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(57) Abrégé/Abstract:
A system for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the system including a locator element to determine a location of the train, a track characterization element to provide information about a track, a sensor for measuring an operating condition of the locomotive consist, a processor operable to receive information from the locator element, the track characterizing element, and the sensor, and an algorithm embodied within the processor having access to the information to create a trip plan that optimizes performance of the locomotive consist in accordance with one or more operational criteria for the train.

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TRIP OPTIMIZATION SYSTEM AND METHOD FOR A TRAIN

ABSTRACT

A system for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the system including a locator element to determine a location of the train, a track characterization element to provide information about a track, a sensor for measuring an operating condition of the locomotive consist, a processor operable to receive information from the locator element, the track characterizing element, and the sensor, and an algorithm embodied within the processor having access to the information to create a trip plan that optimizes performance of the locomotive consist in accordance with one or more operational criteria for the train.

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TRIP OPTIMIZATION SYSTEM AND METHOD FOR A TRAIN

FIELD OF THE INVENTION

The field of invention relates to optimizing train operations, and more particularly to monitoring and controlling a train's operations to improve efficiency while satisfying schedule constraints.

BACKGROUND

Locomotives are complex systems with numerous subsystems, with each subsystem being interdependent on other subsystems. An operator is aboard a locomotive to insure the proper operation of the locomotive and its associated load of freight cars. In addition to insuring proper operations of the locomotive the operator also is responsible for determining operating speeds of the train and forces within the train that the locomotives are part of. 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 perscribeable operating speeds that may vary with the train location along the track. Moreover, the operator is also responsible for assuring in-train forces remain within acceptable limits.

However, even with knowledge to assure safe operation, the operator cannot usually operate the locomotive so that the fuel consumption is minimized for each trip. For example, other factors that must be considered may include emission output, operator's environmental conditions like noise/vibration, a weighted combination of fuel consumption and emissions output, etc. This is difficult to do since, as an example, the size and loading of trains vary, locomotives and their fuel/emissions characteristics are different, and weather and traffic conditions vary. Operators could more effectively operate a train if they were provided with a means to determine the best way to drive the train on a given day to meet a required schedule (arrival time) while using the least fuel possible, despite sources of variability.

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BRIEF DESCRIPTION

Embodiments of the invention disclose a system for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives. In an exemplary embodiment, the system comprises a locator element to determine a location of the train. A track characterization element to provide information about a track is also provided. The system also has a processor operable to receive information from the locator element, and the track characterizing element. An algorithm is also provided which is embodied within the processor having access to the information to create a trip plan that optimizes performance of the locomotive consist in accordance with one or more operational criteria for the train.

An exemplary embodiment of the present invention also discloses a method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives. The method comprises determining a location of the train on a track. The method also determines a characteristic of the track . The method further creates a trip plan based on the location of the train, the characteristic of the track, and the operating condition of the locomotive consist in accordance with at least one operational criteria for the train.

An exemplary embodiment of the present invention also discloses a computer software code for operating a train having a computer processor and one or more locomotive consists with each locomotive consist comprising one or more locomotives. The computer software code comprises a software module for creating a trip plan based on the location of the train, the characteristic of the track, and the operating condition of the locomotive consist in accordance with at least one operational criteria for the train.

An exemplary embodiment of the present invention further discloses a method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train. The method comprises determining a power setting for the locomotive consist based on the trip plan. The method also operates the locomotive consist at the

power setting. Actual speed of the train, actual power setting of the locomotive consist, and/or a location of the train is collected. Actual speed of the train, actual power setting of the locomotive consist, and/or a location of the train is compared to the power setting.

Another exemplary embodiment of the present invention further discloses a method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train based on assumed operating parameters for the train and/or the locomotive consist. The method comprises estimating train operating parameters and/or locomotive operating parameters. The method further comprises comparing the estimated train operating parameters and/or the locomotive consist operating parameters to the assumed train operating parameters and/or the locomotive consist operating parameters.

Another exemplary embodiment of the present invention further discloses a method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train based on a desired parameter. The method comprises determining operational parameters of the train and/or the locomotive consist, determining a desired parameter based on determined operational parameters, and comparing the determined parameter to the operational parameters. If a difference exists from comparing the determined parameter to the operational parameters, the method further comprises adjusting the trip plan.

An exemplary embodiment of the present invention further discloses a method for operating a rail system having one or more locomotive consists with each locomotive consist comprising one or more locomotives. The method comprises determining a location of the train on a track and determining a characteristic of the track. The method further comprises generating a driving plan for at least one of the locomotives based on the locations of the rail system, the characteristic of the track, and/or the operating condition of the locomotive consist, in order to minimize fuel consumption by the rail system.

Another exemplary embodiment of the present invention further discloses a method for operating a rail system having one or more locomotive consists with each locomotive consist comprising one or more locomotives. Towards this end the method comprises determining a location of the train on a track, and determining a characteristic of the track. The method further comprises providing propulsion control for the locomotive consist in order to minimize fuel consumption by the rail system.

DRAWINGS

A more particular description of examples 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, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1 depicts an exemplary illustration of a flow chart of an exemplary embodiment of the present invention;

FIG. 2 depicts a simplified model of the train that may be employed;

FIG. 3 depicts an exemplary embodiment of elements of an exemplary embodiment of the present invention;

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 an exemplary embodiment of a segmentation example;

FIG. 7 depicts an exemplary flow chart of an exemplary embodiment of the present invention;

FIG. 8 depicts an exemplary illustration of a dynamic display for use by the operator;

FIG. 9 depicts another exemplary illustration of a dynamic display for use by the operator; and

FIG. 10 depicts another exemplary illustration of a dynamic display for use by the operator.

DETAILED DESCRIPTION

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.

Exemplary embodiments of the present invention solve the problems in the art by providing a system, method, and computer implemented method for determining and implementing a driving strategy of a train having a locomotive consist determining an approach to monitor and control a train's operations to improve certain objective operating criteria parameter requirements while satisfying schedule and speed constraints. Throughout this disclose the term "present invention" or "invention" is used. Even through the term "exemplary embodiment(s)" does not immediately proceed the above cited term, the intent of "present invention" or "invention" is read to mean "exemplary embodiment(s) of the present invention." The present invention is also operable when the locomotive consist is in distributed power operations. 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.

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.

Broadly speaking, the technical effect is determining and implementing a driving strategy of a train having a locomotive consist determining an approach to monitor and control a train's operations to improve certain objective operating criteria parameter requirements while satisfying schedule and speed constraints. To facilitate an understanding of the present invention, it is described hereinafter with reference to specific implementations thereof. The invention is described in the general context of computer-executable instructions, such as program modules, being executed by a computer. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. For example, the software programs that underlie the invention can be coded in different languages, for use with different platforms. In the description that follows, examples of the invention are described in the context of a web portal that employs a web browser. It will be appreciated, however, that the principles that underlie the invention can be implemented with other types of computer software technologies as well.

Moreover, those skilled in the art will appreciate that 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. 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.

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. The locomotives are connected together where no train cars are in between the locomotives. The train can have more than one consist in its composition.

Specifically, there can be a lead consist, and more than one 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 consist is usually viewed as successive locomotives, those skilled in the art will readily recognize that a consist group of locomotives may also be recognized as a consist even when at least a car separates the locomotives, such as when the consist is configured for distributed power operation, wherein throttle and braking commands are relayed from the lead locomotive to the remote trails 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.

Referring now to the drawings, embodiments of the present invention will be described. 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.

FIG. 1 depicts an exemplary illustration of a flow chart of the present invention. 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 (effective track grade and curvature as function of milepost 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.

This data may be provided to the locomotive 42 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 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.

The track signal system determines the allowable speed of the train. There are many types of track signal systems and the 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 the track is clear and the train may proceed at max allowable speed. They can also indicate 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).

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.

The 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.

Based on the specification data input into the present invention, 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 12. 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. 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 the profiles provides 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 preferred embodiment, instead of operating at the traditional discrete notch power settings, the present invention is able to select a continuous power setting determined as optimal for the profile selected. Thus, for example, if an optimal profile specifies a notch setting of 6.8, instead of operating at notch setting 7, the locomotive 42 can operate at 6.8. Allowing such intermediate power settings may bring additional efficiency benefits as described below.

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.

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 setup 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 setup, 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.

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

$$\frac{dx}{dt} = v; x(0) = 0.0; x(T_f) = D$$

$$\frac{dv}{dt} = T_e(u, v) - G_a(x) - R(v); v(0) = 0.0; v(T_f) = 0.0$$

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, 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 (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 setup 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 setup, 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:

$\min_{u(t)} \int_0^{T_f} F(u(t))dt$ - Minimize total fuel consumption

$\min_{u(t)} T_f$ - Minimize Travel Time

$\min_{u_i} \sum_{i=2}^{n_d} (u_i - u_{i-1})^2$ - Minimize notch jockeying (piecewise constant input)

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

4. Replace the fuel term F in (1) with a term corresponding to emissions production.

A commonly used and representative objective function is thus

$$\min_{u(t)} \alpha_1 \int_0^{T_f} F(u(t))dt + \alpha_3 T_f + \alpha_2 \int_0^{T_f} (du/dt)^2 dt \qquad \text{(OP)}$$

The coefficients of the linear combination will depend on the importance (weight) given for each of the terms. Note that in equation (OP), u(t) is the optimizing variable which is the continuous notch position. If discrete notch is required, e.g. for older locomotives, the solution to equation (OP) would be discretized, which may result in less fuel saving. Finding a minimum time solution (α_1 and α_2 set to zero) is used to

find a lower bound on, the preferred embodiment is to solve the equation (OP) for various values of T_f with α_3 set to zero. For those familiar with solutions to such optimal problems, it may be necessary to adjoin constraints, e.g. the speed limits along the path :

$$0 \leq v \leq SL(x)$$

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:

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

Where 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 present invention.

Reference to emissions in the context of the present invention is actually directed towards cumulative emissions produced in the form of oxides of nitrogen (NOx), unburned hydrocarbons, and particulates. By design, every locomotive must be compliant to EPA standards for brake-specific emissions, and thus when emissions are optimized in the present invention this would be mission total emissions on which there is no specification today. At all times, operations would be compliant with federal EPA mandates. If a key 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.

To solve the resulting optimization problem, in an exemplary embodiment the present invention transcribes a dynamic optimal control problem in the time domain 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 in an exemplary embodiment, suppose a train is traveling a 172-mile stretch of track in the southwest United States. Utilizing the present invention, an exemplary 7.6% saving in fuel used may be realized when comparing a trip determined and followed using the present invention versus an actual driver throttle/speed history where the trip was determined by an operator. The improved savings is realized because the optimization realized by using the present invention produces a driving strategy with both less drag loss and little or no braking loss compared to the trip plan of the operator.

To make the optimization described above computationally tractable, a simplified model of the train may be employed, such as illustrated in FIG. 2 and the equations discussed above. A key 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, leading 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 thermal and electrical limits on the locomotive and inter-car forces in the train.

Referring back to FIG. 1, once the trip is started 12, power commands are generated 14 to put the plan in motion. Depending on the operational set-up of the present invention, one command is for the locomotive to follow the optimized power command 16 so as to achieve the optimal speed. The present invention obtains actual speed and power information from the locomotive consist of the train 18. 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.

