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(54) **METHOD AND SYSTEM FOR VEHICLE TRACTION**

(57) Various methods and systems are provided for automatically applying tractive material during operation of a vehicle. In one embodiment, the application of tractive material for a vehicle is adjusted based on calculated and expected tractive effort for each powered truck, axle,

or wheel of the vehicle. In this way, tractive material application is controlled on a per truck, axle, or wheel basis in order to reduce excessive use of tractive material during operation of the vehicle.

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U. S. Provisional Application No. 63/028,965, entitled "METHOD AND SYSTEMS FOR TRACTION MATERIAL APPLICATION FOR A RAIL VEHICLE", and filed on May 22, 2020. The entire contents of the above-listed application are hereby incorporated by reference for all purposes.

TECHNICAL FIELD

[0002] Embodiments of the subject matter disclosed herein relate to methods and systems for controlling vehicle traction.

DISCUSSION OF ART

[0003] Vehicles require a degree of adhesion between each wheel and a surface of a route. For a locomotive, it may be desirable to produce high tractive effort for heavy haul applications. Thus, the ability to produce desired tractive effort depends on the available or potential adhesion between the wheel and rail. Many railroad rail conditions, such as being wet or covered with snow or ice, require application of tractive material, such as sand, to improve or enhance the adhesion of the wheel to the rail. Therefore, locomotives may include tractive material reservoirs (e.g., sand boxes), and applicators to dispense the tractive material to the rail to improve tractive effort.

[0004] For example, in response to one or more conditions being met, such as one or more wheel axles of the locomotive slipping, application of tractive material may be initiated. In a tractive material application system, flow of tractive material may be initiated simultaneously through two applicators located in front of each locomotive truck when the locomotive is moving forward. Tractive material is thus dispensed at a fixed rate through four sand applicators each time there is a demand for increasing tractive effort from the locomotive controller. Further, tractive material is dispensed for a set period of time, which frequently results in more tractive materials being dispensed than necessary to maximize adhesion between the locomotive wheels and the railroad rail. It may be desirable to have a system or method that differs from those that are currently available.

BRIEF DESCRIPTION

[0005] In one embodiment, a method for a vehicle may comprise controlling application of tractive material for each of one or more wheels, axles, or trucks of the vehicle based on respective individual actual tractive effort of each of the one or more wheels, axles, or trucks.

[0006] By adjusting application of tractive materials for each wheel, axle, or truck individually, excessive consumption of tractive material may be reduced.

[0007] The brief description above is provided to introduce a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 shows a schematic diagram of a rail vehicle, according to an embodiment of the invention.

FIG. 2 shows a schematic diagram of a traction material application system for a rail vehicle, according to an embodiment of the invention.

FIG. 3 shows a flow chart illustrating a high level method for controlling application of tractive material, according to an embodiment of the invention.

FIG. 4 shows a graph illustrating a timeline for adjusting tractive material application during operation of a rail vehicle, according to an embodiment of the invention.

FIG. 5 shows a flow chart illustrating a method for controlling application of tractive material, according to another embodiment of the invention.

FIG. 6 shows a graph illustrating a timeline for adjusting tractive material application during operation of a rail vehicle, according to another embodiment of the invention.

DETAILED DESCRIPTION

[0009] Embodiments of the subject matter disclosed herein relate to methods and systems for controlling vehicle traction. The following description relates to various embodiments for controlling vehicle traction. In one embodiment, the vehicle traction may be controlled via application of tractive material to a route surface proximate to a wheel of a vehicle. A suitable vehicle may be, for the purpose of illustration, a locomotive, such as the locomotive shown at FIG. 1. Other suitable vehicles may include other rail vehicles and non-rail vehicles. Suitable non-rail vehicles may include automobiles, mining equipment, agricultural equipment, and industrial equipment. With regard to rail applications, the pulling capability of the locomotive is based on tractive effort produced by the locomotive. In order to produce desired tractive effort, good adhesion is required between a wheel and a surface of the route, which in this case is a steel rail. In order to improve adhesion, the locomotive includes a tractive material application system for dispensing tractive material in front of one or more wheels of the locomotive in the direction of travel. An exemplary tractive material application system is shown at FIG. 2.

[0010] Tractive material may be dispensed in front of one or more wheels of one or more axles of one or more trucks. In some vehicles, the wheels may have their own propulsive motor. In such an embodiment, the wheels on an axle may have tractive efforts that differ from each other, and thus left and right of a vehicle rather than front and back as contemplated in other embodiments disclosed herein. In another embodiment, each truck may have one or more axles. Often each axle will have at least two wheels, and if coupled to the same axle, the wheels may be mechanically coupled to each other. In one embodiment, the truck may be powered and thereby may provide propulsion for the vehicle. Other, unpowered trucks are not contemplated herein unless mentioned explicitly. Each truck of a vehicle may need increased adhesion between the wheels and the route surface (that is, a demand for increased tractive effort). The tractive effort provided by the locomotive may be evaluated for the locomotive as a whole, and thus, the application of tractive material may be performed at a whole vehicle level. For comparison with the inventive concept, under a current or prior system when vehicle operating conditions indicate a need for increased tractive effort, such as due to one or more wheels slipping, the tractive material may be dispensed via all tractive material applicators (which may be referred to herein as nozzles) and this may lead to unnecessary wastage of tractive material.

[0011] In one embodiment, a method is provided for controlling application of tractive material on a per wheel, axle, or truck basis rather than as a full vehicle. In one example, for a vehicle including a lead truck and a rear truck, operating conditions of each of the lead truck may be evaluated to determine if tractive material application is desired for the lead truck and if so, tractive material is applied (that is dispensed via a first nozzle) in front of the lead truck. Further, the rear truck operating condition may be evaluated, based on which, the vehicle controller may determine whether to apply tractive material in front of the rear truck. Details of adjusting application of tractive material based on operating conditions of each truck of the vehicle are further described below with respect to FIGS. 3 and 4, details of adjusting application of tractive material based on operating conditions of each wheel and/or each truck of the vehicle are further described below with respect to FIGS. 5 and 6.

[0012] In this way, by controlling tractive material application individually for each wheel, axle, or truck, unnecessary wastage of tractive material may be reduced or eliminated. Further, less tractive material may be introduced in a particular location.

[0013] Returning to FIG. 1, a schematic diagram of a vehicle 102 is shown. In this illustrated example, the vehicle is depicted as a locomotive and can run on a route that is a steel rail 114 via a plurality of steel wheels 116. As shown therein, the vehicle may include an engine 10, such as an internal combustion engine. Suitable engines may be a diesel engine, while other suitable engine configurations may be employed, such as a gasoline engine, a biodiesel engine, a natural gas engine, or a gas turbine engine (turbojet, turbofan, turboprop, turboshaft), for example. In one embodiment, rather than an engine another power source may be employed, such as batteries, fuel cells, catenary and third rail power sources and the like.

[0014] The vehicle may be a part of a vehicle group or system (not shown). Suitable vehicle groups may be referred to as a consist, a swarm or a platoon, and as such may be mechanically or communicatively coupled together. For communicative coupling or virtual coupling, a controller may control vehicles in the group to move relative to each other or to another reference point in a coordinated manner. A suitable rail vehicle consist may include a lead vehicle consist, a remote or trail vehicle consist, and plural non-powered rail vehicles (e.g., freight cars) positioned between the lead consist and the remote consist. The lead and remote consists may be subgroups within a larger consist. The lead vehicle consist may include a lead vehicle, such as the vehicle of FIG. 1, and a trail vehicle (not shown). Similarly, the remote vehicle consist may include a lead vehicle and a trail vehicle. In the illustrated embodiment, the rail vehicles in the rail vehicle consist are sequentially mechanically connected together for traveling along a route, such as a rail or other guideway.

[0015] The vehicle includes a lead truck 150 and a rear truck 160. The vehicle further includes a plurality of wheel-axle sets 117A - F. The wheel-axle sets 117A - F includes an axle, two wheels 116 coupled to each corresponding axle, and a traction motor 124. The traction motor 124 of each of the six wheel-axle sets 117A - F may be operably coupled

to the corresponding axle by a gear, a gear system, or the like. In the illustrated FIG. 1, the wheel-axle set 117A is a first front wheel-axle set of the lead truck of the vehicle as it travels along in the forward direction of movement 175. Similarly, the wheel-axle set 117D is a second front wheel-axle set of the rear truck of the vehicle in the direction of travel. Alternatively, the vehicle may move in a direction that is opposite the direction such that the wheel-axle set 117F is the front wheel-axle set and the truck becomes the lead truck. Similarly, when travelling in the direction opposite to the first direction of travel, the truck and wheels switch designations.

[0016] The engine receives intake air for combustion from an intake passage 118. The intake passage receives ambient air from an air filter (not shown) that filters air from outside of the vehicle. Exhaust gas resulting from combustion in the engine is supplied to an exhaust passage 120. Exhaust gas flows through the exhaust passage, and out of an exhaust stack (not shown) of the vehicle.

[0017] In one embodiment, the vehicle is a diesel-electric vehicle. As depicted in FIG. 1, the engine is coupled to an electric power generation system, which includes an alternator/generator 122 and electric traction motors 124. For example, the engine is a diesel engine that generates a torque output that is transmitted to the generator which is mechanically coupled to the engine. The generator produces electrical power that may be stored and applied for subsequent propagation to a variety of downstream electrical components. As an example, the generator may be electrically coupled to a plurality of traction motors and the generator may provide electrical power to the plurality of traction motors. As depicted, each traction motor of the plurality of traction motors is connected to one of a plurality of wheel-axle sets to provide tractive power to propel the vehicle. That is, a propulsion system (the example propulsion system including one or more engines, alternators, generators, traction motors, and gear boxes) may generate designated electrical power to provide separate (e.g., different, individual, or the like) tractive effort to each of the plurality of traction motors to move the corresponding axle and the two wheels of each of the six wheel-axle sets. The designated electrical power may represent an amplitude or waveform for each traction motor to operate in order for each traction motor to move each corresponding axle and two wheels, and thereby move the vehicle along the rail, for example. In other embodiments, the propulsion system may include a battery, a fuel cell, catenary or third rail hook ups, and power electronics to manage the power. In one embodiment, there is one traction motor per wheel, and thus the wheel may be operated separately from other wheels rather than having two wheels on a single axle that are mechanically coupled to each other.

[0018] A suitable vehicle with an engine may include a turbocharger 126 arranged between the intake passage and the exhaust passage. The turbocharger increases air charge of ambient air drawn into the intake passage in order to provide greater charge density during combustion to increase power output and/or engine-operating efficiency. The turbocharger may include a compressor (not shown) which is at least partially driven by a turbine (not shown). While in this case a single turbocharger is included, the system may include multiple turbine and/or compressor stages. Further, in some embodiments, a wastegate may be provided which allows exhaust gas to bypass the turbocharger. The wastegate may be opened, for example, to divert the exhaust gas flow away from the turbine. In this manner, the rotating speed of the compressor, and thus the boost provided by the turbocharger to the engine may be regulated.

[0019] The vehicle may include a tractive material application system 40 for regulating application of tractive material (contained in a reservoir of the vehicle) between the wheels and the rail, via one or more nozzles to increase tractive effort produced by the vehicle. Details of the tractive material application system at discussed below with respect to FIG. 2. As discussed below, the tractive material application system may be regulated to apply tractive material in front of one or more wheels, axles, or trucks of the vehicle. Specifically, in the direction of travel indicated at FIG. 1, the vehicle may include a first nozzle 104 positioned in front of each wheel of first wheel-axle set 117A, and a second nozzle 112 positioned in front of each wheel of wheel-axle set 117D of the rear truck. In the direction opposite to direction indicated by arrow 175, the vehicle may include a third nozzle 116 in front of each wheel of wheel-axle set 117F of the truck and a fourth nozzle 106 in front of each wheel of wheel-axle set 117C of the truck.

[0020] During vehicle operation in the direction of arrow 175, based on the actual and expected operating conditions of each truck, the vehicle controller 12 may command one or more actuators (e.g., valves controlling flow of tractive material through one or more nozzles of the vehicle) of the tractive material application system to dispense tractive material via nozzle 104 in front of wheel-axle set 117A and/or via nozzle 112 in front of wheel-axle set 117D. In this way, application of tractive material is automatically controlled via vehicle controller 12. Similarly, when the vehicle is operating in the direction opposite to arrow 175, based on the actual and expected operating conditions of each truck, the vehicle controller 12 may command the one or more actuators (e.g., valves controlling flow of tractive material through one or more nozzles of the vehicle) of the tractive material application system to dispense tractive material via a nozzle in front of one wheel/axle set and/or via another nozzle in front of another wheel-axle set.

