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(54) APPARATUSES, COMPUTER-IMPLEMENTED METHODS, AND COMPUTER PROGRAM PRODUCTS FOR LANDING DISTANCE PREDICTION

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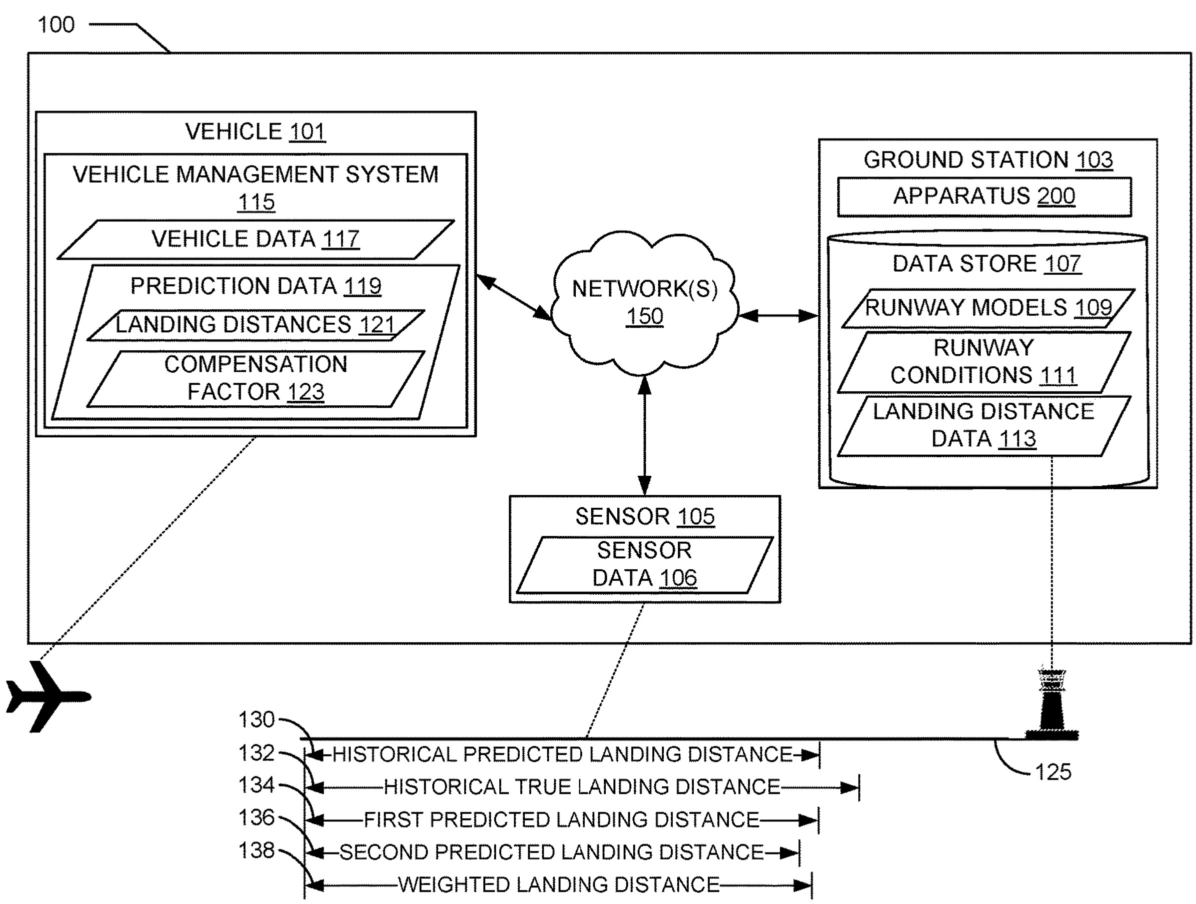
(57) **ABSTRACT**

Embodiments of the disclosure provide for improved landing distance prediction. In the context of a method, the method includes generating an runway condition associated with a runway based on sensor data; retrieving a stored runway model based on the runway condition; generating, using the retrieved runway model, a predicted landing distance for a vehicle based on real-time vehicle data for the vehicle; and providing to the vehicle a historical true landing distance and a historical predicted landing distance for another vehicle and the predicted landing distance for the vehicle to cause the vehicle to: generate a compensation factor based on the historical true and predicted landing distances; generate a second predicted landing distance for the vehicle based on the real-time vehicle data; and generate a weighted landing distance based on the predicted landing distance for the vehicle, the second predicted landing distance, and the compensation factor.



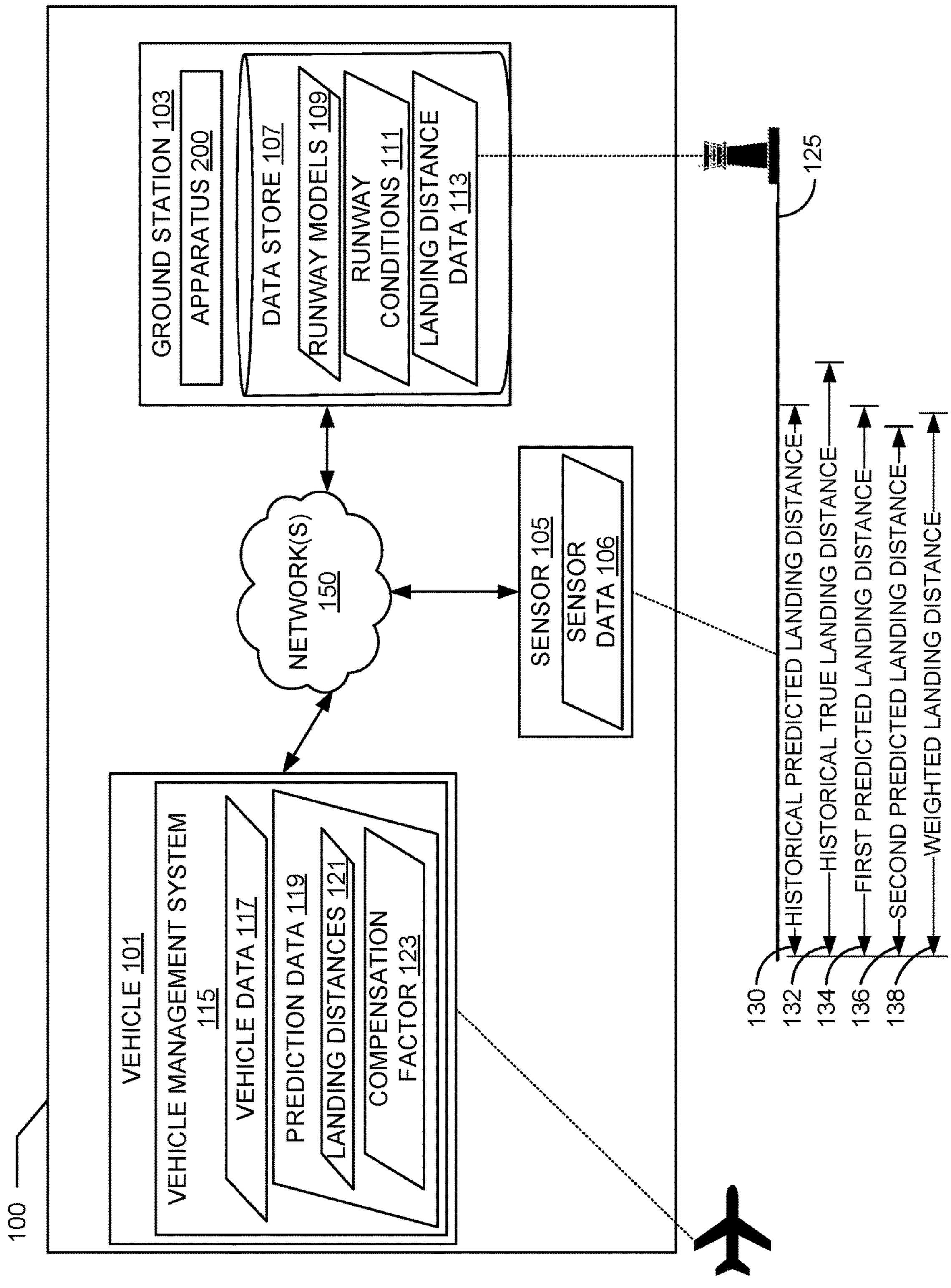

100
VEHICLE 101
VEHICLE MANAGEMENT SYSTEM 115
VEHICLE DATA 117
PREDICTION DATA 119
LANDING DISTANCES 121
COMPENSATION FACTOR 123
NETWORK(S) 150
SENSOR 105
SENSOR DATA 106
GROUND STATION 103
APPARATUS 200
DATA STORE 107
RUNWAY MODELS 109
RUNWAY CONDITIONS 111
LANDING DISTANCE DATA 113
125
130
132
134
136
138
HISTORICAL PREDICTED LANDING DISTANCE
HISTORICAL TRUE LANDING DISTANCE
FIRST PREDICTED LANDING DISTANCE
SECOND PREDICTED LANDING DISTANCE
WEIGHTED LANDING DISTANCE