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 fail 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.

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. More 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 failure 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.

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. The present invention 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. 4 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. 4 from many locomotives could use that information to better coordinate overall train movements to achieve a system-wide advantage in fuel use or throughput.

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 when a train is not on schedule for 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 following a railroad company's desire for how such departures from plan should be handled or manually propose alternatives for the on-board operator and dispatcher to jointly decide the best way to get back on plan. Whenever a plan is updated but 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.

A re-plan 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 a 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 present invention can re-plan the trip to accommodate the delay at expense of increased fuel as described above or to alert the operator and dispatcher how much of the time can be made up at all (i.e. 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 failure and/or equipment temporary malfunction (such as operating too hot or too cold), and/or detection of gross setup errors, such 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.

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 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 present invention wherein the present invention will recalculate the train's trip plan. The present invention 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 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 depend either from schedule or fuel saving benefits, depending on the situation.

For any of the manually or automatically initiated re-plans, the present invention may present more than one trip plan to the operator. In an exemplary embodiment the present invention will present 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.

The present invention has the ability of learning and adapting to key changes in the train and power consist which can be incorporated either in the current plan and/or for 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.

FIG. 3 depicts an exemplary embodiment of elements of the present 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 determine a location of the train 31. Examples of such other systems may 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. Information about travel locations may also be transferred from other trains.

A track characterization element 33 to provide 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 consist 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 by other approaches 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.

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 radio frequency automatic equipment identification (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 present invention 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.

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 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.

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. The present invention 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, track maintenance, etc., 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 present invention may also consider weighting/penalty as a function of time/distance into the future and/or based on known/past experience. Those skilled in the art will readily recognize that such planning and re-planning to take into consideration weather conditions, track conditions, other trains on the track, etc., may be taking into consideration at any time during the trip wherein the trip plan is adjust accordingly.

FIG. 3 further discloses other elements that may be part of the present invention. A processor 44 is provided that is operable to receive information from the locator

element 30, track characterizing element 33, and sensors 38. An algorithm 46 operates within the processor 44. The algorithm 46 is used to compute an optimized trip plan based on parameters involving the locomotive 42, train 31, track 34, and objectives of the mission as described above. 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 algorithm 46 has access to the information from the locator element 30, track characterizing element 33 and/or sensors 38 to create a trip plan minimizing fuel consumption of a locomotive consist 42, minimizing emissions of a locomotive consist 42, establishing a desired trip time, and/or ensuring proper crew operating time aboard the locomotive consist 42. In an exemplary embodiment, a driver, or controller element, 51 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 operating decisions autonomously. In another exemplary embodiment the operator may be involved with directing the train to follow the trip plan.

A requirement of the present invention 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 where the algorithms may be connected together. The waypoint 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 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.

In an exemplary embodiment, the present invention 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 Figure 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 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 3 segment trip is disclosed in FIG. 6 and discussed below. Those skilled in the art will recognize however, through segments are discussed, the trip plan may comprise a single segment representing the complete trip.

FIG. 4 depicts an exemplary embodiment of a fuel-use/travel time curve. 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

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.

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 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 one exemplary embodiment, a coaching mode the present invention displays information 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 is suggested operating conditions that the operator should use. In another exemplary embodiment, acceleration and maintaining a constant speed are performed by the present invention. However, when the train 31 must be slowed, the operator is responsible for applying a braking system 52. In another exemplary embodiment, the present invention commands power and braking as required to follow the desired speed-distance path.

Feedback control strategies are used to provide corrections to the power control sequence in the profile to correct for such events 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 to assure 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.

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The present invention allows 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.

As discussed herein, the present invention may employ a setup as illustrated in the exemplary flow chart depicted in FIG. 5, and as an exemplary 3 segment example depicted in detail in FIGS. 6. As illustrated, the trip may be broken into two or more segments, T1, T2, and T3. Though as discussed herein, 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 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 for an exemplary 3 segment 200 mile trip 97. Further illustrated are grade changes over the 200 mile trip 98. A combined chart 99 illustrating curves for each segment of the trip of fuel used over the travel time is also shown.

Using the optimal control setup described previously, the present 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.

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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.

The present invention finds a fuel-optimal trip from distance D_0 to D_M, traveled in time T, with M-1 intermediate stops at $D_1,\ldots,D_{M-1}$, and with the arrival and departure times at these stops constrained by

$$t_{\min}(i) \le t_{arr}(D_i) \le t_{\max}(i) - \Delta t_i$$
$$t_{arr}(D_i) + \Delta t_i \le t_{dep}(D_i) \le t_{\max}(i) \quad i = 1,\ldots,M-1$$

where $t_{arr}(D_i)$, $t_{dep}(D_i)$, and Δt_i are the arrival, departure, and minimum stop time at the i^{th} stop, respectively. Assuming that fuel-optimality implies minimizing stop time, therefore $t_{dep}(D_i) = t_{arr}(D_i) + \Delta t_i$ which eliminates the second inequality above.

Suppose for each i=1,…,M, the fuel-optimal trip from D_{i-1} to D_i for travel time t, $T_{\min}(i) \le t \le T_{\max}(i)$, is known. Let $F_i(t)$ be the fuel-use corresponding to this trip. If the travel time from D_{j-1} to D_j is denoted T_j, then the arrival time at D_i is given by

$$t_{arr}(D_i) = \sum_{j=1}^{i} (T_j + \Delta t_{j-1})$$

where Δt_0 is defined to be zero. The fuel-optimal trip from D_0 to D_M for travel time T is then obtained by finding T_i, i=1,…,M, which minimize

$$\sum_{i=1}^{M} F_i(T_i) \quad T_{\min}(i) \le T_i \le T_{\max}(i)$$

subject to

$$t_{\min}(i) \le \sum_{j=1}^{i} (T_j + \Delta t_{j-1}) \le t_{\max}(i) - \Delta t_i \quad i = 1,\ldots,M-1$$

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$$\sum_{j=1}^{M}(T_j + \Delta t_{j-1}) = T$$

Once a trip is underway, the issue is re-determining the fuel-optimal solution for the remainder of a trip (originally from D_0 to D_M 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 $D_{i-1} < x \le D_i$. Also, let the current time since the beginning of the trip be t_{act}. Then the fuel-optimal solution for the remainder of the trip from x to D_M, which retains the original arrival time at D_M, is obtained by finding $\tilde{T}_i, T_j, j = i+1,...M$, which minimize

$$\tilde{F}_i(\tilde{T}_i, x, v) + \sum_{j=i+1}^{M} F_j(T_j)$$

subject to

$$t_{\min}(i) \le t_{act} + \tilde{T}_i \le t_{\max}(i) - \Delta t_i$$

$$t_{\min}(k) \le t_{act} + \tilde{T}_i + \sum_{j=i+1}^{k}(T_j + \Delta t_{j-1}) \le t_{\max}(k) - \Delta t_k \quad k = i+1,...,M-1$$

$$t_{act} + \tilde{T}_i + \sum_{j=i+1}^{M}(T_j + \Delta t_{j-1}) = T$$

Here, $\tilde{F}_i(t, x, v)$ is the fuel-used of the optimal trip from x to D_i, traveled in time t, with initial speed at x of v.

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_{i-1} to D_i, with travel time T_i, choose a set of intermediate points $D_{ij}, j = 1,..., N_i$ -1. Let $D_{i0} = D_{i-1}$ and $D_{iN_i} = D_i$. Then express the fuel-use for the optimal trip from D_{i-1} to D_i as

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$$F_i(t) = \sum_{j=1}^{N_i} f_{ij}(t_{ij} - t_{i,j-1}, v_{i,j-1}, v_{ij})$$

where $f_{ij}(t, v_{i,j-1}, v_{ij})$ is the fuel-use for the optimal trip from $D_{i,j-1}$ to D_{ij}, traveled in time t, with initial and final speeds of $v_{i,j-1}$ and v_{ij}. Furthermore, t_{ij} is the time in the optimal trip corresponding to distance D_{ij}. By definition, $t_{iN_i} - t_{i0} = T_i$. Since the train is stopped at D_{i0} and D_{iN_i}, $v_{i0} = v_{iN_i} = 0$.

The above expression enables the function $F_i(t)$ to be alternatively determined by first determining the functions $f_{ij}(\cdot), 1 \le j \le N_i$, then finding $\tau_{ij}, 1 \le j \le N_i$ and $v_{ij}, 1 \le j < N_i$, which minimize

$$F_i(t) = \sum_{j=1}^{N_i} f_{ij}(\tau_{ij}, v_{i,j-1}, v_{ij})$$

subject to

$$\sum_{j=1}^{N_i} \tau_{ij} = T_i$$

$$v_{\min}(i,j) \le v_{ij} \le v_{\max}(i,j) \quad j = 1,\ldots,N_i - 1$$

$$v_{i0} = v_{iN_i} = 0$$

By choosing D_{ij} (e.g., at speed restrictions or meeting points), $v_{\max}(i,j) - v_{\min}(i,j)$ can be minimized, thus minimizing the domain over which $f_{ij}()$ needs to be known.

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 $D_{ij}, 1 \le i \le M, 1 \le j \le N_i$. At point D_{ij}, the new optimal trip from D_{ij} to D_M can be determined by finding $\tau_{ik}, j < k \le N_i, v_{ik}, j < k < N_i$, and $\tau_{mn}, i < m \le M, 1 \le n \le N_m, v_{mn}, i < m \le M, 1 \le n < N_m$, which minimize

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$$\sum_{k=j+1}^{N_i} f_{ik}(\tau_{ik}, v_{i,k-1}, v_{ik}) + \sum_{m=i+1}^{M} \sum_{n=1}^{N_m} f_{mn}(\tau_{mn}, v_{m,n-1}, v_{mn})$$

subject to

$$t_{\min}(i) \le t_{act} + \sum_{k=j+1}^{N_i} \tau_{ik} \le t_{\max}(i) - \Delta t_i$$

$$t_{\min}(n) \le t_{act} + \sum_{k=j+1}^{N_i} \tau_{ik} + \sum_{m=i+1}^{n} (T_m + \Delta t_{m-1}) \le t_{\max}(n) - \Delta t_n \quad n = i+1,\ldots,M-1$$

$$t_{act} + \sum_{k=j+1}^{N_i} \tau_{ik} + \sum_{m=i+1}^{M} (T_m + \Delta t_{m-1}) = T$$

where

$$T_m = \sum_{n=1}^{N_m} \tau_{mn}$$

A further simplification is obtained by waiting on the re-computation of $T_m, i < m \le M$, until distance point D_i is reached. In this way, at points D_{ij} between D_{i-1} and D_i, the minimization above needs only be performed over $\tau_{ik}, j < k \le N_i, v_{ik}, j < k < N_i$. T_i is increased as needed to accommodate any longer actual travel time from D_{i-1} to D_{ij} than planned. This increase is later compensated, if possible, by the re-computation of $T_m, i < m \le M$, at distance point D_i.

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.

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.

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. The present invention accomplishes 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.