[0021] In some examples, the nozzles in front of each wheel-axle set may be controlled in tandem, e.g., nozzle 104 in front of one wheel of the wheel-axle set 117A may be controlled in tandem and in the same manner as another nozzle in front of the other wheel of the wheel-axle set 117A. In such examples, axle slip as a whole may be determined when deciding whether to dispense tractive material via the nozzles, as explained in more detail below. However, in other examples, the two nozzles may be controlled independently, which may allow tractive material to be dispensed only on the right side, only on the left side, or both, depending on individual wheel slip.

[0022] The vehicle may include an exhaust gas recirculation (EGR) system 160, which routes exhaust gas from the exhaust passage upstream of the turbocharger to the intake passage downstream of the turbocharger. The EGR system may include an EGR passage 162 and an EGR valve 164 for controlling an amount of exhaust gas that is recirculated from the exhaust passage of engine to the intake passage of the engine. By introducing exhaust gas to the engine, the amount of available oxygen for combustion is decreased, thereby reducing the combustion flame temperatures and reducing the formation of nitrogen oxides (e.g., NO_x). The EGR valve may be an on/off valve controlled by the engine controller or it may control a variable amount of EGR, for example. The EGR system may further include an EGR cooler 166 to reduce the temperature of the exhaust gas before it enters the intake passage. As depicted in the non-limiting example embodiment of FIG. 1, the EGR system is a high-pressure EGR system. In other embodiments, the vehicle may additionally or alternatively include a low pressure EGR system, routing EGR from a location downstream of the turbocharger to a location upstream of the turbocharger. Additionally, the EGR system may be a donor cylinder EGR system where one or more cylinders provide exhaust gas only to the EGR passage, and then to the intake.

[0023] The vehicle includes an exhaust gas treatment system coupled in the exhaust passage to reduce regulated emissions. In one example embodiment, the exhaust gas treatment system may include a diesel oxidation catalyst (DOC) 130 and a diesel particulate filter (DPF) 132. The DPF may trap particulates, also known as particulate matter (an example of which is soot) produced during combustion. A suitable DPF may be ceramic, such as silicon carbide.

[0024] In other embodiments, the exhaust gas treatment system may include or more of a selective catalytic reduction (SCR) catalyst, three-way catalyst, NO_x trap, and various other emission control devices or combinations thereof. In some embodiments, the exhaust gas treatment system may be positioned upstream of the turbocharger, while in other embodiments, the exhaust gas treatment system may be positioned downstream of the turbocharger.

[0025] The vehicle may include a power setting control. A suitable power setting control may be a throttle 142 that is coupled to engine to indicate or control engine power output levels. In this embodiment, the throttle is depicted as a notch throttle. However, any suitable throttle is within the scope of this disclosure. Each notch of the notch throttle may correspond to a discrete power level. The power level indicates an amount of load, or engine output, placed on the vehicle and this can indirectly affect the speed at which the vehicle will travel. Although eight notch settings are depicted in the example embodiment of FIG. 1, in other embodiments, the throttle notch may have more than eight notches or less than eight notches, as well as notches for idle and dynamic brake modes. Engine notch settings may be selected with regard to optimized operational points for an engine, that is, engines may have optimal settings points and by switching from notch to notch, the system may in effect switch from one optimized operational point to another optimized operational point. Operation of an engine between notches or optimized points may be permissible in some embodiments, with the interstitial operational ranges being referred to as transitional modes. In other embodiments, the engine power is infinitely variable and optimized set points are not included in the engine operational technique. Infinitely variable settings may be sometimes useful in mechanically coupled propulsion systems (as opposed to electric motor driven systems). In some embodiments, the notch setting may be selected by a human operator of the vehicle.

[0026] In one embodiment, a consist controller 22 may control plural vehicles in a vehicle group, and further may receive, implement or determine a trip plan. For example, a trip plan may be generated using trip optimization software including notch settings based on engine and/or vehicle operating conditions. The vehicle group may include multiple vehicles of the same type, or optionally may include multiple vehicles of different vehicle types. In one embodiment, a vehicle may include a vehicle controller 12. A suitable vehicle controller may provide control for the actions and operation of a specific vehicle, such a one vehicle of a vehicle group. The vehicle controller may control various components in, on or related to the vehicle (such as an engine controller) and/or may directly control the vehicle itself (such as the vehicle speed, which is indirectly a function of the engine speed that is controlled by the engine controller). As an example, various components of the vehicle system may be coupled to the engine controller via a communication channel or data bus. In one example, the engine controller and the consist controller each include their own control systems. The engine controller, vehicle controller, and consist controller may additionally or alternatively be coupled to a memory holding non-transitory computer readable storage media (not shown). This may include code for enabling on-board monitoring and control of vehicle operation.

[0027] The various controllers may receive relevant information from a plurality of sensors and may send control signals to a plurality of actuators. The vehicle controller, while overseeing control and management of the vehicle may receive signals from a variety of sensors 150, as further elaborated herein, in order to determine operating parameters and operating conditions, and correspondingly adjust various actuators 152 to control operation of the vehicle. For example, the engine controller may receive signals from various sensors or the engine or the vehicle. Suitable sensors may include those that signal engine speed, engine load, intake manifold air pressure, boost pressure, exhaust pressure, ambient pressure, ambient temperature, exhaust temperature, particulate filter temperature, particulate filter back pressure, compressor health, airline pressure, ambient temperature, ambient humidity, and the like. Correspondingly, the vehicle controller may control the vehicle by sending commands to various components such as the traction motors, the alternator/generator, cylinder valves, fuel injectors, the notch throttle, etc. Other actuators may be coupled to various locations in the vehicle.

[0028] In some embodiments, the vehicle may include a motor controller 30. The motor controller may receive signals from the traction motors (e.g., from control system of respective traction motors) and the vehicle controller, and regulating operations of the traction motors based on the received signals. The motor controller and/or the vehicle controller may receive one or more signals from the traction motors including motor torque, voltage, current, and flux. This may be measured from one or more sensors coupled to the traction motors or may be estimated or calculated. The motor controller may evaluate operating conditions of the traction motors and relay one or more operating conditions of the traction motors to the vehicle controller. The operating conditions of the traction motors may comprise operating conditions of each of the traction motors, and may include a motor current, a rotor speed, a torque, and a motor deration condition, for each of the traction motors. The operating conditions of the traction motors may be considered in determining expected tractive effort for each of the rear truck and the lead truck that may be utilized for controlling application of tractive material, as further discussed below at FIGS. 3 and 4. In other embodiments, the vehicle controller may directly receive signals from and send signals to each traction motor to regulate their operation.

[0029] The vehicle controller may receive signals from one or more of the motor controller, the traction motors, the consist controller, the throttle, the engine, including engine sensors, and the generator, and based on the signals received, the vehicle controller may determine an actual operating condition of the vehicle including actual operating conditions of each of the lead wheel, axle or truck and the rear wheel, axle or truck of the vehicle. Further, the vehicle controller, based on the signals received, may evaluate desired operating conditions of the vehicle, including desired operating conditions of each of the lead wheel, axle or truck and the rear wheel, axle or truck. Thus, the vehicle controller may determine actual and desired (that is, expected) operating conditions at a vehicle level as well as on a per truck basis. As discussed herein at FIGS. 3 and 4, the vehicle controller may evaluate/determine operating conditions for each truck of the vehicle in order to dispense tractive material in front of one or more of lead truck and rear truck based on respective operating conditions of the individual trucks. The operating conditions may include an expected lead truck tractive effort, an expected rear truck tractive effort, an actual lead truck tractive effort, an actual rear truck tractive effort, a lead truck slipping condition, a rear truck slipping condition, a number of lead truck axles slipping, and a number of rear truck axles slipping. In this way, the vehicle controller may selectively apply tractive materials, such as traction sand, in front of one or more trucks of the vehicle based on operating conditions of each truck. Details of controlling application of the tractive material for each truck (that is, on a per truck basis) will be elaborated with respect to FIGS. 2, 3, and 4. Unless context or language specifies otherwise, the term 'truck' as used herein can include wheels and axles, too.

[0030] The consist controller may have a communication portion that is operably coupled to a control signal portion. The communication portion may receive signals from vehicle sensors including vehicle position sensors (e.g., GPS device), environmental condition sensors (e.g., for sensing altitude, ambient humidity, temperature, and/or barometric pressure, or the like), vehicle coupler force sensors, track grade sensors, vehicle notch sensors, brake position sensors, etc. One of the sensors may include a rotary speed sensor that measures the speed at which one or more wheels of the vehicle system rotate. The rotary speed sensor can include a tachometer, for example. Various other sensors may be coupled to various locations in the vehicle. The control signal portion may generate control signals to trigger various vehicle actuators. Example vehicle actuators may include air brakes, brake air compressor, traction motors, etc. Other actuators may be coupled to various locations in the vehicle. Consist controller may receive inputs from the various vehicle sensors, process the data, and trigger the vehicle actuators in response to the processed input data based on instruction or code programmed therein corresponding to one or more routines. Further, consist controller may receive engine data (as determined by the various engine sensors) from engine controller, process the engine data, determine engine actuator settings, and transfer (e.g., download) instructions or code for triggering the engine actuators based on routines performed by the consist controller back to engine controller.

[0031] While FIG. 1 illustrates a vehicle consist in the form of a train, it is to be understood that other fleets of vehicles, mechanically and/or communicatively coupled, are within the scope of this disclosure. Further, while the above example illustrated at FIG. 1 shows a vehicle including two trucks, it will be appreciated that the methods and systems described herein are applicable to a vehicle having any number of trucks. Accordingly, a method for operating a vehicle may include controlling application of tractive material for each of one or more trucks of the vehicle based on respective individual actual tractive effort of each of the one or more trucks; wherein controlling application of tractive material includes, for each of the one or more trucks, responsive to an actual tractive effort for a given truck less than an expected tractive effort of the given truck, and a number of axles of the given truck slipping greater than a threshold number of axles, delivering tractive material via a respective nozzle coupled to the given truck. Further, the actual tractive effort for the given truck is based on one or more of current and speed feedback from one or more traction motors powering one or more axles of the given truck; and wherein the expected tractive effort for the given truck is based on a total actual tractive effort of one or more forward trucks operating in front of the given truck along a direction of movement of the vehicle, a total vehicle tractive effort, and one or more derations applied to the one or more traction motors.

[0032] FIG. 2 illustrates a schematic diagram of the tractive material application system of FIG. 1. The components shown in FIG. 2 will be described with respect to FIG. 1, and discussion of components with same reference numbers will not be repeated for brevity. The exemplary system 40 may include a tractive material container 204 for supplying

tractive material via nozzles 104, 106, 112, and 116. While the present example shows a common tractive material container 204 that may be used to apply tractive material for the lead truck and the rear truck, it will be appreciated that in some embodiments, the tractive material application system may include a front tractive material container for the lead truck and a rear tractive material container for the rear truck. A compressed air reservoir 230 may supply compressed air through plural air valves 232 and 234. A pair of electrically controlled valves 202 and 206 may be provided for the lead truck, and similar valves 212 and 216 may be provided for the rear truck. Valves 202 and 206 may control sand flow through respective nozzles, and the rear truck valves may control sand flow through their respective nozzles. The vehicle controller may control one or more of the air reservoir, the air valves, and respective traction material valves for adjusting the application of tractive material to railroad rails on a per truck basis. In some embodiments, during some vehicle operating conditions, application of tractive material to rails may be controlled at the vehicle level (considering the vehicle as a whole and not considering each truck individually) and therefore when it is desired to apply tractive materials, the tractive materials may be dispensed simultaneously to the lead truck and the rear truck, and during some other conditions, application of tractive materials may be controlled for each truck (that is, on a per truck basis). Controlling application of tractive materials for each truck will be further discussed below at FIGS. 3 and 4.