FIG. 1

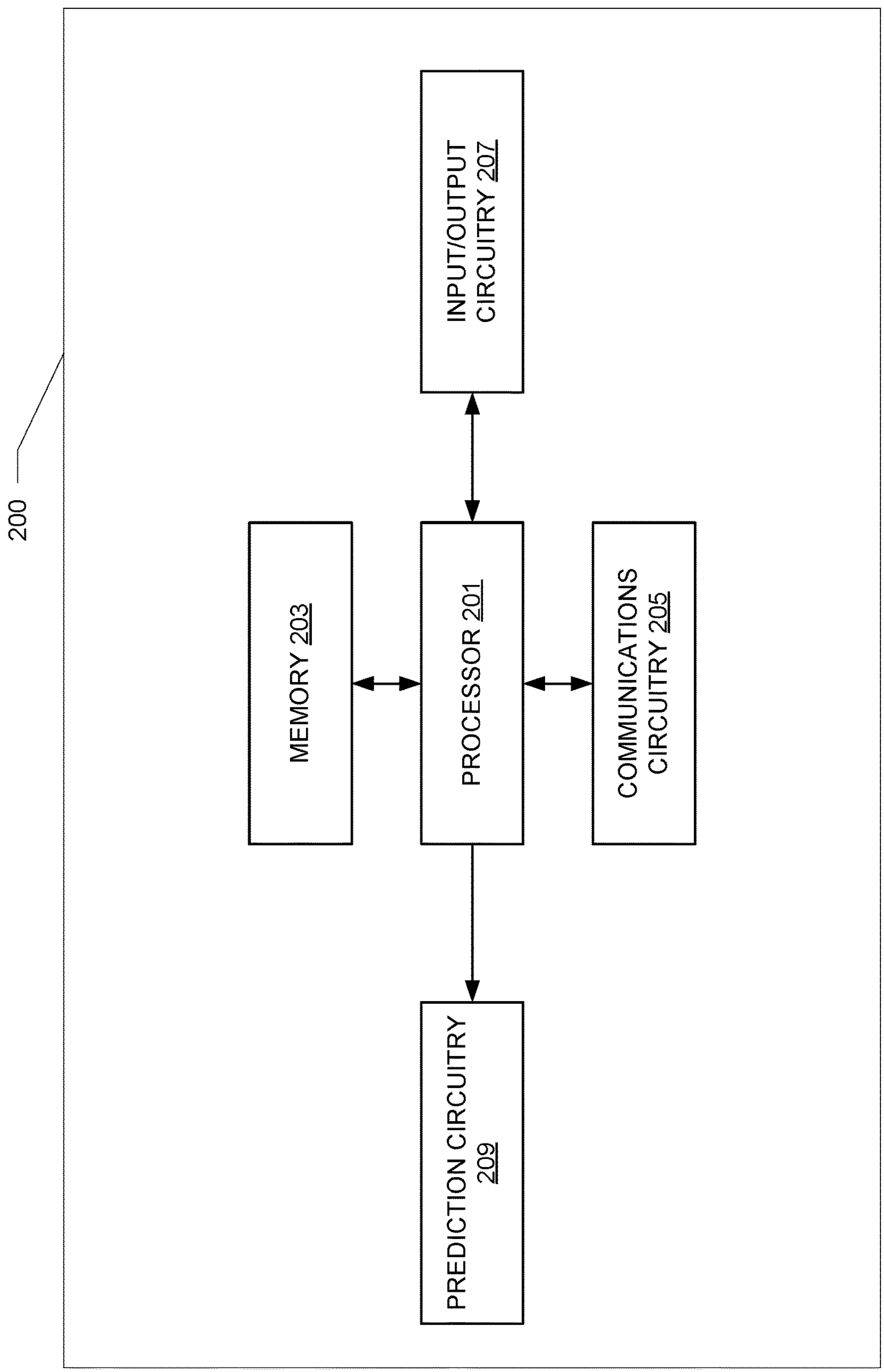

200
INPUT/OUTPUT CIRCUITRY 207
MEMORY 203
PROCESSOR 201
COMMUNICATIONS CIRCUITRY 205
PREDICTION CIRCUITRY 209

FIG. 2

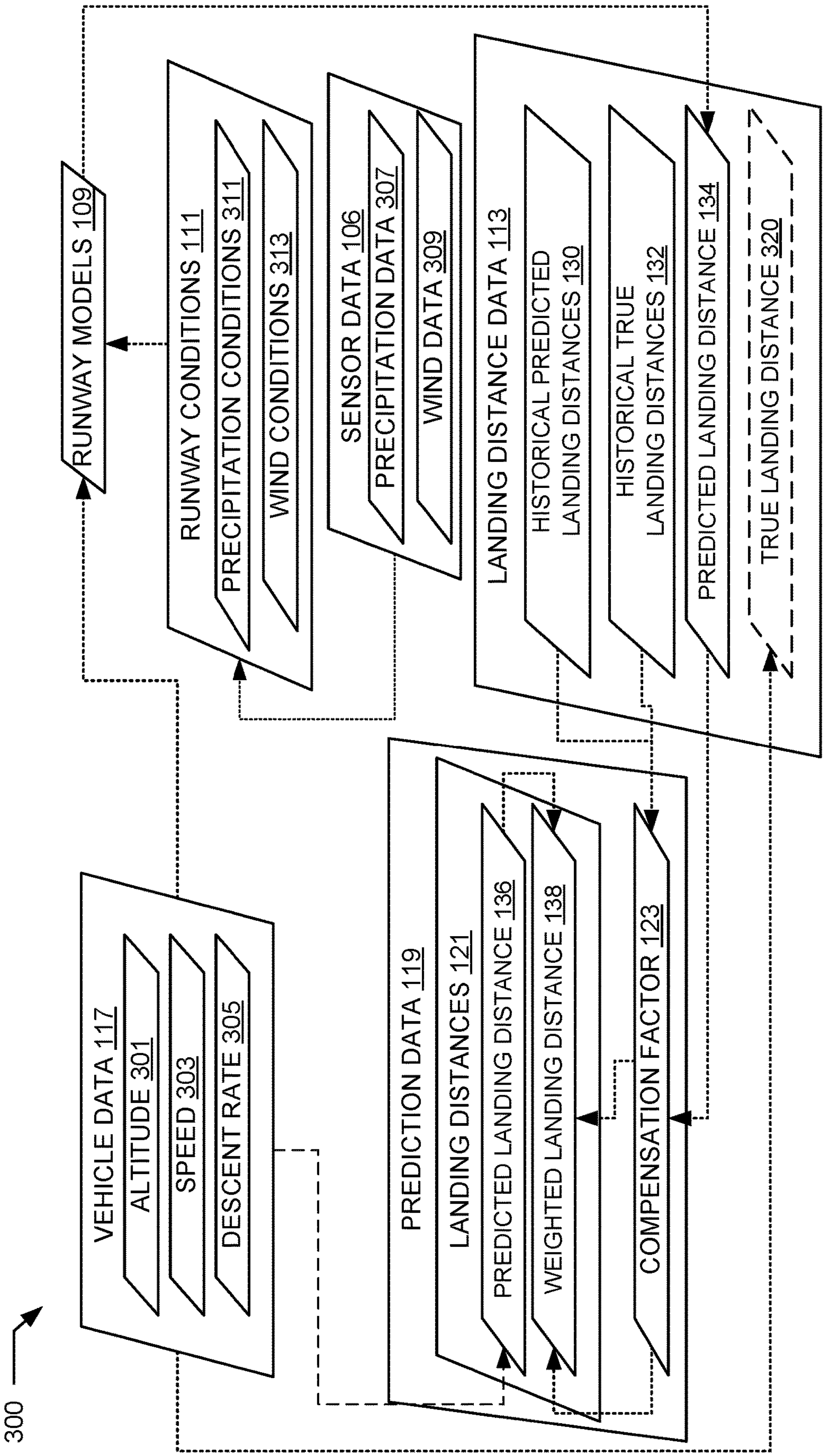

300
VEHICLE DATA 117
ALTITUDE 301
SPEED 303
DESCENT RATE 305
RUNWAY MODELS 109
RUNWAY CONDITIONS 111
PRECIPITATION CONDITIONS 311
WIND CONDITIONS 313
SENSOR DATA 106
PRECIPITATION DATA 307
WIND DATA 309
LANDING DISTACNE DATA 113
HISTORICAL PREDICTED LANDING DISTANCES 130
HISTORICAL TRUE LANDING DISTANCES 132
PREDICTED LANDING DISTANCE 134
TRUE LANDING DISTANCE 320
PREDICTION DATA 119
LANDING DISTANCES 121
PREDICTED LANDING DISTANCE 136
WEIGHTED LANDING DISTANCE 138
COMPENSATION FACTOR 123