The smart cruise control algorithm has three principal components, specifically a modified speed limit profile that serves as an energy-efficient 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

the present invention that do no active braking (i.e. the driver is signaled and assumed to provide the requisite braking) or a variant that does active braking.

With respect to the cruise control algorithm that does not control dynamic braking, the three 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.

Also included in the present invention 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.

FIG. 7 depicts an exemplary flow chart of the present invention. As discussed previously, a remote facility, such as a dispatch 60 can provide information to the present invention. As illustrated, such information is provided to an executive control element 62. Also supplied to the executive control element 62 is locomotive modeling information database 63, information from a track database 36 such as, but not limited to, track grade information and speed limit information, 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 planner 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 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.

As discussed above, the driving advisor 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 locomotive 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 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 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 horse-power and known fuel characteristics to derive the cumulative fuel used.

The train 31 also has a locator device 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.

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.

The present invention 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 present invention may incorporate train-handling rules, such as, but not limited to, tractive effort ramp rates, maximum braking effort ramp rates. These may 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.

In a preferred embodiment the present invention is only installed on a lead locomotive of the train consist. Even though the present invention is 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 Patent Application No. 10/429,596 (owned by the Assignee and both incorporated by reference), functionality 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.

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, on-board operating rules, location determination system, real-time closed loop power/brake control, and sensor feedback, the system shall automatically operate the distributed power system in "independent" mode.

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 other could be in braking) wherein each individual locomotive in the locomotive consist operates at the same notch power. In an exemplary embodiment, with the present invention installed on the train, preferably 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 present invention will communicate this power setting to the remote locomotive consists for implementation. As discussed below, the same is true regarding braking.

The present invention may be used with consists in which the locomotives are not contiguous, e.g., with 1 or more locomotives up front, others in the middle and 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.

In an exemplary embodiment, with the present invention installed on the train, preferably 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 present invention 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 the present invention may include the use of multiple throttle controls to better manage in-train forces as well as fuel consumption and emissions.

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 present invention may be utilized in conjunction with the consist manager to command notch power settings for the locomotives in the consist. Thus based on the present invention, since the consist manager divides a locomotive consist into two groups, 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.

Likewise, when a consist optimizer is used with a locomotive consist, the present invention 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.

Furthermore, as discussed previously, 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.

FIGS. 8, 9 and 10 depict exemplary illustrations of dynamic displays for use by the operator. As provided, FIG. 8, a trip profile is provided 72. 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. 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 estimate 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 exemplary 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.

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 present invention.

FIG. 10 depicts another exemplary embodiment of the display. Data typical of a modern locomotive including air-brake status 72, analog speedometer with digital inset 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, 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.

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 either follow the notch or speed suggested by 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 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.

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. A distance traveled so far in the plan 90, cumulative fuel used 92, where or the distance away the next stop is planned 94, current and projected arrival time 96 expected time to be at next stop are also disclosed. 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).

At all times these displays 68 gives the operator a snapshot of where he 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.

Other features that may be included in the present invention include, but are not limited to, allowing for the generating 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 such information as, but not limited to, operator inputs, time system is operational, fuel saved, fuel imbalance across locomotives in the train, train journey off course, system diagnostic issues such as if GPS sensor is malfunctioning.

Since trip plans must also take into consideration allowable crew operation time, 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 shall be 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, etc. If, as the trip progresses, the trip time may be exceeded, the present invention may be overridden by the operator to meet criteria as determined by the operator. Ultimately, regardless of the operating conditions of the train, such as but not limited to high load, low speed, train stretch conditions, etc., the operator remains in control to command a speed and/or operating condition of the train.

Using the present invention, the train may operate in a plurality of operations. In one operational concept, the present invention may provide commands for commanding propulsion, dynamic braking. The operator then handles all other train functions. In another operational concept, the present invention may provide commands for commanding propulsion only. The operator then handles dynamic braking and all other train functions. In yet another operational concept, the present invention may provide commands for commanding propulsion, dynamic braking and application of the airbrake. The operator then handles all other train functions.

The present invention may also be used by notify the operator of upcoming items of interest of actions to be taken. Specifically, the forecasting logic of the present invention, the continuous corrections and re-planning to the optimized trip plan, 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.

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 shall present and/or notify the operator of required actions. The notification can be visual and/or audible. Examples include notifying of crossings that require the operator activate the locomotive horn and/or bell, notifying of "silent" crossings that do not require the operator activate the locomotive horn or bell.

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 present invention may present the operator 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 shall allow the operator to adjust the trip plan (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).

Based on the information provided above, exemplary embodiments of the invention may be used to determine a location of the train 31 on a track, step 18. A determination of the track characteristic may also be accomplished, such as by using the train parameter estimator 65. A trip plan may be created based on the location of the train, the characteristic of the track, and an operating condition of at least one locomotive of the train. Furthermore, an optimal power requirement may be communicated to train wherein the train operator may be directed to a locomotive, locomotive consist and/or train in accordance with the optimal power, such as through the wireless communication system 47. In another example instead of directing the train operator, the train 31, locomotive consist 18, and/or locomotive may be automatically operated based on the optimal power setting.

Additionally a method may also involve determining a power setting, or power commands 14, for the locomotive consist 18 based on the trip plan. The locomotive consist 18 is then operated at the power setting. Operating parameters of the train and/or locomotive consist may be collected, such as but not limited to actual speed of the train, actual power setting of the locomotive consist, and a location of the train. At least one of these parameters can be compared to the power setting the locomotive consist is commanded to operated at.

In another embodiment, a method may involve determining operational parameters 62 of the train and/or locomotive consist. A desired operational parameter is determined based on determined operational parameters. The determined parameter is compared to the operational parameter. If a difference is detected, the trip plan is adjusted, step 24.

Another embodiment may entail a method where a location of the train 31 on the track 34 is determined. A characteristic of the track 34 is also determined. A trip plan, or drive plan, is developed, or generated in order to minimize fuel consumption. The trip plan may be generated based on the location of the train, the characteristic of the track, and/or the operating condition of the locomotive consist 18 and/or train 31. In a similar method, once a location of the train is determined on the track and a characteristic of the track is known, propulsion control and/or notch commands are provided to minimize fuel consumption.

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WHAT IS CLAIMED IS:

1. A system for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the system comprising:

a) a locator element to determine a location of the train;

b) a track characterization element to provide information about a track;

c) a processor operable to receive information from the locator element, and the track characterizing element; and

d) an algorithm embodied within the processor having access to the information to create a trip plan that optimizes performance of the locomotive consist in accordance with one or more operational criteria for the train.

2. The system of claim 1 further comprises a sensor for measuring an operating condition of the locomotive consist.

3. The system of claim 2 wherein the processor is operable to receive information from the sensor.

4. The system of claim 1 further comprises a controller element for autonomously directing the train to follow the trip plan.

5. The system of claim 1 wherein an operator directs the train to follow the trip plan.

6. The system of claim 1 wherein the algorithm autonomously updates the trip plan as the train progresses on a trip.

7. The system of claim 1 wherein the track characterization element comprises information about at least one of a change in speed restriction along a track, the change in track grade, the change in track curvature, and a change in a traffic pattern on a track.

8. The system of claim 1 wherein the track characterization element further comprises an on-board track database.

9. The system of claim 1 further comprises a user interface element connected to the processor.

10. The system of claim 9 wherein the user interface element allows a user to at least one of monitor the trip as the locomotive consist progresses through the trip, modify the trip plan, and receive notification of at least one of an upcoming item of interest and an action to take.

11. The system of claim 9 wherein the user interface element displays at least one of fuel already used during the trip and future anticipated fuel use during the trip, and locomotive performance data.

12. The system of claim 9 wherein the user interface element is operable to allow the user to enter train operating limits.

13. The system of claim 1 wherein the algorithm updates the trip plan based on operating limits entered by the user.

14. The system of claim 1 wherein a locomotive consist power setting is continuous wherein it is established based on requirements derived from the trip plan rather than discrete pre-defined notch settings.

15. The system of claim 1 further comprises an input device in communication with the processor for transferring information to the processor.

16. The system of claim 15 wherein the input device comprises information provided by at least one of a remote location, a roadside device, and a user.

17. The system of claim 1 wherein the locator element comprises at least one of a GPS locator sensor, tachometer, wayside devices, video determination, and a user entering location information.

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18. The system of claim 1 wherein the information provided shall be used adjust at least one of a power setting of a locomotive and a speed of the train.

19. The system of claim 1 wherein the information includes forecasted performance operable with the on-board track database for adjusting an operating condition of the locomotive consist.

20. The system of claim 1 further comprising an external communication system for communicate between at least one of remote wayside devices and another train.

21. The system of claim 20 wherein the external communication system is used to optimize trip plans when a train has to perform at least one of a meet and a pass with another train.

22. The system of claim 1 wherein the system is located on a first locomotive in the locomotive consist.

23. The system of claim 1 further comprises a consist manager system in communication with the processor so as to command notch power settings for all trail locomotives in a locomotive consist unique from a first locomotive in the locomotive consist to optimize the trip plan.

24. The system of claim 1 further comprises a consist optimizer system in communication with the processor so as to command a notch power setting for each locomotive in the locomotive consist wherein the notch power setting for each locomotive may be different from the other notch power settings of the other locomotives in the locomotive consist so as to allow the locomotive consist to function within the boundaries of the optimized the trip plan.

25. The system of claim 1 wherein trip optimization is further realized by direct communication between each locomotive in the locomotive consist by way of a train communication system.

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26. The system of claim 1 further comprises a distribute power system in communication with the processor so as to command notch power settings for a remote locomotive consist.

27. The system of claim 1 further comprises a database in communication with the processor having at least one of information about the train, optimization about the train from at least prior trip plans and the current trip plan, and locomotive modeling information.

28. The system of claim 17 wherein when an external gathering device is not in electronic communication with the train, the user inputs information based on information received from the external gathering device.

29. The system of claim 28 wherein the external gathering devices comprises at least one of a wayside device and a track-signaling device.

30. The system according to claim 1 further comprises a second algorithm for updating the trip plan based on a predetermined plan parameter.

31. The system according to 30 wherein predetermined plan parameters comprise at least one of condition of track, a request by dispatch, change in condition of locomotive, track speed limits, and operator input.

32. The system according to claim 1, further comprises an arrival time management element.

33. The system according to claim 32, wherein the arrival time management element allows for time to be compared to a trip objective being optimized.

34. The system according to claim 1, further comprising a communication element for communicating information related to at least one of the trip plan and updated trip plan to an operator.

35. The system according to claim 34, wherein at least one of consist data, event data, situation data, action keys, locomotive consist operating conditions, train operating conditions, time management data, information indicating a deviation from

the trip plan, indicia regarding a re-planned trip plan, performance of at least one of the locomotive consist and the train versus the trip plan, and indicia representative of an optimal operating speed for at least one of a locomotive consist and the train is communicated to the operator with the communication element.

36. The system according to claim 1, further comprises a database for logging performance of the locomotive versus the trip plan.

37. The system according to claim 1, wherein the trip plan is used to coach an operator of the locomotive.

38. The system according to claim 1, wherein an optimal power requirement is communicated to at least one of the locomotive consist, train, and operator so as to operate at least one of a locomotive, a locomotive consist, and the train in accordance with the optimal power.