[0033] The tractive material may include particles that are harder than the track to be treated. Suitable types of harder particles include metal, ceramic, minerals, and alloys. A suitable hard metal can be tool grade steel, stainless steel, carbide steel, or a titanium alloy. Other suitable tractive materials may be formed from the bauxite group of minerals. Suitable bauxite material includes alumina (Al_2O_3) as a constituent, optionally with small amounts of titanium (Ti_2O_3), iron oxide (Fe_2O_3), and silica (SiO_2) particles. Other suitable tractive materials can include crushed glass or glass beads. In other embodiments, the tractive material includes one or more particles formed from silica, alumina, or iron oxide. In an embodiment, other suitable tractive material can be an organic material. Suitable organic material can include particles formed from nutshells, such as walnut shells, and materials of biologic origin, such as particles formed from crustacean or seashells (e.g., skeletal remains of mollusks and similar sea creatures). All tractive materials can be used alone or in combination based on the application specific circumstances.

[0034] FIG. 3 shows a flow chart illustrating a high-level method 300 for adjusting application of traction material for a rail vehicle, such as vehicle at FIG. 1. The method may be carried out by a controller. The method may be carried with respect to one vehicle, some vehicles or each and every vehicle in a vehicle group.

[0035] The method begins at step 302. At step 302, the method includes estimating and/or measuring vehicle operating conditions for a vehicle of a rail vehicle consist. The vehicle may be any of a lead vehicle and one or more trail vehicles of the rail vehicle consist. The operating conditions may include traction motor torque of each traction motor, traction motor current for each traction motor, an axle rotational velocity, tractive effort (TE), throttle or notch setting, wheel speed, rate of acceleration or deceleration, braking condition, force, wheel slip/slide, fuel consumption, wheel creep, and engine horsepower. These operating conditions may be estimated and/or measured on per axle, per truck, and/or per vehicle basis. Thus, the vehicle operating conditions may include operating conditions of a lead truck of the vehicle, and operating conditions of a trail truck of the vehicle, such as trail truck, in addition to operating conditions of the vehicle.

[0036] Next, at step 304, the method includes determining an expected tractive effort of the lead truck (Expected_LT_TE) and an actual tractive effort of the lead truck (Actual TE LT). The expected tractive effort of the lead truck may be determined based on a throttle notch of the vehicle or could be based on a tractive effort reference input from the remote or multi-unit vehicle. For example, the throttle notch could be based on operator input or remote vehicle control input. The expected tractive effort for the lead truck of the vehicle may then be obtained from the expected tractive effort calculated for the vehicle. In one example, the expected tractive effort for the lead truck may be calculated as follows:

$$\text{Expected_}(LT_TE) = \text{Expected Vehicle Tractive Effort}/2$$

[0037] In some examples, the expected tractive effort of the lead truck may be further based on one or more derations of the traction motors of the lead truck. Thus, in these examples, the expected tractive effort of the lead truck may be determined as follows:

$$\text{Expected_}(LT_TE) = f(\text{Expected Vehicle Tractive Effort and one or more derations of the traction motors of the lead truck})$$

[0038] In some examples, one or more additional derations may be applied in determining the expected tractive effort. The derations may include derations of the traction motors (e.g., reduced power output of the motors despite a higher torque request) of the lead truck, which may include a thermal deration (e.g., due to high motor temperature) and a wheel slip deration (e.g., due to detected wheel slip). The motor derations may reduce torque, but may also decrease

slip. Further, the actual tractive effort provided by the lead truck may be determined based on traction motor rotor current, air gap flux, and speed for each traction motor driving the wheels of the lead truck. In some examples, other quantities such as applied voltage, stator current, and motor RPM may be used to reconstruct motor torque, via the controller.

[0039] While trucks are disclosed and shown here, in other embodiments the wheels (if moving independently) and axles are monitored for slippage. And, the method (not shown) responds to sensed tractive effort values that are lower than determined threshold values by signaling actuators to provide tractive material and/or compressed air streams to those wheels experiencing the slippage. In one embodiment, the method (via the controller) determines that there is a chance of slippage that is higher than a determined level of chance and implements actions in advance of the slippage being measured. This may be done, for example, via navigation and location information such that the vehicle upon entering an area where slippage has been encountered before determines not to wait for measurement confirmation of slippage before implementing responsive measures to reduce or prevent slippage (e.g., dispensing tractive material). In particular, when a vehicle is rounding a turn it may be that some wheels, axles, or trucks are more prone to slippage, and the controller dispenses tractive material selectively only to those wheels, axles, or trucks that have the higher propensity to slip. In another example, a vehicle mounted video system may note some aspect of the route that indicates a higher risk of slippage (ice patch, worn section of the route, a leaf covering, etc.) and the controller may respond by selectively deploying tractive material only to those wheels, axles, or trucks that are determined to experience the elevated slippage risk. This may be in addition to the otherwise disclosed method of responding to measured or actual tractive effort (or slippage, which is the lack of tractive effort) by dispensing tractive material selectively where needed.

[0040] Next, at step 306, the method includes determining if the actual lead truck tractive effort is within a determined percentage of the expected lead truck tractive effort. That is, the method may include determining if the lead truck is able to provide actual tractive effort that does not deviate more than the determined percentage of the expected lead truck tractive effort. For example, the method includes determining if the actual lead truck tractive effort is within an upper and a lower determined percentage of the expected lead truck tractive effort (e.g., within 10-25% of the expected lead truck tractive effort).

[0041] In some examples, the method may determine if a difference between the expected lead truck tractive effort and the actual lead truck tractive effort is within a threshold difference. Said another way, the method may determine if the actual lead truck tractive effort is within a threshold deviation from the expected lead truck tractive effort.

[0042] The determined percentage and/or the threshold difference (or the threshold deviation) may be based on one or more derations of the one or more traction motors of the lead truck. In one example, if derations are not considered for expected tractive effort calculations for the lead truck (as described above), the derations may be taken into account with respect to the determined percentage and/or the threshold difference. In another example, if some derations are not considered in determining the expected lead truck tractive effort, the derations that were not considered may be utilized to determine the determined percentage. In some other examples, the determined percentage may be based on a weighted percentage of one or more derations applied for the lead truck.

[0043] If the lead truck is within the determined percentage expected tractive effort for the lead truck, the answer at step 306 is YES and the method proceeds to step 312 to evaluate tractive effort of the rear truck as discussed below.

[0044] If the answer at step 306 is NO, the method proceeds to step 308. At step 308, the method includes determining if the lead truck is operating under slipping conditions. Determining lead truck slipping conditions may include determining if one or more axles of the lead truck, such as axles of wheel-axle sets 117A - C of the lead truck, are slipping. Axle slip may be determined based on a traction motor torque of the traction motor powering the corresponding axle, an axle rotational velocity, and an axle rotational acceleration. Specifically, tractive force at a rim of the wheel is proportional to the traction motor torque. Thus, when traction motor torque decrease is detected and the axle rotational velocity and the axle rotational acceleration exceed corresponding threshold values, axle slip may be detected. In this way, each axle in the lead truck may be monitored for slip conditions based on the corresponding traction motor torque, axle rotational velocity, and axle rotational acceleration. If one or more axles are slipping, the lead truck is operating under slipping conditions.

[0045] If the answer at step 308 is NO, the method proceeds to step 312 to evaluate tractive effort of the rear truck as discussed below. If the answer at step 308 is YES, the method proceeds to step 309. At step 309, the method includes determining if the number of axles slipping is greater than a threshold. The threshold number of axles slipping may be a fixed value, such as one axle. In other examples, the threshold number of axles may be based on a total number of axles of the vehicle. For example, a larger number of axles of the vehicle (e.g., six) may result in a threshold number of axles that is larger (e.g., two axles) than when the vehicle includes a smaller number of axles (e.g., the threshold may be one axle when the vehicle includes three axles).

[0046] If the number of axles slipping is less than the threshold, mild slipping conditions exist. During the mild slipping conditions of the lead truck, tractive material may not be applied. Accordingly, when the number of axles slipping is less than the threshold, the answer at step 309 is NO, and the method proceeds to step 312 to evaluate tractive effort of the rear truck as discussed below. However, in some examples, when mild slipping conditions are present (e.g., when the number of axles slipping is less than the threshold), tractive material may be applied, but at a smaller amount than when

the number of axles slipping is equal to or greater than the threshold number of axles. For example, when mild slipping conditions are present, a first, smaller amount of tractive material (e.g., sand) may be applied via a nozzle of the lead truck in the direction of travel by actuating a valve (such as valve 202) to deliver tractive material in front of each wheel of the forward wheel-axle set (e.g., wheel-axle set 117A). The valve may be actuated for short "on" durations separated by "off" durations which may result in a smaller amount of tractive material being applied than when non-mild slipping conditions are present, as explained below.

[0047] If the number of axles slipping is greater than the threshold, the answer at step 309 is YES, and the method proceeds to step 310. At step 310, the method includes applying tractive material to the lead truck in the direction of travel. Applying tractive material to the lead truck may include delivering sand via a sand nozzle of the lead truck in the direction of travel. For example, with reference to FIGS. 1, if the lead truck is travelling in the direction of the arrow, the vehicle controller may command actuation of a valve to deliver tractive material in front of each wheel of the forward wheel-axle set via the corresponding nozzle. In some examples, tractive material delivery may be combined with compressed air delivery, in which case, the vehicle controller may command the air delivery valve to an open position so as to deliver compressed air and sand via nozzle. Note that the compressed air may be used in conjunction with the delivery of sand to actually deliver the sand in one embodiment such that sand is deposited on the route surface proximate to the wheel/route interface, and may be used to clear debris from the route surface further from the wheel/route interface to clean the route surface in another embodiment. These two uses of compressed air may be used independently of each other, or may be used simultaneously to complement each other.

[0048] Further, the amount of tractive material that is applied when more than the threshold number of axles are slipping may be greater than the amount tractive material that is applied when mild slipping conditions are present. This may be achieved by continually actuating the valve, or increasing the duration of the "on" periods relative to the actuation of the valve during the mild slipping conditions. Further still, in some examples, the application of the tractive material and the compressed air may be coordinated, rather than controlled independently. In such an example, during mild slipping conditions, only compressed air or tractive material may be applied, rather than both, while during higher slip conditions, both may be applied. Further still, the decision of whether to apply one or both of the tractive material and the compressed air may be based on the supply of compressed air and the supply of tractive material. For example, if the supply of compressed air is below a threshold, only tractive material may be applied, at least until the compressed air supply is refreshed, which may ensure adequate compressed air is available for the brakes or other compressed air consumers. If the supply of tractive material is below a threshold, compressed air may be applied in both the mild slip and higher slipping conditions, while the tractive material may only be applied when the higher slipping conditions are present, which may conserve the supply of the tractive material. The supply of tractive material may be determined in a suitable manner, such as via a sensor (e.g., a weight sensor) or via a running calculation of how much tractive material has been applied.

[0049] In this way, when the lead truck is operating under slipping conditions and a number of axles slipping is greater than a threshold, tractive material, such as sand, may be applied in front of each wheel of a first wheel-axle set of the lead truck in the direction of travel of the vehicle.

[0050] Next, the method proceeds to step 312. At step 312, the method includes determining expected tractive effort for the rear truck (Expected_RT_TE) and actual tractive effort provided by the rear truck (Actual_RT_TE). The expected tractive effort of the rear truck may be based on actual tractive effort provided by the lead truck and the total expected vehicle tractive effort. In one example, the expected tractive effort of the rear truck may be determined as follows:

$$\text{Expected_RT_TE} = \text{Expected Vehicle Tractive Effort} - \text{Actual Tractive Effort}$$

provided by the lead truck

[0051] Thus, if tractive material is applied as discussed at step 310, actual tractive effort produced by the lead truck may be calculated during application of tractive material in the direction of travel.

[0052] In some examples, the expected tractive effort of the rear truck may be further based on one or more derations of the traction motors of the rear truck. Thus, in these examples, the expected tractive effort of the rear truck may be determined as follows:

$$\text{Expected_RT_TE} = f(\text{Expected Vehicle Tractive Effort}, \text{Actual Tractive Effort}$$

provided by the lead truck, one or more derations of the traction motors of the rear truck)

[0053] In some examples, one or more additional derations may be applied in determining the expected tractive effort.

The one or more additional derations may include a thermal deration and a wheel slip deration, as explained above. Further, the actual tractive effort provided by the rear truck may be determined based on traction motor current, air gap flux, and speed for each traction motor driving the wheels of the rear truck. In some examples, other quantities such as applied voltage, stator current, and motor RPM may be used to reconstruct motor torque, via the controller.