FIG. 3

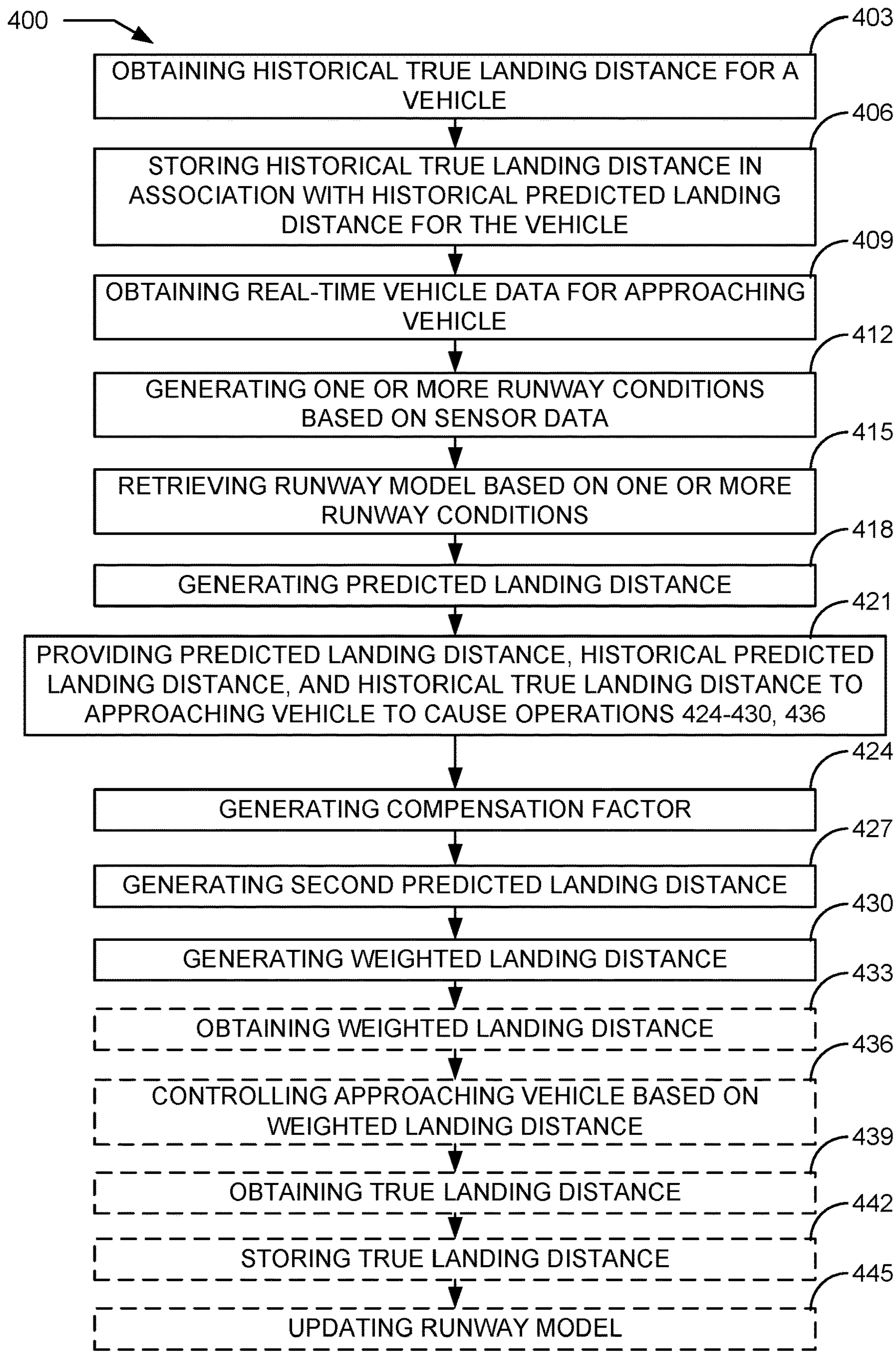

400
403
OBTAINING HISTORICAL TRUE LANDING DISTANCE FOR A VEHICLE
406
STORING HISTORICAL TRUE LANDING DISTANCE IN ASSOCIATION WITH HISTORICAL PREDICTED LANDING DISTANCE FOR THE VEHICLE
409
OBTAINING REAL-TIME VEHICLE DATA FOR APPROACHING VEHICLE
412
GENERATING ONE OR MORE RUNWAY CONDITIONS BASED ON SENSOR DATA
415
RETRIEVING RUNWAY MODEL BASED ON ONE OR MORE RUNWAY CONDITIONS
418
GENERATING PREDICTED LANDING DISTANCE
421
PROVIDING PREDICTED LANDING DISTANCE, HISTORICAL PREDICTED LANDING DISTANCE, AND HISTORICAL TRUE LANDING DISTANCE TO APPROACHING VEHICLE TO CAUSE OPERATIONS 424-430, 436
424
GENERATING COMPENSATION FACTOR
427
GENERATING SECOND PREDICTED LANDING DISTANCE
430
GENERATING WEIGHTED LANDING DISTANCE
433
OBTAINING WEIGHTED LANDING DISTANCE
436
CONTROLLING APPROACHING VEHICLE BASED ON WEIGHTED LANDING DISTANCE
439
OBTAINING TRUE LANDING DISTANCE
442
STORING TRUE LANDING DISTANCE
445
UPDATING RUNWAY MODEL

FIG. 4

APPARATUSES, COMPUTER-IMPLEMENTED METHODS, AND COMPUTER PROGRAM PRODUCTS FOR LANDING DISTANCE PREDICTION

TECHNOLOGICAL FIELD

[0001] Embodiments of the present disclosure are generally directed to predicting a landing distance for a vehicle.

BACKGROUND

[0002] Typical approaches to predicting landing distance for a vehicle rely upon vehicle performance data and runway conditions. For example, a runway condition may be associated with a predefined value for use in landing distance prediction when said condition is present on the target runway. However, the predefined value may be inaccurate when the same or additional runway conditions deviate from the fixed definition based upon which the predefined value was establish. As a result, predicted landing distances may deviate from true landing distances due to inability of the prediction model to capture all factors and interactions thereof that may influence landing distance.

[0003] Applicant has discovered various technical problems associated with accurately predicting landing distance for a vehicle. Through applied effort, ingenuity, and innovation, Applicant has solved many of these identified problems by developing the embodiments of the present disclosure, which are described in detail below.

BRIEF SUMMARY

[0004] In general, embodiments of the present disclosure herein provide for prediction of weighted landing distances based at least in part on compensation factors that capture historical differences in predicted and true landing distances. For example, embodiments of the present disclosure provide for providing historical true and predicted landing distances to a vehicle to cause the vehicle to generate a compensation factor. Further, predicted landing distances may be generated by and provided to the vehicle to cause the vehicle to generate a weighted landing distance based at least in part on the predicted landing distance generated by the vehicle and the second predicted landing distance received by the vehicle from a ground station. The vehicle may apply the compensation factor to the second predicted landing distance to control contribution of the second predicted landing distance to the weighed landing distance computation, thereby controlling for the historical offset in true versus predicted landing distances. Other implementations for predicting landing distance will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional implementations be included within this description be within the scope of the disclosure, and be protected by the following claims.

[0005] In accordance with a first aspect of the disclosure, a computer-implemented method for improved landing prediction is provided. The computer-implemented method is executable utilizing any of a myriad of computing device(s) and/or combinations of hardware, software, firmware. In some example embodiments an example computer-implemented method includes generating, at a ground station, at least one runway condition associated with a runway based at least in part on sensor data from at least one sensor; retrieving, at the ground station, one of a plurality of stored runway models based at least in part on the at least one runway condition; generating, at the ground station and using the retrieved runway model, a predicted landing distance for an approaching vehicle upon the runway based at least in part on model input comprising real-time vehicle data for the approaching vehicle; and providing, from the ground station to the approaching vehicle, a historical true landing distance for at least one vehicle, a historical predicted landing distance for the at least one vehicle, and the predicted landing distance for the approaching vehicle to cause the approaching vehicle to: generate a compensation factor based at least in part on the historical true landing distance for the at least one vehicle and the historical predicted landing distance for the at least one vehicle; generate a second predicted landing distance for the approaching vehicle based at least in part on the real-time vehicle data for the approaching vehicle; and generate a weighted landing distance based at least in part on the predicted landing distance for the approaching vehicle, the second predicted landing distance, and the compensation factor.

[0006] In some embodiments, the method further includes obtaining, at the ground station, a true landing distance of the approaching vehicle upon the runway; and storing, at the ground station, the true landing distance of the approaching vehicle in association with the predicted landing distance for the approaching vehicle. In some embodiments, the ground station receives the true landing distance of the approaching vehicle from the approaching vehicle. In some embodiments, the method further includes receiving, at the ground station, additional real-time vehicle data for the approaching vehicle during landing, wherein the ground station generates the true landing of the approaching vehicle based at least in part on the additional real-time vehicle data.

[0007] In some embodiments, the method further includes receiving, at the ground station, the real-time vehicle data for the approaching vehicle from at least one flight monitoring system of the approaching vehicle. In some embodiments, the method further includes obtaining, at the ground station, the historical true landing distance for the at least one vehicle; and storing, at the ground station, the historical true landing distance in association with the historical predicted landing distance for the at least one vehicle upon the runway. In some embodiments, the method further includes determining at least one classification of the approaching vehicle matches at least one classification of the at least one vehicle; and in response to the determination, providing the historical true landing distance and the historical predicted distance for the at least one vehicle to the approaching vehicle.

[0008] In some embodiments, a respective true landing distance corresponds to a length of a runway used by a vehicle to land upon the runway; and the historical true landing distance is obtained by the ground station from the at least one vehicle. In some embodiments, the method further includes causing an autopilot system of the approaching vehicle to control the approaching vehicle based at least in part on at least one of the compensation factor or the weighted landing distance. In some embodiments, the at least one runway condition comprises at least one precipitation condition associated with the runway.

[0009] In some embodiments, the at least one precipitation condition comprises at least one of snow, ice, or frost. In some embodiments, the at least one precipitation condition comprises snow compaction. In some embodiments, the at least one runway condition comprises at least one wind condition associated with the runway. In some embodiments, the at least one runway condition comprises runway visual range. In some embodiments, the at least one runway condition comprises runway elevation.

[0010] In some embodiments, the method further comprises receiving at least one of the compensation factor, the weighted landing distance, or a true landing distance from the approaching vehicle; and storing at least one of the compensation factor, the weighted landing distance, or the true landing distance in association with at least one of the historical predicted landing distance for the at least one vehicle or the predicted landing distance for the at least one vehicle. In some embodiments, the method further comprises updating a respective runway model based at least in part on at least one of the compensation factor, the weighted landing distance, or the true landing distance. In some embodiments, the method further includes receiving the weighted landing distance from the approaching vehicle; and instructing the approaching vehicle to land on a second runway based at least in part on the weighted landing distance.

[0011] In accordance with another aspect of the present disclosure, a computing apparatus for improved landing distance prediction is provided. The computing apparatus in some embodiments includes at least one processor and at least one non-transitory memory, the at least non-transitory one memory having computer-coded instructions stored thereon. The computer-coded instructions in execution with the at least one processor causes the apparatus to perform any one of the example computer-implemented methods described herein. In some other embodiments, the computing apparatus includes means for performing each step of any of the computer-implemented methods described herein.

[0012] In accordance with another aspect of the present disclosure, a computer program product for improved landing distance prediction is provided. The computer program product in some embodiments includes at least one non-transitory computer-readable storage medium having computer program code stored thereon. The computer program code in execution with at least one processor is configured for performing any one of the example computer-implemented methods described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Having thus described the embodiments of the disclosure in general terms, reference now will be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0014] FIG. **1** illustrates a block diagram of a networked environment that may be specially configured within which embodiments of the present disclosure may operate.

[0015] FIG. **2** illustrates a block diagram of an example apparatus that may be specially configured in accordance with at least some example embodiments of the present disclosure.

[0016] FIG. **3** illustrates an example data architecture in accordance with at least some example embodiments of the present disclosure.

[0017] FIG. **4** illustrates a flowchart depicting operations of an example process for predicting a landing distance in accordance with at least some example embodiments of the present disclosure.

DETAILED DESCRIPTION

[0018] Embodiments of the present disclosure now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all, embodiments of the disclosure are shown. Indeed, embodiments of the disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein, rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

Overview

[0019] Embodiments of the present disclosure provide a myriad of technical advantages in the technical field of predicting landing distances for vehicles. Typically, a vehicle landing distance is predicted by a vehicle operator or vehicle traffic controller based solely upon vehicle data. For example, in an aerial context, the length of runway required to safely land an aerial vehicle may be generated based on vehicle elevation, descent rate, airspeed, and/or the like. In such approaches, a landing distance prediction may be inaccurate due to failure to consider additional factors, such as conditions of the runway. For example, a vehicle may require greater landing distance on a wet runway or ice-covered runway as compared to a dry runway. In instances where such conditions are taken into account for landing distance prediction, the models used to generate landing distance prediction may still generate predictions that differ from true landing distances for the runway.

[0020] Embodiments of the present disclosure overcome the technical challenges of generating accurate landing predictions by generating and providing a compensation factor indicative of differences in historical predicted and true landing distances generated by such models. The various embodiments of the present disclosure may provide the historical predicted and true landing distances for a runway to an approaching vehicle to enable the approaching vehicle to generate a compensation factor that may be used by the vehicle to account for the historical deltas and, thereby, generate a more accurate landing distance.

[0021] For example, when predicting aircraft landing distance on a runway, one of the predicted factors is based on the aircraft performance data, which contains fixed predicted landing distance for different runway conditions (e.g., different thicknesses of snow, ice, etc.). However, runway condition may be more complicated than those pre-defined conditions such that predicted landing distances deviate significantly from true landing distances due to runway factors not captured in the model. When runway conditions deviate from the fixed set of performance numbers represented in the model, the predicted landing distance may demonstrate inaccuracy, potentially resulting in a hard or unsafe landing that may damage the aircraft, its cargo, and/or passengers. In various embodiments, the present method, apparatus, and computer program product provide historical predicted landing distances and true landing distances to a vehicle on approach such that the variation in predicted performance vs. true performance may be compensated for in computation of the landing distance at the vehicle. In doing so, the method, apparatus, and computer program product may enable generated of a weighted landing distance that is more accurate as compared to outputs of previous landing distance techniques.