39. The system according to claim 1, wherein an optimal power requirement is communicated to at least one of the locomotive consist, train, and operator so as to direct an operator to operate at least one of the locomotive, locomotive consist and the train in accordance with the optimal power.

40. The system according to claim 1, wherein an optimal power requirement is communicated so as to automatically operate at least one of a locomotive, locomotive consist and train in accordance with the optimal throttle setting.

41. The system according to claim 1, wherein an optimal notch setting is displayed so as to operate at least one of a locomotive, locomotive consist, and train in accordance with the optimal notch setting.

42. A method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the method comprising:

a) determining a location of the train on a track;

b) determining a characteristic of the track;

c) creating a trip plan based on the location of the train, the characteristic of the track, and the operating condition of the locomotive consist in accordance with at least one operational criteria for the train.

43. The method of claim 42 further comprises determining at least one operating condition of the locomotive consist.

44. The method of claim 42 further comprises revising the trip plan based on new information received during the trip.

45. The method of claim 42 further comprising manually limiting a speed of the train.

46. The method of claim 42 wherein the method for determining a driving strategy is performed autonomously.

47. The method of claim 42 wherein creating a trip plan further comprises creating a trip plan wherein the trip plan is separated into and determined based on multiple segments of the trip.

48. The method of claim 44 further comprises comparing the trip plan to current operational information as the train during the trip and adjusting the trip plan based on new information received while during the trip.

49. The method of claim 47 wherein creating a trip plan further comprises creating a trip plan by combining trip plan optimization of each trip segment.

50. The method of claim 48 wherein creating the trip plan and revising the trip plan further comprises at least one of considering environmental conditions, locomotive consist health, and constraints on train handling.

51. The method of claim 48 further comprises setting a continuous power level determined by at least one of the trip plan and the revised trip plan wherein the power level is not limited by a discrete pre-defined notch setting.

52. The method of claim 47 wherein a comparison of fuel use versus time is created for each trip segment.

53. The method of claim 52 wherein travel time for a trip is allocated over collective segments based on the fuel use versus time determined for each trip segment so that a total travel time realizes a minimized use of at least one of fuel and emissions.

54. The method of claim 42 wherein operating a train further comprises optimizing at least one of fuel use of the locomotive consist, emissions of the locomotive consist, a train travel schedule, a user aboard the train operating time, and load impact.

55. The method of claim 54 wherein optimizing at least one of fuel use of the locomotive consist, emissions of the locomotive consist, a train travel schedule, a user aboard the train operating time, and load impact further comprises considering at least one of the capability and the configuration of the locomotive consist, and health of a locomotive in the locomotive consist.

56. The method of claim 54 further comprises minimizing at least one of auxiliary loads and power transmission losses to further optimize at least one of fuel use of the locomotive consist, emissions of the locomotive consist, a train travel schedule, a user aboard the train operating time, and load impact.

57. The method of claim 56 wherein minimizing at least one of auxiliary loads and power transmission losses comprises utilizing an on-board track database in communication with a forecasted performance requirements assist in minimizing.

58. The method of claim 42 further comprises creating data reports based on at least one of determining a location of the train on a track, determining a characteristic of the track, determining at least one operating condition of the locomotive consist, and creating a trip plan.

59. The method of claim 42 further comprises implementing train handling rules to at least one of determine an optimum trip plan and to control a power setting of the locomotive consist to achieve a target speed.

60. The method of claim 42 further comprises wherein when a plurality of locomotives comprise at least one locomotive consist, determining a power setting for each locomotive in the locomotive consist to optimize the train speed based on the trip plan and the location of the train.

61. The method of claim 42 wherein a plurality of trip plans are provided for a user to determine a trip plan to execute.

62. The method of claim 42 wherein the user may decide when to control at least one of a propulsion system and braking system of the train.

63. The method of claim 42 further comprises including a slack time period within an optimized trip plan based on at least one of a confidence and probability of occurrence of an unplanned delay in the trip plan.

64. The method of claim 42 further comprises monitoring efficiency of the train and updating the trip plan based on the actual efficiency measured.

65. The method of claim 42 further comprises wherein when a plurality of locomotives comprise at least one locomotive consist, determining a first power setting for a first locomotive in the locomotive consist and a second power setting for trail locomotives in the locomotive consist to optimize the train speed based on the trip plan and the location of the train.

66. The method according to claim 42 further comprises the step of updating the trip plan based on a predetermined plan parameter.

67. The method according to claim 66 wherein predetermined plan parameters comprise at least one of condition of track, a request by dispatch, change in condition of locomotive, track speed limits, and operator input.

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68. The method according to claim 42, wherein the step of creating the trip plan comprises the step of arrival time management.

69. The method according to claim 66, wherein the step of updating the trip plan comprises the step of arrival time management.

70. The method according to claim 42, further comprising the step of communicating information related to the trip plan or updated trip plan to an operator.

71. The method according to claim 70, further comprising the step of displaying consist data.

72. The method according to claim 70, further comprising the step of displaying event and situation data.

73. The method according to claim 70, further comprising the step of displaying arrival time management data.

74. The method according to claim 70, further comprising the step of displaying action keys.

75. The method according to claim 70, further comprising the step of displaying indicia representative of at least one of a locomotive consist and a train operating conditions.

76. The method according to claim 70, further comprising the step of displaying indicia representative of an optimal operating speed for at least one of a locomotive consist and the train.

77. The method according to claim 70, further comprising displaying information indicating a deviation from the trip plan.

78. The method according to claim 70, further comprising displaying information indicating re-plan information.

79. The method according to claim 42, further comprising the step of reporting performance of the locomotive versus the trip plan.

80. The method according to claim 42, further comprising the step of logging performance of the locomotive versus the trip plan.

81. The method according to claim 42, further comprising the step of using the trip plan to coach an operator of the locomotive.

82. The method according to claim 42, further comprising the steps of :

a) communicating an optimal power requirement; and

b) operating at least one of a locomotive, a locomotive consist, and the train in accordance with the optimal power.

83. The method according to claim 42, further comprising the steps of:

a) communicating an optimal power requirement; and

b) directing an operator to operate at least one of the locomotive, locomotive consist and the train in accordance with the optimal power.

84. The method according to claim 42, further comprising the steps of:

a) communicating an optimal throttle setting; and

b) automatically operating at least one of a locomotive, locomotive consist, and train in accordance with the optimal throttle setting.

85. The method according to claim 42, further comprising the steps of:

a) displaying an optimal notch setting; and

b) operating at least one of a locomotive, locomotive consist, and train in accordance with the optimal notch setting.

86. A computer software code for operating a train having a computer processor and one or more locomotive consists with each locomotive consist comprising one or more locomotives,, the computer software code comprising a software module for creating a trip plan based on the location of the train, the characteristic of the track, and the operating condition of the locomotive consist in accordance with at least one operational criteria for the train.

87. The computer software code of claim 86 further comprises a computer module for the computer for revising the trip plan based on new information received while the train is on the trip.

88. The computer software code of claim 86 further comprises creating a trip plan wherein the trip plan is separated into and determined based on multiple segments of a trip.

89. The computer software code of claim 88 further comprises a computer module for the computer for comparing the trip plan to current information regarding at least one of information regarding a load being hauled by the locomotive consist, throttle setting of the locomotive consist, locomotive consist configuration information, and speed of the locomotive consist as the train is on the trip and adjusting the trip plan based on the new information gathered.

90. The computer software code of claim 88 wherein creating a trip plan further comprises a computer module for the computer for creating a trip plan by combining trip plan optimization of each trip segment.

91. The computer software code of claim 89 wherein creating the trip plan and revising the trip plan further comprises a computer software module for a computer for at least one of considering environmental conditions, locomotive consist health, and constraints on train handling.

92. The computer software code of claim 88 further comprises a software module for the computer for setting a continuous power level determined by at least one of the

trip plan and a revised trip plan wherein the power level is not limited by a discrete pre-defined notch setting.

93. The computer software code of claim 88 wherein a comparison of fuel use versus time is created for each trip segment.

94. The computer software code of claim 93 wherein travel time for a trip is allocated over collective segments based on the fuel use versus time determined for each trip segment so that a total travel time realizes a minimized use of at least one of fuel and emissions.

95. The computer software code of claim 88 wherein the new information is provided by a user.

96. The computer software code of claim 95 wherein the new information comprises at least one of a not to exceed power setting, a location of the train, health status of a locomotive.

97. The computer software code of claim 86 further comprises a computer software code for controlling at least one of a propulsion system of the locomotive consist and a braking system of the locomotive consist.

98. The computer software code of claim 97 wherein the user controls the braking system of the locomotive consist while the computer software code controls the propulsion system.

99. The computer software code of claim 86 further comprises a computer software code for determining a power setting for each locomotive in the locomotive consist to optimize the train speed based on the trip plan and the location of the train when a plurality of locomotives comprise at least one locomotive consist.

100. The computer software code of claim 86 further comprises a computer software code for determining a first power setting for a first locomotive in the locomotive consist and a second power setting for trail locomotives in the locomotive

consist to optimize the train speed based on the trip plan and the location of the train when a plurality of locomotives comprise at least one locomotive consist.

101. A method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train, the method comprising:

determining a power setting for the locomotive consist based on the trip plan;

operating the locomotive consist at the power setting;

collecting at least one of actual speed of the train, actual power setting of the locomotive consist, and a location of the train; and

comparing at least one of actual speed of the train, actual power setting of the locomotive consist, and a location of the train to the power setting.

102. The method of claim 101 further comprises adjusting the power setting based on at least one of actual speed of the train, actual power setting of the locomotive consist, and a location of the train to the power setting.

103. A method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train based on assumed operating parameters for at least one of the train and the locomotive consist, the method comprising:

estimating at least one of train operating parameters and

locomotive operating parameters; and

comparing at least one of the estimated train operating parameters and the locomotive consist operating parameters to at least one of the assumed train operating parameters and the locomotive consist operating parameters.

104. The method of claim 103 further comprises creating a new trip plan if a difference between the estimated parameters and the assumed parameters is detected.

105. The method of claim 103 further comprises adjusting an expected arrival time to a location when a difference between the estimated parameters and the assumed parameters is detected.

106. The method of claim 103 wherein the steps of estimating and comparing are accomplished at least at a fixed period, when an error is detected and when a user desires.

107. The method of claim 103 wherein the steps of estimating and comparing are performed at least one of on board the train and at an off-board location.

108. The method of claim 103 wherein the steps of estimating and comparing occurs at least one of manually, autonomously, after receiving new information, entry of a user limitation, loss of horsepower, locomotive load has changed, and after an error is detected.

109. A method for operating a train having one or more locomotive consists with each locomotive consist comprising one or more locomotives where a trip plan has been devised for the train based on a desired parameter, the method comprising:

determining operational parameters of at least one of the train and the locomotive consist;

determining a desired parameter based on determined operational parameters;

comparing the determined parameter to the operational parameters; and

if a difference exists from comparing the determined parameter to the operational parameters, adjusting the trip plan.

110. The method of claim 109 wherein the desired parameter comprises at least one of an arrival time, fuel consumed, and emissions.