[0054] Next, upon determining the actual and expected tractive effort of the rear truck, the method proceeds to step 314. At step 314, the method includes determining if the actual rear truck tractive effort (Actual_RT_TE) is within a second determined percentage of the expected rear truck tractive effort (Expected_RT_TE). In one example, the method may determine if the actual rear truck tractive effort is within the second determined percentage of the expected rear truck tractive effort. In some examples, the second determined percentage may be based on one or more derations of the one or more traction motors of the rear truck. Other derations, such as temperature derations and wheel slip derations, may be taken into account in setting the determined percentage of the expected rear truck tractive effort. For example, if some derations are not considered in determining the expected rear truck tractive effort, the derations that were not considered may be utilized to determine the determined percentage. In some other examples, the determined percentage may be based on a weighted percentage of one or more derations applied for the rear truck.

[0055] In another example, the method may determine if a difference between the expected rear truck tractive effort and the actual rear truck tractive effort is within a threshold difference, wherein the threshold difference is based on one or more derations of the traction motors of the rear truck. In one example, if derations are not considered in the calculation of expected rear truck tractive effort, the derations may be taken into account while determining if the expected tractive effort of the rear truck is met as discussed above.

[0056] If the actual rear truck tractive effort is within the second determined percentage of the expected tractive effort, the answer at step 314 is YES, and the method proceeds to step 320 at which the valves of the tractive material application system may be maintained at closed positions and the rear truck compressed air valve may be maintained closed. That is, tractive material is not dispensed (that is, applied) for the rear truck (e.g., not dispensed in front of second front wheel-axle set of the rear truck or any of the wheel-axle sets of the rear truck). The method then ends.

[0057] If the answer at step 314 is NO, the method proceeds to step 316. At step 316, the method includes determining if the rear truck is operating under slipping conditions. Determining if the rear truck is slipping includes determining if one or more axles of the rear truck are slipping. For example, axle slip may be detected based on traction motor torque decrease while the axle rotational velocity and the axle rotational acceleration exceed corresponding threshold values. Thus, rear truck slipping conditions may be confirmed based on detection of one or more axles of the rear truck slipping.

[0058] If the rear truck is not operating at slipping conditions, the answer at step 316 is NO, and the method proceeds to step 320. As discussed above, at step 320, the method includes maintaining the valves of the tractive material application system at closed positions and maintaining the rear truck compressed air valve closed. The method then ends.

[0059] If the rear truck is operating at slipping conditions, the answer at step 316 is YES, the method proceeds to step 317. At step 317, the method includes determining if a number of rear axles slipping is greater than a threshold number of axles. As discussed above with respect to the lead truck at step 309, the threshold number of axles slipping may be a fixed value and/or may be based on a total number of axles of the vehicle. In one example, when a total number of rear axles and a total number of lead axles are same, the threshold number for each of the lead and rear trucks may also be the same, and based on the total number of axles of the vehicle including the lead and rear trucks.

[0060] If the number of rear axles slipping is less than the threshold, the answer at step 317 is NO, and the method proceeds to step 320. At step 320, the method includes maintaining the rear tractive material application valves, and the rear truck compressed air valve at closed positions such that tractive material is not applied to the rear truck. The method then ends.

[0061] In this way, under mild slipping conditions of rear truck, the tractive material is not applied to the rear truck. However, in some examples, during mild slip conditions, tractive material and/or compressed air may be applied, where a smaller amount of tractive material is applied or only compressed air is applied, similar to the reduced amount of tractive material application described above for the lead truck.

[0062] If the number of rear axles slipping is greater than the threshold, the answer at step 317 is YES, and the method proceeds to step 318. At step 318, the method includes applying tractive material to the rear truck in the direction of travel. Applying tractive material to the rear truck may include delivering tractive material via a nozzle of the rear truck in the direction of travel. For example, with reference to FIGS. 1 and 2, if the vehicle is travelling in the direction of the arrow, the vehicle controller may command actuation of a valve to deliver tractive material in front of each wheel of second front wheel-axle set 117D of the rear truck via the respective nozzle. In some examples, tractive material delivery may be combined with compressed air delivery, in which case, the vehicle controller may the command air delivery valve to an open position so as to deliver compressed air and tractive material via a nozzle. The compressed air and tractive material may be delivered independently or in a coordinated manner, as described above.

[0063] Upon applying tractive material in front of each wheel of second front wheel-axle set of the rear truck, the method ends.

[0064] In this way, the requirement for tractive material application may be evaluated on a per truck basis for each

vehicle, and tractive material is applied on a per truck basis and based on a number of axles slipping for each truck. As a result, under mild slipping conditions, excessive use of tractive material is reduced. Consequently, the efficiency of use of tractive material is improved, and tractive material reserves may be maintained above minimum levels for greater duration of travel.

[0065] FIG. 4 shows an example operating sequence 400 for tractive material application on a per truck basis during operation of a vehicle. The vertical markers at time t_0 - t_5 represent times of interest in the sequence. In each plot shown at FIG. 4 and described below, the horizontal axis represents time and time increases from the left side of the plot to the right side of the plot.

[0066] The first graph from the top of FIG. 4 is a plot 402 of number of axles slipping for a lead truck of the vehicle versus time. The vertical axis represents the number of axles slipping for the lead truck, and the number increases in the direction of Y-axis arrow. Horizontal line 405 represents a threshold number of axles above which tractive material is applied in front of a first wheel set of the lead truck in the direction of travel.

[0067] The second graph from the top of FIG. 4 is a plot 404 of number of axles slipping for a rear truck of the vehicle versus time. The vertical axis represents the number of axles slipping for the rear truck, and the number increases in the direction of Y-axis arrow. Horizontal line 410 represents a threshold number of axles above which tractive material is applied in front of a first wheel set of the rear truck in the direction of travel.

[0068] The third graph from the top of FIG. 4 shows a plot 406 of actual tractive effort of the lead truck (actual LT tractive effort) versus time, and a plot 415 of expected tractive effort of the lead truck (also referred to as desired LT tractive effort). The vertical axis represents the tractive effort for the lead truck, and the tractive effort increases in the direction of Y-axis arrow.

[0069] The fourth graph from the top of FIG. 4 shows a plot 408 of actual tractive effort of the rear truck (actual RT tractive effort) versus time, and a plot 420 of expected tractive effort of the rear truck (also referred to as desired RT tractive effort). The vertical axis represents the tractive effort for the rear truck, and the tractive effort increases in the direction of Y-axis arrow.

[0070] The fifth graph from the top of FIG. 4 shows a plot 412 of tractive material application status for the lead truck versus time. The vertical axis represents an ON/OFF status for the tractive material application for the lead truck.

[0071] The sixth graph from the top of FIG. 4 shows a plot 414 of tractive material application status for the rear truck versus time. The vertical axis represents an ON/OFF status for the tractive material application for the rear truck.

[0072] At t_0 , and between t_0 and t_1 , the actual LT tractive effort (plot 406) of the lead truck meets the desired LT tractive effort (plot 415) or within a threshold deviation from the desired LT tractive effort or within a determined percentage from the desired LT tractive effort; and the actual RT tractive effort (plot 408) meets the desired RT tractive effort (plot 420) or within a second threshold deviation from the desired RT tractive effort or within a second determined percentage from the desired RT tractive effort. Further, the number of axles slipping for each of the lead truck (plot 402) and the rear truck (plot 404) is zero. Consequently, tractive material is not applied for the lead truck or the rear truck, as indicated by OFF status for the lead truck tractive material application (plot 412) and the rear truck tractive material application (plot 414). That is, tractive material is not dispensed via a nozzle in front of each wheel of first front wheel-axle set 117A of the lead truck or nozzle in front of each wheel of second front wheel-axle set 117D of the rear truck. While the example sequence illustrated herein at FIG. 4 is described with respect to the actual LT tractive effort meeting the desired LT tractive effort or the actual LT tractive effort decreasing below the desired LT tractive effort, it will be appreciated that the actual LT tractive effort may be evaluated with respect to the threshold deviation from the desired LT tractive effort or with respect to the determined percentage of the desired LT tractive effort. Similarly, while the example sequence illustrated at FIG. 4 is described with respect to the actual RT tractive effort meeting the desired RT tractive effort or the actual RT tractive effort decreasing below the desired RT tractive effort, it will be appreciated that the actual RT tractive effort may be evaluated with respect to the second threshold deviation from the desired RT tractive effort or with respect to the second determined percentage of the desired RT tractive effort.

[0073] At t_1 , and between t_1 and t_2 , the actual LT tractive effort (plot 406) drops below the desired LT tractive effort (plot 415), and the number of lead truck axles slipping (plot 402) is greater than the threshold. In response to the decrease in actual LT tractive effort and the number of axles slipping greater than the threshold, the tractive material is applied towards a first set of wheels of the lead truck in the direction of travel of the vehicle (plot 412). That is, tractive material is dispensed via a nozzle in front of each wheel of first front wheel-axle set 117A of the lead truck. Further, at t_1 and between t_1 and t_2 , the actual RT tractive effort (plot 408) may meet the desired RT tractive effort (plot 420) or be within threshold deviation from the desired RT tractive effort; and the number of rear truck axles slipping (plot 404) may be zero. Therefore, tractive material may not be applied to the rear truck (plot 414).

[0074] At t_2 , and between t_2 and t_3 , in response to application of the tractive material for the lead truck, the actual tractive effort increases but remains below the expected LE tractive effort (plot 406), and the number axles slipping decreases (plot 402) but remains above the determined threshold. Thus, tractive material application is continued for the lead truck (plot 412). At t_2 , and between t_2 and t_3 , the actual RT tractive effort (plot 408) starts to drop below the desired RT tractive effort (plot 420). Further, the number of rear truck axles slipping (plot 404) is greater than the threshold

410. As a result, tractive material is applied towards a first set of wheels of the rear truck (plot 414). That is, tractive material is dispensed via a nozzle in front of each wheel of second front wheel-axle set of the rear truck.

[0075] At t3, and between t3 and t4, the actual LT tractive effort (plot 406) meets the desired LT tractive effort or is within the threshold deviation from the desired LT tractive effort; and the actual RT tractive effort increases (plot 408) but remains below the desired RT tractive effort. Further, the number of rear truck axles slipping (plot 404) is greater than the threshold 410. As a result, the tractive material application for the lead truck is turned OFF (plot 412) and the tractive material application for the rear truck continues (plot 414).

[0076] At t4 and between t4 and t5, the actual LT tractive effort (plot 406) meets the desired LT tractive effort or is within the threshold deviation from the desired LT tractive effort. During this time, deration may be applied to one or more traction motors of the rear truck, and consequently, the actual RT tractive effort (plot 408) continues to remain below the desired RT tractive effort (plot 420). However, the reduction in actual RT tractive effort is due to the derations of the rear traction motor, and the number of rear truck axles slipping is less than the threshold 410 but not zero, indicating mild slip conditions. Responsive to the number of rear axles slipping being less than the threshold 410, even though the actual RT tractive effort does not meet the desired RT tractive effort, tractive material is not applied for the rear truck. Said another way, taking into consideration traction motor derations and mild slip conditions, the rear truck tractive material application is turned OFF (plot 414). Lead truck tractive material is also OFF (plot 412) responsive to the actual LT tractive effort (plot 406) meeting the desired LT tractive effort.

[0077] At t5 and beyond, lead truck and rear truck tractive material application are turned OFF (plots 412 and 414) in response to the actual LT tractive effort meeting the desired LT tractive effort and the actual RT tractive effort meeting the desired RT tractive effort respectively.

[0078] In this way, application of tractive material may be adjusted for each truck of a vehicle based on actual and expected tractive efforts for each truck, and the number of axles slipping for each truck. In one embodiment, the adjustment is made per wheel, and in another embodiment the adjustment is may per axle. And, in one embodiment, the adjustment is made per vehicle in a vehicle group relative to another vehicle in a vehicle group. In this example, if a lead vehicle is experience slippage, the trailing vehicle may be expected to experience slippage while traversing the same portion of the route.