Definitions

[0022] "Vehicle" refers to any apparatus that traverses throughout an environment by any mean of travel. In some contexts, a vehicle transports goods, persons, and/or the like, or traverses itself throughout an environment for any other purpose, by means of air, sea, or land. In some embodiments, a vehicle is ground-based, air-based, water-based, space-based (e.g., outer space or within an orbit of a planetary body, a natural satellite, or artificial satellite), and/or the like. In some embodiments, the vehicle is an aerial vehicle capable of air travel. Non-limiting examples of aerial vehicles include urban air mobility vehicles, drones, helicopters, fully autonomous air vehicles, semi-autonomous air vehicles, airplanes, orbital craft, spacecraft, rotorcraft, and/or the like. In some embodiments, the vehicle is piloted by a human operator onboard the vehicle. For example, in an aerial context, the vehicle may be a commercial airliner operated by a flight crew. In some embodiments, the vehicle is remotely controllable such that a remote operator may initiate and direct movement of the vehicle. Additionally, in some embodiments, the vehicle is unmanned. For example, the vehicle may be a powered, aerial vehicle that does not carry a human operator and is piloted by a remote operator using a control station. In some embodiments, the vehicle is an aquatic vehicle capable of surface or subsurface travel through and/or atop a liquid medium (e.g., water, water-ammonia solution, other water mixtures, and/or the like). Non-limiting examples of aquatic vehicles include unmanned underwater vehicles (UUVs), surface watercraft (e.g., boats, jet skis, and/or the like), amphibious watercraft, hovercraft, hydrofoil craft, and/or the like. As used herein, vehicle may refer to vehicles associated with urban air mobility (UAM).

[0023] "UAM" refers to urban air mobility, which includes all aerial vehicles and functions for aerial vehicles that are capable of performing vertical takeoff and/or vertical landing procedures. Non-limiting examples of UAM aerial vehicles include passenger transport vehicles, cargo transport vehicles, small package delivery vehicles, unmanned aerial system services, autonomous drone vehicles, and ground-piloted drone vehicles, where any such vehicle is capable of performing vertical takeoff and/or vertical landing. In various embodiments, the method, apparatus, and computer program product described herein are configured to generate predicted landing distances, compensation factors, weighted landing distances, and/or the like for UAM vehicles. In at least a subset of such embodiments, the method, apparatus, and computer program product generate predicted landing distances, compensation factors, weighted landing distances, and/or the like using a model associated with landing site conditions, such as wind, temperature, humidity, air pressure, vehicle traffic density, and/or the like.

[0024] "Landing distance" refers to any length of surface used by a vehicle to come to a complete stop or predetermined velocity. For example, in an aerial context, a landing distance may be a length of runway used by an aerial vehicle to touchdown, decelerate, and reach a complete stop or predetermined taxiing speed. As another example, a landing distance may be a length of runway used by a ground-based vehicle to decelerate to a complete stop. In still another example, a landing distance may be a length of a waterway used by an aquatic vehicle to decelerate to a complete stop or idling speed. In some embodiments, landing distance includes a vertical delta and/or horizontal delta of a vehicle respective to a target landing site. For example, in a UAM context, landing distance may include a vertical distance between a vehicle and a landing site.

[0025] "Predicted landing distance" refers to any estimate of surface length that may be required by a vehicle to reach a complete stop or predetermined velocity. For example, in an aerial context, a predicted landing distance may be an estimate of runway length that will be required for an aerial vehicle to reach a complete stop or decelerate to a predetermined taxiing speed following touchdown of the vehicle upon the runway.

[0026] "True landing distance" refers to an actual surface length required by a vehicle to reach a complete stop or predetermined velocity. For example, in an aerial context, true landing distance may be a distance travel upon a runway from a point of vehicle touchdown to a point at which the vehicle comes to a complete stop or decelerates to a predetermined taxiing speed.

Example Systems and Apparatuses of the Disclosure

[0027] FIG. **1** illustrates a block diagram of a networked environment that may be specially configured within which embodiments of the present disclosure may operate. Specifically, FIG. **1** depicts an example networked environment **100**. As illustrated, the networked environment **100** includes one or more vehicles **101**, a ground station **103**, and one or more sensors **105**.

[0028] In some embodiments, the ground station **103** includes an apparatus **200** configured to perform various functions and actions related to enacting techniques and processes described herein for predicting landing distances, generating runway conditions, providing predictions and instructions to a vehicle **101** and/or the like. In some embodiments, the ground station **103** is configured to provide data to and receive data from one or more vehicles **101**, one or more sensors **105**, and/or the like. In some embodiments, the ground station **103** includes one or more data stores **107**. The various data in the data store **107** may be accessible to one or more of the apparatus **200**, the vehicle **101**, and/or the like. The data store **107** may be representative of a plurality of data stores **107** as can be appreciated. The data stored in the data store **107**, for example, is associated with the operation of the various applications, apparatuses, and/or functional entities described herein. The data stored in the data store **107** may include, for example, runway models **109**, runway conditions **111**, landing distance data **113**, and/or the like.

[0029] In some embodiments, the apparatus **200** is configured to receive sensor data **106** from one or more sensors **105**. The sensor **105** may be configured to generate one or more readings associated with a runway **125**, an environment adjacent to the runway **125**, and/or the like. For example, the sensor **105** may generate sensor data **106** indicative of runway moisture, precipitation, wind, visibility, and/or the like. In some embodiments, the sensor **105**

includes anemometers, radar sensors, barometers, thermometers, optical sensors, precipitation sensors, and/or the like.

[0030] In some embodiments, the apparatus **200** is configured to generate one or more runway conditions **111** based at least in part on the sensor data **106**. For example, the apparatus may generate precipitation thicknesses, wind directions and velocities, and/or the like, which may impact landing distances for vehicles **101** attempting to land upon the runway **125**. In some embodiments, the apparatus **200** is configured to retrieve a runway model **109** for use in landing distance prediction based at least in part on the one or more runway conditions **111**. For example, the apparatus **200** may retrieve a runway model **109** that is associated with a predetermined range of snow compaction, ice thickness, frost, and/or the like.

[0031] In some embodiments, the apparatus **200** is configured to receive vehicle data **117** from the vehicle **101**. In some embodiments, the apparatus **200** is configured to generate landing distance data **113** using the runway model **109** and based at least in part on the vehicle data **117**. For example, the apparatus **200** may generate predicted landing distances **134**. In some embodiments, the apparatus **200** obtains true landing distances associated with vehicle landings. In some embodiments, the apparatus **200** stores true landing distances and associated landing distance predictions as historical true landing distances **132** and historical predicted landing distances **130**, respectively. In doing so, the apparatus **200** may enable subsequent retrieval and provision of the historical true and predicted landing distances **132**, **130** to a vehicle management system **115** to enable the vehicle management system **115** to generate compensation factors **123**.

[0032] In some embodiments, the apparatus **200** is configured to generate a first predicted landing distance **134** for an approaching vehicle **101** based at least in part on real-time vehicle data **117** for the vehicle and a runway model **109** retrieved based on current runway conditions **111** on a target runway **125**. In some embodiments, the apparatus **200** retrieves historical predicted landing distances **130** and historical true landing distances **132** associated with the runway. In some embodiments, the apparatus **200** is configured to provide the first predicted landing distance **134**, the historical predicted landing distances **130**, and the historical true landing distances **132** to the vehicle **101**. In doing so, the apparatus **200** may cause the vehicle management system **115** to generate a compensation factor **123** based at least in part on the historical predicted landing distances **130** and the historical true landing distances **132** and generate a weighted landing distance **138** based at least in part on the first predicted landing distance **134**, a second predicted landing distance **136** generated by the vehicle management system, and the compensation factor. The historical predicted landing distances **130** may differ from the historical true landing distances **132**, and the compensation factor **123** may represent an average magnitude of the difference. The vehicle management system **115** may use the compensation factor **123** to generate a weighted landing distance, which may be more accurate to a true landing distance of the vehicle on the runway. Thus, the weighted landing distance may enable safer, more accurate landing of the vehicle upon the runway **125**. Additional aspects of landing distance prediction are shown in the landing distance prediction process shown in FIG. **4** and described herein.

[0033] In some embodiments, the vehicle **101** includes a vehicle management system **115** configured to control operation of the vehicle **101**. For example, the vehicle management system **115** may include one or more vehicle controls (e.g., thrust, brakes, flaps, and/or the like). In some embodiments, the vehicle management **115** includes an autopilot and/or the like that automatically controls the vehicle **101**. In some embodiments, the vehicle management system **115** includes one or more vehicle recording systems configured to obtain and report one or more aspects of the vehicle or operation thereof. For example, the vehicle management system **115** may include a transponder, data uplink system, traffic collision avoidance system (TCAS), automatic dependent surveillance-broadcast (ADS-B), flight recorder, and/or the like.

[0034] In some embodiments, the vehicle management system **115** is configured to receive runway conditions **111**, landing distance data **113**, and/or the like from the ground station **103**. In some embodiments, the vehicle management system **115** is configured to generate and store vehicle data **117**, prediction data **119**, and/or the like. In some embodiments, the vehicle management system **115** includes any number of computing device(s) and/or other system(s) embodied in hardware, software, firmware, and/or the like that generate vehicle data **117**, prediction data **119**, and/or the like. For example, the vehicle management system **115** may generate real-time vehicle data **117** based at least in part on measurements obtained from one or more vehicle recording systems. In another example, the vehicle management system **115** may generate a predicted landing distance **136** based at least in part on the real-time vehicle data **117**. The vehicle management system **115** may generate a compensation factor **123** based at least in part on historical predicted landing distances **130** and historical true landing distances **132**. For example, the vehicle management system **115** may include any number of computing device(s) and/or other system(s) embodied in hardware, software, firmware, and/or the like that generate an average delta or offset based at least in part on differences between historical predicted landing distances and historical true landing distances.

[0035] In some embodiments, the vehicle management system **115** is configured to generate the weighted landing distance **138** based at least in part on a compensation factor **123**, a predicted landing distance **134** from the ground station **103**, and the predicted landing distance **136**. In some embodiments, the vehicle management system **115** applies the compensation factor **123** to the predicted landing distance **134** to configure a level of contribution of the predicted landing distance **134** to computation of the weighted landing distance **138**. In some embodiments, vehicle management system **115** is configured to control the vehicle **101** based at least in part on the weighted landing distance **138**. For example, the vehicle management system **115** may control the landing of the vehicle **101** upon a runway by configuring one or more landing parameters based at least in part on the weighted landing distance **138**. The landing parameters may include descent rate, thrust, speed, nose angle, braking, flap orientation, and/or the like. In some embodiments, the vehicle management system **115** includes one or more displays on which vehicle data **117**, prediction data **119**, runway conditions **111**, landing distance data **113**, sensor data **106**, and/or the like may be rendered.

