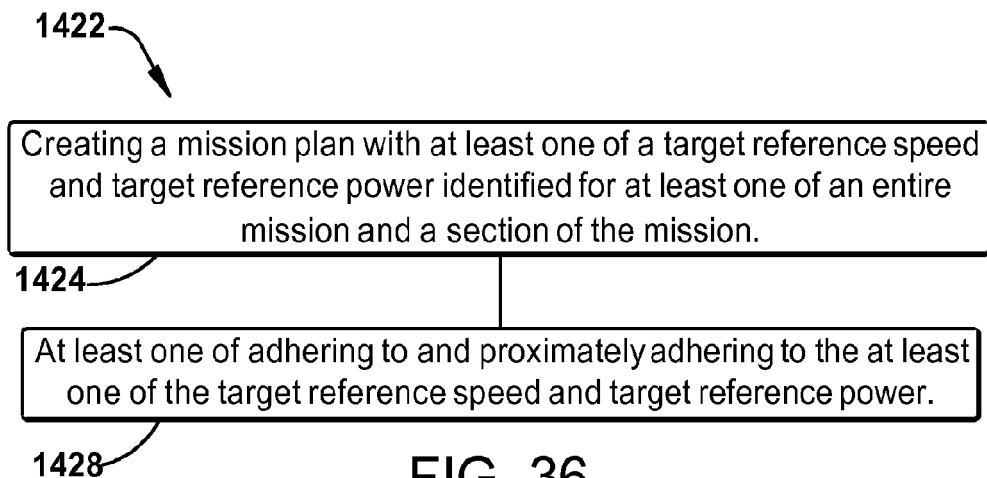


FIG. 36

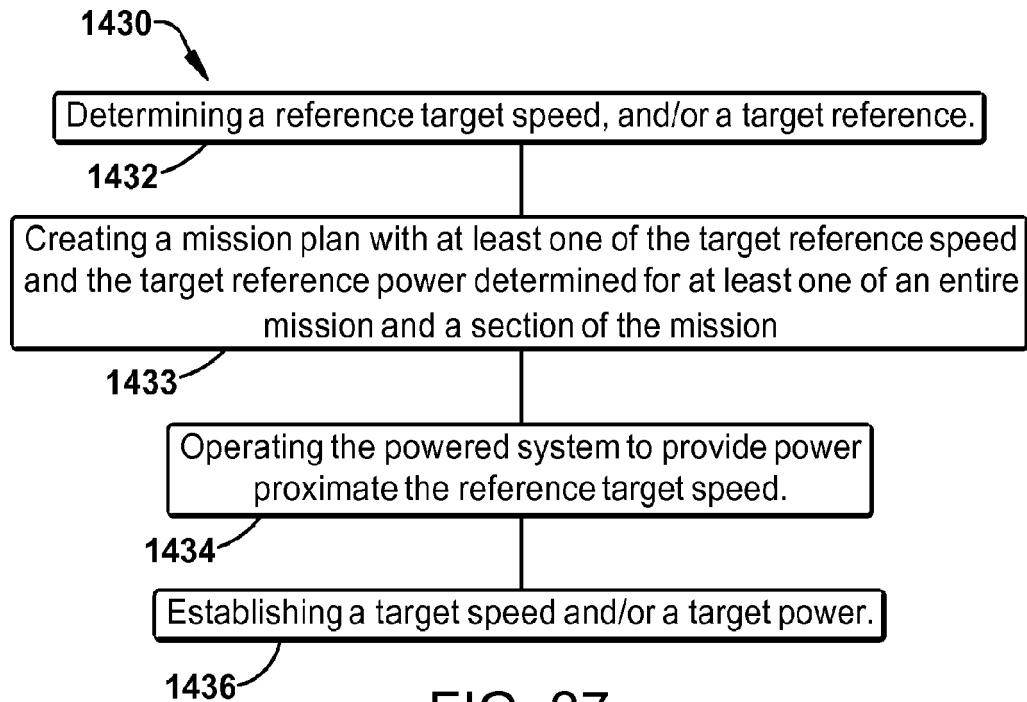