[0079] By adjusting application of tractive material for each truck as discussed above, it may be possible to reduce excessive application of tractive material. That is, less tractive material is utilized while still providing the same or better adhesion between the wheel and the route. This in turn may reduce wear and tear of the wheels and the tracks caused by excessive sanding. Furthermore, by dispensing less tractive material based on the actual need of each truck (instead of the whole vehicle) some of the tractive materials applied to the lead truck may help improve adhesion for the rear truck. Thus, the rear-truck already has some traction provided by applying tractive material to the lead truck. As the tractive efforts and tractive material application requirement for each truck is calculated individually, the traction material application requirement for the subsequent trucks takes into account the tractive material applied to the lead trucks. Consequently, by determining need for traction material application on a per truck basis, the accuracy in determining the tractive material application requirement is greatly improved. The same tractive advantage may be applicable for subsequent vehicles in a multi-unit vehicle. This may reduce tractive material consumption for the full vehicle and/or vehicle group. Taken together, the system as a whole, including the vehicle and the tracks may reduce tractive material usage and mechanical wear and tear. The cost of operation and maintenance may be reduced, too, as reduced sand dispensation may require fewer or less frequent stops to replenish the sand reservoirs.

[0080] FIG. 5 shows a flow chart illustrating a method 500 for adjusting application of traction material for a rail vehicle, such as the vehicle of FIG. 1, according to another embodiment of the disclosure. The method may be carried out by a controller. The method may be carried out with respect to one vehicle, some vehicles, or each and every vehicle in a vehicle group.

[0081] The method begins at step 502. At step 502, the method includes estimating and/or measuring vehicle operating conditions for a vehicle of a rail vehicle consist. The vehicle may be any of a lead vehicle and one or more trailing vehicles of the rail vehicle consist. The operating conditions may include traction motor torque of each traction motor, traction motor current for each traction motor, an axle rotational velocity, tractive effort (TE), throttle or notch setting, wheel speed, rate of acceleration or deceleration, braking condition, force, wheel slip/slide, fuel consumption, wheel creep, and engine horsepower. These operating conditions may be estimated and/or measured on a per wheel, per axle, per truck, and/or per vehicle basis. Thus, the vehicle operating conditions may include operating conditions of a lead truck of the vehicle, and operating conditions of a rear truck of the vehicle in addition to operating conditions of the vehicle.

[0082] Next, at step 504, the method includes determining an expected tractive effort of the lead truck (Expected_LT_TE) and an actual tractive effort of the lead truck (Actual TE LT), as explained above with respect to FIG. 3. At step 506, the method includes determining if the actual lead truck tractive effort is within range of the expected lead truck tractive effort and if no wheel or axle slip is detected. Determining if the actual lead truck tractive effort is within range of the expected lead truck tractive effort may include determining if the actual lead truck tractive effort is within a determined percentage of the expected lead truck tractive effort, or if a difference between the expected lead truck

tractive effort and the actual lead truck tractive effort is within a threshold difference, similar to method 300 explained above.

[0083] If the actual tractive effort of the lead truck is within range of the expected tractive effort for the lead truck and no wheel or axle slip is detected, or alternatively if the actual tractive effort of the lead truck is not within range of the expected tractive effort of the lead truck but no wheel or axle slip is detected, the answer at step 506 is YES and the method proceeds to step 512 to evaluate tractive effort of the rear truck as discussed below.

[0084] If the answer at step 506 is NO, the method proceeds to step 508. At step 508, the method includes determining if the right and left wheels of the lead truck are slipping equally. This may include determining if the right wheel(s) are slipping, if the left wheel(s) are slipping, or if both the right and left wheels are slipping. If both the right and left wheels are slipping, the method may determine if the wheels are slipping by the same amount, or if one of the wheels is slipping more than the other. The determination of the wheel slip may be made on a per-axle basis, e.g., the right wheel of a given axle may be compared to the left wheel of the given axle. In some examples, only one wheel-axle set may be analyzed (e.g., the forward most wheel-axle set in the direction of travel). In other examples, all the wheel-axle sets of the lead truck may be analyzed.

[0085] Wheel slip may be determined based on the traction motor torque of the traction motor powering the corresponding axle, a rotational velocity of each wheel, and a rotational acceleration of each wheel. As explained above, tractive force at a rim of the wheel is proportional to the traction motor torque. Thus, when traction motor torque decrease is detected and the wheel rotational velocity and the wheel rotational acceleration exceed corresponding threshold values, wheel slip may be detected. In this way, each wheel of a given axle (or each wheel of each axle) in the lead truck may be monitored for slip conditions based on the corresponding traction motor torque, wheel rotational velocity, and wheel rotational acceleration. If one or more wheels are slipping, the lead truck is operating under slipping conditions.

[0086] If the answer at step 508 is NO, the method proceeds to step 509 to apply tractive material in proportion to the wheel slip of the lead truck in the direction of travel. For example, if the right wheel of a given axle is slipping but the left wheel is not, tractive material may be applied only to the right side and not the left side of the lead truck. In another example, if the right side is slipping more than the left side, tractive material may be applied to both sides of the lead truck, but more tractive material may be applied to the right side than the left side. As explained previously, applying tractive material may include delivering sand via a sand nozzle of the lead truck in the direction of travel. For example, with reference to FIGS. 1, if the lead truck is travelling in the direction of the arrow, the vehicle controller may command actuation of a valve to deliver tractive material in front of one or both wheels (based on the differential wheel slip) of the forward wheel-axle set via the corresponding nozzle. However, it will be appreciated that similar to the method 300 described above, method 500 may evaluate each axle of the lead truck for wheel slip, and may only apply tractive material when more than a threshold number of wheels are slipping, such as more than one wheel. Method 500 then proceeds to step 512 to evaluate tractive effort of the rear truck as discussed below.

[0087] If the answer at step 508 is YES, the method proceeds to step 510. At step 510, tractive material may be applied to both sides of the lead truck in the direction of travel, as it is determined that both wheels are slipping equally. However, it will be appreciated that similar to the method 300 described above, method 500 may evaluate each axle of the lead truck for wheel slip, and may only apply tractive material when more than a threshold number of wheels are slipping, such as more than wheel. The method then proceeds to step 512.

[0088] At step 512, the method includes determining expected tractive effort for the rear truck (Expected_RT_TE) and actual tractive effort provided by the rear truck (Actual_RT_TE), which may be performed the same as the rear truck tractive effort calculations described above with respect to FIG. 3, such that the expected tractive effort of the rear truck may be based on actual tractive effort provided by the lead truck and the total expected vehicle tractive effort, and may be further based on one or more derations of the traction motors of the rear truck.

[0089] Next, upon determining the actual and expected tractive effort of the rear truck, the method proceeds to step 514. At step 514, the method includes determining if the actual rear truck tractive effort is within range of the expected rear truck tractive effort and if no wheel or axle slip is detected. Determining if the actual rear truck tractive effort is within range of the expected rear truck tractive effort may include determining if the actual rear truck tractive effort is within a determined percentage of the expected rear truck tractive effort, or if a difference between the expected rear truck tractive effort and the actual rear truck tractive effort is within a threshold difference, similar to method 300 explained above.

[0090] If the actual tractive effort of the rear truck is within range of the expected tractive effort for the rear truck and no wheel or axle slip is detected, or alternatively if the actual tractive effort of the rear truck is not within range of the expected tractive effort of the rear truck but no wheel or axle slip is detected, the answer at step 514 is YES and the method proceeds to step 520. At step 520, the method includes maintaining the valves of the tractive material application system at closed positions and maintaining the rear truck compressed air valve closed. That is, tractive material is not dispensed (that is, applied) for the rear truck (e.g., not dispensed in front of second front wheel-axle set of the rear truck or any of the wheel-axle sets of the rear truck). The method then ends.

[0091] If the answer at step 514 is NO, the method proceeds to step 516. At step 516, the method includes determining if the right and left wheels of the rear truck are slipping equally. This may include determining if the right wheel(s) are

slipping, if the left wheel(s) are slipping, or if both the right and left wheels are slipping. If both the right and left wheels are slipping, the method may determine if the wheels are slipping by the same amount, or if one of the wheels is slipping more than the other. The determination of the wheel slip may be made on a per-axle basis, e.g., the right wheel of a given axle may be compared to the left wheel of the given axle. In some examples, only one wheel-axle set may be analyzed (e.g., the forward most wheel-axle set of the rear truck in the direction of travel). In other examples, all the wheel-axle sets of the rear truck may be analyzed.

[0092] Wheel slip may be determined based on the traction motor torque of the traction motor powering the corresponding axle, a rotational velocity of each wheel, and a rotational acceleration of each wheel. As explained above, tractive force at a rim of the wheel is proportional to the traction motor torque. Thus, when traction motor torque decrease is detected and the wheel rotational velocity and the wheel rotational acceleration exceed corresponding threshold values, wheel slip may be detected. In this way, each wheel of a given axle (or each wheel of each axle) in the rear truck may be monitored for slip conditions based on the corresponding traction motor torque, wheel rotational velocity, and wheel rotational acceleration. If one or more wheels are slipping, the rear truck is operating under slipping conditions.

[0093] If the answer at step 516 is NO, the method proceeds to step 517 to apply tractive material in proportion to the wheel slip of the rear truck in the direction of travel. For example, if the right wheel of a given axle is slipping but the left wheel is not, tractive material may be applied only to the right side and not the left side of the rear truck. In another example, if the right side is slipping more than the left side, tractive material may be applied to both sides of the rear truck, but more tractive material may be applied to the right side than the left side. As explained previously, applying tractive material may include delivering sand via a sand nozzle of the rear truck in the direction of travel. For example, with reference to FIGS. 1, if the rear truck is travelling in the direction of the arrow, the vehicle controller may command actuation of a valve to deliver tractive material in front of one or both wheels (based on the differential wheel slip) of the forward wheel-axle set via the corresponding nozzle. However, it will be appreciated that similar to the method 300 described above, method 500 may evaluate each axle of the rear truck for wheel slip, and may only apply tractive material when more than a threshold number of wheels are slipping, such as more than one wheel. Method 500 then ends.

[0094] If the answer at step 516 is YES, the method proceeds to step 518. At step 518, tractive material may be applied to both sides of the rear truck in the direction of travel, as it is determined that both wheels are slipping equally. However, it will be appreciated that similar to the method 300 described above, method 500 may evaluate each axle of the rear truck for wheel slip, and may only apply tractive material when more than a threshold number of wheels are slipping, such as more than wheel. The method then ends.

[0095] In this way, the requirement for tractive material application may be evaluated on a per truck basis for each vehicle, as well as on a per-wheel basis, and tractive material is applied on a per truck basis and per-wheel basis, and in some examples may also be based on a number of wheels or axles slipping for each truck. As a result, under mild slipping conditions, excessive use of tractive material is reduced and the tractive material may be directed to only the slipping wheel(s). Consequently, the efficiency of use of tractive material is improved, and tractive material reserves may be maintained above minimum levels for greater duration of travel.

[0096] FIG. 6 shows an example operating sequence 600 for tractive material application on a per truck and per wheel basis during operation of a vehicle. The vertical markers at time t0-t5 represent times of interest in the sequence. In each plot shown at FIG. 6 and described below, the horizontal axis represents time and time increases from the left side of the plot to the right side of the plot.

[0097] The first graph from the top of FIG. 6 is a plot 602 of number of axles slipping for a lead truck of the vehicle versus time. The vertical axis represents the number of axles slipping for the lead truck, and the number increases in the direction of Y-axis arrow. Horizontal line 604 represents a threshold number of axles above which tractive material is applied in front of a first wheel set of the lead truck in the direction of travel.

[0098] The second graph from the top of FIG. 4 shows a plot 606 of actual tractive effort of the lead truck (actual LT tractive effort) versus time, and a plot 608 of expected tractive effort of the lead truck (also referred to as desired LT tractive effort). The vertical axis represents the tractive effort for the lead truck, and the tractive effort increases in the direction of Y-axis arrow.

[0099] The third graph from the top of FIG. 6 shows a plot 609 of wheel slip state for an axle of the lead truck, such as the forward-most axle. The vertical axis represents three slip states, a left slip state where only the left wheel is slipping, a right slip state where only the right wheel is slipping, and a both wheels slip state where both wheels are slipping. It is to be appreciated that when no wheels are slipping, the plot is not visible (e.g., is aligned with the horizontal axis).

[0100] The fourth graph from the top of FIG. 6 shows a plot 610 of tractive material application status for a right side of the lead truck versus time. The vertical axis represents an ON/OFF status for the tractive material application for the right side of the lead truck.