[0036] Additional example aspects of the sensor data **106**, runway model **109**, runway conditions **111**, landing distance data **113**, vehicle data **117**, prediction data **119** are shown in the data architecture **300** depicted in FIG. **3** and described herein.

[0037] In some embodiments, the ground station **103**, vehicle **101**, and sensor **105** are communicable over one or more communications network(s), for example the communications network(s) **150**. It should be appreciated that the communications network **150** in some embodiments is embodied in any of a myriad of network configurations. In some embodiments, the communications network **150** embodies a public network (e.g., the Internet). In some embodiments, the communications network **150** embodies a private network (e.g., an internal, localized, and/or closed-off network between particular devices). In some other embodiments, the communications network **150** embodies a hybrid network (e.g., a network enabling internal communications between particular connected devices and external communications with other devices). In some embodiments, the communications network **150** embodies a satellite-based communication network. Additionally, or alternatively, in some embodiments, the communications network **150** embodies a radio-based communication network that enables communication between the apparatus **200** and the vehicle **101**. For example, the apparatus **200** may provision landing distance data **113** to and receive prediction data **119** from a vehicle management system **115** via a transponder, communication gateway, and/or the like. The communications network **150** in some embodiments may include one or more transponders, satellites, base station(s), relay(s), router (s), switch(es), cell tower(s), communications cable(s) and/or associated routing station(s), and/or the like. In some embodiments, the communications network **150** includes one or more user-controlled computing device(s) (e.g., a user owner router and/or modem) and/or one or more external utility devices (e.g., Internet service provider communication tower(s) and/or other device(s)).

[0038] Each of the components of the system communicatively coupled to transmit data to and/or receive data from one another over the same or different wireless or wired networks embodying the communications network **150**. Such configuration(s) include, without limitation, a wired or wireless Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN), Wide Area Network (WAN), satellite network, radio network, and/or the like. Additionally, while FIG. **1** illustrate certain system entities as separate, standalone entities communicating over the communications network **150**, the various embodiments are not limited to this particular architecture. In other embodiments, one or more computing entities share one or more components, hardware, and/or the like, or otherwise are embodied by a single computing device such that connection(s) between the computing entities are over the communications network **150** are altered and/or rendered unnecessary.

[0039] FIG. **2** illustrates a block diagram of an example apparatus **200** that may be specially configured in accordance with at least some example embodiments of the present disclosure. The apparatus **200** may carry out functionality and processes described herein to generate runway conditions, obtain true landing distances, generate predicted landing distances, cause performance of functions at a vehicle, and/or the like. In some embodiments, the apparatus **200** includes a processor **201**, memory **203**, communications circuitry **205**, input/output circuitry **207**, and prediction circuitry **209**. In some embodiments, the apparatus **200** is configured, using one or more of the processor **201**, memory **203**, communications circuitry **205**, input/output circuitry **207**, and/or prediction circuitry **209**, to execute and perform the operations described herein.

[0040] In general, the terms computing entity (or "entity" in reference other than to a user), device, system, and/or similar words used herein interchangeably may refer to, for example, one or more computers, computing entities, desktop computers, mobile phones, tablets, phablets, notebooks, laptops, distributed systems, items/devices, terminals, servers or server networks, blades, gateways, switches, processing devices, processing entities, set-top boxes, relays, routers, network access points, base stations, the like, and/or any combination of devices or entities adapted to perform the functions, operations, and/or processes described herein. Such functions, operations, and/or processes may include, for example, transmitting, receiving, operating on, controlling, modifying, restoring, processing, displaying, storing, determining, creating/generating, predicting, monitoring, evaluating, comparing, and/or similar terms used herein interchangeably. In one embodiment, these functions, operations, and/or processes may be performed on data, content, information, and/or similar terms used herein interchangeably. In this regard, the apparatus **200** embodies a particular, specially configured computing entity transformed to enable the specific operations described herein and provide the specific advantages associated therewith, as described herein.

[0041] Although components are described with respect to functional limitations, it should be understood that the particular implementations necessarily include the use of particular computing hardware. It should also be understood that in some embodiments certain of the components described herein include similar or common hardware. For example, in some embodiments two sets of circuitry both leverage use of the same processor(s), network interface(s), storage medium(s), and/or the like, to perform their associated functions, such that duplicate hardware is not required for each set of circuitry. The use of the term "circuitry" as used herein with respect to components of the apparatuses described herein should therefore be understood to include particular hardware configured to perform the functions associated with the particular circuitry as described herein.

[0042] Particularly, the term "circuitry" should be understood broadly to include hardware and, in some embodiments, software for configuring the hardware. For example, in some embodiments, "circuitry" includes processing circuitry, storage media, network interfaces, input/output devices, and/or the like. Additionally, or alternatively, in some embodiments, other elements of the apparatus **200** provide or supplement the functionality of another particular set of circuitry. For example, the processor **201** in some embodiments provides processing functionality to any of the sets of circuitry, the memory **203** provides storage functionality to any of the sets of circuitry, the communications circuitry **205** provides network interface functionality to any of the sets of circuitry, and/or the like.

[0043] In some embodiments, the processor **201** (and/or co-processor or any other processing circuitry assisting or otherwise associated with the processor) is/are in communication with the memory **203** via a bus for passing information among components of the apparatus **200**. In some embodiments, for example, the memory **203** is non-transitory and may include, for example, one or more volatile and/or non-volatile memories. In other words, for example, the memory **203** in some embodiments includes or embodies an electronic storage device (e.g., a computer readable storage medium). In some embodiments, the memory **203** is configured to store information, data, content, applications, instructions, or the like, for enabling the apparatus **200** to carry out various functions in accordance with example embodiments of the present disclosure (e.g., generating runway conditions, generating landing distance predictions, obtaining real-time vehicle data, obtaining sensor data, causing performance of functions at a vehicle and/or the like). In some embodiments, the memory **203** is embodied as a data store **107** as shown in FIG. **1** and described herein. In some embodiments, the memory **203** includes runway models **109**, runway conditions **111**, landing distance data **113**, and/or the like, as further architected in FIG. **3** and described herein.

[0044] The processor **201** may be embodied in a number of different ways. For example, in some embodiments, the processor **201** includes one or more processing devices configured to perform independently. Additionally, or alternatively, in some embodiments, the processor **201** includes one or more processor(s) configured in tandem via a bus to enable independent execution of instructions, pipelining, and/or multithreading. The use of the terms "processor" and "processing circuitry" should be understood to include a single core processor, a multi-core processor, multiple processors internal to the apparatus **200**, and/or one or more remote or "cloud" processor(s) external to the apparatus **200**.

[0045] In an example embodiment, the processor **201** is configured to execute instructions stored in the memory **203** or otherwise accessible to the processor. Additionally, or alternatively, the processor **201** in some embodiments is configured to execute hard-coded functionality. As such, whether configured by hardware or software methods, or by a combination thereof, the processor **201** represents an entity (e.g., physically embodied in circuitry) capable of performing operations according to an embodiment of the present disclosure while configured accordingly. Additionally, or alternatively, as another example in some example embodiments, when the processor **201** is embodied as an executor of software instructions, the instructions specifically configure the processor **201** to perform the algorithms embodied in the specific operations described herein when such instructions are executed.

[0046] As one particular example embodiment, the processor **201** is configured to perform various operations associated with predicting a landing distance for a vehicle and causing the vehicle to generate compensation factors and weighted prediction distances. In some embodiments, the processor **201** includes hardware, software, firmware, and/or the like, that store real-time vehicle data in memory, retrieve runway models, generate runway conditions, update runway models, generate instructions for controlling a vehicle, and/or the like. For example, the processor **201** may generate one or more runway conditions **111** based at least in part on sensor data **106**. As another example, the processor **201** may determine whether a weighted landing distance meets a predetermined threshold for safely landing upon a runway. As another example, the processor **201** may generate an instruction for a vehicle to land upon a particular runway, avoid landing a runway, enter a holding pattern, and/or the like.

[0047] In some embodiments, the apparatus **200** includes input/output circuitry **207** that provides output to a user (e.g., an operating entity of a vehicle **101** or ground station **103**) and, in some embodiments, receives an indication of a user input. For example, in some contexts, the input/output circuitry **207** provides output to and receives input from one or more ground station operators, vehicles, sensors, and/or the like. In some embodiments, the input/output circuitry **207** is in communication with the processor **201** to provide such functionality. The input/output circuitry **207** may comprise one or more user interface(s) and in some embodiments includes a display that comprises the interface(s) rendered as a web user interface, an application user interface, a user device, a backend system, or the like. In some embodiments, the input/output circuitry **207** also includes a keyboard, a mouse, a joystick, a touch screen, touch areas, soft keys a microphone, a speaker, and/or other input/output mechanisms. The processor **201** and/or input/output circuitry **207** comprising the processor may be configured to control one or more functions of one or more user interface elements through computer program instructions (e.g., software and/or firmware) stored on a memory accessible to the processor **201** (e.g., memory **203**, and/or the like). In some embodiments, the input/output circuitry **207** includes or utilizes a user-facing application to provide input/output functionality to a display of a ground station **103**, vehicle **101** and/or other display associated with a user.

[0048] In some embodiments, the apparatus **200** includes communications circuitry **205**. The communications circuitry **205** includes any means such as a device or circuitry embodied in either hardware or a combination of hardware and software that is configured to receive and/or transmit data from/to a network and/or any other device, circuitry, or module in communication with the apparatus **200**. In this regard, in some embodiments the communications circuitry **205** includes, for example, a network interface for enabling communications with a wired or wireless communications network, such as the network **150** shown in FIG. **1** and described herein. Additionally, or alternatively in some embodiments, the communications circuitry **205** includes one or more network interface card(s), antenna(s), bus(es), switch(es), router(s), modem(s), and supporting hardware, firmware, and/or software, or any other device suitable for enabling communications via one or more communications network(s). Additionally, or alternatively, the communications circuitry **205** includes circuitry for interacting with the antenna(s) and/or other hardware or software to cause transmission of signals via the antenna(s) or to handle receipt of signals received via the antenna(s). In some embodiments, the communications circuitry **205** enables transmission to and/or receipt of data from a vehicle management system **115** and/or other external computing devices in communication with the apparatus **200**.