111. The method of claim 109 further wherein determining the arrival time further comprises determining a current location of the locomotive consist and determining the arrival time based on the current location as contained in a track database.

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112. The method of claim 109 wherein determining an arrival time further comprises determining the arrival time including time required for a tunnel purge signal to signify entering a tunnel is allowed when a trip plan requires the train to enter a tunnel.

113. A method for operating a rail system having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the method comprising:

a) determining a location of the train on a track;

b) determining a characteristic of the track ; and

c) generating a driving plan for at least one of the locomotives based on at least one of the locations of the rail system, the characteristic of the track, and the operating condition of the locomotive consist, in order to minimize fuel consumption by the rail system.

114. The method of claim 113 further comprises determining at least one operating condition of the locomotive consist.

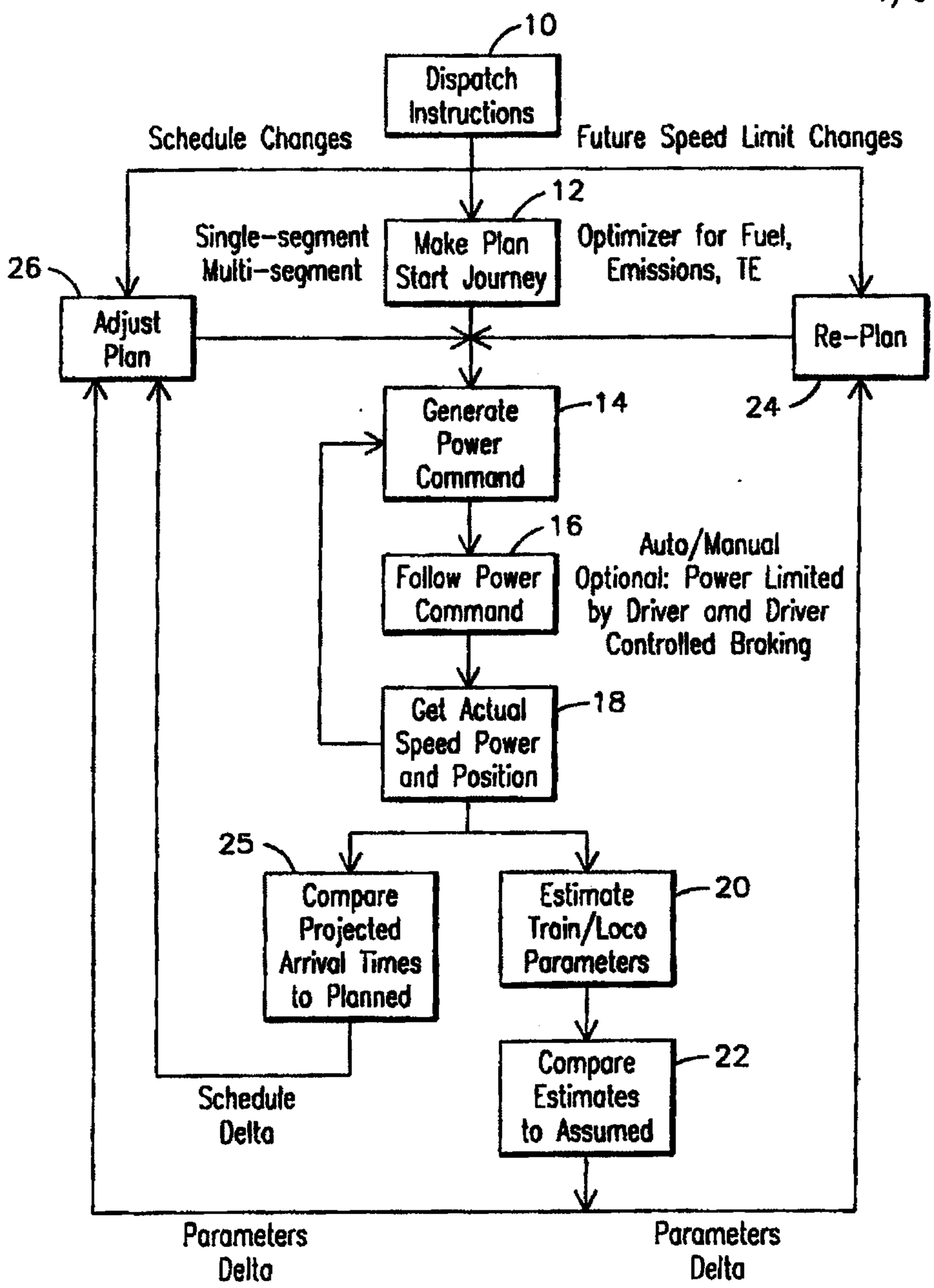
115. A method for operating a rail system having one or more locomotive consists with each locomotive consist comprising one or more locomotives, the method comprising:

a) determining a location of the train on a track;

b) determining a characteristic of the track; and

c) providing propulsion control for the locomotive consist in order to minimize fuel consumption by the rail system.

116. The method of claim 115 further comprises determining at least one operating condition of the locomotive consist.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Future Speed Limit Changes
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Multi-segment
Make Plan Start Journey
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Adjust Plan
Re-Plan
24
Generate Power Command
14
16
Follow Power Command
Auto/Manual
Optional: Power Limited by Driver and Driver Controlled Braking
Get Actual Speed Power and Position
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25
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Estimate Train/Loco Parameters
20
Compare Estimates to Assumed
22
Schedule Delta
Parameters Delta
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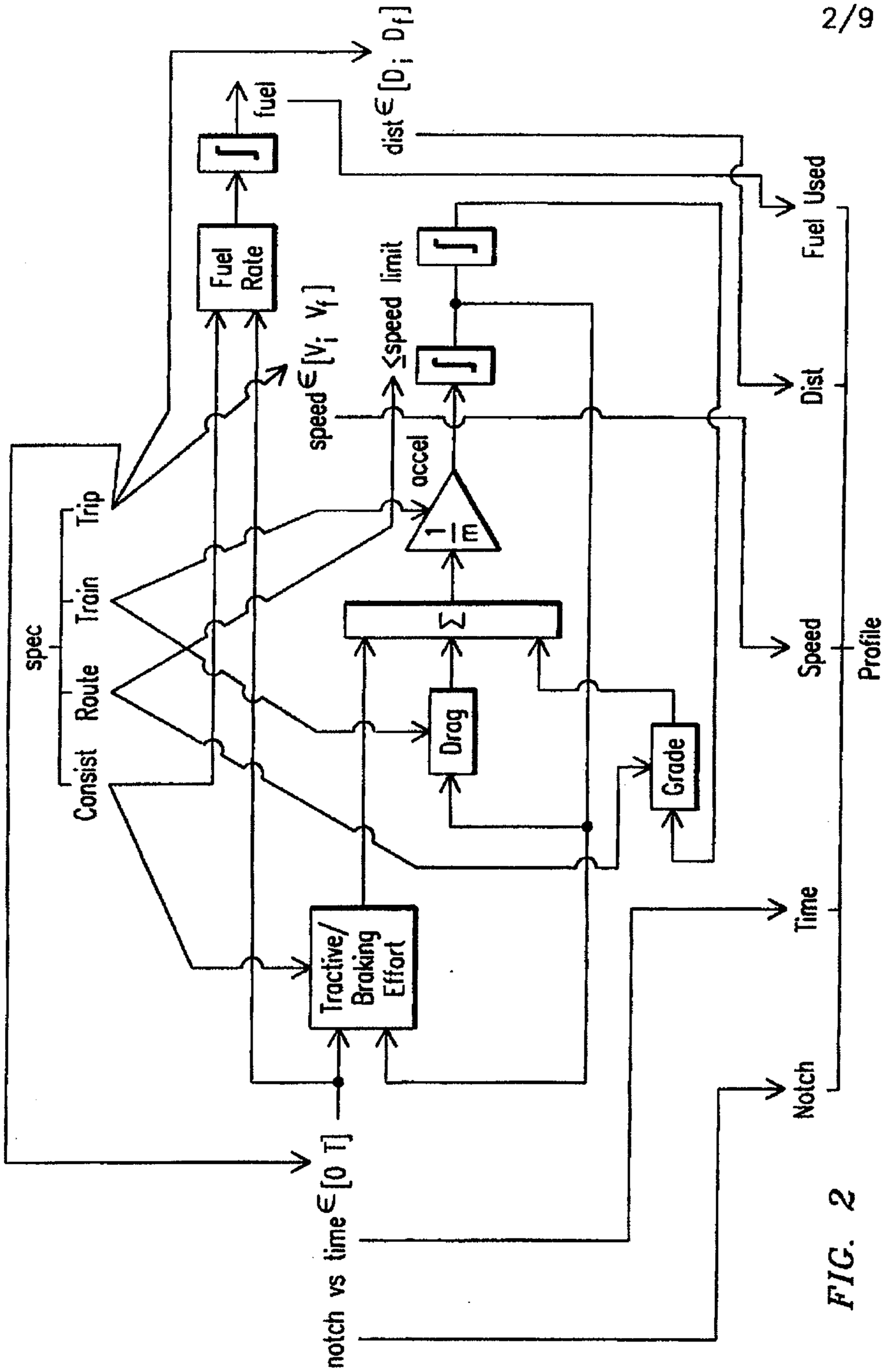
FIG. 1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accel
1/m
Σ
Drag
Grade
Tractive/
Braking
Effort
Fuel Used
Dist
Speed
Profile
Time
Notch