[0101] The fifth graph from the top of FIG. 6 shows a plot 612 of tractive material application status for a left side of the lead truck versus time. The vertical axis represents an ON/OFF status for the tractive material application for the left side of the lead truck.

[0102] FIG. 6 shows a sequence of operations for only the lead truck, in order to maintain visual clarity. However, it is to be appreciated that tractive material may be applied in front of the rear truck in a similar manner (e.g., based on the wheel slip states).

[0103] At t_0 , and between t_0 and t_1 , the actual LT tractive effort (plot 606) of the lead truck meets the desired LT tractive effort (plot 608) or within a threshold deviation from the desired LT tractive effort or within a determined percentage from the desired LT tractive effort. Further, the number of axles slipping for the lead truck (plot 602) is zero. Consequently, tractive material is not applied for the lead truck, as indicated by OFF status for the right side lead truck tractive material application (plot 610) and the left side front truck tractive material application (plot 612).

[0104] At t_1 , and between t_1 and t_2 , the actual LT tractive effort (plot 606) drops below the desired LT tractive effort (plot 608), and the number of lead truck axles slipping (plot 602) is greater than the threshold. Further, the wheel slip state (plot 609) indicates that both the left wheel and the right wheel are slipping. In response to the decrease in actual LT tractive effort, the number of axles slipping greater than the threshold, and both wheels slipping, the tractive material is applied towards each of wheels of the first set of wheels of the lead truck in the direction of travel of the vehicle (plots 610 and 612). That is, tractive material is dispensed via a nozzle in front of each wheel of first front wheel-axle set 117A of the lead truck.

[0105] At t_2 , and between t_2 and t_3 , in response to application of the tractive material for the lead truck, the actual tractive effort increases but remains below the expected LE tractive effort (plot 606), and the number axles slipping is maintained (plot 602) above the determined threshold. However, the wheel slip state (plot 609) changes and only the right wheel is slipping. Thus, tractive material application is continued for the right side of the lead truck (plot 610) but is discontinued for the left side of the lead truck (plot 612).

[0106] At t_3 , and between t_3 and t_4 , the actual LT tractive effort (plot 606) is near the desired LT tractive effort but has not reached the desired LT tractive effort. Further, the number of lead truck axles slipping (plot 602) is equal to the threshold 604, and the wheel slip state (plot 609) shows that the right wheel is still slipping (and not the left wheel). As a result, the tractive material application for the right side of the lead truck is turned OFF (plot 610) and the tractive material application for the left side of the lead truck continues to be shut off (plot 612).

[0107] At t_4 and beyond, right and left side lead truck tractive material applications are turned OFF (plots 610 and 612) in response to the actual LT tractive effort meeting the desired LT tractive effort.

[0108] In this way, application of tractive material may be adjusted for each wheel and for each truck of a vehicle based on actual and expected tractive efforts for each truck, the number of axles slipping for each truck, and wheel slip state differential (e.g., whether both wheels are slipping or just one wheel is slipping). In this embodiment, the adjustment is made per wheel, and in another embodiment the adjustment is made per axle (e.g., as shown in FIG. 4). And, in one embodiment, the adjustment is made per vehicle in a vehicle group relative to another vehicle in a vehicle group. In this example, if a lead vehicle is experiencing slippage, the trailing vehicle may be expected to experience slippage while traversing the same portion of the route.

[0109] By adjusting application of tractive material for each truck and each wheel as discussed above, it may be possible to reduce excessive application of tractive material. That is, less tractive material is utilized while still providing the same or better adhesion between the wheel and the route. This in turn may reduce wear and tear of the wheels and the tracks caused by excessive sanding. Furthermore, by dispensing less tractive material based on the actual need of each truck (instead of the whole vehicle) and/or each wheel, some of the tractive materials applied to the lead truck may help improve adhesion for the rear truck. Thus, the rear-truck already has some traction provided by applying tractive material to the lead truck. As the tractive efforts and tractive material application requirement for each truck is calculated individually, the traction material application requirement for the subsequent trucks takes into account the tractive material applied to the lead trucks. Consequently, by determining need for traction material application on a per truck basis, the accuracy in determining the tractive material application requirement is greatly improved. The same tractive advantage may be applicable for subsequent vehicles in a multi-unit vehicle. This may reduce tractive material consumption for the full vehicle and/or vehicle group. Taken together, the system as a whole, including the vehicle and the tracks may reduce tractive material usage and mechanical wear and tear. The cost of operation and maintenance may be reduced, too, as reduced sand dispensation may require fewer or less frequent stops to replenish the sand reservoirs. In some embodiments, the vehicle controller may include instructions in non-transitory memory for: during a first rail vehicle operating condition, controlling application of the tractive material on a vehicle basis for each vehicle of the rail vehicle; and during a second different rail vehicle operating condition, controlling application of the tractive material on a per truck basis for each vehicle of the rail vehicle. Determination of tractive material application for each truck of a vehicle of the rail vehicle is discussed herein at FIGS. 3 and 4. Determining tractive material application on a vehicle basis includes determining an actual vehicle tractive effort based on total traction motor torque, speed, and current of all the traction motors of the vehicle and determining an expected vehicle tractive effort based on a desired notch current based on a notch position set by an operator. Determining tractive material application on a vehicle basis further includes responsive to the difference between the expected vehicle tractive effort and the actual vehicle tractive effort greater than a threshold difference or responsive to the actual vehicle tractive force not equal to the expected vehicle tractive effort, determining a number of

axles slipping for the vehicle. Determining tractive material application on a vehicle basis further includes, when the number of axles slipping for the vehicle is greater than a threshold number of axles, actuating, via the vehicle controller, traction material application nozzle to deliver sand to each of a lead truck and a rear truck of the vehicle. In this way, in some embodiments, during certain rail vehicle operating conditions, the application of tractive material may be performed for the vehicle instead of determining tractive effort individually for each truck and adjusting tractive material application for each truck based on the respective individual tractive effort of each truck. In one example, the first rail vehicle operating condition during which the determination of application of tractive material is performed for the vehicle includes operating conditions when an amount of tractive material in a tractive material reservoir is greater than a threshold amount. In this case, when the amount of tractive material decrease below the threshold amount, tractive material application determination may be performed on a per truck basis to conserve tractive material. In another example, the first rail vehicle operating condition during which the determination of application of tractive material is performed for the vehicle may additionally or alternatively include operating conditions when expected tractive effort is greater than a higher threshold expected tractive effort. For example, during certain vehicle operating conditions, when high rail vehicle operating speed is desired (e.g., high power notch setting), and/or when tractive material amount in the reservoir is above the threshold amount, application of tractive material may be decided on a vehicle level. In these scenarios, when the expected vehicle tractive effort is below the higher threshold and/or when the tractive material amount is at or below the threshold, application of tractive material for the vehicle may be decided on a per truck basis.

[0110] In one embodiment, an additional system and associated set of components is provided with the tractive material application system. In this embodiment, an air nozzle system may be disposed proximate to the wheel/route interface. Unlike the tractive material application system, the air nozzle system directs an accelerated stream of air at the route surface, which may be angled in a determined manner. In one embodiment, the angle may be in a direction that is away from the wheel while the tractive material is directed towards the wheel (and specifically the wheel/route interface). The air may impact the route (e.g., the rail's top surface) to remove debris and material and thus increase adhesion of the wheel, which results in an increase of tractive effort for the wheel, axle and/or truck. Naturally, the air nozzle system should not be applied antagonistically to remove tractive material dispensed by the air nozzle system. However, the controller may select the air nozzle system in place of the air nozzle system, or vice versa. Or the controller may select both for use - simultaneously or during adjacent periods - so that the route surface is cleaned by the air nozzle system and the wheel route interface receives tractive material from the tractive material application system. As with the methods described herein, the controller may actual the air nozzle system to increase tractive effort independently for a wheel, axle or truck based on the adhesion level for that given wheel, axle or truck. In this way, rather than conserving tractive material what may be conserved is compressed air. While compressed air is replenishable via a compressor (not shown) it may not be replenished as quickly as it may be needed for operations, and therefore may be considered a valuable commodity in that capacity. Further, the more compressed air that is used, the harder a compressor must work and therefore the life of that compressor may shorten. In one embodiment, the air nozzle system may be used to extend the working period for a given amount of tractive material. The tractive material having a finite volume, and the need for replenishment when the store has been depleted.

[0111] Furthermore, references to "one embodiment" of the invention do not exclude the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising," "including," or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property. The terms "including" and "in which" are used as the plain-language equivalents of the respective terms "comprising" and "wherein." Moreover, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements or a particular positional order on their objects. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory and may be carried out by the control system including the controller in combination with the various sensors, actuators, and other engine hardware. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the engine control system, where the described actions are carried out by executing the instructions in a system including the various engine hardware components in combination with the electronic controller.

[0112] This written description uses examples to disclose the invention, including the best mode, and also to enable a person of ordinary skill in the relevant art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the

scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

5 Claims

1. A method for a vehicle, comprising:
controlling application of tractive material for each of one or more wheel, axle, or truck of the vehicle based on
respective individual actual tractive effort of each of the one or more wheel, axle, or truck.
2. The method of claim 1, wherein controlling application of tractive material includes delivering tractive material re-
sponsive to an actual tractive effort for a given wheel, axle, or truck being less than an expected tractive effort of
the given wheel, axle, or truck.
3. The method of claim 1, wherein the actual tractive effort for the given truck is based at least in part on one or more
of stator current, applied voltage, air gap flux, and speed feedback from one or more traction motors powering one
or more axles of the given truck.
4. The method of claim 1, wherein controlling application of tractive material for each of the one or more wheel, axle,
or truck includes controlling application of tractive material individually for a lead wheel, axle, or truck and a rear
wheel, axle, or truck.
5. The method of claim 4, wherein controlling application of tractive material individually for the lead wheel, axle, or
truck and the rear wheel, axle, or truck includes responding to a sensed lead wheel, axle, or truck tractive effort
being less than an expected lead wheel, axle, or truck tractive effort.
6. The method of claim 1, further comprising delivering tractive material to a wheel, axle, or truck in response to a
signal indicating slipping of that specific wheel, axle, or truck.
7. The method of claim 2, further comprising delivering a stream of compressed air to a portion of a route in advance
of an interface of a wheel with the route, and not disturbing or removing tractive material from the route via the
stream of compressed air.
8. The method of claim 1, further comprising derating a lead truck traction motor, a rear truck traction motor, or both
a lead and rear truck motor based at least in part on an expected lead truck tractive effort.
9. The method of claim 2, wherein delivering tractive material includes delivering compressed air along with delivering
tractive material.
10. A controller for a vehicle having one or more of a wheel, axle, or truck, comprising:
one or more processors configured to initiate an application of tractive material for the one or more of the wheel,
axle, or truck of the vehicle based on respective individual actual tractive effort of the one or more of the wheel,
axle, or truck.
11. The controller of claim 10, wherein the controller is configured to apply tractive material responsive to an actual
tractive effort for a given wheel, axle, or truck being less than an expected tractive effort of the given wheel, axle,
or truck.
12. The controller of claim 11, wherein the actual tractive effort for the given truck is based at least in part on one or
more of stator current, applied voltage, air gap flux, and speed feedback from one or more traction motors powering
one or more axles of the given truck.
13. The controller of claim 10, wherein the vehicle further includes a tractive material reservoir coupled to a plurality of
nozzles, each nozzle positioned to deliver the tractive material to the one or more of the wheel, axle, or truck.
14. The controller of claim 10, wherein the one or more processors are configured to initiate the application of the tractive
material for a first wheel of the vehicle independent of application of the tractive material for a second wheel of the
vehicle, the first and second wheels positioned on a same axle.

15. The controller of claim 10, wherein the one or more processors are configured to initiate the application of the tractive material for a first truck of the vehicle independent of application of the tractive material for a second truck of the vehicle.

16. The controller of claim 10, wherein the vehicle further includes a compressed air source configured to deliver a stream of compressed air to a portion of a route in advance of an interface of a wheel with the route, and not disturb or remove tractive material from the route via the stream of compressed air.