[0049] The prediction circuitry **209** includes hardware, software, firmware, and/or a combination thereof, that predict landing distances. For example, in some contexts, the prediction circuitry **209** includes hardware, software, firmware, and/or the like, that process real-time vehicle data using a runway model to generate a predicted landing distance for a vehicle eon approach to a runway. In some embodiments, the prediction circuitry **209** includes hardware, software, firmware, and/or the like, that determine one of a plurality of runway models to utilize for landing distance prediction based at least in part on one or more runway conditions. In some embodiments, the prediction circuitry **209** includes hardware, software, firmware, and/or the like, that update a runway model based on a true landing distance, compensation factor, and/or the like. In some embodiments, the prediction circuitry **209** includes a separate processor, specially configured field programmable gate array (FPGA), and/or a specially programmed application specific integrated circuit (ASIC).

[0050] Additionally, or alternatively, in some embodiments, two or more of the processor **201**, memory **203**, communications circuitry **205**, input/output circuitry **207**, and/or prediction circuitry **209** are combinable. Additionally, or alternatively, in some embodiments, one or more of the sets of circuitry perform some or all of the functionality described associated with another component. For example, in some embodiments, two or more of the sets of circuitry **201-209** are combined into a single module embodied in hardware, software, firmware, and/or a combination thereof. Similarly, in some embodiments, one or more of the sets of circuitry, for example the memory **203**, communication interface **205**, and/or prediction circuitry **209** is/are combined with the processor **201**, such that the processor **201** performs one or more of the operations described above with respect to each of these sets of circuitry **203-209**.

Example Data Architecture of the Disclosure

[0051] Having described example systems and apparatuses in accordance with embodiments of the present disclosure, example architectures of data in accordance with the present disclosure will now be discussed. In some embodiments, the systems and/or apparatuses described herein maintain data environment(s) that enable the workflows in accordance with the data architectures described herein. For example, in some embodiments, the systems and/or apparatuses described herein function in accordance with the data architectures depicted and described herein with respect to FIG. **3** are maintained via the apparatus **200**.

[0052] FIG. **3**. illustrates an example data architecture **300** in accordance with at least some example embodiments of the present disclosure. In some embodiments, the vehicle data **117** includes altitude **301**, speed **303**, descent rate **305**, and/or the like. In some embodiments, the speed **303** includes airspeed, vertical speed, groundspeed, and/or the like. Additionally, in some embodiments, the vehicle data **117** includes heading, pitch, roll, yaw, and/or the like. In some embodiments, the vehicle data **117** includes a current location of the vehicle, engine performance (e.g., thrust settings, fuel flow, temperatures, pressures, and/or the like), vehicle control inputs, and/or the like. In some embodiments, the vehicle data **117** include statuses of hydraulic systems, electrical systems, plumbing systems, vehicle control systems, and/or the like, that are onboard the vehicle **101**.

[0053] In some embodiments, the sensor data **106** includes precipitation data **307**, wind data **309**, and/or the like. In some embodiments, precipitation data **307** includes measurements of precipitation density, volume, or other dimensions. For example, precipitation data **307** may include a depth of snow, ice, slush, sleet, and/or the like, present on a runway. In another example, precipitation data **307** may include measurements of snow texture, ice particle size, precipitation rate, precipitation duration, and/or the like. In some embodiments, precipitation data **307** includes one or more measurements indicative of runway visual range (RVR) based on fog or other forms of precipitation. In sone embodiments, wind data **309** includes measurements of wind velocity, direction, frequency, duration, and/or the like. In some embodiments, wind data **309** includes measurements of wind velocity and direction at one or more elevations at or above a runway, one or more distances proximate to the runway, one or more time intervals, and/or the like. In some embodiments, sensor data **106** includes measurements of humidity, pressure, temperature, runway moisture, and/or the like.

[0054] In some embodiments, one or more runway conditions **111** are generated based at least in part on sensor data **106**. In some embodiments, the runway conditions **111** include precipitation conditions **311**, wind conditions **313**, and/or the like. In some embodiments, precipitation conditions **311** include snow thickness, snow compactness, ice thickness, slush thickness, slipperiness (e.g., runway moving coefficient of friction, and/or the like), frost coverage, water depth, and/or the like. In some embodiments, wind conditions **313** include headwind, crosswind, tailwind, or gust magnitude, direction, and/or frequency. In some embodiments, a runway condition **111** includes runway visible range (RVR). In some embodiments, a runway condition **111** includes runway elevation. In some embodiments, a runway condition **111** includes humidity.

[0055] In some embodiments, a runway model **109** includes any algorithmic, statistical, and/or machine learning model that generates a landing distance prediction based at least in part on one or more inputs. In some embodiments, a runway model **109** is associated with a particular runway, runway condition, vehicle classification, and/or the like. For example, in an aerial context, an airport may include a first runway model **109** associated with a first runway and a second runway model **109** associated with a second runway model. In another example, a runway model **109** may be associated with runways demonstrating a particular precipitation condition **311**, such as a predetermined range of snow thickness, snow compactness, ice thickness, RVR, and/or the like. In another example, a runway model **109** may be associated with a particular vehicle make, vehicle model, vehicle weight, and/or the like. A runway model **109** may be associated with a combination of runway conditions, vehicle classifications, and/or the like, as can be appreciated.

[0056] In some embodiments, a runway model **109** is configured to generate a predicted landing distance **134** based at least in part on vehicle data **117**, one or more runway conditions **111**, one or more vehicle classifications, and/or the like. In some embodiments, based at least in part one or more runway conditions **111** and/or vehicle classifications, a particular runway model **109** of a plurality of stored runway models may be used to generate the predicted landing distance. In some embodiments, a runway model **109** may be updated by the apparatus **200** based at least in part on true landing distances **320**. For example, subsequent to a runway model **109** generating a landing prediction for an approaching vehicle, the runway model **109** may be updated based at least in part on a true landing distance for the vehicle to enable improvement of model accuracy in future landing distance predictions.

[0057] In some embodiments, landing distance data **113** includes one or more historical predicted landing distances **130** and one or more historical true landing distances **132**, where a respective pair of historical predicted and true landing distances may be associated with a vehicle that previously landed upon a runway. In some embodiments, the historical predicted landing distance **130** and historical true landing distance **132** are associated with a runway identifier, vehicle classification, environmental condition, runway model identifier, and/or the like, such that relevant historical data may be subsequently retrieved and provided to a vehicle approaching the same runway under similar or the same conditions (e.g., and where, in some embodiments the approaching vehicle may share one or more of the same classifications). In some embodiments, the landing distance data **113** includes a predicted landing distance **134** that is associated with a vehicle approaching a runway. In some embodiments, the landing distance data **113** includes a plurality of predicted landing distances associated with the approaching vehicle respective to different time intervals and, thereby, different vehicle data. For example, the landing distance data **113** may include a plurality of predicted landing distances associated with multiple stages of approach to a runway. In some embodiments, the landing distance data **113** includes a true landing distance **320** for the approaching vehicle, which may be received from the vehicle or generated by the ground station **103**. Additionally, in some embodiments, the landing distance data includes predicted landing distances, compensation factors, weighted landing distances, and/or the like generated by the approaching vehicle.

[0058] In some embodiments, the prediction data **119** includes landing distances **121** and one or more compensation factors **123**. In some embodiments, the landing distances **121** include predicted landing distances **134** received by an approaching vehicle from a ground station. In some embodiments, the landing distances **121** include predicting landing distances **136** generated by the vehicle management system based at least in part on real-time vehicle data **117**. In some embodiments, the compensation factor **123** is generated based at least in part on one or more pairs of historical predicted landing distances **130** and historical true landing distances **132**. For example, a respective delta between pairs of historical predicted landing distance and historical true landing distance may be generated, and an average offset of the true landing distance to the historical predicted landing distance may be generated based on the delta values. In some embodiments, a weighted landing distance **138** is generated based on the compensation factor, the predicted landing distance **136** generated by the vehicle, and the predicted landing distance **134** generated by the landing distance data **113**. The compensation factor **123** may be applied to the predicted landing distance **134** to control the contribution of the predicted landing distance **134** to the computation of the weighted landing distance **138**. For example, in an instance where predicted landing distances of the ground station demonstrate a large delta from corresponding true landing distances, the compensation factor may cause a reduction in the contribution of the predicted landing distance **134** to the weighted landing distance computation. In an instance where predicted landing distances of the ground station demonstrate a small delta versus true landing distances, the predicted landing distance **134** may provide a greater contribution to the weighted landing distance as compared to the predicted landing distance **136**.

Example Processes of the Disclosure

[0059] Having described example systems and apparatuses, data architectures, and data flows in accordance with the disclosure, example processes of the disclosure will now be discussed. It will be appreciated that each of the flowcharts depicts an example computer-implemented process that is performable by one or more of the apparatuses, systems, devices, and/or computer program products described herein, for example utilizing one or more of the specially configured components thereof.

[0060] The blocks indicate operations of each process. Such operations may be performed in any of a number of ways, including, without limitation, in the order and manner as depicted and described herein. In some embodiments, one or more blocks of any of the processes described herein occur in-between one or more blocks of another process, before one or more blocks of another process, in parallel with one or more blocks of another process, and/or as a sub-process of a second process. Additionally, or alternatively, any of the processes in various embodiments include some or all operational steps described and/or depicted, including one or more optional blocks in some embodiments. With regard to the flowcharts illustrated herein, one or more of the depicted block(s) in some embodiments is/are optional in some, or all, embodiments of the disclosure. Optional blocks are depicted with broken (or "dashed") lines. Similarly, it should be appreciated that one or more of the operations of each flowchart may be combinable, replaceable, and/or otherwise altered as described herein.

[0061] FIG. **4** illustrates a flowchart depicting operations of an example process **400** for predicting a landing distance of a vehicle approaching a runway in accordance with at least some example embodiments of the present disclosure. In some embodiments, the process **400** is embodied by computer program code stored on a non-transitory computer-readable storage medium of a computer program product configured for execution to perform the process as depicted and described. Additionally, or alternatively, in some embodiments, the process **400** is performed by one or more specially configured computing devices, such as apparatus **200** alone or in communication with one or more other component(s), device(s), system(s), and/or the like. In this regard, in some such embodiments, the apparatus **200** is specially configured by computer-coded instructions (e.g., computer program instructions) stored thereon, for example in the memory **203** and/or another component depicted and/or described herein and/or otherwise accessible to the apparatus **200**, for performing the operations as depicted and described.

[0062] In some embodiments, the apparatus **200** is in communication with one or more internal or external apparatus(es), system(s), device(s), and/or the like, to perform one or more of the operations as depicted and described. For example, the apparatus **200** may communicate with one or more sensors **105**, one or more vehicle management systems **115**, and/or the like to perform one or more operations of the process **400**.