FIG. 2

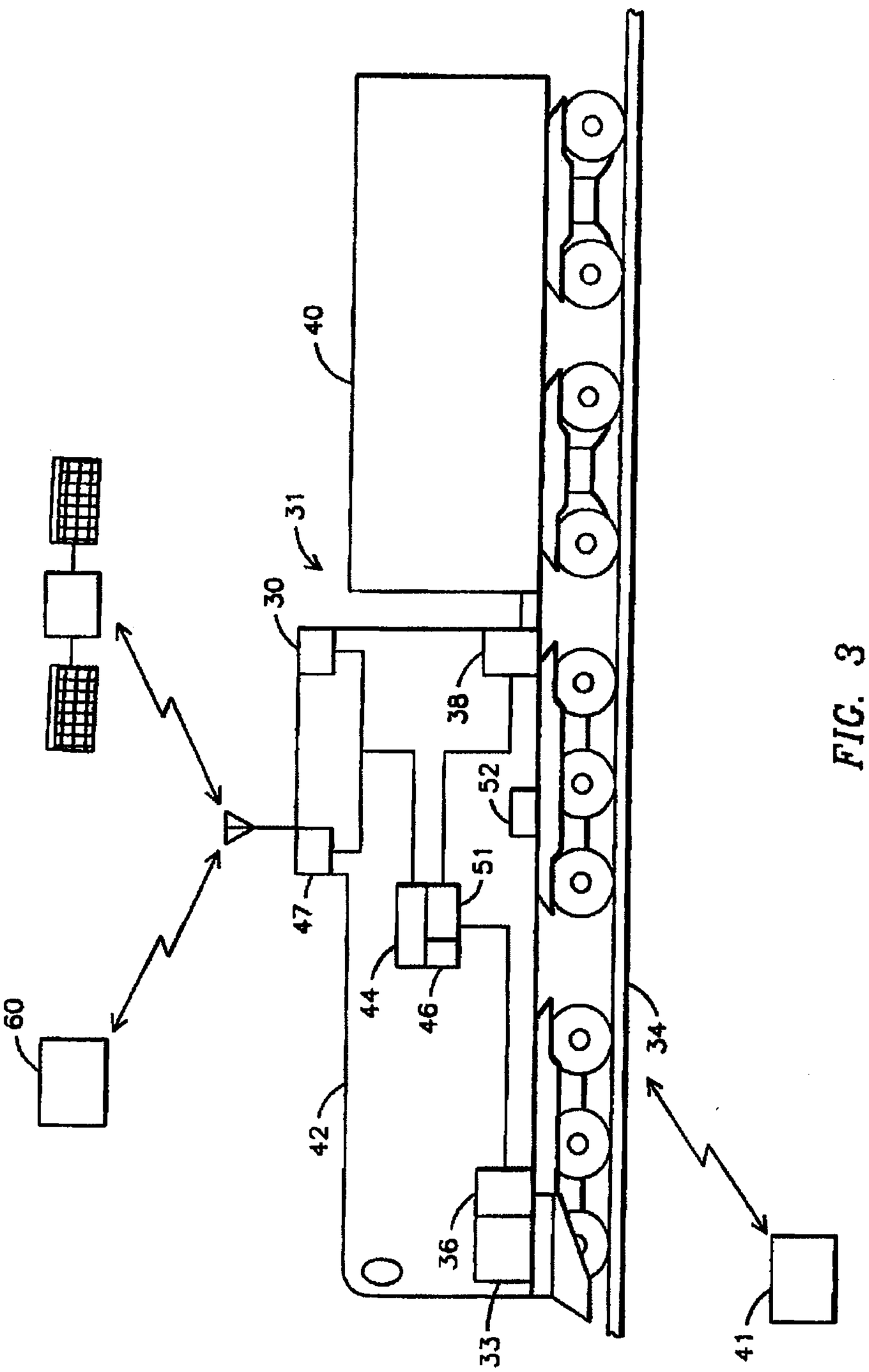

FIG. 3

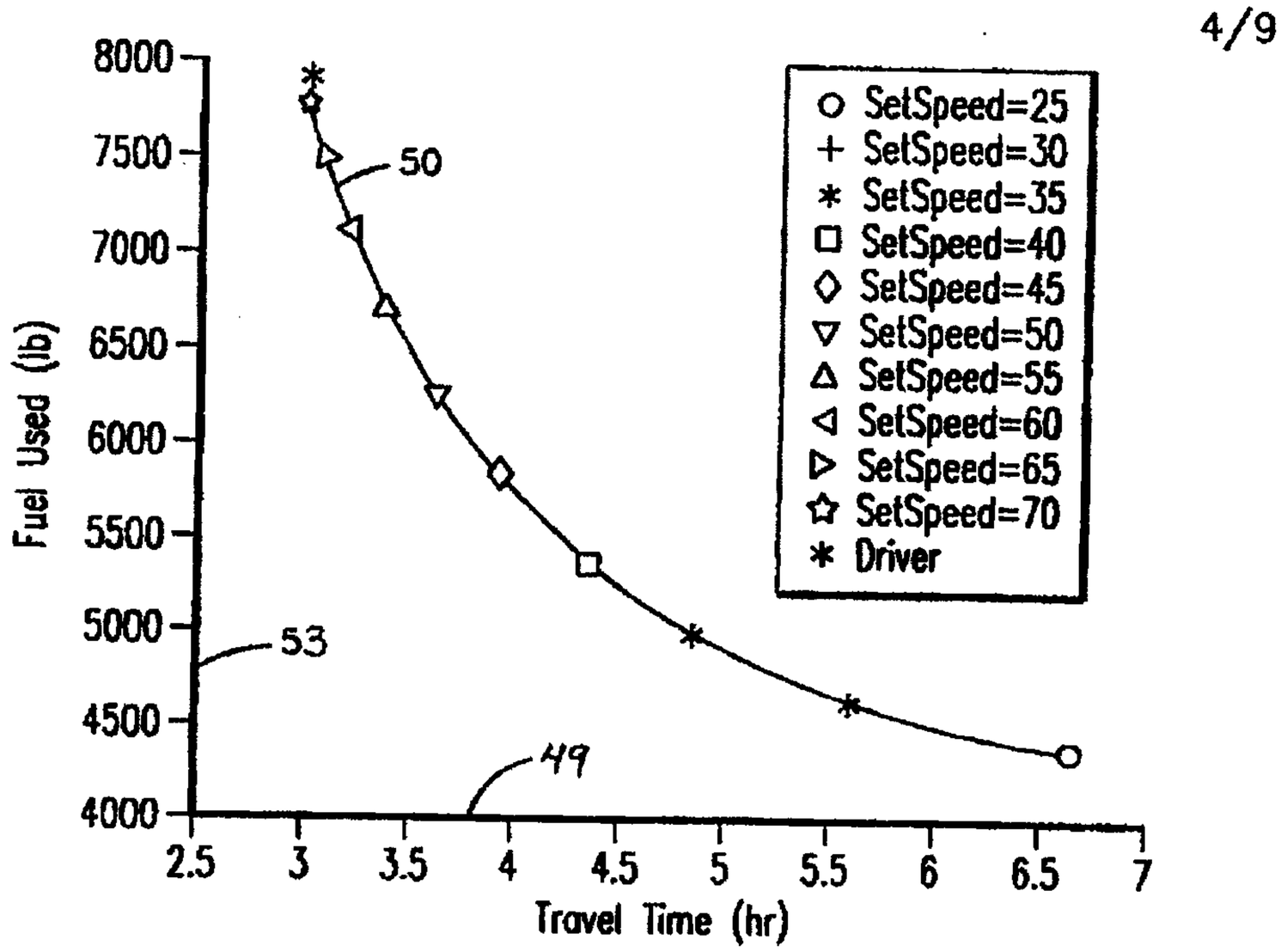
8000
7500
7000
6500
6000
5500
5000
4500
4000
Fuel Used (lb)
50
53
49
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
Travel Time (hr)
SetSpeed=25
SetSpeed=30
SetSpeed=35
SetSpeed=40
SetSpeed=45
SetSpeed=50
SetSpeed=55
SetSpeed=60
SetSpeed=65
SetSpeed=70
Driver

FIG. 4

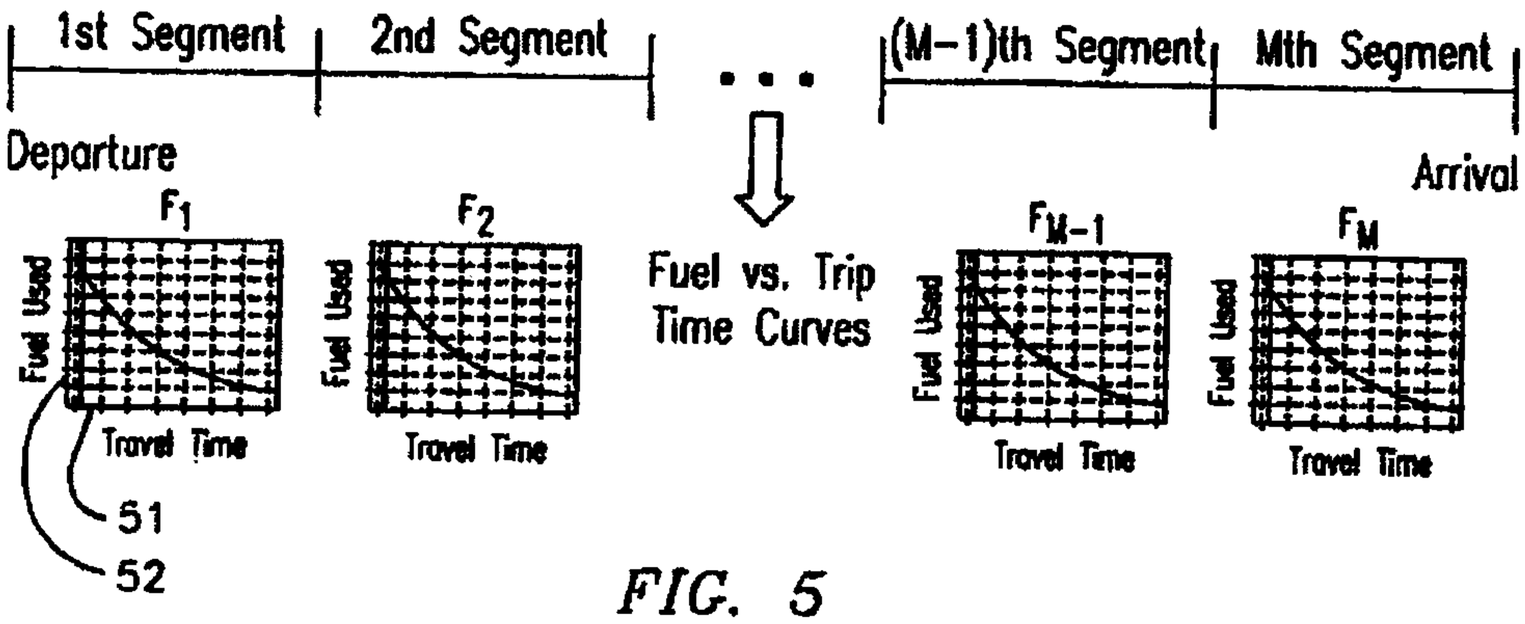
1st Segment
2nd Segment
(M−1)th Segment
Mth Segment
Departure
Arrival
F1
F2
FM−1
FM
Fuel Used
Travel Time
Fuel vs. Trip Time Curves
51
52