FIG. 37

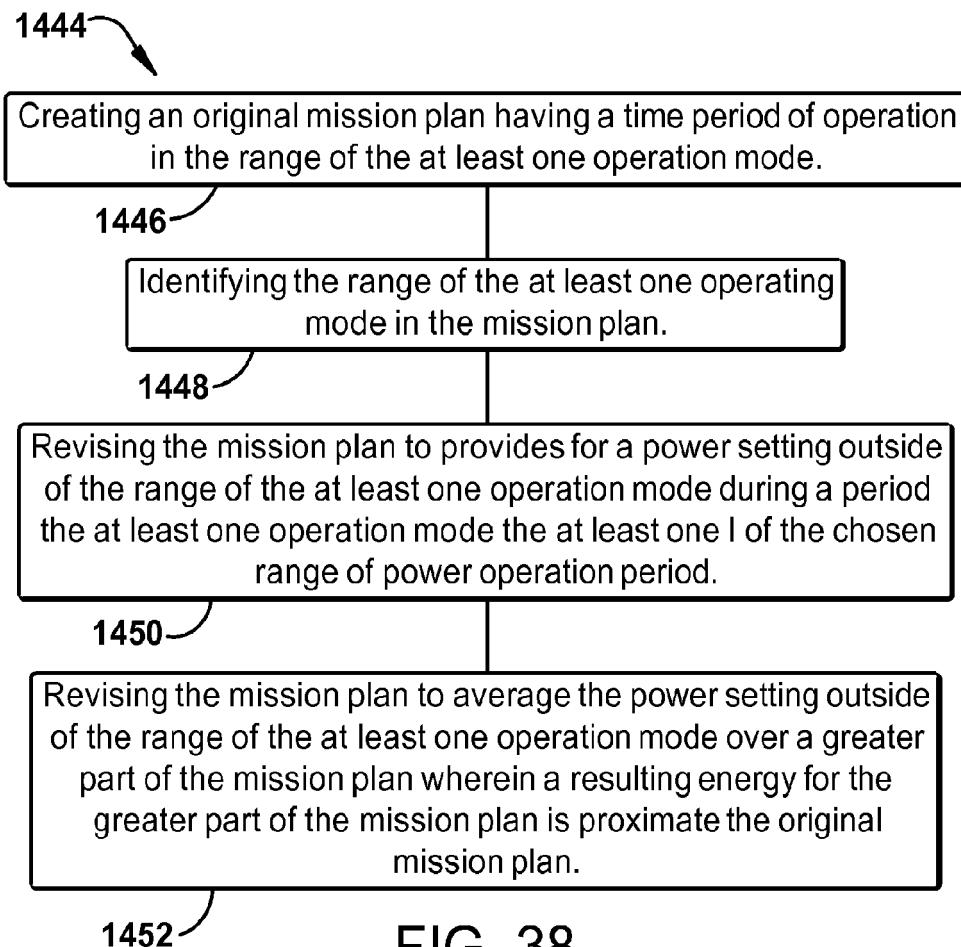