[0063] At operation **403**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that obtain a respective historical true landing distance for one or more vehicles. For example, the apparatus **200** may receive from a vehicle **101** a true landing distance for the vehicle upon a particular runway. As another example, the apparatus **200** may generate a true landing distance of the vehicle **101** based at least in part on sensor data from one or more sensors, radar arrays, and/or the like. In various embodiments, the historical true landing distance obtained at operation **403** is associated with a vehicle for which the apparatus **200** previously generated a predicted landing distance. For example, prior to obtaining the true landing distance, the apparatus **200** may obtain real-time vehicle data for the vehicle on approach to the runway and generate a predicted landing distance of the vehicle upon the runway.

[0064] At operation **406**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that store the historical true landing distance in association with a historical predicted landing distance for the vehicle. For example, the apparatus **200** may store the historical true landing distance of operation **403** in association with a historical predicted landing distance previously generated for the same vehicle **101** prior to landing upon the runway. In some embodiments, the apparatus **200** stores the historical true and predicted landing distances in association with one or more classifications of the vehicle, one or more runway conditions, one or more runway models, and/or the like. For example, the apparatus **200** may store the historical true and predicted landing distances in association with a vehicle make, vehicle model, vehicle weight, vehicle speed, vehicle descent rate, landing timestamp, precipitation condition, wind condition, runway elevation, runway visual range (RVR), and/or the like.

[0065] At operation **409**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that obtain real-time vehicle data for a vehicle approaching the runway. For example, the apparatus **200** may receive from an approaching vehicle **101** real-time vehicle data including vehicle airspeed, descent rate, altitude, bearing, thrust, flap orientation, weight, and/or the like. As another example, the apparatus **200** may receive real-time vehicle data from one or more ground-based vehicle monitoring systems, such as radar arrays, vehicle traffic systems, automatic dependent surveillance-broadcast (ADS-B) receivers, skywatchers, and/or the like. In some embodiments, the real-time vehicle data includes one or more vehicle classifications and/or vehicle information based upon which the apparatus **200** may associate the approaching vehicle with one or more vehicle classifications. For example, the real-time vehicle data may include a make, model, weight, cargo, and/or the like of the vehicle. In another example, the real-time vehicle data may include an identifier of the vehicle based upon which the apparatus **200** may associate the vehicle with one or more vehicle classifications, such as make, model, weight, braking capability, landing speeds, and/or the like.

[0066] At operation **412**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that generate one or more runway conditions for the runway based at least in part on sensor data from one or more sensors. For example, the apparatus **200** may receive sensor data from one or more sensors **105** configured to measure one or more phenomena related to the runway. In some embodiments, the sensor data includes readings related to precipitation. For example, the sensor data may include ice level, snow level, snow density, moisture content, sleet level, slush level, and/or the like. As another example, the sensor data may include wind velocity, wind direction, gust velocity, gust direction, gust frequency, and/or the like, any of which may be further based upon one or more elevations relative to the runway. In another example, the sensor data may include measurements of fog, dust, smoke, or other visibility-impacting phenomena present on the runway. In still another example, the sensor data may include runway elevation, runway length, foreign object debris volume, and/or the like.

[0067] In some embodiments, the apparatus **200** generates one or more precipitation conditions, one or more wind conditions, and/or the like. For example, the apparatus **200** may generate an ice thickness, snow thickness, slush thickness, frost thickness, snow compaction, and/or the like based at least in part on the sensor data. In another example, the apparatus **200** generates one or more wind conditions based at least in part on the sensor data, such as headwind, crosswind, tailwind, or gust magnitude, direction, and/or frequency. In some embodiments, the apparatus **200** generates a runway visual range (RVR) based at least in part on the sensor data. In some embodiments, the apparatus **200** generates a runway length, runway elevation, and/or the like based at least in part on the sensor data. Additionally, or alternatively, in some embodiments, the apparatus **200** retrieves one or more historical runway conditions from a data store **107**. For example, the apparatus **200** may retrieve a runway elevation, runway length, and/or the like from the data store **107**.

[0068] At operation **415**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that retrieve a stored runway model based at least in part on the one or more runway conditions. For example, the apparatus **200** may retrieve one of a plurality of runway models based at least in part on the runway conditions generated at operation **412**. For example, in response to generating a runway condition of ice thickness within a predetermined range, the apparatus **200** may retrieve a runway model **109** associated with modeling landing distances along a runway comprising ice thickness within the predetermined range. As another example, in response to generating a runway condition of headwind within a predetermined velocity range, the apparatus **200** may retrieve a runway model **109** associated with the headwind condition and velocity range. In some embodiments, the apparatus **200** retrieves the runway model based at least in part on one or more classifications of the approaching vehicle. For example, the apparatus **200** may retrieve a particular runway model **109** of a plurality of stored runway models **109** based at least in part on a make, model, weight, cargo, and/or the like that is associated with the approaching vehicle.

[0069] At operation **418**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that generate a predicted landing distance for the approaching vehicle upon the runway. For example, the apparatus **200** may generate a predicted landing distance for the approaching vehicle using the retrieved runway model and based at least in part on the real-time vehicle data associated with the approaching vehicle. In some embodiments, the apparatus **200** stores the predicted landing distance at the data store

107. For example, the apparatus may store the predicted landing distance in association with an identifier of the approaching vehicle, the runway model, and/or the like.

[0070] At operation **421**, the apparatus **200** includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that provide the predicted landing distance for the approaching vehicle, the one or more historical true landing distances, and the one or more historical predicted landing distances to the approaching vehicle. For example, the apparatus **200** may provide the predicted landing distance and historical true and predicted landing distances to the approaching vehicle via one or more networks **150**. Additionally, in some embodiments, the apparatus **200** provides the one or more runway conditions to the approaching vehicle. In some embodiments, in performance of operation **421**, the apparatus **200** causes the approaching to perform operations **424**, **427**, **430**, and/or **436**. For example, the apparatus **200** may cause the approaching vehicle **101** to generate a compensation factor (operation **424**), generate a second predicted landing distance based on real-time vehicle data (operation **427**), generate a weighted predicted landing distance (operation **430**), and/or the like. The apparatus **200** may further cause the vehicle to be controlled (e.g., by a vehicle operator, autopilot, and/or the like) based at least in part the weighted landing distance, the one or more runway conditions, and/or the like (operation **436**).

[0071] At operation **424**, the approaching vehicle includes means such as the vehicle management system that generate a compensation factor based at least in part on the historical predicted landing distances and associated historical true landing distances for the one or more vehicles. For example, the vehicle management system **115** of the approaching vehicle **101** may generate a compensation factor **123** based at least in part on respective differences between the historical predicted and historical true landing distances for one or more vehicles previously landed upon the runway. In some embodiments, the approaching vehicle **101** renders the compensation factor, the historical predicted landing distances, the historical true landing distances, the one or more runway conditions, and/or the like on one or more displays associated with the vehicle management system.

[0072] At operation **427**, the approaching vehicle includes means such as the vehicle management system that generate a second predicted landing distance for the approaching vehicle based at least in part on real-time vehicle data. For example, the vehicle management system **115** may generate a second predicted landing distance based at least in part on the real-time vehicle data of operation **409**, additional real-time vehicle data generate subsequent to operation **409**, and/or the like. In some embodiments, the vehicle management system generates the second predicted landing distanced further based at least in part on one or more runway conditions received from the apparatus **200**.

[0073] At operation **430**, the approaching vehicle includes means such as the vehicle management system that generate a weighted landing distance based at least in part on the compensation factor, the first predicted landing distance generated by the apparatus **200**, and the second predicted landing distance generated by the vehicle management system. For example, the vehicle management system **115** may generate a weighted average of the first predicted landing and the second predicted landing distance based at least in part on the compensation factor. In some embodiments, the vehicle management system applies the compensation factor to the first predicted landing distance to generate a compensated landing distance prediction and generates the weighted landing distanced based on the compensated landing distance prediction and the second predicted landing distance. The weighted predicted landing distance may be less than, greater than, or equal to either of the first or second predicted landing distances based on the compensation factor.

[0074] At operation **433**, the apparatus **200** includes optionally means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that obtain the weighted landing distance from the approaching vehicle. For example, the apparatus **200** may receive the weighted landing distance from the vehicle management system **115** via one or more networks **150**. Additionally, in some embodiments, the apparatus **200** obtains the compensation factor, the second predicted landing distance, and/or the like from the approaching vehicle. In some embodiments, the apparatus **200** stores the weighted landing distance, compensation factor, second predicted landing distance, and/or the like in association with the first predicted landing distance, the runway model, information identifying the approaching vehicle, and/or the like. In some embodiments, the apparatus **200** renders the weighted landing distance, compensation factor, second predicted landing distance, and/or the like on one or more displays such that a ground station operator may observe the landing prediction information.

[0075] At operation **436**, the apparatus **200** optionally includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that cause the approaching vehicle to be controlled based at least in part on the weighted landing distance. For example, the apparatus **200** may cause an operator of the approaching vehicle, an autopilot function of the approaching vehicle, and/or the like, to land the vehicle upon the runway based at least in part on the weighted landing distance. In some embodiments, the apparatus **200**, the vehicle management system **115**, the vehicle operator, and/or the like may generate one or more landing parameters based at least in part on the weighted landing distance. For example, the landing parameters may include descent rate, thrust, speed, nose angle, braking, flap orientation, and/or the like.

[0076] In some embodiments, the apparatus **200** instructs and/or causes the approaching vehicle to land on an alternative runway based at least in part on the weighted landing distance. For example, the apparatus **200** may determine that the weighted landing distance exceeds a predetermined landing threshold for the runway based at least in part on a comparison between the weighted landing distance and one or more predetermined thresholds, such as runway length, landing distance safety factor, vehicle speed, vehicle braking capability, and/or the like. In some embodiments, the apparatus **200** determines an alternative runway upon which the approaching vehicle may land. The apparatus **200** may communicate the alternative runway to the vehicle management system of the approaching vehicle using one or more networks. In some embodiments, the apparatus **200** determines that the approaching vehicle cannot safely land on the runway based at least in part on the weighted landing distance. In some embodiments, in response to the determination, the apparatus **200** instructs the approaching vehicle to land at a different location, enter a holding pattern, and/or the like.

[0077] At operation **439**, the apparatus **200** optionally includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that obtain a true landing distance for the approaching vehicle following landing. For example, the apparatus **200** may receive the true landing distance from the vehicle management system **115** of the vehicle **101**. As another example, the apparatus **200** may generate the true landing distance of the vehicle **101** based at least in part on sensor data **106** from one or more sensors **105**, such as one or more radar arrays, motion sensors, velocity measurement devices, and/or the like.