FIG. 5

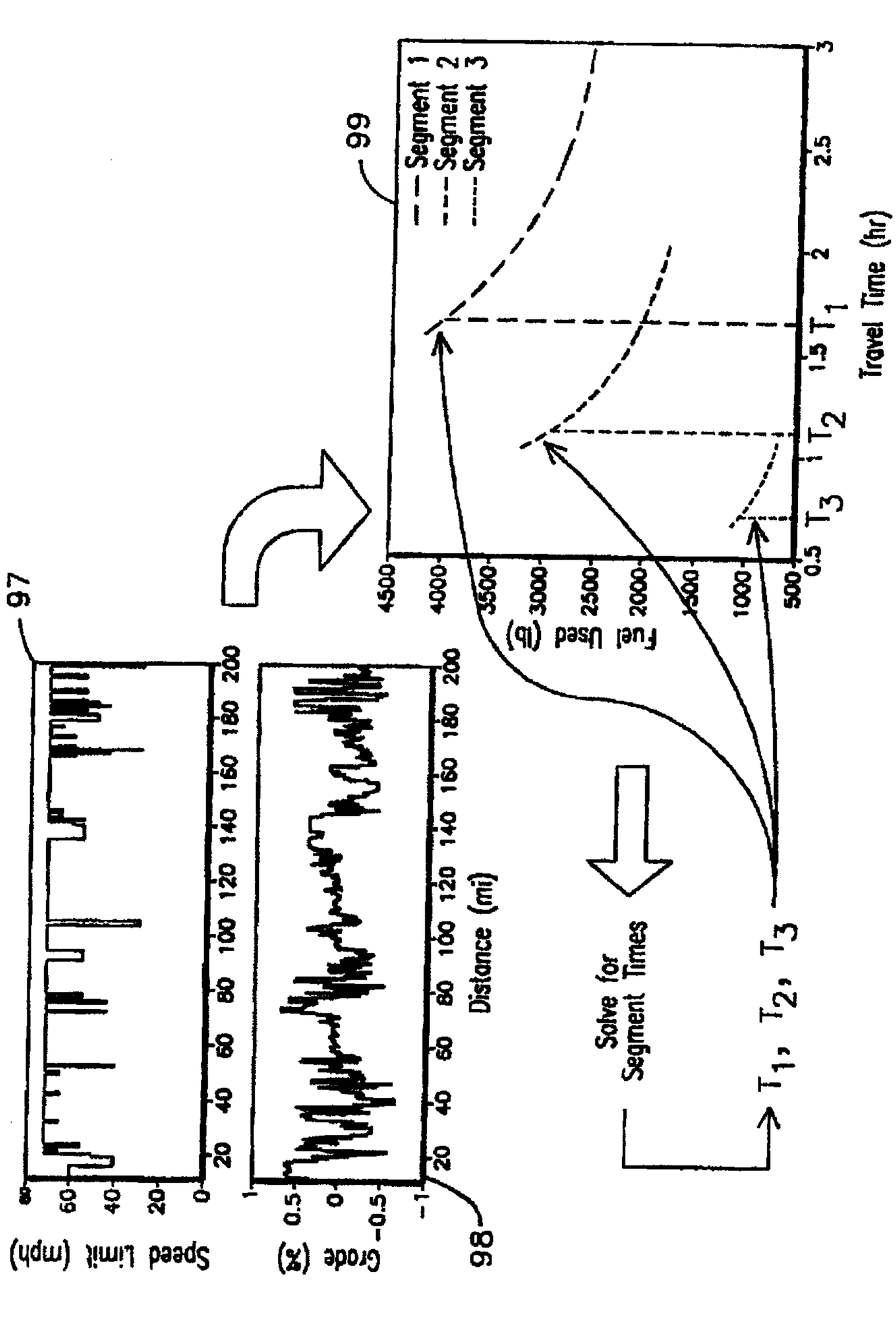
97
99
Segment 1
Segment 2
Segment 3
Travel Time (hr)
0.5
1
1.5
2
2.5
3
T_1
T_2
T_3
Fuel Used (lb)
500
1000
1500
2000
2500
3000
3500
4000
4500
Solve for Segment Times
T_1, T_2, T_3
98
Speed Limit (mph)
Grade (%)
Distance (mi)

FIG. 6

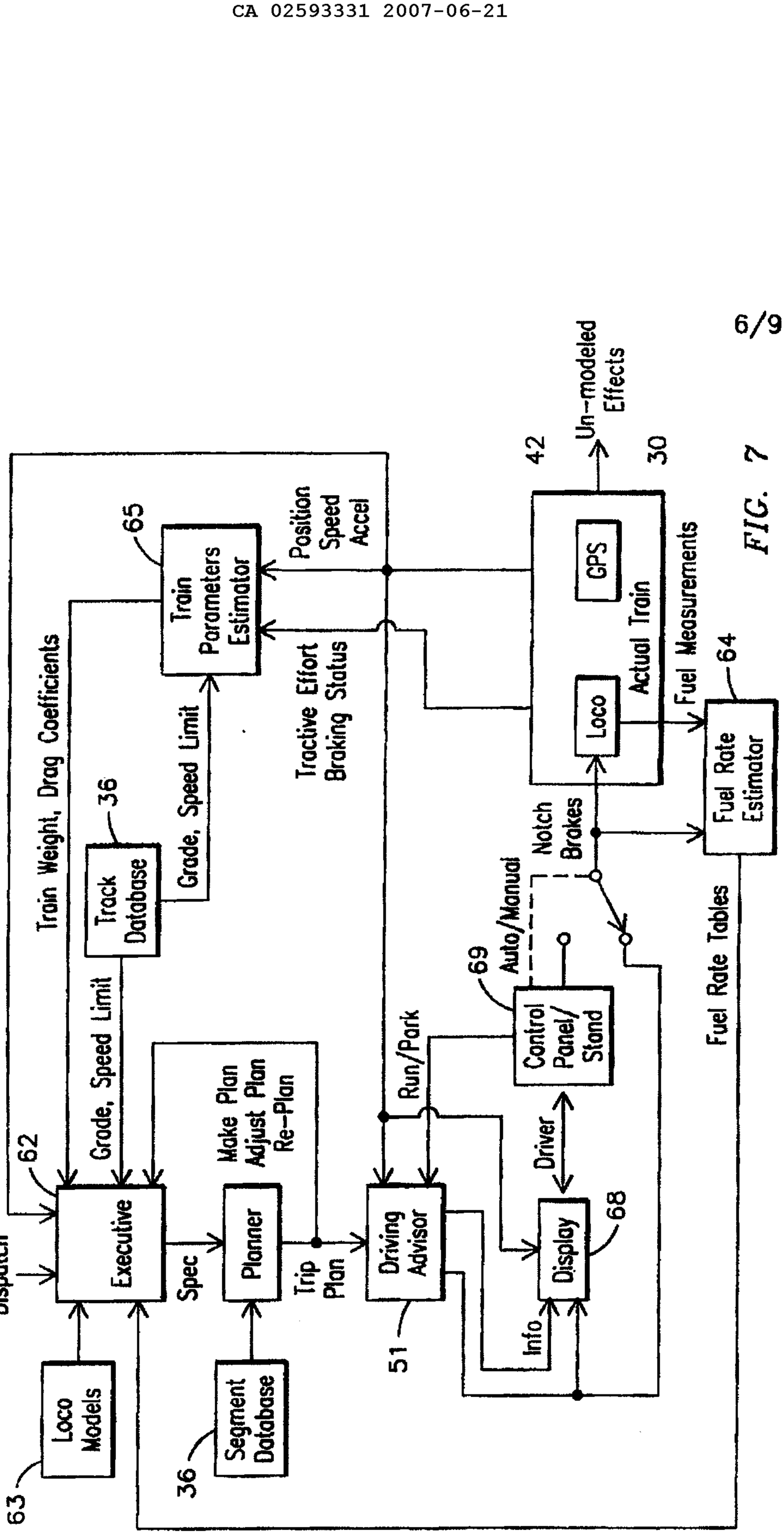
Train Weight, Drag Coefficients
Track Database
36
Grade, Speed Limit
Train Parameters Estimator
65
Position
Speed
Accel
Tractive Effort
Braking Status
Un-modeled Effects
42
30
GPS
Actual Train
Loco
Fuel Measurements
64
Fuel Rate Estimator
Notch
Brakes
Auto/Manual
69
Control Panel/ Stand
Run/Park
Driver
Display
68
Info
Driving Advisor
51
Make Plan
Adjust Plan
Re-Plan
Trip Plan
Spec
Planner
Executive
62
Dispatch
60
Loco Models
63
Segment Database
36
Fuel Rate Tables

FIG. 7

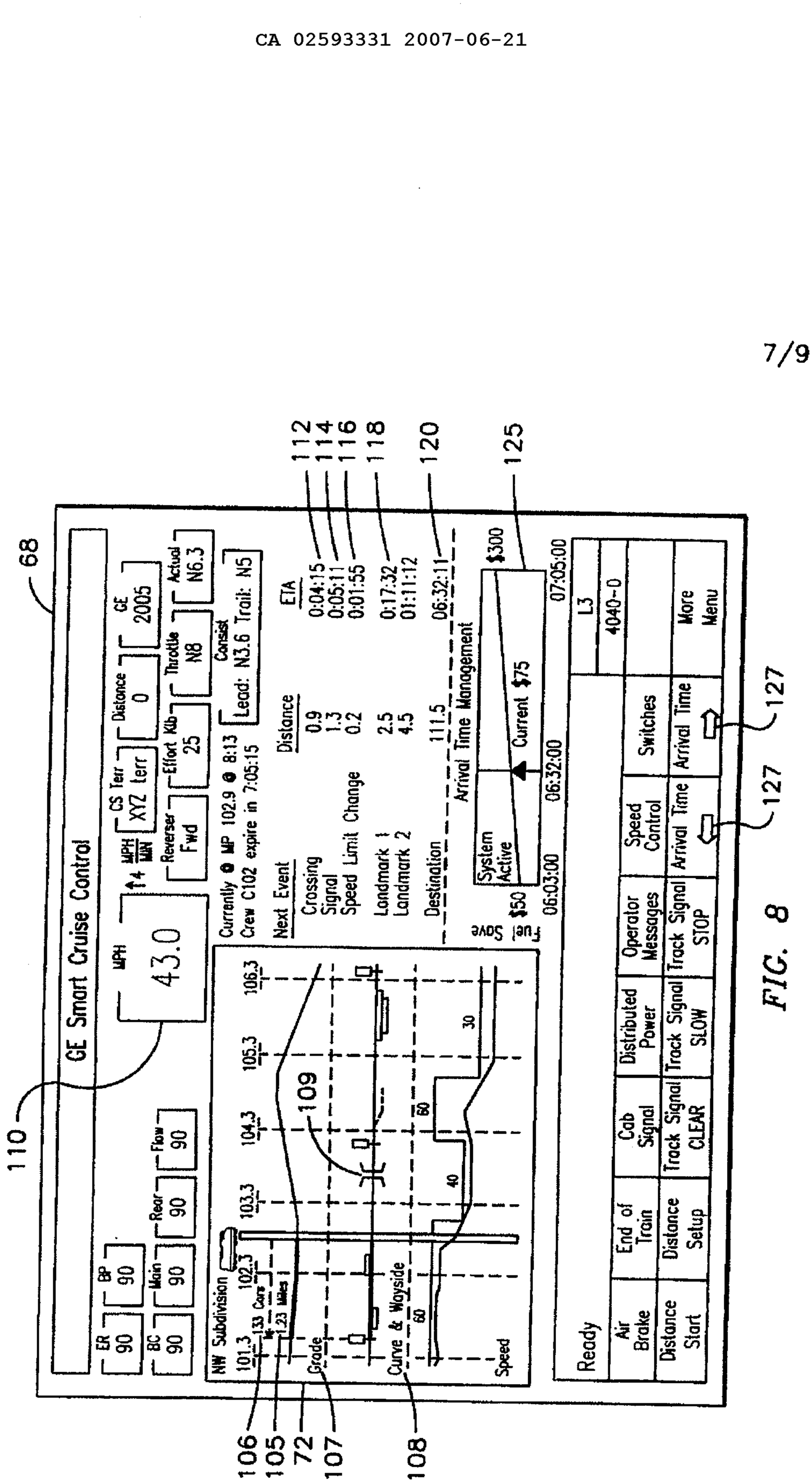
68
112
114
116
118
120
125
GE Smart Cruise Control
MPH
43.0
MPH/MIN
CS Terr
XYZ terr
Distance
0
GE
2005
Reverser
Fwd
Effort Klb
25
Throttle
N8
Consist
Actual
N6.3
Currently MP 102.9 8:13
Crew C102 expire in 7:05:15
Lead: N3.6 Trail: N5
Next Event
Distance
ETA
Crossing
0.9
0:04:15
Signal
1.3
0:05:11
Speed Limit Change
0.2
0:01:55
Landmark 1
2.5
0:17:32
Landmark 2
4.5
01:11:12
Destination
111.5
06:32:11
Arrival Time Management
$50
$300
System Active
Current $75
06:03:00
06:32:00
07:05:00
L3
4040-0
Speed Control
Switches
Arrival Time
Arrival Time
More Menu
Operator Messages
Track Signal STOP
Distributed Power
Track Signal SLOW
Cab Signal
Track Signal CLEAR
End of Train
Distance Setup
Air Brake
Distance Start
Ready
ER 90
BP 90
BC 90
Main 90
Rear 90
Flow 90
NW Subdivision
101.3
102.3
103.3
104.3
105.3
106.3
133 Curve
1.23 Miles
Grade
Curve & Wayside
Speed
60
40
30
109
110
127
127
106
105
72
107
108