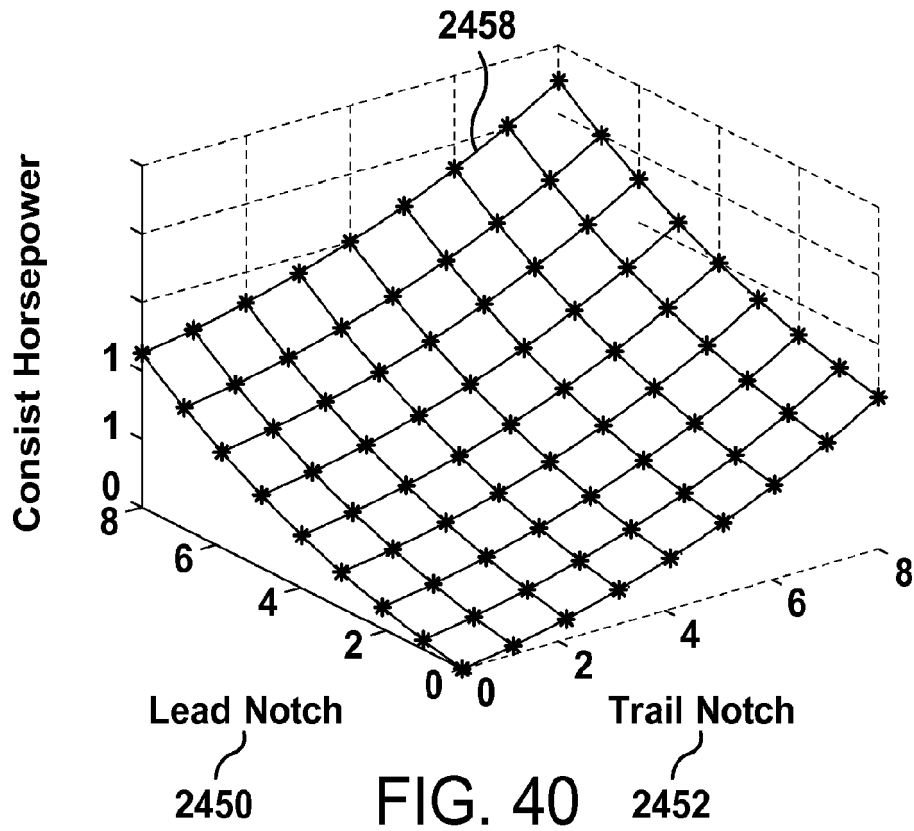
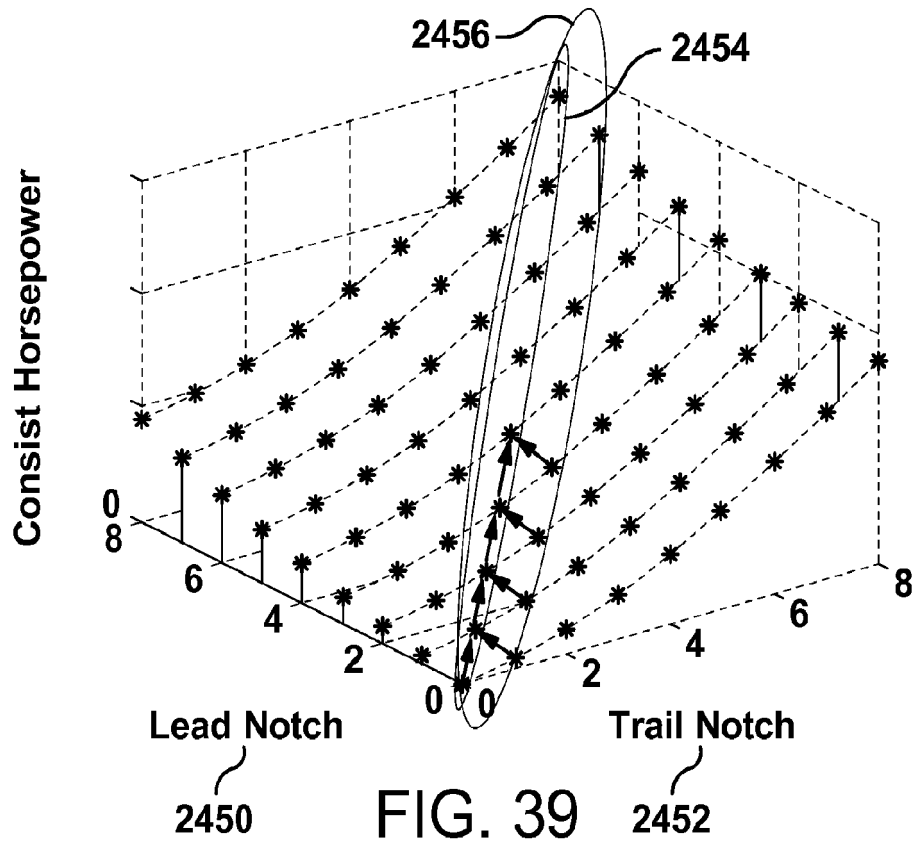