[0078] At operation **442**, the apparatus **200** optionally includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that store the true landing distance. For example, the apparatus **200** may store the true landing distance at the data store **107**. In some embodiments, the apparatus **200** stores the true landing distance in association with the predicted landing distance of operation **418**, the runway model, the one or more runway conditions, and/or the like. In some embodiments, the apparatus **200** stores the true landing distance in association with one or more vehicle classifications of the approaching vehicle and the runway upon which the vehicle landed. Additionally, in some embodiments, the apparatus **200** stores a landing speed, braking rate, landing angle, and/or the like of the vehicle.

[0079] At operation **445**, the apparatus **200** optionally includes means such as the prediction circuitry **209**, the communications circuitry **205**, the input/output circuitry **207**, the processor **201**, and/or the like, or a combination thereof, that update the runway model of operation **415** based at least in part on data associated with landing of the vehicle. For example, the apparatus **200** may update the runway model **109** based at least in part on the true landing distance of the vehicle. In doing so, the apparatus **200** may improve accuracy of the runway model **109** in generating subsequent landing distance predictions for the runway, the landed vehicle, vehicles sharing one or more classifications of the vehicle, and/or the like.

CONCLUSION

[0080] Although an example processing system has been described above, implementations of the subject matter and the functional operations described herein can be implemented in other types of digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them.

[0081] Embodiments of the subject matter and the operations described herein can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Embodiments of the subject matter described herein can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on computer storage medium for execution by, or to control the operation of, information/data processing apparatus. Alternatively, or in addition, the program instructions can be encoded on an artificially-generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal, which is generated to encode information/data for transmission to suitable receiver apparatus for execution by an information/data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially-generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

[0082] The operations described herein can be implemented as operations performed by an information/data processing apparatus on information/data stored on one or more computer-readable storage devices or received from other sources.

[0083] The term "data processing apparatus" encompasses all kinds of apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, a system on a chip, or multiple ones, or combinations, of the foregoing. The apparatus can include special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application-specific integrated circuit). The apparatus can also include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a repository management system, an operating system, a cross-platform runtime environment, a virtual machine, or a combination of one or more of them. The apparatus and execution environment can realize various different computing model infrastructures, such as web services, distributed computing and grid computing infrastructures.

[0084] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, object, or other unit suitable for use in a computing environment. A computer program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or information/data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub-programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0085] The processes and logic flows described herein can be performed by one or more programmable processors executing one or more computer programs to perform actions by operating on input information/data and generating output. Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and information/data from a read-only memory or a random-access memory or both. The essential elements of a computer are a processor for performing actions in accordance with instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive information/data from or transfer information/data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto-optical disks, or optical disks. However, a computer need not have such devices. Devices suitable for storing computer program instructions and information/data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0086] To provide for interaction with a user, embodiments of the subject matter described herein can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information/data to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's client device in response to requests received from the web browser.

[0087] Embodiments of the subject matter described herein can be implemented in a computing system that includes a back-end component, e.g., as an information/data server, or that includes a middleware component, e.g., an application server, or that includes a front-end component, e.g., a client computer having a graphical user interface or a web browser through which a user can interact with an implementation of the subject matter described herein, or any combination of one or more such back-end, middleware, or front-end components. The components of the system can be interconnected by any form or medium of digital information/data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), an inter-network (e.g., the Internet), and peer-to-peer networks (e.g., ad hoc peer-to-peer networks).

[0088] The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In some embodiments, a server transmits information/data (e.g., an HTML page) to a client device (e.g., for purposes of displaying information/data to and receiving user input from a user interacting with the client device). Information/data generated at the client device (e.g., a result of the user interaction) can be received from the client device at the server.

[0089] In some embodiments, some of the operations above may be modified or further amplified. Furthermore, in some embodiments, additional optional operations may be included. Modifications, amplifications, or additions to the operations above may be performed in any order and in any combination.

[0090] Many modifications and other embodiments of the disclosure set forth herein will come to mind to one skilled in the art to which this disclosure pertains having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the embodiments are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe example embodiments in the context of certain example combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

[0091] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any disclosures or of what may be claimed, but rather as descriptions of features specific to particular embodiments of particular disclosures. Certain features that are described herein in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0092] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0093] Thus, particular embodiments of the subject matter have been described. Other embodiments are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results. In addition, the processes depicted in the accompanying figures do not necessarily require the particular order shown, or sequential order, to achieve desirable results. In certain implementations, multitasking and parallel processing may be advantageous.

What is claimed is:

1. A computer-implemented method to improve landing distance prediction, comprising:

generating, at a ground station, at least one runway condition associated with a runway based at least in part on sensor data from at least one sensor;

retrieving, at the ground station, one of a plurality of stored runway models based at least in part on the at least one runway condition;

generating, at the ground station and using the retrieved runway model, a predicted landing distance for an approaching vehicle upon the runway based at least in part on model input comprising real-time vehicle data for the approaching vehicle; and

providing, from the ground station to the approaching vehicle, a historical true landing distance for at least one vehicle, a historical predicted landing distance for the at least one vehicle, and the predicted landing distance for the approaching vehicle to cause the approaching vehicle to:

generate a compensation factor based at least in part on the historical true landing distance for the at least one vehicle and the historical predicted landing distance for the at least one vehicle;

generate a second predicted landing distance for the approaching vehicle based at least in part on the real-time vehicle data for the approaching vehicle; and

generate a weighted landing distance based at least in part on the predicted landing distance for the approaching vehicle, the second predicted landing distance, and the compensation factor.

2. The method of claim **1**, further comprising:

obtaining, at the ground station, a true landing distance of the approaching vehicle upon the runway; and

storing, at the ground station, the true landing distance of the approaching vehicle in association with the predicted landing distance for the approaching vehicle.

3. The method of claim **2**, wherein:

the ground station receives the true landing distance of the approaching vehicle from the approaching vehicle.

4. The method of claim **2**, further comprising:

receiving, at the ground station, additional real-time vehicle data for the approaching vehicle during landing, wherein the ground station generates the true landing of the approaching vehicle based at least in part on the additional real-time vehicle data.

5. The method of claim **1**, further comprising:

receiving, at the ground station, the real-time vehicle data for the approaching vehicle from at least one flight monitoring system of the approaching vehicle.

6. The method of claim **1**, further comprising:

obtaining, at the ground station, the historical true landing distance for the at least one vehicle; and

storing, at the ground station, the historical true landing distance in association with the historical predicted landing distance for the at least one vehicle upon the runway.

7. The method of claim **6**, further comprising:

determining at least one classification of the approaching vehicle matches at least one classification of the at least one vehicle; and

in response to the determination, providing the historical true landing distance and the historical predicted distance for the at least one vehicle to the approaching vehicle.

8. The method of claim **1**, wherein:

a respective true landing distance corresponds to a length of a runway used by a vehicle to land upon the runway; and

the historical true landing distance is obtained by the ground station from the at least one vehicle.

9. The method of claim **1**, further comprising:

causing an autopilot system of the approaching vehicle to control the approaching vehicle based at least in part on at least one of the compensation factor or the weighted landing distance.

10. An apparatus comprising at least one processor and at least one non-transitory memory having computer-coded instructions stored thereon that, in execution with at least one processor, cause the apparatus to:

generate, at a ground station, at least one runway condition associated with a runway based at least in part on sensor data from at least one sensor;

retrieve, at the ground station, one of a plurality of stored runway models based at least in part on the at least one runway condition;

generate, at the ground station and using the retrieved runway model, a predicted landing distance for an approaching vehicle upon the runway based at least in part on model input comprising real-time vehicle data for the approaching vehicle; and

provide, from the ground station to the approaching vehicle, a historical true landing distance for at least one vehicle, a historical predicted landing distance for the at least one vehicle, and the predicted landing distance for the approaching vehicle to cause the approaching vehicle to:

generate a compensation factor based at least in part on the historical true landing distance for the at least one vehicle and the historical predicted landing distance for the at least one vehicle;

generate a second predicted landing distance for the approaching vehicle based at least in part on the real-time vehicle data for the approaching vehicle; and

generate a weighted landing distance based at least in part on the predicted landing distance for the approaching vehicle, the second predicted landing distance, and the compensation factor.

11. The apparatus of claim **10**, wherein:

the at least one runway condition comprises at least one precipitation condition associated with the runway.

12. The apparatus of claim **11**, wherein:

the at least one precipitation condition comprises at least one of snow, ice, or frost.

13. The apparatus of claim **10**, wherein:

the at least one precipitation condition comprises snow compaction.

14. The apparatus of claim **10**, wherein:

the at least one runway condition comprises at least one wind condition associated with the runway.

15. The apparatus of claim **10**, wherein:

the at least one runway condition comprises runway visual range.

16. The apparatus of claim **10**, wherein:

the at least one runway condition comprises runway elevation.

17. The apparatus of claim **10**, wherein:

the computer-coded instructions, in execution with the at least one processor, further cause the apparatus to:

receive at least one of the compensation factor, the weighted landing distance, or a true landing distance from the approaching vehicle; and

store at least one of the compensation factor, the weighted landing distance, or the true landing distance in association with at least one of the historical predicted landing distance for the at least one vehicle or the predicted landing distance for the at least one vehicle.

18. The apparatus of claim **17**, wherein:

the computer-coded instructions, in execution with the at least one processor, further cause the apparatus to:

update a respective runway model based at least in part on at least one of the compensation factor, the weighted landing distance, or the true landing distance.

19. The apparatus of claim **17**, wherein:

the computer-coded instructions, in execution with the at least one processor, further cause the apparatus to:

receive the weighted landing distance from the approaching vehicle; and

instruct the approaching vehicle to land on a second runway based at least in part on the weighted landing distance.

20. A computer program product comprising at least one non-transitory computer-readable storage medium having computer program code stored thereon that, in execution with at least one processor, is configured to:

generate, at a ground station, at least one runway condition associated with a runway based at least in part on sensor data from at least one sensor;

retrieve, at the ground station, one of a plurality of stored runway models based at least in part on the at least one runway condition;

generate, at the ground station and using the retrieved runway model, a predicted landing distance for an approaching vehicle upon the runway based at least in part on model input comprising real-time vehicle data for the approaching vehicle; and

provide, from the ground station to the approaching vehicle, a historical true landing distance for at least one vehicle, a historical predicted landing distance for the at least one vehicle, and the predicted landing distance for the approaching vehicle to cause the approaching vehicle to:

generate a compensation factor based at least in part on the historical true landing distance for the at least one vehicle and the historical predicted landing distance for the at least one vehicle;

generate a second predicted landing distance for the approaching vehicle based at least in part on the real-time vehicle data for the approaching vehicle; and

generate a weighted landing distance based at least in part on the predicted landing distance for the approaching vehicle, the second predicted landing distance, and the compensation factor.

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