FIG. 8

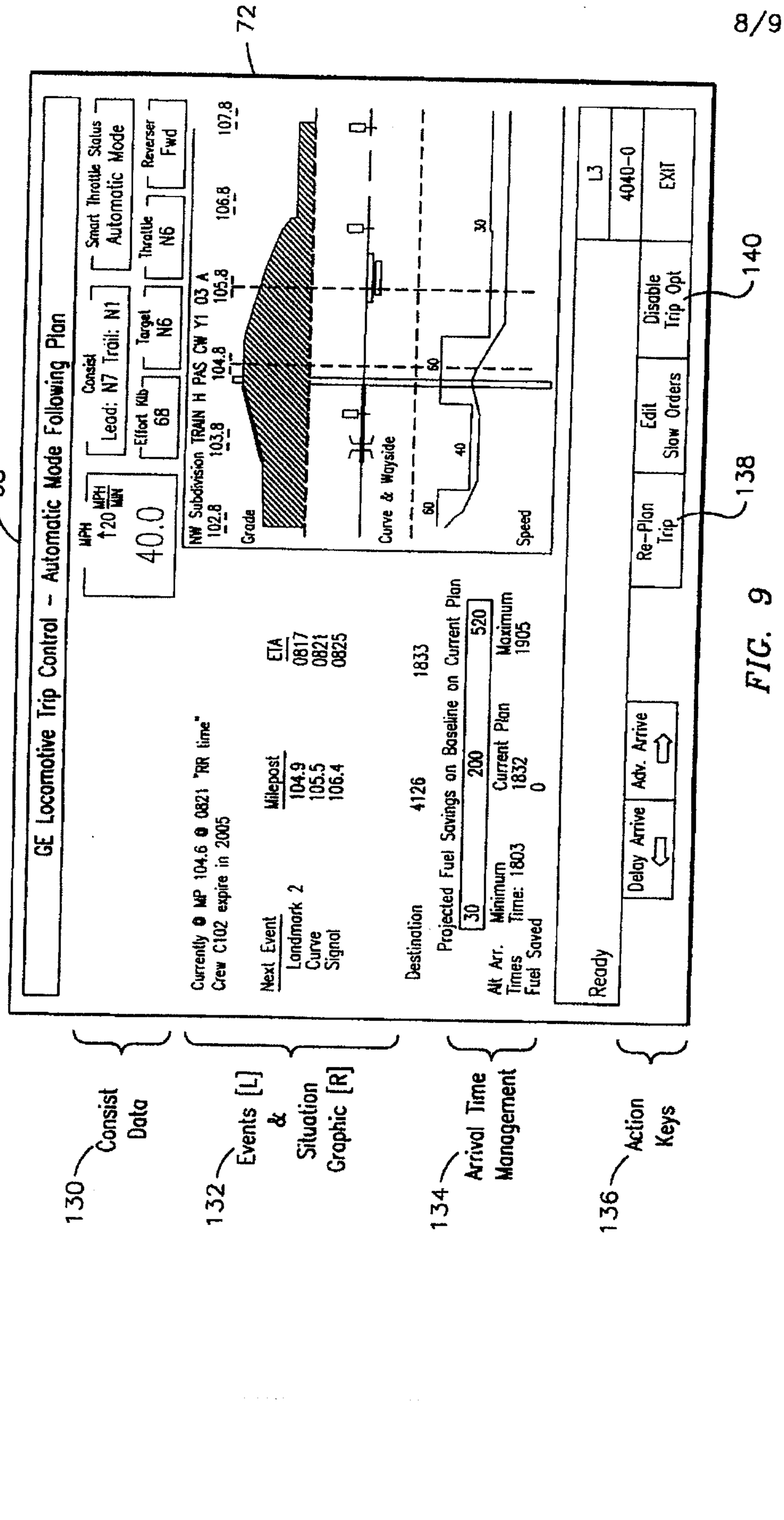
72
68
GE Locomotive Trip Control - Automatic Mode Following Plan
MPH
120 MPH/MIN
40.0
Consist
Lead: N7 Trail: N1
Effort Klb
68
Target
N6
Throttle
N6
Smart Throttle Status
Automatic Mode
Reverser
Fwd
NW Subdivision TRAIN H PAS CW Y1 03 A
102.8 103.8 104.8 105.8 106.8 107.8
Grade
Curve & Wayside
Speed
60
40
30
60
L3
4040-0
EXIT
Disable Trip Opt
140
Edit Slow Orders
Re-Plan Trip
138
Currently @ MP 104.6 @ 0821 "RR time"
Crew C102 expire in 2005
Next Event
Landmark 2
Curve
Signal
Milepost
104.9
105.5
106.4
ETA
0817
0821
0825
Destination
4126
1833
Projected Fuel Savings on Baseline on Current Plan
30
200
520
Alt Arr. Times
Minimum Time: 1803
Current Plan 1832
Maximum 1905
Fuel Saved
0
Ready
Delay Arrive
Adv. Arrive
130 Consist Data
132 Events [L] & Situation Graphic [R]
134 Arrival Time Management
136 Action Keys

FIG. 9

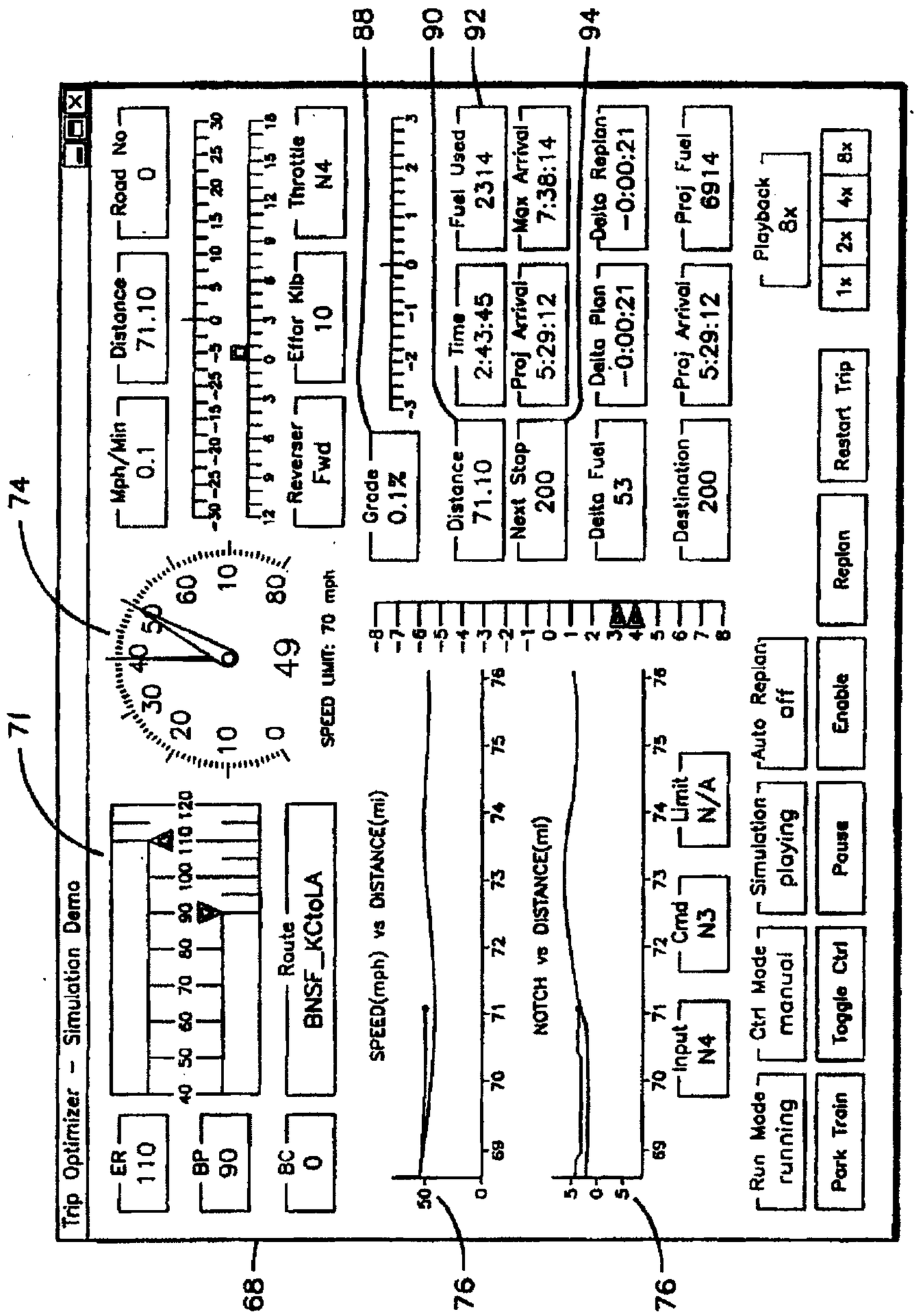
74
71
88
90
92
94
68
76
76
Trip Optimizer - Simulation Demo
Mph/Min 0.1
Distance 71.10
Road No 0
Effor Klb 10
Throttle N4
Reverser Fwd
Grade 0.1%
Time 2:43:45
Fuel Used 2314
Distance 71.10
Proj Arrival 5:29:12
Max Arrival 7:38:14
Next Stop 200
Delta Plan -0:00:21
Delta Replan -0:00:21
Delta Fuel 53
Proj Arrival 5:29:12
Proj Fuel 6914
Destination 200
Playback 8x
1x
2x
4x
8x
Restart Trip
SPEED LIMIT: 70 mph
ER 110
BP 90
BC 0
Route BNSF_KCtoLA
SPEED(mph) vs DISTANCE(mi)
NOTCH vs DISTANCE(mi)
Input N4
Cmd N3
Limit N/A
Run Mode running
Ctrl Mode manual
Simulation playing
Auto Replan off
Park Train
Toggle Ctrl
Pause
Enable
Replan

FIG. 10