17. A vehicle comprising the controller of claim 10.

18. A vehicle system comprising:

a lead truck including a lead truck drive system including one or more lead truck traction motors coupled in driving relationship to a plurality of wheels of the lead truck, the one or more traction motors configured to provide motive power for the lead truck;

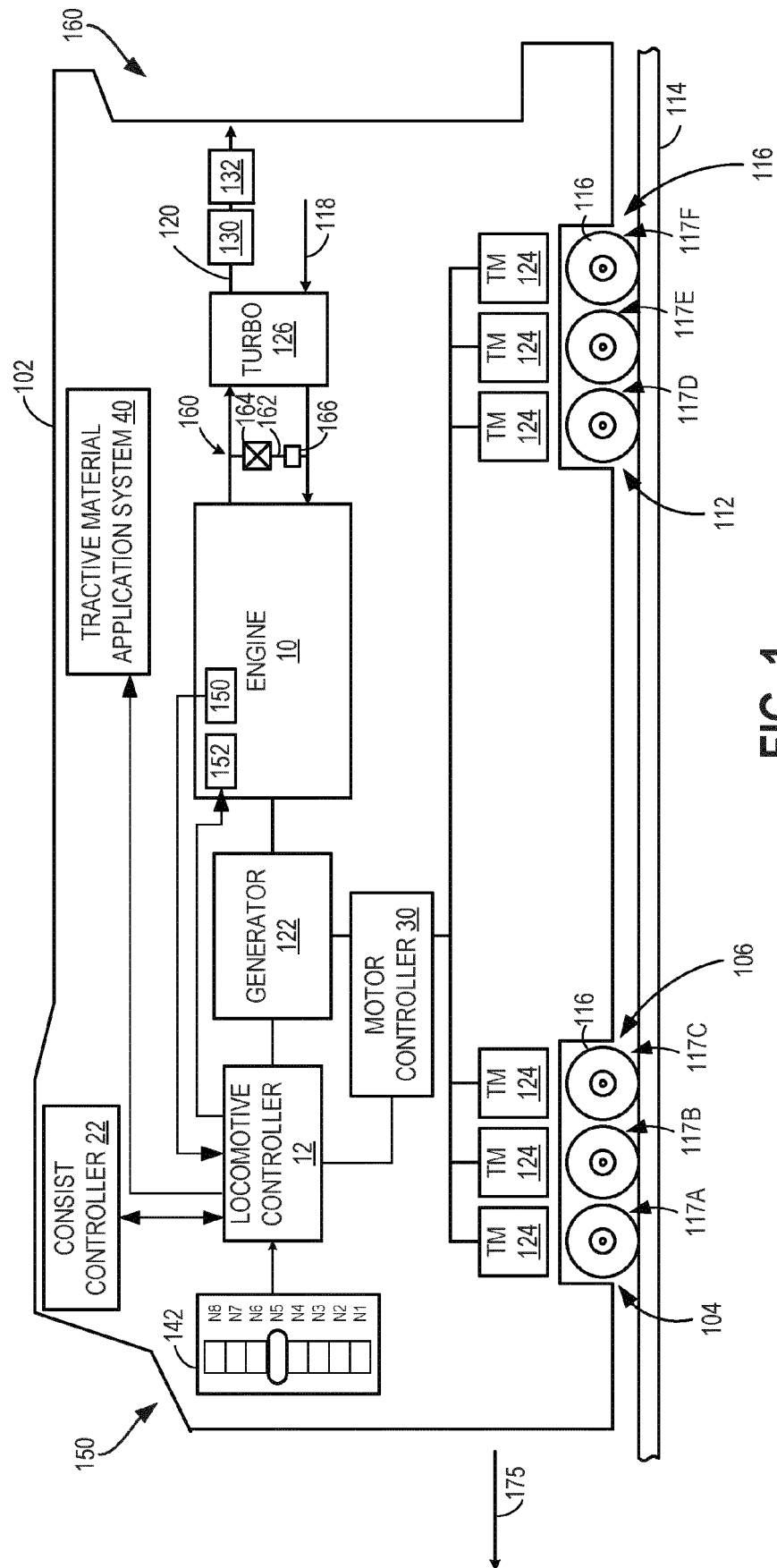
a rear truck including a rear truck drive system including one or more rear truck traction motors coupled in driving relationship to a plurality of wheels of the rear truck, the one or more traction motors configured to provide motive power for the rear truck;

a tractive material application system including a common reservoir for tractive material, the common reservoir fluidly coupled to one or more lead truck nozzles and one or more rear truck nozzles, the one or more lead truck nozzles and the one or more rear truck nozzles delivering tractive material ahead of the plurality of lead truck wheels and plurality of rear truck wheels respectively;

a controller configured with instructions in non-transitory memory that when executed cause the controller to: responsive to the lead truck slipping and a number of lead truck axles slipping greater than a threshold number, deliver tractive material via the one or more lead truck nozzles; otherwise operate the vehicle without delivering tractive material via the one or more lead truck nozzles; and responsive to the rear truck slipping and a number of rear truck axles slipping greater than the threshold number, deliver tractive material via the one or more rear truck nozzles; otherwise operate the vehicle without delivering tractive material via the one or more rear truck nozzles.

19. The vehicle system of claim 18, wherein the lead truck slipping is based on an actual tractive effort of the lead truck being less than an expected lead truck tractive effort, the expected lead truck tractive effort based on an expected vehicle tractive effort; and the rear truck slipping based on an actual tractive effort of the rear truck being less than an expected rear truck tractive effort, the expected rear truck tractive effort based on the actual lead truck tractive effort and the expected vehicle tractive effort.

20. The vehicle system of claim 19, wherein the controller includes further instructions that when executed causes the controller to: adjust the expected lead truck tractive effort based on one or more deration conditions of the one or more lead truck traction motors; and adjust the expected rear truck tractive effort based on one or more deration conditions of the one or more rear truck traction motors.