FIG. 38



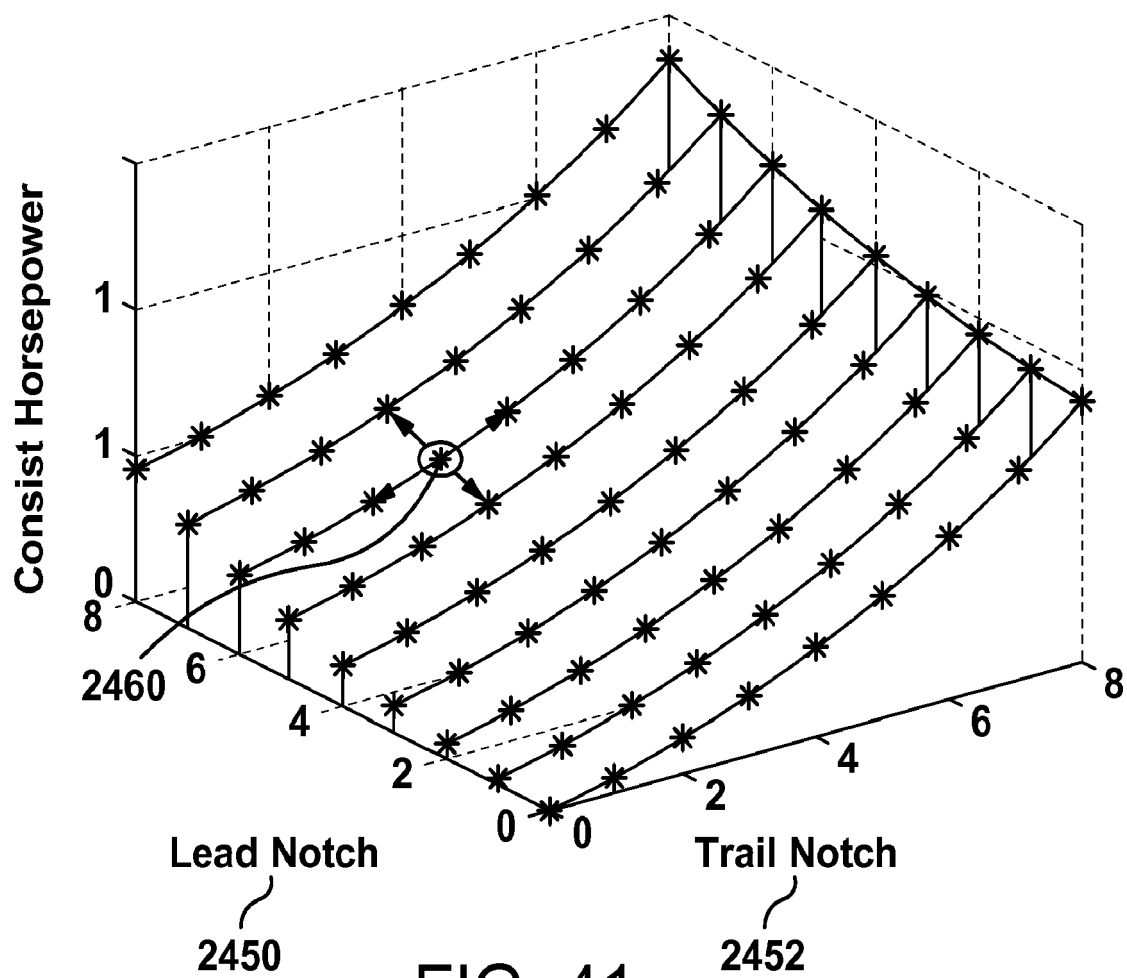


FIG. 41

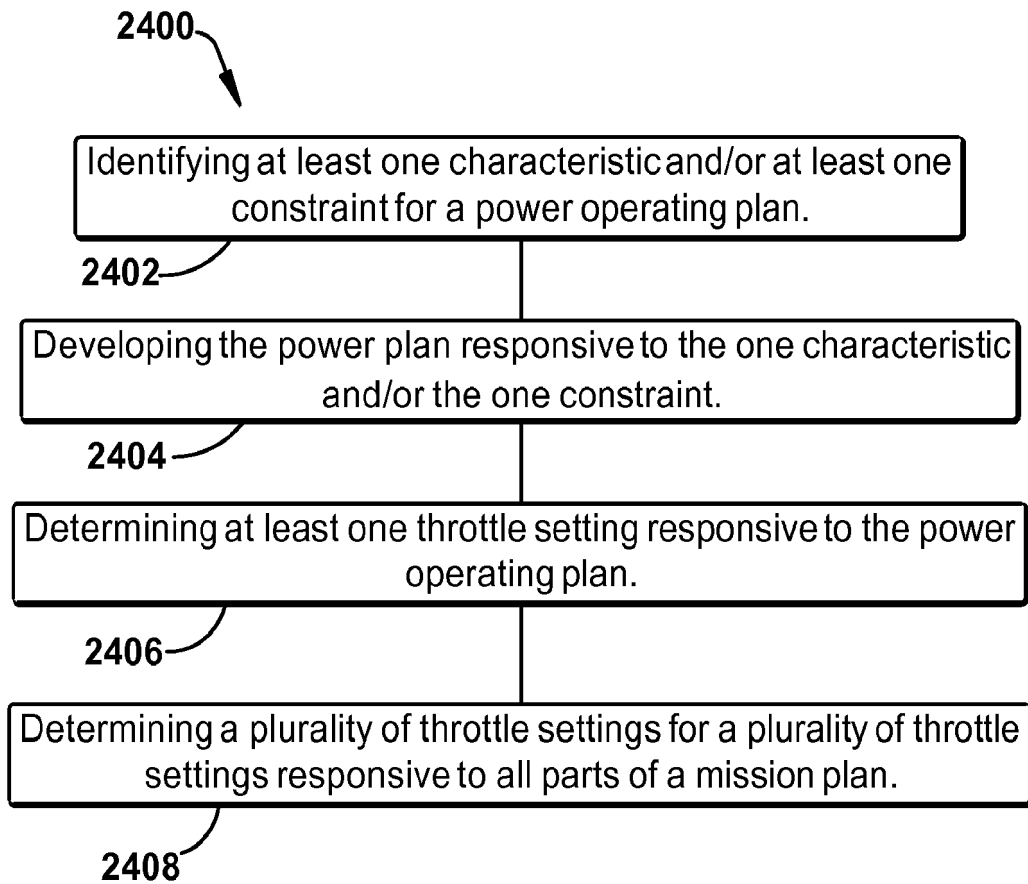


FIG. 42

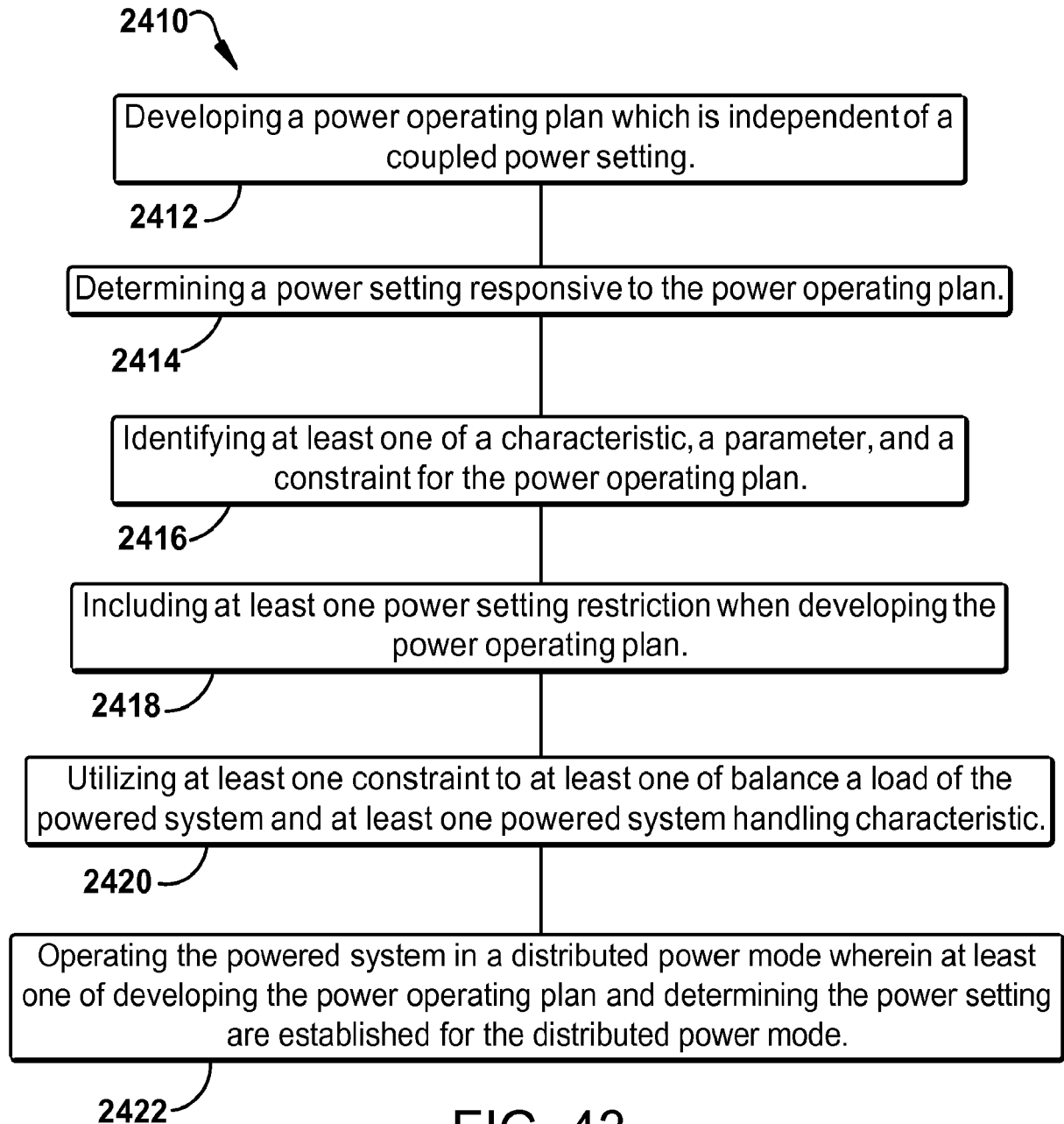


FIG. 43

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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