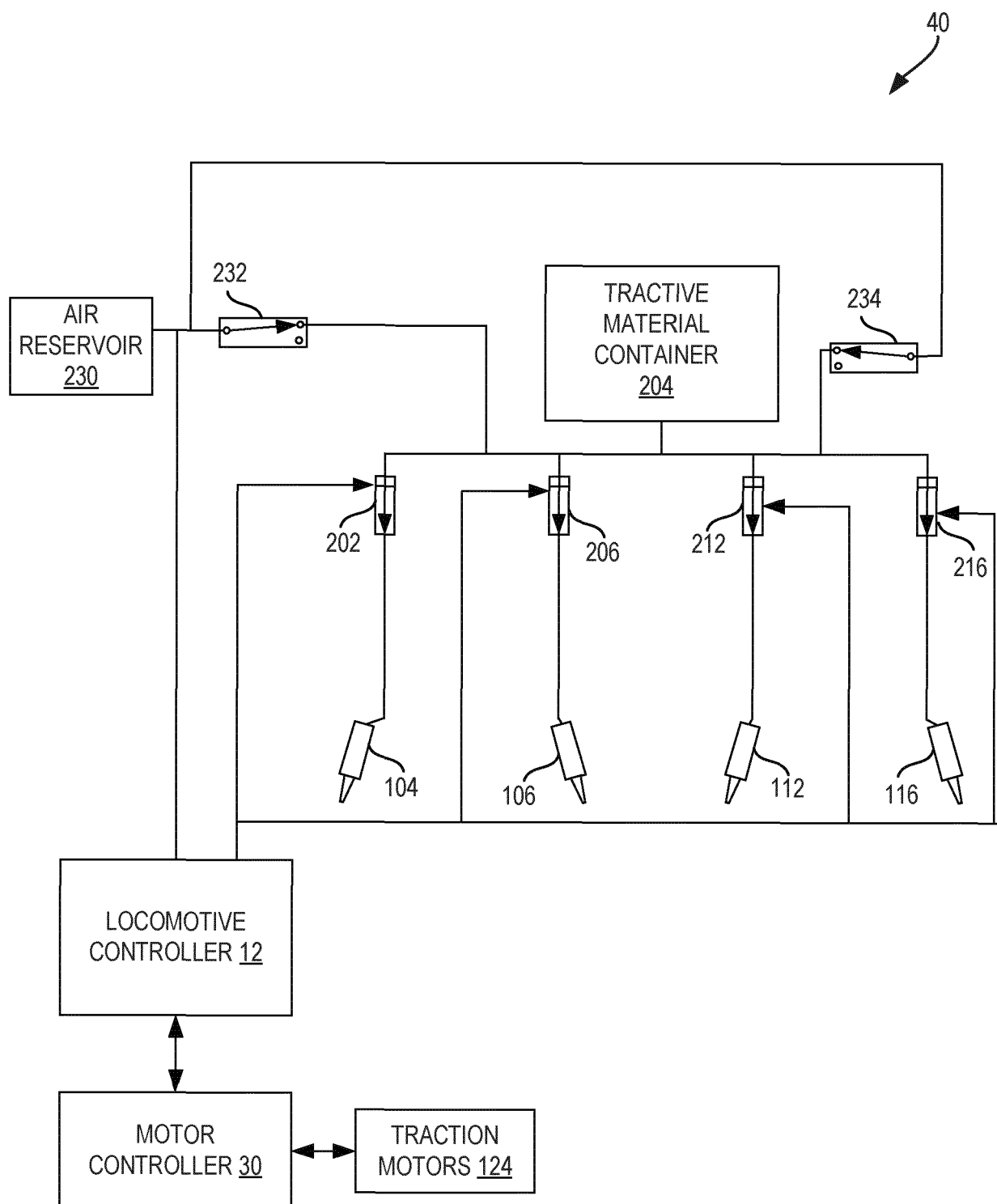


FIG. 2

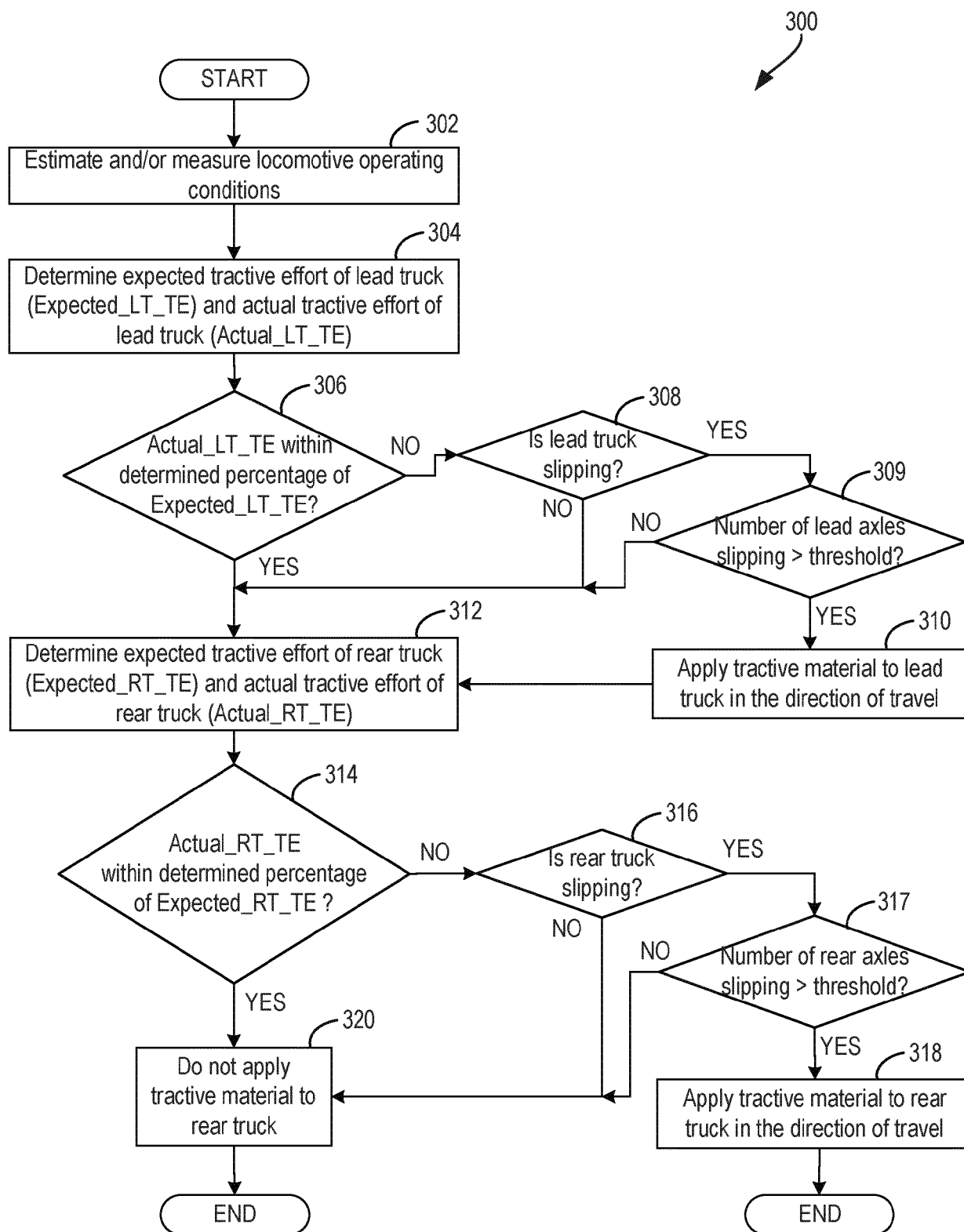


FIG. 3

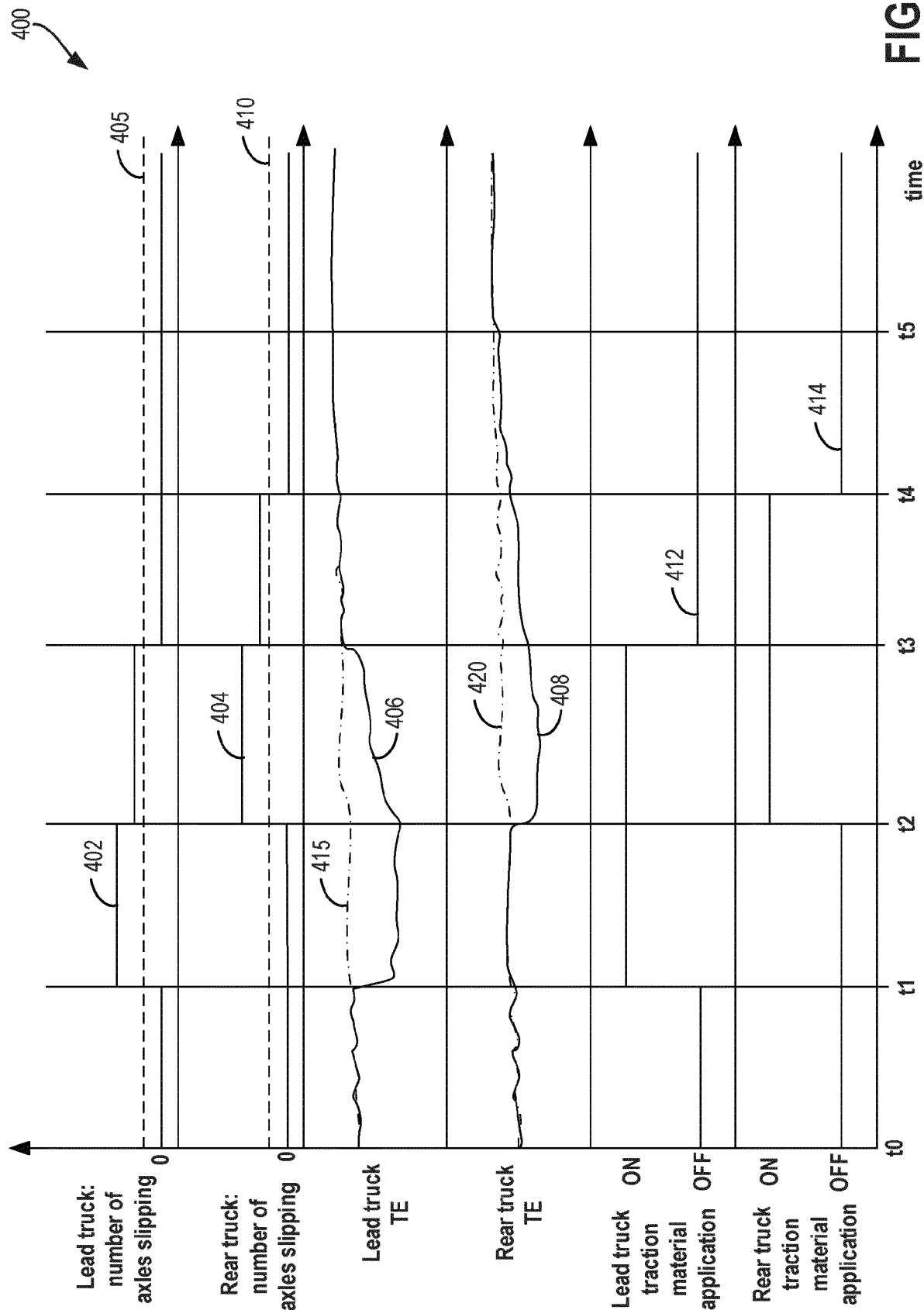


FIG. 4

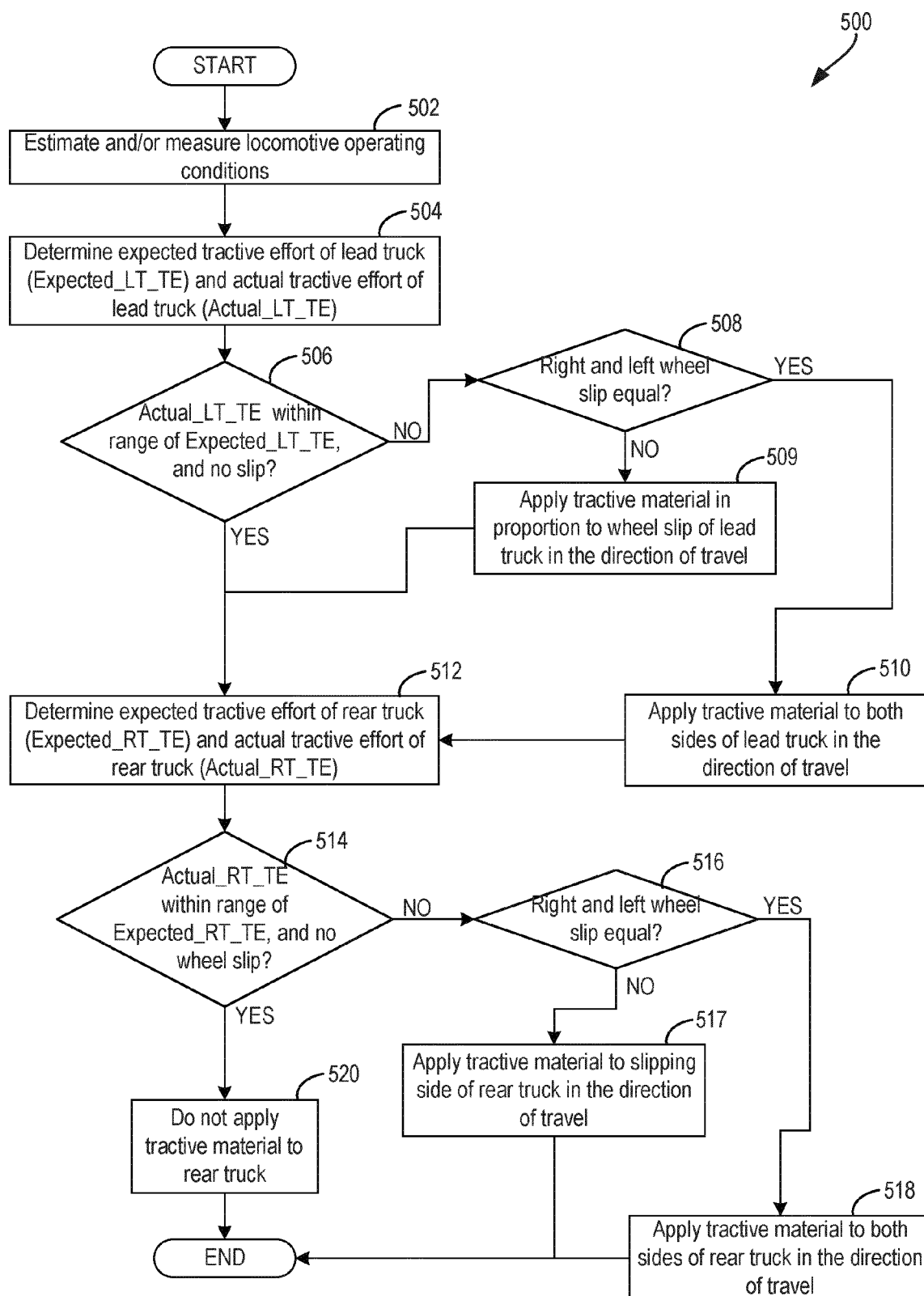


FIG. 5

600

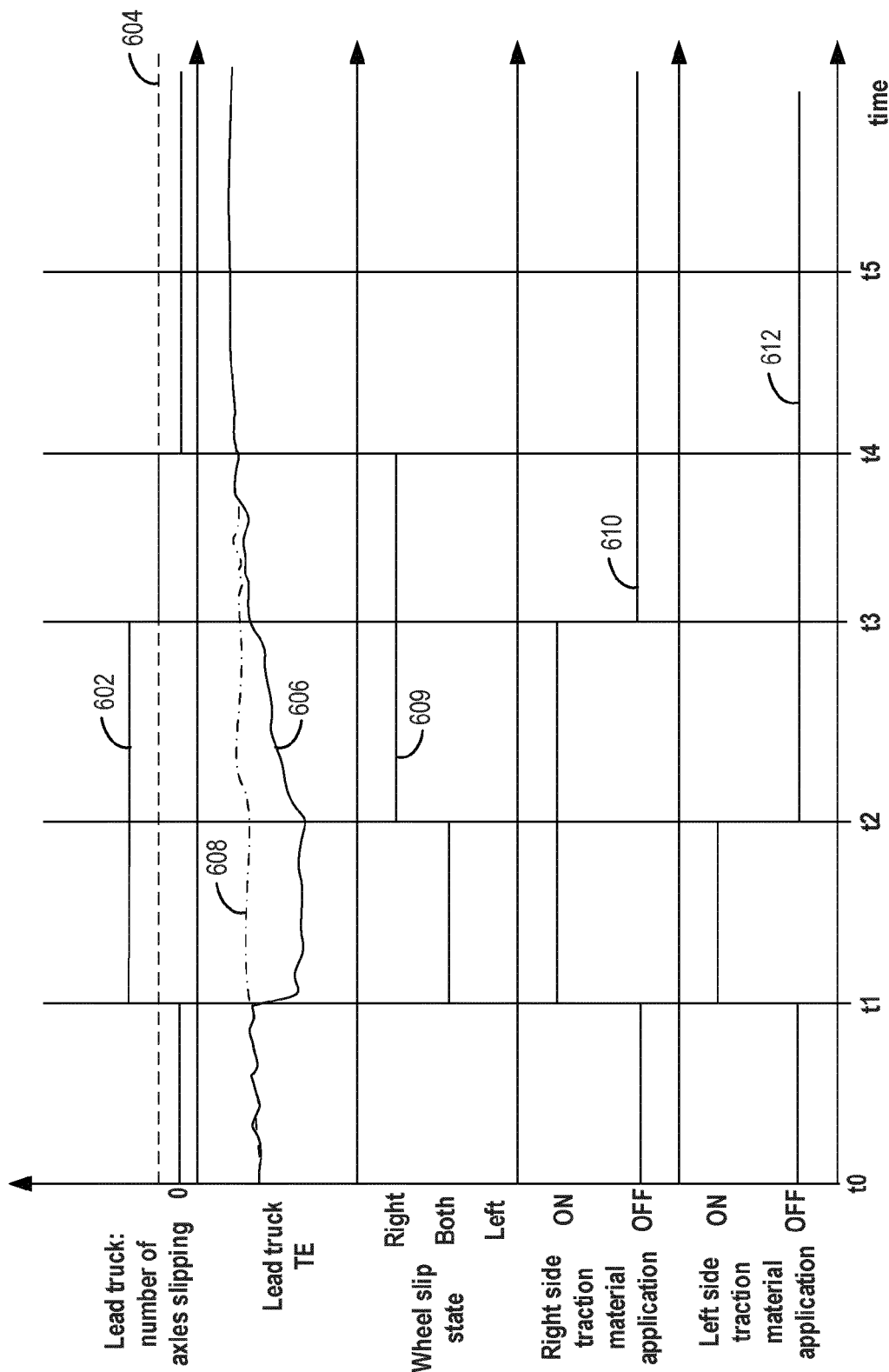


FIG. 6



EUROPEAN SEARCH REPORT

Application Number
EP 21 17 5817

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